REINFORCEMENT OF WOOD MATERIALS: A REVIEW

William M. Bulleit

Assistant Professor

Department of Civil Engineering, Michigan Technological University, Houghton, MI 49931

(Received March 1983)

ABSTRACT

Wood materials have been successfully reinforced in the laboratory but rarely reach commercial markets. Even though this situation may continue for some time, reinforced wood materials should continue to be considered. The changing forest resource guarantees the change in economics of these materials in the future. In this paper, past work in this area is reviewed and a discussion of the future of some reinforced wood products and manufacturing processes is presented.

Keywords: Wood materials, reinforcement, mechanical properties.

INTRODUCTION

Attempts to reinforce wood and wood-based materials have been successful in the laboratory. Why, then, are these materials not reaching commercial markets? The overwhelming reason is economics. Reinforced wood materials are generally expensive to fabricate, usually because the reinforcing process requires at least one additional manufacturing step.

This is not to say that reinforced wood materials are never used commercially. Plywood with steel, aluminum, or fiberglass reinforced plastic placed on its surfaces is used in the transportation and packaging industries. The surface reinforcement enhances its mechanical properties, durability, and maintainability.

The range of literature on reinforced wood, plywood, and particleboard is wide and varied. However, the majority of these materials have never been used commercially. This paper will be a review of the literature on reinforced wood materials and a discussion of the future of some of these processes and products. Polymer-impregnated wood will not be considered here. Although some might consider it a reinforced wood material, it will not be placed in that category for this paper.

METAL REINFORCEMENT

Metal-reinforced timber dates back to the 1940s (Boomsliter 1948) and some patents exist from the 1920s (Krueger 1973). The flitch-beam, where a metal plate is sandwiched between two joists so that the three act as a composite, was known in the last century. In 1954, Granholm (1954) used square rods placed in grooves that had been cut in the bottom and top surfaces of both rectangular and I-cross-section timber beams. By the early and middle 1960s, work on metal-reinforced timber was being performed in many quarters (Anon. 1964; Bohannan 1962a, b; Bond 1965, 1966; Bond and Sidwell 1965; Lantos 1964a, b; Lantos and Harvey 1964; Lantos and Wellner 1966; Mark 1961a, b, 1963; Peterson 1965; Sliker 1962).

One method of reinforcing timber is to use prestressed steel reinforcement. Horizontally laminated wood beams were prestressed by post-tensioning high strength steel strands in the tension zone of the beams (Bohannan 1962a, b). Each strand was placed in a channel. The tensioned strands were not bonded to the

Wood and Fiber Science, 16(3), 1984, pp. 391–397

wood, just anchored at each end. This method of prestressing produced an increase in ultimate flexural strength but no change in stiffness when compared to similar unreinforced beams. Another method used to prestress timber was to bond stressed steel plate to the tension side of laminated beams (Peterson 1965). This method produced significant increases in bending strength and stiffness. It also decreased the variability in the bending strength.

The more common method of reinforcing timber is to use unstressed steel or aluminum. Some early work with reinforced wood used aluminum as the reinforcing material. Sliker (1962) reinforced both horizontally and vertically laminated wood beams with aluminum sheeting placed between selected laminations. Wood-to-wood bonding was accomplished using a resorcinol resin; and wood to aluminum bonds were made with an epoxy resin. Increases in stiffness were reported, but ultimate moment capacity showed only slight increases. Generally, as the amount of reinforcing was increased, the mode of failure shifted from compression or tension to shear. Some delamination of the wood to aluminum bonds occurred due to moisture effects on the wood. Mark (1961a, b, 1963) reinforced small rectangular and trapezoidal wood beams with aluminum. Beams with a rectangular cross section were reinforced by bonding aluminum facings to the top and bottom of the beams. Failure was usually initiated by buckling of the aluminum facing in the compression zone. Beams with a trapezoidal cross section were reinforced with aluminum facings that enclosed all four sides and had an extended aluminum flange on the wider base of the trapezoid. The wide flange was placed in compression. Beam failure was generally initiated by tension failure of the aluminum facings in the tension zone. The beams were analyzed both elastically and inelastically.

Reinforcement of timber with steel rods was examined at the Timber Research and Development Association in Great Britain (Anon. 1964; Lantos 1964a, b; Lantos and Harvey 1964; Lantos and Wellner 1966). Both square and round cross-section rods were used to reinforce laminated timber. The bars were placed in grooves prior to the laminating process. Bars were located in either the tension zone or the tension and compression zones. Bond between the steel and the wood was developed in two ways. The first method was to treat the smooth steel bar with a latex base primer and then use the phenol-resorcinol formaldehyde resin used in the laminating process. The second method was to use serrated rods placed in undersized grooves. The serrations on the rods were pressed into the wood during the laminating operation and acted in combination with the resin.

