PROCEEDINGS OF THE WORKSHOP ON WOOD-PLASTIC COMPOSITES

Editors:

B.W. Karaim and T. Szabo
1988

Papers for these proceedings were presented at the workshop sponsored by the Forest Industry Development Division of Alberta Department of Forestry, Lands and Wildlife in cooperation with the Northern Forestry Research Centre of the Canadian Forestry Service and the University of Alberta. The workshop was held at the University of Alberta on November 3, 1987, in Edmonton, Alberta. These papers lack in-depth technical review and are either printed from the author-prepared copy or taken directly from the transcript.

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Edmonton, Alberta
February 1988

DISCLAIMER

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The views, conclusions, and recommendations are those of the authors. The exclusion of certain manufactured products does not necessarily imply disapproval nor does the mention of other products necessarily imply endorsement by the Canadian Forestry Service or the Alberta Forest Service.

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OPENING REMARKS

Alberta still has a large untapped forest resource awaiting utilization, especially aspen/poplar. This province is also rich in petrochemicals, which we often refer to as plastics. The traditional markets for wood products are decreasing but for plastics the opposite trend applies. By combining the best qualities of wood or wood fiber with the best properties of appropriate plastics in a supporting fashion, one could create a range of superior value added products for endless applications. One of the main purposes of this workshop is to examine the possibility of integrating these two resource areas in terms of combined uses that will lead to the manufacture of wood/plastic composites.

Research in wood properties and forest products development is an important element in the broad spectrum of forestry practice which ranges from land management for sustained yield of timber, to harvesting, manufacturing and marketing. Its importance lies in increasing wood utilization to ease demands on our forests and lands, for improving utilization to increase our management options, and to enhance the ability of our forest industry to make its fundamental economic contribution.

Research is not only important but interesting, with the challenge to learn more about these "natural polymers" which we call wood, and the host of useful purposes to which they may be put in the service of mankind. It is a stimulating field of endeavor.

Many researchers have been working in and contributing to this field, and we welcome our speakers as notable scientists and innovators. We appreciate them travelling here from such diverse locations to share their knowledge with us. And thanks to you, our participants, for joining us. We at the government and the university are also pleased to be participants in this workshop and we also look forward to greater Alberta involvement in research and education in this rapidly unfolding field of wood and plastics.

This workshop is being sponsored by the Canada/Alberta Forest Resource Development Agreement and a proceeding will be printed on the presentations.

Welcome to Alberta and to the University of Alberta, and best wishes for an illuminating and stimulating day.

Peter J. Murphy, R.P.F., Ph.D.
Associate Dean (Forestry)
University of Alberta

J.A. Brennan
Executive Officer
Forest Industry Development Division

PROGRAM AGENDA

WORKSHOP

ON

WOOD-PLASTIC COMPOSITES

November 3, 1987

14:00	Opportunities of Treating Alberta Wood Products with Vinyl Monomers - D.A. Tingley, Wood Science and Technology Institute, University of New Brunswick
14:45	COFFEE
15:00	Use of Wood Fibers in Thermoplastic Composites - Dr. B.V. Kokta, Universite due Quebec a Trois-Rivieres
15:45	Advanced Wood-Fiber Composite - Dr. W.E. Hsu, Forintek Canada Corp.
16:30	Research and Development at the Alberta Research Council - Dr. L. Bach, Alberta Research Council
17:15	DISCUSSION
18:00	Closing Remarks by - Dr. M.M. Micko, Moderator, University of Alberta - T. Szabo, Forest Industry Development Division - B.W. Karaim, Forest Industry Development Division

PLASTIC-WOOD COMPOSITES WORKSHOP

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OPPORTUNITIES OF

TREATING ALBERTA WOOD PRODUCTS

WITH VINYL MONOMERS

D.A. Tingley, P.Eng.
Vice-President
Board of Directors
WPC Processes Ltd.

NOTE: Mr. Tingley was previously affiliated with the Wood Science and Technology Center of the University of New Bruswick in the capacity of Director of Sales and Engineering

INTRODUCTION

WSTI Wood™ is the most advanced wood polymer composite in the world to date. Developed by WPC Processes Ltd. Fredericton, New Brunswick, it now provides economical methods of impregnating solid woods and composites with various polymers to achieve more desirable characteristics with regards to:

- dimensional stability,
- hardness and surface abrasion resistance, and
- strength.

Essentially the servicability of plastics with the esthetics of wood. Enclosed is a WSTI Wood™ brouchure and Wood Science and Technology Center brouchure (see Appendix I).

WOOD - POLYMER MATERIALS

Although wood is widely used because it is abundant, relatively inexpensive and easily fabricated, it does have two (2) major deficiencies:

1) dimensional instability, and
2) low resistance to microbiological decay.

TARS, PITCHES, CREOSOTE, SALTS

Traditionally used to coat wood or fill its porous structure, thereby enhancing its dimensional stability and resistance to decay.

ADVENT OF THE PLASTICS AGE IN THE 1930'S

Phenol-formaldehyde was the most successful of these new chemicals.

Benefits: Excellent dimensional stability and hardness properties conferred to wood.

Disadvantage: Acid and base catalysts used to promote the resin curing degraded the cellulose chain resulting in a loss of toughness.

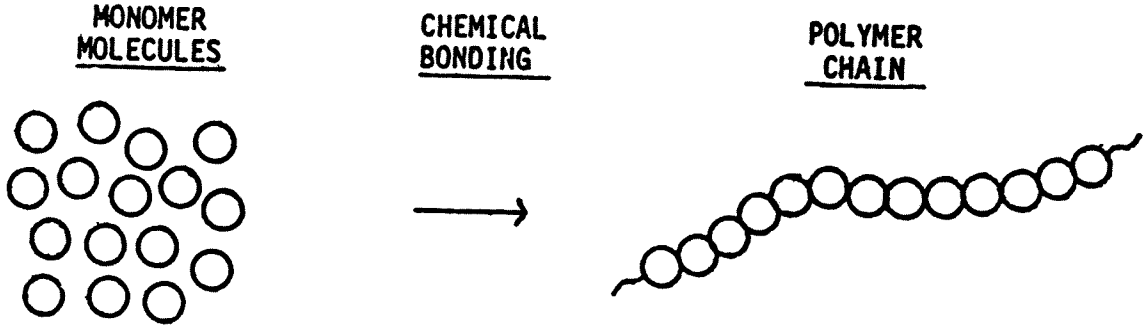
VINYL POLYMERS - LATE 1950'S

A new class of plastics became available to the wood technologist.

Wood is impregnated with a very low viscosity liquid which is subsequently solidified within the wood. Since the void volume in the wood is filled and sealed with a polymer, not only is the dimensional stability enhanced, but the wood acquires increased strength through the reinforcing effect of the polymer.

WHAT IS A POLYMER AND HOW IS IT FORMED?

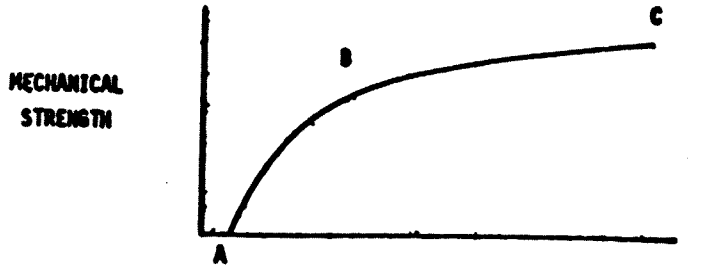
The term polymer is derived from Greek words meaning "many parts" and is a material prepared by a process known as polymerization, which involves the chemical combination of many small molecules called monomers ("single parts").



The number of repeating units in a polymer chain can be in the hundreds or thousands and is termed the degree of polymerization.

WHY DOES A POLYMER POSSESS STRUCTURAL STRENGTH?

The additive effect of intermolecular interactions between the repeating units along the polymer chain results in the attainment of useful properties.



Degree of Polymerization
or
Length of Polymer Chain

Below "A" - Polymers with very low degrees of polymerization are not useful structural materials.

At "B" - Polymer has sufficient strength to be useful.

"B" To "C" - Range where polymer has practical application.

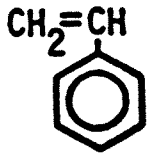
WHAT ADVANTAGES ARE THERE IN USING VINYL-TYPE MONOMERS TO TREAT WOOD

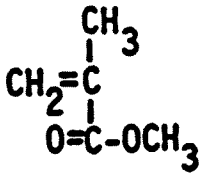
1) They have minimal viscosities and can penetrate wood easily.

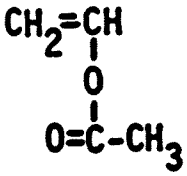
2) The polymerization is a neutral reaction which does not degrade wood nor reduce its toughness.

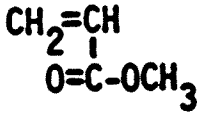
3) Tailor-made strength properties can be incorporated into the wood.

COMMON VINYL MONOMERS



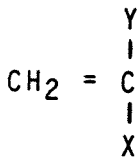






	STYRENE	METHYL METHACRYLATE	VINYL ACETATE	METHYL ACRYLATE
Nature of polymer	hard & brittle	hard & tough	weak	soft & rubbery
Softening temp. °C	100	90	30	0

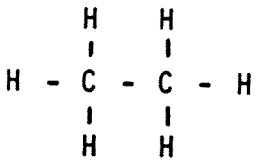
4) Monomers can be copolymerized to produce intermediate properties.



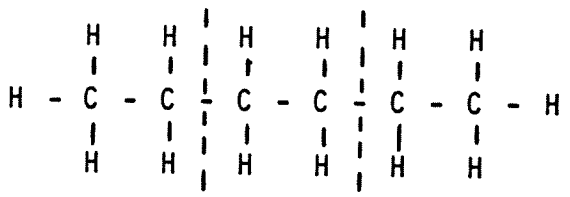
VINYL

THE INFLUENCE OF MOLECULAR WEIGHT ON MATERIALS HAVING PARAFFINLIKE STRUCTURES

DP	Molecular Weight (g/mol)	Material	Properties
1	30	Ethane	Gas at STP
3	86	Hexane	Liquid with a boiling point of 69°C.
20-34	562-954	Paraffin	Waxy, semisolid with a melting point of 50-55°C.
~700	~20,000	Polyethylene	Fairly hard, tough solid with a melting point of 95-135°C.
~150,000	~4 x 10^6	Ultrahigh-molecular weight polyethylene.	Hard, tough solid with a melting point of 120-135°C and exceptional abrasion resistance.



ETHANE



HEXANE

WOOD-POLYMER MATERIALS

WHAT IS A WOOD-POLYMER MATERIAL

Wood that has been impregnated with a very low viscosity liquid (monomer) which is subsequently solidified (polymerized) within the wood.

WHAT ARE THE BENEFITS?

Since the void volume in the wood is filled and sealed with a polymer, not only is the dimensional stability enhanced, but the wood acquires increased strength through the reinforcing effect of the polymer.

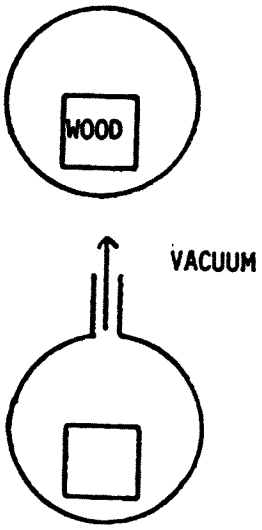
TWO-STAGE METHOD OF PRODUCTION

1) Impregnation Stage - To produce a wood-monomer combination.

2) Polymerization (or curing) Stage - To produce a wood-polymer material.

