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DEVELOPMENT OF FIRE-RESISTANT WOOD STRUCTURAL PANELS

FINAL REPORT

by

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and

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TABLE OF CONTENTS

FOREWORD

This report summarizes the results of a study for the "Development of Fire-Resistant, Wood Structural Panels" aiming specifically at improving flame-spread resistance, but including preliminary work to evaluate another resin binder to provide an equal or better resistance to burn-through than was previously obtained with the Kerimid 500 resin. The work was conducted between March 23, 1976 and April 7, 1977 and was performed under National Aeronautics and Space Administration Contract No. NAS 2-9184. Mr. Paul Sawko was the NASA Technical Monitor.

The Principal Investigator for Elmendorf Research, Inc., was Mr. Thomas W. Vaughan, with Mr. Roland Etzold providing technical engineering expertise.

SUMMARY

Structural panels made with Xylok 210 resin as the binder had a burn-through resistance at least equal to the structural panels made with Kerimid 500 in the prior program under P. O. No. A-4843-B. Therefore, because of its comparative ease of handling, Xylok 210 was selected as the resin binder to provide the baseline panel for the study of a means of improving the flame-spread resistance of the structural panels.

In the investigation aimed at improving the flame-spread resistance of the baseline panel, five endothermic fillers were evaluated to include concentration, blends, and location in the oriented panel.

The final resin-filler system consisted of Xylok 210 binder with the addition of ammonium oxalate and ammonium phosphate to the strands of the surface layers, using 24% of each salt based upon the air-dry weight of the strands. This system resulted in a panel with a flame-spread code of about 60, a Class II classification. A standard phenolic based structural panel had a flame-spread greater than 200 for laboratory prepared panels. The burn-through tests at NASA-Ames indicated an average burn-through time of 588 seconds for the specimens made with the final system. This compares to an average burn-through time of 287 seconds for the standard phenolic base structural specimen. One full-size panel was made with the final system.

INTRODUCTION

A second-phase program was undertaken with the Ames Research Center of the National Aeronautics and Space Administration to improve the flame-spread resistance of wood-based structural particleboard while maintaining the increased burn-through time of 30 to 35% achieved from the previous study under NASA P. O. No. A-4843-B.

The oriented particleboard developed by ERI provides a structural panel with higher strength properties than state-of-the-art particleboard. It was the major objective of this program to upgrade the oriented structural board to include fire-resistance and low flame-spread, thereby providing a unique panel for a variety of construction efforts.

DISCUSSION - STRUCTURAL PANELS

A. Panel Preparation - Structural Panels

A review of the manufacture of flat, structural panels made with wood strands oriented into parallelism (SPB) is given in our previous report of August, 1975, which was prepared under P.O. No. A-4843-B. ERI's U. S. patents and patent application covering the products and systems of orientation are listed under References 1, 2, 3, 4 and 5.

The step-by-step general description, as given, is as follows:

Step 1 - Raw wood (round wood or residues) is flaked to desired size, about 40 mm x 40 mm x 0.4 mm (thickness).

Step 2 - Flakes are split in a hammermill to strands, size about 6 mm x 40 mm x 0.4 mm.

Step 3 - Strands are dried to 4-5% moisture content.

Step 4 - A water-based adhesive (binder) is applied to the strands.

Step 5 - Strands are air-felted and aligned as specified in each layer; layer thickness may be varied.

Step 6 - Successive layers are laid down with alignment 90° apart to form a mat; the number of layers may be varied.

Step 7 - Mat of several layers is prepressed.

Step 8 - Mat is moved to hot press and pressed into a panel to desired thickness or density, simultaneously heat-curing the adhesive.

Step 9 - Panel is moved from press to air cooler, to trimming station, where excess is removed.

Step 10 - Trimmed panel is moved to finishing station, where sanding, painting, etc. is performed.

The laboratory is mainly concerned with Steps 4 through 10. Step 4, application of the adhesive to the strands, is generally accomplished in a small laboratory blender, which consists of a slowly revolving drum and an inner rotor, with short lengths of chain revolving at a higher rpm. The blender is charged with 200 grams to 500 grams of strands, which are fluffed continuously by the inner rotor. The adhesive (binder) is sprayed onto the strands in the blender. This laboratory procedure simulates the action of the large commercial blenders in particleboard plants.

During addition of the liquid binder or chemicals to small quantities of fine wood particles for exploratory purposes, the binder is slowly dripped onto the particles in a conventional kitchen mixer while "stirring."

The liquid binders are diluted with an appropriate diluent to a spraying consistency. The water-based phenolic resin binders are reduced to 33% solids. The amount of binder and diluent for the other binders is shown in the tables listing the specimens.

B. Wood Species Evaluation

Strands cut from Douglas fir were used in the previous program under P.O. No. A-4843-B. However, because of a shortage in the laboratory of Douglas fir strands, we proposed using strands cut from Eastern white cedar.

Specimens using Eastern white cedar strands were made with different binders, duplicating specimens in the previous program. These are shown in Tables 1, 2, and 3, and the specimens made with the NASA binders, Xylok 210 and Kerimid 500, gave the same good burn-through results as did specimens having Douglas fir strands, which were previously made and tested.

Materials used in this program are shown in Appendix I, List of Materials.

C. Resin Evaluation

Simultaneously with evaluating strands cut from Eastern white cedar, a comparison was also made between specimens having different binders, namely conventional phenolic, Xylok 210, and Kerimid 500. Phenolic binders are presently used to manufacture exterior grade particleboard. Xylok 210, a condensation product of an aralkyl ether and phenol, had not previously been evaluated. Kerimid 500 is a high-temperature polyamideimide adhesive.

Specimens made with Kerimid 500 in the previous program (P.O. No. A-4843-B) resulted in an appreciable increase in burn-through resistance over specimens made with conventional phenolic resins.

Laboratory tests showed the superiority, based on strength in transverse bending, of specimens made with Xylok 210 as a binder over those made with Kerimid 500. It had been noted previously that the solvent, 1-Methyl-2-Pyrrolidinone (NMP), used with Kerimid 500 prevented proper bonding of strand to strand if not adequately removed. This appeared to be more of a problem when Kerimid 500 was used on cedar strands and appears to be the reason for the lower strength of the cedar-Kerimid 500 specimens.

