A LITERATURE REVIEW OF ALTERNATE SPECIES IN ORIENTED STRAND BOARD AND WAFERBOARD

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ABSTRACT

The objective of this report was to gather research conducted on particleboard, flakeboard, waferboard, and oriented strand board with species other than trembling aspen and to arrange it in a textbook fashion so that future efforts can be directed towards filling the gaps in knowledge. Literature was collected from numerous publications and classified according to species and study focus. Abstracts were excerpted from or written for each reference and indexed by species. Series of tables relating species to process (ie., flaking or pressing), investigated variables, evaluation measures, age of study, and product type were constructed and indexed by reference number. This report is useful for identifying areas for future research efforts, demonstrating the utility of alternate species in particle/flake/wafer/strand type boards, and facilitating information searches for specific process areas. It has been prepared in such a way that omissions and future research may be included.

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INTRODUCTION

Diminishing forest resources and the expanding structural panel market has prompted the forest products industry to turn to alternative raw materials for product manufacture. The production of waferboard and oriented strand board (OSB) is a case in point. In Canada, waferboard and OSB have been traditionally manufactured almost exclusively with trembling aspen. However, the market demand has driven production capacity to levels that are not sustainable with only aspen as a raw material. To meet the demand, aspen must be supplemented or replaced by other species.

Although this is a relatively new problem to Canadian producers, U.S. mills have been utilizing a variety of species for a long time. Species utilized in the United States share many similar performance and processing properties with native Canadian species. Valuable insight can be gained from their experiences with alternate single and mixed species.

Oriented strand board is the result of product evolution. Its technological roots were founded in the particleboard product. As experience and technology evolved, particleboard gave birth to flakeboard in the U.S. and waferboard in Canada. Strandboard was developed to take advantage of flake geometry effects and evolved into oriented strand board to capitalize on the anisotropic effects of grain alignment. The technology differs little between the four products with process parameters and panel properties being likewise similar.

The objective of this report was to gather research conducted on particleboard, flakeboard, waferboard and oriented strand board with species other than trembling aspen and to arrange it in a textbook fashion so that future efforts can be directed towards filling the gaps in knowledge.

MATERIALS AND METHODS

Reference material was collected from the Alberta government and the libraries of both (east and west) divisions of Forintek. Publications not found in either Forintek library were ordered from the source (eg. Forest Products Society). Collection and validation were facilitated through computer searches of the Forintek database, performed by the INMAGIC cataloguing software. The various databases comprised the whole inventory of the eastern laboratory as well as a complete listing for material published by the USDA Forest Service. Internet access enabled searches of other online libraries such as the Virginia Tech Library System and the Library of Congress.

The literature was reviewed and each reference was indexed by species (Appendix I). Seventy-six species were identified from the literature. Abstracts for each reference were either extracted from the literature or written by the report author (Appendix II). Series of matrix tables were constructed to identify the study focus, age of study, and panel type. The following primary study classifications were included in appendices:

Appendix III	FLAKING STUDIES: Governing Parameters and Properties
Appendix IV	DRYING STUDIES: Governing Parameters and Properties
Appendix V	BLENDING STUDIES: Governing Parameters and Additive Distribution

Appendix VI	FORMING STUDIES: Governing Parameters and Forming Properties
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Appendix XIII	PANEL TYPE STUDIED

The tables in Appendices III through XIII were constructed two-dimensionally with axes represented by species and study trait.

Appendix XIV was inserted at the request of the Alberta government to further distinguish studies by isolating ones performed on Alberta woods. As with the other tables, the axes were represented by species and study focus. Comments concerning the use this table are located in the appendix.

GUIDE TO THE LOOK-UP TABLES

FLAKING STUDIES

Machine parameters designated the use and description of different flaking machines and/or formal experimental investigations with machine parameters as variables (ie., knife angle). Resource parameters were indicated when certain wood characteristics were identified and/or studied (ie., temperature, moisture content and grain angle). Strand quality denoted the classification of strands according to physical characteristics (ie., length and width). Strand yield was the proportional loss of material, rejected as too small for use in the product.

DRYING STUDIES

Drying parameters included drying temperature and wood moisture content. Strand properties consisted of strand quality (determined either by direct strand quality or final board quality) and strand moisture content.

BLENDING STUDIES

Study variables included machine parameters (ie., blender rotation speed, paddle size and angle and nozzle size), resource parameters (ie., surface roughness and moisture content), and additives (ie., resin type, wax and other treatments). Entries to these tables were based solely on studies pertaining to effects on additive distribution. Studies that related resin type and content variables to final board performance were classified in the pressing study section.

FORMING STUDIES

These studies investigated the effects of forming machine parameters (ie., free fall distance and plate spacing) and resource parameters (ie., flake geometry) on strand alignment and distribution (horizontal and vertical) of strands in the mat.

PRESSING STUDIES

The pressing studies were more meticulously classified due to the large number and variety found. Subheadings were furnish parameters, press parameters, press size and type and board properties. Major furnish parameters included: resin content, wax content, strand alignment (qualitative and quantitative measures), flake moisture content, strand geometry, layer ratio (included both face-to-core weight ratios and species variation), single and/or mixed species, target board density, treatment (ie., resin impregnation, surface activation by heat or chemical application, and decay protection) and resin type (ie., Phenol-formaldehyde powder or liquid and Urea-formaldehyde resins).

Press parameters included: platen temperature, pressing schedule (ie., closing time and total press time), applied pressure (ie., maximum pressure), and steam pressure (in the case of steam injection studies). As with the other studies, study traits were indicated only when they were variable.

Press size and type indicated whether the study was conducted on a laboratory scale (further divided into conventional and steam presses), pilot plant scale or at the mill level.

The board properties evaluated as a measure of performance were: both dry and aged moduli of elasticity (MOE) and rupture (MOR), internal bond (IB), plate shear modulus, interlaminar shear strength, edgewise shear strength, linear expansion (LE), thickness swell (TS), thickness edge swell, water absorption (WA), average board density, vertical density profile, board moisture content out of the press and fungal decay resistance. Other board properties of interest which were not included (due to limited representation) were: creep, nail withdrawal, hardness, impact and obscure bending and shear tests.

OTHER STUDIES

Studies reported as reviews or summaries of studies (with no supporting methods) were classified as literature reviews. The modelling classification denotes the construction of formulae to mathematically describe variable and property relationships. Economic feasibility studies are included to demonstrate the cost effectiveness of using a given species in the production of commercial board. Thermal character denotes studies investigating the flammability and fire rating of the board.

TIME PERIOD OF STUDY

Studies were collected from as far back as the early 1950's. Given the improvement in all facets of technology, indication of the time period of the study permits the rating of study relevance to more modern product processes. For example, a study conducted in 1954 may seem primitive and irrelevant by current standards. But, no matter how archaic the studies seem, all have some innate value.

PANEL TYPE STUDIED

Studies were classified according to the product used. This is a further indication of the age of the study as well as the processes and variables involved. Some studies concentrated on process parameters which affect all panel types (ie., resource parameters in flaking), and were therefore applied to all classes.

CONCLUSIONS

This report is useful to anyone wishing to gauge the utility of a species for a waferboard/OSB product. It minimizes the likelihood of redundant research and enables future efforts to be directed towards filling the gaps in knowledge. It has been prepared in such a way that omissions and future research may be included.

Some noticeable areas lacking study were in overall flaking, drying, blending and forming studies. These processes provide the proper medium for efficient consolidation and final performance and should not be considered inconsequential.

Furnish parameters lacking emphasis in the pressing studies were: wax content, moisture content, strand alignment, layer ratio and treatment. With the exception of the more utilized species, there was an over-all lack of studies with press parameter variables.

Most of the studies were conducted on laboratory-sized presses. There is a definite need to apply the small-scale research to full-size presses (pilot plant and mill trials), to gauge the actual worth of the research efforts.

While bending properties, internal bond and standard dimensional stability performance have been amply represented, future efforts might include more shear evaluations and edge swell measures. Thickness swell problems in practice occur when edge flaring results in uneven floors and nail popping (swelling forces withdraw the nail from the underlying support).

Economic feasibility studies are perhaps the most important type of study, given that technical research would be a waste of time and money if the species were too expensive to use in a commodity-type product. This classification was underrated because studies were omitted if they lacked technical content.

Thermal character research (fire resistance) has been limited due to waferboard/OSB's superior performance compared to other substitution products. However, this assumption may change with the recent fire problems on the western coast of the US.

The lion's share of the research was done in the 1970's and early 80's. Manufacturing processes and research efficiency have steadily improved, necessitating more comprehensive studies to match research with current technology. This supposition is supported by the limited number of studies conducted on the OSB product. It (OSB) is the current structural panel product of choice and logic dictates that the benefits of strand geometry and alignment should be investigated more extensively.

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APPENDICES

Appendix I. SPECIES INDEX

Common name	Latin Binomial	Reference
Aceituna	*Simaruba amara*	63
Afrormosia	*Pericopsis elata*	168
Alder (black)	*Alnus glutinosa*	36
Alder (red)	*Alnus rubra*	11, 30, 122, 173
Ash (green)	*Fraxinus pennsylvanica*	72, 73, 89, 91, 141
Ash (white)	*Fraxinus americana*	30, 40, 75, 76, 79, 81
Ash	*Fraxinus spp.*	21, 30, 84
Aspen (large-tooth)	*Populus grandidentata*	30, 33, 34, 75, 108, 149, 151, 174
Banak	*Virola koschyni*	63
Basswood (American)	*Tilia americana*	67, 159
Basswood (white)	*Tilia heterophylla*	147
Beech (American)	*Fagus grandifolia*	33, 34, 155, 163
Birch (black)	*Betula lenta*	147
Birch (white)	*Betula papyrifera*	7, 10, 17, 17, 30, 35, 56, 57, 58, 72, 73, 83, 89, 91, 103, 127, 130, 155, 156, 163
Birch (yellow)	*Betula alleghaniensis*	103, 109, 155, 163
Cedar (eastern white)	*Thuja occidentalis*	163
Cherry (black)	*Prunus serotina*	75, 157
Cottonwood	*Populus deltoides*	25, 81
Cottonwood (black)	*Populus trichocarpa*	102, 164

Common name	Latin Binomial	Reference
Douglas-fir	*Pseudotsuga menziesii*	27, 28, 29, 32, 43, 44, 45, 46, 47, 48, 49, 52, 53, 54, 64, 65, 68, 69, 70, 71, 93, 94, 95, 96, 103, 106, 110, 111, 112, 113, 114, 115, 116, 117, 118, 120, 123, 124, 125, 144, 160, 166, 167, 171, 173
Elm (American)	*Ulmus americana*	21, 30, 67, 141
Fir (balsam)	*Abies balsamea*	7, 8, 20, 30, 31, 33, 85
Fir (grand)	*Abies grandis*	39, 154
Fir (white)	*Abies concolor*	13, 14, 92, 103, 116, 123
Gallina	*Jacaranda copaia*	63
Hackberry	*Celtis occidentalis*	21, 141, 172
Hemlock (eastern)	*Tsuga canadensis*	19, 33
Hemlock (western)	*Tsuga heterophylla*	70, 116, 123, 173
Hickory (mockernut)	*Carya tomentosa*	142, 143, 146
Hickory	*Carya spp.*	15, 25, 30, 40, 52, 67, 75, 76, 77, 78, 79, 81, 84, 103, 104, 105, 107, 135, 137, 138, 139, 140, 159, 172
Jobo	*Spondias mombin*	63
Kiri	*Paulownia tomentosa*	36, 81, 168
Limba	*Terminalia superba*	168
Locust (black)	*Robinia pseudoacacia*	36
Maple (red)	*Acer rubrum*	30, 34, 40, 41, 42, 59, 72, 73, 75, 76, 79, 83, 89, 90, 91, 108, 149, 155, 163, 174
Maple (silver)	*Acer saccharinum*	30, 165

Common name	Latin Binomial	Reference
Maple (sugar)	*Acer saccharum*	26, 30, 103, 128, 150, 151, 155, 158, 163
Maple	*Acer spp.*	67
Oak (overcup)	*Quercus lyrata*	141
Oak (post)	*Quercus stellata*	40, 75, 76, 79, 81
Oak (northern red)	*Quercus rubra*	26, 33, 45, 47, 48, 60, 66, 72, 73, 87, 88, 89, 91, 126, 157, 170
Oak (southern red)	*Quercus falcata*	21, 22, 30, 40, 41, 42, 52, 67, 75, 76, 77, 78, 79, 80, 81, 82, 84, 104, 105, 107, 132, 135, 137, 138, 139, 140, 141, 142, 143, 159
Oak (scarlet)	*Quercus coccinea*	97, 98, 133, 134
Oak (water)	*Quercus nigra*	129, 141
Oak (white)	*Quercus alba*	21, 22, 30, 34, 40, 52, 75, 76, 79, 80, 81, 82, 84, 104, 105, 107, 132, 135, 137, 138, 139, 140, 146, 176
Oak	*Quercus spp.*	172
Olive (autumn)	*Elaeagnus umbellata*	36
Pecan	*Carya illinoensis*	21, 82, 84, 141
Pine (jack)	*Pinus banksiana*	31, 50, 123
Pine (loblolly)	*Pinus taeda*	77, 82, 135, 137, 138, 139, 142, 143, 146, 154
Pine (lodgepole)	*Pinus contorta*	64, 103, 115, 121, 123, 125, 142, 143, 144
Pine (ponderosa)	*Pinus ponderosa*	12, 28, 103, 123, 154, 173
Pine (red)	*Pinus resinosa*	119

Common name	Latin Binomial	Reference
Pine (scrub)	*Pinus virginiana*	28
Pine (slash)	*Pinus elliottii*	74, 103
Pine (eastern white)	*Pinus strobus*	19, 157, 163
Pine (western white)	*Pinus monticola*	121
Pine (southern yellow)	*Pinus echinata*	23, 24, 43, 55, 129, 166
Pine (northern)	*Pinus spp.*	123, 125
Pine (southern)	*Pinus spp.*	41, 42, 52, 69, 104, 105, 107, 118, 123, 137, 138, 139, 140, 148, 162
Poplar (balsam)	*Populus balsamifera*	1, 2, 3, 4, 5, 6, 16, 30, 57, 86, 102, 125, 127, 130, 131, 152, 164
Poplar (hybrid)	*Populus spp.*	50, 51, 177
Redwood	*Sequoia sempervirens*	37, 43, 103, 166
Spruce (black)	*Picea mariana*	7, 30
Spruce (Engelmann)	*Picea engelmannii*	115
Spruce (red)	*Picea rubens*	9
Spruce (Sitka)	*Picea sitchensis*	166, 167
Spruce (white)	*Picea glauca*	30, 38, 169
Spruce	*Picea spp.*	103, 106, 125, 153
Sweetbay	*Magnolia virginiana*	30, 40, 75, 76, 79, 81, 129
Sweetgum	*Liquidambar styraciflua*	21, 22, 23, 24, 30, 40, 41, 42, 52, 55, 62, 75, 76, 77, 78, 79, 80, 81, 82, 104, 105, 107, 129, 132, 135, 136, 137, 138, 139, 140, 141, 142, 143, 146, 147, 162, 172, 176

Common name	Latin Binomial	Reference
Sycamore	*Platanus occidentalis*	36, 103, 145
Tamarack	*Larix laricina*	30, 50, 58
Tupelo (black)	*Nyssa sylvatica*	30, 34, 40, 75, 76, 79, 81, 129
Virola	*Virola spp.*	168
Yellow-poplar	*Liriodendron tulipifera*	22, 30, 34, 55, 62, 67, 99, 100, 101, 129, 137, 138, 139, 146, 147, 159, 161, 175

Appendix II. REFERENCE ABSTRACTS

1. *Alberta Research Council. 1987. Aspen vs. Black Poplar Differences: Phase I - Waferboard/OSB.*

Specimens of aspen and black (balsam) poplar trees were logged from the same site near Slave Lake, Alberta and then waferized at Weldwood of Canada's OSB mill. Thirty 2 by 4-foot panels of aspen and black poplar at three resin levels were manufactured and an analysis of anatomical, chemical, and physical properties of the two species was conducted. In the wood quality analysis, black poplar was found to have higher moisture content, wider vessels and coarser texture than aspen. The panel production phase of this study concluded that high quality panels could be manufactured using 100% black poplar. However, conjecture held that black poplar would increase manufacturing costs, ie. higher moisture content/lower density gives a higher delivered log cost per ton of dry fiber; difficulties in waferizing results in gum-ups and shorter knife life; higher moisture content increases drying cost; and increased panel variability due to aspen/black poplar ratio control results in degrading. The solution put forth was to segregate by species, process (waferize and dry) separately, then meter together before blending.

2. *Alberta Research Council. 1988. Mixed Species -- Final Report.*

This summary report was the culmination of work performed on eight separate projects. Laboratory 4 by 8 foot panels were manufactured and subsequent testing demonstrated that it was technically feasible to make panels of 100% black poplar and of mixtures of aspen and black poplar, and that the properties of panels made from black poplar were not significantly different from those made from aspen. Although green aspen flaked more easily than green black poplar, it was found that when the logs of both species were preconditioned to lower moisture contents, there was practically no difference in the quality of flakes produced. Laboratory 2 by 4-foot panels were manufactured with 19 different flake geometries and noted that: bulk density increased with thickness and decreased with length; length variability decreased as length increased; modulus of elasticity, dry modulus of rupture and wet modulus of rupture increased with both increased length and decreased width; internal bond increased with decreased thickness; and thickness swell and linear expansion both decreased with increased length or decreased thickness. The results of a black poplar mill trial proved inconclusive in flaking, drying and pressing process evaluations due to the shortness of the trial run. However, many practical difficulties in waferizing and manufacturing panels were identified. Included in the study was a description of a software package developed to run the PANELMAX computer model which related panel properties to common production parameters.

3. *Alberta Research Council. 1990. Mixed Species -- Summary Report.*

This study was carried out in three separate parts. Part I considered the physical conditions of flaking. Logs of aspen and black poplar were flaked at 4 different temperatures and 2 moisture content levels and evaluated for strand yield and quality. The best conditions for both species called for a high log temperature (50°C) and low moisture content (~70%). Part II of the study studied the effects of drying temperature on OSB quality. Strands of aspen and black poplar were dried at 4 temperatures and 2 by 4 foot panels were manufactured. High drying temperatures resulted in lower internal bond and diminished thickness swell for both species. Part III reported the results of a pilot plant and mill trial (Weldwood - Slave Lake, Alberta) conducted using black poplar in the face and aspen in the core. Only a slight loss of panel properties were experienced with the pilot plant trials, but the mill trial produced OSB with too low density (600 kg/m^3) to be compared with regular production. Panels of similar specifications to commercial OSB were made with black poplar which exceeded CAN3-0437 0-2 requirements.

4. *Alberta Research Council. 1990. OSB Furnish.*

This study reported the results of pilot plant and mill trials (Weyerhaueser - Edson, Alberta). The pilot plant trials studied 4 different allocations of black poplar and aspen to the face and core layers of panels and the mill trial had aspen in the face and black poplar in the core. Results of panel testing showed that panels manufactured from 100% aspen had the best properties, followed closely by panels with aspen in the face and black poplar in the core. Results were comparable for the mill trial and the aspen face - black poplar core pilot plant trial and overall performance was acceptable by industrial standards. All three groups containing black poplar had thickness swell between 23 to 25% as compared to 20% for 100% aspen panels. A pilot plant waferizing study was performed to investigate the effects of species and knife angle on flakeability. Knife angles of 27° and 32° were used to produce strands of 0.7 mm (0.027 in.) thickness, 75 mm (3 in.) length, and random width. Power consumption appeared greater for the 27° knife angle, but no difference was found between the two species. Strand thickness increased by 0.004 inches with the 27° knife angle with no accompanying difference between species. The black poplar furnish had a greater percentage of fines as compared to the aspen furnish, but screen fractions were similar for both knife angles.

5. *Alberta Research Council. 1992. Composite Furnish.*

A mill trial was conducted to evaluate panel performance with 20% black poplar content. The 20:80 mix of black poplar and aspen was assured directly from the green end of the mill. The advantage of this was that the aspen would continually clean the knife edges of the waferizer during operation which would otherwise be plugged by the black poplar. In addition, there appeared to be no differences in furnish quality with the limited addition of black poplar. Results showed that there was no significant loss of panel properties due to a 20% mix of black poplar. A few minor alterations to the drying and pressing processes were required to compensate for the increased moisture content and lower density of the black poplar. It was reported that due to the positive results of the study, the mill was utilizing black poplar on a regular basis. The study also reported a mill trial of the Iggesund Tools TURNKNIFE system on the mill's CAE waferizer. The results of the trial reported prolonged knife life, but with insufficient breakup of the strands and high variability in strand thickness. The problems were resolved with correction by knife adjustments.

6. *Alexopoulos and Shields. 1982. Structural Performance of Waferboard Made from Alternate Wood Supplies -- Balsam Poplar and Aspen Poplar.*

Four categories of waferboards were made from balsam poplar, aspen poplar, and their mixtures. Based on weight, they were: 100% aspen; 85% aspen, 15% balsam poplar; 50% aspen, 50% balsam poplar; and 100% balsam poplar. The results of MOR, MOE, aged MOR, and IB tests indicated that waferboards made from 100% balsam poplar and mixtures with aspen had properties comparable to those made from 100% aspen poplar. All properties were above the minimum standard specifications.

7. *Alexopoulos and Shields. 1982. Structural Performance of Waferboard Made from Alternate Wood Supplies -- Black Spruce, Balsam Fir and White Birch Grown in Eastern Canada.*

The usable yield of wafers from aspen, black spruce, balsam fir and white birch grown in eastern Canada, including aspen, balsam poplar and spruce tops, was determined by screen fraction. The aspen yield was 92.8%, with balsam poplar exhibiting a higher yield (96%) and white birch approximately equal. The yield of black spruce and spruce tops was slightly lower at 87% while that of balsam fir was significantly lower at 80%. In the case of balsam fir, the numerous small knots with the cross grain around them resulted in much wafer breakage. Results of MOR, MOE, aged MOR and IB (internal bond strength) for single-species waferboards indicated that black spruce and balsam fir produced waferboard with properties quite similar to those of trembling aspen, while white birch specimens had significantly lower bending properties than had the other three species. The results for the homogenous mixed waferboards of the three species showed that the inclusion of white birch at the 25 percent range had a minimal effect on the strength properties. However, further increases to 33⅓% and 50% reduced the properties, but not to the extent that they did not comply with standard requirements.

8. *Alexopoulos and Shields. 1982. Structural Performance of Waferboard Made from Alternate Wood Supplies -- Budworm-attacked Balsam Fir.*

Budworm-attacked balsam fir logs which had been stored for 0, 12, and 20 months were studied in terms of usable wafers produced and the properties of boards produced from these wafers. The screen analysis of wafers indicated that a large amount of undersized material was generated, especially with increasing exposure time. It is assumed that this was due to decay. Differences in MOR, MOE, and IB among the different storage periods were found to be significant at the 0.05 level. Fresh-cut logs had the highest values in MOR, MOE, and IB. All properties complied with the minimum requirements of the CAN3-0188.2-M78 standard.

9. *Alexopoulos and Shields. 1982. Structural Performance of Waferboard Made from Alternate Wood Supplies -- Budworm-attacked Red Spruce.*

The properties of waferboards made from three classes of red spruce trees were investigated: the first consisted of normal spruce trees with no significant budworm attack; the second, of spruce trees with 60% to 90% of leaves defoliated or dried out due to budworm attack; the third, of spruce trees that had been dead for one to two years and which were totally defoliated or dried out due to budworm attack. The differences in MOR, MOE, aged MOR, and IB among the three wood-quality categories were found to be insignificant at the 0.05 level of significance.

10. *Alexopoulos and Shields. 1982. Structural Performance of Waferboard Made from Alternate Wood Supplies -- Mixed Hardwoods.*

For single-species particleboard, it has been found that wood density is the most important species variable influencing board properties. Species of lower density are preferred because, for the same density of board, they provide a greater compression ratio (ratio of board density to wood density) as a result of better inter-particle bonding. Consequently, it has been found that increasing species density results in a decrease in modulus of rupture (MOR) and modulus of elasticity (MOE).

Experiments were carried out on waferboard specimens made from 100% aspen poplar wafers (based on weight), 50:50 mixture of aspen and white birch wafers, 30:70 mixture of aspen and white birch wafers, and 100% white birch wafers. Modulus of rupture and modulus of elasticity values were adjusted to three density levels (ie., 641, 673, and 705 kg/m^3). The results indicated that both MOR and MOE decreased with increasing weight proportions of white birch wafers; also, they decreased with decreasing board density. Specimens made from 100% white birch wafers had MOR and MOE approximately 40 and 30 percent lower, respectively, than specimens made from 100% aspen poplar wafers. All specimens complied with the minimum requirements of the CAN3-0188.2-M78 standard.

11. ***Alexopoulos and Shields. 1982. Structural Performance of Waferboard Made from Alternate Wood Supplies -- Red Alder and Aspen Poplar.***

Red alder produced boards with properties (MOR, MOE, IB and thickness swelling after 24-hour soak) superior to those of aspen poplar specimens. Aged MOR was slightly lower; however, it was well above the minimum standard requirement. In addition, red alder had excellent processing characteristics (ie., it was easy to waferize, dry, handle, etc,.), and the wafers produced were exceptionally smooth with no loose fibre.

12. ***Anderson, Wu, and Wong. 1974. Utilization of Ponderosa Pine Bark and Its Extract in Particleboard.***

This study was undertaken to evaluate the suitability of ponderosa pine bark extract as a bonding agent for particleboard and the use of the bark as core furnish in a three-layer particleboard. When para-formaldehyde was added to wood particles which had been sprayed with concentrated bark extract and processed into board, formaldehyde released during the hot-press cycle reacted in situ with polyphenolic compounds present in the extract and formed a waterproof bonding agent. Bark containing a small amount of para-formaldehyde was used as core in a three-layer board, and bark extract was used as the bonding agent for the outer wood-particle layers. Each type of board met specifications for a medium-density particleboard and was comparable to some synthetic phenol exterior-type particleboards in moisture resistance. Production costs could be markedly reduced by employing bark extract as bonding agent and bark as core in a three-layer particleboard.

13. ***Anderson, Wong, and Wu. 1974. Utilization of White Fir Bark in Particleboard.***

This study was undertaken to evaluate the suitability of white fir bark for making particleboard. Bark boards without additives proved unsatisfactory. However, when a small amount of para-formaldehyde was added to the bark furnish, the formaldehyde released during the hot-press cycle reacted with the polyphenolic extractive components forming a water resistant bonding agent. While the bark board had good internal bond, water absorption, and thickness swelling values, it had a low MOR and high linear expansion. When the bark furnish was used as core stock in a three-layer wood-bark particleboard, the strength properties were greatly improved, which together with a very low linear expansion resulted in a board with good overall properties. Homogeneous boards containing around 25 percent bark also had good properties.

14. ***Anderson, Wong, and Wu. 1974. Utilization of White Fir Bark and its Extract in Particleboard.***

This study was undertaken to evaluate the suitability of white fir bark extract as a bonding agent for particleboard and the use of bark as core furnish in a three-layer particleboard. When para-formaldehyde was added to wood particles which had been sprayed with concentrated bark extract and processed into board, formaldehyde released during the hot-press cycle reacted in situ with polyphenolic compounds present in the extract and formed a waterproof bonding agent. Also, bark containing a small amount of para-formaldehyde was used as core in a three-layer board and bark extract was used as the bonding agent for the outer wood-particle layers. Each type of board met specifications for medium-density particleboard and was comparable to some synthetic phenolic resin exterior-type particleboards in moisture resistance. Production costs could be reduced by employing bark extract as bonding agent and bark as core in a three-layer particleboard. The yield of white fir bark extract solids amounted to around 340 pounds per ton of bark.

15. ***Anthony and Moslemi. 1969. Strength and Dimensional Properties of Hickory Flakeboard.***

The purpose of this note was to provide preliminary information on the properties of hickory flakeboards. Experimental panels of 45 pounds-per-cubic-foot density were manufactured with 0.015 by 2-inch flakes, dried to 7 percent moisture content and blended with 8 percent urea-formaldehyde resin. The hand-formed mats were pressed with a moisture content of 11.5 percent, platen temperature of 275°F, and applied pressure of 350 psi for 8 minutes. Mechanical and dimensional values for the hickory flakeboard were: 998,000 psi MOE; 6,581 psi MOR; 232 psi IB; 0.146% LE; and 7.5% thickness swell.

16. ***Aston. 1993. Balsam Poplar/Cottonwood as a Furnish Material for the Manufacture of Oriented Strandboard.***

Large stands of balsam poplar/cottonwood exist in Alberta and British Columbia. There is interest in using this underutilized species in the manufacture of OSB. A review of the relevant research literature confirmed that satisfactory OSB panels could be prepared with the balsam poplar species; however, several processing parameter constraints were noted by the researchers. The constraints pertained to log thawing, waferizing and drying problems, associated with the balsam poplar/cottonwood as a result of its short fiber length and high moisture variability.

17. ***Au and Gertjejansen. 1989. Influence of Wafer Thickness and Resin Spread on the Properties of Paper Birch Waferboard.***

Laboratory paper birch waferboards, bonded with commercial powdered phenol-formaldehyde (PF) resin, were manufactured over a density range of 38 to 46 pcf from wafers 0.018, 0.027, and 0.036 inch thick at 2 percent PF and from 0.018-inch wafers at 3 percent PF. Except for internal bond strength (IB) at low and medium densities, thin wafers resulted in improved properties at the 2 percent PF level. A 2-hour boil durability test showed that thin wafers, and particularly thin wafers at 3 percent PF, significantly reduced thickness swelling, linear expansion, and loss of modulus of rupture (MOR). The superior panel, all properties considered, was that made from 3 percent PF and

0.018-inch wafers. This panel met the minimum IB, MOR, modulus of elasticity, and bond durability requirements of recognized standards at approximately 40 pcf density or less. The results also indicate that thin paper birch wafers have potential as a waferboard core material at a PF level between 2 and 3 percent.

18. ***Au, Gertjejansen and Larntz. 1992. Use of Response Surface Methodology to Maximize Paper Birch Utilization in a Three-Layer, Two-Species Oriented Strandboard.***

Response surface methodology (RSM) was used to maximize the use of paper birch in a laboratory three-layer aspen oriented strandboard (OSB) at a minimum core resin spread. The minimum possible resin spread for the core and maximization of paper birch usage were achieved by simultaneously varying the core strand thickness and reducing the face-to-core weight ratio. Sequential experimentation and model fitting procedures of RSM enabled the prediction of the response and the location of the optimum operating conditions. Simultaneous optimization of the ten board properties indicated that at a density of 39 pcf, a laboratory aspen OSB made with a core spread of 1.50 lb/1000 ft^2 and 45 percent by weight of 0.025-inch-thick paper birch core strands would satisfy the minimum requirements of the performance standard. Overall, paper birch was a good supplemental furnish for the core of a three-layer aspen OSB.

19. ***Avramidis and Smith. 1989. The Effect of Resin Content and Face-to-core Ratio on Some Properties of Oriented Strand Board.***

The effect of different resin content levels and face-to-core ratios on some mechanical and physical properties of laboratory-made oriented strand boards were studied. Three-layer 1/2-inch oriented boards were made from a mixture of eastern white pine (*Pinus strobus*), hemlock (*Tsuga canadensis*), and aspen (*Populus tremuloides*) in a by-weight proportion of 60:20:20, respectively. Phenol-formaldehyde resin was applied at 4, 5, and 6 percent based on oven-dry weight and face-to-core ratios of 60/40 and 50/50. The results showed that increased resin content levels and face-to-core ratios resulted in improved mechanical and physical properties of the OSB specimens, in particular when tested parallel to the face alignment.

20. ***Barnes and Sinclair. 1983. A Review of Balsam Fir Utilization Research.***

Balsam fir can serve as the raw material for a variety of wood and fiber products having desirable properties. There is the potential for increased use of balsam fir in the manufacture of dimension lumber as lumber markets continue to improve. Good log quality and lumber grade yields both contribute to its suitability as a raw material for stud sizes of dimension lumber. Waferboard panels made from living balsam fir have the potential to exceed the established minimum product standards. Certain properties of panels from balsam fir may even exceed those of panels made from aspen. The potential for producing panels from the combined furnish of balsam fir and aspen also appears promising. Additionally, combinations of living balsam fir, dead balsam fir and aspen may be successfully incorporated into waferboard panels. Budworm-killed balsam fir also may have certain utility in the production of wood pulp. Since pulp yields and certain physical properties may be affected when using budworm-killed material, the use of only spruce budworm-killed material in pulping may prove economically undesirable. Therefore, making use of budworm-killed material in combination with material from living trees may be the best current solution for utilizing budworm-killed material in pulp production.

21. ***Beer. 1982. Flaking High Density Species for Structural Board.***

High quality flakes produced for structural panel products differ vastly according to species and flaker operating characteristics. The high-density species investigated were ash (*Fraxinus spp.*), elm (*Ulnus americana* L.), sweetgum (*Liquidambar styraciflua* L.), hackberry (*Celtis spp.*), hickory (*Carya*), red oak (*Quercus rubra*), white oak (*Quercus alba*) and trembling aspen (*Populus tremuloides*). Species properties such as green density, modulus of rupture, modulus of elasticity and tensile strength perpendicular to the grain, as well as anatomical species characteristics such as type of growth rings, vessel length, fiber length, vessel volume and fiber volume all affect flake quality. Higher density species with ring and semi-ring porous structures are very difficult to cut into quality flakes such that the flakes split as the wide vessels collapse. A strand configuration is recommended in these cases.

22. ***Biblis. 1985. Properties of Three-layer Oriented Strandboard from Southern Hardwoods.***

Experimental test results are presented for three-layer, 1/2-inch-thick, 4 by 8-foot oriented strandboards, made from two mixtures of southern hardwoods using a 6 percent solids liquid phenol-formaldehyde resin. Mixture 1 consisted of 35 percent red oak, 15 percent white oak, 35 percent sweetgum and 15 percent yellow-poplar. Mixture 2 consisted of 55 percent red oak, 15 percent white oak and 30 percent sweetgum. Test results corresponding to the average board densities of 45.3 pcf indicate that the flexural properties of the OSB were lower than those of commercial CDX 1/2-inch southern pine plywood; but in other properties, such as rail shear strength, interlaminar shear strength, and plate shear modulus, the OSBs were considerably stronger and stiffer than 1/2-inch plywood. Linear dimensional changes of the OSB with MC changes from 65 percent relative humidity to 48-hour soaked condition were equal to those of aspen waferboard and lower than those of southern pine plywood. However, thickness swelling of mixtures 1 and 2 of the OSB was 2 percent and 8 percent higher than that of aspen waferboard. The experimental results indicate that appropriate mixtures of high and low density southern hardwoods may be used to fabricate commercially acceptable 1/2-inch-thick oriented boards for sheathing in housing. Such boards, although 5 to 10 percent denser than aspen waferboards, should also be substantially stronger and stiffer.

23. ***Biblis. 1989. Properties of Commercial OSB from Three Southern Pine Mills.***

The results of an evaluation of certain mechanical and physical properties of OSB from three southern pine mills are presented. Boards from one mill consisted of 50 percent southern pine and 50 percent sweetgum. Boards from the other two mills were made from 100 percent southern pine. Although boards from all three mills met the requirements of the APA performance standards for sheathing exposure 1, the test results, as expected, indicated significant differences in properties among boards from the three mills. The maximum differences in board properties among the three mills occurred in flexural stiffness and strength parallel to face orientation. The differences among the mills in these properties for boards tested in the original condition were 31 percent for modulus of elasticity (MOE) and 35 percent for modulus of rupture (MOR). The differences in boards tested after cycling were 69 percent for MOE and 62 percent for MOR. The inclusion of sweetgum appeared to negatively affect the final strength properties; however, this could possibly have been due to operating parameters of the respective mills.

24. *Biblis. 1990. Performance of Southern OSB Overlaid with Resin-impregnated Paper.*

The performance of southern oriented strandboard (OSB) panels overlaid with resin-impregnated paper was evaluated according to: certain APA-performance standards for siding that included 21-day water-spraying on the overlay; edge weatherability of ANSI-AHA A135.6 standards; and certain physical and mechanical tests of ASTM D 1037. The results obtained indicate that phenolic resin-impregnated paper overlays can be bonded successfully to OSB made of southern pine and hardwood mixtures (ie., primarily sweetgum and yellow-poplar) with a bond stronger than the internal bond strength of the OSB substrate. The resin-impregnated paper, when overlaid onto one surface of the OSB substrate, can provide a structural improvement of between 10 and 15 percent for various mechanical properties. When OSB panels overlaid with resin-impregnated paper are appropriately primed, painted, and edge-sealed, thickness swelling and checking of the drip edge, after exposure to 21-day continuous water-spraying, can be controlled effectively if the back surface is kept dry. Under these conditions, however, the overlaid surface becomes rough with undesirable visual effects known as "telegraphing," which are protrusions of swollen flakes in the overlayer without rupturing the overlay. Telegraphing cannot be eliminated or controlled with application of primers or paints. More work is needed to solve the problem of telegraphing of the overlaid surface.