IMPREGNATION STAGE

END VIEW OF PRESSURE VESSEL

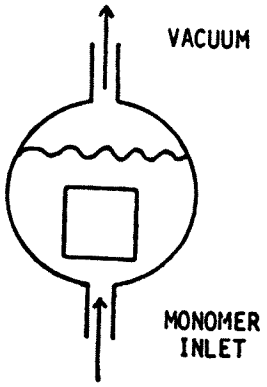


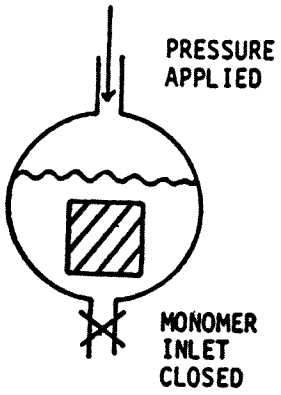
IMPREGNATION STEPS

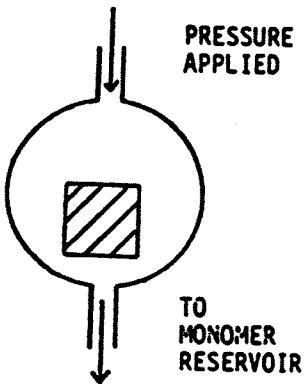
1. A pressure vessel is charged with the wood.

2. Air is removed from the wood by means of a mechanical pump down to a predetermined pressure.

END VIEW OF
PRESSURE VESSEL







IMPREGNATION STEPS

3. A low viscosity polymerizable liquid (monomer) is admitted while maintaining this pressure until the wood is covered with an excess of the monomer.

4. The pressure is restored to 1 atmosphere and super-atmospheric pressure can then be applied to drive the monomer into the wood. The soak period depends upon the species of wood.

   For example - 30 inch length.

   A) Sugar maple - approx. 1 hour.

   B) Black walnut - approx. 24 hours.

5. The excess monomer is returned to a reservoir under pressure. The impregnated wood can then be removed for curing.

POLYMERIZATION STAGE

Polymerization can be initiated using either:

A) temperature-sensitive catalysts; or

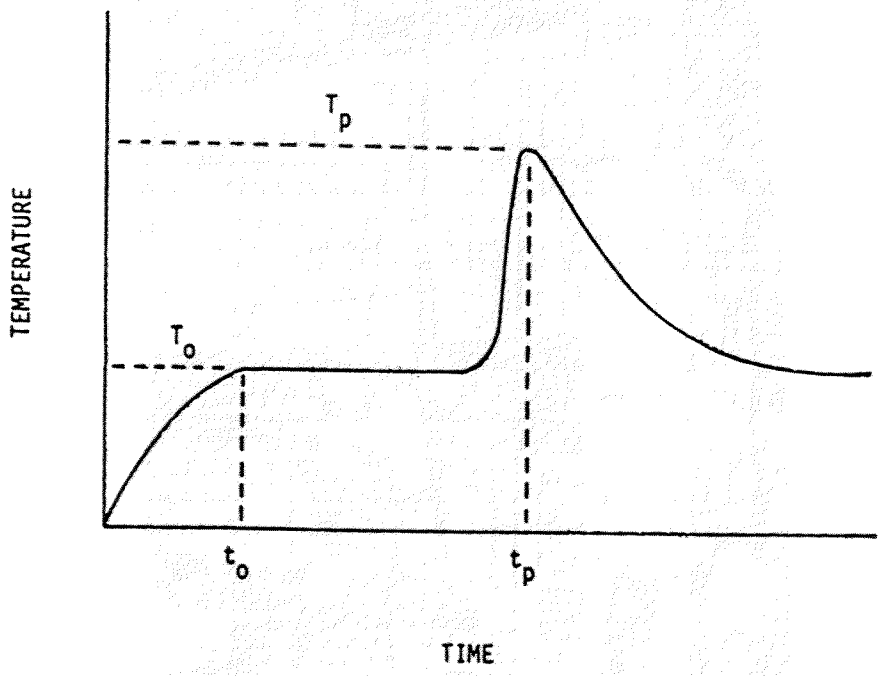
B) cobalt-60 gamma radiation.

A) HEAT-CATALYST PROCESS

Heat must be introduced into the wood-monomer combination to decompose the catalyst, thereby initiating the polymerization.

The polymerization reaction is exothermic and once it begins the heat flow is reversed. Because wood is such a good insulator, the heat flow out of the wood is much slower than the rate at which the heat is generated by the polymerization.

To illustrate this heat transfer process consider the temperature-time polymerization curve shown below. The temperature is measured at the center of the impregnated sample and indicates 4 stages in the polymerization.



i) Time to t_o indicates the time for the wood-monomer mass to reach the curing temperature, T_o.

ii) The period of constant temperature indicates the removal of polymerization inhibitors (used to prolong the storage life of the monomer) by the decomposing catalyst.

iii) With the inhibitors eliminated, the exothermic polymerization takes place and the temperature rises to a maximum, T_p. The rapid temperature increase is attributable to an autoacceleration in the reaction and increased decomposition of the remaining catalyst.

iv) Polymerization then continues at a reduced rate and the temperature gradually returns to that of the curing oven.

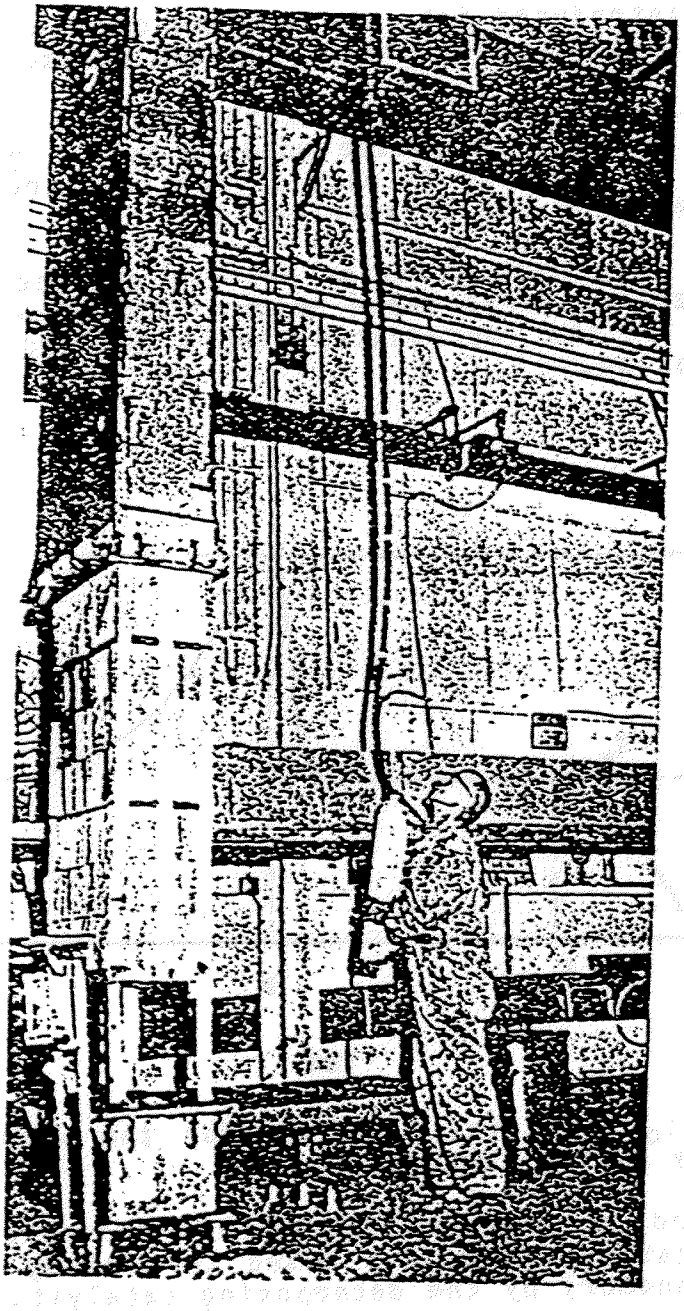


FIGURE 1: An impregnation and irradiation canister is being loaded with parquet flooring for treatment.

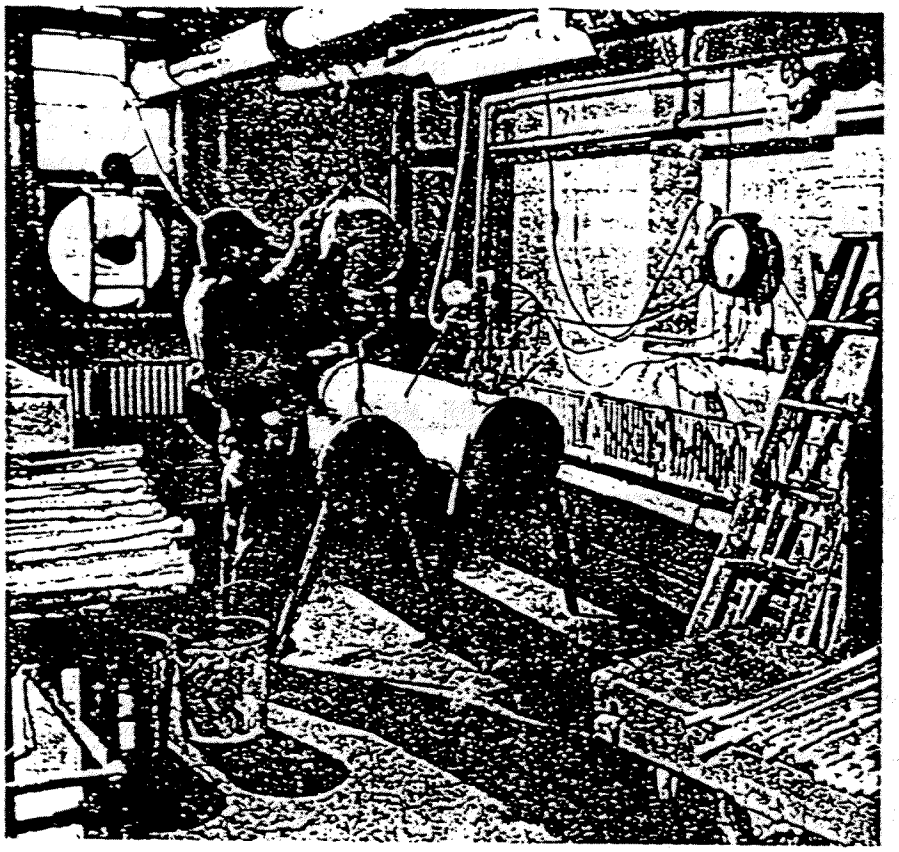


FIGURE 2: This wood impregnation vessel is being used to saturate the wood with monomers.

In a heat-catalyst process, the potential for reaction runaway is high and can result in gross shrinkage and distortion of the original wood shape. The wood-polymer material must therefore be machined to a final shape after treatment.

The heat-catalyst process is limited to the production of high cost, low volume items. For example, golf clubs, drumsticks, billiard cues, archery bows, musical instruments, etc. There is world-wide production of these items.

B) RADIATION PROCESS

Reaction control is achieved through adjustment of the radiation dosage, avoiding the possibility of reaction runaway. High volume products can therefore be produced by this process.

The only commercial operation presently in existence is Permagrain Products Inc. of Media, Penn., manufacturers of acrylic wood flooring. This company also produces smaller quantities of acrylic handrails, windowsills, stair treads and plywood sheets.

Capital cost to set up the radiation facility alone is estimated to be $3 million. Production is roughly 500,000 sq. ft. a month. The treatment doubles the cost of the item.

CHARACTERISTICS OF WOOD-PLASTIC MATERIALS

1) TYPICAL STRENGTH PROPERTY IMPROVEMENTS

PROPERTY	INCREASE RELATIVE TO UNTREATED WOOD*
Compression strength	70 - 140 %
Bending strength	40 - 70 %
Elastic modulus	15 - 35 %
Hardness	6 - 12 times
Abrasion resistance	2 - 9 times

* The actual % change depends on the density of the untreated wood.

