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# The Research and Development of COM-PLY Lumber

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# The Research and Development of COM-PLY Lumber

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ABSTRACT

Between 1974 and 1986, a Southeastern Station Research Work Unit developed standards for composite studs, joists, and truss lumber and manufactured and demonstrated the materials. Economic feasibility was considered in every stage of research. Further development is left to industry.

KEYWORDS: Construction lumber, composite lumber, truss lumber, joists, studs, performance standards.

The characteristics of U.S. timber supplies have changed markedly in recent decades, and further changes are coming. Within 10 years, half of our softwood timber will be coming from trees that were planted (USDA Forest Service 1982). We have roughly 470 million acres of forest land. Softwoods occupy 200 million acres and hardwoods 270 million acres (USDA Forest Service 1974b) (fig. 1). Most of the hardwoods are in the East, close to the major construction markets, but these markets are almost exclusively softwood. Almost two-thirds of the annual timber cut of 12 to 13 billion board feet (USDA Forest Service 1982) goes into the construction, remodeling and repair of buildings (fig. 2). Most of the wood that goes into construction is softwood. That means that there is a lot of pressure on the softwood timber resource. A major problem is to find some means of using more hardwoods in construction.

A second problem is utilization. We do not use our timber efficiently. When we harvest a stand of timber, we bring only about 70 percent of the wood volume to the mill (Koenigshof 1977). We leave the small, crooked, or rotten trees and trees of undesirable species in the woods.

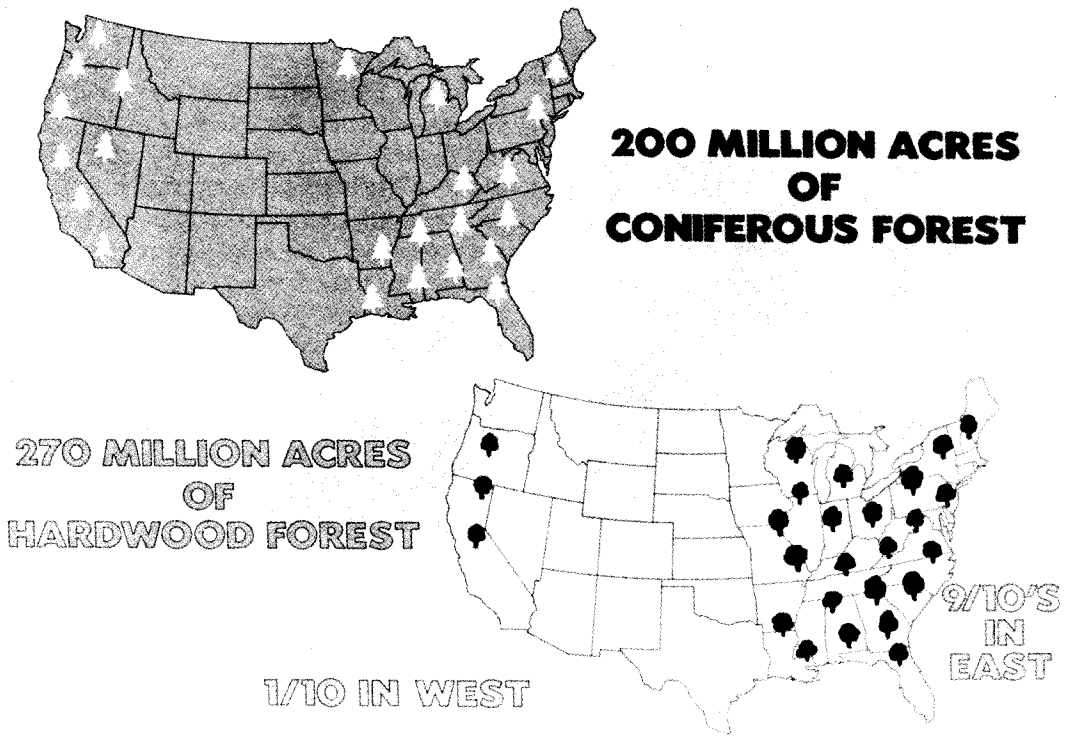


Figure 1.—Acreage of coniferous and hardwood forests in the continental United States.