Reference to specimens Nos. 63-39-D and 63-39-E, Table 3, shows that the Kerimid 500 specimen (E) has a substantially greater density than the Xylok 210 specimen (D), even though both have about the same amount of resin solids and wood and are about equal in thickness. The additional weight of the Kerimid 500 specimen is due to entrapment of the solvent (NMP).

The specimens shown in Tables 1 and 2 have a lower specific gravity than specimens previously made under P.O. No. A-4843-B. Therefore, additional specimens having the correct specific gravity were made with Xylok 210 as the binder and are shown in Table 3. It was determined from NASA T-3 Fire Tests that the burn-through resistance of the specimens made with Xylok 210 (Table 3) was somewhat better than that of specimens made with Kerimid 500, and substantially better than that of those made with a conventional phenolic binder. An additional six (6) specimens were made, identical with No. 63-39-B, and tested at NASA. These are reported in Table 4. The same good resistance to burn-through was obtained on the six specimens. In accordance with paragraph B2 of the Statement of Work, No. 2-26220, Xylok 210 was designated as the binder for the panels remaining to be made in the program.

Paragraph B3 of the Statement of Work required the preparation of 18 baseline structural panels using the selected binder system (Xylok 210). At this point, it was decided that only twelve (12) such panels be made and that the remaining six (6) panels be used for additional treatment, such as incorporation of an interlayer of an endothermic filler-Xylok 210 combination or surface coatings.

D. Endothermic Fillers

Four endothermic fillers, namely, ammonium fluoborate, ammonium oxalate, hydrated alumina and zinc borate, had been specified for study to determine their effectiveness, if any, in providing improved flame-spread resistance to baseline panels.

1. Preliminary Work

Initially, the endothermic fillers were dispersed in Xylok 210 binder at two concentrations, 5% and 20%, based on the solids content (60%) of Xylok 210. Films were prepared with the mixtures and cured at 174° C. for 75 minutes. Differential thermal analysis (DTA) tests at NASA on the mixtures indicated some potential improvement in flame-spread resistance of wood structural panels might result with the use of either zinc borate or ammonium oxalate at 20% concentration. Additional films were made with the aforesaid two salts at 30% and 40% concentrations and tested.

However, the results indicated that no appreciable improvement might be obtained over use of the 20% concentration.

The tests also indicated that ammonium oxalate was superior to zinc borate; however, since the heat adsorption occurred at a different temperature for the two fillers (salts), films were made blending the two, one film with 10% of each salt and the other with 20% of each. The DTA tests did not indicate any improvement by blending the salts.

2. Specimens

Ammonium oxalate was selected as the endothermic filler for use with Xylok 210 in order to provide improved flame-spread resistance of baseline type panels.

The recheck tests on the six specimens shown in Table 4 confirmed that baseline panels made with Xylok 210 as the binder provide good resistance to burn-through. The objective then was to determine whether the use of ammonium oxalate would improve the flame-spread resistance of baseline panels. One specimen was made with an interlayer of ammonium oxalate-Xylok 210 between one face layer and the core layer. Everything else was identical to a baseline panel. This specimen, No. 63-44-1, is shown in Table 5. No improvement over a baseline panel in either flame-spread or burn-through resistance was obtained. Two specimens were made having ammonium oxalate dispersed in the Xylok 210 binder when coating strands. One specimen, No. 63-42-B-1, had 20% ammonium oxalate on the solids content of Xylok 210, and the other, No. 63-42-A-1, had 33% ammonium oxalate. Neither specimen showed any appreciable improvement in flame-spread resistance.

It was agreed to explore the use of overlays on baseline panels, such as paper or sawdust which had been impregnated or coated with a binder, and also incorporate an additive to give flame-spread retardancy. The purpose was to determine whether concentrating a binder system of Xylok 210-ammonium oxalate on the surface would improve flame-spread resistance. Ammonium phosphate, sodium silicate, and conventional phenolic binder were also evaluated in this surface concentration phase. Initially ten (10) specimens were made, Nos. 63-49-1 to -10. These are shown in Table 6. Specimens Nos. 63-49-1 to -4 consist of previously made baseline panels from series No. 63-39-B. The specimens were overlaid with a standard kraft paper toweling in a secondary hot-pressing. The toweling had been impregnated with the additives and binders shown in Table 6. All impregnated toweling was dried before bonding to the baseline panels in a hot press. Since sodium silicate is not miscible with Xylok 210, the paper for specimen No. 63-49-4 was first impregnated with sodium silicate (N-Brand), dried, then lightly coated both sides with Xylok 210, and dried again.

Specimens Nos. 63-49-5 to -10 comprise a core of the same weight and materials as a baseline panel plus an overlay both sides of fines (sawdust-like material) from cedar. The fines are coated with a binder and additives for fire-retardancy as shown. The strands, fines layer, and paper overlay (when used) are formed into a mat and hot-pressed to consolidate in one pressing.

Ammonium oxalate, when used, is dispersed into the Xylok 210 binder before coating the fines with the binder. When sodium silicate or ammonium phosphate is used, the fines are coated separately with these, dried, then coated with the binder.

The flame-spread tests on the ten (10) specimens were conducted by NASA. Substantial flame-spread improvement was observed on specimens Nos. 63-49-7, -9, and -10;an FSC of 73, 70, and 70 was obtained, respectively, and an FSC of 200 on Specimen No. 63-49-8. The use of impregnated overlays on baseline panels, Specimen Nos. 63-49-1 to -4 provided no improvement.

Using NASA's recommendations, Specimens Nos. -7, -8, -9, and -10 were repeated, with the exception that the amount of fire-retardant additive was at least doubled. These are specimens Nos. 63-49-7-V, -8-V, -9-V, and -10-V, shown in Table 6. At the same time two specimens were made without a fines layer, but incorporating the fire-retardant additives of Specimens Nos. -9 and -10 on the surface layer of strands. These are also shown in Table 6, Specimens Nos. 63-49-9-V (A), and -10-V (A). It was reported that increasing the amount of endothermic fillers on the fines (Nos. 63-49-7-V to -10-V) resulted in some improvement in the resistance to flame-spread, and also that eliminating the fines layer and incorporating the binder-additive systems used on the fines layer of Nos. -7-V and -10-V on the face layer of strands resulted in about the same flame-spread resistance as the specimen with the fines layer. The two specimens made without the fines layer are Nos. 63-49-9-V (A) and -10-V (A).