2) PHYSICAL AND CHEMICAL PROPERTIES

PROPERTY	COMMENTS
A) Dimensional stability	Greatly improved.
B) Resistance to chemicals, solvents and stains	Greatly improved.
C) Resistance to micro-biological attack	Good.
D) Appearance	The grain figure of the natural wood is retained or even enhanced.

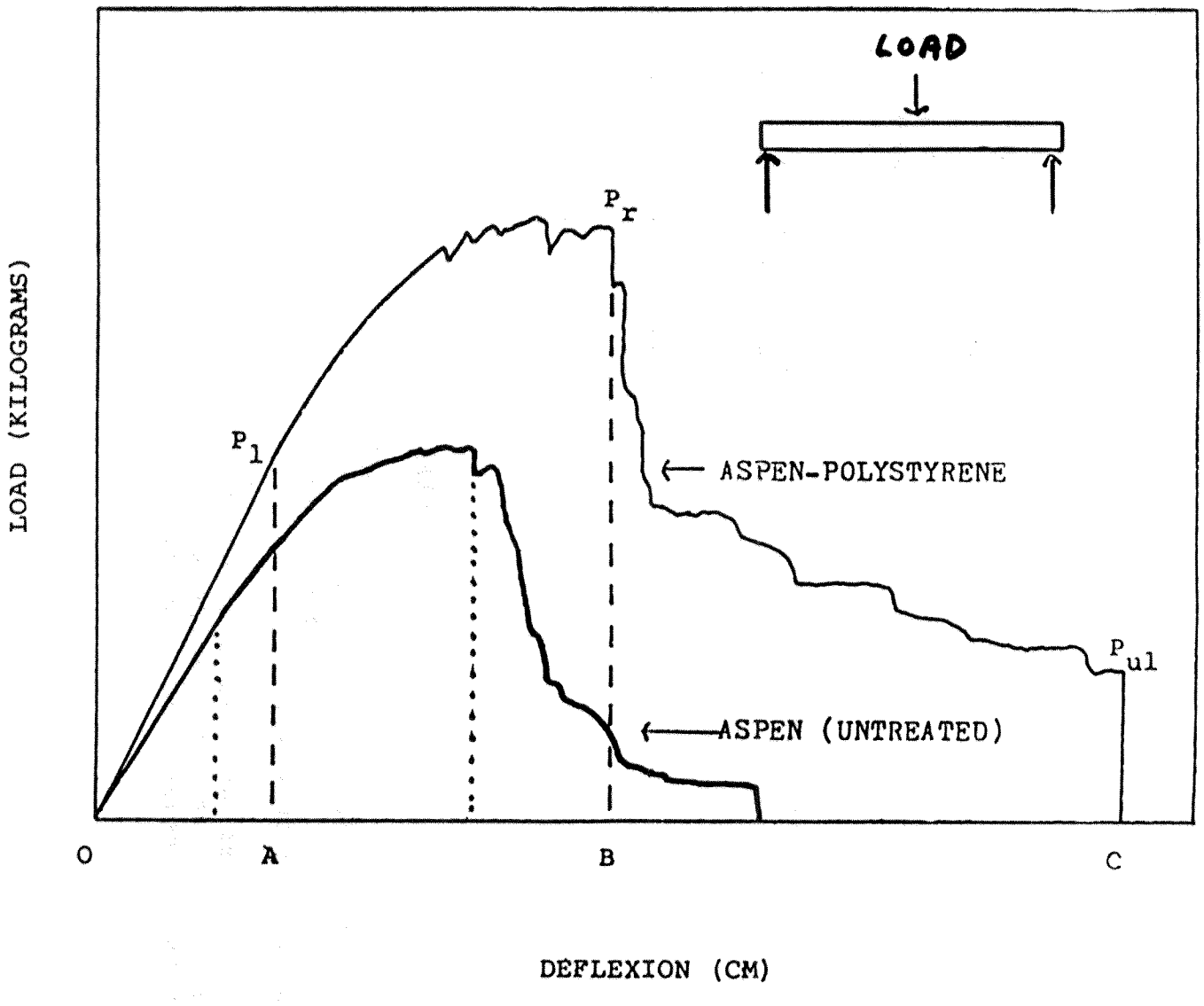


FIGURE 1- Load-Deflexion diagram for a complete static bending test

2) PHYSICAL AND CHEMICAL PROPERTIES (CONT'D)

PROPERTY	COMMENTS
E) Machining	Wood-plastics can be sawn, planed, drilled and jointed by conventional wood-working techniques. Carbide tipped tools are required.
F) Finishing	Because of good machining characteristics and filled voids, there is a reduced need for finishing. The plastic component ensures that the surfaces are effectively self-polishing.
G) Gluing and fastening	Wood-plastics must be fastened by straight shank bolts because they are too hard for nailing or conventional tapered wood screws. Good adhesive bonding can be achieved with epoxy, resorcinol and poly- (vinyl acetate) based glues.

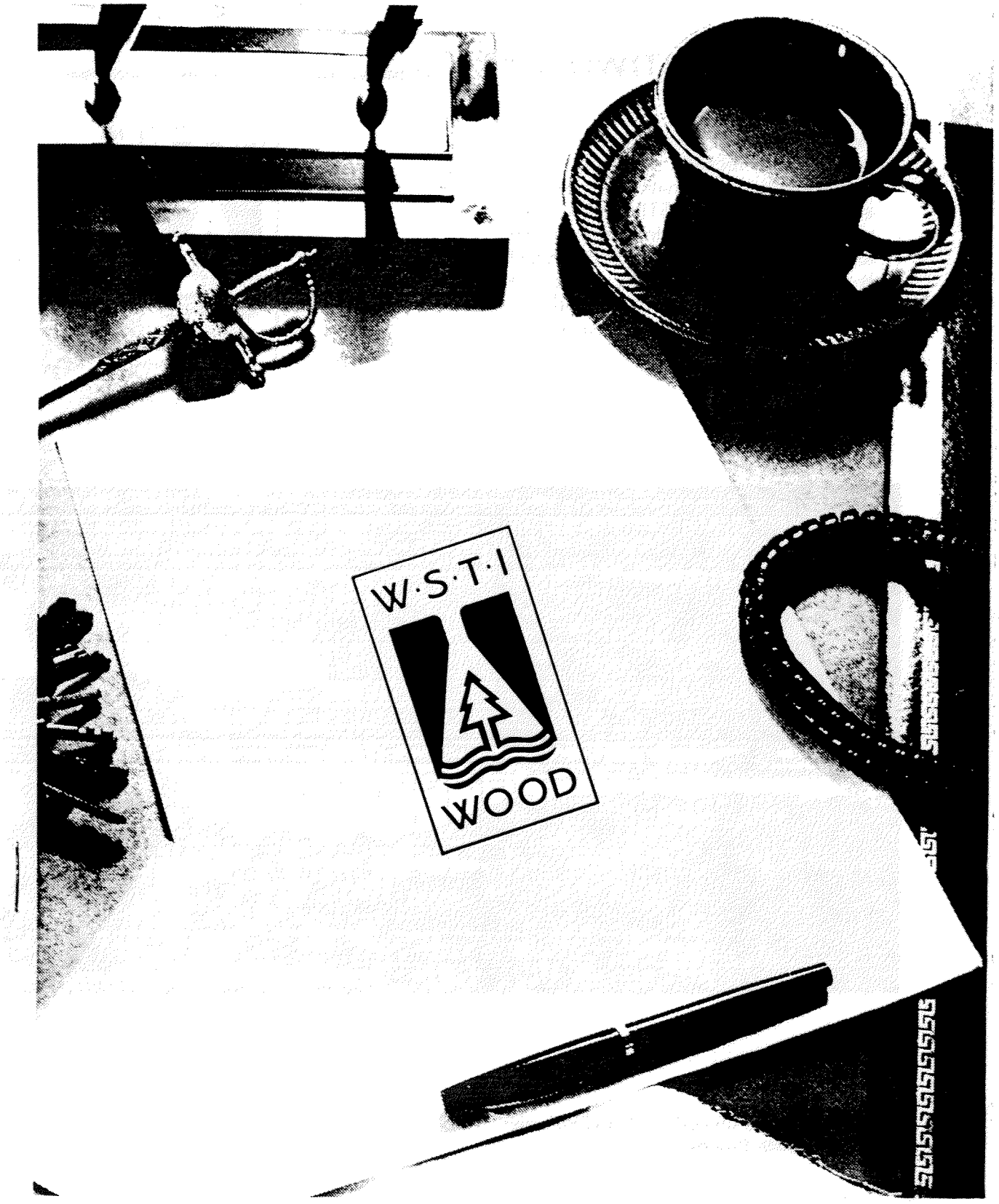
SUMMARY

In conclusion the application of WSTI Wood™ to primary and secondary woodworking firms in Alberta is exciting. Already several have tried initial samples ranging from OSB to poplar spindle, achieving considerable success.

Any inquiries on this presentation and the technology should be directed to Dan Tingley c/o W.P.C. Processes Ltd., P.O. Box 3548, Station B, Fredericton, New Brunswick, E3A 5J8.

APPENDIX I

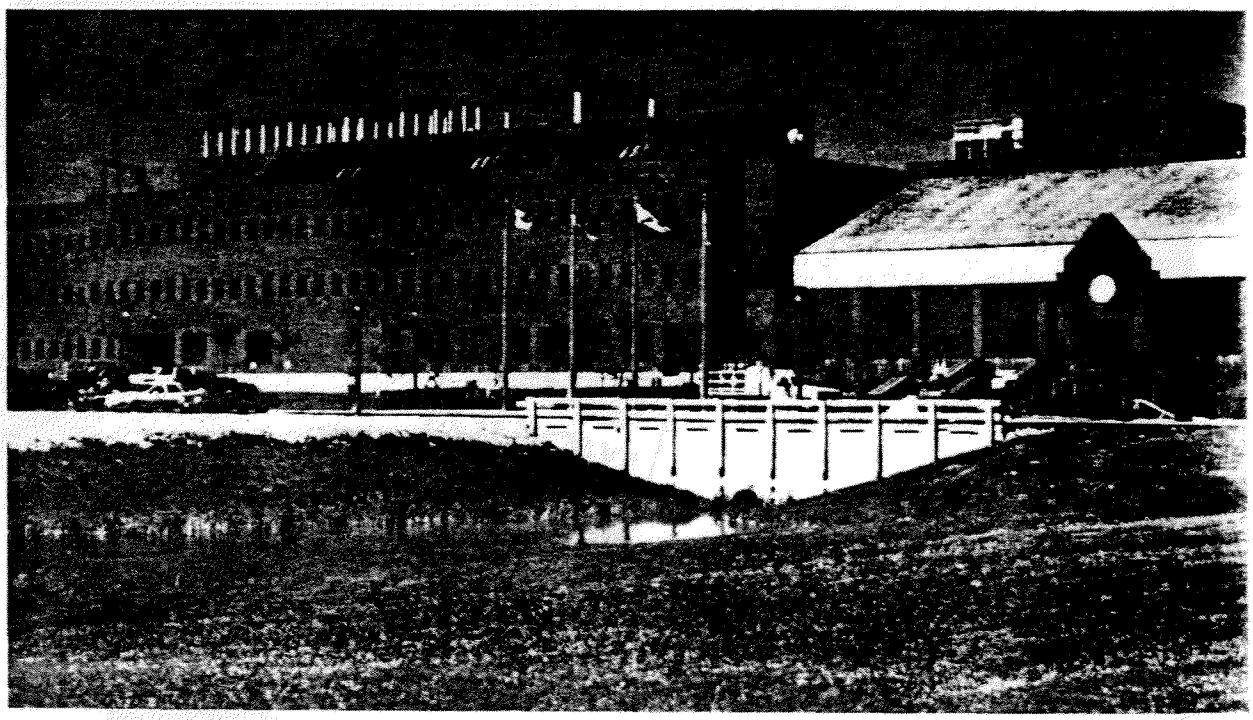
WSTI Wood™ Brochure


W·S·T·I
WOOD

WHAT IS WSTIWOOD™*?