25. *Bhagwat. 1971. Physical and Mechanical Variations in Cottonwood and Hickory Flakeboards Made from Flakes of Three Sizes.*

Variation in physical and mechanical properties of cottonwood and hickory flakeboards made from three flake sizes was studied. The values of MOE, MOR, maximum stress and internal bond increased significantly with increased flake sizes. The lower density wood (cottonwood) flakeboards were superior in strength to higher density wood (hickory) flakeboards at board density of 40 pounds-per-cubic-foot. However, a comparison of average values of the flakeboards with established standards indicated that all the boards had acceptable strength. The experiment was carried out under laboratory conditions, but similar results may be anticipated on an industrial scale.

26. *Blankenhorn, Labosky, Stover and Nicholls. 1989. Selected Chemical Modifications of Red Oak and Hard Maple Flakes for Flakeboard Manufacturing.*

The feasibility of using low chemical concentrations, time and pressure for modifying red oak (*Quercus rubra*) and hard maple flakes (*Acer saccharum*) was investigated. Red oak and hard maple flakes were pretreated with water, sodium hydroxide and acetic acid for different times and pressures to determine weight loss. The chemically modified flakes were processed into flakeboards. Untreated aspen, red oak and hard maple panels were used as controls. Compared to the hard maple controls, hard maple panels had a reduction in press closing time for all treatment levels. However, a reduction in press closing time for treated red oak compared to red oak controls was evident only for very high weight loss values. Weight loss for red oak and hard maple can be controlled, and it appeared that acetic acid treatments produced better properties for both species compared to sodium hydroxide or water treatments. Mechanical properties were reduced in hard maple for all treatments and in red oak for some treatments, particularly sodium hydroxide treatments. Bending strength values for acetic acid-treated red oak panels were not significantly different from red oak control values. Water and acetic acid treatments for red oak produced similar dimensional stability values compared to red oak controls. This indicated that weight loss can be controlled without detriment to the dimensional stability of the panels. Density, internal bond, thickness swell, water absorption and linear expansion values for red oak control and acetic acid-treated red oak panels compared favorably with aspen control panels. Density, internal bond, thickness swell, water absorption and linear expansion values for hard maple control and linear expansion values for water and acetic acid-treated hard maple panels also compared favorably with aspen control panels.

27. *Brady and Kamke. 1988. Effects of Hot-pressing Parameters on Resin Penetration.*

The objective of this study was to evaluate the penetration of a liquid phenolic resin adhesive into wood under conditions similar to those found during hot-pressing. Aspen and Douglas-fir flakes were used with test parameters of temperature, time, pressure and flake moisture content (MC). Penetration was evaluated using fluorescence microscopy and a manual digitization technique. The natural variability of wood appeared to have the largest influence on the uniformity of resin penetration. The penetration of resin was approximately three times greater in Douglas-fir earlywood than latewood. Cell wall fractures aided penetration by providing additional paths for hydrodynamic flow. Viscosity, as it relates to hydrodynamic flow, controlled the penetration for a given substrate. Pressure provided the driving force for hydrodynamic flow. MC, temperature and time interacted in their influence on resin viscosity during hot-pressing.

28. *Brown, Kenaga and Gooch. 1966. Impregnation to Control Dimensional Stability of Particleboard and Fiberboard.*

Dimensional instability of particleboard follows a pattern similar to that demonstrated for other reconstituted, wood-based, panel products. The irreversible swell experienced and the attendant loss of physical integrity severely limit the utility of these reconstituted products in uses involving constant stress and severe moisture conditions. Flakes, prepared from scrub pine (*Pinus virginiana*, Mill.), and ponderosa pine (*Pinus ponderosa*), were impregnated by several techniques with various levels of PF resin, and of UF and PF resins mixes, and pressed into panels. Impregnation of the furnish prior to board manufacture provided significant control of irreversible swell, and this control was correlated with high retention of tensile strength and modulus of elasticity at water-soaked conditions.

29. *Brumbaugh. 1960. Effect of Flake Dimensions on Properties of Particle Boards.*

This study was undertaken to provide a more detailed picture of the flake geometry's and board properties' interrelationships and to determine the applicability of published length-thickness (aspect) ratios to a wider range of specific gravity and resin content, and to other physical tests in addition to bending strength. Douglas-fir flakes of 4 sizes (ie., 1/2, 1, 2 and 4-inch-length; 0.009, 0.012, 0.015

and 0.018-inch-thick) were made into boards with 2 levels (ie., 3 and 5 percent) of resin and 3 levels (ie., 0.65, 0.75 and 0.85) of board specific gravity. The results showed that long flakes produced high modulus of rupture, short thick flakes gave good internal bonds, long thin flakes promoted dimensional stability and the optimum aspect ratio was 150-250.

30. ***Brunette. 1991. Properties of Waferboard/OSB Manufactured from Alternate and/or Mixed Species: A Literature Review.***

This study reviewed the uses of species such as: ashes, balsam poplar, balsam fir, spruces, maples, oaks, trembling aspen, tamarack, white birch, yellow-poplar, sweetgum, sweetbay, black tupelo, hickorys and elms in the production of oriented strandboard. Mechanical properties of waferboard are affected to a large extent by the density of the wood species used. Mixing species with different physical and anatomical characteristics generally results in boards with inferior properties. It is possible to enhance all mechanical properties by utilizing special construction techniques and optimizing flake geometry, moisture and press closing time. A three-layer construction thus allows a greater utilization of medium and high-density species with an aspen furnish. There appear to be limits however, at which the manipulation of these variables can no longer compensate for the detrimental effects of low compaction resulting from the inclusion of large amounts of dense hardwoods. The utilization of these species on a large scale may require a number of changes in current waferboard manufacturing practices, notably in log preparation and handling, flake geometry and species arrangement, type and level of resin and panel density. Modulus of elasticity appears to be the critical property limiting the utilization of high-density species at conventional board densities. This suggests that dense hardwoods could best be used as core material. A three-layer construction appears to provide the best opportunity for the production of acceptable panels from mixed low-density/high-density hardwoods at conventional board densities. The inclusion of low-density species in face layers should provide the density gradient necessary for the development of good bending properties. The utilization of isocyanate resins may provide satisfactory IB strength with high density wood furnish in the core without unduly increasing board density. Further research is recommended to evaluate the technical and economical feasibility of bonding mixed hardwood species with isocyanate resins.

31. ***Brunette. 1993. Strandboard from Mixed Species.***

Strands were produced in the laboratory using a CAE 6/36 disk waferizer. Results of screen analyses indicated that the strand size distributions of furnish produced from freshly cut spruce (*Picea glauca*), pine (*Pinus banksiana*) or fir (*Abies balsamea*) slabs were generally similar to those generated from softwood logs of the same species. Strand yield was affected to some extent by the infeeding method used to process the slabs. Material freshness was, however, more crucial to achieve an acceptable level of strand yield and quality. All single-species or mixed-species panels made with softwood furnish produced from fresh slabs, achieved MOR, MOE and IB values that exceeded CAN3-0437 R-1 minimum requirements. Bending properties of panels made from fresh slabs were generally equivalent to those of panels made from softwood logs of the same species. Internal bond strength of panels made from fresh spruce, pine or fir was equivalent to that of panels made from 100 percent aspen. Thickness swelling (TS) after 24-hour soaking was slightly lower for aspen panels than for those made from spruce, pine or fir and mixing softwood furnish with aspen tended to increase thickness swelling. With the exception of balsam fir, the performance of panels made from softwood logs was not significantly better than that of panels made with slab material (fresh or dry). Thickness swelling values were generally higher for balsam fir panels than for those made from pine or spruce. The infeeding method used to process slabs (ie., radial cut vs. tangential cut) did not seem to have a significant impact on thickness swelling. All panels exceeded the maximum TS level allowed under CAN3-0437 R-1. TS values for aspen panels were, however, only marginally higher than the 10 percent level allowed for panels with a nominal thickness of 12.7 mm or less.

32. *Burrows. 1961. Some Factors Affecting Resin Efficiency in Flake Board.*

The objective of the study was to investigate several factors suspected of influencing resin efficiency. Extensive observations were made on the wood particles (flakes), atomization of the synthetic binder (phenol-formaldehyde resin), and glue bond in the pressed board. Flakes measuring 0.015 by 1.0 by 1.0-inch were produced from Douglas-fir lumber of 2 moisture contents (ie., 116 and 23 percent) and manufactured into boards with 2 moisture content conditions (ie., 6 and 9 percent) and 2 resin levels (ie., 6 and 2 percent). Qualitative evaluations of the flakes showed that damage from flaking was restricted to flake surfaces and extended on cell, or sometimes two cell widths, inward. Surface roughness (as qualified by several lighting techniques) was not found to be related to moisture content. One observation during this evaluation was that fast grown examples of flakes exhibited smoother surfaces than slower grown flakes. Quantitative evaluations demonstrated that both internal bond (IB) and modulus of rupture (MOR) were sensitive to resin content and moisture content. MOR and IB both increased when the resin content was augmented from 2 to 6 percent. Moisture content at time of flaking had a negative effect where the lower level (ie., 23 percent) produced higher MOR and IB in the panel. Degree of resin atomization had a significant positive effect on IB, but no effect on MOR.

33. *Carll. 1989. Influence of Some Factors on Curvature of Disk-cut Flakes.*

This study examined curvature of disk-cut flakes in relation to wood species (ie., balsam fir, eastern hemlock, large-tooth aspen, red oak, and American beech), flake face grain, rake angle, inclination angle, flaker disk speed, and method of flake drying. Flake curvature was measured at each flake end by comparison with a template of concentric circles. All factors studied influenced curvature in at least some cases, and the factors often interacted. Species was the most important factor; flakes from high-density species (beech and oak) curved more than those from low-density species (aspen, fir, and hemlock). In most species, rake angle was inversely related to flake curvature. Flakes cut at a 45-degree rake angle generally had tighter curvature radii than those cut at 60 degrees. Species and rake angle also influenced the effect of the other factors. Because of these interactions, the general influence of face grain, inclination angle, drying method and disk speed was marked by exceptions. Nonetheless, tangential-grain flakes generally had smaller curvature radii than corresponding radial grain flakes, and flakes cut at a 0-degree inclination angle generally had smaller curvature radii than corresponding flakes cut at 19 degrees. Drying method had significant influence only for aspen flakes cut at a 60-degree rake angle; reconditioned oven-dried flakes had smaller curvature radii than corresponding reconditioned air-dried flakes. Disk speed was important for only oak and aspen flakes cut at a 60-degree rake angle; flakes cut at 1,046 nominal disk revolutions per minute (rpm) had tighter curvature than corresponding flakes cut at 1,543 nominal rpm.

34. *Carll. 1989. Ring Flakes from Small-Diameter Eastern Hardwoods.*

Ring-cut flakes were produced from stems of six species of eastern hardwoods (ie., large-tooth aspen, American beech, red maple, white oak, black tupelo and yellow poplar). Stems were 6 inches or smaller in diameter and were not debarked. Despite the fact that meticulous care was exercised to keep stems and chips clean, flaker knives dulled rapidly. The rapid dulling appears to result from the high silica content chips of most of the species and probably reflects bark content. Bulk density measurements and screen analyses were performed, and results of these evaluations were reported. Flakes from the larger screen fractions were measured. The vibratory screener used in this study appeared to sort flakes more effectively by width than by length.

35. *Chen, Popowitz, Gertjejansen, and Ritter. 1992. Paper Birch as a Core Material for Aspen Oriented Strandboard and Waferboard.*

Three-inch-long paper birch strands and wafers of two widths and two thicknesses were used for the cores (33% by weight) of laboratory phenol-formaldehyde-bonded aspen oriented strandboards (OSB) and waferboards over a density rage of 37 to 43 pcf. Properties evaluated were internal bond (IB), moduli of elasticity (MOE) and rupture (MOR), and, after a 2-hour boil bond durability test, thickness swelling (TS), irreversible thickness swelling (ITS), linear expansion and loss of MOR. For the critical properties of IB, TS and ITS, panels from thin-wide birch core strands and wafers were statistically superior to the all-aspen panels, with the exception of the OSB IBs, which were statistically equal. Thick birch core geometries generally had deleterious effects on the critical core properties of IB, TS and ITS. Geometry of core strands and wafers had little or no influence on MOR and MOE.

36. *Chow, Rolfe, and Xiong. 1988. Oriented Strand Boards Made from Six Three-Year-Old Hardwood Species.*

Both oriented strand boards and homogeneous flakeboards were made from three-year-old, short-rotation tree stems of autumn olives (*Elaeagnus umbellata* Thumb.), black alder (*Alnus glutinosa* L.), black locust (*Robinia pseudoacacia* L.), poplar (*Populus spp.*), royal paulownia (*Paulownia tomentosa* Thumb., Steudel), sycamore (*Platanus occidentalis* L.) and a mixture of four species. These plantations were planted on marginal agricultural land that was not suitable for food production in Illinois. A factorial experiment was designed. The dependent variables were bending modulus of elasticity, internal bond, thickness swelling, water absorption and linear expansion properties. The treatments involved tree species, board density, resin content, board construction, cutting direction and exposure conditions (air-dry and 2-hour water boil). Most of the flakeboards produced in the laboratory met specifications required for the exterior grade type of flakeboard. The black locust appears to be a desirable tree species for oriented strand board production. Black alder flakeboards obtained the highest retention values of modulus of rupture, modulus of elasticity and internal bond after specimens exposed to the 2-hour boil. The flake alignment increased values of modulus of rupture and modulus of elasticity in the direction of the alignment and also affected the average linear expansion. The test results indicated that these juvenile hardwood plantations have a good potential for use as a raw material for the structural flakeboard industry.

37. ***Dost. 1971. Redwood Bark Fiber in Particleboard.***

Three-layer particleboards prepared from redwood particles including 0, 10, 20 and 30 percent redwood bark fiber were studied at three resin levels. In general, board performance became poorer as bar fiber content increased. At least part of this decline may be attributed to factors other than bark level. Among these are lack of uniformity of resin application at different bark levels and lack of uniformity in the blended furnish.

38. ***Drechsel, Kutscha and Shuler. 1978. Spent Sulfite Liquor Binder for Eastern Spruce Flakeboard.***

The purpose of this study was to investigate the possibility of producing a structural flakeboard utilizing eastern spruce and a spent sulfite liquor binder. Experimental panels were produced with 2 eastern spruce flake types (ie., engineered flakes and wafers), 2 binder sizes (ie., accepts and rejects as defined by 200-mesh screen), 2 resin quantities (ie., 2.5 and 4.5 percent) and 3 different mat lay-ups (ie., all engineered flakes, all wafers, or wafer faces and engineered flake core). Smaller binder particles gave a better distribution over the surfaces of the wafers and flakes. The smallest binder size at the highest resin application level exhibited the lowest percentage thickness swell. Bending strength increased with the highest resin application, smallest binder size and wafers on the surface of the board. Internal bond (IB) increased with the smaller binder size and with the wafer-sized material. Torsion-shear strength increased with the smaller binder size. The layered panel outperformed both all-wafer and all-flake boards. The average dry moduli of rupture and elasticity and wet modulus of rupture of this board class exceeded the commercial standard requirements; however, the average IB was slightly less than that required of a 2B2 particleboard.

39. ***Filho. 1981. Influence of Wood Furnish Type on Properties of Oriented Strand Panels.***

Panels made from oriented strands or flakes provide good structural properties but previous data have indicated only strands from roundwood produced adequate structural properties. Strands from pulp chips produced weak boards. This study was made to determine if suitable panels could be made with mixtures of grand fir roundwood strands and pulp chip strands. Furnish including 25 percent of grand fir pulp chip strands provided panels with 99 percent of the modulus of rupture and 98 percent of the modulus of elasticity (in the aligned direction) found in all-roundwood strand panels. Linear expansion perpendicular to alignment was also about the same with two types of furnish. Larger additions of pulp chip strands have an increasingly deleterious effect on strength properties and linear expansion. Internal bond strength increased with pulp chip strand additions up to 45 percent but decreased as the proportion of pulp chip strands increased above that amount. Thickness swell was not influenced by the addition of pulp chip strands. Overall the data indicate that some pulp chip strands can be used in structural flakeboard or oriented strand panels with no damage to the structural performance of the panels.

40. ***Furuno, Hse, and Côté. 1983. Observation of Microscopic Factors Affecting Strength and Dimensional Properties of Hardwood Flakeboard.***

To determine microstructural factors affecting strength and dimensional stability of hardwood flakeboard, fluorescence microscopy was used to observe the internal structure, distribution of resin on the flake surface and fracture surfaces of tested flakeboard specimens. Among the wood species (ie., white oak, red oak, post oak, sweetbay, red maple, white ash, black tupelo and sweetgum) examined, sweetbay proved to be an ideal species for the production of flakeboard because it provides good bonding or contact of flakes and because it has good conformability when compressed, thus yielding few cracks in the flakes. At the other extreme, microchecks were always observed in flakeboard containing oak, regardless of species mixture and mixture ratio. Oak was the prime cause of separation between the flakes due to poor bonding. The effect of resin application variables -- such as drum speed, quantity of flakes, resin content, species mix, powder resin, flake moisture content and flake type -- on resin (cured and uncured) distribution on hardwood flakes before board formation was also examined. In high-density species, it was found that the pore zone portion is one of the main factors leading to poor bonding because it diminishes the amount of effective bonding surface of the flakes. Resin tends to concentrate in the vessel lumens, where it cannot contribute to the bond.

41. ***Gardner and Elder. 1990. Bonding Surface Activated Hardwood Flakeboard with Phenol-formaldehyde Resin: I. Physical and Mechanical Properties.***

In an attempt to improve flakeboard properties and reduce phenol-formaldehyde resin levels in flakeboard production, surface activation by hydrogen peroxide, nitric acid or sodium hydroxide was used to pretreat flakes prior to bonding with phenol-formaldehyde resin. Physical and mechanical properties of the flakeboard panels made from red oak, red maple, sweetgum and southern pine were assessed by determination of internal bond, static bending measurements and thickness swell and water absorption measurements after 24-hour soak and 2-hour boil tests. The surface activation treatments significantly improved the modulus of rupture and modulus of elasticity values, but the internal bond values and dimensional properties were significantly reduced. Increasing the phenol-formaldehyde level from one to four percent improved board properties. Individual species responded differently to the surface treatments examined. Sweetgum had the most positive response to surface treatment, but overall, it produced a very inferior board. The sodium hydroxide treatment appears to be the most promising surface activator examined, particularly with red oak. Lowering phenol-formaldehyde levels in flakeboard below four percent does not appear to be practical when using surface activation treatments.

42. ***Gardner, Ostmeyer and Elder. 1991. Bonding Surface Activated Hardwood Flakeboard with Phenol-formaldehyde Resin. II. Flake Surface Chemistry.***

The effect of surface activation on flake chemistry of several southern species (ie., red oak, red maple, sweetgum and southern pine) were evaluated by the application of solid-state analytical instrumentation. Analytical methods included X-ray photoelectron spectroscopy, diffuse reflectance Fourier transform infrared spectroscopy and carbon-13 nuclear magnetic resonance spectroscopy with cross polarization and magic angle spinning. Differences in flake surface chemistry among species were detected, and the surface treatments showed varied effects on modifying flake surface chemical functionality. Earlier work showed that surface activation treatments react with phenol-formaldehyde resin, and the results of this study support the earlier findings that the activating agents react chemically to a greater extent with the phenol-formaldehyde resin gap filler than the flakes surfaces in the flakeboard bonding process.

43. *Gatchell, Heebink and Hefty. 1966. Influence of Component Variables on Properties of Particleboard for Exterior Use.*

This exploratory study of exterior-type particleboard was designed to evaluate the influence of the major component variables on end-use properties. A "standard" 40-pound-per-cubic-foot Douglas-fir flakeboard was adopted containing 6 percent phenolic resin and 1 percent wax. The uncompressed mat was prepressed under 400 pounds-per-square-inch prior to insertion into a hot-press heated to 350°F. After being pressed for 15 minutes, the board was cooled, conditioned to equilibrium at 80°F, 65 percent relative humidity, and sanded on both faces. The component variables chosen for evaluation were resin content, wax content, board density, mat moisture content and flake geometry. In addition, post treatments of paint, paper overlay and water repellent were included. The species of the "standard" board was varied to include redwood, aspen and southern pine. Several special constructions were added. The experimental boards were evaluated according to ASTM D1037-64 standards and in-house methods for static bending and internal bond strength, dimensional stability (linear expansion), thickness swell after accelerated aging and thickness swell after 1 year of exposure site conditioning. Resin content was identified as the most significant variable affecting the performance in all tests. Thinner flakes resulted in improved thickness swell characteristics. The addition of wax improved the resistance to weather, but no difference was found among 1, 2 or 4 percent wax contents. Of minor influence on overall properties were prepressing pressure and mat moisture content prior to hot-pressing. An increase in density resulted in an increase in the amount of compressive strains with a resultant increase in thickness swell.

44. *Geimer. 1976. Flake Alinement in Particleboard as Affected by Machine Variables and Particle Geometry.*

The extent of alinement achieved varied with the flake type (Douglas-fir), but in general was limited by flake length. Defining flakeboard with randomly dispersed flakes as being 0 percent alined, a maximum alinement of 26 percent was attained with 3/4-inch ring flakes, while a 74 to 76 percent alinement was possible with 2 and 3-inch disk flakes. Free fall, that distance from the bottom of the alinement machine to the top of the mat, is an important factor in achieving alinement. With the apparatus under consideration, the effect of flake width in determining degree of alinement varied with the type of flake and plate spacing, but in general was of minor importance. When the top surface of all alinement plates is in the same plane, rate of material feed dependent on the interaction between plate spacing, vibration frequency, vibration amplitude and flake type. Staggering the height of alternate plates led to as much as a thirteen-fold increase in feed angle. Average alinement angle can be estimated from the ratio of MOE parallel to MOE perpendicular, and is well correlated with linear expansion perpendicular to the alined direction. MOR correlates well with MOE throughout the total range of flake alinement. Flake dispersion, measured by the standard deviation of the flake alinement angle, is reduced as the percent of alinement increases. Consequently, as better alinement is approached, small changes in the average alinement angle create progressively larger changes in bending characteristics. MOE's of over 1,100,000 pounds per square inch and MOR's over 6,500 pounds per square inch are obtainable by a 40 percent alinement of 0.5 by 2-inch disk flakes, prior to the point where LE perpendicular to the alinement direction exceeds the limit established for a type 2B2 board in CS 236-66. Alinement of high quality flakes will allow construction of species panels with extremely good bending properties in one direction. In addition, flake alinement makes possible the use of lower quality wood to increase the raw material available for structural products.

45. ***Geimer. 1979. Data Basic to the Engineering Design of Reconstituted Flakeboard.***

Flakeboards made with uniform densities throughout their thicknesses and different degrees of flake alignment were used to establish relationships between bending, tension and compression values of modulus of elasticity or modulus of rupture (or stress to maximum load) and the variables of specific gravity and flake alignment. Three types of Douglas-fir flakes and three types of northern red oak flakes were used to construct experimental panels at 4 density levels and at each of 4 degrees of alignment with the Douglas-fir flakes. An equation using sonic velocity as an indicator of alignment was developed that describes the relations over a broad range with a high degree of confidence. Bending stiffness of boards having a density gradient were predicted within approximately ±20% using the derived relationships.

46. ***Geimer. 1980. Predicting Flakeboard Properties: Improvements in Bending Properties by Aligning a Mixture of Flakes.***

The bending properties of random and oriented flakeboards, fabricated from a mixture of Douglas-fir flake types, vary in accordance with the percent of each flake type used. Stiffness and strength of aligned boards can be predicted from the properties of similar random boards if the degree of flake alignment is known. Less variation in localized compaction ratios (horizontal density gradients) in aligned boards may account for less thickness swelling and lower internal bonds than found in random flakeboards.

47. ***Geimer. 1981. Predicting Shear and Internal Bond Properties of Flakeboard.***

This report presents the analysis of interlaminar shear, rail (or edgewise) shear, and internal bond data. Evaluations are made of several flake types, two species (ie., Douglas-fir and northern red oak), and several degrees of flake alinement. Relations defining interlaminar shear and rail shear in terms of specific gravity and flake alinement of flakeboard have been developed for several flake types. Equations relating internal bond to specific gravity are also given. Prediction of rail shear values using the above equations was relatively accurate. Considerable variation existed in predictions of interlaminar shear and internal bond properties.

48. ***Geimer. 1982. Dimensional Stability of Flakeboards as Affected by Board Specific Gravity and Flake Alignment.***

The objective was to determine the relationship between the variables specific gravity (SG) and flake alignment and the dimensional stability properties of flakeboard. Douglas-fir and northern red oak boards manufactured without a density gradient were exposed to various levels of relative humidity and a vacuum-pressure soak (VPS) treatment. Changes in moisture content (MC), thickness swelling and linear expansion were measured and used to develop regression equations. Under board saturation conditions resulting from VPS, dimensional movement could be defined as a function of SG without regard to MC. The relationship between SG and MC was essential in defining dimensional stability changes at exposure conditions resulting in MC's below fiber saturation because equilibrium MC and equilibrium dimensional stability are independently time-related to SG and they vary with flake type and exposure conditions. Derived regression equations were used to predict thickness swelling in three-layer boards with reasonable accuracy. Reliable prediction of linear expansion depends on the analysis of many board properties.

49. *Geimer. 1982. Steam Injection Pressing.*

A process developed at the U.S. Forest Products Laboratory injects saturated steam into a flakeboard mat during press closure to reduce the time needed to bring the centerline of the flakeboard to resin curing temperatures. Total press-time for a ½-inch (13 mm), 40 lb/ft^3 (641 kg/m^3), phenolic-bonded Douglas-fir flakeboard has been reduced by 60%, without degrading internal bond or flexure properties. Control over plasticization of the mat reduces press closing pressures and provides a means to significantly alter the vertical density profile.

50. *Geimer. 1986. Properties of Structural Flakeboard Manufactured from 7-year-old Intensively Cultured Poplar, Tamarack, and Pine.*

The objective of this study was to determine the effect of species and clonal variation on structural properties, and to compare the results to those obtained previously when 6-year-old material was used. Structural flakeboard made from 7-year-old intensively cultured tamarack and jack pine was less durable and had poorer mechanical properties than either of two poplar hybrid clones grown under the same conditions. With few exceptions, the tamarack boards were superior to those made from jack pine. A severe reduction in board specific gravity for both coniferous species, a result of excessive "out of press" thickness change (springback) was attributed to presence of bark in the furnish. Both bending and dimensional stability properties suffered from the inclusion of the bark. Boards made with 7-year-old *Populus* material had reduced bending but increased internal bond properties when compared to boards made with similar 6-year-old material. The same strength differences attributed to clonal variation in younger poplars were also found in the boards made from the 7-year-old material.

51. *Geimer and Crist. 1980. Structural Flakeboard from Short-rotation Intensively Cultured Hybrid Populus Clones.*

Raw material from 4 to 6-year-old hybrid poplars, grown under short-rotation, intensive culture (SRIC), was used to fabricate structural flakeboards. The physical and mechanical properties of these flakeboards were studied for the effects of such raw material variables as clone type, age, growth rate and plant spacing. Processing variables included chipping methods and several bark, twig, bud and fines compositions. Both homogeneous and three-layer board configurations differing in flake geometry and orientation were manufactured using several resin contents and types. Anatomical and physical characteristics of the raw materials were used to explain differences in the physical and mechanical properties of the boards. These data indicate the *Populus* raw material from SRIC has potential for fabrication of structural flakeboard. Bending stiffness (MOE) values above 450 kpsi (3,103 MPa) were attained with 6-year-old material, using a random flake configuration in a homogeneous board. Alignment of face flakes increased MOE and MOR in the direction of alignment to maximum values of 950 kpsi (6,650 MPa) and 6,900 psi (47.6 MPa), respectively. Data indicate that differences in the raw materials due to clone and cultural practices can affect board quality.

52. ***Geimer and Price. 1978. Construction Variables Considered in Fabrication of a Structural Flakeboard.***

Flake geometry, flake quality, flake alignment, average density, density gradients, layer thicknesses and resin content were factors considered in determining the final construction details on structural flakeboards made from western softwood (ie., Douglas-fir) and southern hardwood and softwood (ie., white oak, hickory, southern red oak, sweetgum and southern pine) residues. After making compromises between board properties, a three-layer design was recommended for both board types. Long, thin face flakes enhanced bending properties while thick core flakes maximized internal bond strengths. The lower compaction ratio associated with high-density hardwood species restricted the range of the variables used, as compared to those considered by the softwood board. The use of high-quality surface flakes and a surface water spray were other methods used to improve the performance of the hardwood board. Alignment of face flakes substantially increased the bending properties in the aligned direction for both board types. Being bound on one hand by economics and on the other by strength and durability requirements, a liquid phenolic resin content of 5 to 6 percent was used for the binder. By carefully choosing construction variables and fabrication techniques, acceptable panels from forest and mill residues were recommended for structural application.

53. ***Geimer, Montrey and Lehmann. 1975. Effects of Layer Characteristics on the Properties of Three-layer Particleboards.***

Three-layer Douglas-fir particleboards were constructed in three thicknesses, using both random and oriented flake alignment. Face layer density and consequently board bending stiffness increased with an increase in either face weight or board thickness. Face density was further altered by "steam shock" methods. The resulting fast closure increased face density at the expense of flake bonding quality. Graphs are included showing the dependency of board effective MOE on the amounts and types of core and face material. Linear expansion is compared for boards having aligned and random face flakes. Bending stiffness predictions made with mathematical formulas developed for three-layer and multilayer particleboards were verified by several test methods. Results show that variation in stiffness predictions using layer characteristics is comparable to variation experienced with board properties and test methods.

54. ***Geimer, Mahoney, Loehnertz and Meyer. 1985. Influence of Processing-induced Damage on Strength of Flakes and Flakeboards.***

The objective of this study was to characterize surface and internal flake quality in terms of the type and extent of degradation caused by both the flaking and hot-pressing processes. In addition, the study was designed to assess the effect of variations in these processes on the strength properties of flakes and flakeboards. Microscopic examination of Douglas-fir flakes using polarized light failed to reveal any internal damage in the form of collapsed or sheared cell walls, slip planes or compression wrinkles caused by the flaking process. However, cellular structural damage in the form of cell-wall buckling, shearing, tension and bending failures was noted in microtomed sections prepared after the flakes had been exposed to a series of pressing operations in which closing speed, board specific gravity and press temperatures were varied. Most of the failures were found in the earlywood and were caused by crushing from latewood areas of overlapping adjacent flakes. No differences in the type of flake damage caused by various combinations of the pressing variables were noted. Damage varied only in degree; the higher the specific gravity of the board, the greater the damage to the flakes. Tension tests on individual flakes both before and after pressing showed the extreme variability of this property. Statistical analysis showed an overall decrease in the average strength and stiffness of flakes subjected to pressing (13 and 34 percent, respectively), but indicated that high press temperatures favor flake strength. This was attributed to either a reduction in damage due to increased plasticization or a repair of damage by lignin flow. Test results on boards made from flakes visually characterized as good and poor confirmed our observations. Tensile and internal bond strengths of boards made from poor flakes and pressed at low temperatures averaged only 55 percent of the strength of boards made from good flakes. The strength of boards made with poor flakes but pressed at high temperatures averaged 78 percent of the strength of boards made with good flakes. These results suggest that pressing temperature influences the performance of damaged flakes more than either board specific gravity or press closure rate.

55. ***Generalla, Biblis and Carino. 1989. Effect of Two Resin Levels on the Properties of Commercial Southern OSB.***

The effect of two resin levels of liquid phenol-formaldehyde, 4.5 and 6.5 percent resin solids, on certain physical and mechanical properties of commercially fabricated oriented flakeboards was determined at 65 percent relative humidity (RH), 72°F; after 48-hour soaking; and after soaking and then reconditioning back to original condition. The panels used in this study were fabricated in a commercial plant in the U.S. South from flakes consisting of approximately 60 percent southern yellow pine (*Pinus echinata*) and a 40 percent mixture of sweetgum and yellow-poplar. In general, board properties improved at the higher resin level. At the original condition, observed improvement ranged from 6 percent in internal bond (IB) strength to 14 percent in modulus of rupture (MOR)-perpendicular; however, these increases were not statistically significant. At the cycled condition, increased resin level significantly increased the MOR-parallel (15%), MOR-perpendicular (23%) and the IB (25%). The average strength retention after cycling was 66 percent; boards with 6.5 percent resin had approximately 10 percent higher strength retention than the boards with 4.5 percent resin. Dimensional changes were generally less at 6.5 percent than at the lower resin level.

56. ***Gertjejansen and Hedquist. 1982. Influence of Paper Birch on the Properties of Aspen Waferboard: A Mill Trial.***

The properties of 7/16-inch commercial waferboard manufactured from a wafer mixture of 70 percent aspen - 30 percent paper birch by weight compared favorably to those of all-aspen waferboard. Modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond (IB) of the aspen-birch board ranged from 90 to 96 percent of those of the all-aspen board. After the Canadian Waferboard Standard CAN-0188.0-M78 2-hour boil, the MOR and MOE of the aspen-birch boards were, respectively, 87 and 96 percent of those of the all-aspen boards. The information from previous laboratory studies indicates that if birch content were reduced to 10 to 15 percent there would be little or no differences between aspen-birch and all-aspen boards.

57. *Gertjejansen and Panning. 1985. Method for Waferizing Balsam Poplar.*

When waferizing balsam poplar, waferizer knives eventually can become wrapped with gelatinous fibers which reduces their effectiveness and results in poor quality wafers and an increased amount of fines. Using a laboratory waferizer, it was found that waferizing balsam poplar alternately with paper birch improved wafer quality and reduced the amount of fines because the fiber-wrapped knives were cleaned when they came in contact with the high-density birch.

58. *Gertjejansen, Haygreen, Hyvarinen and French. 1973. Physical Properties of Phenolic Bonded Wafer-type Particleboard from Mixtures of Aspen, Paper Birch, and Tamarack.*

Phenolic bonded wafer-type particleboards were made at densities of 38, 43 and 48 lb./ft.^{3} from pure aspen, paper birch and tamarack and from seven mixtures of the three. Aspen and tamarack were superior raw materials at the lower densities. The strength properties of all mixtures were good for the high-density class. The average property values of the three density levels showed that birch and tamarack, when compared to aspen, decreased MOE and linear stability but increased thickness stability. Birch decreased MOR, and tamarack increased IB and resistance to decay fungi.

59. *Girschner and Stokke. 1991. Structural Flakeboards from Aspen-Red Maple Mixtures.*

Aspen is the main furnish used by flakeboard mills in the Great Lakes States. Unfortunately, the aspen supply is decreasing while the red maple supply is increasing in this region. If this trend continues, alternatives to aspen and increased usage of red maple may become necessary. Many mills avoid using significant quantities of red maple due to its high density. However, by mixing it with aspen, the overall furnish density could be reduced to achieve adequate compaction during pressing. To examine this possibility, flakeboards were made from mixtures of aspen and red maple disk flakes. The boards were made with a 40 pound per cubic foot target density and had the following aspen to red maple weight ratios: 100:0, 85:15, 70:30, 50:50 and 0:100. The boards were conditioned and then tested for mechanical and dimensional properties dry, and after soaking and reconditioning. The dry moduli of rupture and elasticity decreased with increasing red maple content. Dry internal bond (IB) strength was not adversely affected by high amounts of red maple. Thickness swelling stability improved with increasing red maple content as did the percentage of internal bond strength retained. Results indicate that boards having acceptable properties could potentially be produced with significant amounts of red maple with no substantial change in manufacturing practices. High quantities of red maple should perform well as a core furnish for flakeboard.

60. *Harpole. 1978. Economics of Producing Flakeboard Decking from Hardwoods.*

Techniques for producing thick flakeboard roof decking from dense hardwoods have been determined. This paper describes the techniques used and the results of economic assessments of the commercial potential for manufacturing roof decking at a hypothetical southern Indiana site. Analyses of several possible design specifications for hardwood flakeboard roof decking led to a least-cost specification for 1.125-inch (28.6 mm) thick, three-layer red oak board. Economic analysis indicated that red oak roof decking could be manufactured and profitably sold for approximately $317 per-1,000-ft^2 (2.65 m^3) on a 1.125-inch basis (based on 1976 costs). A price as high as $362 per-1,000-ft^2 could become price competitive with ribbed steel and insulation board systems.