Work on reinforced timber continued through the late 1960s and into the 1970s (Borgin et al. 1968; Curtis 1971; Hoyle 1975; Kao 1967; Kobetz and Krueger 1976; Krueger 1973; Krueger and Eddy, Jr. 1974; Krueger and Sandberg 1974; Lantos 1970; Lorenzen 1971). Borgin et al. (1968) used vertically oriented steel strips to reinforce horizontally laminated wood beams. The beams were reinforced by bonding steel strips into vertical grooves using an epoxy resin. Reinforcement was placed on either the compression side or both the compression and tension sides. Increases in both strength and stiffness were reported. Beams reinforced on the compression side alone failed from either wood tension failure or horizontal shear failure. Beams reinforced on both sides failed in the reinforced lamina in either tension or compression.

Another method of reinforcing wood beams is provided by the Lindal "Steelam" Beam (Hoyle 1975). This is a mechanically connected, vertically laminated, steel-reinforced beam. It consists of wood laminations held together by a pair of toothed steel plates at each interface. One plate is in the compression zone and one is in the tension zone. The mechanical connections were not loosened by repeated load cycles in the elastic range. Increases in stiffness were reported.

Krueger and his associates have examined the reinforcing of wood with a composite of epoxy resin and woven steel wire with a bronze coating (Kobetz and Krueger 1976; Krueger 1973; Krueger and Eddy, Jr. 1974; Krueger and Sandberg 1974). The beams were reinforced by removing appropriate sections in tension and replacing them with the epoxy-steel composite. The goal of this work was to determine methods and criteria for ultimate strength design of reinforced timber. Included were studies on the compression failure of wood, evaluation of the design parameters, and moment rotation characteristics of the reinforced beam.

None of the reinforced timber discussed above has been used commercially to any great extent, if at all. One form of metal-reinforced wood product that has been used, and is still being used, is plywood overlaid with metal (Anon. 1967; Mitzner et al. 1979; White 1967). The material is used in truck and trailer doors, truck bodies, railroad cars, heavy duty shelving, elevators, and instrument boxes. Plywood cores with steel or aluminum facings are the most common materials used. Particleboard and hardboard have also been used for core material (White 1967). The most common material combinations are: 1) plywood with zinc-coated steel bonded to one or both sides, 2) plywood with aluminum alloy 3003 bonded to one or both sides, and 3) type 18-8 stainless steel bonded to plywood on one side only or with zinc-coated steel on the other. The American Plywood Association has performed tests on plywood overlaid with metal (Mitzner et al. 1979). The tests included: bending strength and stiffness, abuse resistance, and bolt-bearing.

Another metal-reinforced wood product that is still used is a sandwich construction of aluminum and balsa wood (Sliker pers. comm.). The product consists of aluminum skins bonded to the end grain of the wood. This laminate was used as the outer skins of jet aircraft during and after World War II. A material of similar construction is employed today in the pallets used during military air drops (Sliker pers. comm.).

FIBERGLASS AND OTHER REINFORCEMENT

Fibers, usually in the form of fiberglass-reinforced plastic, have been used successfully to reinforce wood materials. Wangaard (1964) and Biblis (1965) both reinforced various species of wood by applying unidirectional fiberglass strands impregnated with epoxy resin to the board surfaces. Both studies were examining analysis techniques when core specific gravity varied from 0.08 to 0.92. The analysis techniques gave reasonably accurate results.

Reinforcing laminated beams with fiberglass was examined by Theakston (1965). He considered both a water base adhesive and an epoxy resin. The water base adhesive was rejected because of poor performance. The types of fiberglass mats examined were rovings, woven rovings, cloth mats, and chopped strand mats. Unidirectional nonwoven roving mats were found to be most suitable. Increases in strength and stiffness were reported when the member was wrapped in the fiberglass-epoxy composite or when the composite was placed between horizontal laminations. Placing glass-fiber or glass-fiber mat in the gluelines of laminated wood beams reduced the bending creep (Vermaas 1974).