WSTIWOOD™ is a wood polymer composite (WPC) recently developed that is produced using combinations of chemicals and processes. In WSTIWOOD™, the wood and polymer are intimately linked, forming a true composite. WSTIWOOD™ is stronger than wood, has a smoother harder surface, and a much higher dimensional stability. It is available in various colours.

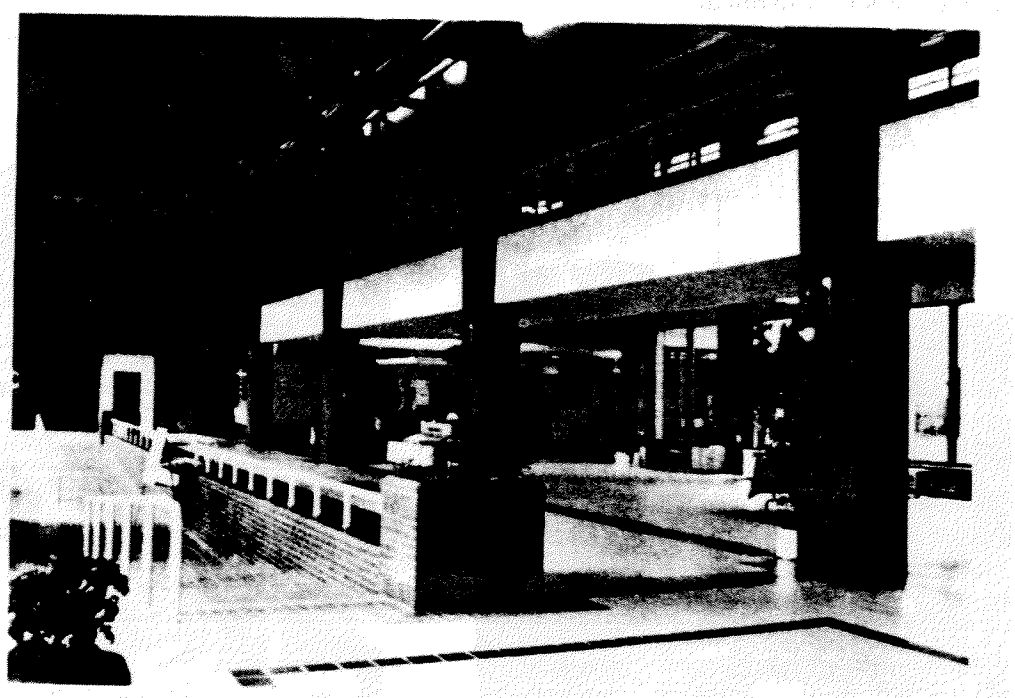
W·S·T·I ™
WOOD



* Trade name, owned by Wood Polymer Composite Processes Ltd.

THE DEVELOPMENT OF WSTIWOOD™

The development work for WSTIWOOD ™ has taken place at the Wood Science and Technology Centre, which is affiliated with the University of New Brunswick.



"Contract research is perhaps most important in bridging the gap between 'town' & 'gown'.
Canadian Manufacturers Association

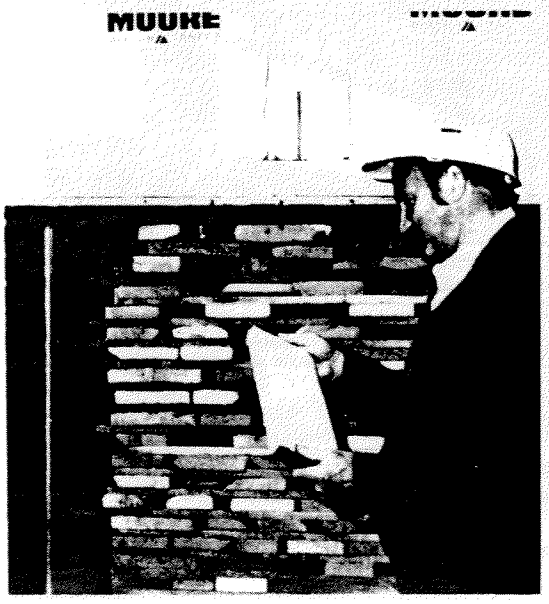
MANUFACTURING OF WSTIWOOD™

All permeable woods (such as maple, birch and poplar) and semi-permeable woods (such as walnut) can be used to produce WSTIWOOD™. Wood fibre and particle composites can also be treated with WSTIWOOD™ chemicals.

Vinyl-type and other monomers, blended with suitable additives, are used to produce WSTIWOOD™.

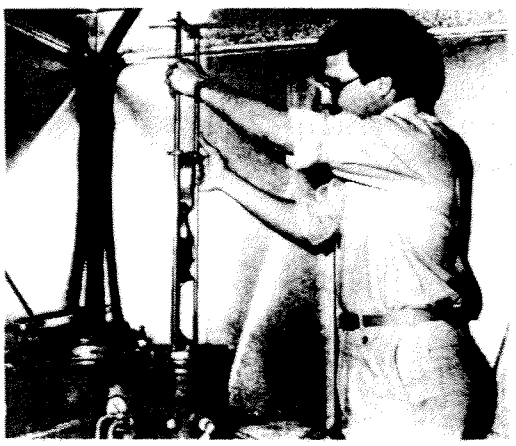
Monomer is forced into wood using vacuum or vacuum-pressure processes.

Polymerization (or curing) of WSTIWOOD™ is effected using a heat-catalyst process.



RAW MATERIALS

CURING



IMPREGNATION OF A BOW RISER

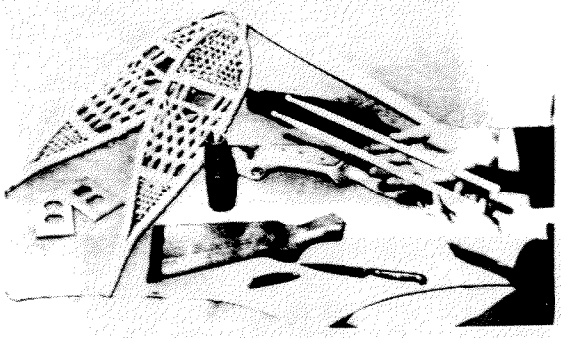
TECHNOLOGICAL ADVANTAGES

WSTIWOOD ™ has two important advantages over the traditional wood polymer composites Impreg, Compreg, and Acrylic WPC.

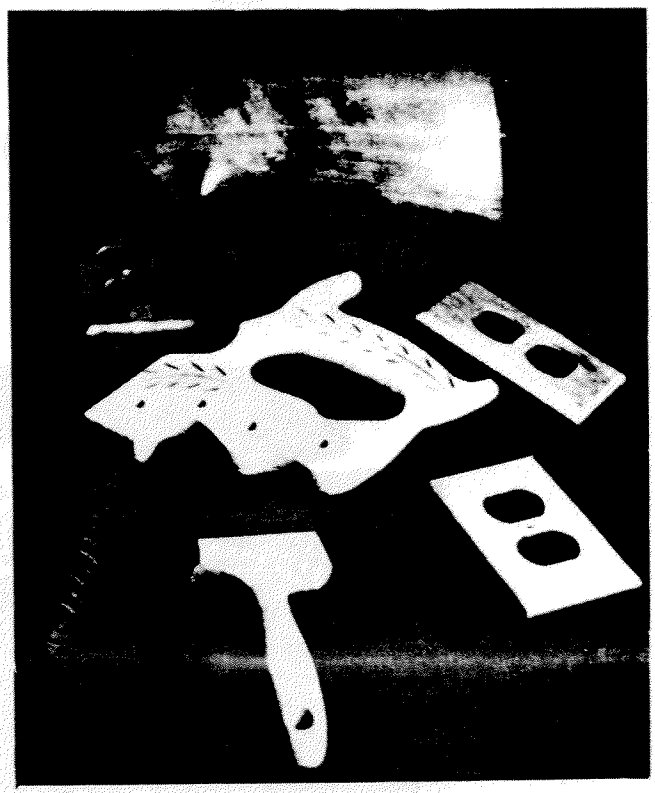
1. It uses new chemcial formulations. One of these formulations has low volatility, flammability, and toxicity, and is therefore safer in the workplace. A special feature of this formulation is that it can be modified to give partial penetration into solid wood. Another formulation imparts high dimensional stability to wood in harsh environments, such as a dishwasher. This second treatment can be used on Canadian sugar maple to simulate ebony, and with modification, rosewood.

2. It uses new processing parameters. Solid wood stock or finished wooden parts can be impregnated and exhibit little, or no, distortion or surface chemical depletion. The stability of the chemical formulations allows longer treatment cycles to better impregnate more difficult wood species such as walnut.

These advances in technology, in concert with an ongoing development program, make WSTIWOOD ™ a more attractive product for industrial implementation than its predecessors.

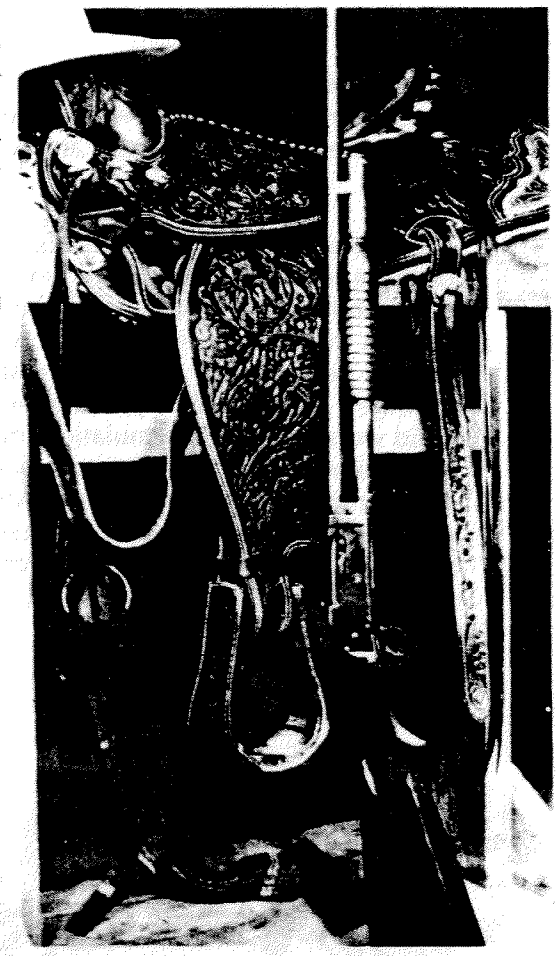


The Wood Science and Technology Centre has strengthened everything from knife handles to snow-shoes to bats.



Winchester is excited about the potential that wood polymer composites pose for the wooden components in the construction of Winchester firearms. We are currently experimenting with the new process in the manufacture of these firearms and the results are very promising.