61. ***Harpole and Ethington. 1978. Cost of Manufacturing Structural Flakeboard from Forest Residues.***

U.S. Forest Service research indicates that structural flakeboard products can be produced from both hardwood and softwood forest residues. Production costs were computed for sixteen possible structural flakeboard manufacturing sites based on experimental results with three-layer board compositions and estimates of investment and operating costs. Costs computed include taxes, profits, and other manufacturing costs. By computing production costs, excluding wood costs and computing the coefficient for converting wood cost per ovendry ton to production costs that include associated increases in selling, tax, and profit costs, total production cost is expressed in an "a + bX" equational form. Feasibility can then be assessed by matching expected production costs to likely FOB mill market values for product output.

62. ***Hart and Rice. 1963. Some Observations on the Development of A Laboratory Flake Board Process.***

Changes in laboratory procedures and materials resulted in pronounced improvement of flakeboard quality. This study was conducted to determine the relative importance of these various changes. Two types of flakes (ie., sweetgum planer and yellow-poplar veneer), two blender designs, two spray systems (airless and air), two resin temperatures at time of spraying and two concentrations of resin solids in the mix were investigated. The type of flake and the blender design proved to be the factors primarily responsible for increasing board quality by more than 100 percent.

63. ***Haygreen and French. 1971. Some Characteristics of Particleboards from Four Tropical Hardwoods of Central America.***

The bending strength (MOR) of three flake-type particleboards from Central American hardwoods (ie., aceituna, banak and gallina) varies from 6000-6800 psi as compared to 5200 psi for an aspen control. The boards were produced at a density of 45 pounds per cubic foot with a urea-formaldehyde resin content of 8 percent resin solids. A fourth tropical species (jobo) was found unsuitable for flaking so a splinter-type board was produced which was somewhat inferior to the other tropical boards, but about equal in strength to the aspen board. A board type was produced from a combination of species and found to be equal in properties, except thickness swelling, to the single species products. Weight losses of particleboard samples of the various board varied from 3 to 56 percent when subjected to two fungi for 3 months in a soil-block test.

64. ***Heebink. 1974. Particleboards from Lodgepole Pine Forest Residue.***

Typical unbarked lodgepole pine forest residue (minimum diameter, 3 inches) was used to produce structural-type flakeboards. Douglas-fir flakeboards were fabricated for comparison. Results indicate no technical difficulties in producing structural flakeboards (either an all-flake board or a flake-faced board with a sliver core). Minimum performance requirements for U.S. acceptance require definition before specific structural boards can be recommended and designed. Interior core-type particleboards were made by processing pulp chips produced in the field. Several additional types of core-type particleboards which meet current specifications were also made without encountering technical difficulties.

65. *Heebink. 1975. Grain Angle Through Flake Thickness: Effect on Properties of a Structural Flakeboard.*

The strength and stiffness of solid wood is affected greatly by the slope of grain through the specimen. This raises the question of whether the strength of a flake-type structural particleboard is affected in a similar manner with similar slopes of grain through the flake thickness. To explore this relationship, 0.020- by 1/2- by 2-inch Douglas-fir flakes were made at various carefully controlled grain angles through the thickness. Tests on 1/2-inch-thick flakeboards made with 5 percent phenolic resin showed that the reduction in strength as related to slope in grain was almost identical to that in solid wood. With a slope in grain of 1:5, the tensile strength parallel to the face was slightly less than 40 percent of that in test specimens having parallel grain. The linear movement of the flakeboards was also appreciably affected by slope in grain, being about five times as much with a slope of 1:5 as it was with parallel grain. Similar reductions were found in bending strength and stiffness. All of these tests emphasize the importance of doing whatever can be done practically to keep the grain angle approximately parallel to the length of the flake if high strength, stiffness and low linear movement are desired.

66. *Heebink and Hann. 1959. How Wax and Particle Shape Affect Stability and Strength of Oak Particle Boards.*

The primary purpose was to determine the effect of particle shape and inclusion of wax on the dimensional changes in particle boards conditioned to constant weight at various relative humidities. Secondary objectives were to consider the effect of different particle shapes on strength properties, and to learn about the amount of fines produced. Six types of particles were produced from northern red oak. The results showed that boards made with 1-inch-long flakes were the strongest in all respects and the most linearly stable. Other boards, in order of strength, were of 1/4-inch-long flakes, planer shavings, slivers, fines and sawdust.

67. *Heebink and Lehmann. 1977. Particleboards from Lower Grade Hardwoods.*

Properties and characteristics are reviewed for particleboards prepared from hardwood residues of number of species (ie., basswood, yellow-poplar, red oak, hickory, aspen, elm, and maple). In general, hardwood particleboards met or exceeded the minimum properties defined in Commercial Standard CS 236 for both Type 1 (interior) and Type 2 (exterior) applications. However, certain anomalies in the data suggest a need for further research in the areas of wood-adhesive interactions, particularly with the higher density hardwoods. An appendix of research references is included for hardwood usage in composite panel products other than particleboard.

68. *Heebink, Hann and Haskell. 1964. Particleboard Quality as Affected by Planer Shaving Geometry.*

Prepared flakes produce better quality particleboard than do planer shavings. The research reported here centers primarily on redesign of the planer to yield more flake-like shavings. Properties of Douglas-fir particleboards were correlated to variations in planer design, including head diameter, feed rate, depth of cut, head angle, throat design, rake angle and combinations of these variables.

Properties of the test boards were compared to those of high-quality flakeboards of the same species and density. Variations in the planing operation, especially in the head angle and knife-mounting details, resulted in notable improvement in the properties of particleboards produced from these improved shavings.

69. ***Heebink, Lehmann and Hefty. 1972. Reducing Particleboard Pressing Time: Exploratory Study.***

Minimum press-times depended primarily on a suitable combination of time and temperature to cure the binder and dispel sufficient moisture to avoid steam blisters. An adequate 1/2-inch-thick board was produced in as little as 1 minute press-time by proper selection of variables. Variables most effective in reducing press-times were higher press temperature, fast press closing and nonuniform mat moisture contents. Data were obtained from strength tests on more than 90 boards with five replicate tests per board and three species (ie., Douglas-fir, aspen and southern pine).

70. ***Heebink, Schaffer, Chern and Haskell. 1977. Structural Flakeboards Using Ring Flakes from Fingerling Chips.***

Forest residues consist of wood sections which vary in size and shape. A convenience when processing forest residues as raw material for flakeboards is to reduce the material to "fingerlings"---wood pieces 2 to 3 inches in length and 3/4 to 1 inch in cross-sectional area. In this study, West Coast forest residues of Douglas-fir and western hemlock were made first into fingerlings and then onto flakes. Homogeneous flakeboards using ring flakes made from the fingerlings were evaluated for bending strength (MOR) and stiffness (MOE), both before and after accelerated aging. Strength values of fingerling-ring flake panels were compared to the values for disk-flake panels, because disk flakes are more commonly used for structural flakeboards. The fingerling-ring-flake panels were 14 percent lower in initial MOR than disk-flake panels, and 15.5 percent lower in MOE. Thus it appears difficult to produce a random three-layer panel from fingerling ring flakes that is as strong as one from conventional disk flakes.

71. ***Holmes, Eickner, Brendan and White. 1979. Fire Performance of Structural Flakeboard from Forest Residue.***

Fire performance properties were determined for the Forest Service (FS) structural Douglas-fir flakeboard made from forest residues and for three commercial structural flakeboard products. Tests include fire endurance of wall systems, fire penetration, room corner-wall performance, 8- and 25-foot tunnel furnace, FPL rate of heat release, and smoke development by NBS smoke density chamber. Walls with the FS board met HUD Minimum property Standards for a 20-minute exterior dwelling wall. The board also met Class B flamespread Criteria, and in general, performed equal to or better than the commercial reference boards.

72. *Hoover, Hunt, Lattanzi, Bateman and Youngquist. 1992. Modeling Mechanical Properties of Single Layer, Aligned, Mixed Hardwood Strand Panels.*

Regression equations were estimated to predict the properties of mixed species single-layer panels. The species used were northern red oak, red maple, paper birch, green ash and trembling aspen. The first step was to produce a set of single-layer boards for each species. The regression equations developed to predict bending MOE and MOR, edgewise shear modulus and strength and tensile modulus and strength had an overall coefficient of determination of 0.63. The next step was to develop prediction equations for mixed species boards and produce a set of mixed species panels to test species boards and produce a set of mixed species panels to test the prediction equations. The single species equations were combined using the rule-of-mixtures -- the mixed species panel properties predicted to be the weighted average of the properties of the single species boards. On average, bending MOE and MOR predictions varied less than 5 percent in the aligned and 17 percent in the cross aligned direction from the realized mixed panel properties. Edgewise shear modulus and strength predictions varied less than 17 percent overall from the realized. Adequate prediction of complex properties such as IB and edgewise shear modulus may not be possible with an empirical approach.

73. *Hoover, Hunt, Lattanzi, Maloney and Youngquist. 1985. Implications of a Design Approach for Mixed Hardwood Structural Flakeboard.*

A technique for designing structural oriented strand panels composed of mixtures of hardwood species is presented. In addition, the role of product design and processing models in the development and implementation of competitive strategies in the structural panel industry is discussed. Single species, oriented strand panels were produced and tested for the development of regression equations to predict the single-layer properties of a multilayered panel. Species used were trembling aspen, paper birch, green ash, red maple and northern red oak. The input parameters included in the model were flake length, flake thickness, flake alignment and panel density. Mixed species panels were then produced to test whether the properties of mixed species layers could be predicted as a weighted average of the single-species prediction equations, the so-called rule of mixtures. This technique successfully predicted all properties except plate shear modulus and internal bond. It is proposed to use this approach to design multilayered, mixed species structural panels. Product design and process models increase the capability of firms in the structural panel industry to carry out differentiation, and focus on competitive strategies. Reliance of existing competitors on a cost leadership strategy provides an opportunity for less-risk averse firms to develop a sustainable competitive advantage with these alternative strategies. For a differentiation strategy, the models provide the capability to achieve cost proximity while incorporating the differentiated attributes at the least cost. For a focus strategy, the models provide the capability to achieve cost or differentiation attributes or cost structure necessary to capture the required share of the targeted market segments. Cooperative strategies for attacking nonwood markets are also discussed.

74. *Howard. 1973. Slash Pine Rootwood in Flakeboard.*

Flakes 3 inches along the grain, 3/8-inch-wide, and 0.02-inch-thick were machined from the taproots (with 6-inch-high stump) and second logs of eight 31-year-old slash pines. Specific gravity (O.D. weight, green volume) of stems averaged 0.52; rootwood averaged 0.43 and decreased sharply with depth below ground. Forty-four-lb/cu.ft. structural-type particleboards were prepared with random orientation of flakes and 5 percent phenol-formaldehyde solids. Stemwood boards were stiffer (737,000 psi MOE) than rootwood boards (643,00 psi MOE), but bending strength was lower (4,800 psi MOR) for stemboards than for rootboards (5,500 psi MOR). MOE/MOR ratio was 155 for stemboards and 118 for rootboards. The two types of boards did not differ in nail-withdrawal resistance (96 and 97 lb.). Internal bond of rootboards (114 psi) was almost double that of stemboards (60 psi); the difference was associated in part with the greater densification of rootwood (x 1.36). Root flakes were more conformable but had higher proportions of grain deviation and damaged surfaces. Rootboards had greater dimensional movement in both planes, greater soaked moisture content, greater thickness springback and greater recovery from linear swell. Interrelations of board properties differed for the two materials. Differences appeared to be primarily due to anatomical characteristics, lower inherent strength of rootwood, degree of densification and machinability.

75. *Hse. 1975. Formulation of an Economical Fast-Cure Phenolic Resin for Exterior Hardwood Flakeboard.*

Phenolic resins are excellent adhesives for exterior plywood , and a similar formulation technique can be readily applied to make an exterior flakeboard resin. Optimum viscosity for a flakeboard resin, however, is considerably lower than that of the conventional plywood resin. Consequently, the resin for flakeboard is far less advanced and requires a longer press-time to cure completely than plywood resin (ie., 8 to 10 minutes for flakeboard resin as opposed to 3 to 5 minutes for plywood resin). To reduce panel press-time, therefore, it is necessary to formulate a phenolic resin that will have maximum chemical reactivity. The investigation reported in this paper is one of a series of studies to develop fast-cure phenolic resin for manufacturing structural exterior flakeboard from mixed southern hardwoods (ie., southern red oak, hickory and sweetgum).

76. *Hse. 1975. Properties of Flakeboards from Hardwoods Growing on Southern Pine Sites.*

Boards 0.5 inch thick were made from 3-inch-long flakes of 9 species of southern hardwoods (ie., sweetgum, hickory, black tupelo, red oak, post oak, white oak, sweetbay, white ash and red maple) commonly found on pine sites. The main effects of species were due to variation in wood density; low-density species compacted readily when pressed, and the resulting good flake contact improved bonding and gave boards of high strength. With species having specific gravities above 0.6, it was difficult to form stiff boards without increasing density unduly. In black tupelo cross-grained flakes yielded boards of exceptionally low MOE, even though wood specific gravity was below 0.6. In white oak boards, substantial delamination occurred after a 5-hour-boil test. Within the range of the experiment, all species except white oak and post oak yielded boards of acceptable dimensional stability at board densities of 44.5 pounds per cubic foot or less.

77. *Hse. 1976. Exterior Structural Composite Panels with Southern Pine Veneer Faces and Cores of Southern Hardwood Flakes.*

One-half-inch-thick, structural exterior composite panels of various constructions were made in a one-step process, with faces of southern pine (loblolly) veneer and cores of southern pine (loblolly) veneer and cores of mixed southern hardwood (ie., red oak, hickory and sweetgum) flakes. The flakes were precisely machined to be 3/8-inches long, and 0.015-inch-thick. Two veneers, cross-laminated on each face over an oriented flake core, yielded the strongest panels. Panels with single veneer faces and random cores were most stable parallel to the grain of face plies. Average MOR of 9,153 psi and MOE of 1,731,000 psi for panels with single-veneer faces and random cores are considered more than adequate for most applications, even though these values are slightly lower than those of panels with two veneers on each face. Within the range of the experiment, the combinations of 1/16-inch, single-ply faces with a random core provided adequate strength and good dimensional stability. The simplicity of single-ply faces and the ease of forming random-flakes cores made such construction the best candidate for a one-step hot-press operation in existing panel plants. The panels had an average MOR of 10,400 psi and MOE of 1,696,000 psi. In vacuum-pressure-soak cycles the panels had water absorption of 101 percent and thickness swell of 24.2 percent; linear expansion parallel and perpendicular to the grain of face plies averaged 0.142 and 0.617 percent. Whole-panel density (at 5% MC) was about 41.8 pcf.

78. *Hse. 1978. Development of a Resin System for Gluing Southern Hardwood Flakeboards.*

A series of experiments was conducted to develop an effective economical resin system for gluing flakeboard of mixed southern hardwoods (ie., southern red oak, hickory and sweetgum). First, a phenolic resin was formulated with a second formaldehyde addition at reaction concentration of 47.5 percent and reaction temperature of 95°C. Such resin yielded satisfactory bonds in laboratory boards made of mixed hardwoods with: 1) a minimum resin content of 4 percent; 2) a minimum hot-press time of 4 minutes; 3) a maximum mat moisture content of 14 percent; and 4) a hot-press temperature of 325°F. The effects of board and wood density on bonding strength may best be expressed by flake compaction in the panel. Board strength increases in proportion to compaction ratio (i.e., the ratio between board density and wood density). Because high-density flakes require higher panel density than low density flakes to attain an adequate compaction ratio, boards of high-density species tend to be excessively heavy. To produce a flakeboard of acceptably low density from wood of many species and densities, a phenolic alloy of phenol-formaldehyde resin and polyisocyanate was developed. The key to this alloying process is first applying minor amounts of polyisocyanate before application of major amounts of phenolic resin on wood furnish, and then reacting the combined adhesive in situ to obtain an improved thermosetting adhesive resin suitable for hardwood flakeboard. The performance of the new phenolic alloy is superior to that of phenolic resin under high flake moisture content, low resin content, and low panel density.

79. *Hse. 1980. Effect of Resin Types and Formulation on Internal Bond Strength and Dimensional Stability of Hardwood Flakeboard.*

A series of experiments was conducted to develop effective and economical resin systems to improve dimensional stability or southern hardwood flakeboards. First, boards 0.5 inch thick were made from 3-inch-long flakes of nine species of southern hardwoods (ie., sweetbay, red maple, sweetgum, black tupelo, white ash, southern red oak, hickory, post oak and white oak). Dimensional stability was measured following 5-hour boil, vacuum-pressure soak and 50 to 90 percent RH exposure test. Within the range of the experiment, all species except white oak and post oak yielded boards of acceptable dimensional stability at board density of 44.5 per cubic foot or less. To improve dimensional stability, a resorcinol modified phenolic system was developed and tested. Although resorcinol adhesives have outstanding durability under severe test conditions, a resorcinol modified phenolic system resulted in little improvement in dimensional stability of hardwood flakeboard. To produce a flakeboard of acceptably high durability from wood of high-density species, a phenolic alloy of phenol-formaldehyde resin and polyisocyanate was developed. The key to this alloying process is to first apply minor amounts of polyisocyanate before application of major amounts of phenolic resin on wood furnish. Next would be to react to the combined adhesive in situ to obtain an improved thermosetting adhesive resin suitable for hardwood flakeboard. The performance of the new phenolic alloy is superior to phenolic resin under high flake moisture content, low resin content, and low panel density. The internal bond strength of all white oak and southern red oak panels with application of polyisocyanate before phenolic resin is more than 500 percent greater than the one with phenolic alone. Since IB is one of the most critical factors controlling the acceptable minimum panel density, the substantially greater IB "is considered a favorable factor for reducing panel density to improve dimensional stability.

80. ***Hse. 1982. Effect of Resin Alkalinity on Dimensional Stability of Hardwood Flakeboards.***

Hardwood flakeboards were prepared from sweetgum, red oak and white oak with 10 liquid phenolic resins. The phenolic resins were formulated with four molar ratios (0.4, 0.6, 0.8 and 1.0) of sodium hydroxide (NaOH to phenol). The ten resin formulations were obtained by adding the NaOH at two different times, one during resin preparation and one prior to resin application, and by varying the amount of NaOH applied at each addition time. The best dimensional properties were obtained with the resin formulated with 0.2 moles of NaOH applied during resin preparation plus 0.6 moles of NaOH added just prior to resin application. For sweetgum flakeboards, the internal bond increased as total NaOH content of the resin increased. The maximum internal bond for the oak flakeboards occurred with 0.8 mole of NaOH in the resin.

81. ***Hse. 1987. Bonding Dense Hardwoods for Structural Products.***

The objective of this project was to provide the technical data necessary to assess the feasibility of producing an acceptable flakeboard made with dense hardwoods. To accomplish this objective, the study consisted of a series of four experiments to: 1) determine the effects of species on flakeboard properties; 2) evaluate the properties of flakeboards made with species mixture of white oak and low-density hardwoods; 3) determine the effect of resin type on bonding of hardwood flakeboards; and 4) evaluate the performance of modified resins for manufacturing of dense hardwood flakeboard. Experiment 1 produced boards from the species with a density higher than 40 pounds per cubic foot (ie., this includes white ash, hickory, red oak, post oak and white oak) and the physical and mechanical properties were determined. Experiment 2 involved the fabrication of boards with a mixture of high and low-density species. High-density white oak was mixed with the lower-density species (ie., sweetgum, black tupelo, sweetbay, red maple, cottonwood and kiri) in various proportions. For Experiment 3, panels were manufactured with two resin types (powdered and liquid), two flake types (lathe and disk) and eight hardwood species (sweetgum, black tupelo, red maple, white ash, hickory, red oak, post oak and white oak). Experiment 4 investigated the red oak and white oak flakeboard fabricated with three resin systems (resorcinol-phenolic, melamine-phenolic and polyisocyanate-phenolic). The most important problem for bonding high-density hardwood is how to attain the desired strength at acceptable panel density. Mixing flakes from high-density woods with low-density hardwood flakes improves strength properties and dimensional stability of flakeboards. Lowering the panel density not only provided flexibility but also improved economic aspects of gluing dense hardwood by reducing essential wood and resin costs. Improvement of phenolic resins by addition of a second component or to form phenolic-alloy systems has demonstrated the potential for developing new adhesive systems for bonding dense hardwoods.

82. *Hse, McMillin, Koch, and Price. 1975. Laboratory-Scale Development of a Structural Exterior Flakeboard from Hardwoods Growing on Southern Pine Sites.*

A series of experiments was conducted to develop a 1/2-inch-thick, structural, exterior, mixed-species flakeboard functionally competitive with sheathing grades of plywood. The board design settled on is comprised of equal-weight portions throughout of *Carya* spp., *Quercus alba* L., and *Quercus falcata* Michx., *Liquidambar styraciflua* L., and southern pine (e.g., *Pinus taeda* L.). These species were cut with a shaping-lathe headrig to yield face flakes 0.015 inch thick and core flakes 0.025 inch thick. All flakes were 3 inches long; those used in the core were reduced in width by milling. Phenol-formaldehyde binder (5.5%) was blended with flakes initially at 4 percent moisture content. Just prior to pressing the mat was water-sprayed on both sides. Press-time was 5 minutes at 335^0 F. All panels had random flake orientation in the core; half the panels had random faces; the other half had faces comprised of aligned flakes. Properties observed in 18-inches-square panels at 50 percent relative humidity for random and aligned face flakes, respectively, were: 47.5 and 45.5 pound-per-cubic-foot densities; 83 and 82 psi IB's; 800,000 and 1,090,000 psi MOE's and; 5,300 and 6,625 psi MOR's.

83. *Hsu. 1978. Waferboard Made from Mixed Hardwood Species.*

The main purposes of this study were to evaluate the feasibility of making waferboard from mixed Canadian wood species employing conventional techniques of waferboard manufacture, and to develop data on their properties. To fulfill these purposes, 5 separate experiments were carried out investigating the effects of single-species, mixed-species, binder types, wafer geometry, and processing variables on the performance of the panel. Aspen, red maple and white birch were the hardwood species used for the investigation. The results of the experiments showed that the mechanical properties of waferboards made from the mixture of white birch and aspen wafers decrease with increasing weight proportion (from 50 to 100 percent) of white birch. Waferboards made from the mixture of aspen and a high percentage of white birch wafers were found to have a large variability in board properties. Waferboards made from layers of aspen and red maple had excellent mechanical properties. Making waferboard by layering low- and high-density wafers could be a good method for incorporating high-density species into the product.

84. *Hsu. 1982. Structural Panels Made from Southern Hardwoods.*

This study was undertaken to determine to what extent the current waferboard manufacturing process, which has developed around the aspen resource, can be utilized with a mixture of medium to high density wood species (ie., ash, hickory, pecan, red oak, sweetgum and white oak) from the southern U.S. It has established that medium-density (41-42 pcf) structural panels can be produced in the laboratory, but a number of deviations from current practice appear to be necessary. Within the limitations of this study, some important findings can be summarized as follows: (1) Liquid phenol-formaldehyde (PF) resin has better performance than powdered PF resin for flakeboard made from southern hardwood species, especially white oak; (2) To achieve satisfactory board properties in the medium-density range, wafer thickness should be in the order of 0.020-inch; (3) Although 3 percent liquid PF resin (based on solids) seems sufficient with mixed species, a higher resin content is required for making flakeboard from white oak; (4) At a given board density (in the 41 to 44 pcf range), and with given process variables, low-density species tend to give slightly better strength properties; (5) Good wafers could not be obtained from most of the species studied. Instead, most yielded strands which seemed to give satisfactory results; (6) Because of the negative effect of white oak on board properties, the technical and economical benefits of its exclusion should be considered; (7) As with all waferboards/strand boards, especially of mixed high-density species, large wafers tend to not only generally increase properties but also variability of these properties. The choice between long (2.5 to 3-inch) and short (1.5-inch) wafers or strands warrants a technical and economic study; (8) As a result of the low compactness ratio, and for the board thickness range considered, the benefits of alignment are doubtful; (9) The appearance of 41 to 42 pcf mixed hardwood species panels may cause marketing problems. It can be improved by increasing density to about 44 pcf. Other solutions, such as paper overlay or specific applications, should be considered.

85. ***Hughes and Gertjejansen. 1984. Spruce Budworm-killed Balsam Fir as a Raw Material for Flakeboard and Waferboard.***

Laboratory phenol-formaldehyde (PF) bonded waferboards (3% powdered PF) and flakeboards (6% liquid PF) were manufactured from 100 percent healthy balsam fir; 100 percent healthy aspen; and from 50-50 percent combinations of aspen with each balsam fir raw material type except that waferboards were not made from the 3-month-dead balsam fir. Wafer size averaged 1.5 inches long by 0.03-inch-thick by random width. Flakes were made by ring flaking 5/8-inch-long chips; flake thickness averaged 0.018-inch. All panel types exceeded the minimum property requirements, including bonding system durability, of American National Standard ANSI A208.1-1979 for grades 2-MW and 2-MF particleboards. Statistical comparisons of strength properties showed that the panels containing the balsam fir raw material types were superior to the 100 percent aspen panels in more cases than they were inferior. In other words, balsam fir, either alive or dead, has definite potential as a complete or supplemental raw material for waferboard and flakeboard. More specifically, waferboards from healthy balsam fir and balsam fir dead 1 year or less were equal to or better than 100 percent aspen waferboard except for the following: the non-aged internal bond strengths (IBs) of the 100 percent and 50-50 healthy balsam fir waferboards and the moduli of rupture and elasticity of the 100 percent 1-year or less, either by themselves or in 50-50 combination with aspen, resulted in flakeboards with properties equal to or better than those of the 100 percent aspen flakeboard. Strength properties, notably IBs, of waferboards and flakeboards made with 2-year-dead balsam fir were sometimes lower than panels made from 100 percent aspen. Therefore, the amount of that material that could be used in combination with aspen and the other balsam fir raw material types apparently would be something less than 50 percent if the objective were to meet the IBs of the 100 percent aspen panels.

86. ***Hujanen. 1972. Comparison of Three Methods for Dimensionally Stabilizing Wafer-Type Particleboard.***

Particleboard was manufactured in the laboratory from balsam poplar (*Populus balsamifera*) wafers which had been pretreated with 3, 6 or 12 percent impregnating phenol formaldehyde (IPF) resin and nonimpregnated wafers. Nonimpregnated boards were tested with no treatment, after poststeaming in 360°F saturated steam for 10 minutes, or after post-heat-treatment for 2 hours at 425°F. All treatments had favorable effects upon thickness stability. The most effective treatments were poststeaming and 12 percent IPF resin. These two treatments were equally effective in controlling dimensional stability, while postheating compared closely with 6 percent IPF resin. Pretreatment with 12 percent IPF resin and poststeaming were the only treatments to significantly reduce linear swell. The addition of any level of IPF resin appeared to effectively control linear springback.

87. *Hunt, Hoover and Harpole. 1983. Hardwood Structural Flakeboard for Industrial/Commercial Roof Decking: Successes and Problems to Solve.*

The industrial/commercial roof decking market appears to offer an opportunity to utilize low-grade hardwoods. Using the identified engineering and economic use requirements for long-span roof decking as design constraints, thick, three-layer hardwood structural flakeboards were designed to satisfy these constraints. Designs were developed for aspen and northern red oak, representing the practical extreme density species of the potential eastern hardwoods resource. It was reasoned that if success was realized with the extreme density species, then research would be focused on the practical problem of species mixtures. Laboratory panels 2 by 3-foot (0.61 by 0.91 m) and 2 by 8-foot (0.61 by 2.44 m) in size were manufactured successfully according to the design specifications. Results indicated that the aspen industrial/commercial roof decking product could be commercialized using existing oriented strand board plants and would complement these plants' product mixes. The red oak designs produced a product which satisfied the use requirements, while their densities were less than or equal to the density of the wood from which they were made. Inadequate interlaminar shear strength was obtained when scaling up red oak designs to full-size panels [2-1/2 by 12-foot (0.76 by 3.66 m)]. Although the shear strength did not meet specification, the large panels, when tested in full-scale structural assemblies simulating roof sections, satisfied building code requirements. Preliminary projections of economic feasibility were promising, based on the economic situation before the recession of 1981-1983.

88. *Hunt, Hoover, Fergus, Lehmann and McNatt. 1979. Red Oak Structural Particleboard.*

Demand for softwood timber will rise more rapidly than supply through the year 2000. At the same time, demand for hardwood timber is expected to grow at a slower rate than supply, continuing the current pattern of expanding inventories. However, much of this underutilized inventory is in small size, low quality, or cull trees. Further, relatively dense species predominate in the mixed hardwood stands of the eastern United States. Manufacture of well-bonded, nonstructural particleboard entirely from dense hardwoods has customarily been accomplished by producing panels that are too dense and heavy for traditional uses. Expectedly this weight problem would be magnified if the intended product was a relatively lightweight, high-performance, structural particleboard. A three-layer structural particleboard with faces of aligned particles was manufactured entirely from northern red oak (*Quercus rubra* L.) furnish. After evaluating its engineering and dimensional stability properties, it was concluded that it is possible to manufacture a high-performance, durable structural particleboard from high-density species at an overall panel density equal to or less than the density of the raw material. This research suggests the possibility of manufacturing structural particleboard from an underutilized resource that is in close proximity to the major construction markets of the eastern United States.

89. ***Hunt, Hoover, Lattanzi and Youngquist. 1984. A Design Approach for Mixed Hardwood Structural Flakeboard.***

Single-species, aligned wood-strand panels were produced and tested for the development of regression equations to predict the single-layer properties of a multilayered panel. The species used in this study were aspen, paper birch, green ash, red maple and northern red oak. The input parameters included in the models were flake length, flake thickness, flake alignment and panel density. Mixed species panels were then produced to test whether the properties of mixed species layers can be predicted as a weighted-average of the single-species prediction equations, the so-called rule of mixtures. This technique successfully predicted all properties except plate shear modulus and internal bond. It is proposed to use this approach to design multilayered, mixed-species structural panels.

90. ***Jackowski and Smulski. 1988. Isocyanate Adhesive as a Binder for Red Maple Flakeboard.***

The possibility of using an isocyanate adhesive as a binder in red maple flakeboard was investigated. The modulus of elasticity, modulus of rupture, accelerated exposure modulus of rupture and linear expansion of experimental isocyanate-bonded flakeboards was equal to that of phenol-formaldehyde-bonded controls. Internal bond and thickness swell properties of isocyanate-bonded flakeboards were superior to those of flakeboards bonded with phenol-formaldehyde. It was concluded that the use of isocyanate adhesive as a binder in red maple flakeboard was feasible.

91. ***Johns, Rammon and Youngquist. 1985. Chemical Effects of Mixed Hardwood Furnish on Panel Properties.***

Wood from five species of hardwoods (aspen, green ash, paper birch, red maple, and northern red oak) were characterized for pH, buffering potential, bound and soluble acids, water and alcohol-benzene soluble extractive. In addition, all acidity tests were performed on mixtures of these five species. Flakeboard panels were produced from matched wood samples and the correlations between chemical qualities of the wood and mechanical properties of the panels were developed. Chemical tests showed that wood mixtures do not follow ideal mixture behavior. The degree of nonideality depended on the individual species involved. Statistical analysis showed that strong correlations exist between the pH, bound acid, and soluble acid of both individual species and mixtures of species and the internal bond of panels. Shear strengths were also correlated with these chemical factors. For individual species, internal bond regressed against bound acids, $r = 0.99$, while for mixtures $r = 0.97$.

92. ***Johns, Layton, Nguyen and Woo. 1978. The Nonconventional Bonding of White Fir Flakeboard Using Nitric Acid.***

Techniques for the nonconventional bonding of wood, an approach which attempts to induce chemical changes at the surface of wood, are briefly reviewed. The properties of flakeboards manufactured by treating white fir flakes, first with nitric acid followed by an aqueous mixture of ammonium lignosulfonate-furfuryl alcohol-maleic acid, are discussed. Comparisons with phenol-formaldehyde bonded control boards show that the nonconventional bonding technique yielded boards with higher MOE and lower thickness swell and absorption, while the phenolic bonded boards had higher MOR and IB values. Effects of nitric acid concentration, application rate, assembly time, pot life of cross-linking mixture and total assembly time on the physical properties of the nonconventionallly bonded panels are discussed.

93. ***Jokerst. 1968. Long Term Durability of Laboratory-made Douglas-fir Flakeboard.***

Douglas-fir flakeboards containing different resin binders in varying amounts and having different densities were tested by exposure to the weather, to an accelerated aging exposure of the American Society for Testing and Materials (ASTM), and to four laboratory-controlled exposures. After exposure the flakeboards were tested to determine the amount of deterioration. Tests after 1, 2, 3, 4 and 8 years of exposure outdoors indicated that much of the deterioration of the specimens occurred during the first year. Deterioration continued at a lesser rate throughout the exposure period, with some specimens completely disintegrating. Painted flakeboards were more durable than unpainted and showed little if any change in their mechanical and physical properties. After 8 years of outdoor exposure, boards with phenolic-resin binders proved to be considerably more durable than those with urea or melamine-urea binders. Test-fence exposure of 8 years was more severe than six cycles of the ASTM accelerated aging on phenolic-bonded flakeboards. The six-cycle ASTM test and the repeating cyclic exposure of 158°F. and 20 percent relative humidity followed by 80°F. and 90 percent relative humidity were the only controlled exposures that approached the severity of outdoor weathering.

94. ***Jokerst. 1989. Weatherability of Xylitol-Modified Phenolic-bonded Flakeboard.***

The purpose of this investigation was to determine if the water repellency exhibited by Douglas-fir flakeboard bonded with a xylitol-modified phenolic adhesive would improve the performance of the flakeboard during 1 year of exterior exposure. Before and after exposure, static bending, internal bond, thickness swell and weight gain, and linear expansion of these flakeboards were compared to those properties of flakeboards bonded with a commercial phenolic adhesive. The static-bending properties of panels bonded with xylitol-modified phenolic adhesive or commercial phenolic adhesive were not significantly different before or after exterior exposure. Similarly, internal bond strength was not affected by exposure. However, in the 24-hour water-soak test, thickness swell and weight gain of panels bonded with xylitol-modified phenolic adhesive were less than that of panels bonded with the commercial phenolic adhesive, before and during exposure. After exposure, the thickness swell of panels was the same for both adhesive systems. Linear expansion from 30 to 90 percent relative humidity was the same for both adhesive systems before and after exposure. This indicates that initially the mechanism of action of the xylitol-modified phenolic adhesive is similar to that of wax. It reduces adsorption of liquid water, but not of water vapor.

95. ***Jokerst. 1990. Hydroxymethylated Lignin-bonded Douglas-fir Flakeboard.***

A hydroxymethylated lignin (HML) adhesive system is one of several alternative adhesive systems being investigated by the Forest Products Laboratory. Douglas-fir flakeboards bonded with HML were evaluated by measuring modulus of rupture, modulus of elasticity, thickness swell, water absorption and internal bond strength before and after accelerated aging. The values obtained were compared with those from Douglas-fir flakeboards of similar density bonded with 6 percent (oven-dry basis) commercial phenolic resin. The HML-bonded flakeboards compared favorably with flakeboards bonded with the commercial phenolic resin when a mat moisture content (MC) of $\geq$ 16 percent and a total adhesive content of 12 percent (oven-dry basis) were used. The high mat MC of the HML-bonded flakeboards necessitated the use of long press-times at a fairly high press temperature to prevent blown boards. Nonetheless, the combination of high mat MC and long press-time improved the dimensional stability of the flakeboards. In addition, Fourdrinier screens used as release mechanisms were found to aid in venting steam from the panel surfaces. This resulted in higher core temperatures in the panels during the press cycle. Cost data are unavailable for the HML adhesive system, and therefore an economic comparison between this adhesive and other adhesives cannot be made at this time.

96. ***Jokerst and Conner. 1988. Evaluation of Flakeboard bonded with Xylitol-modified Alkaline Phenolic Resin.***

Douglas-fir flakeboards bonded with a xylitol-modified alkaline phenolic resin were compared with similar flakeboards bonded with a commercial phenolic flakeboard resin. The properties compared were modulus of rupture (MOR), modulus of elasticity (MOE) internal bond (IB) strength, and thickness swell after 2 and 24 hours of water soaking. The MOR and MOE values obtained were not significantly different for the flakeboards made with the different resins. IB of the flakeboards was compared before and after accelerated-aging exposure. Before the aging exposure, IB strength did not differ significantly for the two resin types. After accelerated aging, IB strength was significantly lower in specimens bonded with the xylitol p-modified phenolic resin than in those bonded with a commercial phenolic resin. However, the average IB strength for the flakeboard bonded with xylitol-modified phenolic resin exceeded the minimal requirements for type 2MF as specified by ANSI A208.1. Measurements taken after the 24-hour water-soak exposure indicated that material bonded with xylitol-modified phenolic resin increased in thickness substantially less than material bonded with a commercial phenolic resin. The xylitol-modified resin apparently makes flakeboard more water repellent than the commercial phenolic resin.