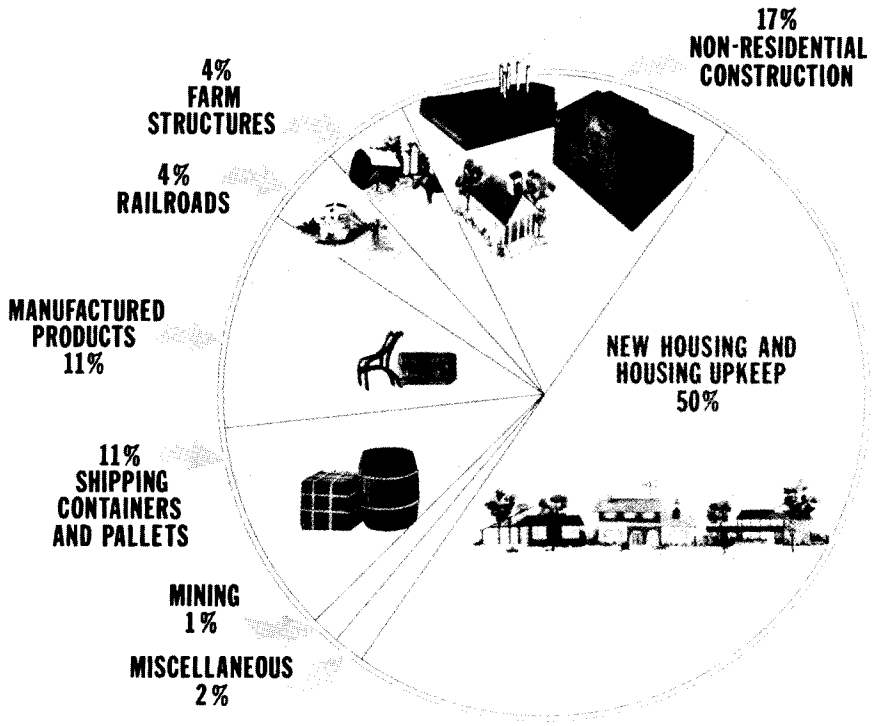


Figure 2.—How wood is consumed in the United States; 1970 data.

Of the 70 percent brought to the sawmill, only about 45 percent is recovered as lumber (Koenigshof 1977) (fig. 3). The same factor applies to plywood plants. Forty-five percent of 70 percent is a little over 30 percent. We recover a lot of the waste in secondary products and fuel, but, at best, we are using only 50 to 60 percent of stand volume.

As early as 1972 many people could see that there was likely to be a serious softwood timber supply problem in the United States by the year 2000 (USDA Forest Service 1974b). The pressure on the softwood resource would create shortages and rising prices. We needed to develop structural products that utilized more than 30 percent of the stand volume and used both hardwood and softwood timber in structural lumber and panel products.

It appeared that some type of composite product had the best chance of meeting the major goals. Most of the stress on both framing and structural panels is concentrated on the outermost fibers. It makes sense to put the strongest, stiffest wood on the outside and put the lower quality material on the inside. One solution is to glue strong stiff veneers cut from the outer portions of the best trees to a particleboard core made from ground-up particles of wood and bark from the lower quality and less desirable trees. This concept was the basis for COM-PLY (fig. 4) (Koenigshof 1977).

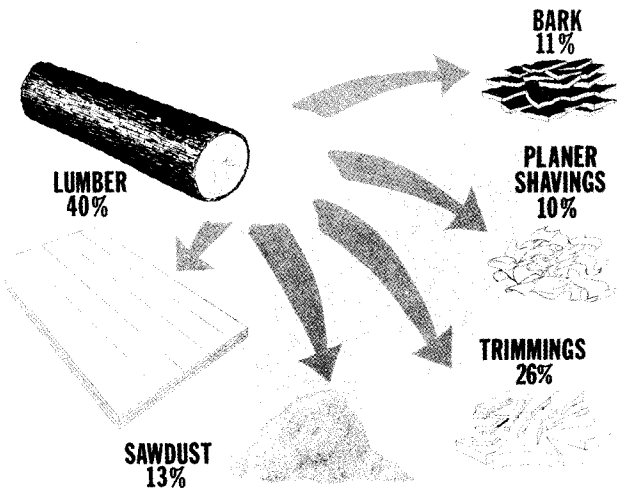


Figure 3.—Conversion of logs into sawed lumber.