The binder-additive system of 63-49-10-V (A) was selected as a candidate system in making a full-size panel. Therefore, seven replicates of No. 63-10-V (A) were made, Table 7, three for confirmation tests on the flame-spread resistance, and three in order to determine whether exposure to high humidity might result in loss of salt additive and, therefore, a change in flame-spread resistance. The three specimens for the environmental effect on flame-spread resistance were exposed for five weeks to a relative humidity of 95% at 38° C. (100° F.), after which the specimens were dried to equilibrium at room temperature (approximately 50% relative humidity), then tested at NASA. The flame-spread tests on the six specimens verified the previous good results and showed that the resistance to flame-spread was not affected by exposure to high humidity. The final system resulted in a panel having an average burn-through time of 588 seconds and an average flame-spread of 60, compared with 287 seconds and a flame-spread greater than 200 for laboratory-prepared panels of standard phenolic based structural board. It was then decided to make one full-size panel with the binder-additive system of specimen No. 63-49-10-V (A) as the final step in the program.

E. Full-Size Panel

Since sufficient strands cut from Eastern white cedar were available in the laboratory to make all the specimens for the program, these were used. During the latter stages of the program, consideration was being given to producing six or seven full-size panels. Cedar strands were not available for even one large panel, since considerably more strands were used in the program than anticipated. However, strands cut from Douglas fir were available to us in any amount required. Although we were confident that changing the species of wood strand from Eastern white cedar to Douglas fir would not affect the flame-spread resistance with the selected binder-additive system, a check test was made with Specimen No. 63-55-10V (A). It was the same as Specimen No. 63-49-10V (A), except that the strands were cut from Douglas fir rather than cedar. The specimen is reported in Table 8. The test at NASA showed that it had the same flame-spread rating as the 63-49-10V (A) series.

We were also asked to prepare a brief report on the technical and economic feasibility of the system developed under this contract in order to determine whether only one or more full-size panels should be made. Based on this report, shown in Appendix II, it was decided to make only one full-size panel. The report showed that at present-day prices for Xylok 210, the cost for Xylok 210 to make $100m^2$ of 12.5 mm thick structural board is about $806, whereas the cost of conventional phenolic binder is about $24 for $100m^2$ of 12.5 mm thick board. A flame-spread resistant board is made by Duraflake in Albany, Oregon, and sells for about $203 for $100m^2$, based on 12.5 mm thick particleboard. Therefore, we concluded that the use of Xylok 210 with the substantial concentration of salts (48% based on the A. D. weight of wood) and added production costs for the greatly extended time in a hot press, ventilation of fumes, and other special requirements make the system not economically feasible at this time, even though Duraflake, to our knowledge, is the only manufacturer of a flame-spread resistant particleboard in the U. S. Discussions with the personnel of Duraflake and other board manufacturers indicated that current sales volume of fire-resistant board is very small.

An estimate of the cost to make one, three, or seven full-size panels was prepared and is shown in Appendix III. A panel was made at a plant in Healdsburg, California, which has a hot press of sufficient size to make the full-size panel. The press is available on a rental basis for making experimental panels. When making the one panel, the strands were coated in 500g batches in the laboratory. The strands for the two face layers were coated first with a water solution of ammonium phosphate, applying 24% ammonium phosphate on the weight of the air-dry strands, air-drying the strands after coating, then all the strands were coated with ammonium oxalate dispersed in Xylok 210, applying 24% ammonium oxalate and 12% Xylok 210 solids on the weight of the air-dry strands. The coated strands were taken to Healdsburg. A three-layered mat, size 130 cm x 260 cm, was formed manually on a metal caul plate. The strands were oriented into parallelism; each face layer comprising 25% of the total material and the strands of the core layer oriented in a direction perpendicular to that of the surface layers. The mat was hot pressed at 170° C. at a pressure of 12.3 kg/cm^2 for 75 minutes. After 75 minutes the board was removed from the press and placed on edge to cool.

F. Miscellaneous

Potlatch Corp. is a licensee of Elmendorf Research, Inc., for the manufacture of wood structural panels. From their development program they produced full-size (1220 mm x 2440 mm), 3-layer wood structural panels (Stranwood) in their pilot plant.

For comparative purposes, these samples of Stranwood were measured for flame-spread resistance at NASA. The results were compared with specimens made in the laboratory having the same wood strands, amount of phenolic binder, and relative manufacturing conditions. The specimens tested at NASA are shown in Table 9.

Reference to Table 9 shows the following:

1. The resistance to flame-spread of the thinner panels (9.5 to 10.0 mm thickness) was less than that of thicker panels (13.0 mm thickness).

2. The flame-spread rating (FSC) of Stranwood made by Potlatch Corp. in their pilot plant is about 75. Stranwood is less resistant to flame-spread than the panel made with the final binder-additive system (Specimen No. 63=49-10-V (A) for this contract.)

3. Douglas fir plywood has a flame-spread rating (FSC) of about 72, therefore, about the same as for Stranwood.

4. The "Stranwood" type specimens made in the ERI laboratory, Nos. 63-56-1 and -2, were substantially less fire-resistant than Stranwood made in the Potlatch pilot plant.

5. The amount of phenolic binder used, 3% vs 6%, did not appreciably affect the FSC.

The considerable variation in the FSC of Stranwood made in the Potlatch pilot plant and that of the "Stranwood-type" panels made in the laboratory cannot be explained at this time. (Specimens Nos. 63-56-1 and -2, 63-57-1 and -2 vs. P-x-1, P-y-1, and 63-53-1 and -2.)

The Potlatch people have used phenolic resin binder from several manufacturers. The Potlatch people do not know the manufacturer of the resin binder used on the Stranwood panels they sent us about two years ago. It does not seem reasonable to expect a difference in flame-spread from conventional phenolic binders obtained from different manufacturers, particularly since the volume of binder used is extremely small relative to the immense volume of wood, when 6% resin solids is used based upon the air-dry weight of the wood strands.

Two specimens, Nos. 63-56-1 and -2, were made in an attempt to duplicate the relatively faster closing of the press in the Potlatch pilot plant as against the slower rate of closing of the press in our laboratory. These specimens were more flame-spread resistant than specimens pressed at a slower closing rate (No. 63-57-1). The results indicate that the manner of hot-pressing might be a factor.

The last five specimens shown in Table 9 have not been tested for flame-spread resistance. The specimens include oriented lamina made commercially by Potlatch and specimens from full-size panels made by Potlatch in their pilot plant with strands cut from wood sent from Japan and include low-density specimens Nos. 35-1256-D-1 and -D-2.