97. ***Jorgensen and Murphey. 1961. Particle Geometry and Resin Spread: Its Effect on Thickness and Distribution of Glue-Line in Oak Flakeboard.***

The purpose of this study was to investigate the effects of particle geometry and resin spread on the thickness and distribution of glue-line in scarlet oak (*Quercus coccinea*) flakeboard. The combinations of flake length and thicknesses used in this study encompass those used in typical commercial operations. Four flake lengths (ie., 0.5, 1, 2 and 4-inch), four flake thicknesses (ie., 0.006, 0.012, 0.025 and 0.050-inch), and three resin spreads (ie., 3.27, 6.54 and 13.07 g/m^2) were used to construct the experimental boards. The glue-line thickness was not influenced by flake thickness or resin spread at the smallest flake length; however, at the other three lengths the spread significantly affects the glue-line thickness.

98. ***Jorgensen and Odell. 1961. Dimensional Stability of Oak Flake Board ... as affected by particle geometry and resin spread.***

The purpose of this study was to investigate the effects of particle geometry and resin spread on the dimensional stability of scarlet oak flakeboard. Four flake lengths (ie., 0.5, 1, 2 and 4-inch), four flake thicknesses (ie., 0.006, 0.012, 0.025 and 0.050-inch), and three resin spreads (ie., 3.27, 6.54 and 13.07g/m^2) were used to construct the experimental boards. Thin flakes and high resin spreads give a board with good thickness stability properties. Equilibrium moisture content was increased by increases in resin spread, while thickness changes were limited. Unassembled flakes that had the resin treatment also equalized at a higher equilibrium moisture content in absorption than either the dried or freshly cut flakes.

99. ***Kamke and Casey. 1988. Fundamentals of Flakeboard Manufacture: Internal-mat Conditions.***

Real-time measurements were made of temperature, gas pressure and compaction pressure in the face and core regions of flakeboard panels during manufacture. Data from the manufacture of 24 yellow-poplar flakeboard panels are presented. The effects of press closing time, initial mat moisture content, and platen temperature on internal-mat conditions are discussed. The trends in mat temperature and gas pressure are explained in terms of fundamental concepts of heat and mass transfer, stress relaxation and phase equilibria. These phenomena occur simultaneously and are strongly interrelated. Internal temperature and gas pressure data can be used to help explain the formation of density gradients in wood-particle composites.

100. ***Kamke and Casey. 1988. Gas Pressure and Temperature in the Mat During Flakeboard Manufacture.***

Local internal-mat conditions of temperature, moisture content, gas pressure, and stress history interact to affect adhesive cure, wood densification and the subsequent panel properties. Data is presented to illustrate the effects of press temperature and initial moisture content on measured gas pressure at the face and core layers of a yellow-poplar flakeboard mat. Face and core gas pressures increase at different rates, but quickly equalize early in the press cycle. The internal temperature and gas pressure are in part related to the saturated water vapor pressure.

101. ***Kamke and Wolcott. 1991. Fundamentals of Flakeboard Manufacture: Wood-moisture Relationships.***

A procedure is presented to estimate the relative vapor pressure, equilibrium moisture content, average flake temperature and average flake moisture content in a yellow-poplar flakeboard mat during hot-pressing. This method is based on measurements of temperature and total gas pressure in the mat during hot-pressing. A heat and mass transfer model was adapted from the literature to predict the temperature and moisture content inside an individual flake. Significant moisture gradients are predicted to develop within flakes. Convective heat transfer appears to control the change of moisture content within a flake. Thermodynamic equilibrium between the gas phase and the wood component is not achieved during hot-pressing.

102. ***Kellogg and Swan. 1986. Physical Properties of Black Cottonwood and Balsam Poplar.***

The objective of this study was to characterize selected properties of black cottonwood and balsam poplar to determine whether these species should be distinguished in their utilization. At present, black cottonwood is excluded from the "northern aspen" species group embraced by the National Lumber Grading Agency grading rules for dimension lumber and from use as core material in softwood plywood. Samples of black cottonwood were obtained from three sites in British Columbia. Samples of balsam poplar were obtained from three sites in Alberta. Ten trees were randomly selected from each site and a single 130 cm long bolt was collected immediately above breast height (1.36 m) from each tree. From two trees on each site, three additional bolts of the same length were collected immediately above the height positions located at 25, 50 and 75% of total tree height. The average basic specific gravity of the two species did not differ significantly (black cottonwood, 0.338; balsam poplar, 0.337) in this study. However, differences do exist between site averages, at least for black cottonwood. The initial green moisture contents differ significantly (black cottonwood, 160.5%; balsam poplar, 120.6%) and may be expected to affect their drying requirements differentially. For both species, the specific gravity increases and the green moisture content decreases with increasing height position in the tree. The average fiber length of black cottonwood is significantly longer than that of balsam poplar. The bending properties of strength and stiffness for black cottonwood were found to be significantly greater than for balsam poplar. Variation of these properties with height position in the tree was studied. Fiber length was found to decrease with increasing height position, while the bending strength properties were not affected by height position.

103. ***Kelly. 1977. Critical Literature Review of Relationships Between Processing Parameters and Physical Properties of Particleboard.***

The pertinent literature has been reviewed, and the apparent effects of selected processing parameters on the resultant particleboard properties, as generally reported in the literature, have been determined. Species referenced include aspen, yellow birch, hickory, slash pine, redwood, ponderosa pine, white fir, sycamore, paper birch, lodgepole pine, Douglas-fir and sugar maple. Resin efficiency, type and level, furnish, and pressing conditions are reviewed for their reported effects on physical, strength and moisture and dimensional properties. A serious deficiency in the research appears to be lack of consideration of the within-panel density gradient and its effects on physical properties.

104. ***Kelly and Price. 1982. Durability of Structural Flakeboard from Southern Hardwoods Species.***

Flakeboard panels made with individual species (sweetgum, hickory, red oak, white oak and pine) and with a 20 percent mixture of each species were subjected to a series of exposure conditions. Mechanical and physical properties were determined and compared to commercial waferboard. At 50 percent RH condition, sweetgum, red oak and hickory panels had properties similar to the commercial waferboard at a similar density (42 pcf). However, after the APA 6-cycle exposure and the oven-dry-vacuum-pressure soak exposure, only sweetgum retained physical properties equal to waferboard.

105. ***Kelly and Price. 1985. Effect of Species and Panel Density on Durability of Structural Flakeboard.***

Structural flakeboard panels made with species of sweetgum, hickories, red oaks, white oaks and southern pines, and with a 20 percent mixture of each species group, were subjected to a series of exposure conditions. One of the exposure conditions consisted of a Xenon arc lamp with an intermittent water spray from conventional weatherometer test equipment. Other exposure conditions were the APA six-cycle and the over-dry-vacuum-pressure soak exposures. Mechanical and physical properties were determined and compared to commercial waferboard. At 50 percent RH, sweetgum, red oak, hickory, pine and the mixed-species panels all had properties similar to the commercial waferboard at a similar density (42 pcf). However, after the APA six-cycle exposure and the oven-dry-vacuum-pressure soak exposure, only sweetgum retained physical properties equal to waferboard. Experimental panels of all species groups with higher panel densities than waferboard had similar property retentions as waferboard when exposed to the conditions in this study. None of the experimental panels performed as well as the commercial waferboard in the weatherometer tests. White oak panels were unacceptable after all exposures.

106. ***Kieser and Steck. 1978. The Influence of Flake Orientation on the MOR and MOE of Strandboards.***

The purpose of this paper is to cite certain important technological factors pertaining to oriented strandboards as products unto themselves and as related to their use as corestock for composite panels. The premise is that board stability and other properties are influenced by the controlled orientation of the long, slender flake particulate or strands. An essential element in producing strandboard panels is a mat forming machine that is capable of orienting the strand materials with controlled consistency. A new former for accomplishing orientation will be presented followed by a discussion of panels and their properties as produced using the new former. Board properties for spruce oriented strand board and composite panels (ie., Douglas-fir veneer faces and spruce oriented strand board cores) were reported.

107. ***Koch. 1976. New Approaches, New Machines to Utilize Hardwoods on Pine Sites.***

This paper describes the operation and product of the shaping-lathe headrig which produces cants and flakes from debarked wood. A structural flakeboard made of hickory, white oak, southern red oak, sweetgum and southern pine flakes produced by the shaping-lathe headrig is reported.

108. ***Kuklewski, Blankenhorn and Rishel. 1985. Comparison of Selected Physical and Mechanical Properties of Red Maple (Acer Rubrum L.) and Aspen (Populus Grandidentata Michx.) Flakeboard.***

Wood from red maple (*Acer rubrum* L.) and aspen (*Populus grandidentata* Michx.) was processed and fabricated into flakeboards with a target density of 50 lb/ft^3. The data collected served as a basis for evaluating red maple as a potential raw material for flakeboard. Within the study parameters, random and aligned flake orientations were compared for both species. Moisture content, density and flake alignment measurements revealed within and between-board uniformity. Red maple flakeboards equaled or exceeded the performance of aspen flakeboards in static bending, internal bond and nail withdrawal tests. In addition, red maple flakeboards containing randomly oriented flakes required higher loads to failure in nail withdrawal and internal bond tests compared to mechanically aligned flakes. Dimensional stability data of the flakeboards were obtained by measuring thickness swell, water absorption and linear expansion. For both the random and aligned boards, the measured values indicated no substantial difference between the aspen and red maple specimens. In addition, mechanical alignment of the flakes improved some of the properties of the flakeboards compared to the randomly oriented flakeboards.

109. ***Larmore. 1959. Influence of Specific Gravity and Resin content on Properties of Particle board.***

The objective of this study was to determine the character of the relationships of the specific gravity of the species, specific gravity of the particleboard, resin content of the panel with strength and dimensional stability of flakeboards made from aspen and yellow birch. Aspen boards were found to be stronger and more stable than the yellow birch boards. The lower density aspen was compressed more to achieve the board thickness and thereby provided better contact for efficient resin cure. With both species, boards with a higher resin content expanded less.

110. ***Lehmann. 1965. Improved Particleboard Through Better Resin Efficiency.***

The study was conducted in two parts. In both parts, the method of spraying, the solids content of resin and the temperature of resin were studied with commercial Douglas-fir flakes. In the second part, the degree of atomization and the time required to apply resin also were studied. Standard pressing conditions were followed as far as possible. Both urea and phenol binders were used; a dye was added to determine distribution of resin on flakes. Duplicate boards were prepared for each experiment, and duplicate specimens from each board were tested for strength and stability. Specimens were also exposed out of doors for periodic measurements of dimensional stability and for strength tests after suitable periods. Viscosities of resin were measured, sizes and volumes of droplets were determined and microscope slides of cross sections were prepared form the boards. Fine atomization and a suitable length of time to allow uniform distribution of resin were much more important in producing boards of high quality than methods of spraying, solid content of resin or the temperature at application.

111. ***Lehmann. 1968. Resin Distribution in Flakeboard Shown by Ultraviolet Light Photography.***

This note is intended as a supplement to Lehmann's 1965 report presented in the Forest Products Journal. Douglas-fir boards, bonded with 6 percent urea-formaldehyde resins and 4 percent phenol-formaldehyde resins, were evaluated for average diameter of resin spray droplets and number of droplets in a given area. The illustrations showed that almost continuous gluelines could be obtained by fine spray and uniform distribution of resin on wood flakes with as little as 4 percent resin in the board. When resin efficiencies are compared by resin-droplet analyses, total droplets as well as average diameters should be considered.

112. ***Lehmann. 1970. Resin Efficiency in Particleboard as Influenced by Density, Atomization, and Resin Content.***

Resin efficiency in particleboards was studied using a Douglas-fir flake-particle mixture. Two levels of board density and resin atomization and three levels of resin content were studied. All variables were found to have controlling influences on board properties. Bending strength approached optimum levels between 4 and 8 percent resin content, while internal bond strength continued to increase with increasing resin content. Equations showed that savings in raw materials, either wood particles or resin, could be attained by use of proper resin application techniques. A simple technique using a reflection photometer to estimate coverage of wood particles with dyed resin was presented.

113. ***Lehmann. 1974. Properties of Structural Particleboards.***

Particleboards of adequate strength, durability and stability for structural applications may be produced if a suitable selection of manufacturing variables is used. In this study, optimum resin spread was found to be 1 pound of resin solids per 1000 square feet of flake surface, and optimum panel properties were obtained with Douglas-fir flakes 0.02 by 2 inches in size with a panel density of about 40 pcf. Such panels maintained at least 80 percent of MOR, 85 percent of MOE and 60 percent of IB after accelerated aging. Greater directional properties could be obtained by orientation of surface flakes or by the use of veneer overlays.

114. ***Lehmann. 1977. Durability of Composition Board Products.***

This study was designed to determine the effects of resin and wax content, as well as particle geometry, on panel properties after exposure to natural weathering and several accelerated aging regimes. A limited number of commercial panel products were included for comparison purposes. Experimental 40 lbs/ft^3 panels were made from Douglas-fir flakes and a liquid phenolic resin. Commercial panels included a three-ply exterior plywood, three-layer oriented strand board, three-ply oriented strand board (laminated), aspen waferboard and exterior shavings board. With exception of the waferboard, all products were of western softwoods. External exposure tests were run for 6 months, 1, 2, 5 and 10 years. Accelerated aging tests were conducted according to ASTM D 1037-72a (soak, steam, freeze, dry, steam and dry), VSPD (vacuum, soak, pressure and dry), ASTM D 2898-72 (spray, dry) and CSA 0188 (2-hour boil). Results showed that increased resin content had only minimal effects on bending properties (MOE and MOR), but significantly improved internal bond (IB) and thickness swell (TS) in both artificial and natural aging tests. Addition of wax also improved IB and TS for both aging situations. No consistent correlations were found between natural and accelerated weathering tests or between the various accelerated aging tests. The ASTM D 1037 test was the most severe, followed by the VSPD and the ASTM D 2898 test was least severe of all the cyclic tests studied.

115. ***Lehmann. 1978. Cyclic Moisture conditions and their Effect on Strength and Stability of Structural Flakeboards.***

Durability of phenol-bonded particleboards under accelerated aging conditions has been a matter of concern for many years. This exploratory study outlines a series of cyclic accelerated exposures on laboratory-prepared Douglas-fir, lodgepole pine and Engelmann spruce flakeboards and the effects of the exposure cycles on dimensional movement and strength retention. Exposures included the ASTM D-1037 test, vacuum-pressure-soak and OD cycles and high-low RH cycles. Generally, specimens which performed well in one exposure also performed well in others, but several new relationships were found. In particular, specimens responded differently in some ways to wet-dry cycles as compared to high-low humidity cycles. For instance, high-low humidity does not produce the longitudinal shrinkage associated with wet-dry cyclic conditions. Also, specimens which fared poorly in strength retention after wet-dry cycles often performed in an improved fashion following high-low humidity cycles. Thus, a wet-dry cyclic test may not be best for judging durability of products not intended for wet-dry cyclic exposures.

116. ***Lehmann and Geimer. 1974. Properties of Structural Particleboards from Douglas-fir Forest Residues.***

Strong, stable, durable structural particleboards can be manufactured from Douglas-fir forest residues. Panels were prepared utilizing various proportions of sound wood, bark, dead wood, decayed wood and branches. An expanded study investigated the effects of using mixtures of Douglas-fir and true fir/hemlock forest residues. Adequate properties were maintained as long as extreme amounts of bark and/or branchwood were not included in the panels. In addition, ash and silica contents of the residues were determined as well as the longitudinal dimensional stability of wood from the various residue size classes.

117. ***Lehmann and Hefty. 1973. Resin Efficiency and Dimensional Stability of Flakeboards.***

Dimensional stability was studied in Douglas-fir particleboards prepared from a flake-particle mixture. Three levels of resin content and two levels of resin atomization and board density were used, with dimensional stability measured in both relative humidity and water-soak exposures. Below 80 percent relative humidity, study variables had virtually no effect on amount of movement in either thickness or length. More change occurred between 80 and 90 percent relative humidity but only resin content affected the amount of movement. In contrast, all variables affected degree of stability in oven-dry-vacuum-pressure-soak conditions. Thus, while the soak test is fast and may be related to the relative humidity test, caution should be exercised in interpreting soak test data, especially where interior end uses are concerned.

118. ***Lehmann, Geimer and Hefty. 1973. Factors Affection Particleboard Pressing Time: Interaction with Catalyst Systems.***

Two catalysts were evaluated with the UF bonded boards and 3 catalysts for the PF bonded boards. Species investigated were Douglas-fir, aspen and southern pine. Upon determination of the best catalyst systems for both resin types, a second round of evaluation was performed with 5 different press recipes for the UF board and 2 for the PF board. In laboratory manufacture of particleboards, use of catalyst, high press temperature, fast closing, and nonuniform mat moisture content produced adequate 1/2-inch-thick, urea-bonded Douglas-fir panels in 1 minute and phenolic-bonded panels in 2 minutes press-time. The use of a catalyst allows the reduction of press-time by approximately 1 minute for urea-formaldehyde (UF) resin systems, but no reduction was obtained with catalyzed phenol-formaldehyde (PF) systems.

119. ***Li, Gertjejansen and Ritter. 1991. Red Pine Thinnings as a Raw Material for Waferboard.***

Red pine plantation thinnings were evaluated as a raw material for laboratory waferboards bonded with 2.5 percent powdered phenolic resin. Variables studied were red pine content (red pine/aspen ratios from 0/100 to 100/0), red pine wafer thickness and panel density. Generally, red pine thinnings were a comparable raw material to aspen. Static bending properties were independent of red pine/aspen mixtures, but internal bond and thickness swelling increased as red pine content increased. Thin red pine wafers improved static bending properties and thickness dimensional stability in 100 percent red pine panels.

120. ***Maloney. 1975. Use of Short-Retention-Time Blenders with Large-Flake Furnishes.***

The use of short-retention-time blenders with large-flake furnishes has been of concern because such blenders may act as attrition mills and break up the flakes. The object of this study, therefore, was to determine the effect on flakeboard properties when using short-retention-time blenders with large-flake furnish and to evaluate the damage to the flakes. Douglas-fir boards were produced with blending accomplished in a short-retention-time blender commonly used in the "conventional" particleboard process. Variables included three blender speeds, three liquid phenolic resin levels and three board specific gravity levels. These experimental boards were matched with control boards prepared in a laboratory rotary blender. In general terms, large -flakes furnish processed with the blender running at 600 rpm had an inadequate coverage of the resin. The furnish at 1,800 rpm suffered considerable damage. At the speed of 1,200 rpm, flakes suffered little damage and had an adequate resin distribution. Modulus of elasticity values were all similar, including those of the control boards, with the exception of some lower values at 600 rpm. Apparently the long flakes made the modulus of elasticity rather insensitive to resin distribution. Modulus-of-rupture relationships were basically the same as those for modulus of elasticity. The boards at 0.70 specific gravity made by means of the short-retention-time blender were about 15 percent to 30 percent lower in internal bond than the controls, depending on the resin level. These values were considered to be adequate for most applications. Those boards made with the short-retention-time blender running at 1,200 rpm exhibited the better values, particularly at the lowest resin level.

121. ***Maloney, Talbott, Strickler and Lentz. 1977. Composition Board from Standing Dead White Pine and Dead Lodgepole Pine.***

Dead trees of western white pine *(Pinus monticola)* and lodgepole pine *(Pinus contorta)*, while normally unacceptable for plywood and with limited acceptance for lumber, constitute an important potential resource for wood construction materials in the form of dry-process composition boards. It was demonstrated that, even after standing dead many years, the wood of such trees changed very little from that of live trees in characteristics important to composition board manufacture. A wide spectrum of desirable particles, ranging from flakes to fiber, can be produced. Compatibility with commercial composition board resin appears to be retained, as determined by chemical tests of the wood and internal-bond strength tests. It was concluded that the dead material of both white pine and lodgepole pine could be used effectively in various types of composition board formulations, but these would be reasonable changes according to today's board technology. Suitable properties were found in almost all cases studied. Lodgepole pine composition boards had relatively poor linear expansion, exceeding commercial standards, except in flakeboards. It appeared that this was due to a species effect. Of the particles studied, hammermilled, ring-cut flakes, atmospheric-and pressure-refined fiber appeared to be best. Drum-cut flakes were difficult to glue because of apparent surface quality damage due to flaking dry wood.

122. ***Maloney, Lentz, Saunders, Huffaker and Rammon. 1984. Alder as a Raw Material for Structural Panels.***

Red alder (*Alnus rubra*) is an abundant, low-density hardwood species readily available in western Washington and Oregon. It has great potential for use in composition board types of structural panels. This research explored the potential of structural panels by evaluating appropriate particle production and by producing experimental panels assessing bonding, bending properties, durability, dimensional stability and the effect of particle size, thickness and orientation. It was found that of the particle types evaluated, good wafers, ring-cut flakes from pulp chips and 1-1/8 and 2-inch strands could be easily produced. No bonding problems were found with conventional powder and liquid phenolic resins. Experimental panels, all of randomly oriented particles, met appropriate standards at conventional board specific gravities. Increasing board specific gravity enhanced physical properties, but had no effect on dimensional stability. Orienting the ring-cut flakes and the strands dramatically improved bending properties and linear expansion in the oriented directions. Orientation incorporated into panels to form crosslapped layers analogous to plywood could possibly reduce board density markedly while still maintaining suitable board properties. According to the durability evaluation conducted (*two-hour boil)*, the alder panels, generally, were good. Particle thickness at the two higher levels (ie., 0.020, 0.030- inch) had little effect on internal bond in boards of ring-cut flakes and 1-1/8 and 2-inch-long strands. A small difference (in internal bond) was observed in waferboard with the boards of 0.020-inch wafers being the best. In all boards, the thinnest particle (0.010-inch) yielded boards with the lowest internal bonds, but minimum property levels were easily met. Flake thickness did not affect modulus of rupture (*MOR)* and modulus of elasticity (*MOE)* in boards of wafer or ring-cut flakes. The thinner (0.010-inch) particle, however, in the two strand boards resulted in the higher MOR and MOE values. In both the linear expansion in a high humidity atmosphere and after drying and soaking, all of the different types of board had the lowest and, therefore, the best value when made with the 0.010-inch particles. As the particle thickness decreased, the surface area of the particles in a given board increased tremendously (approximately 50% when going from 0.030-inch to 0.020-inch particles and 300 % when the particle thickness was 0.010-inch). Nevertheless, board properties were relatively constant no matter which of the three particle thicknesses were used, although resin level was held constant by weight. Evidently, better comingling of the thin particles made more efficient use of the applied resin. This showed that consideration of flakes thickness solely as a measure of resin coverage and, therefore, resin efficiency is not appropriate. The oriented boards showed promise as construction grade lumber as they exceeded the design values for fiber stress in bending and approximated the modulus of elasticity values for several softwood species.

123. ***McNatt. 1973. Basic Engineering Properties of Particleboard.***

The amount of particleboard produced in the United States in 1971 was more than 20 times that produced in 1956. Use has been primarily restricted to interior applications. However, the development of exterior grades will create new possibilities for particleboard as structural components. To insure correct application where the materials is now being used and to provide the information necessary for developing uses in new areas, data on the basic engineering properties of particleboard are needed. Information on the effects of moisture content, rate of loading, repeated loading and long-term loading is also needed. This report presents the results of evaluating strength and elastic properties in tension, compression, bending and shear of nine commercial particleboards conditioned to equilibrium moisture content at 75°F and 64 percent relative humidity. The nine commercial panels sampled were constructed as: 1) three-layer 5/8-inch, 50% Douglas-fir, 40% white fir, 10% pine mix; 2) graduated 5/8-inch, 60% Douglas-fir, 40% hemlock mix; 3) homogeneous 5/8-inch, southern pine; 4) graduated 3/4-inch, ponderosa and lodgepole pine; 5) and 6) three-layer 5/8-inch, Douglas-fir; 7) three-layer 3/4-inch, jack pine face and aspen and mixed northern hardwood core; 8) three-layer 3/4-inch, southern pine face and southern pine and mixed southern hardwood core; 9) homogeneous 1/4-inch aspen. Included for comparison are properties of the standard Forest Products Laboratory 1/2-inch particleboard of urea-bonded Douglas-fir. All 10 particleboards can be classified as medium-density grade. Properties closely related to each other, determined by least squares regression, were interlaminar shear strength and internal bond strength, shear modulus and modulus of elasticity, tensile strength and edgewise shear strength and tensile strength and modulus of rupture. Relating board properties to manufacturing variables was complicated because of the combinations of wood species and by the processing methods used. Variability of the properties of nine of the 10 particleboardswas not considered excessive if compared to similar data from commercial hardboards. The greater variability of the tenth board was related to variation in density, to large particle and to panel thickness.

124. ***McNatt. 1978. Manufacture and Performance of Full-Size Structural Flakeboards from Douglas-Fir Forest Residues.***

The Forest Products Laboratory manufactured and assessed the performance of 4 by 8-foot structural flakeboard panels from Douglas-fir forest residues after target performance goals were developed. The 42 pcf, three-layer boards were 1/2 inch thick with high quality disk cut flakes for the faces and lower quality flakes processed through a ring flaker in the core. More than 200 panels were produced. Basic mechanical and physical properties were evaluated, as well as durability and performance under concentrated and impact loading, racking strength of wall and floor sections and fire exposures. Bending strength and stiffness were both below the target goals. Most other goals were met; including those for shear and nailholding properties, internal bond and hardness. Panels used as wall sheathing exceeded specified acceptance standards for full-size walls. Under concentrated load, panels met maximum load and deflection recommendations of the Uniform Building Code for roofs and floors. Under fire exposure, the panels had a class B flame spread rating and exceeded the fire endurance requirement for exterior walls of one-and two family dwellings.

125. *Morrison-Knudsen Forest Products. 1987. Ring Flaked Maxi-Chips: The Manufacture, Testing and Evaluation of Composite Board Made from Alberta Woods.*

The purpose of this study was to investigate the feasibility of utilizing ring-cut maxi-chips to produce three-layer structural panels. Species examined were native to Alberta; where the spruce/pine would come from sawmill residues and the aspen and black poplar would be utilized as round wood. Single-layer panels were produced from the three species for both face and core applications. An orientation index was determined for each panel using the Metriguard stress wave timer and the panels were tested for parallel and perpendicular moduli of elasticity (MOE) and parallel and perpendicular linear expansion (LE). Black poplar panels exhibited the highest orientation index while aspen produced the highest MOE and lowest LE. Based on these measured properties and appropriate engineering calculations, estimations of parallel MOE and perpendicular LE were made for various layer combinations of the different species for 7/16 and 1/2-inch three-layer panels. Three-layer panel estimations with 41 lb/ft^3 densities, revealed that 7/16 and 1/2-inch oriented panels should easily pass the APA 24/16 and 32/16 roof/floor uniform load span ratings, respectively. Upon review of the preliminary test results, four types of panels at 38 lb/ft^3 densities were manufactured for evaluation (ie., 100% aspen; 70% aspen and 30% black poplar; 1/3 aspen, 1/3 black poplar and 1/3 spruce/pine; and 100% spruce/pine). The results of a previous study of panels made with ring-cut flakes from 7/8-inch lodgepole pine pulp chips , 7/8-inch Douglas-fir pulp chips and 5/8-inch Douglas-fir pulp chips were included for comparison. The lodgepole pine chips were from Montana and the Douglas-fir chips were from western Oregon. As with the above, single-layer oriented panels (face and core) were produced for each chip type. All face layer MOE's were significantly lower than those from aspen, black poplar and spruce/pine. Causes for this deficiency were related to species differences, lower aspect ratios and orientation indexes for the pulp chips. The lodgepole pine pulp chip core panels exhibited MOE's similar to the core panels of the Alberta maxi-chips; the Douglas-fir core panels were about 20% lower. Pulp chips and maxi-chips had similar LE's.

126. *Nicholls, Blankenhorn and Labosky. 1991. The Effects of Mild Chemical Extractions on the Dimensional Stability of UF and PF Bonded Red Oak Flakeboard.*

Red oak (*Quercus rubra L.*) flakes were chemically extracted under mild conditions to determine the effects on red oak flakeboard properties, particularly dimensional stability. Flakes were extracted with weak acetic acid solutions or water under selected treatment pressures and treatment times. Weight loss values of extracted flakes ranged from 4 to 25 %. Phenol formaldehyde (PF) and urea formaldehyde (UF) bonded flakeboards were manufactured using either red oak or chemically extracted red oak flakes. Physical and mechanical properties evaluated were modulus of elasticity, modulus of rupture, internal bond, water immersion related properties and linear expansion. Static bending properties of flakeboards using extracted flakes for both resins, even at high levels of flake weight loss, were similar to boards from unextracted flakes. Internal bond average values for the extracted flakes were lower for the PF boards compared to the controls. Internal bonds values for the UF boards were similar for the extracted and control boards. Dimensional stability tests on the UF boards produced the following results: (1) 2-hour dimensional stability values for the extracted boards were similar to the control boards (2) 24-hour dimensional stability values for the extracted boards were similar to the control boards; and (3) linear expansion values for the extracted boards were similar to the control values.

127. *Pagano and Gertjejansen. 1989. The Effect of Mixing High and Low Density Hardwoods on Bond Development in Waferboard.*

The internal bond strengths (IB) of small void-free cross laminates (miniature plywood) manufactured from wafers of paper birch, balsam poplar and two different mixtures of the two species were compared to each other and to the IBs of laboratory waferboards from the same species and species mixtures. The thin (0.020-inch) paper birch wafers resulted in the highest IBs in both the cross laminates and the waferboards and at very low compaction ratios. Mixing balsam poplar with birch reduced IBs of the cross laminates and waferboards, and an analysis of the cross laminate failures indicated balsam poplar wafers were the weak link in tension perpendicular to the grain. Static bending properties of the waferboards decreased with an increase in birch content, suggesting that thin paper birch wafers would be an ideal core material for 3-layer waferboards made with balsam poplar or conventional aspen faces.

128. *Palardy, Story and Shaler. 1989. Improving Flakeboard Quality and Reducing Costs by Pressing at High Moisture Content and Moderate Temperature.*

The wood composite panel industry is in need of new technologies that overcome the problems associated with conventional pressing methods such as high dryer temperatures, intolerance of dense wood species and panel springback. This paper describes research which addresses these problems by pressing flakeboards at high mat moisture content and moderate press temperature using diphenylmethane diisocyanate adhesive. Aspen (*Populus tremuloides)* flakeboards were pressed at a platen temperature of 230°F and 20% mat moisture content for 300 seconds using 3.0% diphenylmethane diisocyanate. Internal bond strength and thickness stability improved when target panel density was reduced from 40 to 35 lb/ft^3. Addition of selected amine and organo-metallic compounds also significantly improved internal bond and thickness stability. Both the aspen panels and hard maple (*Acer saccharum)* flakeboards pressed at the high moisture, moderate temperature conditions exhibited strength properties similar to panels pressed under conventional conditions at the same adhesive level. The thickness stability of the high moisture, moderate temperature panels was superior to that of the conventional panel group in water immersion and reversible swelling tests.

129. *Pallmann. 1990. Improved Flake and Particle Generation for the Board Industry.*

A new standard is being set in the board manufacturing industry for the production of high-quality flat flakes of almost any geometric shape and consistency. This concept provides only for the lowest standard deviation in flake thickness and the lowest fines generation from logs, slabs, edgings, branches, tops, etc. For the first time in the history of board manufacturing, a machine is available which cuts wood parallel-to-the-grain without splinters or "beaver tails" being discharged into the furnish and with a constant cutting velocity over the full length of the knives. The equipment that makes this possible is the new PZU Knife-Ring Long Log Flaker. This piece of equipment eliminates slashing for flaking which reduces labor costs, power consumption and mechanical maintenance. This, in return, produces a higher yield. Flake thickness distributions of various southern species (ie., black gum, water oak, southern yellow pine, yellow-poplar, sweetgum and sweetbay) were presented to demonstrate the effectiveness of the flaker.

130. ***Panning and Gertjejansen. 1985. Balsam Poplar as a Raw Material for Waferboard.***

Results showed that small diameter (5-inch) balsam poplar and aspen bolts both required approximately the same length of time to thaw, but for large diameter bolts (10-inch), a considerably longer time was required to thaw balsam poplar. Balsam poplar was difficult to waferize because of its high gelatinous fiber content. Fibers would wrap around knife edges greatly reducing their effectiveness. Laboratory phenolic bonded waferboards were made from 100 percent aspen, 100 percent balsam poplar, 50 percent balsam poplar-50 percent paper birch and 70 percent aspen-15 percent balsam poplar-15 percent paper birch. Waferboard from 100 percent balsam poplar had excellent mechanical properties but greater thickness swelling than the other paper types. Fifteen percent paper birch mixed with 15 percent balsam poplar and 70 percent aspen resulted in acceptable panels, but using 50 percent birch with 50 percent birch with 50 percent balsam poplar required higher panel densities to achieve properties similar to those of panels from 100 percent aspen or 100 percent balsam poplar. Linear expansion increased as birch content increased from 0 percent to 15 percent to 50 percent.

131. ***Pfaff. 1988. Status of Balsam (Black) Poplar Utilization in Waferboard/OSB Production.***

By request of Canadian industry and government, a task force was set up to review the utilization potential of black poplar (*Populus balsamifera* L.) for the production of oriented strand board and waferboard. This report summarizes the balsam poplar "situation" and the opinions and recommendations forwarded by the task force as of November 1, 1987. Species characteristics and differences between balsam poplar and aspen poplar are reported. Balsam poplar panel strength and dimensional stability properties and mixing implications to an aspen-based board are summarized from various published sources. Industrial experience and concerns were accounted and an action statement was prepared for future efforts.

132. ***Plagemann, Price and Johns. 1982. The Response of Hardwood Flakes and Flakeboard to High Temperature Drying.***

This study assesses the effect of high temperature drying on chemical and mechanical properties of southern red oak, white oak and sweetgum flakes and correlates changes in flake quality with board properties. The high temperature drying of flakes was found to have a significant effect on the internal bond (IB) of the resulting panels. The highest IB values were observed in boards produced from flakes dried at 150°C. Boards produced from flakes dried at 20°C and 350 °C exhibited consistently lower values for IB. Opposite trends were noted for total acid content of flake. Multiple regression and correlation analysis revealed a strong relationship between IB, total acid content and dryer temperature. A significant species effect was also present. Increased levels of flake total acids, acid buffering capacity and the ratio of acid to base buffering capacities resulted in decreased board property values. Flakes bending tests indicated that, in general, the strength and stiffness of the flakes were adversely affected by high temperature drying. This effect did not manifest itself, however, in the resulting panels. Possible reasons for this phenomenon are discussed.

133. ***Post. 1958. Effect of Particle Geometry and Resin Content on Bending Strength of Oak Flake Board.***

The objective of this study was to determine the effects of particle geometry and resin content upon such properties as bending strength, screw withdrawl, internal bond and dimensional stability. A series of scarlet oak boards were made with a range of resin content applications (ie., 3.27, 6.54 and 13.07 g/m^2), flake lengths (ie., 0.5, 1, 2 and 4-inch), and flake thicknesses (ie., 0.006, 0.012, 0.025 and 0.050-inch). Resin was added on the basis of surface area. Results of boards tested in bending were analyzed on the basis of the modulus of rupture. Bending strength increased with increases in flake length up to 4 inches. Effect of resin content was secondary to flake geometry. Increased flake thickness decreased strength markedly, although this may be partially due to differences in flake surface quality. Strength increased with the length-to-thickness ratio up to 300.

134. ***Post. 1961. Relationship of Flake Size and Resin Content to Mechanical and Dimensional Properties of Flake Board.***

This paper reports the effect of particle shape and size and resin content on a number of physical and mechanical properties of flakeboard. A series of scarlet oak boards were made with a range of resin content applications (ie., 3.27, 6.54 and 13.07 g/m^2), flake lengths (ie., 0.5, 1, 2 and 4-inch), and flake thicknesses (ie., 0.006, 0.012, 0.025 and 0.050-inch). Mechanical properties evaluated were moduli of rupture and elasticity, and fiber stress at proportional limit. Dimensional properties determined were thickness swell and linear expansion. Results inferred that the ratio of flake length-to-thickness (aspect ratio) is a better indicator of flake board properties than is either independently. Increases in resin spread increased bending strength only moderately. Neither thickness swelling or linear expansion are greatly affected by changes of flake length or thickness for flakes below 0.012-inch in thickness; however, above this point both properties decreased with increasing thickness and decreasing length.