Barry Miller
Director of Engineering
U.S. Repeating Arms Company (Winchester)
New Haven, Connecticut



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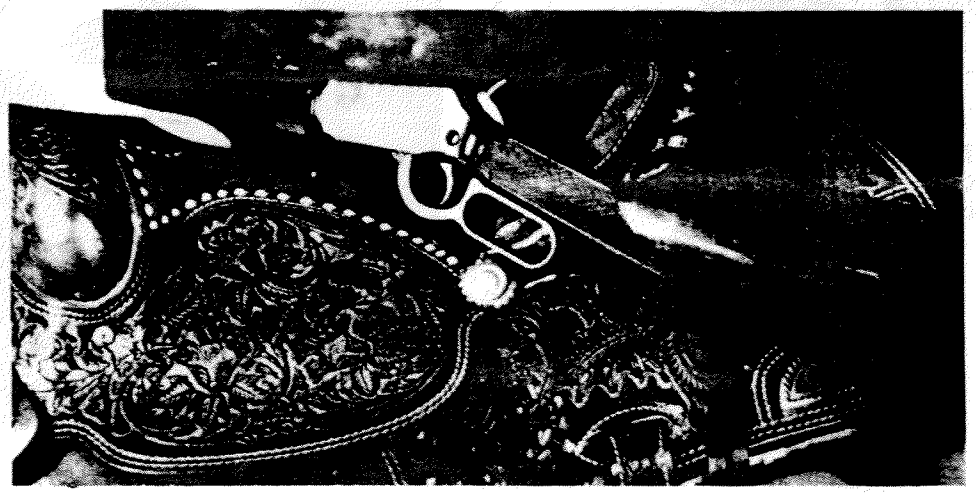
U.S. Repeating Arms Company
New Haven, Connecticut 06511
Winchester Trademarks Licenced from Olin Corporation



WSTIWOOD™ PROPERTIES

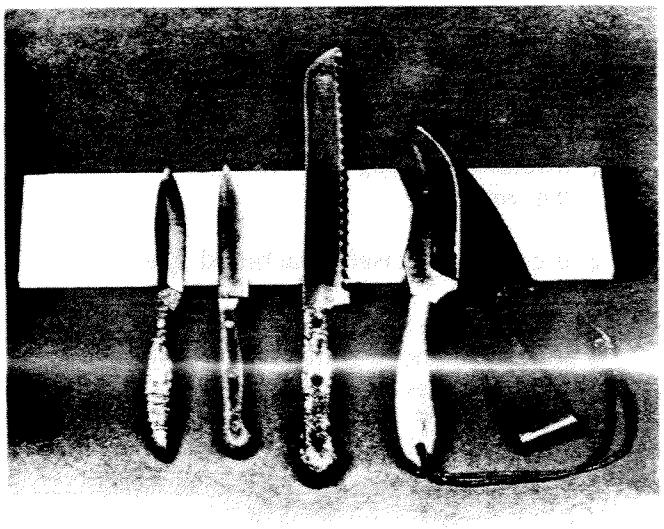
WSTIWOOD™ has several properties which make it an attractive industrial material:

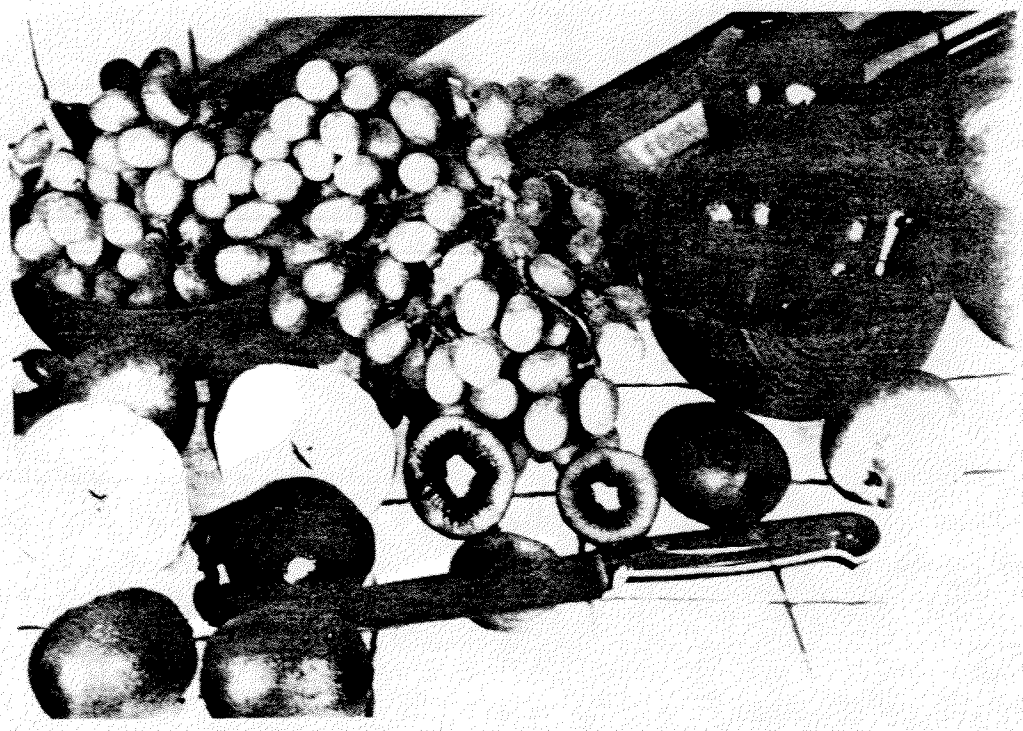
1. It retains the appearance and feel of the wood.
2. It can be precisely machined like plastic.
3. It has enhanced dimensional stability with changes in moisture.
4. It is stronger and harder than the parent wood.
5. It has increased resistance to chemicals, heat and abrasion.
6. It can be coloured throughout. Colours include black, browns, the primaries, and their mixtures.
7. It can be finished without using coatings. Sanding and buffing are all that are required for a high-quality finish.
8. Marred surfaces can easily be repaired without totally refinishing the product.

APPLICATIONS OF WSTIWOOD™

1. Domestic use:
   (A) Flooring
   (B) Countertops
   (C) Furniture
   (D) Knife handles

GROHMANN
KNIVES

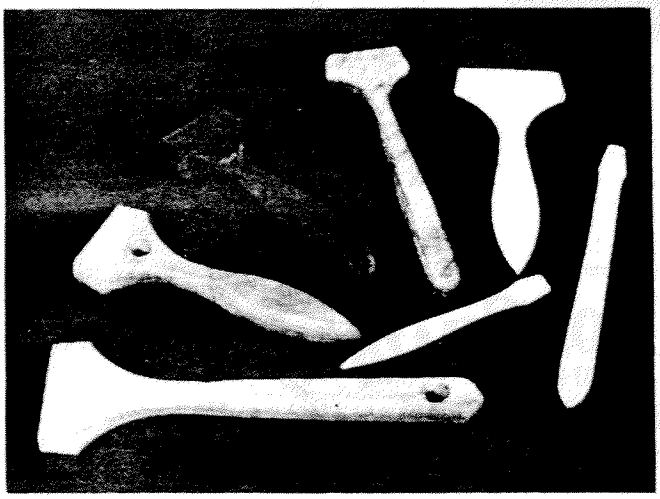




DOMINION CHAIR
(1985) LTD
• BASS RIVER N.S. •

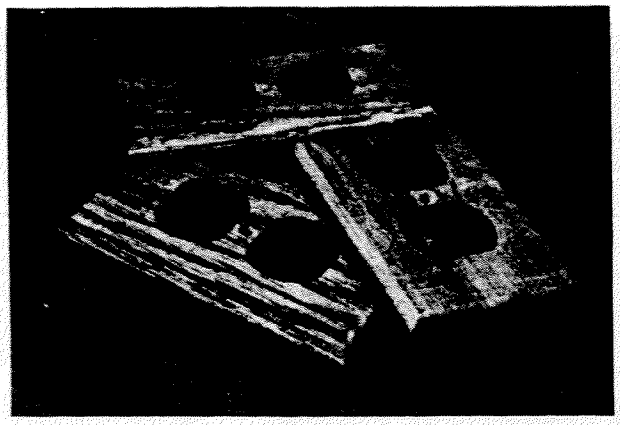
2. Industrial use:
   (A) Brushes
   (B) Chandler trade
   (C) Striking tool handles

THE CANADA SPOOL &
BOBBIN CO. LTD.



SIMMS

T S SIMMS & CO LIMITED
P O BOX 820 SAINT JOHN NEW BRUNSWICK
CANADA E2L 4C5



OAK LEAF
ENTERPRISES LTD.

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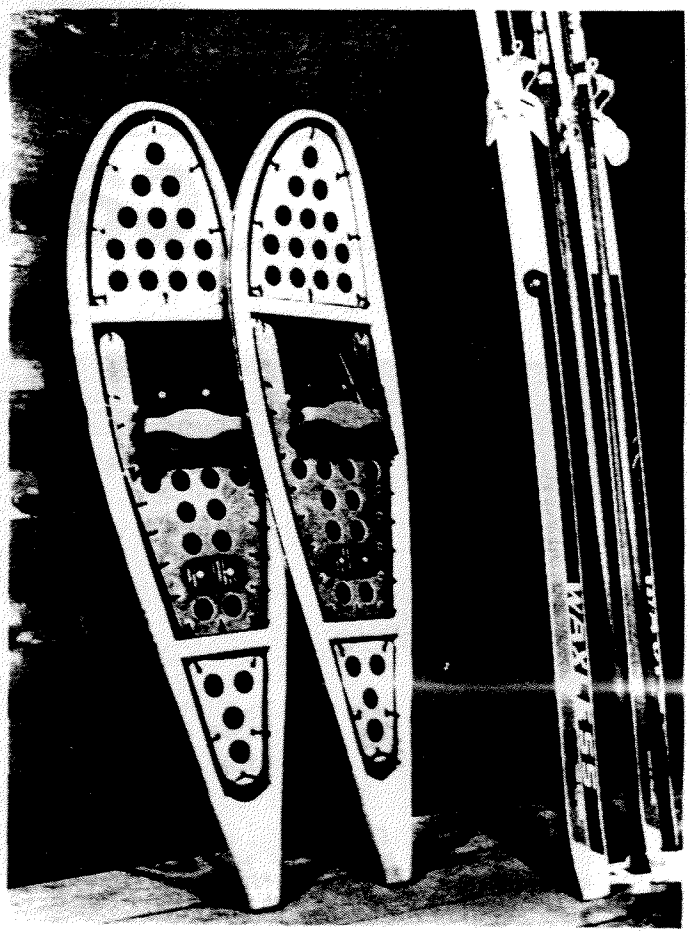
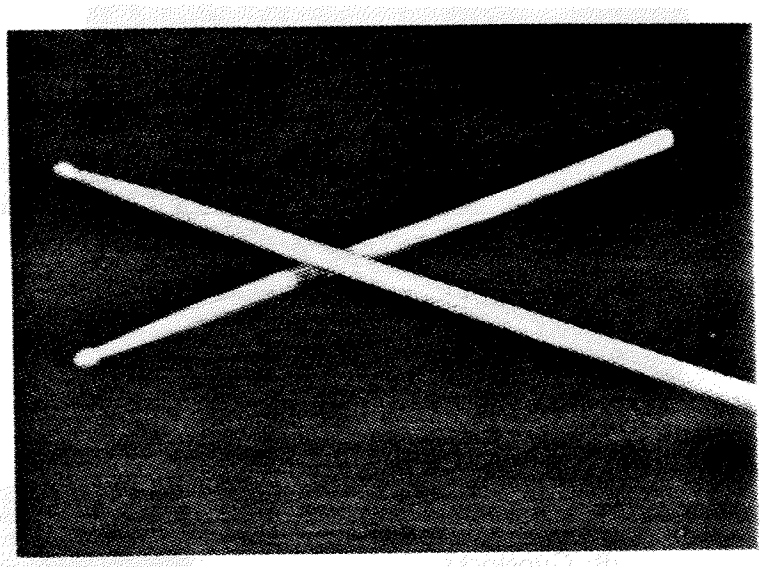
P. O. Box 873
Saint John. N.B. E2L 4C3