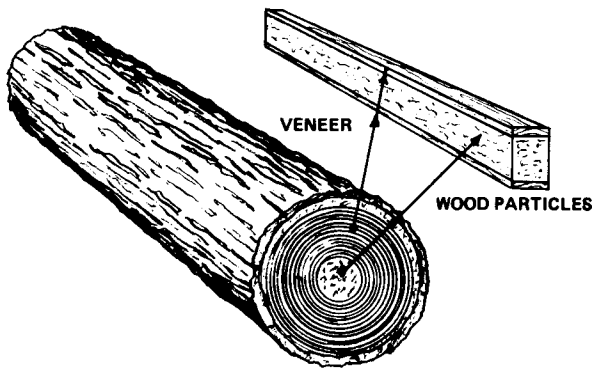


Figure 4.—The composite structural lumber concept.

Originally, we calculated that 15 percent veneer would be enough to give us the strength and stiffness that we needed for structural framing. What is more, it appeared that hardwoods would be suitable for both the veneer facings and the particleboard core.

When a log is sawed into boards, much of the strongest, stiffest, clearest, highest density wood from the outside of the tree is turned into chips, slabs, and edgings. Meanwhile, a high proportion of the wood from the center of the tree becomes lumber, even though the wood is knotty, less dense, and contains juvenile wood, which may cause warp and twist when the lumber is dried.

COM-PLY takes the strong, stiff, high-density wood from the outer portion of the tree stem and uses it where it can add maximum strength and stiffness to the composite lumber or panel. The lower quality wood from the center of the stem goes into the particleboard core, and 90 percent of the log ends up in the high-value primary product.

The concept is neat and elegant, but 15 years ago no one was sure that it would work. In 1973, the Department of Housing and Urban Development (HUD) gave a research grant to the USDA Forest Service to look into the COM-PLY concept. The work was assigned to a small Research Work Unit (RWU) of the Southeastern Forest Experiment Station located in Athens, GA. The COM-PLY work was headed initially by Richard F. Blomquist and, after Blomquist's retirement, by Gerald A. Koenigshof. The members of the research team and their areas of expertise were: Dorothy H. Costa and Priscilla L. Floyd, Project Secretaries; John E. Duff, wood/moisture relations and fire; Louis I. Gaby, preservative treatments and fastener corrosion; Nolan Malcolm, Physical Science Technician; Robert H. McAlister, mechanical properties and forest resources; Charles B. Vick, adhesives and gluing; Roy M. Walker, Physical Science Technician; Dick C. Wittenberg, fasteners and mechanical testing; and Harold F. Zornig, engineering uses.

This report describes the research team's approaches and the findings. Information is provided in three sections, The first briefly outlines the subject. The second describes research on COM-PLY studs through the pilot-plant production run and the demonstration houses that used only the 2 by 4 studs. The third describes the development of COM-PLY joists, COM-PLY truss lumber, and an improved flakeboard core.

## Outline of Progress

We started by looking at residential framing and at the least critical structural member, the stud. A lot of the structural lumber in a house frame is in studs or other 2 by 4's, and we thought we had a good chance of producing a COM-PLY stud that would perform at least as well as the studs that were being sold in the marketplace. The first question was "What should a COM-PLY stud look like?" We decided that it should be solid, 1.5 by 3.5 inches, and fully compatible with traditional construction practice for cutting and fastenings (fig. 5).