135. ***Price. 1975. Initial Test of Large Panels of Structural Flakeboard from Southern Hardwoods.***

A strong structural exterior flakeboard from mixed southern hardwoods has been developed on a laboratory scale; the problem is transfer of the technique to pilot-plant scale in the manufacture of 4 by 8-foot panels. A species mix of 20% each of hickory (*Carya* spp.), white oak (*Quercus alba* L.), southern red oak (*Quercus falcata* Michx.), sweetgum (*Liquidambar styraciflua* L.) and southern pine (ie., *Pinus taeda* L.) was used to produce the panels. From the pilot-plant trial reported, it is concluded that a specific platen pressure of at least 575 psi and a hot-press closing time of about 45 seconds is required to make a 1/2-inch-thick panel (with random flake orientation throughout) having modulus of elasticity of 700,000 psi.

136. ***Price. 1976. Determining Tensile Properties of Sweetgum Veneer Flakes***

Rotary-cut sweetgum veneer flakes measuring 3 inches along the grain, 3/8 inch wide, and 0.015 inch thick, were stressed in tension parallel to the grain at gage lengths from 0.50 to 1.25 inches for unpressed control and at 0.75-inch gage length for flakes pressed in a flakeboard mat. The control flakes had an average tensile strength of 9,400 psi for the smaller gage length classes, 8,000 psi for the upper range or gage lengths, and moduli averaging from 460,000 psi to 675,000 psi. Platen pressure with heat increased core flake density by 6.3 percent and face flake density by 13.9 percent above that of untreated control flakes. Core flakes, which had an average MC of 6.3 percent, decreased 6.5 percent and 7.25 percent in tensile strength and modulus, respectively. Face flakes, which had an average MC of 5.5 percent, had 7.6 percent greater tensile strength and 9.8 percent greater modulus than unpressed controls. Unpressed control flakes had an average MC of 6.5 percent.

137. ***Price. 1977. Basic Properties of Full-Size Structural Flakeboards Fabricated with Flakes on a Shaping Lathe.***

Structural exterior flakeboards manufactured in 4 by 8-foot (1.22 by 2.44 m) size with phenolic resin and flakes produced on a shaping-lathe headrig were evaluated for plate shear modulus, internal bond, bending properties, and 24-hour water soak stability. Both mixed and single-species flakeboards were produced. Panels with mixed flakes had 20% by weight of hickory, white oak, red oak, sweetgum and southern pine. The variables in fabricating these panels were as follows: Two densities of aligned face and core flakes in panel thicknesses of 1/2-inch (12.7 mm) and 5/8-inch (15.9 mm); and two densities of random face and core flakes in panel thicknesses of 1/2-inch (12.7 mm) and 5/8-inch (15.9 mm). Singles-species boards of one density class, 1/2-inch (12.7 mm) thick were fabricated with randomly oriented flakes of either yellow-poplar or loblolly pine. Experimentally determined regression equations for the mixed species panels indicated that at 46 lbs/ft^3 density, a shear modulus of 192,000 psi (1323 MPa) would be obtained for the oriented panels. Random panels of this density would have 35% larger shear modulus. Based on specimen's initial dimensions, 60% of the bending strength was retained, while the modulus of elasticity increased after accelerated aging exposure. Initial bending properties depended on panel direction tested and on flake orientation. Oriented panels stressed along the 8-foot (2.44 m) axis had the highest bending strength [5,412 psi (37.3 MPa) for 1/2-inch (12.7 mm) panels]; bending strength across the 4-foot (1.22 m) width was lower (3,346 psi or 23.1 MPa). Modulus of elasticity reflected panel directional properties more than the bending strength; there was a modulus of elasticity of 967,000 psi (6667 MPa) along the 8-foot (2.44 m) axis and 377,400 psi (2602 MPa) across the panel. Random panels stressed along the 8 and 4-foot (2.44 and 1.22 m) axes had bending strengths of 5,034 psi (34.7 MPa) and 4,214 psi (29.1 MPa) and moduli of elasticity of 710,400 psi (4898 MPa) and 554,000 psi (3819 MPa) respectively. When bending strength and modulus of elasticity were averaged over both directions, the oriented panels averaged higher than the random panels. Internal bond of all panels after accelerated aging exposure decreased from the initial acceptable internal bond [greater than 700 psi (0.48 MPa)] to below 30 psi (0.21 MPa).

138. ***Price. 1977. Structural Flakeboards from Southern Hardwoods.***

Mixed-species, laboratory-size (0.457-m-square) flakeboards that are functionally competitive with sheathing grades of plywood were compared to full-size panels (1.22 by 2.44 m). Full-size panels were tested at thicknesses of 12.7 mm and 15.9 mm. The panel design called for equal-weight portions throughout of flakes of hickory, white oak, southern red oak, sweetgum and southern pine. Experimentally determined regression equations for the large panels indicated that initial bending properties varied by direction and flake orientation. Oriented flake panels stressed along the 2.44-m axis had the highest bending strength (37.32 MPa at 0.736 g/cc), a strength retention 75% that of laboratory panels. Bending strength across the 1.22-m width was lower (23.07 MPa). Modulus of elasticity calculations reflected panel directional properties more than bending strength. MOE was 6,667.5 MPa along panels stressed along the 2.44-m axis (80% retention) and 2,602.2 MPa across the panel. Random panels stressed along the 2.44 and 1.22-m axis showed bending strength of 34.71 MPa (89% retention) and 29.06 MPa, and modulus of elasticity of 4,898.2 MPa (84% retention) and 3,819.8 MPa, respectively.

139. ***Price. 1978. Properties of Flakeboard Panels Made from Southern Species.***

Structural exterior flakeboards manufactured with phenolic resin and flakes produced on a shaping-lathe headrig were evaluated for plate shear modulus, internal bond, bending properties, uniform loading, concentrated loading and impact resistance. Both mixed-and single-species 4- by 8-foot flakeboards were produced. Panels with mixed flakes had 20 percent by weight of hickory, white oak, southern red oak, sweetgum and southern pine. The variables in fabricating these panels were: aligned (oriented face and core) flakes in panels of two densities and thicknesses of 1/2 and 5/8-inch; and randomly oriented (random) face core flakes in panels of two densities and thicknesses of 1/2 and 5/8-inch. Single-species, 1/2-inch-thick boards of one density class were fabricated with random flakes of yellow-poplar and loblolly pine. Regression equations for the mixed-species panels indicated that at 45 pcf density, a shear modulus of 192,000 psi would be obtained for the oriented panels. Random panels of this density would have 35 percent larger shear modulus. Based on a specimen's initial dimensions, 70 percent of the bending strength was retained, while the modulus of elasticity increased after accelerated aging exposure. Initial bending properties depended on panel direction tested and on flake orientation. Oriented panels stressed along the 8-foot axis had the highest bending strength (5,412 psi for 1/2-inch panels); bending strength across the 4-foot width was lower (3,346 psi.) Modulus of elasticity was more affected by flake alignment than was bending strength. In oriented panels modulus of elasticity was 967,000 psi along the 8-foot axis and 377,400 psi across the panel; random panels stressed along the 8 and 4-foot axes had bending strengths of 5,034 psi and 4,214 psi and moduli of elasticity of 710,400 psi. When bending strength and modulus of elasticity were averaged over both directions, the oriented panels averaged higher than the random panels. Internal bond of all panels after accelerated aging exposure decreased from the initial acceptable internal bond (greater than 70 psi) to below 30 psi. For 200 and 300-pound concentrated loads applied 2-½ inches from the edge on 1 and 3-inch disks, respectively, oriented and random panels had similar deflection values. However, failure loads applied on the disks were higher for the random panels than for the oriented panels. Also, the random panels retained more strength after a 3-day water spray than the oriented panels. In general, the oriented panels deflected less than random panels in tests of distributed load over a 24-inch span. For a 16-inch span, dry-tested 5/8-inch random panels deflected less than oriented panels. Oriented and random mixed-species flakeboard had less impact resistance than southern pine plywood. Oriented flakeboards of 1/2-inch thickness had less impact resistance than random flakeboards of this thickness. In 5/8-inch thickness, random mixed-species flakeboards tested wet had greater impact resistance than oriented flakeboards; when tested dry oriented boards of this thickness had greater impact resistance.

140. ***Price. 1985. Creep Behavior of Flakeboards Made with a Mixture of Southern Species.***

Deflection of oriented flakeboards, random flakeboards and southern pine plywood was evaluated for small size bending specimens and concentrated loads applied to panels nailed on framing lumber. The flakeboards contained a mixture of southern hardwoods (ie., sweetgum, red oak, white oak and hickory) and southern pine; the plywood was 3-ply 1/2-inch and 4-ply 5/8-inch construction. Tests of both panel directions, all load levels and RH cycles showed plywood bending specimens with the smallest deflection increase, and both random and oriented flakeboard bending specimens showed more increases. The plywood relative creep averaged 1.76; the flakeboard relative creep averaged 2.26 and 2.30 for oriented and random construction, respectively. For the concentrated loading, oriented flakeboard panels with the smallest initial deflection had the largest creep after 32 days. Random flakeboard and plywood showed less creep.

141. *Price and Hse. 1983. Bottomland Hardwoods for Structural Flakeboards.*

Seven species (ie., sweetgum, hackberry, American elm, red oak, green ash, overcup oak and pecan) found growing in bottomland hardwood sites were evaluated for their potential in being utilized in a structural flakeboard. The evaluation process consisted of three phases of investigation. Phase I investigated properties of flakeboards fabricated with several flake lengths and thicknesses using all seven species. In Phase II, properties of panels made with single-species and mixtures of all high-density species (ie., red oak, green ash, overcup oak and pecan), all low-density species (ie., sweetgum, hackberry and American elm), and combinations of high and low-density species were obtained. For Phase III, an alternative flaker disk was used to generate flakes for panel fabrication. Phase III panels were fabricated with flakes generated from both heated and ambient temperature conditioned bolts. Also, powder and liquid phenolic resins were used in the Phase III investigation. The data indicated a panel with acceptable properties is technically feasible using several fabrication arrangements.

142. *Price and Lehmann. 1978. Flaking Alternatives.*

Three-layer structural flakeboards were prepared at two densities and two resin contents (5 and 8 percent) from flakes cut on a shaping-lathe headrig and on disk, drum and ring flakers. Panels were made from lodgepole pine (*Pinus contorta* Dougl.), loblolly pine (*Pinus taeda* L.), sweetgum (*Liquidambar styraciflua* L.), southern red oak (*Quercus falcata* Michx.) and mockernut hickory (*Carya tomentosa* Nutt.). The ring flaker produced 23.78 percent fines; the drum, lathe, and disk produced only 7.7, 3.5 and 2.2 percent fines. Of the flakes used for panel fabrication (i.e., those retained on 1/16-inch and larger screens), lathe and disk-cut flakes had the lowest specific surface and therefore most resin applied per thousand square feet of flake surface area. Flakes averaged about 2.25 inches long (except ring-cut oak and hickory flakes, which were slightly shorter). Flakes were slightly less than 0.02-inch thick (except for disk-cut flakes which were slightly thicker). When panels of the low-density species (lodgepole and loblolly pines and sweetgum) were analyzed, bending strength, modulus of elasticity, internal bond, linear expansion and thickness swell were all strongly influenced by interactions of main factors (ie., flaker, species, resin content and compression ratio). Such interactions would not allow simple comparisons of the main factors. Flaker types were therefore compared over a range of compression ratios for each individual species of wood. Lodgepole pine boards had highest bending strength and modulus of elasticity when made from lathe-cut flakes, and highest internal bond strength when made from ring-cut flakes. The flake-type yielding least linear expansion and thickness swell varied with conditioning cycle (24-hour water soak, 30 to 90 percent RH or ovendry vacuum-pressure soak). Loblolly pine boards made at low compression ratios were strongest and stiffest if made from disk-cut flakes; at high compression ratios lathe-cut flakes made boards of the highest bending strength and modulus of elasticity. Internal bond strength of loblolly pine boards was highest when made from ring cut flakes, but boards made from lathe-cut flakes had the most stability. At high compression ratios, sweetgum panels had the highest bending strength and modulus of elasticity when made from disk-cut flakes, but highest internal bond strength when made from ring-cut flakes. Sweetgum boards were most stable when fabricated from lathe-cut flakes. At any compression ratio from 1.20 to 1.50, lodgepole pine boards generally had the lowest modulus of rupture, modulus of elasticity and internal bond strength. Loblolly pine and sweetgum boards often had similar properties. When oak and hickory boards were evaluated, those made from lathe-cut flakes had the highest bending strength and stiffness. Increasing resin content from 5 to 8 percent improved bending properties; the degree of improvement was affected by species and flaker type. Internal bond strength was highest in boards made of ring-cut flakes and was greatly influenced by resin content and species. Linear expansion values were low in panels of drum-cut flakes pressed to high compression ratios and for boards of lathe-cut flakes at low compression ratios. Thickness swell of oak and hickory boards were inversely correlated with resin content. Most properties of red oak flakeboards of 52.6 pcf density were superior to hickory boards of the same density, but were inferior at equivalent compression ratios. Overall, use of disk and lathe flakers yielded boards with higher bending strength and modulus of elasticity for initial test conditions (50 percent RH) and after accelerated aging. Internal bond strength of boards made of ring-cut flakes (132 psi) was the highest. Despite their higher internal bond strengths, boards made of ring-cut and drum-cut flakes were less stable after being subjected to environmental conditioning than boards made from lathe-and disk-cut flakes. In general, species with higher wood densities had higher measured property values. Also, the higher density species generally had a larger percent loss in properties after aging.

143. ***Price and Lehmann. 1978. Flakeboard Properties as Affected by Flake Cutting Techniques.***

Flakeboards were prepared from flakes obtained from disk, drums, and ring flakers, and a shaping-lathe headrig. Species used were lodgepole pine, loblolly pine, sweetgum, southern red oak and mockernut hickory at 1.25 compression ratio and two resin contents (5 and 8%). The three-layer panels had 25 percent of the largest flakes on each surface; all other material retained on screens 1/16-inch or larger was put in the core. Flakes were cut 2.25-inches long and 0.02-inch thick. The target flake length was obtained or exceeded for all but red oak and hickory flakes made in the ring flaker. Except for disk-cut flakes, the flakes were less than 0.02-inch thick. Screen analysis varied significantly among flakes and species. The ring flaker produced the most fines. Effects of species and resin content on the strength, stability and durability of flakeboard depend on the flaker. For panels from each flaker an increase in resin content slightly increased strength and improved panel stability. Although panels were fabricated at equivalent compression ratios, the higher density species yielded panels with greater strength but these panels deteriorated most after accelerated aging. One flaker was not clearly superior to the others. Generally, the strengths and MOE of lathe-and disk-cut flake panels were similar and higher than those of the ring-and drum-cut flake panels. The ring-cut flake panels had the highest IB, but the high IB did not result in lower dimensional stability measurements based on the 24-hour water-soak test. By limiting flaker evaluation to one species and certain test properties, a flaker could be chosen that would yield a panel superior to panels fabricated with flakes produced on other flakers.

144. ***Ramaker and Lehmann. 1976. High-performance Structural Flakeboards from Douglas-Fir and Lodgepole Pine Forest Residues.***

Process requirements were investigated toward making a flakeboard using forest residues which could meet performance goals of the U.S. Forest Service "Structural Flakeboard from Forest Residue" program. These goals represent an estimate of minimum design properties for satisfactory performance of flakeboard as floor and roof sheathing. A first group of panels was made which varied in species (ie., Douglas fir, lodgepole pine), flake alinement, density and resin quantity, and then was evaluated. A second group was made to investigate structural properties with varying flake moisture content, length of disk face flakes, thickness of ring core flakes and press closing time. The panel type chosen as most warranting more thorough study was of Douglas-fir random flakes in three-layer construction, with 0.02 by 2-inch face flakes and a core of 0.05 by 2-inch ring flakes. The panel was bonded with 5 percent phenolic resin and pressed to a density of approximately 40 pounds per cubic foot.

145. ***Rice. 1973. Particleboard from "Silage" Sycamore - - Laboratory Production and Testing.***

As a part of a larger program of development in short-rotation wood production and its utilization, this study was undertaken to evaluate the suitability of young sycamore saplings for use on a whole-tree basis in the production of several flakeboard types. In addition to studying the general suitability of this type of wood as a raw material for flakeboard manufacture, material and process factors relating to weather resistance, and particularly to panel thickness swelling, were also examined. Influences of board density, resin content and wax content, as well as the type and duration of swelling testing, were reported.

146. ***Rice. 1982. Compaction Ratio and Resin Coverage Effects on Properties of Thick, Phenolic-Bonded Flakeboard.***

Flakeboards 1.5-inch thick were made with various wood densities (ie., yellow-poplar, sweetgum, white oak, mockernut hickory and lobolly pine), board densities, flake thicknesses and weight percent resin contents. Property data were analyzed for dependence on compaction ratio (C/R) and resin coverage (R/C). Linear regression analyses showed that some 72% of the variation in MOR, MOE and IB data was explainable through dependence upon C/R and R/C, thus suggesting that these parameters may be useful in preliminary analysis of untested board compositions. For a 24-hour water-soak thickness swelling, a dependence on R/C was significant but accounted for only 35% of the variation in the swelling data. However, C/R did not significantly affect the swelling.

147. ***Rice and Carey. 1978. Wood Density and Board Composition Effects on Phenolic Resin-Bonded Flakeboard.***

Selected factors affecting particleboards resistance to accelerated aging were studied. Emphasis was placed on variables thought to relate to compaction, crushing and the role of interparticle bonding as they affect the permanence of panel consolidation. A range of wood densities (ie., white basswood, yellow-poplar, sweetgum and black birch), board densities and resin contents were studied, paying particular attention to the "compaction ratio" concept of board and wood density interaction. Special problems were encountered in flaking and pressing with the lower-density wood (basswood). However, trends in the effect of compaction ratio are seen in that the higher ratios seem to lead to higher mechanical property values but also to higher thickness swelling especially in the WCAMA six-cycle accelerated-aging test. Insofar as particleboard's weather resistance is dependent upon permanence of original panel consolidation, these data suggest that moderate compaction ratios and higher resin contents are a step in the right direction. Substantial further study is indicated and some important unresolved issues are outlined.

148. ***Rowell, Wang, and Hyatt. 1986. Flakeboards Made From Aspen And Southern Pine Wood Flakes Reacted With Gaseous Ketene.***

Southern pine and aspen wood flakes were chemically modified by reaction at ca. 55°C with ketene in the absence of solvent. Reactions were relatively slow, with weight gains of up to 17% and 20%, respectively, obtained. Acetyl content correlated with weight gain only up to the 12% level. Water and solvent extraction of ketene-modified southern pine and aspen flakes showed very little loss in acetyl. Flakeboards made from southern pine and aspen flakes treated with ketene showed a greatly reduced rate and extent of swelling resulting from liquid water sorption as compared to control boards. Similar results were obtained in swelling tests done in water vapor. Ketene modification had a much greater effect on improving dimensional stability properties of aspen flakeboards than on southern pine flakeboards.

149. ***Shaler and Blankenhorn. 1989. Composite Model Prediction of Elastic Moduli for Flakeboard.***

The objective of this research was to develop a model to predict the flexural modulus of elasticity of oriented flakeboards. Variables incorporated into the model included flake geometry, flake orientation, density, resin content and species. Verification of the model was accomplished by comparing predictions with flexural modulus of elasticity (MOE) values measured parallel and perpendicular to the flake alignment direction of 192 specimens made from two species (*Populus grandidentata* Michx. and *Acer rubrum* L.) at 4 resin levels (3,5,7 and 9%) and 3 target densities (35, 42, and 52 pcf). Use of the longitudinal Halpin-Tsai equations in conjunction with measured and estimated wood and resin properties, predicted the moduli of aspen and red maple flakeboard specimens with a standard error of estimate of 93,985 psi, a coefficient of determination of 89.5% and an average of 25% below experimental values. The statistical correlations were influenced by grouping of data using flake alignment direction and species. Important issues of vertical density gradient, inhomogeneities and resin compatibility were not accounted for. The approach was easily computed and gave reasonably accurate predictions of elastic moduli of a single oriented flakeboard manufactured over a range of resin levels, density, alignment, flake geometry and species conditions.

150. ***Shen. 1971. Phenolic Flakeboard Made of Hard Maple.***

Hard maple (*Acer saccharum*) flakeboard made at 45 pcf density range, bonded with 2.0% liquid phenolic resin showed high strength properties which exceed considerably the requirements for a building board of Grade P set forth in CSA-0188 (68). It was found that powdered phenolic resin would not adhere to the hard maple flakes. Also, a uniform mat was difficult to obtain in thin boards when thick flakes were used. This exploratory work has not answered all the technical questions associated with this high-density wood species; such as machining characteristics of maple for flake or wafer manufacture, machinability of this type of board made from hard and dense wood, the lack of mat uniformity on thin board felted with thick flakes, and the great swelling tendency. Further laboratory work is needed to examine these questions.

151. ***Shen. 1973. Steam-Press Process for Curing Phenolic-Bonded Particleboard.***

A new pressing process has been developed to cure phenolic-bonded particleboard in a very short press-time. This new process involves the injection of high pressure steam through the mat surface using specially designed press platens and a sealing frame. By directly injecting high pressure steam into the mat, the cure of resin binder in the particleboard can be rapidly achieved. For example, 1-inch thick phenolic sugar maple (*Acer saccharum*) particleboard at 45-pound density was fully cured in 1 minute at a steam pressure of 300 psi (430°F). The same board would take at least 15 minutes at 430°F platen temperature using the conventional platen pressing method. Five-inch thick particleboard was fully cured in less than 11 minutes at a steam pressure of 200 psi (380°F). Large-tooth aspen (*Populus grandidentata*) board was also produced for species comparison. Strength properties of the steam-pressed boards were found to equal those of conventionally pressed boards. However, thickness expansion and water absorption for the steam-pressed boards were considerably reduced. This new steam-pressing technique should have great potential for development into an industrial process.

152. ***Shen. 1980. The Past Headaches and Future Outlook of Canadian Waferboard.***

The first Canadian waferboard plant was built at Hudson Bay, Saskatchewan, and ran into some early difficulties from the point of view of plant design and production processes. The plant was designed to allow use of a maximum of 10 percent of black poplar (*Populus balsamifera* L.) in waferboard production. At the time, black poplar was considered bad material to use from plywood's experiences with flaking and drying. Rapid dulling of waferizer knives and high moisture blows were among the problems labelling the species.

153. ***Shuler and Kelly. 1976. Effect of Flake Geometry on Mechanical Properties of Eastern Spruce Flake-Type Particleboard.***

Laboratory flake-type particleboards produced from eastern spruce flakes were evaluated for selected mechanical properties. The flakes were cut on a rotary lathe, and flake geometry variables were length (1 and 3-inch) and thickness (0.010 and 0.020-inch). Boards were made with 6 percent by weight urea-formaldehyde adhesive and pressed to one-half inch thickness at densities of 40 and 50 pcf. Board density was significant for all properties except linear expansion. Flake thickness was significant for MOE, IB and screw withdrawal from the panel face. Flake length was significant for MOE, MOR and IB. The highest average values of MOR and MOE (7,326 psi and 1.103×10^6 psi, respectively) were obtained with the 50 pcf board made with 3 by 0.010-inch flakes.

154. ***Snodgrass, Saunders, and Syska. 1973. Particleboard of Aligned Wood Strands.***

This report represents the results of three years of study which was based on the wish to cause orientation in a controlled manner and to learn what the results are in terms of board characteristics. Experimental 1/4-inch, 48 pounds-per-cubic-foot single-layer panels were manufactured with grand fir and southern pine strands fully aligned in one principal direction or formed randomly. Directional MOR, MOE and LE were markedly improved with orientation. However, cross-wise MOR, MOE and LE properties suffered with orientation. Unpublished data of oriented ponderosa pine panels was included to further demonstrate the effects imparted by different material densities.

155. ***Springate. 1980. The Use of Different Species in Waferboard Production.***

Prior to the construction of the Northwood waferboard plant in Chatham, New Brunswick, tests were made which indicated that red maple and white birch could be used in the manufacture of high-quality waferboard. Developed to utilize low-value aspen poplar resources, waferboard was made with black poplar and white birch in 1975 at the Thunder Bay mill of MacMillan Bloedel. Insufficient poplar supplies in New Brunswick led to trials with other woods. A series of tests using varying species (ie., aspen, white birch, red maple, yellow birch, sugar maple and beech) composition yielded close results. Homogeneous mixtures of aspen, red maple and white birch are equal in quality to layered panels with only aspen in the face layers. Excessive volumes of red maple in the face layers can result in panels with lower than normal internal bond. The use of only beech in the core layers can result in low-quality panels. However, if mixed with other hardwoods, up to 10 percent of beech can be used.

156. ***Stayton, Gertjejansen, Hyvarinen and Haygreen. 1971. Aspen and Paper Birch Mixtures As Raw Material for Particleboard.***

Aspen and paper birch flakes 0.014 inches thick and 0.5 inches long were used pure, mixed in 2:1 and 1:2 proportions and bonded with 8 percent urea and 6 percent phenol formaldehyde resin to make 0.5 inch-thick, one-layer particleboard in a test of strength, stiffness, dimensional stability, and appearance. All boards had commercially acceptable moduli of rupture and elasticity, internal bond, and linear and thickness swell. The best board was all-aspen phenol board. Paper birch reduced quality, but even the all-birch board still had 80 percent of the strength of all-aspen board. There were no problems in board formation, pressing, adhesive cure or bonding.

157. ***Steinhagen. 1977. Heating Times for Frozen Veneer Logs - New Experimental Data.***

Frozen tree sections with thermal insulation at the end faces were heated in agitated water while their temperature history was recorded. Green sections from aspen, black cherry, red oak and white pine were used in the investigation. Due to the end face insulation, the sections performed like "long" logs in which radial heating predominates and longitudinal heating is unimportant. It was suggested that wood sugars in the waters could depress the freezing point to below 32°F. Heating frozen logs may take substantially longer than heating nonfrozen logs so that heating-time charts in use for nonfrozen wood are inadequate for frozen wood. MC and moisture distribution were not appreciably altered after freezing and subsequent heating.

158. ***Stewart. 1970. Cross-Grain Knife Planing Hard Maple Produces High-Quality Surfaces and Flakes.***

Hard maple (*Acer saccharum*) panels of short clear cuttings were aligned parallel and perpendicular to the feed direction so the material could be knife planed parallel to and across the grain. The panels were planed at 36 prescribed machining combinations of four rake angles (10, 20, 30 and 45 degrees), three depths of cut (1/32, 1/16 and 1/8-inch), and three feed rates (10, 20 and 30 knife marks per inch). Maximum surface roughness was less for planing cross grain than for planing parallel to the grain, but average surface roughness was about the same for both methods. Further, a high-quality flake for particleboard could be manufactured simultaneously with a finish knife-planed surface when planing cross-grain, thus reducing waste disposal problems.

159. ***Stewart and Lehmann. 1973. High-Quality Particleboard from Cross-Grain Knife-Planed Hardwood Flakes.***

A factorial experimental design was used to study the effects of four hardwood species (ie., basswood, yellow-poplar, red oak and hickory), three panel densities and three cross-grain flake thicknesses on particleboard strength and dimensional properties, flake geometries and species-particleboard-density relationships. Cross-grain knife planing produces satisfactory surfaces and flakes which are an excellent source of raw material for particleboard. In the species and density range studied, panels exceeded the bending and internal bond requirements of the commercial Standard at a panel density of 37 pounds per cubic foot. Bending strengths can be predicted from species and panel densities tested and could probably be predicted for other hardwoods within this density range. Basswood and yellow poplar panels performed better in MOE and MOR than red oak or hickory, but had inferior performance in IB. Exceptional linear dimensional stability was also obtained using cross-grain, knife planed flakes. Dimensional stability was more dependant on strand geometry than on species, but red oak consistently demonstrated inferior performance (compared to the other species).

160. ***Strickler. 1959. Effect of Press Cycles and Moisture Content on Properties of Douglas-fir Flakeboard.***

The study used 0.008 by 1/2-inch Douglas-fir flakes to produce 3/4 inch urea-formaldehyde bonded panels. Panels were produced with 5, 9 and 12% moisture contents at a press temperature of 290°F and press cycle variations designated on the basis of the duration of maximum pressure application. Heat transmission rate was monitored and evaluated for each panel type and final layer density was measured. Press cycles, moisture content and moisture distribution affect such physical properties of particle boards as layer density, moduli of rupture and elasticity, internal bond strength and dimensional stability. These three factors also affect the penetration rate of platen heat to the board center, and rate of temperature rise in the center determines resin polymerization time and, therefore, rate of production.

161. ***Suchsland and Xu. 1991. Model Analysis of Flakeboard Variables.***

A model consisting of thin narrow veneer strips was used to demonstrate the development and the consequences of horizontal density variations in yellow-poplar flakeboards. The durability of the model (survival at severe exposure conditions) and, by implicating, the durability of flakeboard are substantially affected by the severity of this horizontal density variation, which during exposure of the board to severe conditions generates normal stresses on gluelines, resulting in glueline failure and excessive thickness swelling. An increase in resin content can overcome these difficulties to some extent. Heat treatment of the veneer strips reduces gluebond quality, possibly by wood surface modification. Heat treatment of finished boards appears to be beneficial.

162. ***Suchsland, Woodson and Keinert. 1979. Veneer-Reinforced Structural Composition Board.***

In certain structural applications of particleboard, linear expansion might be the critical characteristic. Numerous fiberboard, particleboard and flakeboard panels were fabricated with veneer sheet in the core. When inexpensive veneer, either single-ply or cross-laminated two-ply, was placed in the center of southern pine particleboards, linear expansion was reduced greatly. Linear expansion was somewhat reduced in sweetgum fiberboards but was affected little in sweetgum flakeboards. In this scheme board dimensions are not limited by veneer dimensions, and even large open defects would have little effect on board appearance. Press cycles are not limited by the crushing strength of the veneer.

163. ***Sudan. 1978. Waferboard Development; Waferboard Technology Based on Eastern Canadian Hardwoods and Coniferous Species.***

Eastern Canadian wood species (ie., aspen, yellow and white birch, maple, beech, white pine and white cedar) from New Brunswick and Nova Scotia regions were studied. The studies indicated that a technically acceptable waferboard produced from the Eastern Canadian mixed wood species is feasible and can compete successfully with the commercially successful whole-aspen waferboard. These studies, carried out at the Reichhold Limited's waferboard composition laboratory in Ste. Therese, PQ over the past two years, also point out that certain "wafer" geometry and board composition can greatly influence the quality of the final board. Results showed that the lower density wood should be kept on the surface layer if there were sufficient quantity (>25% of the total mix). In other cases when the soft species make up less than 20% of the mix, they should be homogeneously blended with the rest of the wood species. Recommendations were against the use of softwoods in the core due to their tendency for collapse. Other conclusions stipulated a thinner wafer with a higher moisture content in the surface layer of the panel.

164. ***Swan and Kellogg. 1986. Chemical Properties of Black Cottonwood and Balsam Poplar.***

Taxonomically, black cottonwood and balsam poplar are varieties of the same species. However, black cottonwood is excluded from the "northern aspen" species group embraced by the National Lumber Grading Agency grading rules for dimension lumber and from the use as core material in softwood plywood. This study examines the chemical properties of these two species varieties to assess whether continuing differentiation in their utilization is justified. Black cottonwood was sampled at three sites in British Colombia (Fraser Valley, Squamish Valley, Kingcome Inlet) and balsam poplar was sampled at three sites in Alberta (Lodgepole, Slave Lake, Lac La Biche). Representative subsamples of wood and bark meal were prepared from each original sample. Black cottonwood and balsam poplar did not differ significantly in lignin content. Within each species, the heartwood had higher lignin contents than the sapwood. The mean extractive content of the female trees is higher than that of the male trees, but this was statistically significant for only the benzene-alcohol extractive content of the black cottonwood sapwood. The pH and acidity did not differ significantly between species. However, there was a large difference between heartwood and sapwood pH values in both species; sufficient to provide a basis for their differentiation. Acidity values were higher for both sapwoods than for heartwoods. The chemical component contents of black cottonwood and balsam poplar bark were the same, except for the benzene-alcohol extractive content, which was twice as great in balsam poplar. However, the same chemical components were found in each extractive mixture. Results do not provide any basis for separate commercial utilization of these two varieties of the same species.

165. ***Symonette, Kuo and Hall. 1988. Properties of Flakeboard from Short-rotation, Intensive Culture Silver Maple (Acer saccharinum L.).***

A study of the strength and dimensional properties of silver maple flakeboard was conducted. Homogeneous, phenolic flakeboards (42 pcf) were produced from 6-year-old short-rotation, intensive culture (SRIC) stem and branch material. Emphasis was placed on analyzing the effects of including bark within the furnish materials. In addition, the effects of parent-stock origin were analyzed for material grown from seeds collected in Illinois, Iowa, Kansas, Minnesota, Nebraska and Wisconsin. Including bark in the furnish significantly reduced internal bond strength. The genetic origin of the furnish significantly affected bending stiffness (MOE). Boards surpassed the National Particleboard Association (NPA) standards for type 2-MF boards, except in MOE. Although failing to meet the NPA minimum standard, MOE probably could be improved by particle alignment, layering or combining silver maple furnish with furnish of other species. Results indicate that medium-density, exterior-grade flakeboard that meets minimum commercial standards, except MOE, could be produced from SRIC silver maple stem and branch material containing bark.

166. ***Talbott. 1959. Flapreg Flakeboard... Resin-Impregnated, Compressed Wood Flakes.***

The FLAPREG process, for producing fully impregnated and compressed board, was demonstrated. The process comprised: preparation of the flakes; initial drying of the flakes; impregnation by spray application of resin solution; re-drying of the impregnated flakes; machine felting; and pressing and curing. Properties of a typical Douglas-fir 1/2-inch FLAPREG with 0.008 by 1/4 by 1/2-inch flakes, 35% resin, and a 325°F, 25 minute press time were reported. Properties of a Sitka spruce board fabricated by a similar process (COMPREG) were compared. Other species targeted for the process were redwood and southern yellow pine.

167. ***Turner. 1954. Effect of Particle Size and Shape on Strength and Dimensional Stability of Resin-bonded Wood-Particle Panels.***

Precisely cut Douglas-fir and Sitka spruce wood particles in the form of flat flakes, thin strands, helical ribbons, and cubes were converted to resin bonded panels. The panels ranged from 0.5 to 1.05 specific gravity. They contained variously either 2, 4 or 8 percent phenolic resin and, in some cases, developed strength and dimensional stability comparable to plywood. Several particles derived from commercial materials are also included in this comparison. Particle shape, resin content and density effects are related to bending strength, thickness change after water soaking and linear expansion during cyclic exposure to 30 percent and 90 percent relative humidity. Panels made with 4 percent resin, of various surface texture and having excellent properties, are technically feasible when based upon particles of sound fiber structure.

168. ***Vital, Lehmann and Boone. 1974. How Species and Board Densities Affect Properties of Exotic Hardwood Particleboards.***

Four exotic hardwood species, kiri (*Paulownia tomentosa*), virola (*Virola* spp.), limba (*Terminalia superba*) and afrormosia (*Pericopsis elata*) were used to make three-layer particleboards with one species and in combinations of equal parts of two, three and four species. Mechanical properties were determined by static bending and IB tests. dimensional stability properties were measured after exposure to 30 to 90 percent and 50 to 90 percent RH and by a 24-hour water-soak test. MOR and MOE increased linearly with increase in wood density and particleboard density. IB increased as board and species density increased, but also was affected to some extent by inherent characteristics of each species. MOR and MOE of mixed species were equal to the weighted mean of the properties of boards made of single species at the same board density. No linear relation was found between dimensional stability and board density, but water absorption was inversely proportional to board density. Thickness swelling was inversely proportional to board density and directly proportional to solid wood volumetric change and, in multiple regression, was directly proportional to water absorption and solid wood volumetric change. Within the species, an increase in board density generally resulted in a decrease in thickness swelling and an increase in linear expansion.

169. ***Weyerhaeuser Canada Ltd. 1992. White Spruce Utilization for OSB Phase 1 - Lab Evaluation.***

The Weyerhaeuser Edson OSB Plant wish to utilize white spruce in their production. This report covered Phase 1 of the project, which was the laboratory evaluation of utilizing white spruce in OSB. Logs of aspen and white spruce were waferized, the furnish was evaluated, and then used to produce three groups of panels of: 100% aspen; 100% white spruce; and 80% aspen/10% white spruce mix panels. These panels were then tested and the results of this phase of the project showed that for similar waferizing settings, white spruce waferized with a greater percentage of fines and strands were thicker than aspen. At similar moisture contents, white spruce required more compaction pressure in pressing than aspen. Panels made of a mix of 80% aspen and 20% white spruce had similar properties to 100% aspen panels, whereas the panels made with 100% white spruce had lower properties of MOE, MOR, thickness swell and linear expansion than both other sets.