Fiberglass-reinforced plastic was used to reinforce wood transmission poles (Mark et al. 1968; Tang and Adams 1973). The poles were wrapped with six plies of the reinforced plastic. Three of the plies had the reinforcing oriented helically and three had it oriented longitudinally. The reinforcing increased both strength and stiffness. An added benefit was a lowered incidence of woodpecker attack on the reinforced poles.

An in-depth series of tests on plywood overlaid with fiberglass-reinforced plastic were performed by the American Plywood Association (Anon. 1972; Mitzner 1973; Poplis and Mitzner 1973). Vinyl-ester resin or polyester resin was used with unidirectional glass fiber, chopped strand mat, and woven roving. The testing included bending strength and stiffness measurements, impact resistance, fastener tests, durability tests, and maintenance considerations. Strength, stiffness, and impact resistance were enhanced by all mat types. The reinforced boards were quite durable and were easily maintained and repaired. This reinforced wood material is used outside the laboratory in the transportation industry. It has had extensive use in cargo shipping containers, railroad cars, and truck vans.

Fiberglass impregnated with phenol-resorcinol formaldehyde has been used to increase the tension and bending strength of impression finger joints (Spaun 1979, 1981). The strengths were increased from 10 to 40% over unreinforced joints. The butt joints in parallel laminated wood tension members were reinforced with a graphite-epoxy composite (Larson 1981). The tensile strength of the material was increased by about 30%.

A unique attempt was made to incorporate prestressed fiberglass strands into nominal 2- × 4-inch structural members made from wood flakes (Saucier and Holman 1975). The strands were prestressed and coated with resin; and the ring-cut flakes were formed into a matrix around the strands. The prototype machine produced poor boards when urea-melamine resin was used and slightly higher quality boards when a phenolic resin was used.

Steinmetz (1977) placed glass yarn scrim on the surface of dry-formed, medium-density and high-density hardboards. The scrim was bonded to the surface using a phenolic resin. The surface reinforcement increased bending strength and stiffness by 35 and 25%, respectively. Linear expansion was significantly reduced.

A fairly extensive study was performed in Germany using solid wood, plywood, and particleboard (Boehme 1976a, b; Boehme and Schulz 1974). Fiberglass-reinforced plastic incorporating a polyester resin was bonded to the surfaces of the core material in a wet process. A considerable improvement in the strength and stiffness properties was obtained; and a significant reduction in creep was reported.

The author has worked with surface-reinforced particleboard using fiberglass-reinforced plastic (Bulleit 1980, 1981). The particleboard core was made from ring-cut flakes; and the unidirectional nonwoven roving fiberglass mat was impregnated with phenol-resorcinol formaldehyde. In bending tests of particleboard beams reinforced with one layer of the resin-impregnated glass, strands oriented longitudinally, the stiffness and ultimate moment capacity were increased substantially. Furthermore, the beams exhibited a great deal of residual strength after reaching the ultimate load. Surface-reinforced particleboard plates were tested and analyzed. The plates had either one layer of reinforcement on each surface with strands oriented in the same direction or two layers of reinforcement on each surface with strands in each layer oriented perpendicular to the other. The elastic bending behavior of the reinforced plates was adequately modeled using the theory of laminated plates.

A patent for a process for making reinforced particleboard was obtained by Flanders (1979). The board has fiberglass reinforcing just under the surfaces. Properties and applications of the reinforced board are not known.

DISCUSSION: THE FUTURE

The possibility of using reinforced wood materials on a commercial basis seems unlikely for materials such as reinforced laminated timber. Other materials, such as reinforced particleboard and plywood, seem to have a better chance for further commercial development.

Reinforced laminated timber is not a cost-effective material. Many methods have been used successfully to reinforce laminated timber, but all have proved too costly to be commercially useful. The cause of this seems to be the amount of labor involved in the fabrication in combination with the cost of the reinforcing material. Localized reinforcement of scarf joints and finger joints in laminated timber and butt joints in parallel laminated veneer appears to be a viable possibility. A few possible reinforcement materials for localized reinforcing are: fiberglass, steel fibers, carbon fibers, or aromatic polyamide fibers. This type of reinforcement could increase the member's strength and could possibly decrease the variability in strength. Only minimal work has been done in the area of localized reinforcement, and research is necessary to show if it is a useful method of reinforcing laminated wood products.