CONCLUSIONS

The conclusions reported are based on the resins and endothermic fillers recommended by NASA-Ames. The quantitative improvement, if any, on flame-spread resistance (FSC) was determined at NASA-Ames. Various preliminary tests were made in the ERI laboratory as a guide to determine miscibility of resins and fillers, and potential of techniques in handling the materials, as well as flammability of the base materials.

Based upon the laboratory work described herein, we conclude as follows:

1. Xylok 210 is superior to Kerimid 500 as a resin binder for wood structural panels. Xylok 210 provides a panel equal or better in burn-through resistance, having higher strength in transverse bending, and lower density than a panel made with Kerimid 500.
2. The use of only one of the salts used in this program, namely, ammonium fluoborate, hydrated alumina, zinc borate, ammonium phosphate, or ammonium oxalate, did not provide as good resistance to flame-spread as the dual use of the ammonium oxalate and ammonium phosphate with wood structural panels.
3. Based on laboratory-made specimens, the resistance to flame-spread was substantially improved by the use of the dual-salt system, namely, ammonium oxalate and ammonium phosphate, with Xylok 210 as the binder.
4. There is some discrepancy noted in flame-spread resistance of specimens made in the laboratory with that of similar panels (Stranwood) made in the Potlatch Corp. pilot plant. The latter

were considerably more flame-spread resistant. This difference cannot be accounted for with present knowledge of facts.

5. A review of the technical and economic feasibilities indicates that the binder-salt system developed is not economically feasible based on current requirements.

RECOMMENDATIONS

The program to provide a flame-spread resistant wood structural panel was undertaken with the assumption that the base panel, upon which improvements to increase flame-spread resistance would be evaluated, must first have a high resistance to burn-through. That assumption might not be correct.

If a high burn-through resistance is not essential to providing high resistance to flame-spread, then most likely various other binders can be used with the appropriate salts system.

In conventional wood structural systems for housing elements, the cost of the individual structural components is of paramount importance. Besides material costs, other production costs are important to the total cost of a product. These other production costs are minimal in the manufacture of commodity products, such as particleboard and plywood. The manufacture of wood structural panels using oriented strands is analogous to that of particleboard, which uses water-based binders and has short hot-press cycles in the range of 4 to 10 minutes. Therefore, in the development of fire-retardant synthetic boards, it appears imperative to use systems which can be employed with the manufacturing facilities in existing particleboard-type plants, and will provide production rates close to those existing today.

REFERENCES

Patents

1. U. S. Patent No. 2,974,697, Method and Apparatus for Making a Veneer Product.
2. U. S. Patent No. 3,164,511, Oriented Strand Board.
3. U. S.Patent No. 3,202,743, Method of Forming a Composite Panel.
4. U. S. Patent No. 3,478,861, Orienting Wood Strands.
5. U. S. Patent Application Serial No. 535,079, Apparatus and Method for Aligning Elongated Ligno-Cellulosic Elements into Parallelism.

APPENDIX I

List of Materials

1. Phenolic resin binder No. 193-32, about 50% solids, from Borden Chemical Company.

2. Wax emulsion, No. WS 178-140, 50% solids, from Borden Chemical Company.

3. Douglas fir strands from Potlatch Corp. pilot plant, 40 mm maximum length, av. 5 mm width, and 0.5 mm thickness.

4. Douglas fir strands from Potlatch Corp. pilot plant, 70 mm maximum length, av. 5 mm width, and 0.5 mm thickness.

5. Eastern white cedar strands from Canada, 40 mm maximum length, av. 5 mm width, and 0.4 mm thickness.

6. Kerimid 500, a high temperature polyamideimide adhesive from Rhodia, Paris, France.

7. Dicumyl peroxide (Dicup), catalyst for use with 6.

8. 1-methyl-2-pyrrolidinone (NMP), Eastman Kodak Company.

9. Xylok 210, a condensation product of an aralkyl ether and phenol, from CIBA-GEIGY Corporation.

10. Ammonium fluoborate and ammonium oxalate (Tech grade) from Central Scientific Co., Chicago, Illinois.

11. Zinc borate and ammonium phosphate from Chemtech Research, Inc., Hayward, California.

12. Hydrated alumina, RH-31F, from Harrison and Crossfield, Emeryville, California.

13. Sodium silicate, N-Brand, from Philadelphia Quartz.

14. Kraft paper, weight of 5.1 $kg/100m^2$, 0.115 mm thick, source unknown. Standard high-wet-strength kraft toweling paper.

APPENDIX II

Preliminary Report for NASA - April 25, 1977

During our meeting with Messrs. Riccitiello and Sawko at NASA on March 17, we were asked to prepare a preliminary report regarding the feasibility of the system developed under this Contract NAS 2-9184, which results in improved burn-through and flame-spread resistance of structural panels and to determine the extent of the market for fire-resistant structural panels.

Introduction

The manufacturing process for the Elmendorf Oriented Strand Board (OSB) is analogous to the manufacture of conventional particleboard. In the process water soluble resins are used as binders. The output of such plants is in the range of 300 to 600 tons/day. Generally, multiple-opening hot presses are used, and the total press cycle is in the range of 5 to 6 minutes for 1/2-inch (12.5 mm) thick panels. The formation of the mat is continuous at a rate of about 50 to 80 lineal feet/minute. Fire-resistant particleboards for exterior use, Class I rating, are being manufactured by at least one manufacturer. Others make an interior-grade fire-resistant board. Generally, a salt or combination of salts is combined with the water-based binder, or applied separately to the wood furnish. The press cycle is not appreciably affected.

Technical Feasibility

In the system developed to date for NASA under the above contract, Xylok 210, a solvent-based binder is used. In addition, two salts are employed. Ammonium phosphate is dissolved in water and sprayed onto the wood strands. The strands are dried, then ammonium oxalate is dispersed in the Xylok 210 binder and the dispersion sprayed onto the phosphate-coated strands. After the mat is formed, it is hot-pressed for 75 minutes at 174° C. (340° F.) to consolidate into a board.

In summary, present-day plants use a water soluble binder and have a hot-press cycle of about 5 to 6 minutes for 12.5 mm thick panels, whereas the Xylok 210 system employs a solvent-based binder and a long hot-press cycle. In our opinion, these two factors must be modified before consideration, from a technical viewpoint, would be given to the system by a manufacturer. The binder might be emulsified or a water-based binder of a similar type employed. The press cycle must be substantially reduced.