170. ***White and Schaffer. 1981. Thermal Characteristics of Thick Red Oak Flakeboard.***

As part of a cooperative project between Purdue University and the U.S. Forest Products Laboratory, 1-3/16-inch-thick red oak structural flakeboard was tested for fire penetration, flame spread, and thermal resistance. The small-scale testing indicated satisfactory thermal characteristics for a wood-based product. Fire penetration performance exceeded that of a 1-1/8-inch-thick plywood accepted as roof decking in heavy timber construction. Flame-spread performance met the class C criteria of 200 or less. Thermal resistance was consistent with suggested insulative desing values for particleboard.

171. ***Wilson. 1980. Is there an isocyanate in your future?***

Physical properties were compared for conventional U.S. particleboard and flakeboard bonded with varying amounts of either urea-formaldehyde or phenol-formaldehyde, and isocyanate (PMDI and EMDI) binders. Green Douglas-fir lumber was flaked to 0.016 by 1.0 by 1.0-inch blended with either PF or PMDI (2.5% resin content) and pressed to a 1/2-inch thick flakeboard panel. Commercially prepared Douglas-fir furnish, blended with equal quantities (5%) of UF, PF, EMDI and PMDI, was used for the particleboard comparisons. Cost comparisons were made on board performance. Compared with urea-formaldehyde and phenol-formaldehyde resins, isocyanates (PDMI and EMDI) had excellent bond strength for particleboard and flakeboard, as determined by modulus of rupture and internal bond. Dimensional stability properties such as thickness swelling and linear expansion were also better for isocyanate-bonded board. The ability of isocyanates to cure in half the time of phenol-formaldehyde, to use less resin for equivalent performance, and to use higher (10-20%) moisture content furnish than that commonly used with phenol-formaldehyde (3-6% reduces production costs, which helps offset the much higher initial cost of PMDI.

172. ***Winistorfer and DiCarlo. 1988. Furnish Moisture Content, Resin Nonvolatile Content, and Assembly Time Effects on Properties of Mixed Hardwood Strandboard.***

The objective of this research was to investigate the effects of three levels each of furnish moisture content (MC) (ie., 2, 5 and 8%), resin nonvolatile content (ie., 50.8, 54.8 and 58.8%), and assembly time (ie., 0, 20 and 40 minutes) on the strength [modulus of rupture (MOR) and internal bond (IB)] and dimensional stability (thickness swell (TS), linear expansion and water absorption) of strandboard panels made from a combination of mixed hardwoods (60% sweetgum and 40% hackberry, mixed oak species and hickory). MOR and IB were both significantly affected by furnish MC and resin solids percent, increasing with decreasing levels of each. TS increased significantly with increasing levels of furnish MC and resin solids percent. An ovendry-vacuum/pressure/soak cycle resulted in significant reductions in MOR and IB. Assembly time was not significant for any measured property. Linear expansion was not affected by any treatment.

173. ***Wisherd. 1979. Bark as a Supplement to Wood Furnish for Particleboard.***

Strength properties of laboratory-fabricated homogeneous particleboard of medium density were evaluated to determine the effects of substituting bark for 5, 10 and 20 percent (OD weight) of standard wood furnish. Three types of bark (Douglas-fir, ponderosa pine and red alder) were individually substituted to the Douglas-fir and western hemlock wood furnish. The resulting boards, an equal number bonded with urea-formaldehyde (UF) resin and phenol-formaldehyde (PF) resin, were compared to each other and to control boards (100% wood furnish bonded with either resin) for differences in physical properties. Red alder bark with PF resin improved IB strength from 6 to 15 percent. Adding ponderosa pine bark with PF resin improved linear expansion and thickness swelling, with these decreasing as much as 18 and 35 percent, respectively. Douglas-fir bark added at the 5 percent level with PF resin did not affect strength properties. Otherwise, the three barks performed similarly. Increasing the rate of bark substitution linearly decreased strength properties, but had little effect on dimensional stability. On the average, increasing the rate of bark substitution from 5 to 20 percent decreased MOR 7 to 24 percent, decreased MOE 4 to 17 percent, and decreased IB 5 to 20 percent.

174. ***Wojcik, Blankenhorn and Labosky. 1988. Comparison of Red Maple (Acer Rubrum L.) and Aspen (Populus Grandidentata Michx) 3-layered Flakeboards.***

Three-layered flakeboards were fabricated using long and short flakes of red maple (*Acer rubrum* L.) and aspen (*Populus grandidentata* Michx). Panels were fabricated using three layers of a single species or face layers of a single species with a core layer of the other species. Static bending, internal bond, and nail withdrawal values indicated that red maple and aspen boards for the most part were comparable. A mixed-species board with aspen in the face layers and red maple in the core layer had some of the highest static bending values. Dimensional stability values were acceptable among all boards with the mixed-species boards producing some of the lowest values. Red maple 3-layered flakeboards were similar to aspen 3-layered boards and it appeared that red maple and aspen may be mixed to produce quality 3-layered flakeboards.

175. ***Wolcott, Kamke and Dillard. 1988. Fundamentals of Flakeboard Manufacture: Viscoelastic Behavior of the Wood Component.***

Theories of the viscoelastic behavior of amorphous polymers are reviewed and are used to describe the density gradient formation in flakeboard. This technique utilizes measured temperature and gas pressure at discrete locations inside a flake mat during hot pressing to predict the glass transition temperature of wood as a function of press-time. The difference between the flake temperature and the predicted glass transition temperature is a relative indicator of the amount of flake deformation and stress relaxation at a location in the mat. A knowledge of the stress history imposed in the mat is then used to relate flake deformation and stress relaxation to the formation of a density gradient. This analysis allows for a significant portion of the density gradient to develop after the hot-press has closed. Experimental data for various density gradients in yellow-poplar flakeboard support the theories presented here.

176. ***Yeh, Tang and Hse. 1990. Flexural Creep of Structural Flakeboards Under Cyclic Humidity.***

Flexural creep behavior of randomly oriented structural flakeboards under cyclic humidity is presented. Specimens fabricated with 5 and 7 percent phenol-formaldehyde resin were subjected to constant concentrated load in bending under slow and fast cyclic relative humidity (RH) between 65 and 95 percent for 100 days. The temperature was set at a constant 75°F through the test duration and each humidity level was maintained for 33 days (slow cycle) and 2 days (fast cycle). Boards made with sweetgum flakes showed better creep resistance than those made of white oak. Significant effect on the creep resistance was observed when the resin content was increased from 5 to 7 percent under highly humid environments. Large deflections occurred and large permanent deformations remained for both groups after the relaxation. However, fast RH cycles had a greater weakening effect on creep resistance than did slow change. Creep moduli and relative creep, often considered to be the indices of the long-term performance of flakeboards, were significantly influenced by the change of RH. The resulting information may provide a better understanding of the long-term engineering performance of structural flakeboards as affected by the changes of RH conditions.

177. ***Zhou. 1989. A Study of Oriented Structural Board Made from Hybrid Poplar.***

The objective of this paper was to study the influences of four main factors of a mechanical orientation forming installation (ie., the distance between two neighbouring saws (D), the moving frequency of the saws (F), the moving length of saws (L) and the height of strand free-fall (H)) on orientation effectiveness of strands. The average strand orientation angle was measured and used to evaluate the effectiveness of the strand orientation. The results showed that both factor D and factor H had a significant influence on the orientation of strands, factor L only had marginal influence and factor F exerted little or no influence.

Appendix III. FLAKING STUDIES: Governing Parameters and Properties

FLAKING STUDIES: Governing Parameters and Properties

SPECIES *Latin Binomial*	FLAKING PARAMETERS Machine	Resource	STRAND PROPERTIES Quality	Yield
Aceituna *Simaruba amara*				
Afrormosia *Pericopsos elata*				
Alder (Black) *Alnus glutinosa*		36	36	36
Alder (red) *Alnus rubra*	122	122	122	122
Ash (green) *Fraxinus pennsylvanica*		141	141	
Ash (white) *Fraxinus americana*				
Ash species *Fraxinus spp.*	21		21	21
Aspen (largetooth) *Populus grandidentata*	33, 34	33, 34, 108	33, 34, 108	34, 108
Banak *Virola koschyni*				
Basswood (American) *Tilia americana*		159	159	159

FLAKING STUDIES: Governing Parameters and Properties

SPECIES *Latin Binomial*	FLAKING PARAMETERS Machine	Resource	STRAND PROPERTIES Quality	Yield
Basswood (white) *Tilia hertorphylla*				
Beech (American) *Fagus grandifolia*	33, 34	33, 34	33, 34	34
Birch (black) *Betula lenta*				
Birch (white) *Betula papyrifera*		57		7
Birch (yellow) *Betula alleghaniensis*				
Cedar (eastern white) *Thuja occidentalis*				
Cherry (black) *Prunus serotina*				
Cottonwood *Populus deltoides*				
Cottonwood (black) *Populus trichocarpa*				
Douglas-fir *Pseudotsuga menziesii*	29 , 32, 43, 44, 54, 68, 125	29, 32, 43, 44, 54, 65, 68, 70, 116, 120, 125	29, 32, 44, 54, 65, 68, 116, 120, 125	32, 70, 116, 120, 125

FLAKING STUDIES: Governing Parameters and Properties

SPECIES *Latin Binomial*	FLAKING PARAMETERS		STRAND PROPERTIES	
	Machine	Resource	Quality	Yield
Elm (American) *Ulmus americana*	21	141	21, 141	21
Fir (balsam) *Abies balsamea*	31, 33	31, 33, 85	31, 33	7, 31, 33
Fir (grand) *Abies grandis*	39	39	39	39
Fir (white) *Abies concolor*				
Gallina *Jacaranda copaia*				
Hackberry *Celtis occidentalis*	21	141	21, 141	21
Hemlock (eastern) *Tsuga canadensis*	33	33	33	
Hemlock (western) *Tsuga heterophylla*		70		70
Hickory (mockernut) *Carya tomentosa*	142, 143	142, 143	142, 143	142, 143
Hickory species *Carya spp.*		159	159	159

FLAKING STUDIES: Governing Parameters and Properties

SPECIES *Latin Binomial*	FLAKING PARAMETERS Machine	Resource	STRAND PROPERTIES Quality	Yield
Jobo *Spondias mombin*				
Kiri *Paulownia tomentosa*		36	36	36
Limba *Terminalia superba*				
Locust (black) *Robinia pseudoacacia*		36	36	36
Maple (red) *Acer rubrum*	34	34, 108	34, 108	34, 108
Maple (silver) *Acer saccharinum*				
Maple (sugar) *Acer saccharum*	158	158	158	
Maple species *Acer spp.*				
Oak (overcup) *Quercus lyrata*		141	141	
Oak (post) *Quercus stellata*				

FLAKING STUDIES: Governing Parameters and Properties

SPECIES *Latin Binomial*	FLAKING PARAMETERS		STRAND PROPERTIES	
	Machine	Resource	Quality	Yield
Oak (northern red) *Quercus rubra*	33	33	33	
Oak (southern red) *Quercus falcata*	21, 142, 143	141, 142, 143, 159	21, 141, 142, 143, 159	21, 142, 143, 159
Oak (scarlet) *Quercus coccinea*	133			
Oak (water) *Quercus nigra*	129	129, 141	129, 141	
Oak (white) *Quercus alba*	21, 34	34	21, 34	21, 34
Oak species *Quercus spp.*				
Olive (autumn) *Elaeagnus umbellata*		36	36	36
Pecan *Carya illinoensis*	21	141	21, 141	21
Pine (jack) *Pinus banksiana*	31	31	31	31
Pine (loblolly) *Pinus taeda*	142, 143	142, 143	142, 143	142, 143

FLAKING STUDIES: Governing Parameters and Properties

SPECIES *Latin Binomial*	FLAKING PARAMETERS		STRAND PROPERTIES	
	Machine	Resource	Quality	Yield
Pine (lodgepole) *Pinus contorta*	121, 125, 142, 143	121, 125, 142, 143	121, 125, 142, 143	121, 125, 142, 143
Pine (ponderosa) *Pinus ponderosa*				
Pine (red) *Pinus resinosa*				
Pine (scrub) *Pinus virginiana*				
Pine (slash) *Pinus elliottii*				
Pine (eastern white) *Pinus strobus*				
Pine (western white) *Pinus monticola*	121	121	121	121
Pine (southern yellow) *Pinus echinata*	43, 129	43, 129	129	
Pine (northern) *Pinus spp.*	125	125	125	125
Pine (southern) *Pinus spp.*				

FLAKING STUDIES: Governing Parameters and Properties

SPECIES *Latin Binomial*	FLAKING PARAMETERS Machine	Resource	STRAND PROPERTIES Quality	Yield
Poplar (balsam) *Populus balsamifera*	4, 5	2, 3, 4, 5, 57, 130	2, 3, 4, 5, 130	2, 3, 4, 5, 130
Poplar (hybrid) *Populus spp.*				
Redwood *Sequoia sempervirens*	43	43		
Spruce (black) *Picea mariana*				7
Spruce (Engelmann) *Picea engelmannii*				
Spruce (red) *Picea rubens*				
Spruce (Sitka) *Picea sitchensis*				
Spruce (white) *Picea glauca*	31, 169	31, 169	31, 169	31, 169
Spruce species *Picea spp.*	125	125	125	125
Sweetbay *Magnolia virginiana*	129	129	129	

FLAKING STUDIES: Governing Parameters and Properties

SPECIES *Latin Binomial*	FLAKING PARAMETERS		STRAND PROPERTIES	
	Machine	Resource	Quality	Yield
Sweetgum *Liquidambar styraciflua*	21, 62, 129, 142, 143	62, 129, 136, 141, 142, 143	21, 62, 129, 136, 141, 142, 143	21, 142, 143
Sycamore *Platanus occidentalis*		36	36	36
Tamarack *Larix laricina*				
Tupelo (black) *Nyssa sylvatica*	34, 129	34, 129	34, 129	34
Virola species *Virola spp.*				
Yellow-poplar *Liriodendron tulipifera*	34, 62, 129	34, 62, 129, 159	34, 62, 129, 159	34, 159

Appendix IV. DRYING STUDIES: Governing Parameters and Properties

DRYING STUDIES: Governing Parameters and Properties

SPECIES *Latin Binomial*	DRYING PARAMETERS Temperature	 Moisture	STRAND PROPERTIES Quality	 Moisture
Aceituna *Simaruba amara*				
Afrormosia *Pericopsos elata*				
Alder (Black) *Alnus glutinosa*				
Alder (red) *Alnus rubra*				
Ash (green) *Fraxinus pennsylvanica*				
Ash (white) *Fraxinus americana*				
Ash species *Fraxinus spp.*				
Aspen (largetooth) *Populus grandidentata*	33	33	33	33
Banak *Virola koschyni*				
Basswood (American) *Tilia americana*				

DRYING STUDIES: Governing Parameters and Properties

SPECIES *Latin Binomial*	DRYING PARAMETERS		STRAND PROPERTIES	
	Temperature	Moisture	Quality	Moisture
Basswood (white) *Tilia hertorphylla*				
Beech (American) *Fagus grandifolia*	33	33	33	33
Birch (black) *Betula lenta*				
Birch (white) *Betula papyrifera*				
Birch (yellow) *Betula alleghaniensis*				
Cedar (eastern white) *Thuja occidentalis*				
Cherry (black) *Prunus serotina*				
Cottonwood *Populus deltoides*				
Cottonwood (black) *Populus trichocarpa*				
Douglas-fir *Pseudotsuga menziesii*				

DRYING STUDIES: Governing Parameters and Properties

SPECIES *Latin Binomial*	DRYING PARAMETERS Temperature	Moisture	STRAND PROPERTIES Quality	Moisture
Elm (American) *Ulmus americana*				
Fir (balsam) *Abies balsamea*	33	33	33	33
Fir (grand) *Abies grandis*				
Fir (white) *Abies concolor*				
Gallina *Jacaranda copaia*				
Hackberry *Celtis occidentalis*				
Hemlock (eastern) *Tsuga canadensis*	33	33	33	33
Hemlock (western) *Tsuga heterophylla*				
Hickory (mockernut) *Carya tomentosa*				
Hickory species *Carya spp.*				

DRYING STUDIES: Governing Parameters and Properties

SPECIES *Latin Binomial*	DRYING PARAMETERS		STRAND PROPERTIES	
	Temperature	Moisture	Quality	Moisture
Jobo *Spondias mombin*				
Kiri *Paulownia tomentosa*				
Limba *Terminalia superba*				
Locust (black) *Robinia pseudoacacia*				
Maple (red) *Acer rubrum*				
Maple (silver) *Acer saccharinum*				
Maple (sugar) *Acer saccharum*				
Maple species *Acer spp.*				
Oak (overcup) *Quercus lyrata*				
Oak (post) *Quercus stellata*				

DRYING STUDIES: Governing Parameters and Properties

SPECIES *Latin Binomial*	DRYING PARAMETERS		STRAND PROPERTIES	
	Temperature	Moisture	Quality	Moisture
Oak (northern red) *Quercus rubra*	33	33	33	33
Oak (southern red) *Quercus falcata*	132		132	
Oak (scarlet) *Quercus coccinea*				
Oak (water) *Quercus nigra*				
Oak (white) *Quercus alba*	132		132	
Oak species *Quercus spp.*				
Olive (autumn) *Elaeagnus umbellata*				
Pecan *Carya illinoensis*				
Pine (jack) *Pinus banksiana*				
Pine (loblolly) *Pinus taeda*				

DRYING STUDIES: Governing Parameters and Properties

SPECIES *Latin Binomial*	DRYING PARAMETERS		STRAND PROPERTIES	
	Temperature	Moisture	Quality	Moisture
Pine (lodgepole) *Pinus contorta*				
Pine (ponderosa) *Pinus ponderosa*				
Pine (red) *Pinus resinosa*				
Pine (scrub) *Pinus virginiana*				
Pine (slash) *Pinus elliottii*				
Pine (eastern white) *Pinus strobus*				
Pine (western white) *Pinus monticola*				
Pine (southern yellow) *Pinus echinata*				
Pine (northern) *Pinus spp.*				
Pine (southern) *Pinus spp.*				

DRYING STUDIES: Governing Parameters and Properties

SPECIES *Latin Binomial*	DRYING PARAMETERS Temperature	Moisture	STRAND PROPERTIES Quality	Moisture
Poplar (balsam) *Populus balsamifera*	3	3	3	
Poplar (hybrid) *Populus spp.*				
Redwood *Sequoia sempervirens*				
Spruce (black) *Picea mariana*				
Spruce (Engelmann) *Picea engelmannii*				
Spruce (red) *Picea rubens*				
Spruce (Sitka) *Picea sitchensis*				
Spruce (white) *Picea glauca*				
Spruce species *Picea spp.*				
Sweetbay *Magnolia virginiana*				

DRYING STUDIES: Governing Parameters and Properties

SPECIES *Latin Binomial*	DRYING PARAMETERS		STRAND PROPERTIES	
	Temperature	Moisture	Quality	Moisture
Sweetgum *Liquidambar styraciflua*	132		132	
Sycamore *Platanus occidentalis*				
Tamarack *Larix laricina*				
Tupelo (black) *Nyssa sylvatica*				
Virola species *Virola spp.*				
Yellow-poplar *Liriodendron tulipifera*				

Appendix V. BLENDING STUDIES Governing Parameters and Additive Distribution

BLENDING STUDIES: Governing Parameters and Additive Distribution

SPECIES *Latin Binomial*	BLENDING PARAMETERS Machine	Resource	Additives	ADDITIVE DISTRIBUTION
Aceituna *Simaruba amara*				
Afrormosia *Pericopsos elata*				
Alder (Black) *Alnus glutinosa*				
Alder (red) *Alnus rubra*				
Ash (green) *Fraxinus pennsylvanica*				
Ash (white) *Fraxinus americana*	40	40	40	40
Ash species *Fraxinus spp.*				
Aspen (largetooth) *Populus grandidentata*				
Banak *Virola koschyni*				
Basswood (American) *Tilia americana*				

BLENDING STUDIES: Governing Parameters and Additive Distribution

SPECIES *Latin Binomial*	BLENDING PARAMETERS Machine	Resource	Additives	ADDITIVE DISTRIBUTION
Basswood (white) *Tilia hertorphylla*				
Beech (American) *Fagus grandifolia*				
Birch (black) *Betula lenta*				
Birch (white) *Betula papyrifera*				
Birch (yellow) *Betula alleghaniensis*		109	109	109
Cedar (eastern white) *Thuja occidentalis*				
Cherry (black) *Prunus serotina*				
Cottonwood *Populus deltoides*				
Cottonwood (black) *Populus trichocarpa*				
Douglas-fir *Pseudotsuga menziesii*	27, 28, 32, 110, 111, 112, 120	27, 32, 110, 111, 112, 120	28, 32, 110, 111, 112, 120	27, 32, 110, 111, 112, 120

BLENDING STUDIES: Governing Parameters and Additive Distribution

SPECIES *Latin Binomial*	BLENDING PARAMETERS Machine	Resource	Additives	ADDITIVE DISTRIBUTION
Elm (American) *Ulmus americana*				
Fir (balsam) *Abies balsamea*				
Fir (grand) *Abies grandis*		39		
Fir (white) *Abies concolor*		14, 92	14, 92	
Gallina *Jacaranda copaia*				
Hackberry *Celtis occidentalis*				
Hemlock (eastern) *Tsuga canadensis*				
Hemlock (western) *Tsuga heterophylla*				
Hickory (mockernut) *Carya tomentosa*				
Hickory species *Carya spp.*	40	40	40	40

BLENDING STUDIES: Governing Parameters and Additive Distribution

SPECIES *Latin Binomial*	BLENDING PARAMETERS Machine	Resource	Additives	ADDITIVE DISTRIBUTION
Jobo *Spondias mombin*				
Kiri *Paulownia tomentosa*				
Limba *Terminalia superba*				
Locust (black) *Robinia pseudoacacia*				
Maple (red) *Acer rubrum*	40, 41, 42	40, 41, 42	40, 41, 42	40, 41, 42
Maple (silver) *Acer saccharinum*				
Maple (sugar) *Acer saccharum*			26	
Maple species *Acer spp.*				
Oak (overcup) *Quercus lyrata*				
Oak (post) *Quercus stellata*	40	40	40	40

BLENDING STUDIES: Governing Parameters and Additive Distribution

SPECIES *Latin Binomial*	BLENDING PARAMETERS			ADDITIVE DISTRIBUTION
	Machine	Resource	Additives	
Oak (northern red) *Quercus rubra*				
Oak (southern red) *Quercus falcata*	40, 41, 42	40, 41, 42	40, 41, 42	40, 41, 42
Oak (scarlet) *Quercus coccinea*	133	97, 133	97	97
Oak (water) *Quercus nigra*				
Oak (white) *Quercus alba*	40	40	40	40
Oak species *Quercus spp.*				
Olive (autumn) *Elaeagnus umbellata*				
Pecan *Carya illinoensis*				
Pine (jack) *Pinus banksiana*				
Pine (loblolly) *Pinus taeda*				

BLENDING STUDIES: Governing Parameters and Additive Distribution

SPECIES *Latin Binomial*	BLENDING PARAMETERS Machine	Resource	Additives	ADDITIVE DISTRIBUTION
Pine (lodgepole) *Pinus contorta*	121	121	121	
Pine (ponderosa) *Pinus ponderosa*	28	12	12, 28	28
Pine (red) *Pinus resinosa*				
Pine (scrub) *Pinus virginiana*	28		28	28
Pine (slash) *Pinus elliottii*				
Pine (eastern white) *Pinus strobus*				
Pine (western white) *Pinus monticola*	121	121	121	
Pine (southern yellow) *Pinus echinata*				
Pine (northern) *Pinus spp.*				
Pine (southern) *Pinus spp.*	41, 42	41, 42	41, 42	41, 42

BLENDING STUDIES: Governing Parameters and Additive Distribution

SPECIES *Latin Binomial*	BLENDING PARAMETERS Machine	 Resource	 Additives	ADDITIVE DISTRIBUTION
Poplar (balsam) *Populus balsamifera*				
Poplar (hybrid) *Populus spp.*				
Redwood *Sequoia sempervirens*		37	37	
Spruce (black) *Picea mariana*				
Spruce (Engelmann) *Picea engelmannii*				
Spruce (red) *Picea rubens*				
Spruce (Sitka) *Picea sitchensis*				
Spruce (white) *Picea glauca*				
Spruce species *Picea spp.*				
Sweetbay *Magnolia virginiana*	40	40	40	40

BLENDING STUDIES: Governing Parameters and Additive Distribution

SPECIES *Latin Binomial*	BLENDING PARAMETERS Machine	Resource	Additives	ADDITIVE DISTRIBUTION
Sweetgum *Liquidambar styraciflua*	40, 41, 42, 62	40, 41, 42,62	40, 41, 42, 62	40, 41, 42
Sycamore *Platanus occidentalis*				
Tamarack *Larix laricina*				
Tupelo (black) *Nyssa sylvatica*	40	40	40	40
Virola species *Virola spp.*				
Yellow-poplar *Liriodendron tulipifera*	62	62	62	

Appendix VI. FORMING STUDIES: Governing Parameters and Forming Properties

FORMING STUDIES: Governing Parameters and Forming Properties

SPECIES *Latin Binomial*	FORMING PARAMETERS		FORMING PROPERTIES	
	Machine	Resource	Alignment	Distribution
Aceituna *Simaruba amara*				
Afrormosia *Pericopsos elata*				
Alder (Black) *Alnus glutinosa*				
Alder (red) *Alnus rubra*				
Ash (green) *Fraxinus pennsylvanica*				
Ash (white) *Fraxinus americana*				
Ash species *Fraxinus spp.*				
Aspen (largetooth) *Populus grandidentata*				
Banak *Virola koschyni*				
Basswood (American) *Tilia americana*				

FORMING STUDIES: Governing Parameters and Forming Properties

SPECIES *Latin Binomial*	FORMING PARAMETERS		FORMING PROPERTIES	
	Machine	Resource	Alignment	Distribution
Basswood (white) *Tilia hertorphylla*				
Beech (American) *Fagus grandifolia*				
Birch (black) *Betula lenta*				
Birch (white) *Betula papyrifera*				
Birch (yellow) *Betula alleghaniensis*				
Cedar (eastern white) *Thuja occidentalis*				
Cherry (black) *Prunus serotina*				
Cottonwood *Populus deltoides*				
Cottonwood (black) *Populus trichocarpa*				
Douglas-fir *Pseudotsuga menziesii*	44	44, 45, 46, 47, 48	44, 45, 46, 47, 48	47

FORMING STUDIES: Governing Parameters and Forming Properties

SPECIES *Latin Binomial*	FORMING PARAMETERS		FORMING PROPERTIES	
	Machine	Resource	Alignment	Distribution
Elm (American) *Ulmus americana*				
Fir (balsam) *Abies balsamea*				
Fir (grand) *Abies grandis*				
Fir (white) *Abies concolor*				
Gallina *Jacaranda copaia*				
Hackberry *Celtis occidentalis*				
Hemlock (eastern) *Tsuga canadensis*				
Hemlock (western) *Tsuga heterophylla*				
Hickory (mockernut) *Carya tomentosa*				
Hickory species *Carya spp.*				

FORMING STUDIES: Governing Parameters and Forming Properties

SPECIES *Latin Binomial*	FORMING PARAMETERS Machine	Resource	FORMING PROPERTIES Alignment	Distribution
Jobo *Spondias mombin*				
Kiri *Paulownia tomentosa*				
Limba *Terminalia superba*				
Locust (black) *Robinia pseudoacacia*				
Maple (red) *Acer rubrum*				
Maple (silver) *Acer saccharinum*				
Maple (sugar) *Acer saccharum*				
Maple species *Acer spp.*				
Oak (overcup) *Quercus lyrata*				
Oak (post) *Quercus stellata*				

FORMING STUDIES: Governing Parameters and Forming Properties

SPECIES *Latin Binomial*	FORMING PARAMETERS		FORMING PROPERTIES	
	Machine	Resource	Alignment	Distribution
Oak (northern red) *Quercus rubra*		45, 47, 48	45, 47, 48	
Oak (southern red) *Quercus falcata*				
Oak (scarlet) *Quercus coccinea*				
Oak (water) *Quercus nigra*				
Oak (white) *Quercus alba*				
Oak species *Quercus spp.*				
Olive (autumn) *Elaeagnus umbellata*				
Pecan *Carya illinoensis*				
Pine (jack) *Pinus banksiana*				
Pine (loblolly) *Pinus taeda*				

FORMING STUDIES: Governing Parameters and Forming Properties

SPECIES *Latin Binomial*	FORMING PARAMETERS Machine	 Resource	FORMING PROPERTIES Alignment	 Distribution
Pine (lodgepole) *Pinus contorta*				
Pine (ponderosa) *Pinus ponderosa*				
Pine (red) *Pinus resinosa*				
Pine (scrub) *Pinus virginiana*				
Pine (slash) *Pinus elliottii*				
Pine (eastern white) *Pinus strobus*				
Pine (western white) *Pinus monticola*				
Pine (southern yellow) *Pinus echinata*				
Pine (northern) *Pinus spp.*				
Pine (southern) *Pinus spp.*				

PRESSING STUDIES: Furnish Parameters

SPECIES *Latin Binomial*	RESIN CONTENT	WAX CONTENT	STRAND ALIGNMENT	MOISTURE CONTENT
Aceituna *Simaruba amara*				
Afrormosia *Pericopsos elata*				
Alder (Black) *Alnus glutinosa*	36		36	36
Alder (red) *Alnus rubra*	122, 173		122	
Ash (green) *Fraxinus pennsylvanica*	141	141	72, 73, 89	
Ash (white) *Fraxinus americana*	75, 78			
Ash species *Fraxinus spp.*	84			84
Aspen (largetooth) *Populus grandidentata*	75, 78, 149		108, 149	
Banak *Virola koschyni*				
Basswood (American) *Tilia americana*				

PRESSING STUDIES: Furnish Parameters

SPECIES *Latin Binomial*	RESIN CONTENT	WAX CONTENT	STRAND ALIGNMENT	MOISTURE CONTENT
Basswood (white) *Tilia hertorphylla*	147			
Beech (American) *Fagus grandifolia*				
Birch (black) *Betula lenta*	147			
Birch (white) *Betula papyrifera*	17, 35, 156		35, 72, 73, 89	156
Birch (yellow) *Betula alleghaniensis*	109			
Cedar (eastern white) *Thuja occidentalis*				
Cherry (black) *Prunus serotina*	75, 78			
Cottonwood *Populus deltoides*				
Cottonwood (black) *Populus trichocarpa*				
Douglas-fir *Pseudotsuga menziesii*	27, 28, 29, 32, 43,68, 93, 110, 111, 112, 113, 114, 115, 117, 120, 144, 167, 171, 173	43, 93, 114, 115	44, 46, 47, 48, 106, 125, 144	27, 32, 43, 69, 93, 110, 144, 160, 171

PRESSING STUDIES: Furnish Parameters

SPECIES *Latin Binomial*	RESIN CONTENT	WAX CONTENT	STRAND ALIGNMENT	MOISTURE CONTENT
Elm (American) *Ulmus americana*	67, 141	141		
Fir (balsam) *Abies balsamea*	85			
Fir (grand) *Abies grandis*			39, 154	
Fir (white) *Abies concolor*	13			
Gallina *Jacaranda copaia*				
Hackberry *Celtis occidentalis*	141, 172	141		172
Hemlock (eastern) *Tsuga canadensis*	19			
Hemlock (western) *Tsuga heterophylla*	173			
Hickory (mockernut) *Carya tomentosa*	142, 143, 146			
Hickory species *Carya spp.*	75, 78, 84, 172		77, 82, 107, 135, 137, 138, 139, 140	75, 78, 84, 172

PRESSING STUDIES: Furnish Parameters

SPECIES *Latin Binomial*	RESIN CONTENT	WAX CONTENT	STRAND ALIGNMENT	MOISTURE CONTENT
Jobo *Spondias mombin*				
Kiri *Paulownia tomentosa*	36		36	36
Limba *Terminalia superba*				
Locust (black) *Robinia pseudoacacia*	36		36	36
Maple (red) *Acer rubrum*	41, 75, 78, 149		72, 73, 89, 108, 149	
Maple (silver) *Acer saccharinum*				
Maple (sugar) *Acer saccharum*	151			128
Maple species *Acer spp.*	67			
Oak (overcup) *Quercus lyrata*	141	141		
Oak (post) *Quercus stellata*				

PRESSING STUDIES: Furnish Parameters

SPECIES *Latin Binomial*	RESIN CONTENT	WAX CONTENT	STRAND ALIGNMENT	MOISTURE CONTENT
Poplar (balsam) *Populus balsamifera*	1, 86		2, 4, 125	
Poplar (hybrid) *Populus spp.*	51		50	
Redwood *Sequoia sempervirens*	37, 43	43		37, 43
Spruce (black) *Picea mariana*				
Spruce (Engelmann) *Picea engelmannii*	115			
Spruce (red) *Picea rubens*				
Spruce (Sitka) *Picea sitchensis*	167			
Spruce (white) *Picea glauca*	38			38, 169
Spruce species *Picea spp.*			106, 125	
Sweetbay *Magnolia virginiana*				

PRESSING STUDIES: Furnish Parameters

SPECIES *Latin Binomial*	RESIN CONTENT	WAX CONTENT	STRAND ALIGNMENT	MOISTURE CONTENT
Sweetgum *Liquidambar styraciflua*	40, 41, 55, 62, 75, 78, 79, 84, 141, 142, 143, 146, 147, 172, 176	141	77, 82, 107, 135, 137, 138, 139, 140	40, 75, 78, 79, 84, 172
Sycamore *Platanus occidentalis*	36, 145	145	36	36
Tamarack *Larix laricina*				
Tupelo (black) *Nyssa sylvatica*				
Virola species *Virola spp.*				
Yellow-poplar *Liriodendron tulipifera*	55, 62, 146, 147, 161			99, 100, 101, 175

PRESSING STUDIES: Furnish Parameters

SPECIES *Latin Binomial*	STRAND GEOMETRY	LAYER RATIO	SINGLE SPECIES	MIXED SPECIES
Elm (American) *Ulmus americana*	141		67, 141	67, 141
Fir (balsam) *Abies balsamea*	85		7, 8, 31, 85	7, 31
Fir (grand) *Abies grandis*	39, 154		39, 154	
Fir (white) *Abies concolor*	116, 123	13, 14	13, 14, 92	116, 123
Gallina *Jacaranda copaia*			63	
Hackberry *Celtis occidentalis*	141		141	141
Hemlock (eastern) *Tsuga canadensis*	19	19		19
Hemlock (western) *Tsuga heterophylla*	70, 116, 123, 173		70	70, 116, 123, 173
Hickory (mockernut) *Carya tomentosa*	142, 143, 146		142, 143, 146	146
Hickory species *Carya spp.*	25, 40, 67, 84, 159	77	15, 25, 40, 67, 75, 76, 78, 79, 81, 84, 104, 105, 159	67, 75, 77, 78, 82, 84, 104, 105, 107, 135, 137, 138, 139, 140, 172

PRESSING STUDIES: Furnish Parameters

SPECIES *Latin Binomial*	STRAND GEOMETRY	LAYER RATIO	SINGLE SPECIES	MIXED SPECIES
Jobo *Spondias mombin*			63	
Kiri *Paulownia tomentosa*	36, 168	36	36, 168	36, 81, 168
Limba *Terminalia superba*	168		168	168
Locust (black) *Robinia pseudoacacia*	36	36	36	36
Maple (red) *Acer rubrum*	40, 59, 72, 73, 81, 83, 89, 149, 174	83, 155	40, 41, 59, 72, 73, 75, 76, 78, 79, 81, 83, 89, 90, 108, 149, 174	40, 59, 72, 73, 75, 78, 81, 83, 89, 91, 149, 155
Maple (silver) *Acer saccharinum*			165	
Maple (sugar) *Acer saccharum*	150, 151	155	26, 128, 150, 151	155
Maple species *Acer spp.*			67	67
Oak (overcup) *Quercus lyrata*	141		141	141
Oak (post) *Quercus stellata*	40, 81		40, 75, 76, 78, 79, 81	40