3. Sporting goods:
   (A) Golf club heads
   (B) Gunstocks
   (C) Billiard cues
   (D) Drumsticks
   (E) Bow Risers

FABER & CO. INC.
FABER
TRADE MARK
LORETTEVILLE, QUE. CANADA

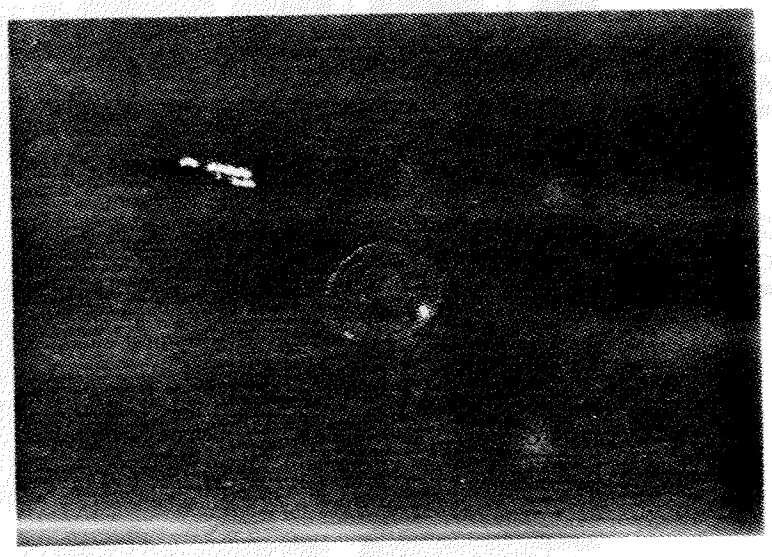


4. Musical instruments:
   (A) Guitar parts
   (B) Piano keys
   (C) Bag pipe chanters



REGAL TIP® PRODUCTS

calato



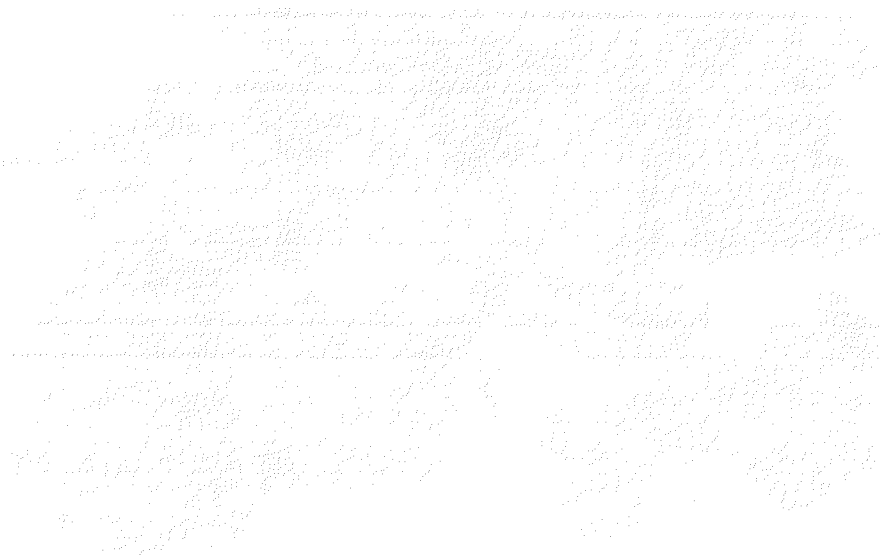
5. Assorted Wooden Components:
   (A) Jewelery
   (B) Clock parts
   (C) Journal bearing blocks

FUTURE MARKET POTENTIAL

WSTIWOOD™ has excellent market potential. A notable example is the furniture industry. Current finishing systems could be replaced by simple sanding and buffing facilities if WSTIWOOD™ were used. The impregnated surface would be difficult to mar or burn with cigarettes and virtually impossible to damage with water or household liquids. On-the-spot repairs can be made with an abrasive such as fine steel wool.

For further information please write or phone:
WOOD POLYMER COMPOSITE
PROCESSES LTD.
P.O. BOX 3548
STN 'B'
FREDERICTON, N.B.
E3A 5J8
PHONE: (506) 452-9709
TELEX: 014-46202

FAX NO: AVAILABLE



USE OF WOOD FIBERS

IN

THERMOPLASTIC COMPOSITES

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Professeur
Centre de Recherche en
Pates et Papiers
Universite du Quebec a Trois-Rivieres

INTRODUCTION

Polymers belong to the most important class of materials. Their volume of production first caught up with metals in 1978, and surpassed it in 1983 by 29% (1). The growing demand for polymers may be explained by the fact that they produce items with tailor-made properties, by their high tensile strength per weight unit, as well as by their relatively affordable price.

The main disadvantage of polymers lies in their somewhat low elastic modulus for certain applications. To increase polymer rigidity, more and more reinforcing agents are being used and the resulting polymer composites are stronger and/or less expensive. The use of reinforcing or filling agents (glass fibers, kaolin, mica, etc.) in the plastic industry in 1978 was 1,000,000 metric tons and the estimated volume for 1986 is 3,000,000 tons (2). According to estimates, in 1990 the production of thermoplastic polymers will reach 40,000,000 tons with 30 to 50 percent of that volume in the form of composites (1).

So far, the use of wood fibers for reinforcing thermoplastic polymers has been limited, mainly because of the following reasons: (i) a compatibility problem between hydrophylic wood fibers and hydrophobic thermoplastic; (ii) thermal instability at temperature above 150°C; (iii) dimensional stability due to excessive water uptake; (iv) phase separation under stress, especially at subzero temperatures.

As we have recently suggested (3), that the short wood fibers could present considerable advantages in the reinforcement of thermoplastics if the above-mentioned problems are overcome. Compared to inorganic fillers, they show the following benefits: (i) lower cost per unit volume, (ii) flexibility during processing, (iii) lower equipment abrasion, (iv) no health problems, (v) low density, (vi) high ability for surface modification, and (vii) use of renewable, abundant resources especially in a form of hardwood fibers (4).

It is well-known that there is an enormous amount of unused hardwood fibers in Canada. These hardwood fibers (as in the case of aspen) have a relatively high aspect ratio with a modulus several times higher than that of most thermoplastics (5).

The problem of the compatibility of wood fibers with thermoplastics can be overcome by attaching to their surface a polymeric segment with solubility parameters similar to those of the polymeric matrix. The mechanical properties of grafted aspen fiber-filled polyethylene composites were several times higher than those of pure LLDPE (3). In addition, their properties generally surpassed those of glass fiber or mica filled LLDPE composites. At the same

time, the estimated production cost of grafted aspen fibers ($250-$500/ton) are more economical than silane-treated mica ($700/ton) or glass fibers ($2,900/ton).

Recently, Woodhams et al. (6) showed that softwood pulp composites equal or exceed the stiffness-weight efficiencies of most traditional construction materials including steel, aluminum, glass fiber composites and talc-filled polyolephins, while retaining a major cost advantage.

Kokta et al. (7) prepared composites from aspen or birch chemithermomechanical pulps grafted with polystyrene. He found improvement in the composites mechanical properties in the 40% range compared to the original polystyrene when 40% of wood fibers were used.

In a recent study (8), it was shown that the fibers of aspen or birch can improve mechanical properties of polymethylmethacrylate such as elastic modulus: +95%; energy at break: +2,000%; breaking strength +400%; and elongation at break: +166%.

The same authors (9) have also reported that the aspen fibers in the form of chemithermomechanical pulp have improved mechanical properties of linear low density polyethylene by a factor of: 2.6 for modulus, 2.3 for stress, 2.1 for energy (all properties measured at yield point) when used in a weight proportion of 40%. In addition, it has been also demonstrated, that the above mentioned composites behave extremely well under extreme conditions (i.e. when exposed to low or high temperatures as well as after immersion in boiling water).

Olephinic polymers like polypropylene and polyethylene are the most used thermoplastics for industrial as well as domestic applications and they represented almost 44% of all polymers sold in the U.S.A. in 1985. On the other hand statistics from the U.S.A. (10) show that only 2.6% of polypropylene and almost 0% of polyethylene are being reinforced in 1985. If all the predictions as far as the increase of reinforced thermoplastics is concerned for 1990 (increase from 2.6 to 30%) and in consideration of possible penetration of market with reinforced polyethylene, it seems logical to assume that the possible domestic sales of PE and PP composites may be in the range of 15 to 65 millions of pounds/year and international sales in the range of 100 to 650 millions of pounds/ year.

In 1985, (10), only 0.9% of styrenic polymers were reinforced. Assuming that by 1995 30% of styrene polymers will be reinforced, this will represent a potential of another 500 millions of pounds/year of reinforcement fibers, like hardwood aspen fibers, to be used in styrenics.

According to the latest statistics for 1986 (11) the production of thermoplastic polymers in the U.S.A. being 70 kg/capita has

increased by 5% but the production of reinforced thermoplastics has increased by 20% when compared to statistics of 1985 (10).

The possible applications of reinforced thermoplastics are expected to be in: the auto industry, construction, toys, shipping, furniture, etc.

EXPERIMENTAL

Materials and Procedures

Birch (Betula Papyfera Marsh), aspen (Populus Tremuloides Michx) and some black spruce and balsam fir were used in the study.

Wood fibers in the form of mechanical pulp, CTMP, explosion pulp or sawdust were grafted, compression molded and included using the procedures already published previously (i.e. 3, 7, 8, 9).

RESULTS AND DISCUSSION

Wood Fiber Reinforced Composites

As was mentioned in the introduction, wood fibers are quite suitable for the reinforcement of thermoplastics because they are short and have high modulus as well as high tensile strength.

In table 1, the advantages of wood fibers are summarized when compared with presently-used inorganic fillers. The economical advantage of wood fibers as reinforcers is indicated in table 2.

The enormous potential of wood fibers is further enhanced by the fact that even the cheapest sawdust is strong enough to substantially reinforce (and not only fill) thermoplastics.

In table 3, the reinforcement potential of grafted aspen, fir and spruce fibers are compared. The study, performed with sawdust, indicates that aspen fibers of Mesh size 60 are excellent reinforcers of polytyrene (8).

In table 4, the reinforcement characteristics of grafted aspen or birch are compared to polymethylmethacrylate reinforced with either mica or very expensive glass fibers. From these results, there is no doubt that the wood fibers as a reinforcement agent are even better than expensive glass fibers (8). The excellent reinforcing behavior of aspen wood fibers were also confirmed for extreme conditions in the case of LLDPE (3, 9).

CONCLUSION

Wood fibers or sawdust have reinforcement potential for polystyrene, polymethylmethacrylate and polyethylene.

ACKNOWLEDGEMENT

The financial support of NSERC, FCAR, Ministere de l'Energie et Resources du Quebec is appreciated.

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(11) Modern Plastics, "Heading for 50 billion pounds", 55-65 (Jan. 1987).

TABLE 1: Use of Wood Fibers as Reinforcement in Thermoplastic Composites.

ADVANTAGES:

- Low price
- Flexibility during production
- Lower density
- Lower equipment abrasion
- Low health hazard
- Renewable resource

TABLE 2: Price $/Tonne

Grafted aspen (birch) CTMP fibers	$450 - 550
Grafted aspen (birch) explosion fibers	$400 - 500
Grafted aspen (birch) sawdust spruce, fir	$100 - 200
Treated mica	$700 - 750
Glass fibers (E)	$2,900 - 3,100

TABLE 3: Physical properties improvement of polystyrene composites with 30% of fibers.

	MODULUS	ENERGY	BREAKING LENGTH
Aspen	+ 49%	+ 67%	+ 92%
Fir	+ 40%	+ 58%	+ 92%
Spruce	+ 33%	+ 36%	+ 56%

TABLE 4: Mechanical properties of grafted birch or aspen - PMMA composites.

POLYMER	FILLER	WEIGHT FRACTION OF FILLER (%)	STRESS (MPa)	ELONGATION (%)	MODULUS (MPa)	ENERGY (KJm)
PMMA	0	0	12	4.5	267	2
	Birch	10	60	12	518	32
	Aspen	10	68	13	523	42
	Mica	10	14	4	377	2
	Glass	10	19	4	494	2
	Birch	30	50	9	560	19
	Aspen	30	53	9	586	21
	Mica	30	25	4.5	564	4
	Glass	30	31	5.0	610	6

TABLE 5: Mechanical properties of grafted aspen polyethylene composites.