Economic Feasibility

The Koppers Company impregnates wood with inorganic chemicals for fire-retardancy. NON-COM is Koppers trademark for such treated wood for interior use. NON-COM plywood has a Class I rating. Its flamespread is about 15. For exterior use, it is called NCX (NON-COM Exterior). The fire-retardant solution is not sold as such, but Koppers sells treated panels or treats panels for manufacturers. In the latter case, the cost to unload, impregnate panels, dry the panels, and reload them onto rail cars is $247/100 M^2 ($230 per M sq. ft.) of 12.5 mm thick panels (1400 M^2 minimum).

OSB and exterior-type particleboards use about 5% to 6% solids of a phenolic binder based on the O.D. weight of the wood. The solids cost of the phenolic binder is about $0.573 per kilogram ($0.26 per pound). A 12.5 mm (1/2-inch) board @ 0.68 sp. gr. weighs about 854.4 kgs/100 M^2 (1750 lbs./M ft^2). It has 813.7 kgs. of wood and 40.7 kgs. of phenolic binder. The cost of the binder per 100 M^2 of board is about $23.32.

With Xylok 210 as the binder, 12% solids are used based on the O.D. weight of the wood. Lowest present-day price for Xylok 210 is $8.82 per kg. of solids. A 12.5 mm board @ 0.68 sp. gr. has 763 kgs. of wood and 91.4 kgs. of Xylok 210 solids per 100 M^2. Therefore, the cost of the binder is $806.00 per 100 M^2 of board. Other factors increase the cost substantially, such as that of the two salts and the lowered production rate due to the long press cycle required for this process.

The use of Xylok 210 with the substantial concentration of salts (48% based on the O.D. weight of wood) and added production costs for pressing, ventilation and other special requirements make the system economically unfeasible at this time.

Market

Duraflake in Albany, Oregon, manufactures about 175,000,000 sq. ft. of particleboard per year, 3/4-inch (19 mm) basis. According to our information, they developed a system to give them a fire-resistant particleboard, interior grade. They did extensive promotion and national advertising, but sold only 1,500,000 sq. ft. of the fire-retardant board in 1976.

The U. S. Plywood Division of Champion International manufactured a fire-resistant Novo-Ply particleboard in their Anderson, California plant. This plant burned out one year ago. Even though U. S. Plywood has several other Novo-Ply and particleboard manufacturing plants in the South, Midwest, and Eastern U. S., they have not instituted manufacture of the fire-resistant board in another plant. They contend major sales were for an interior fire-retardant board as a core board for Formica-type overlays or as a paint-grade partition.

Statistically, in 1975, only about 4,000,000 cu. ft. of wood products were treated for fire-resistance, whereas about 244,000,000 cu. ft. were treated with preservatives.

It appears that at this time the market for an exterior fire-resistant structural panel is limited. There is activity by forest products manufacturers in developing proprietary systems, but such activity appears to be geared for sales some time in the future when code authorities become more restrictive. Here again, interior use, such as prefinished plywood, is stressed.

TWV/bth

Thomas W. Vaughan

APPENDIX III

FULL-SIZE STRUCTURAL PANELS FOR NASA

Binder: **12% Xylok 210**

Surface Layers:
- 12% Xylok 210 solids on weight of strands
- 24% ammonium oxalate on weight of strands
- 24% ammonium phosphate on weight of strands

Core layer:
- 12% Xylok 210 solids on weight of strands
- 24% ammonium oxalate on weight of strands

Strands: Douglas fir from Potlatch

Material Wt.: For one 4' x 8' panel - 3/8" thick
(1.28 lb./ sq. ft. = 41 lbs./4' x 8')

52 lbs. strands
6.24 lbs. Xylok solids (@ 60% solids = 10.5 lbs. liq. Xylok 210)
6.24 lbs. Oxalate) On face strands
6.24 lbs. Phosphate)
6.24 lbs. oxalate on core strands

Operations:

1. Make Orienting fin box.
2. Air classifying strands.
3. Coating 50% of strands for face layers with phosphate, drying, then coating same strands with Xylok 210 --oxalate blend.
4. Coating remaining 50% strands for core xith Xylok 210--oxalate blend.
5. Trucking strands and equipment to Healdsburg. It is anticipated that three trips will be made delivering strands to Healdsburg to make 7 panels.
6. Make 3-layer mats and hot press to consolidate into fire-resistant structural panels.

ESTIMATED COST TO MAKE 4' X 8' FIRE-RESISTANT STRUCTURAL PANELS FOR NASA

Cost Item	1 Panel	3 Panels	7 Panels
Press Rental	\$ 300 (1 day)	\$ 600 (2 days)	\$1,200 (4 days)
Truck Rental	50	90	180
Materials			
a) Strands	40	120	120
b) Oxalate--6.25 lb/panel	125	250	560
c) Phosphate--6.25 lb/panel	65	90	100*
d) Xylok 210--10.5 lb.liq/panel	110	220	440
e) Release sheets	50	50	50
f) Fin Box	700	700	700
Labor (Coating strands)	180	250	550
Tech. Time and Additional labor	800	1,400	2,800
Travel	30	110	220
Contingency	270	320	480
TOTAL	\$2,720	\$4,200	\$7,400

* - Tech. grade.

ELMENDORF RESEARCH INC.
Palo Alto, California

March 17, 1977

TABLE 1 - FIRE-RESISTANT WOOD - BASED STRUCTURAL PANEL

Initial specimens made with Xylok 210 resin and comparison with phenolic and Kerimid 500 resins

SPEC. No.	MAT SIZE mm.	STRANDS AND BINDER FOR SINGLE LAYER, RANDOM, HOMOGENEOUS SPECIMEN	See NOTE No.	HOT PRESSING Time min.	Temp. °C.	Pressure to Stops	SPECIMEN Thickness mm	Wt. kg/m^2	Sp. Gr.	Transverse Bending Strength MOR kg/cm^2
63-36-1	165 x 337	320 g strands (1) 65 g Xylok 210 (5) 5 g isopropyl alcohol	(1) (5) (2) (3)	45 (2) (3)	165	9.5mm	0.396	--	0.58	271
63-36-2	"	" " "	(4)	30 (4)	"	"	0.388	--	0.61	410
63-36-3	337 x 337	625 g strands (1) 290 g Kerimid 500 (5) 3 g Dicup	(1) (5) (2)	90 (2)	"	"	0.398	--	0.79	84 (7)
63-36-4	165 x 337	320 g strands (1) 54 g phenolic, 193-32 (6)	(1) (6)	10	"	"	0.387	--	0.61	410
63-36-5	"	320 g strands (1) 80 g phenolic, 193-32 (5)	(1) (5)	10	"	"	0.388	--	0.63	414

NOTES:

(1) Strands cut from eastern white cedar
(2) Remained in hot press for 16 hrs. as press cooled
(3) Strands coated and hot pressed immediately
(4) Strands coated then air dried 3 days
(5) 12% resin solids on wt. of strands
(6) 8% resin solids on wt. of strands
(7) Bond of strand to strand extremely poor

RESULTS: Burn-through tests at ERI laboratory indicated that specimens made with Xylok 210 were not better in burn-through resistance than those made with phenolic resin. Kerimid 500 specimen delaminated early in test--see(7).