PRESSING STUDIES: Furnish Parameters

SPECIES *Latin Binomial*	STRAND GEOMETRY	LAYER RATIO	SINGLE SPECIES	MIXED SPECIES
Oak (northern red) *Quercus rubra*	45, 47, 48, 66, 72, 73, 89		26, 45, 47, 48, 66, 67, 72, 73, 87, 88, 89, 126	67, 72, 73, 89, 91
Oak (southern red) *Quercus falcata*	40, 67, 81, 84, 141, 142, 143, 159	77	40, 41, 67, 75, 76, 78, 79, 80, 81, 84, 104, 105, 132, 141, 142, 143, 159	22, 40, 67, 75, 77, 78, 79, 82, 84, 104, 105, 107, 135, 137, 138, 139, 140, 141
Oak (scarlet) *Quercus coccinea*	98, 133, 134		97, 98, 133, 134	
Oak (water) *Quercus nigra*	141		141	141
Oak (white) *Quercus alba*	40, 81, 84, 146		40, 75, 76, 78, 79, 80, 81, 84, 104, 105, 132, 146, 176	22, 40, 81, 82, 84, 104, 105, 107, 135, 137, 138, 139, 140, 146
Oak species *Quercus spp.*				172
Olive (autumn) *Elaeagnus umbellata*	36	36	36	36
Pecan *Carya illinoensis*	84, 141		84, 141	84, 141
Pine (jack) *Pinus banksiana*	50, 123		31, 50	31, 123
Pine (loblolly) *Pinus taeda*	142, 143, 146, 154		137, 138, 139, 142, 143, 146, 154	

PRESSING STUDIES: Furnish Parameters

SPECIES *Latin Binomial*	STRAND GEOMETRY	LAYER RATIO	SINGLE SPECIES	MIXED SPECIES
Pine (lodgepole) *Pinus contorta*	64, 115, 121, 123, 125, 142, 143, 144	115, 125	64, 121, 125, 142, 143, 144	115, 123
Pine (ponderosa) *Pinus ponderosa*	123, 173	12	12, 28, 154	123, 173
Pine (red) *Pinus resinosa*	119		119	119
Pine (scrub) *Pinus virginiana*			28	
Pine (slash) *Pinus elliottii*			74	
Pine (eastern white) *Pinus strobus*	19	19		19
Pine (western white) *Pinus monticola*	121		121	
Pine (southern yellow) *Pinus echinata*	43		23, 24, 43	23, 24, 55
Pine (northern) *Pinus spp.*	125	125		125
Pine (southern) *Pinus spp.*	123, 162		41, 69, 104, 105, 118, 123, 148, 162	82, 104, 105, 107, 123, 135, 137, 138, 139, 140

PRESSING STUDIES: Furnish Parameters

SPECIES *Latin Binomial*	STRAND GEOMETRY	LAYER RATIO	SINGLE SPECIES	MIXED SPECIES
Poplar (balsam) *Populus balsamifera*	2, 125	3, 4, 125	1, 2, 3, 4, 5, 6, 86, 125, 127, 130	2, 3, 4, 5, 6, 125, 127, 130
Poplar (hybrid) *Populus spp.*	50, 51	50, 51	50, 51, 177	
Redwood *Sequoia sempervirens*	37, 43		37, 43	
Spruce (black) *Picea mariana*			7	7
Spruce (Engelmann) *Picea engelmannii*	115	115		115
Spruce (red) *Picea rubens*			9	
Spruce (Sitka) *Picea sitchensis*	167		166, 167	
Spruce (white) *Picea glauca*	38	38	31, 38, 169	31, 169
Spruce species *Picea spp.*	123, 125, 153	106, 125	153	106, 123, 125
Sweetbay *Magnolia virginiana*	40		40, 75, 76, 78, 79	40, 81

PRESSING STUDIES: Furnish Parameters

SPECIES *Latin Binomial*	STRAND GEOMETRY	LAYER RATIO	SINGLE SPECIES	MIXED SPECIES
Sweetgum *Liquidambar styraciflua*	40, 62, 81, 84, 141, 142, 143, 146, 162	77	40, 41, 62, 75, 76, 78, 79, 80, 81, 84, 104, 105, 132, 141, 142, 143, 146, 162, 176	22, 23, 24, 40, 55, 75, 77, 78, 79, 81, 82, 84, 104, 105, 107, 135, 137, 138, 139, 140, 141, 146, 147, 172
Sycamore *Platanus occidentalis*	36	36	36, 145	36
Tamarack *Larix laricina*	50		50, 57	57
Tupelo (black) *Nyssa sylvatica*	40, 81		40, 75, 76, 78, 79, 81	40
Virola species *Virola spp.*	168		168	168
Yellow-poplar *Liriodendron tulipifera*	62, 67, 146, 159		62, 67, 99, 100, 101, 137, 138, 139, 146, 159, 161, 175	22, 55, 67, 146, 147

PRESSING STUDIES: Furnish Parameters

SPECIES *Latin Binomial*	TARGET DENSITY	TREATMENT	RESIN TYPE	
Aceituna *Simaruba amara*				
Afrormosia *Pericopsos elata*	168			
Alder (Black) *Alnus glutinosa*	36			
Alder (red) *Alnus rubra*	122		122, 173	
Ash (green) *Fraxinus pennsylvanica*	89, 141		141	
Ash (white) *Fraxinus americana*	40, 79, 81		81	
Ash species *Fraxinus spp.*			84	
Aspen (largetooth) *Populus grandidentata*	149			
Banak *Virola koschyni*				
Basswood (American) *Tilia americana*	67, 159			

PRESSING STUDIES: Furnish Parameters

SPECIES *Latin Binomial*	TARGET DENSITY	TREATMENT	RESIN TYPE	
Basswood (white) *Tilia hertorphylla*	147			
Beech (American) *Fagus grandifolia*				
Birch (black) *Betula lenta*	147			
Birch (white) *Betula papyrifera*	10, 17, 35, 57, 83, 89, 127, 130		156	
Birch (yellow) *Betula alleghaniensis*	109			
Cedar (eastern white) *Thuja occidentalis*				
Cherry (black) *Prunus serotina*				
Cottonwood *Populus deltoides*				
Cottonwood (black) *Populus trichocarpa*				
Douglas-fir *Pseudotsuga menziesii*	29, 43, 45, 47, 48, 49, 54, 64, 69, 93, 106, 112, 113, 117, 118, 120, 144, 160, 167	28, 166	69, 93, 94, 95, 96, 110, 111, 118, 123, 171, 173	

PRESSING STUDIES: Furnish Parameters

SPECIES *Latin Binomial*	TARGET DENSITY	TREATMENT	RESIN TYPE	
Oak (northern red) *Quercus rubra*	45, 47, 48, 67, 87, 88, 89	26, 126	126	
Oak (southern red) *Quercus falcata*	40, 67, 76, 79, 81, 82, 104, 105, 135, 137, 138, 139, 140, 141, 142, 143, 159	41	75, 78, 79, 80, 81, 84, 141	
Oak (scarlet) *Quercus coccinea*				
Oak (water) *Quercus nigra*	141		141	
Oak (white) *Quercus alba*	40, 76, 79, 81, 82, 104, 105, 135, 137, 138, 139, 140, 146, 176		79, 80, 81, 84	
Oak species *Quercus spp.*				
Olive (autumn) *Elaeagnus umbellata*	36			
Pecan *Carya illinoensis*	141		84, 141	
Pine (jack) *Pinus banksiana*			123	
Pine (loblolly) *Pinus taeda*	142, 143, 146			

PRESSING STUDIES: Furnish Parameters

SPECIES *Latin Binomial*	TARGET DENSITY	TREATMENT	RESIN TYPE	
Pine (lodgepole) *Pinus contorta*	64, 121, 142, 143, 144	64	12, 64, 121, 123	
Pine (ponderosa) *Pinus ponderosa*	154	28	28, 123, 173	
Pine (red) *Pinus resinosa*	119			
Pine (scrub) *Pinus virginiana*		28	28	
Pine (slash) *Pinus elliottii*				
Pine (eastern white) *Pinus strobus*				
Pine (western white) *Pinus monticola*	121		121	
Pine (southern yellow) *Pinus echinata*	43			
Pine (northern) *Pinus spp.*				
Pine (southern) *Pinus spp.*	69, 104, 105, 118, 135, 137, 138, 139, 140	41, 148	43, 69, 118, 123	

PRESSING STUDIES: Furnish Parameters

SPECIES *Latin Binomial*	TARGET DENSITY	TREATMENT	RESIN TYPE	
Poplar (balsam) *Populus balsamifera*	127, 130	86	86	
Poplar (hybrid) *Populus spp.*				
Redwood *Sequoia sempervirens*	43		43	
Spruce (black) *Picea mariana*				
Spruce (Engelmann) *Picea engelmannii*				
Spruce (red) *Picea rubens*				
Spruce (Sitka) *Picea sitchensis*	167	166		
Spruce (white) *Picea glauca*			38	
Spruce species *Picea spp.*	106, 153		123	
Sweetbay *Magnolia virginiana*	40, 76, 79			

PRESSING STUDIES: Furnish Parameters

SPECIES *Latin Binomial*	TARGET DENSITY	TREATMENT	RESIN TYPE	
Sweetgum *Liquidambar styraciflua*	40, 76, 79, 81, 82, 104, 105, 135, 137, 138, 139, 140, 141, 142, 143, 146, 147, 176	41	75, 78, 79, 80, 81, 84, 141	
Sycamore *Platanus occidentalis*	36, 145		145	
Tamarack *Larix laricina*	57			
Tupelo (black) *Nyssa sylvatica*	40, 76, 79		81	
Virola species *Virola spp.*	168			
Yellow-poplar *Liriodendron tulipifera*	67, 146, 147, 159	161		

Appendix VIII. PRESSING STUDIES: Press Parameters

PRESSING STUDIES: Press Parameters

SPECIES *Latin Binomial*	TEMPERATURE	SCHEDULE	APPLIED PRESSURE	STEAM PRESSURE
Aceituna *Simaruba amara*				
Afrormosia *Pericopsos elata*				
Alder (Black) *Alnus glutinosa*		36	36	
Alder (red) *Alnus rubra*	173	173		
Ash (green) *Fraxinus pennsylvanica*				
Ash (white) *Fraxinus americana*		75, 78		
Ash species *Fraxinus spp.*	84	84	84	
Aspen (largetooth) *Populus grandidentata*		75, 78		
Banak *Virola koschyni*				
Basswood (American) *Tilia americana*				

PRESSING STUDIES: Press Parameters

SPECIES *Latin Binomial*	TEMPERATURE	SCHEDULE	APPLIED PRESSURE	STEAM PRESSURE
Basswood (white) *Tilia hertorphylla*				
Beech (American) *Fagus grandifolia*				
Birch (black) *Betula lenta*				
Birch (white) *Betula papyrifera*	156	35, 130		
Birch (yellow) *Betula alleghaniensis*				
Cedar (eastern white) *Thuja occidentalis*				
Cherry (black) *Prunus serotina*		75, 78		
Cottonwood *Populus deltoides*				
Cottonwood (black) *Populus trichocarpa*				
Douglas-fir *Pseudotsuga menziesii*	27, 45, 47, 48, 49, 54, 59, 93, 110, 118, 171, 173	27, 28, 45, 47, 48, 49, 53, 54, 69, 93, 96, 110, 115, 118, 144, 160, 171, 173	27, 29, 45, 47, 48, 49, 69, 118, 167	49

PRESSING STUDIES: Press Parameters

SPECIES *Latin Binomial*	TEMPERATURE	SCHEDULE	APPLIED PRESSURE	STEAM PRESSURE
Elm (American) *Ulmus americana*				
Fir (balsam) *Abies balsamea*	85			
Fir (grand) *Abies grandis*			39	
Fir (white) *Abies concolor*				
Gallina *Jacaranda copaia*				
Hackberry *Celtis occidentalis*				
Hemlock (eastern) *Tsuga canadensis*				
Hemlock (western) *Tsuga heterophylla*	173	173		
Hickory (mockernut) *Carya tomentosa*				
Hickory species *Carya spp.*	75, 78, 84, 137, 138, 139, 140	75, 78, 84	84, 137, 138, 139, 140	

PRESSING STUDIES: Press Parameters

SPECIES *Latin Binomial*	**TEMPERATURE**	**SCHEDULE**	**APPLIED PRESSURE**	**STEAM PRESSURE**
Jobo *Spondias mombin*				
Kiri *Paulownia tomentosa*		36	36	
Limba *Terminalia superba*				
Locust (black) *Robinia pseudoacacia*		36	36	
Maple (red) *Acer rubrum*		75, 78		
Maple (silver) *Acer saccharinum*				
Maple (sugar) *Acer saccharum*	128	128, 151		151
Maple species *Acer spp.*				
Oak (overcup) *Quercus lyrata*				
Oak (post) *Quercus stellata*	40	40		

PRESSING STUDIES: Press Parameters

SPECIES *Latin Binomial*	TEMPERATURE	SCHEDULE	APPLIED PRESSURE	STEAM PRESSURE
Oak (northern red) *Quercus rubra*	45, 47, 48, 126	45, 47, 48, 126	45, 47, 48	
Oak (southern red) *Quercus falcata*	40, 75, 78, 84, 137, 138, 139, 140	40, 75, 78, 84	84, 137, 138, 139, 140	
Oak (scarlet) *Quercus coccinea*				
Oak (water) *Quercus nigra*				
Oak (white) *Quercus alba*	40, 84, 137, 138, 139, 140	40, 84, 176	84, 137, 138, 139, 140, 176	
Oak species *Quercus spp.*				
Olive (autumn) *Elaeagnus umbellata*		36	36	
Pecan *Carya illinoensis*	84	84	84	
Pine (jack) *Pinus banksiana*				
Pine (loblolly) *Pinus taeda*	137, 138, 139		137, 138, 139	

PRESSING STUDIES: Press Parameters

SPECIES *Latin Binomial*	TEMPERATURE	SCHEDULE	APPLIED PRESSURE	STEAM PRESSURE
Pine (lodgepole) *Pinus contorta*	121	115, 121, 144		
Pine (ponderosa) *Pinus ponderosa*	28, 173	173		
Pine (red) *Pinus resinosa*				
Pine (scrub) *Pinus virginiana*			28	
Pine (slash) *Pinus elliottii*				
Pine (eastern white) *Pinus strobus*				
Pine (western white) *Pinus monticola*	121	121		
Pine (southern yellow) *Pinus echinata*				
Pine (northern) *Pinus spp.*				
Pine (southern) *Pinus spp.*	69, 118, 137, 138, 139, 140	69, 118	69, 118, 137, 138, 139, 140	

PRESSING STUDIES: Press Parameters

SPECIES *Latin Binomial*	TEMPERATURE	SCHEDULE	APPLIED PRESSURE	STEAM PRESSURE
Poplar (balsam) *Populus balsamifera*		130		
Poplar (hybrid) *Populus spp.*				
Redwood *Sequoia sempervirens*				
Spruce (black) *Picea mariana*				
Spruce (Engelmann) *Picea engelmannii*		115		
Spruce (red) *Picea rubens*				
Spruce (Sitka) *Picea sitchensis*			167	
Spruce (white) *Picea glauca*				
Spruce species *Picea spp.*				
Sweetbay *Magnolia virginiana*				

PRESSING STUDIES: Press Parameters

SPECIES *Latin Binomial*	TEMPERATURE	SCHEDULE	APPLIED PRESSURE	STEAM PRESSURE
Sweetgum *Liquidambar styraciflua*	40, 75, 78, 81, 84, 137, 138, 139, 140	40, 75, 78, 81, 84, 176	84, 137, 138, 139, 140, 176	
Sycamore *Platanus occidentalis*		36	36	
Tamarack *Larix laricina*				
Tupelo (black) *Nyssa sylvatica*				
Virola species *Virola spp.*				
Yellow-poplar *Liriodendron tulipifera*	99, 100, 137, 138, 139, 175	99	137, 138, 139	

Appendix IX. PRESSING STUDIES: Press Size and Type

PRESSING STUDIES: Press Size and Type

SPECIES *Latin Binomial*	LABORATORY Conventional	LABORATORY Steam	PILOT PLANT	MILL TRIAL
Aceituna *Simaruba amara*	63			
Afrormosia *Pericopsos elata*	168			
Alder (Black) *Alnus glutinosa*	36			
Alder (red) *Alnus rubra*	11, 122, 173			
Ash (green) *Fraxinus pennsylvanica*	72, 73, 89, 91, 141			
Ash (white) *Fraxinus americana*	40, 75, 78, 79, 81			75, 78
Ash species *Fraxinus spp.*	84			
Aspen (largetooth) *Populus grandidentata*	75, 78, 108, 149, 174			75, 78
Banak *Virola koschyni*	63			
Basswood (American) *Tilia americana*	67, 159			

PRESSING STUDIES: Press Size and Type

SPECIES *Latin Binomial*	LABORATORY Conventional	LABORATORY Steam	PILOT PLANT	MILL TRIAL
Basswood (white) *Tilia hertorphylla*	147			
Beech (American) *Fagus grandifolia*	155			
Birch (black) *Betula lenta*	147			
Birch (white) *Betula papyrifera*	7, 10, 17, 35, 57, 72, 73, 83, 89, 91, 127, 130, 155, 156			56
Birch (yellow) *Betula alleghaniensis*	109, 155			
Cedar (eastern white) *Thuja occidentalis*				
Cherry (black) *Prunus serotina*	75, 78			75, 78
Cottonwood *Populus deltoides*	25			
Cottonwood (black) *Populus trichocarpa*	81			
Douglas-fir *Pseudotsuga menziesii*	27, 28, 29, 32, 43, 44, 45, 46, 47, 48, 53, 54, 64, 65, 68, 69, 70, 93, 94, 95, 96, 110, 111, 112, 113, 114, 115, 116, 117, 118, 120, 123, 124, 125, 144, 160, 166, 167, 171, 173	49	124	106, 123

PRESSING STUDIES: Press Size and Type

SPECIES *Latin Binomial*	LABORATORY Conventional	 Steam	PILOT PLANT	MILL TRIAL
Elm (American) *Ulmus americana*	67, 141			
Fir (balsam) *Abies balsamea*	7, 8, 31, 85			
Fir (grand) *Abies grandis*	39, 154			
Fir (white) *Abies concolor*	13, 14, 92, 116			123
Gallina *Jacaranda copaia*	63			
Hackberry *Celtis occidentalis*	141, 172			
Hemlock (eastern) *Tsuga canadensis*	19			
Hemlock (western) *Tsuga heterophylla*	70, 116, 173			123
Hickory (mockernut) *Carya tomentosa*	142, 143, 146			
Hickory species *Carya spp.*	15, 25, 40, 67, 75, 76, 77, 78, 79, 81, 82, 84, 104, 105, 107, 159, 172		135, 137, 138, 139, 140	107

PRESSING STUDIES: Press Size and Type

SPECIES *Latin Binomial*	LABORATORY Conventional	Steam	PILOT PLANT	MILL TRIAL
Jobo *Spondias mombin*	63			
Kiri *Paulownia tomentosa*	36, 81, 168			
Limba *Terminalia superba*	168			
Locust (black) *Robinia pseudoacacia*	36			
Maple (red) *Acer rubrum*	40, 41, 59, 72, 73, 75, 76, 78, 79, 81, 83, 89, 90, 91, 108, 149, 155, 174			75, 78
Maple (silver) *Acer saccharinum*	165			
Maple (sugar) *Acer saccharum*	26, 128, 150, 151, 155	151		
Maple species *Acer spp.*	67			
Oak (overcup) *Quercus lyrata*	141			
Oak (post) *Quercus stellata*	40, 75, 76, 78, 79, 81			

PRESSING STUDIES: Press Size and Type

SPECIES *Latin Binomial*	LABORATORY Conventional	Steam	PILOT PLANT	MILL TRIAL
Oak (northern red) *Quercus rubra*	26, 45, 47, 48, 66, 69, 72, 73, 87, 89, 91, 126		87, 88	
Oak (southern red) *Quercus falcata*	40, 41, 67, 75, 76, 77, 78, 79, 80, 81, 82, 84, 104, 105, 107, 132, 141, 142, 143, 159		22, 135, 137, 138, 139, 140	107
Oak (scarlet) *Quercus coccinea*	98, 133, 134			
Oak (water) *Quercus nigra*	141			
Oak (white) *Quercus alba*	40, 75, 76, 78, 79, 80, 81, 82, 84, 104, 105, 107, 132, 146, 176		22, 135, 137, 138, 139, 140	107
Oak species *Quercus spp.*	172			
Olive (autumn) *Elaeagnus umbellata*	36			
Pecan *Carya illinoensis*	84, 141			
Pine (jack) *Pinus banksiana*	31, 50			123
Pine (loblolly) *Pinus taeda*	142, 143, 146, 154		137, 138, 139	

PRESSING STUDIES: Press Size and Type

SPECIES *Latin Binomial*	LABORATORY Conventional	LABORATORY Steam	PILOT PLANT	MILL TRIAL
Pine (lodgepole) *Pinus contorta*	64, 115, 121, 125, 142, 143, 144			123
Pine (ponderosa) *Pinus ponderosa*	12, 28, 173			123
Pine (red) *Pinus resinosa*	119			
Pine (scrub) *Pinus virginiana*	28			
Pine (slash) *Pinus elliottii*	74			
Pine (eastern white) *Pinus strobus*	19			
Pine (western white) *Pinus monticola*	121			
Pine (southern yellow) *Pinus echinata*	43			23, 24, 55
Pine (northern) *Pinus spp.*	125			
Pine (southern) *Pinus spp.*	41, 69, 82, 104, 105, 107, 118, 148, 162		135, 137, 138, 139, 140	107, 123

PRESSING STUDIES: Press Size and Type

SPECIES *Latin Binomial*	LABORATORY Conventional	LABORATORY Steam	PILOT PLANT	MILL TRIAL
Poplar (balsam) *Populus balsamifera*	1, 2, 3, 4, 6, 86, 125, 127, 130		2, 3, 4	2, 3, 4, 5
Poplar (hybrid) *Populus spp.*	50, 51, 177			
Redwood *Sequoia sempervirens*	37, 43			
Spruce (black) *Picea mariana*	7			
Spruce (Engelmann) *Picea engelmannii*	115			
Spruce (red) *Picea rubens*	9			
Spruce (Sitka) *Picea sitchensis*	166, 167			
Spruce (white) *Picea glauca*	31, 38, 169			
Spruce species *Picea spp.*	125, 153			106, 123
Sweetbay *Magnolia virginiana*	40, 75, 76, 78, 79, 81			

PRESSING STUDIES: Press Size and Type

SPECIES *Latin Binomial*	LABORATORY Conventional	LABORATORY Steam	PILOT PLANT	MILL TRIAL
Sweetgum *Liquidambar styraciflua*	40, 41, 62, 75, 76, 77, 78, 79, 80, 81, 82, 84, 104, 105, 107, 132, 141, 142, 143, 146, 147, 162, 172, 176		22, 135, 137, 138, 139, 140	23, 24, 55, 107
Sycamore *Platanus occidentalis*	36, 145			
Tamarack *Larix laricina*	50, 57			
Tupelo (black) *Nyssa sylvatica*	40, 75, 76, 78, 79, 81			
Virola species *Virola spp.*	168			
Yellow-poplar *Liriodendron tulipifera*	62, 67, 99, 100, 146, 147, 159, 161, 175		22, 137, 138, 139	55

Appendix X. PRESSING STUDIES: Board Properties

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	MOE - DRY	MOE - WET	MOR - DRY	MOR - WET
Aceituna *Simaruba amara*	63		63	
Afrormosia *Pericopsos elata*	168		168	
Alder (Black) *Alnus glutinosa*	36	36	36	36
Alder (red) *Alnus rubra*	11, 122, 173		11, 122, 173	11, 122
Ash (green) *Fraxinus pennsylvanica*	72, 73, 89, 141	72, 73, 89, 141	72, 73, 89, 91, 141	72, 73, 89, 141
Ash (white) *Fraxinus americana*	81		81	
Ash species *Fraxinus spp.*	84		84	84
Aspen (largetooth) *Populus grandidentata*	108, 149, 174		108, 174	
Banak *Virola koschyni*	63		63	
Basswood (American) *Tilia americana*	67, 159		67, 159	

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	MOE - DRY	MOE - WET	MOR - DRY	MOR - WET
Basswood (white) *Tilia hertorphylla*	147		147	
Beech (American) *Fagus grandifolia*	155		155	
Birch (black) *Betula lenta*	147		147	
Birch (white) *Betula papyrifera*	7, 10, 17, 35, 56, 58, 72, 73, 83, 89, 127, 130, 155, 156	17, 35, 56, 72, 73, 89, 130,	7, 10, 17, 35, 56, 58, 72, 73, 83, 89, 91, 127, 130, 155, 156	7, 10, 17, 35, 56, 72, 73, 89, 130
Birch (yellow) *Betula alleghaniensis*	109, 155		109, 155	
Cedar (eastern white) *Thuja occidentalis*				
Cherry (black) *Prunus serotina*				
Cottonwood *Populus deltoides*	25, 81		25, 81	
Cottonwood (black) *Populus trichocarpa*				
Douglas-fir *Pseudotsuga menziesii*	28, 43, 44, 45, 46, 49, 53, 54, 64, 65, 69, 70, 93, 94, 95, 96, 110, 111, 112, 113, 114, 115, 116, 118, 120, 123, 124, 125, 144, 160, 166, 173	28, 44, 53, 70, 93, 94, 113, 114, 115, 116, 124, 144	29, 32, 43, 44, 45, 46, 49, 53, 64, 65, 68, 69, 70, 93, 94, 95, 96, 106, 110, 111, 112, 113, 114, 115, 116, 118, 120, 123, 124, 125, 144, 160, 166, 167, 171, 173	44, 53, 70, 93, 94, 113, 114, 115, 116, 124, 125, 144, 167

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	MOE - DRY	MOE - WET	MOR - DRY	MOR - WET
Elm (American) *Ulmus americana*	67, 141	67, 141	67, 141	67, 141
Fir (balsam) *Abies balsamea*	7, 8, 31, 85	85	7, 8, 31, 85	7, 8, 31, 85
Fir (grand) *Abies grandis*	39, 154		39, 154	
Fir (white) *Abies concolor*	92, 116, 123	116	13, 14, 92, 116, 123	92, 116
Gallina *Jacaranda copaia*	63		63	
Hackberry *Celtis occidentalis*	141	141	141, 172	141, 172
Hemlock (eastern) *Tsuga canadensis*	19		19	
Hemlock (western) *Tsuga heterophylla*	70, 116, 123, 173	70, 116	70, 116, 123, 173	70, 116
Hickory (mockernut) *Carya tomentosa*	142, 143, 146	142, 143	142, 143, 146	142, 143
Hickory species *Carya spp.*	15, 25, 67, 75, 76, 77, 78, 81, 82, 84, 104, 107, 135, 137, 138, 139, 159	104, 137, 138, 139	15, 25, 67, 75, 76, 77, 78, 84, 82, 84, 104, 107, 135, 137, 138, 139, 159, 172	84, 104, 137, 138, 139, 172

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	MOE - DRY	MOE - WET	MOR - DRY	MOR - WET
Jobo *Spondias mombin*	63		63	
Kiri *Paulownia tomentosa*	36, 81, 168	36	36, 81, 168	36
Limba *Terminalia superba*	168		168	
Locust (black) *Robinia pseudoacacia*	36	36	36	36
Maple (red) *Acer rubrum*	41, 59, 72, 73, 76, 81, 83, 89, 90, 108, 149, 155, 174	59, 72, 73, 89	41, 59, 72, 73, 76, 81, 83, 89, 90, 91, 108, 155, 174	59, 72, 73, 89, 90
Maple (silver) *Acer saccharinum*	165	165	165	165
Maple (sugar) *Acer saccharum*	26, 128, 150, 155		26, 128, 150, 155	
Maple species *Acer spp.*	67	67	67	67
Oak (overcup) *Quercus lyrata*	141	141	141	141
Oak (post) *Quercus stellata*	76, 81		76, 81	

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	MOE - DRY	MOE - WET	MOR - DRY	MOR - WET
Oak (northern red) *Quercus rubra*	26, 45, 66, 67, 72, 87, 88, 89, 126	67, 72, 87, 88, 89	26, 45, 66, 67, 72, 88, 89, 91, 126	67, 72, 88, 89
Oak (southern red) *Quercus falcata*	22, 41, 67, 75, 76, 77, 78, 81, 82, 84, 104, 107, 132, 135, 137, 138, 139, 141, 142, 143, 159	22, 104, 137, 138, 139, 141, 142, 143	22, 41, 67, 75, 76, 77, 78, 81, 82, 84, 104, 107, 132, 135, 137, 138, 139, 141, 142, 143, 159	22, 84, 104, 132, 137, 138, 139, 141, 142, 143
Oak (scarlet) *Quercus coccinea*	134		133, 134	
Oak (water) *Quercus nigra*	141	141	141	141
Oak (white) *Quercus alba*	22, 76, 81, 82, 84, 104, 107, 132, 135, 137, 138, 139, 146	22, 104, 137, 138, 139	22, 76, 81, 82, 84, 104, 107, 132, 135, 137, 138, 139, 146, 176	22, 84, 104, 132, 137, 138, 139
Oak species *Quercus spp.*			172	172
Olive (autumn) *Elaeagnus umbellata*	36	36	36	36
Pecan *Carya illinoensis*	84, 141	141	84, 141	84, 141
Pine (jack) *Pinus banksiana*	31, 50, 123	50	31, 50, 123	31, 50
Pine (loblolly) *Pinus taeda*	137, 138, 139, 142, 143, 146, 154	137, 138, 139, 142, 143	137, 138, 139, 142, 143, 146, 154	137, 138, 139, 142, 143

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	MOE - DRY	MOE - WET	MOR - DRY	MOR - WET
Pine (lodgepole) *Pinus contorta*	64, 115, 121, 123, 125, 142, 143, 144	115, 142, 143, 144	64, 115, 121, 123, 125, 142, 143, 144	115, 125, 142, 143, 144
Pine (ponderosa) *Pinus ponderosa*	28, 123, 154, 172	28	12, 123, 154, 173	
Pine (red) *Pinus resinosa*	119	119	119	119
Pine (scrub) *Pinus virginiana*				
Pine (slash) *Pinus elliottii*	74		74	
Pine (eastern white) *Pinus strobus*	19		19	
Pine (western white) *Pinus monticola*	121		121	
Pine (southern yellow) *Pinus echinata*	23, 24, 43, 55	23, 55	23, 24, 43, 55	23, 55
Pine (northern) *Pinus spp.*	125		125	125
Pine (southern) *Pinus spp.*	41, 69, 82, 104, 107, 118, 123, 135, 137, 138, 139, 162	104, 137, 138, 139	41, 69, 82, 104, 107, 118, 123, 135, 137, 138, 139	104, 137, 138, 139

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	MOE - DRY	MOE - WET	MOR - DRY	MOR - WET
Poplar (balsam) *Populus balsamifera*	1, 2, 3, 4, 5, 6, 125, 127, 130	130	1, 2, 3, 4, 5, 6, 125, 127, 130	1, 2, 3, 4, 5, 6, 125, 130
Poplar (hybrid) *Populus spp.*	50, 51, 177	50, 51	50, 51, 177	50, 51
Redwood *Sequoia sempervirens*	37, 43		37, 43	
Spruce (black) *Picea mariana*	7		7	7
Spruce (Engelmann) *Picea engelmannii*	115	115	115	115
Spruce (red) *Picea rubens*	9		9	9
Spruce (Sitka) *Picea sitchensis*	166		166, 167	167
Spruce (white) *Picea glauca*	31, 38, 169		31, 38, 169	31, 38, 169
Spruce species *Picea spp.*	123, 125, 153		106, 123, 125, 153	125
Sweetbay *Magnolia virginiana*	76, 81		76, 81	

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	MOE - DRY	MOE - WET	MOR - DRY	MOR - WET
Sweetgum *Liquidambar styraciflua*	22, 23, 24, 41, 55, 75, 76, 77, 78, 81, 82, 84, 104, 107, 132, 135, 137, 138, 139, 141, 142, 143, 146, 147, 162	22, 23, 55, 104, 137, 138, 139, 141, 142, 143	22, 23, 24, 41, 55, 62, 75, 76, 77, 78, 81, 82, 84, 104, 107, 132, 135, 137, 138, 139, 141, 142, 143, 146, 147, 172, 176	22, 23, 55, 84, 104, 132, 137, 138, 139, 141, 142, 143, 172
Sycamore *Platanus occidentalis*	36, 145	36	36, 145	36
Tamarack *Larix laricina*	50, 58	50	50, 58	50
Tupelo (black) *Nyssa sylvatica*	76, 81		76, 81	
Virola species *Virola spp.*	168		168	
Yellow-poplar *Liriodendron tulipifera*	22, 55, 67, 137, 138, 139, 146, 147, 159	22, 55, 137, 138, 139	22, 55, 62, 67, 137, 138, 139, 146, 147, 159	22, 55, 137, 138, 139

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	IB	PLATE SHEAR MODULUS	INTERLAMINAR SHEAR	EDGEWISE SHEAR
Aceituna *Simaruba amara*	63			
Afrormosia *Pericopsos elata*	168			
Alder (Black) *Alnus glutinosa*	36			
Alder (red) *Alnus rubra*	11, 122, 173			
Ash (green) *Fraxinus pennsylvanica*	72, 73, 91, 141		72, 73, 89, 91	72, 73, 91
Ash (white) *Fraxinus americana*	75, 78, 108, 174			
Ash species *Fraxinus spp.*	84			
Aspen (largetooth) *Populus grandidentata*	75, 78, 108, 174			
Banak *Virola koschyni*	63			
Basswood (American) *Tilia americana*	67, 159			

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	IB	PLATE SHEAR MODULUS	INTERLAMINAR SHEAR	EDGEWISE SHEAR
Basswood (white) *Tilia hertorphylla*	147			
Beech (American) *Fagus grandifolia*	155			
Birch (black) *Betula lenta*	147			
Birch (white) *Betula papyrifera*	7, 10, 17, 35, 56, 58, 72, 73, 83, 91, 127, 130, 155, 156		72, 73, 89, 91	72, 73, 91
Birch (yellow) *Betula alleghaniensis*	109, 155			
Cedar (eastern white) *Thuja occidentalis*				
Cherry (black) *Prunus serotina*	75, 78			
Cottonwood *Populus deltoides*	25, 81			
Cottonwood (black) *Populus trichocarpa*				
Douglas-fir *Pseudotsuga menziesii*	28, 29, 32, 43, 44, 45, 46, 47, 49, 53, 54, 64, 65, 67, 69, 70, 93, 94, 95, 96, 110, 111, 112, 113, 114, 115, 116, 118, 120, 123, 124, 125, 144, 160, 166, 17 1, 173	123, 124	45, 47, 123, 124	45, 47, 123, 124

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	IB	PLATE SHEAR MODULUS	INTERLAMINAR SHEAR	EDGEWISE SHEAR
Elm (American) *Ulmus americana*	67, 141			
Fir (balsam) *Abies balsamea*	7, 8, 31, 85			
Fir (grand) *Abies grandis*	39, 154			
Fir (white) *Abies concolor*	13, 14, 92, 116, 123	123	123	123
Gallina *Jacaranda copaia*	63			
Hackberry *Celtis occidentalis*	141, 172			
Hemlock (eastern) *Tsuga canadensis*	19			
Hemlock (western) *Tsuga heterophylla*	70, 116, 123, 173	123	123	123
Hickory (mockernut) *Carya tomentosa*	142, 143, 146			
Hickory species *Carya spp.*	15, 25, 67, 75, 76, 78, 79, 81, 82, 84, 104, 107, 135, 137, 138, 139, 159, 172	137, 138, 139		

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	IB	PLATE SHEAR MODULUS	INTERLAMINAR SHEAR	EDGEWISE SHEAR
Jobo *Spondias mombin*	63			
Kiri *Paulownia tomentosa*	36, 81, 168			
Limba *Terminalia superba*	168			
Locust (black) *Robinia pseudoacacia*	36			
Maple (red) *Acer rubrum*	41, 59, 72, 73, 75, 76, 78, 79, 81, 83, 90, 91, 108, 155, 174		72, 73, 89, 91	72, 73, 91
Maple (silver) *Acer saccharinum*	165			
Maple (sugar) *Acer saccharum*	26, 128, 150, 155			
Maple species *Acer spp.*	67			
Oak (overcup) *Quercus lyrata*	141			
Oak (post) *Quercus stellata*	75, 76, 78, 79, 81			

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	IB	PLATE SHEAR MODULUS	INTERLAMINAR SHEAR	EDGEWISE SHEAR
Oak (northern red) *Quercus rubra*	26, 45, 47, 66, 67, 72, 73, 88, 91, 126		45, 47, 72, 73, 88, 89, 91	45, 47, 72, 73, 88, 91
Oak (southern red) *Quercus falcata*	22, 41, 67, 75, 76, 78, 79, 80, 81, 82, 84, 104, 107, 132, 135, 137, 138, 139, 141, 142, 143, 159	22, 137, 138, 139	22	22
Oak (scarlet) *Quercus coccinea*	134			
Oak (water) *Quercus nigra*	141			
Oak (white) *Quercus alba*	22, 75, 76, 78, 79, 80, 81, 82, 84, 104, 107, 132, 135, 137, 138, 139, 146	22, 137, 138, 139	22	22
Oak species *Quercus spp.*	172			
Olive (autumn) *Elaeagnus umbellata*	36			
Pecan *Carya illinoensis*	84, 141			
Pine (jack) *Pinus banksiana*	31, 50, 123	123	123	123
Pine (loblolly) *Pinus taeda*	137, 138, 139, 142, 143, 146, 154	137, 138, 139		