POLYMER	FILLER	WEIGHT FRACTION OF FILLER (%)	STRESS (MPa)	ELONGATION (%)	MODULUS (MPa)	ENERGY (KJm)
LLDPE	0	0	14.8	34.6	43.5	37.1
	Aspen	20	23.2	39.2	59.1	40.9
	Mica	20	20.1	20	100.5	22.2
	Glass	20	15.2	29	52.8	17.1
	Aspen	40	34.9	30.6	114.1	42.4
	Mica	40	22.0	09	238.7	6.7
	Glass	40	12.2	19	65.1	20.9

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ADVANCED WOOD-FIBER COMPOSITES

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Research Scientist
Forintek Canada Corp.
Eastern Laboratory

INTRODUCTION

An advanced wood-fiber composite is a wood-fiber-based composite, containing two or more materials in addition to wood fibers. It is developed to improve mechanical and physical properties such as stiffness, strength, toughness and dimensional stability as well as to expand applications of wood-fiber products. The properties of advanced wood-fiber composites can be easily tailored to exceed those of conventional wood-fiber composites or in some cases the properties are simply unobtainable conventionally. The mechanical and physical properties of a wood-fiber composite are governed by the properties and amount of wood fibers, resins and reinforcements. The application of wood-fiber composites can be dramatically expanded if they can be molded into various profiles and shapes. The moldability of wood fibers can be greatly improved by using molding resins and by adding synthetic fibers.

We have already witnessed shifts in demand for traditional materials as innovative producers introduce novel substitutes to reduce the cost without impairing the performance of their products. For example, waferboard is substituting plywood and laminated veneer lumber is replacing high grade lumber in the housing industry. A variety of plastics are displacing wood in housing and steel in automobiles and commuter aircrafts. Alternatively, wood fibers have regained some market share for body panels in automobiles.

Since wood fibers are much less expensive than plastics, metals and alloys and have some distinctive characteristics such as thermal stability, non-toxicity, and a non-rusting nature, a wide range of high performance wood-fiber-based materials can be produced economically to compete with traditional materials in many applications. The introduction of advanced wood-fiber composites could be the most revolutionary development in the history of the wood industry. It could stop or reverse the loss of wood markets to plastics and steel in housing, recreational materials, automobiles and even aircrafts. Our ability to develop and compete industrially will determine the size of the opportunity.

RESINS

Despite many new thermosetting and thermoplastic materials being introduced over the past few decades, the use of phenolic resins continues to grow. No other type of resin can offer as wide a range of properties as phenolic resins. They have been widely used in wood industry and proved to be excellent binders for wood-based materials. Also, being relatively inexpensive, phenolic resins are the most promising resin candidates for advanced wood-fiber composites. However, if glass fibers are used as reinforcement, epoxy modified phenolic resins should be selected to improve the adhesion with glass fibers.

Since most advanced wood fiber composites would be molded into special shapes, molding phenolic resins should be used to facilitate molding. Like all thermosets, phenolic resins have the following disadvantages:

- long manufacturing cycles
- cannot be recycled
- low degree of toughness.

To avoid these disadvantages, thermoplastic resins can be employed but the cost of improved performance is normally much higher than for phenolic resins. Lower priced thermoplastic resins usually do not perform as well as phenolic resin. Therefore, the relative merit of phenolic resins and other resins should warrant careful consideration.

REINFORCEMENTS

Reinforcements provide certain mechanical properties to the composites which are not easy to achieve from wood fibers alone. The most widely used reinforcements in advanced composites are:

- glass fibers
- aromatic polyamide fibers containing para-oriented linkages (Kevlar)
- graphite
- boron.

They are available in a variety of forms:

- continuous strands and roving
- chopped fibers
- woven fabrics
- non-woven mats or scrims.

Reinforcements can be impregnated with a partially cured resin or thermoplastic resin to improve their mechanical, chemical and physical properties, (commonly called 'prepregs'). Prepregs are widely used in manufacturing of high-performance components. In addition, reinforcements are often sized with a coupling agent. Coupling agents are ingredients that are designed with molecular end groups suitable for bonding to inorganic reinforcements on one end and the organic material on the other end.

DRAWABLE FIBERS

From the technical viewpoint of molding, the main drawback of wood fibers is a lack of fluidity. This fact makes it as difficult to

mold sharp (low draft angle) and deep profiles. To overcome this, textile staple fibers can be blended with wood fibers, resin or reinforcement and formed into a strong drawable mat. Various textile fibers can be used to improve drawability. Included are:

- polyester
- nylon
- orlon
- polypropylene.

Of course, many other types of synthetic fibers can be considered if available in a suitable form and at a reasonable price.

MOLDING

Since wood fibers are much lower in density as compared with other materials such as resins and inorganic fillers or reinforcements and since the volume ratio of resin to wood fibers used is normally kept very low for the sake of economics, the molding mixture has very low fluidity even at elevated temperatures. As a result, compression molding is probably the best method for molding wood fiber products. A full understanding of the method, requires an appreciation of many factors such as resin behaviour, ratio of resin to wood fibers, molding machine, molds and the parameters affecting the polymerization of resin.

In its simplest form, compression molding is carried out in the following manner:

- A quantity of thermosetting mixture is placed in the bottom half of an open heated mold which is mounted in a press.

- The press is then closed, bringing the bottom half of the mold against the top half under pressure. As the hot mold halves come together under pressure, the resin begins to soften facilitating the molding of the composite.

ELEMENTS OF THE PROCESS

The compression molding process is made up of five major elements: (1) part design; (2) material selection; (3) mold design and construction; (4) molding machine and (5) operator. The process must take into account the requirements of the final products and the behaviour of molding compounds during the pressing stage.

PROCESSING VARIABLES

A number of variables, many of them interdependent, play significant roles in the compression molding process.

A) Molding Mixtures: Molding mixtures by themselves bring to mind a lot of variables such as the formulation of the resin, characteristics of each component of the molding materials used, ratios and compositions of molding materials.

From a process viewpoint, the viscosity-time curve of any thermosetting compound is very critical. Most molding resins are powdered or granular at room temperature. When exposed to heat, the powders or granules melt and become fluid. Under continued heating, crosslinking occurs and the material eventually solidifies. As the resin goes from solid to fluid to solid, the viscosity changes are related directly to the temperature. Ideally, the shape and final dimensions of the products should be formed during the state of optimum low viscosity to ensure that continuous pressing will not cause the induction of unnecessary stresses.

B) Temperature and Time: Most thermosetting resins will crosslink over a wide range of temperature and time. The majority of thermosetting resins must be heated to approximately 300°F for optimum cure. But it is not necessary to have a complete cure during molding because further crosslinking by residual heat can occur after removing from the molds. The cure time required depends on the molding temperature, product thickness, resin characteristics, moisture content of molding materials, etc. If the temperature is too high, precure may occur and the resin may not have a sufficiently long period of low viscosity for satisfactory molding. If the temperature is too low, a long cure time is required and thus productivity will be reduced.

C) Breathing and Dwell: Some thermosetting molding resins such as phenolic resins give off gaseous products as part of the condensation polymerization, coupled with the moisture in the wood fibers or additives produces an internal gas pressure at the elevated temperature of the molding cycle. Under high pressure, these gases can be contained in the molded parts until curing is fairly complete; the molded products then may be removed from the mold without damage if the density is not too high. However, if the molding cycle is short and the density of the molded product is high, delaminations, blisters or rupture will occur when the press is opened. To avoid the damage caused by excessive gas pressure, the mold can be opened at some preset times during the press cycle to allow 'breathing' or 'degassing' to occur. The length of time that the mold remains slightly open for degassing is called the 'dwell' and depends on the size and configuration of the molded object. This

step also reduces the cure time because even the undercured resin can withstand lower internal gas pressures.

D) Pressure: The molding materials with wood fibers are normally low in density before molding. In order to develop adequate strength properties, pressure is required to compress and consolidate the material. The pressure used should be high enough to consolidate molding materials during the period of low viscosity of resin.

PROPERTIES

Table 1 shows dramatic changes in mechanical and physical properties when wood and spinner glass are blended and bonded with phenolic resin. It appears that wood fibers have strengthened spinner glass and spinner glass has enhanced the dimensional stability of wood fiber composites even at a relatively low resin content.

In addition to the excellent mechanical and physical properties of advanced wood-fiber composites, the materials can be blended together and formed into strong mats which then can be easily molded into various shapes.

COST ESTIMATE OF MATERIALS

The driving forces for developing advanced wood-fiber composites are competition and economics. The greatest advantage for using wood fibers is that wood fibers are very inexpensive and are from renewable sources. The costs of various materials are estimated and summarized in Table 2.

APPLICATIONS

Since the technology is not fully developed and the products are not well-publicized, applications are very limited at present. However, the potential applications could be immense as the users become more aware of the products and the potential savings on material costs. Some specific applications for the advanced wood-fiber composites are described briefly in this report.

AUTOMOBILES

The replacement of plastics and steel in automobile bodies could offer one of the largest opportunities for the application of

advanced wood-fiber composites. The potential opportunity is quite large because today automobile manufacturers are becoming more conscious of competition and economics than ever. Automakers are under severe pressure to reduce costs in order to compete with imported cars.

At one time, automobile manufacturers seemed to be convinced of the idea of using plastics to replace steel. However, the high cost of plastic materials is a major obstacle for this objective. Advanced wood-fiber composites are less espensive than plastics and in many cases, they could have equal to or higher performance than the plastics. Therefore, the automakers may accept the idea of replacing some plastics and steel in the automobile bodies in the near future as the technology of advanced wood-fiber composite progresses.

COMMERCIAL TRANSPORT AIRCRAFT

All the major manufacturers of commercial transport aircraft are incorporating large numbers of composite parts. Some parts such as interior panels and cargo liners, closets and partitions could be made from advanced wood-fiber composites.

PALLETS

A standard for 'Small Parts Containers' has been accepted by the North American automobile industry. It specifies plastic tote boxes to be used in shipping small parts. This virtually eliminates wooden and corregated containers in the auto industry end use. In order to retain tote boxes safely, the pallets used for their transportation require deck surface features that can interlock and be compatible with the tops and bottoms of the tote boxes. As a result, wood pallets have been replaced by molded plastic pallets for transporting small parts in the automobile industry. Of course there are some drawbacks to the use of plastic pallets, such as high costs and brittleness in cold weather. Molded advanced wood-fiber pallets could compete with high quality plastic pallets in terms of price and performance.

EXTERIOR AND FIRE-RESISTANT DOOR SKINS

Molded wood-fiber door skins have been produced and widely used for interior doors. However, no exterior applications of the wood-fiber door skins have reached commericalization at present because the conventional wood-fiber products are lacking dimensional stability and durability. Exterior and fire resistant door skins

could become a value-added product for advanced wood-fiber composites.

In the long term prospective, as advanced wood-fiber composite technology reaches a more mature state, users' interest will likely increase and more application developments will occur.

CONCLUSIONS

Advanced wood-fiber composites with excellent mechanical and physical properties can be produced from various combinations of wood fibers, resin, textile fibers and glass fibers or other reinforcements. This new technology offers potential opportunities to the wood industry in terms of growth and diversification and provides a key to the development of new industries.

However, the development of this new technology is still in an early stage. Concerted efforts are required to develop better processes and products. At present, there is only a limited amount of research and development on advanced wood-fiber composites. Our ability to recognize the opportunities will determine the future development of advanced wood-fiber composites in Canada.