The next question was "How good does a stud have to be?" That was a bigger problem because no performance criteria existed for studs. Studs were studs. The first suggestion, by HUD, was that the COM-PLY stud had to be as good as a lodgepole pine stud. We looked at the grading rules and the

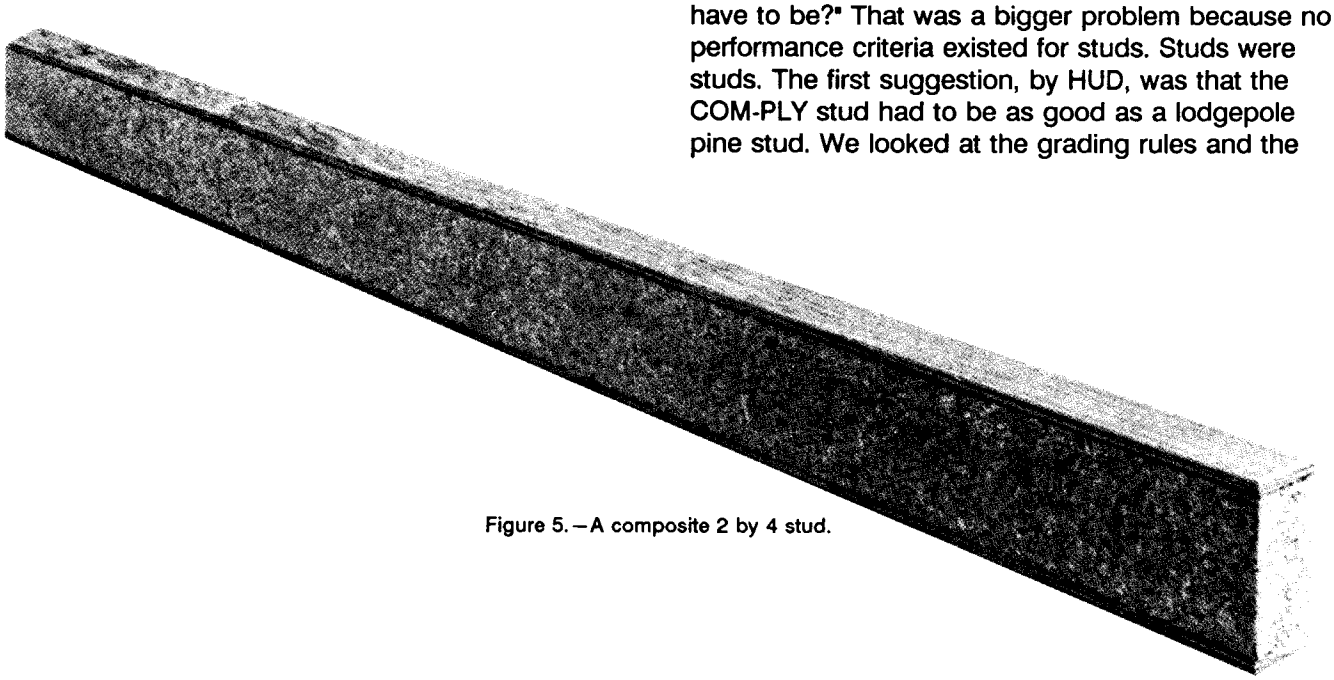

Figure 5.—A composite 2 by 4 stud.