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	IB	PLATE SHEAR MODULUS	INTERLAMINAR SHEAR	EDGEWISE SHEAR
Pine (lodgepole) *Pinus contorta*	64, 115, 121, 123, 125, 142, 143, 144	123	123	123
Pine (ponderosa) *Pinus ponderosa*	12, 28, 123, 173	123	123	123
Pine (red) *Pinus resinosa*	119			
Pine (scrub) *Pinus virginiana*				
Pine (slash) *Pinus elliottii*	74			
Pine (eastern white) *Pinus strobus*	19			
Pine (western white) *Pinus monticola*	121			
Pine (southern yellow) *Pinus echinata*	23, 24, 43, 55	23, 24, 55		23, 24, 55
Pine (northern) *Pinus spp.*	125			
Pine (southern) *Pinus spp.*	41, 69, 82, 104, 107, 118, 123, 135, 137, 138, 139, 162	123, 137, 138, 139	123	123

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	IB	PLATE SHEAR MODULUS	INTERLAMINAR SHEAR	EDGEWISE SHEAR
Poplar (balsam) *Populus balsamifera*	1, 2, 3, 4, 5, 6, 125, 127, 130			
Poplar (hybrid) *Populus spp.*	50, 51			
Redwood *Sequoia sempervirens*	37, 43			
Spruce (black) *Picea mariana*	7			
Spruce (Engelmann) *Picea engelmannii*	115			
Spruce (red) *Picea rubens*	9			
Spruce (Sitka) *Picea sitchensis*	166			
Spruce (white) *Picea glauca*	31, 38, 169		38	
Spruce species *Picea spp.*	123, 125, 153	123	123	123
Sweetbay *Magnolia virginiana*	75, 76, 78, 79, 81			

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	IB	PLATE SHEAR MODULUS	INTERLAMINAR SHEAR	EDGEWISE SHEAR
Sweetgum *Liquidambar styraciflua*	22, 23, 24, 41, 55, 62, 75, 76, 78, 79, 80, 81, 82, 84, 104, 107, 132, 135, 137, 138, 139, 141, 142, 143, 146, 147, 162, 172	22, 23, 24, 55, 137, 138, 139	22	22, 23, 24, 55
Sycamore *Platanus occidentalis*	36, 145			
Tamarack *Larix laricina*	50, 58			
Tupelo (black) *Nyssa sylvatica*	75, 76, 78, 79, 81			
Virola species *Virola spp.*	168			
Yellow-poplar *Liriodendron tulipifera*	22, 62, 67, 137, 138, 139, 146, 147, 159, 161	22, 137, 138, 139	22	22

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	LE	THICKNESS SWELL	EDGE SWELL	WATER ABSORPTION
Aceituna *Simaruba amara*	63	63		
Afrormosia *Pericopsos elata*	168	168		168
Alder (Black) *Alnus glutinosa*	36	36		36
Alder (red) *Alnus rubra*	122, 173	11, 122, 173		
Ash (green) *Fraxinus pennsylvanica*	141	141		141
Ash (white) *Fraxinus americana*	79, 81	99, 81		
Ash species *Fraxinus spp.*	84	84		
Aspen (largetooth) *Populus grandidentata*	108, 174	108, 174		108, 174
Banak *Virola koschyni*	63	63		
Basswood (American) *Tilia americana*	67, 159	67, 159		159

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	LE	THICKNESS SWELL	EDGE SWELL	WATER ABSORPTION
Basswood (white) *Tilia hertorphylla*		147		
Beech (American) *Fagus grandifolia*				
Birch (black) *Betula lenta*		147		
Birch (white) *Betula papyrifera*	17, 35, 58, 130, 156	17, 35, 56, 58, 130, 156		
Birch (yellow) *Betula alleghaniensis*	109	109		
Cedar (eastern white) *Thuja occidentalis*				
Cherry (black) *Prunus serotina*				
Cottonwood *Populus deltoides*	81	81		
Cottonwood (black) *Populus trichocarpa*				
Douglas-fir *Pseudotsuga menziesii*	28, 29, 43, 44, 45, 46, 48, 49, 53, 64, 65, 67, 70, 94, 110, 111, 113, 115, 116, 117, 120, 124, 125, 144, 160, 167, 171, 173	28, 29, 43, 45, 46, 48, 49, 53, 64, 65, 67, 70, 93, 94, 95, 96, 110, 111, 112, 113, 114, 115, 116, 117, 124, 144, 160, 166, 167, 171, 173		28, 29, 45, 46, 48, 53, 93, 94, 95, 96, 110, 111, 113, 115, 116, 117, 124, 144, 160, 166, 171

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	LE	THICKNESS SWELL	EDGE SWELL	WATER ABSORPTION
Poplar (balsam) *Populus balsamifera*	1, 2, 3, 4, 5, 86, 125, 130	1, 2, 3, 4, 5, 86, 130		5
Poplar (hybrid) *Populus spp.*	50, 51	50, 51		50, 51
Redwood *Sequoia sempervirens*	37, 43	37, 43		37
Spruce (black) *Picea mariana*				
Spruce (Engelmann) *Picea engelmannii*	115	115		115
Spruce (red) *Picea rubens*				
Spruce (Sitka) *Picea sitchensis*	167	166, 167		166
Spruce (white) *Picea glauca*	169	31, 38, 169		31, 169
Spruce species *Picea spp.*	125, 153			
Sweetbay *Magnolia virginiana*	76, 79, 81	76, 79, 81		76

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	LE	THICKNESS SWELL	EDGE SWELL	WATER ABSORPTION
Sweetgum *Liquidambar styraciflua*	22, 23, 24, 55, 76, 77, 79, 80, 81, 84, 105, 137, 138, 139, 141, 142, 143, 162, 172	22, 23, 24, 41, 55, 62, 76, 77, 79, 80, 81, 84, 105, 135, 137, 138, 139, 141, 142, 143, 146, 147, 162, 172	24	22, 23, 24, 41, 55, 76, 77, 105, 135, 137, 138, 139, 141, 146, 172
Sycamore *Platanus occidentalis*	36	36, 145		36
Tamarack *Larix laricina*	50	50		50
Tupelo (black) *Nyssa sylvatica*	76, 79, 81	76, 79, 81		76
Virola species *Virola spp.*	168	168		168
Yellow-poplar *Liriodendron tulipifera*	22, 55, 67, 137, 138, 139, 159	22, 55, 62, 67, 137, 138, 139, 146, 147, 159, 161		22, 55, 137, 138, 139, 146, 159

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	BOARD DENSITY	DENSITY PROFILE	MOISTURE CONTENT	DECAY RESISTANCE
Aceituna *Simaruba amara*	63		63	63
Afrormosia *Pericopsos elata*	168		168	
Alder (Black) *Alnus glutinosa*	36			
Alder (red) *Alnus rubra*	122	122		
Ash (green) *Fraxinus pennsylvanica*	72, 73, 141		141	
Ash (white) *Fraxinus americana*	75, 78, 81			
Ash species *Fraxinus spp.*				
Aspen (largetooth) *Populus grandidentata*	108, 174		174	
Banak *Virola koschyni*	63	63		63
Basswood (American) *Tilia americana*	67, 159			

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	BOARD DENSITY	DENSITY PROFILE	MOISTURE CONTENT	DECAY RESISTANCE
Basswood (white) *Tilia hertorphylla*				
Beech (American) *Fagus grandifolia*	155			
Birch (black) *Betula lenta*				
Birch (white) *Betula papyrifera*	10, 17, 35, 58, 72, 73, 155, 156			58
Birch (yellow) *Betula alleghaniensis*	109, 155		109	
Cedar (eastern white) *Thuja occidentalis*				
Cherry (black) *Prunus serotina*				
Cottonwood *Populus deltoides*	25			
Cottonwood (black) *Populus trichocarpa*				
Douglas-fir *Pseudotsuga menziesii*	28, 32, 43, 45, 46, 47, 48, 49, 53, 54, 64, 69, 70, 93, 94, 95, 96, 106, 111, 112, 113, 114, 115, 116, 118, 120, 123, 124, 125, 144, 166, 167	45, 47, 49, 54, 106, 124, 160	28, 32, 69, 116, 118, 123, 144	

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	BOARD DENSITY	DENSITY PROFILE	MOISTURE CONTENT	DECAY RESISTANCE
Elm (American) *Ulmus americana*	67, 141		141	
Fir (balsam) *Abies balsamea*	31, 85			
Fir (grand) *Abies grandis*	39	39		
Fir (white) *Abies concolor*	13, 14, 92, 116, 123		116, 123	
Gallina *Jacaranda copaia*	63		63	63
Hackberry *Celtis occidentalis*		172		
Hemlock (eastern) *Tsuga canadensis*	19		19	
Hemlock (western) *Tsuga heterophylla*	70, 116, 123		116, 123	
Hickory (mockernut) *Carya tomentosa*	142, 143, 146			
Hickory species *Carya spp.*	15, 25, 67, 75, 76, 78, 81, 82, 107, 137, 138, 139, 159	172	76, 137, 138, 139	

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	BOARD DENSITY	DENSITY PROFILE	MOISTURE CONTENT	DECAY RESISTANCE
Jobo *Spondias mombin*	63		63	63
Kiri *Paulownia tomentosa*	36, 168		168	
Limba *Terminalia superba*	168		168	
Locust (black) *Robinia pseudoacacia*	36			
Maple (red) *Acer rubrum*	41, 59, 72, 73, 75, 76, 78, 108, 155, 174	59	76, 174	
Maple (silver) *Acer saccharinum*	165			
Maple (sugar) *Acer saccharum*	26, 128, 150, 151, 155		128, 151	
Maple species *Acer spp.*	67			
Oak (overcup) *Quercus lyrata*	141		141	
Oak (post) *Quercus stellata*	75, 76, 78, 81		76	

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	BOARD DENSITY	DENSITY PROFILE	MOISTURE CONTENT	DECAY RESISTANCE
Oak (northern red) *Quercus rubra*	26, 45, 47, 48, 67, 72, 73, 87, 88, 126	45, 47, 88	88	
Oak (southern red) *Quercus falcata*	22, 41, 67, 75, 76, 78, 81, 82, 107, 137, 138, 139, 141, 142, 143, 159	132	22, 76, 137, 138, 139, 141	
Oak (scarlet) *Quercus coccinea*	133			
Oak (water) *Quercus nigra*	141		141	
Oak (white) *Quercus alba*	22, 75, 76, 78, 81, 82, 107, 137, 138, 139, 146	132	22, 76, 137, 138, 139	
Oak species *Quercus spp.*		172		
Olive (autumn) *Elaeagnus umbellata*				
Pecan *Carya illinoensis*	141		141	
Pine (jack) *Pinus banksiana*	31, 50, 123		123	
Pine (loblolly) *Pinus taeda*	137, 138, 139, 142, 143, 146		137, 138, 139	

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	BOARD DENSITY	DENSITY PROFILE	MOISTURE CONTENT	DECAY RESISTANCE
Pine (lodgepole) *Pinus contorta*	64, 115, 123, 125, 142, 143, 144		123, 144	
Pine (ponderosa) *Pinus ponderosa*	12, 28, 123		28, 123	
Pine (red) *Pinus resinosa*	119			
Pine (scrub) *Pinus virginiana*	28			
Pine (slash) *Pinus elliottii*				
Pine (eastern white) *Pinus strobus*				
Pine (western white) *Pinus monticola*				
Pine (southern yellow) *Pinus echinata*	23, 24, 43, 55		55	
Pine (northern) *Pinus spp.*	125			
Pine (southern) *Pinus spp.*	41, 69, 82, 107, 118, 123, 137, 138, 139		69, 118, 123, 137, 138, 139	

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	BOARD DENSITY	DENSITY PROFILE	MOISTURE CONTENT	DECAY RESISTANCE
Poplar (balsam) *Populus balsamifera*	1, 2, 3, 4, 5, 86, 125		1, 2, 3, 4, 5	
Poplar (hybrid) *Populus spp.*	50, 51			
Redwood *Sequoia sempervirens*	43			
Spruce (black) *Picea mariana*				
Spruce (Engelmann) *Picea engelmannii*	115			
Spruce (red) *Picea rubens*				
Spruce (Sitka) *Picea sitchensis*	166, 167			
Spruce (white) *Picea glauca*	31, 169		169	
Spruce species *Picea spp.*	106, 123, 125	106	123	
Sweetbay *Magnolia virginiana*	75, 76, 78		76	

PRESSING STUDIES: Board Properties

SPECIES *Latin Binomial*	BOARD DENSITY	DENSITY PROFILE	MOISTURE CONTENT	DECAY RESISTANCE
Sweetgum *Liquidambar styraciflua*	22, 23, 24, 41, 55, 75, 76, 78, 82, 107, 137, 138, 139, 141, 142, 143, 146	132, 172	22, 55, 76, 137, 138, 139, 141	
Sycamore *Platanus occidentalis*	36			
Tamarack *Larix laricina*	50, 58			58
Tupelo (black) *Nyssa sylvatica*	75, 76, 78		76	
Virola species *Virola spp.*	168		168	
Yellow-poplar *Liriodendron tulipifera*	22, 55, 67, 137, 138, 139, 146, 159	175	22, 55, 137, 138, 139	

Appendix XI. OTHER STUDIES

Other Studies

Species *Latin Binomial*	Literature Review	Modelling	Economic Feasibility	Thermal Character
Aceituna *Simaruba amara*				
Afrormosia *Pericopsos elata*		168		
Alder (Black) *Alnus glutinosa*				
Alder (red) *Alnus rubra*		122, 173		
Ash (green) *Fraxinus pennsylvanica*		72, 73, 89, 91	73	
Ash (white) *Fraxinus americana*				
Ash species *Fraxinus spp.*	30			
Aspen (largetooth) *Populus grandidentata*		149		
Banak *Virola koschyni*				
Basswood (American) *Tilia americana*		67, 159		

Other Studies

Species *Latin Binomial*	Literature Review	Modelling	Economic Feasibility	Thermal Character
Basswood (white) *Tilia hertorphylla*		147		
Beech (American) *Fagus grandifolia*	163			
Birch (black) *Betula lenta*		147		
Birch (white) *Betula papyrifera*	30, 103, 163	18, 72, 73, 89, 91	73	
Birch (yellow) *Betula alleghaniensis*	103, 163			
Cedar (eastern white) *Thuja occidentalis*	163			
Cherry (black) *Prunus serotina*				
Cottonwood *Populus deltoides*				
Cottonwood (black) *Populus trichocarpa*				
Douglas-fir *Pseudotsuga menziesii*	52, 103	44, 45, 46, 47, 48, 113, 115, 117, 120, 123, 125, 167, 173	125, 171	71, 124

Other Studies

Species *Latin Binomial*	**Literature Review**	**Modelling**	**Economic Feasibility**	**Thermal Character**
Elm (American) *Ulmus americana*	30	67		
Fir (balsam) *Abies balsamea*	20, 30			
Fir (grand) *Abies grandis*		39		
Fir (white) *Abies concolor*	103	123		
Gallina *Jacaranda copaia*				
Hackberry *Celtis occidentalis*				
Hemlock (eastern) *Tsuga canadensis*				
Hemlock (western) *Tsuga heterophylla*		123, 173		
Hickory (mockernut) *Carya tomentosa*				
Hickory species *Carya spp.*	30, 52, 103	67, 137, 138, 139, 159	107	

OTHER STUDIES

SPECIES *Latin Binomial*	LITERATURE REVIEW	MODELLING	ECONOMIC FEASIBILITY	THERMAL CHARACTER
Jobo *Spondias mombin*				
Kiri *Paulownia tomentosa*		168		
Limba *Terminalia superba*		168		
Locust (black) *Robinia pseudoacacia*				
Maple (red) *Acer rubrum*	163	72, 73, 89, 91, 149	73	
Maple (silver) *Acer saccharinum*				
Maple (sugar) *Acer saccharum*	103, 163			
Maple species *Acer spp.*	30	67		
Oak (overcup) *Quercus lyrata*				
Oak (post) *Quercus stellata*				

OTHER STUDIES

SPECIES *Latin Binomial*	LITERATURE REVIEW	MODELLING	ECONOMIC FEASIBILITY	THERMAL CHARACTER
Oak (northern red) *Quercus rubra*		45, 47, 48, 67, 72, 73, 87, 89, 91	60, 73, 87	170
Oak (southern red) *Quercus falcata*	52	67, 132, 137, 138, 139, 159		
Oak (scarlet) *Quercus coccinea*				
Oak (water) *Quercus nigra*				
Oak (white) *Quercus alba*	52	132, 137, 138, 139	107	
Oak species *Quercus spp.*	30			
Olive (autumn) *Elaeagnus umbellata*				
Pecan *Carya illinoensis*				
Pine (jack) *Pinus banksiana*		123		
Pine (loblolly) *Pinus taeda*		137, 138, 139		

OTHER STUDIES

SPECIES *Latin Binomial*	LITERATURE REVIEW	MODELLING	ECONOMIC FEASIBILITY	THERMAL CHARACTER
Pine (lodgepole) *Pinus contorta*	103	115, 123, 125	125	
Pine (ponderosa) *Pinus ponderosa*	103	123, 173		
Pine (red) *Pinus resinosa*				
Pine (scrub) *Pinus virginiana*				
Pine (slash) *Pinus elliottii*	103			
Pine (eastern white) *Pinus strobus*	163			
Pine (western white) *Pinus monticola*				
Pine (southern yellow) *Pinus echinata*				
Pine (northern) *Pinus spp.*		125	125	
Pine (southern) *Pinus spp.*	52	123, 137, 138, 139	107	

Other Studies

Species *Latin Binomial*	**Literature Review**	**Modelling**	**Economic Feasibility**	**Thermal Character**
Poplar (balsam) *Populus balsamifera*	16, 30, 131, 152	2, 125		
Poplar (hybrid) *Populus spp.*				
Redwood *Sequoia sempervirens*	103			
Spruce (black) *Picea mariana*				
Spruce (Engelmann) *Picea engelmannii*		115		
Spruce (red) *Picea rubens*				
Spruce (Sitka) *Picea sitchensis*		167		
Spruce (white) *Picea glauca*				
Spruce species *Picea spp.*	30	123, 125		
Sweetbay *Magnolia virginiana*	30			

OTHER STUDIES

SPECIES *Latin Binomial*	LITERATURE REVIEW	MODELLING	ECONOMIC FEASIBILITY	THERMAL CHARACTER
Sweetgum *Liquidambar styraciflua*	30, 52	132, 136, 137, 138, 139, 147	107	
Sycamore *Platanus occidentalis*	103			
Tamarack *Larix laricina*	30			
Tupelo (black) *Nyssa sylvatica*	30			
Virola species *Virola spp.*		168		
Yellow-poplar *Liriodendron tulipifera*	30	67, 137, 138, 139, 147, 159, 161, 175		

Appendix XII. TIME PERIOD OF STUDY: Relevance to Current Technology

TIME PERIOD OF STUDY: Relevance to Current Technology

SPECIES *Latin Binomial*	1950 - 59	1960 - 69	1970 - 79	1980 - 84
Aceituna *Simaruba amara*			63	
Afrormosia *Pericopsos elata*			168	
Alder (Black) *Alnus glutinosa*				
Alder (red) *Alnus rubra*			173	11, 122
Ash (green) *Fraxinus pennsylvanica*				89, 141
Ash (white) *Fraxinus americana*			75, 78	40, 79
Ash species *Fraxinus spp.*				21, 84
Aspen (largetooth) *Populus grandidentata*			75, 78	
Banak *Virola koschyni*			63	
Basswood (American) *Tilia americana*			67, 159	

TIME PERIOD OF STUDY: Relevance to Current Technology

SPECIES *Latin Binomial*	**1950 - 59**	**1960 - 69**	**1970 - 79**	**1980 - 84**
Basswood (white) *Tilia hertorphylla*			147	
Beech (American) *Fagus grandifolia*			163	155
Birch (black) *Betula lenta*			147	
Birch (white) *Betula papyrifera*			58, 83, 103, 156, 163	7, 10, 56, 89, 155
Birch (yellow) *Betula alleghaniensis*	109		103, 163	155
Cedar (eastern white) *Thuja occidentalis*			163	
Cherry (black) *Prunus serotina*			75, 78, 157	
Cottonwood *Populus deltoides*			25	
Cottonwood (black) *Populus trichocarpa*				
Douglas-fir *Pseudotsuga menziesii*	160, 166, 167	28, 29, 32, 43, 68, 93, 110, 111	44, 45, 52, 53, 64, 65, 69, 70, 71, 103, 106, 112, 113, 114, 115, 116, 117, 118, 120, 123, 124, 144, 173	46, 47, 48, 49, 171

TIME PERIOD OF STUDY: Relevance to Current Technology

SPECIES *Latin Binomial*	1950 - 59	1960 - 69	1970 - 79	1980 - 84
Elm (American) *Ulmus americana*			67	21, 141
Fir (balsam) *Abies balsamea*				7, 8, 85
Fir (grand) *Abies grandis*			154	39
Fir (white) *Abies concolor*			13, 14, 92, 103, 116, 123	
Gallina *Jacaranda copaia*			63	
Hackberry *Celtis occidentalis*				21, 141
Hemlock (eastern) *Tsuga canadensis*				
Hemlock (western) *Tsuga heterophylla*			70, 116, 123, 173	
Hickory (mockernut) *Carya tomentosa*			142, 143	146
Hickory species *Carya spp.*		15	25, 52, 67, 75, 76, 77, 78, 82, 103, 107, 135, 137, 138, 139, 159	40, 79, 84, 104

TIME PERIOD OF STUDY: Relevance to Current Technology

SPECIES *Latin Binomial*	1950 - 59	1960 - 69	1970 - 79	1980 - 84
Jobo *Spondias mombin*			63	
Kiri *Paulownia tomentosa*			168	
Limba *Terminalia superba*			168	
Locust (black) *Robinia pseudoacacia*				
Maple (red) *Acer rubrum*			75, 76, 78, 83, 163	40, 79, 89, 155
Maple (silver) *Acer saccharinum*				
Maple (sugar) *Acer saccharum*			103, 150, 151, 158, 163	155
Maple species *Acer spp.*			67	
Oak (overcup) *Quercus lyrata*				141
Oak (post) *Quercus stellata*			75, 76, 78	40, 79

TIME PERIOD OF STUDY: Relevance to Current Technology

SPECIES *Latin Binomial*	1985 - 89	1990 - PRESENT		
Elm (American) *Ulmus americana*		30		
Fir (balsam) *Abies balsamea*	33	30, 31		
Fir (grand) *Abies grandis*				
Fir (white) *Abies concolor*				
Gallina *Jacaranda copaia*				
Hackberry *Celtis occidentalis*	172			
Hemlock (eastern) *Tsuga canadensis*	19, 33			
Hemlock (western) *Tsuga heterophylla*				
Hickory (mockernut) *Carya tomentosa*				
Hickory species *Carya spp.*	81, 105, 140, 172	30		

TIME PERIOD OF STUDY: Relevance to Current Technology

SPECIES *Latin Binomial*	**1985 - 89**	**1990 - PRESENT**		
Jobo *Spondias mombin*				
Kiri *Paulownia tomentosa*	36, 81			
Limba *Terminalia superba*				
Locust (black) *Robinia pseudoacacia*	36			
Maple (red) *Acer rubrum*	34, 73, 81, 90, 91, 108, 174	41, 42, 59, 72, 149		
Maple (silver) *Acer saccharinum*	165			
Maple (sugar) *Acer saccharum*	26, 128			
Maple species *Acer spp.*		30		
Oak (overcup) *Quercus lyrata*				
Oak (post) *Quercus stellata*	81			

TIME PERIOD OF STUDY: Relevance to Current Technology

SPECIES *Latin Binomial*	1985 - 89	1990 - PRESENT		
Oak (northern red) *Quercus rubra*	26, 33, 73, 91	72, 126		
Oak (southern red) *Quercus falcata*	22, 81, 105, 140	41, 42		
Oak (scarlet) *Quercus coccinea*				
Oak (water) *Quercus nigra*		129		
Oak (white) *Quercus alba*	22, 34, 81, 105, 140	176		
Oak species *Quercus spp.*	172	30		
Olive (autumn) *Elaeagnus umbellata*	36			
Pecan *Carya illinoensis*				
Pine (jack) *Pinus banksiana*	50	31		
Pine (loblolly) *Pinus taeda*				

TIME PERIOD OF STUDY: Relevance to Current Technology

SPECIES *Latin Binomial*	1985 - 89	1990 - PRESENT		
Pine (lodgepole) *Pinus contorta*	125			
Pine (ponderosa) *Pinus ponderosa*				
Pine (red) *Pinus resinosa*		119		
Pine (scrub) *Pinus virginiana*				
Pine (slash) *Pinus elliottii*				
Pine (eastern white) *Pinus strobus*	19			
Pine (western white) *Pinus monticola*				
Pine (southern yellow) *Pinus echinata*	23, 55	24, 129		
Pine (northern) *Pinus spp.*	125			
Pine (southern) *Pinus spp.*	105, 140, 148	41, 42		

TIME PERIOD OF STUDY: Relevance to Current Technology

SPECIES *Latin Binomial*	1985 - 89	1990 - PRESENT		
Poplar (balsam) *Populus balsamifera*	1, 2, 3, 57, 125, 127, 130, 131, 164	4, 5, 16, 30		
Poplar (hybrid) *Populus spp.*	50, 177			
Redwood *Sequoia sempervirens*				
Spruce (black) *Picea mariana*				
Spruce (Engelmann) *Picea engelmannii*				
Spruce (red) *Picea rubens*				
Spruce (Sitka) *Picea sitchensis*				
Spruce (white) *Picea glauca*		31, 169		
Spruce species *Picea spp.*	125	30		
Sweetbay *Magnolia virginiana*	81	30, 129		

TIME PERIOD OF STUDY: Relevance to Current Technology

SPECIES *Latin Binomial*	**1985 - 89**	**1990 - PRESENT**		
Sweetgum *Liquidambar styraciflua*	22, 23, 55, 81, 105, 140, 172	24, 30, 41, 42, 129, 176		
Sycamore *Platanus occidentalis*	36			
Tamarack *Larix laricina*	50	30		
Tupelo (black) *Nyssa sylvatica*	34, 81	30, 129		
Virola species *Virola spp.*				
Yellow-poplar *Liriodendron tulipifera*	22, 34, 55, 99, 100	30, 101, 129, 161, 175		

Appendix XIII. PANEL TYPE STUDIED

Panel Type Studied

Species *Latin Binomial*	Particleboard	Flakeboard	Waferboard	OSB
Aceituna *Simaruba amara*	63			
Afrormosia *Pericopsos elata*	168			
Alder (Black) *Alnus glutinosa*		36		36
Alder (red) *Alnus rubra*	173	122	11, 122	122
Ash (green) *Fraxinus pennsylvanica*		91, 141		72, 73, 89
Ash (white) *Fraxinus americana*		40, 75, 78, 79, 81		
Ash species *Fraxinus spp.*		84	30	30
Aspen (largetooth) *Populus grandidentata*		33, 34, 75, 78, 108		108, 149, 174
Banak *Virola koschyni*	63			
Basswood (American) *Tilia americana*	67	159		

PANEL TYPE STUDIED

SPECIES *Latin Binomial*	PARTICLEBOARD	FLAKEBOARD	WAFERBOARD	OSB
Basswood (white) *Tilia hertorphylla*		147		
Beech (American) *Fagus grandifolia*		33, 34	155, 163	
Birch (black) *Betula lenta*		147		
Birch (white) *Betula papyrifera*		91, 156	7, 10, 17, 30, 35, 57, 58, 83, 127, 130, 155, 163	18, 30, 35, 72, 73, 89
Birch (yellow) *Betula alleghaniensis*	109		155, 163	
Cedar (eastern white) *Thuja occidentalis*			163	
Cherry (black) *Prunus serotina*	157	75, 78, 157	157	157
Cottonwood *Populus deltoides*		25, 81		
Cottonwood (black) *Populus trichocarpa*				
Douglas-fir *Pseudotsuga menziesii*	28, 68, 69, 110, 111, 112, 113, 114, 116, 118, 123, 167, 173	27, 29, 32, 43, 49, 52, 53, 54, 64, 65, 68, 70, 71, 93, 94, 95, 96, 115, 117, 120, 124, 144, 160, 166, 171		44, 45, 46, 47, 48, 106, 125, 144

PANEL TYPE STUDIED

SPECIES *Latin Binomial*	PARTICLEBOARD	FLAKEBOARD	WAFERBOARD	OSB
Elm (American) *Ulmus americana*	67	21, 141	30	30
Fir (balsam) *Abies balsamea*		31, 33, 85	7, 8, 20, 30, 85	30
Fir (grand) *Abies grandis*				39, 154
Fir (white) *Abies concolor*	13, 14, 116, 123	92		
Gallina *Jacaranda copaia*	63			
Hackberry *Celtis occidentalis*		21, 141, 172		
Hemlock (eastern) *Tsuga canadensis*		33		19
Hemlock (western) *Tsuga heterophylla*	116, 123, 173	70		
Hickory (mockernut) *Carya tomentosa*		142, 143, 146		
Hickory species *Carya spp.*	67	15, 25, 40, 52, 75, 76, 77, 78, 79, 81, 82, 84, 104, 105, 107, 135, 137, 138, 139, 140, 159, 172	30	30, 77, 135, 137, 138, 139, 140

PANEL TYPE STUDIED

SPECIES *Latin Binomial*	PARTICLEBOARD	FLAKEBOARD	WAFERBOARD	OSB
Jobo *Spondias mombin*	63			
Kiri *Paulownia tomentosa*	168	36, 81		36
Limba *Terminalia superba*	168			
Locust (black) *Robinia pseudoacacia*		36		36
Maple (red) *Acer rubrum*		34, 40, 41, 42, 59, 75, 76, 78, 79, 81, 90, 91, 108	83, 155, 163	72, 73, 89, 108, 149, 174
Maple (silver) *Acer saccharinum*		165		
Maple (sugar) *Acer saccharum*	151	26, 128, 150, 158	155, 163	
Maple species *Acer spp.*	67		30	30
Oak (overcup) *Quercus lyrata*		141		
Oak (post) *Quercus stellata*		40, 75, 76, 78, 79, 81		

PANEL TYPE STUDIED

SPECIES *Latin Binomial*	**PARTICLEBOARD**	**FLAKEBOARD**	**WAFERBOARD**	**OSB**
Oak (northern red) *Quercus rubra*	66, 67, 157	26, 33, 60, 66, 91, 126, 157, 170	157	22, 45, 47, 48, 72, 73, 87, 88, 89, 157
Oak (southern red) *Quercus falcata*	67	21, 40, 41, 42, 52, 75, 76, 77, 78, 79, 80, 81, 82, 84, 104, 105, 107, 132, 135, 137, 138, 139, 140, 141, 142, 143, 159		77, 135, 137, 138, 139, 140
Oak (scarlet) *Quercus coccinea*		97, 98, 133, 134		
Oak (water) *Quercus nigra*	129	129, 141		
Oak (white) *Quercus alba*		21, 34, 40, 52, 75, 76, 78, 79, 90, 81, 82, 84, 104, 105, 107, 132, 135, 137, 138, 139, 140, 146, 176		22, 135, 137, 138, 139, 140
Oak species *Quercus spp.*		172	30	30
Olive (autumn) *Elaeagnus umbellata*		36		36
Pecan *Carya illinoensis*		21, 84, 141		
Pine (jack) *Pinus banksiana*	123	31, 50		
Pine (loblolly) *Pinus taeda*		137, 138, 139, 142, 143, 146		154

PANEL TYPE STUDIED

SPECIES *Latin Binomial*	PARTICLEBOARD	FLAKEBOARD	WAFERBOARD	OSB
Pine (lodgepole) *Pinus contorta*	121, 123	64, 115, 121, 142, 143, 144		125, 144
Pine (ponderosa) *Pinus ponderosa*	12, 123, 173	28		154
Pine (red) *Pinus resinosa*			119	
Pine (scrub) *Pinus virginiana*		28		
Pine (slash) *Pinus elliottii*		74		
Pine (eastern white) *Pinus strobus*	157	157	157, 163	19, 157
Pine (western white) *Pinus monticola*	121	121		
Pine (southern yellow) *Pinus echinata*	129	43, 129, 166		23, 24, 55
Pine (northern) *Pinus spp.*				125
Pine (southern) *Pinus spp.*	69, 118, 123, 162	41, 42, 52, 82, 104, 105, 107, 135, 137, 138, 139, 140, 148		135, 137, 138, 139, 140

PANEL TYPE STUDIED

SPECIES *Latin Binomial*	PARTICLEBOARD	FLAKEBOARD	WAFERBOARD	OSB
Poplar (balsam) *Populus balsamifera*		2, 3	1, 6, 16, 30, 57, 86, 127, 130, 131, 152	2, 3, 4, 5, 16, 30, 125, 131
Poplar (hybrid) *Populus spp.*		50, 51		50, 177
Redwood *Sequoia sempervirens*	37	43, 166		
Spruce (black) *Picea mariana*			7	
Spruce (Engelmann) *Picea engelmannii*		115		
Spruce (red) *Picea rubens*			9	
Spruce (Sitka) *Picea sitchensis*	167	166		
Spruce (white) *Picea glauca*		31, 38		169
Spruce species *Picea spp.*	123	153	30	30, 106, 125
Sweetbay *Magnolia virginiana*	129	40, 75, 76, 78, 79, 81, 129	30	30

PANEL TYPE STUDIED

SPECIES *Latin Binomial*	PARTICLEBOARD	FLAKEBOARD	WAFERBOARD	OSB
Sweetgum *Liquidambar styraciflua*	129	21, 40, 41, 42, 52, 62, 75, 76, 77, 78, 79, 80, 81, 82, 84, 104, 105, 107, 129, 132, 135, 136, 137, 138, 139, 140, 141, 142, 143, 146, 147, 162, 172, 176	30	22, 23, 24, 30, 55, 77, 135, 137, 138, 139, 140
Sycamore *Platanus occidentalis*	145	36		36
Tamarack *Larix laricina*		50	30, 58	30
Tupelo (black) *Nyssa sylvatica*	129	34, 40, 75, 76, 78, 79, 81, 129	30	30
Virola species *Virola spp.*	168			
Yellow-poplar *Liriodendron tulipifera*	67, 129	34, 62, 99, 100, 101, 129, 137, 138, 139, 146, 147, 159, 161, 175	30	22, 30, 55

Appendix XIV. STUDIES PERFORMED ON ALBERTA WOODS

GUIDE TO THE USE OF THE ALBERTA TABLE

Study characterization (ie., flaking) denotes a formal study or part of a study that addresses one distinct phase of the panel production process. The four types of panels included were particleboard, flakeboard, waferboard and oriented strand board -- all four have similar processes.

Bibliographic information for the references are found in the Literature cited section of the main text and study abstracts are found in Appendix II.

A more indepth breakdown of the study traits can be found in Appendices III - XIII. Matching Appendix numbers for the headings of the Alberta table are:

Flaking	Appendix III
Drying	Appendix IV
Blending	Appendix V
Forming	Appendix VI
Pressing	Appendices VII - X
Other	Appendix XI

Appendices XII and XIII identify the age of the study and panel type investigated, respectively.

References are indexed by species in Appendix I. This includes other studies in addition to the ones performed on Alberta woods. The other studies are similarly indexed in Appendices II - XIII.

STUDIES PERFORMED ON ALBERTA WOODS

SPECIES *Latin Binomial*	FLAKING	DRYING	BLENDING	FORMING	PRESSING	OTHER
Birch (white) *Betula papyrifera*						
Cottonwood (black) *Populus trichocarpa*						102, 164
Fir (balsam) *Abies balsamea*						
Fir (alpine) *Abies lasiocarpa*						
Pine (jack) *Pinus banksiana*						
Pine (lodgepole) *Pinus contorta*	125				125	125
Poplar (balsam) *Populus balsamifera*	4, 5	3			1, 2, 3, 4, 5, 125	102, 125, 131, 164
Poplar (hybrid) *Populus spp.*						
Spruce (black) *Picea mariana*						
Spruce (Englemann) *Picea engelmannii*						
Spruce (white) *Picea glauca*	169				169	
Tamarack *Larix laricina*						

These species are found in abundance or are commercially valuable in Alberta. The studies indexed in the table are ones that were performed on species with an Albertan provenance. Please note that there are more studies on these particular species from other geographic areas.