Table 1. Mechanical and Physical Properties of Advanced Wood Fiber Composites

Products	Compositions of Composite, Parts by Weight						Properties							
	Wood Fiber	Spinner Glass	Resin		Poly-ester	Nylon	Specific Gravity	Bending		Tension		2 Hour Boil		
			Phenolic	Epoxy				MOR 10^3psi	MOE 10^6psi	MOR 10^3psi	MOE 10^6psi	Bending MOR 10^3psi	TS[a] %	LE[b] %
A	41	41	10	0	8	0	1.49	20	1.61	12	1.71	14	4.5	0.11
B	36	36	21	0	7	0	1.47	19	1.54	12	1.64	14	0.7	0.14
C	0	50	40	13	10	0	1.56	9	1.54	11	1.90	8	0	0.10
D	0	56	33	13	10	0	1.61	9	1.61	9	1.70	5	2.2	0.14
E	75	0	30	0	0	15	1.16	15	0.94	-	-	-	2.3	-
F	75	0	30	0	0	15	0.88	9	0.53	-	-	-	11.5	-
G	75	0	30	0	0	15	0.78	6	0.37	-	-	-	10.9	-

[a] Thickness swelling.

[b] Linear expansion.

Source: The data of Products A, B, C and D were supplied by Mr. Hunter W. Brooks - President of Brooks Associates Ltd., Michigan, U.S.A.

TABLE 2: Estimated cost of various materials.

MATERIALS	COST, $/lb.
Wood Fibers	0.16
Spinner Glass	0.47
Textile Staple Fibers	0.80
Phenolic Resin	0.70 - 1.20
Steel	1.50
E-glass	1.50
S-glass	7.00
Kevlar	20.00

RESEARCH AND DEVELOPMENT AT THE ALBERTA RESEARCH COUNCIL

Dr. L. Bach, Ph.D., P.Eng.
Alberta Research Council

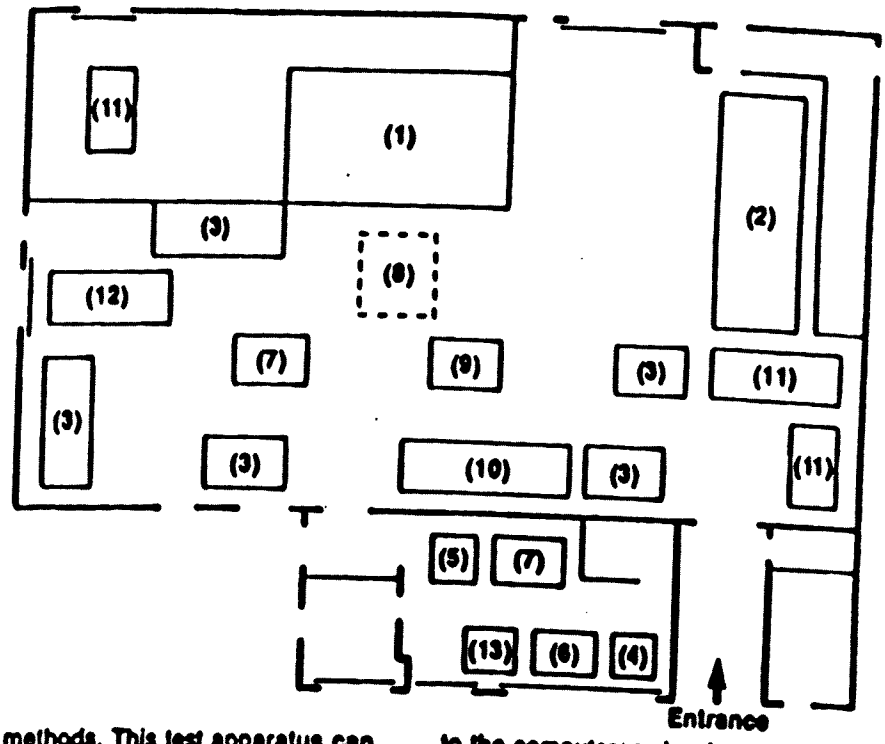
TESTING LABORATORY

Forest Products Program

Guide to the

Testing Laboratory

Product evaluations are conducted for industrial clients and for the Forest Products Research Program. The laboratory has been certified by the Standards Council of Canada and Canada Mortgage and Housing Corporation.



Sample Preparation and Conditioning

Sample Preparation (1)

- Samples are cut, identified, weighed, measured and all data recorded.

Sample Conditioning

- The samples are stored in conditioning rooms under controlled temperature and humidity conditions to stabilize moisture content. (2) This is very important as the strength of wood depends on its moisture content.
- Boil tanks, vacuum and pressure vessel, steam tank, ovens, cooling baths and conditioning (soak) tank. (3) These provide various combinations of temperature and humidity that, when applied in cycles, simulate actual exposure to the weather. The ovens are also used to dry the samples which aids in determining moisture content.

Small Sample Testing

Instron Universal Testing Machine (4)

- Samples are subjected to bending or tension forces to calculate Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) or Internal Bond.

Globe Shear Tester (5)

- Samples are subjected to shear forces to determine internal shear stresses at the failure load.

Vibration Testing (6)

- Samples are subjected to a vibrating force and their resonance is measured. The samples' stiffness and MOE are then calculated.

Linear Expansion (7)

- Samples that have been subjected to varying temperature and humidity conditions can be checked for dimensional stability (swelling).

Creep Tests (8)

- Samples are loaded continuously for long periods of time. Deflection is measured as a function of time.

Large Sample Testing

Machine Stress Rating (MSR) (9)

- A method that determines a panel's stiffness by nondestructive methods. This test apparatus can be installed in-line in a manufacturing plant to grade all panels in terms of strength and stiffness.

Post Flexure Machine (10)

- Full-size panels are subjected to a pure moment to calculate MOE and MOR. The testing conforms to ASTM D3043.

A.P.A. Test Floor (11)

- These two setups conform to A.P.A. standards. The test floors simulate both static and impact concentrated loads on an actual floor or roof panel component.

Stressed Skin Tester (12)

- A test apparatus which subjects the stressed skin panel to either a uniformly distributed load or a series of point loads. The MOR and MOE of the panel are calculated from the data collected.

Data Processing and Management

Recording Data (13)

- Personal computers are used to record data, reducing human error. However, before the output from the electronic measuring device is sent to the computer, a visual verification is made by a technologist.

Reporting Data

- A spread sheet program calculates all necessary sample properties from the input data and produces a table suitable for inserting into a formal report.

For further information

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ALBERTA RESEARCH COUNCIL

PANEL DEVELOPMENT LABORATORY

Forest Products Program

Guide to the

Panel Development Laboratory

This laboratory is equipped with four panel presses for the research and development (R&D) of panel products. These facilities are available for use by and for industrial clients as well as in-house R&D.

The laboratory presses and auxiliary equipment are capable of processing chips, wafers, strands and fibrous wood materials from the reduced form (chips, fibres, etc.) to the finished panel. Testing of the product according to various specifications such as ASTM or CSA can then be carried out in-house by the Testing Laboratory.

Chip or Fibre Preparation

Drying and preparation

- A large walk-in (electrically heated) drying oven with a six tray wheel rack is available for drying the raw materials. (1)
- Two sizes of shaker screens for grading chip or stranded wood are available. One unit is 30" x 30" while the other is a pilot size 24" x 72" unit. (2)
- Two resin blenders for adding wax and resins to the furnish are available. These units are drum type blenders which can be fitted with a hot wax spraying apparatus.
- One of the blenders is for use with a powder resin (3), while the second is a pilot-scale liquid resin blender fitted with a spinning disc liquid resin distributor. (4)

Mat Formers and Presses

The four presses in the laboratory are graded in size so that development work can be conducted from a small scale preliminary investigation to the full-size panel product level. The equipment includes:

- A 12" x 12" electrically heated hydraulic press capable of producing 100 tons of force or 1100 psi on a 12" x 12" board. The mat is either laid up by hand for this unit or it may be produced on a mat former and cut to size. (5)

Programmable controls are used in the unit for product reproducibility.

- A 28" x 52" electrically heated hydraulic press with a capacity of 500 tons force or 680 psi on a 28" x 52" pressed board. (6a)

Programmable controls for heat, pressure, displacement and time are used on this unit in order to permit reproducible cycles.

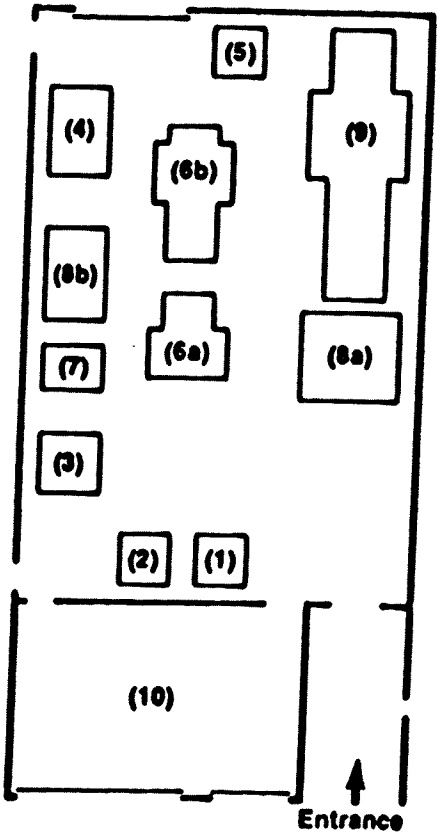
This unit includes a former with picker rolls similar to a plant unit which produces a random orientation. It also has a removable orienter which can orient the strands in a crosswise direction. Longitudinal orientation can be attained by changing the orientation of the caul plate (perpendicular to the rolls). (6b)

Variable speed drives are used on the metering belt, picker rolls, orienting heads, and caul drive.

A weigh scale is mounted on the caul drive so that continuous weight monitoring can be conducted for reproducibility.

- A 34" x 34" steam heated hydraulic press with a capacity of 380 tons or 660 psi on a 34" x 34" pressed board. This unit is fitted with platens which can be used to inject steam into the mat. The mat can be formed by hand or on the former associated with the 28" x 52" press. (7)
- A 4' x 8' (nominal) hydraulic press with a capacity of 2000 tons or 660 psi on a 58" x 104" pressed board. (8a) This unit is heated by steam produced on a 150 kW steam boiler with a capacity of 600 psi saturated steam. (8b)

The furnish may be formed in a random waferboard or an oriented strandboard with an orienter (9) similar to that used in Alberta OSB plants. All motor drives on the former and orienter are variable speed to give flexibility in selecting conditions.



A small laboratory (10) is associated with this area where small-scale testing of the products can be conducted. However, full-scale testing of the product can also be done in the testing laboratory.

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ALBERTA RESEARCH COUNCIL

CLOSING REMARKS

by

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Mr. B.W. Karaim
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and

Dr. M.M. Micko, Ph.D., P.Eng.
Moderator
University of Alberta

The speakers have provided excellent topics and the lengthy dicussion following each presentation tends to indicate that there is a keen interest in wood/plastic composites.

Mr. Tingley's process appears to have immediate application to many products produced in Alberta.

Dr. Kokta's polymer grafting and Dr. Hsu's advanced polymer techniques certainly fall in the scope of near term wood-based products development.

The description of the R&D program and facilities at the Alberta Research Council have convinced all of us that they are in a leading position, particularly in the area of panel products and evaluation.

We understand some of the speakers have arranged a number of meetings with industry, so it appears that some technology transfer is already on the way.

Again we would like to thank the speakers for their stimulating practical presentations and the audience for their constructive participation.

Our intention is to print the proceedings as soon as possible.

Thanks to all of you for this interesting workshop and have a safe journey home.

ACKNOWLEDGEMENT

Special thanks to the University of Alberta for providing the excellent facilities for this workshop.

Also, our gratitude is expressed to Ms. D. Couwenberg for her assistance in the preparation of these proceedings.