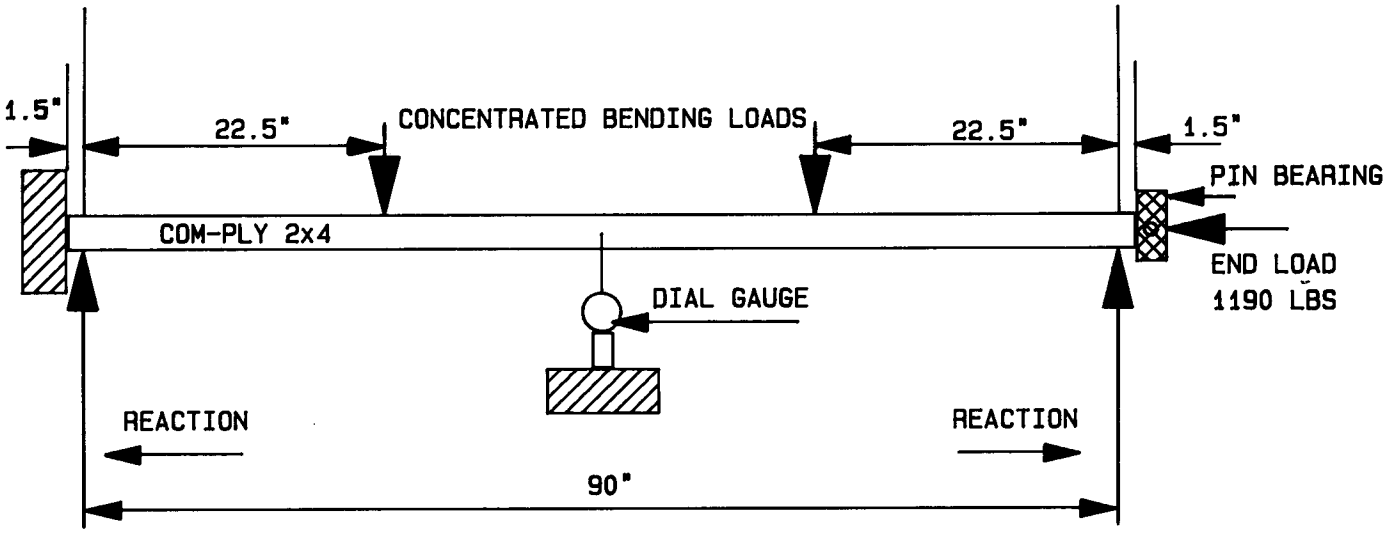


Figure 6.—Schematic of loading method for combined bending test and end-loading.

published engineering design values for lodgepole pine (WWPA 1978) and figured that we could meet the criteria with very little problem. In fact, we decided to try to do a little better, since at that time very few lodgepole pine studs were being sold. Our first job, then, was to develop the performance standards for composite studs.

The approach we used was to select a standard house, 30 feet wide and two stories high, and apply Federal Housing Authority (FHA) suggested design loads to the roof, floors, and side walls (Blomquist and others 1978). Studs were spaced 16 inches on center in the first-story walls and 24 inches on center in the second-story walls. Loads for individual studs were then determined by standard engineering procedures. It turned out that the second-story studs 24 inches on center were the most critical with an axial load of 1,190 pounds and a bending load of 40 pounds per linear foot (due to wind). These loads were used to develop strength performance criteria. Deflection criteria were developed for combined loading of 1,190 pounds axial compression and 30 pounds per linear foot bending (see fig. 6 for loading diagram). Maximum allowable deflection was 1/240 of the test span of 90 inches or 0.375 inch (Blomquist and others 1978).

In the performance standards for composite studs, we developed a formula to account for variability, repetitive member loading, a factor of safety, and the difference between the 10- to 15-minute loading of test specimens and the long-term loading of members in service. This expression became known as the HUD formula because key features of the variability adjustments were proposed by Howard C. Hilbrand, an engineer with FHA-HUD. The HUD formula is presented in figure 7.

HUD Allowable Design Load Formula

$$LOAD_{allow} = \left( \bar{X} - \frac{t_{.05}\, S}{\sqrt{N}} - t_{.05}\, S \right) \frac{F_r}{F_s\ F_s}$$

where:

$\bar{X}$ = average load

$t_{.05}$ = $t_{.05}$ for n-1 d.f.

S = standard deviation

N = number of samples

$F_r$ = repetitive member (1.15)

$F_s$ = factor of safety (1.5)

$F_t$ = time of test factor (1.18)

Figure 7.—The HUD formula for calculating allowable design loads for engineering properties of composite structural lumber.