The second type of reinforced wood material that seems to hold some promise is reinforced particleboard made from low-grade particles. The problem of increased labor must still be overcome. A possible solution to this problem would be to use discontinuous fibers, which could be placed in the mat during the felting operation. If this proved feasible, it might be possible to place the discontinuous fibers in with the particles of the surface layers only, thereby obtaining a three-layer board. The board would have enhanced properties but use a minimum of reinforcement. A similar operation is commercially performed using low-quality particles in the core and higher quality flakes in the surface layers. Recently a new polyester fiber was introduced by Hercules, Inc. (Galligan 1982) which, in addition to fiberglass and other fibers, might prove useful in particleboard reinforced with discontinuous fibers.

Railroad ties using reinforced particleboard have been considered (Howe 1976); but the increased labor for fabrication of the ties is again a problem.

The final type of reinforced board is the multiple operation surface-reinforced particleboard or plywood. This material will most likely continue to be used in industrial packaging and the transportation industry. The increased use of particleboard cores would seem to be a natural extension. It would seem, also, that the use of low-quality particles in a particleboard core in conjunction with a surface reinforcement could be used in structural applications. The low-quality particles would be less expensive than high-quality flakes or veneer, and the surface reinforcement would greatly enhance the board properties. Furthermore, the surface layers could act as a moisture barrier reducing moisture effects on the core.

SUMMARY

Many of the reinforced materials discussed in this review will continue to be uneconomical, although some of the materials considered in the discussion may yet find commercial application. This will come about only when a need is seen for this type of material and an interest is taken in performing the research that is required before any such product can become commercially viable.

REFERENCES

ANONYMOUS. 1964. Gluelam timber beams stiffened with steel. Engineering (London) 198(5132): 260.

———. 1967. Composite materials: Metal-wood laminates. Mater. Design Eng. 64(5):420.

———. 1972. Plywood overlaid with fiberglass-reinforced plastic: Basic panel properties. American Plywood Association Laboratory Report 119, Part 1. APA Tacoma, WA.

BIBLIS, E. J. 1965. Analysis of wood-fiberglass composite beams within and beyond the elastic region. For. Prod. J. 15(2):81–88.

BOEHME, C. 1976a. The constructive behavior of GFK-wood sandwiches—Comparison of experimental results with various computation methods. Holz Roh- Werkst. 34(5):155–161.

———. 1976b. Improvement in creep behavior of wood-based materials by glass fiber reinforced plastic coating. Holz Roh- Werkst. 34(12):453–458.

———, AND U. SCHULZ. 1974. Load bearing behavior of a GFK sandwich. Holz Roh- Werkst. 32(7): 250–256.

BOHANNAN, B. 1962a. Prestressing wood members. For. Prod. J. 12(12):596–602.

———. 1962b. Prestressed laminated wood beams. U.S. Forest Service Research Paper FPL 8, Forest Products Laboratory, Madison, WI.

BOND, D. 1965. Reinforced plywood beams. Civil Engineering (London) 60(711):1485–1488.

———. 1966. Reinforced timber beams. Civil Engineering Public Works Review 61:1227–1229.

———, AND E. H. SIDWELL. 1965. Prestressed timber beams. Civil Engineering (London) 60(705): 547–550.

BOOMSLITER, G. P. 1948. Timber beams reinforced with spiral drive dowels. West Virginia University Bulletin, October, Morgantown, WV.

BORGIN, K. B., G. F. LOEDOLFF, AND C. R. SAUNDERS. 1968. Laminated wood beams reinforced with steel strips. ASCE J. Struct. Div. 94(ST7):1681–1705.

BULLEIT, W. M. 1980. Behavior of fiberglass reinforced particleboard beams and plates in flexure. Unpublished Ph.D. thesis, Washington State University, Pullman, WA.

———. 1981. Models for reinforced particleboard in flexure. Proceedings of the Fifteenth Washington State University International Symposium on Particleboard. Pullman, WA.

CURTIS, J. O. 1971. Steel reinforced wood beams. Paper No. 71-401. American Society of Agricultural Engineers 1971 Annual Meeting, Washington State University, Pullman, WA.

FLANDERS, R. D. 1979. Process for making a reinforced board made from lignocellulosic particles. Patent No. 4,127,636.

GALLIGAN, W. L. 1982. Pacific Northwest meeting focuses on modern technology. For. Prod. J. 32(2):5.

GRANHOLM, H. 1954. Reinforced timber. Transactions of Chalmers University of Technology, Gothenburg, Sweden.

HOWE, J. P. 1976. Look for wood in crossties. For. Prod. J. 26(1):14–16.

HOYLE, R. J., JR. 1975. Steel reinforced wood beam design. For. Prod. J. 25(4):17–23.