TABLE 2 - FIRE-RESISTANT WOOD-BASED STRUCTURAL PANEL

Comparison of Xylok 210 (12% resin solids on strands) with phenolic resin (12% and 8% resin solids on strands) as binders for eastern white cedar strands

SPEC. NO.	MAT SIZE mm	WT. OF MATERIALS (1)	See NOTE No.	HOT PRESSING Time Min.	Temp. °C.	Pressure to Stops	SPECIMEN Thickness mm.	Wt. Kg/m^2	Sp. Gr.
63-38-1	337 x 337	625 g. strands 125 g. Xylok 210 40 g. isopropyl alcohol		30	165	9.5mm stops	9.70	5.86	0.60
63-38-2	"	625 g. strands 150 g. phenolic resin 193-32 (2) 50 g. water	(2)	10	"	"	9.72	5.86	0.60
63-39A	"	625 g. strands 100 g. phenolic resin 193-32 (3) 30 g. water	(3)	10	"	"	9.80	5.71	0.58

NOTES:

(1) 3-layer specimens, each face layer has 25% of total material. All 3 layers oriented.
(2) 12% resin solids on wt. of strands.
(3) 8% resin solids on wt. of strands.

TABLE 3 - FIRE-RESISTANT WOOD-BASED STRUCTURAL PANEL

Variables: Xylok 210 binder with and without zinc borate
(eastern white cedar strands)
Xylok 210 binder plus borate vs. Kerimid 500 binder (no borate)
(Douglas fir strands)

SPEC. NO.	MAT SIZE mm	WT. OF MATERIALS (1)	See NOTE No.	HOT PRESSING Time Min.	Temp. °C	Pressure to Stops	SPECIMEN Thickness mm.	Wt. Kg/m²	Sp. Gr.
63-39-B	337 x 337	700 g. strands (2) 145 g. Xylok 210 50 g. isopropyl alcohol	(2)	75	174	9.5mm stops	9.78	6.44	0.66
63-39-C	"	700 g. strands (2) 145 g. Xylok 210 60 g. isopropyl alcohol 29 g. zinc borate	(2)	60	"	"	9.78	6.64	0.68
63-39-D	"	660 g. strands (3) 140 g. Xylok 210 55 g. isopropyl alcohol 28 g. zinc borate	(3)	75	"	"	9.85	6.59	0.67
63-39-E	"	660 g. strands (3) 304 g. Kerimid 500 3 g. Dicup 175 g. NMP	(3)	90	"	"	9.78	8.06	0.82

NOTES: (1) All specimens, 3 layers of oriented strands; each face layer has 25% of total material and 12% resin solids on wt. of strands.
(2) Eastern white cedar strands.
(3) Douglas fir strands.

TABLE 4 - FIRE-RESISTANT WOOD-BASED STRUCTURAL PANEL

Constants: Each specimen, 3 layers of oriented strands; each face layer has 25% of total material, 12% resin solids (Xylok 210) on wt. of strands; strands from eastern white cedar. Strands air dried for 48 hours after coating with Xylok 210 before forming mat and hot pressing.

SPEC. NO.	MAT SIZE mm	WT. OF MATERIALS (1)	HOT PRESSING Time Min.	Temp. °C.	Pressure to Stops	SPECIMEN DATA Thickness mm	Wt. Kg/m^2	Sp. Gr.
63-39-B-1	337x 337	700 g. strands 145 g. Xylok 210 50 g. isopropyl alcohol	75	174	9.5mm stops	9.72	6.54	0.67
63-39-B-2	"	"	"	"	"	9.72	6.62	0.68
63-39-B-3	"	"	"	"	"	9.80	6.57	0.67
63-39-B-4	"	"	"	"	"	9.70	6.50	0.67
63-39-B-5	"	"	"	"	"	9.70	6.55	0.68
63-39-B-6	"	"	"	"	"	9.72	6.47	0.67

TABLE 5 - FIRE-RESISTANT WOOD-BASED STRUCTURAL PANEL

Constants: Each specimen, 3 layers of oriented strands; each face layer has 25% of total material, 12% resin solids (Xylok 210) on wt. of strands; strands from eastern white cedar. Strands air dried for 48 hours after coating with Xylok 210 before forming mat and hot pressing.

Variables: Endothermic filler dispersed in the Xylok 210 binder vs. an interlayer of endothermic filler. For general comparison, Kerimid 500 as the binder on eastern white cedar strands

SPEC. NO.	MAT SIZE	WT. OF MATERIALS (1)				HOT PRESSING			SPECIMEN DATA		
		Strands	Xylok 210	Ammonium Oxalate	Isopropyl alcohol	Time	Temp.	Pressure to stops	Thickness	Wt.	Sp. Gr.
	mm.	g.	g.	g.	g.	Min.	°C.		mm	Kg/m^2	
63-42-A-1	337 x 337	700	145	29(1)	60	75	174	9.5mm stops	9.56	6.90	0.72
63-42-B-1	"	700	145	18(1)	60	75	174	"	9.63	6.74	0.70
63-44-1	"	700	145	-- (2)	50	75	174	"	9.63	7.18	0.74
63-43-1	"	660g. Strands 304 g. Kerimid 500 3 g. Dicup 175 g. NMP				60 (3)	174	"	9.27	7.26	0.78

(1) Ammonium oxalate dispersed into Xylok 210-alcohol mix before spraying onto strands.

(2) No filler in Xylok 210 binder, but an interlayer of "dry powder" between one face and core. "Dry powder" denoted 17.5 g. of ammonium oxalate dispersed in 40 g. of Xylok 210, dried, then ground into fine powder.