Another criterion of performance is durability. The original thinking was that composite studs might be exposed to the weather for up to a year due to construction delays. Therefore the composite studs should retain most of their strength and stiffness after 1 year of unprotected direct exposure to the environment. One-year tests were not practical for evaluation of alternative materials, but there were no widely recognized accelerated tests to simulate 1 year of outdoor weathering. However, the ASTM D1037 6-cycle accelerated aging test (ASTM 1979) was accepted as simulating several years of outdoor weathering for particleboards. One cycle of this procedure involves soaking in 200 °F water, freezing at 10 °F, drying at 210 °F, steaming at 210 °F, and drying again at 210 °F. We decided that if the composite studs retained at least 50 percent of their strength and stiffness after the 6-cycle D1037 test, they would be sufficiently durable.

Dimensional stability was also part of the performance standard for composite studs. The consensus was that composite studs, after soaking and drying, should exhibit changes of dimension in width, thickness, length, and warp that did not exceed the comparable values for sawed studs.

If we had done nothing more than develop performance standards for studs, the research would have been worthwhile. But, we did much more. All through the process we tested components and different combinations of components to see how close we could come to meeting our own performance standards. We also analyzed softwood and hardwood timber resources to see if there was enough material, particularly high-quality veneer, to make manufacture of composite studs feasible, while utilizing all, or nearly all, of the timber in typical stands (McAlister and Clark 1983; McAlister and Taras 1978).

Two problems were evident at the start. The first problem was a suitable particleboard core. No one was producing a phenolic binder particleboard 1-1/2 inches thick, and the only phenolic particleboards that were being produced had a density of 55 to 65 pounds per cubic foot (PCF). Boards of that density split when nails are driven into the ends. We found some medium-density urea binder boards that were about right at 40 to 42 pounds PCF. It turned out that a density of 38 to 42 PCF was a practical optimum for all properties. Eventually we had some 1-1/2-inch-thick phenolic board made to order in a particleboard plant in southern Georgia. The second problem was with the percentage of veneer required in the composite stud. We had originally assumed that two plies of 1/8-inch veneer on each edge of the stud would be sufficient. In order to meet the deflection criteria of 0.375 inch deflection for a load of 40 pounds per linear foot over a span of 90 inches, we had to use at least two plies of 1/6-inch veneer on each edge. That meant that studs would be 20 percent veneer and 80 percent particleboard. The resource studies indicated that there was enough southern pine grade C and better veneer in typical stands to support the manufacture of composite studs with enough left over to utilize the tops to a 4-inch diameter.

By 1974, we had developed a composite stud that looked very promising. We were anxious to evaluate it on site in building trials. The first pilot-plant run was made to produce some 3,000 studs (Vick 1977a). This limited run and the demonstration houses built with the studs were a success. The COM-PLY studs were used and handled just like standard studs. A demonstration house was constructed at each of four locations: Columbia, MD; Aurora, IL (fig. 8); Vancouver, WA; and Augusta, GA (Koenigshof and others 1977). Builders commented favorably. They noted, however, that the COM-PLY studs were heavier (11 pounds vs. 9 pounds for spruce) and that the 8-percent phenolic binder in the particleboard dulled ordinary steel saw blades very quickly.

Figure 8.—COM-PLY studs were used in demonstration houses using standard construction practices.

Figure 9.—COM-PLY veneer-faced truss lumber and COM-PLY 2 by 6 studs and plates were used in the NAHB Research Foundation EER-II house in Damascus, MD, in 1982.

A lot more research remained to be done. We were convinced that we could develop satisfactory COM-PLY joists, and COM-PLY truss lumber seemed a good possibility. We hoped COM-PLY could be used for all the structural framing in residential construction, but these uses had not yet been studied. In addition, building code officials, engineers, and architects were asking many questions that we could not answer. They asked about fire resistance, acoustical qualities, creep under long-term loading, and probable costs in relation to sawed lumber. And we still had not looked at the potential of the hardwood resource.

These questions occupied us from 1975 through 1986, when the Composite Research RWU was terminated. We had some big milestones along the way. Our joist work was far enough along so that a demonstration house was built in Marietta, GA, in 1978 that used COM-PLY joists, COM-PLY studs, and COM-PLY panels for subfloor and roof sheathing. Performance standards were developed and used to evaluate the composite joists in that home (Duff and others 1978).