KAO, Y. C. 1967. The ultimate flexural, strength of post-tensioned prestressed laminated wood beams. Master's thesis, Cornell University, Ithaca, NY.

KOBETZ, R. W., AND G. P. KRUEGER. 1976. Ultimate-strength design of reinforced timber: Biaxial stress failure criteria. Wood Sci. 8(4):252–262.

KRUEGER, G. P. 1973. Ultimate-strength design of reinforced timber: State of the art, 1973. Wood Sci. 6(2):175–186.

———, AND F. M. EDDY, JR. 1974. Ultimate-strength design of reinforced timber: Moment rotation characteristics. Wood Sci. 6(4):330–344.

———, AND L. B. SANDBERG. 1974. Ultimate-strength design of reinforced timber: Evaluation of design parameters. Wood Sci. 6(4):316–330.

LANTOS, G. 1964a. Reinforced and post-tensioned glue-laminated beams under development at TRADA labs. Civil Engineering and Public Works Review, London 59(690).

———. 1964b. Test results on mild steel reinforced glulam timber beams. Civil Engineering (London), November.

———. 1970. The flexural behavior of steel reinforced laminated timber beams. Wood Sci. 2(3): 136–143.

———, AND R. HARVEY. 1964. Tests on flitch and plank beams. Timber Research and Development Association (England).

———, AND G. L. WELLNER. 1966. Steel reinforced plywood-web box beams. Timber Research and Development Association (England).

LARSON, D. S. 1981. The technical and marketing feasibility of producing synthetically reinforced parallel laminated veneer material. Master's thesis, Michigan Technological University, Houghton, MI.

LORENZEN, R. T. 1971. Ultimate flexural strength of post-tensioned prestressed laminated wood beams. Paper No. 71-403. American Society of Agricultural Engineers 1971 Annual Meeting, Washington State University, Pullman, WA.

MARK, R. 1961a. Mechanical behavior of wood-aluminum composite beams with edge facings and flanges. Yale School of Forestry.

———. 1961b. Wood-aluminum beams within and beyond the elastic range. Part I: Rectangular sections. For. Prod. J. 11(10):477–484.

———. 1963. Wood-aluminum beams within and beyond the elastic range. Part II: Trapezoidal sections. For. Prod. J. 13(11):508–516.

———, S. F. ADAMS, AND M. MAITI. 1968. Design of a composite pole laminate. For. Prod. J. 18(4): 23–28.

MITZNER, R. C. 1973. Plywood overlaid with fiberglass-reinforced plastic: Durability and maintenance. American Plywood Association Laboratory Report 119, Part 3. APA, Tacoma, WA.

———, P. W. POST, AND G. A. ZIEGLER. 1979. Plywood overlaid with metal. American Plywood Association Research Report 137. APA, Tacoma, WA.

PETERSON, J. L. 1965. Wood beams prestressed with bonded tension elements. ASCE J. Struct. Div. 91(ST1):103–119.

POPLIS, J. A., AND R. C. MITZNER. 1973. Plywood overlaid with fiberglass-reinforced plastic: Fastener tests. American Plywood Association Laboratory Report 119, Part 2. APA, Tacoma, WA.

SAUCIER, J. R., AND J. A. HOLMAN. 1975. Structural particleboard reinforced with glass fiber—Progress in its development. For. Prod. J. 25(9):69–72.

SLIKER, A. 1962. Reinforced wood laminated beams. For. Prod. J. 12(2):91–96.

SPAUN, F. D. 1979. Reinforcement of the tensile strength and bending stiffness of wood with fiberglass. Unpublished Master's thesis, Washington State University, Pullman, WA.

———. 1981. Reinforcement of wood with fiberglass. For. Prod. J. 31(4):26–33.

STEINMETZ, P. E. 1977. Resin systems and glass reinforcements to improve dry-formed hardboard. USDA Forest Service, Forest Products Laboratory Report, FPL284.

TANG, R. C., AND S. F. ADAMS. 1973. Application of reinforced plastics for laminated transmission poles. For. Prod. J. 23(10):42–46.

THEAKSTON, F. H. 1965. A feasibility study for strengthening timber beams with fiberglass. Canadian Agricultural Engineering, January.

VERMAAS, H. F. 1974. Creep in laminated wooden members. South African For. J. 89:21–25.

WANGAARD, F. F. 1964. Elastic deflection of wood-fiberglass composite beams. For. Prod. J. 14(6): 256–260.

WHITE, D. 1967. Plywood and metal are combined in stress-skin panels. Plywood and Panel, June: 34–37.