(3) Specimen remained in press for 16 hours more as it cooled.

TABLE 6 - FIRE-RESISTANT WOOD-BASED STRUCTURAL PANEL

Specimens made to evaluate flame-spread resistance of various surface treatments.
Nos. 1 through 4 are standard baseline specimens which are overlaid in a secondary operation.
Nos. 5 through 10 have a fines layer, additives incorporated in the fines.
Nos. 7-V through 10-V have increased amounts of additives in fines.
Nos. 7-V(A) through 10-V(A) are made without fines layers and have additive incorporated on strands of one surface layer.
Size of mat: 337 mm x 337 mm

SPEC. NO.	3 LAYERS OF STRANDS		2 LAYERS OF FINES					Impregnant for paper Overlay	SPECIMEN		
	Wt. of Strands g.	Binder Type & Wt. of Solids g.	Wt. g.	Binder Type & Wt. of Solids g.	Ammonium Oxalate g.	Sodium Silicate g.	Ammonium Phosphate g.		Thickness mm	Wt. Kg/m^2	Sp. Gr.
63-49-1)	Baseline Spec.		None	--	--	--	--	Phen.Resin	9.83	7.02	0.71
63-49-2)	Series #63-39-B		None	--	--	--	--	Xylok 210	9.53	7.07	0.74
63-49-3)	(1) Xylok 210 binder		None	--	--	--	--	" & Amm.Ox.	9.47	6.95	0.73
63-49-4)	12% solids on wt. of strands (0.68 sp. gr. mm thick)		None	--	--	--	--	Sodium Silicate (Xylok 210 Adhesive)	9.58	6.99	0.73
63-49-5	700	(1)145 g. Xylok 210 50 g. Isopropyl alcohol	250	Phenolic 200 g	(40% phenolic solids on wt. of fines)			Phenolic Resin	11.43	9.67	0.84
63-49-6	700	"	250	(1) Xylok 210 50 g. 75 g. Isopropyl Alcohol	(1) 30	--	--	Ammonium Oxalate plus Xylok 210 coating 2 sides	11.48	9.60	0.83
63-49-7	700	168 g. phen olic (1)	250	60 g. Phenolic (1)	--	88 (2)	--	No Overlay	12.45	10.80	0.86
63-49-8	700	Same as Nos.5 & 6	250	(1) 50 g Xylok 210 16g Isopropyl Alcohol	--	88 (2)	--	No Overlay	11.73	10.02	0.85

Please see Page 3 for NOTES

TABLE 6 - Fire-Resistant Wood-Based Structural Panel

SPEC. NO.	3 LAYERS OF STRANDS		2 LAYERS OF FINES					Impregnant for paper Overlay	SPECIMEN		
	Wt. of Strands g.	Binder Type & Wt. of Solids g.	Wt. g.	Binder Type & Wt. of Solids g.	Ammonium Oxalate g.	Sodium Silicate g.	Ammonium Phosphate g.		Thickness mm	Wt. Kg/m^2	Sp. Gr.
63-49-9	700	Same as Nos. 5 & 6	250	(1) 50 g. Xylok 210 16 g. Isopropyl Alcohol	--	--	(1) 30	Same as No. 6	11.40	9.76	0.85
63-49-10	700	Same as Nos. 5 & 6	250	"	(1) 30	--	(1) 30	No Overlay	11.33	9.56	0.84
63-49-7-V	700	168g. phenolic (1)	250	(1) 60 g. phenolic	--	175 (3)	--	No Overlay	12.98	9.72	0.75
63-49-8-V	700	145g.Xylok 210 plus 50g.Isopropyl Alcohol	250	Same as No. 8	--	"	--	No Overlay	12.93	10.23	0.79
63-49-9-V	700	"	250	Same as No. 8	--	--	82 (3)	No Overlay	13.03	9.54	0.73
63-49-10-V	700	"	250	Same as No. 6	(4) 60	--	82 (3)	No Overlay	12.98	9.52	0.73
No fines -- strands plus additives for one face layer											
63-49-9-V (A)	525 (6)	(1) 109g Xylok 210 38 g. alcohol	175 g. strands	(1) 36 g Xylok 210 40 g. alcohol	--	--	42 (4) (7)	No Overlay	10.06	7.00	0.69
63-49-10-V(A)	525 (6)	"	"	(1) 36 g Xylok 210 75 g. alcohol	42 (4)	--	"	No Overlay	10.06	6.95	0.69

Please see Page 3 for NOTES.

NOTES:

(1) 12% solids on wt. of wood (strands or fines)

(2) 16.5% solids on wt. of fines

(3) 33% solids on wt. of fines

(4) 24% solids on wt. of fines

(5) 40% solids on wt. of fines

(6) Wt. of strands and binder for core layer (2/3 of total) and one face layer (1/3 of total)

(7) Equivalent wt. of ammonium phosphate on one face layer as on Nos. 9-V and 10-V

(8) Hot-pressing at 340° F to stops for thickness
Specimens with Xylok 210 binder hot-pressed for 75 min.
Specimens with Phenolic binder hot-pressed for 15 min.

TABLE 7 - FIRE-RESISTANT WOOD-BASED STRUCTURAL PANELS

Replicate specimens made to evaluate flame-spread resistance and environmental effect on flame-spread resistance
Replicates of specimen No. 63-49-10V(A)
Binder: Xylok 210, 12% Solids on weight of strands (3)

(1) 24% on weight of strands
(2) Ammonium oxalate dispersed in Xylok 210 in ball mill at NASA. Some MEK added there.
(3) Strands spray coated with ammonium phosphate solution, air dried, then coated with Xylok 210-ammonium oxalate dispersion.
(4) 2/3 of total material used for core layer, and remaining 1/3 for the back face layer.
(5) Specimens 1 and 2 have less total face material due to error.

SPECIMEN NO. 63-49-	2 LAYERS OF STRANDS (4) Strands Wt. g.	2 LAYERS OF STRANDS (4) Binder Wt. g.	FACE LAYER (5) Strands Wt. g.	FACE LAYER (5) Binder Wt. g.	FACE LAYER (5) Ammonium Oxalate (2) g.	FACE LAYER (5) Ammonium Phosphate (3) g.	SPECIMEN Thickness mm.	SPECIMEN Wt. Kg/m^2	SPECIMEN Sp. Gr.
10-V(A)-1	525	109g. + 50g isopropyl alcohol	145	30g + 70g alcohol	(1) 35	(1) 35	7.09	0.386	0.72
10-V(A)-2	525	" "	145	" "	(1) 35	(1) 35	7.21	0.353	0.80
10-V(A)-3	525	" "	175	36g + 75g alcohol (2)	(1) 42	(1) 42	7.56	0.387	0.78
10-V(A)-4	525	" "	175	" "	(1) 42	(1) 42	7.49	0.386	0.76
10-V(A)-5	525	" "	175	" "	(1) 42	(1) 42	7.49	0.384	0.77
10-V(A)-6	525	" "	175	" "	(1) 42	(1) 42	7.38	0.382	0.76
10-V(A)-7	525	" "	175	" "	(1) 42	(1) 42	7.52	0.385	0.77

TABLE 8 - FIRE-RESISTANT WOOD-BASED STRUCTURAL PANELS

(1) 24% on weight of strands.
(2) Ammonium oxalate dispersed in Xylok 210 in ball mill at NASA.
(3) Strands spray-coated with ammonium phosphate solution, air dried, then coated with Xylok 210-ammonium oxalate dispersion.
(4) 2/3 of total material used for core layer, remaining 1/3 for back face layer.
(5) Phenolic resin binder #193-32 from Borden Chemical Co.

Specimen No.	2 LAYERS OF STRANDS: Strands Wt. g.	2 LAYERS OF STRANDS: Binder Wt. g.	FACE LAYER: Strands Wt. g.	FACE LAYER: Binder Wt. g.	FACE LAYER: Ammonium Oxalate g.	FACE LAYER: Ammonium Phosphate g.	SPECIMEN DATA: Thickness mm.	SPECIMEN DATA: Wt. Kg/m^2	SPECIMEN DATA: Sp. Gr.
63-55-10V(A)	525 (Doug.fir) (4)	109g.Xylok 210 + 50g. alcohol	175 (Doug.Fir)	36g Xylok 210 + 75g.alcohol	42 (1) (2)	42 (1) (3)	9.80	6.95	0.71
63-54-1 and 63-54-1A	700 g. eastern white cedar strands (for each specimen) 42 g. phenolic resin binder solids (5) 1/4 of total used for each face layer 1/2 of total for core layer						10.03 10.03	6.41 6.46	0.64 0.64

All specimens 3 layers, oriented strands.

Size of mat: 337 mm x 337 mm.

TABLE 9 - FLAME-SPREAD TESTS ON VARIOUS WOOD-BASED STRUCTURAL PANELS.

SPECIMEN NO.	MAT SIZE	WEIGHT OF MATERIALS (1)	NOTES	SPECIMEN Thickness mm	SPECIMEN Weight Kg/m^2	SPECIMEN Sp. Gr.	FLAMESPREAD RATING FSC (5)
63-54-1	337 x 337	700g. strands (cedar) 42g phenolic solids (6% on strands)	*	9.98	6.41	0.64	200
63-54-1A	"	" " "	*	10.03	6.45	0.64	229
63-56-1	"	1,000g. strands (Doug. fir) 60g. phenolic solids (6%) 10g. wax solids (1% on strands)	(2) *	13.15	8.64	0.66	123
63-56-2	"	" " "	*	13.15	8.66	0.66	145
63-57-1	"	700g strands (Douglas fir) 42g. phenolic solids (6%) 7g. wax solids	(2) *	9.55	6.15	0.67	228
63-57-2	"	700g strands (Doug. fir) 21g. phenolic solids (3%) 7g. wax solids	(2) *	9.65	6.09	0.66	200
P-x-1	15.87mm (5/8")	Douglas fir plywood	(6)	15.24	7.96	0.52	72
P-y-1	11.1mm (7/16")	Douglas Fir plywood (resawn textured surface)		11.07	5.80	0.52	72
x-1		Stranwood	(3)	12.50	8.43	0.68	76
y-1		Stranwood	(3)	13.11	8.84	0.67	74
63-53-1		Stranwood	(3)	13.06	8.41	0.64	72
63-53-2		Stranwood	(3)	13.28	8.93	0.67	76
63-59-1		Potlatch 1/4" oriented lamina	(4)	13.28	9.38	0.72	
63-59-2		2 pcs. laminated for each spec. to 12.5mm thickness	(4)	12.85	8.93	0.70	
63-59-3-B-1		Stranwood	(3)	12.24	9.05	0.74	
35-1256-D-1		Stranwood	(3) (6)	12.52	6.63	0.53	
35-1256-D-2		Stranwood	(3) (6)	12.47	7.15	0.57	

TABLE 9 - FLAME-SPREAD TESTS ON VARIOUS WOOD-BASED STRUCTURAL PANELS

NOTES:

* - Specimen hot-pressed in lab for 8 minutes at 165°C. to stops.

(1) 3-layer specimens, each face layer has 25% of total material. All 3 layers oriented. (similar to Potlatch Stranwood)

(2) Douglas fir strands received from Potlatch Corp. These are the same strands used by Potlatch Corp. in the manufacture of Stranwood and oriented lamina (specimens Nos. 63-59-1 and 63-59-2).

(3) Stranwood, denotes specimens cut from full-size 3-layer oriented strand board made by Potlatch Corp. in their pilot plant with Douglas fir strands, 6% phenolic binder solids, and 1% wax solids.

(4) 6.25 mm thick oriented strand lamina manufactured commercially by Potlatch Corp., used as replacement for veneer core in plywood product named Plystran. Two, 625 mm laminae glued together to make 12.5 mm thickness. No. 63-59-1 has many wide strands on surface; No. 63-59-2 has narrow strands on surface.

(5) Flame-Spread Rating. The lower the number, the more resistant to flame-spread.

(6) Sanded surfaces.

Variables:

(a) ERI laboratory-made vs. Potlatch pilot-plant made.

(b) 3-layer Stranwood vs. oriented lamina (63-59-3-B-1 vs. 63-59-1 and -2).

(c) Cedar vs. Douglas fir strands (63-54-1 vs. 63-54-1A).

(d) 6% vs. 3% resin binder on weight of strands (63-57-1 vs. 63-57-2).

(e) Oriented Strand Boards vs. Douglas fir plywood.

(f) Low-density Stranwood vs. higher density Stranwood (63-1256-D-1 and -D-2 vs. all other Stranwood specimens).