Our search for improved fire resistance in COM-PLY floor joists led to the development of a homogeneous, fully oriented strandboard that turned out to be the key for the commercial development of composite structural lumber. This development was in cooperation with Tom M. Maloney and Roy Pellerin of Washington State University (Peters 1983). The stiffness of the fully oriented strandboard was three times that of the randomly oriented flakeboards. Particle orientation increased the modulus of elasticity (MOE) of composite joists from 1.1 million pounds per square inch (PSI) to 1.6 million PSI, which is comparable to the MOE of No. 2 southern pine.

Another accomplishment was the Energy Efficient Residence II (EER-II) (fig. 9) that was designed and built by the National Association of Home Builders Research Foundation in Damascus, MD, in 1982. We fabricated composite studs, composite floor joists, composite truss lumber, and special foundation grade (FDN) 2 by 6 studs treated with chromated copper arsenate for the EER-II all-weather wood foundation. Thus, we demonstrated that composites could be used as framing anywhere in residential construction.

We found that we did not need to limit the veneer used to the higher grades. Grade D veneer of both pine and hardwoods was acceptable if certain guidelines were followed (McAlister 1983). This discovery made the full utilization of existing timber for COM-PLY a definite possibility.

We determined that hardwoods could be used in composite structural lumber almost interchangeably with southern pine. In fact, yellow-poplar and sweetgum veneers proved superior to southern pine veneers in some respects (McAlister 1979; McAlister 1982). The yield of veneer from the hardwoods is a little less than from the pine, but use of hardwood veneer makes it possible to fully utilize the timber containing mixtures of pine and hardwoods (McAlister 1980).

We showed that composite lumber made with a fully oriented strandboard core was suitable for trusses. The loading properties for truss plates in oriented flakeboard are slightly lower than those for truss plates in southern pine, but the loads are well within the useful range of design values (McAlister 1986).

The timber supply and utilization problems seen in 1972 still exist, and we are beginning to have problems with the fast-grown plantation trees (Megraw 1985). The petroleum shortages have been delayed, but they seem inevitable. The cost of phenolic resins, which are petrochemicals, is an important determinant of the cost of composite structural products. Nevertheless, composite structural materials hold much promise for the future. They could change forest management in major ways.

## Composite Studs: Concept to Reality

The research effort on composite framing materials grew out of a Housing RWU. The mission of this unit was "More effective use of wood in housing." Work on innovative framing materials was underway in 1968 when Zornig designed the FS-SE-5 house that used a spaced Gothic-arch rafter made from 1 by 2's and 2 by 4 blocks (Anderson and Zornig 1972). Vick did some exploratory work on spaced columns that combined 1 by 1's or 1 by 2's with hardboard webs.

In early 1972 the Housing RWU was looking for new areas of research. The unit had developed several designs for low-cost housing which used traditional wood-framing materials quite efficiently. The plans, which had been published by the U.S. Government Printing Office, were "best sellers." We were told to develop a new mission statement that would be more concerned with the problems associated with the use of southern woods in building construction. Gerald Koenigshof, from the Washington Office, USDA Forest Service, Division of Economics, came to Athens to discuss a concept he had developed for combining veneer with particleboard. Koenigshof's presentation was illustrated with professionally prepared drawings originally used for a TV program produced and shown in the Washington, DC, area. These illustrated the problems of a shrinking resource base, smaller trees, inefficient conversion of trees to lumber and plywood by conventional processing, and the underutilization of hardwood species in construction.

Koenigshof had presented the composite concept to Orville G. Lee and Howard C. Hildebrand of FHA-HUD. They committed $400,000 to study the concept if a satisfactory research unit was willing to undertake the work. Koenigshof had approached the Forest Products Laboratory at Madison, WI, with the proposal, but its resources were already fully committed to other high-priority research studies. The members of the Housing RWU team in Athens were convinced that the composite concept had merit and that there was a good chance of solving most of the problems within 5 years. The $400,000 from FHA-HUD would provide a large share of the operating funds needed to study the concept. Also, the unit had acquired from excess property a 120,000-pound-capacity universal test machine. This large machine made it possible to do the full-scale testing of structural members that would be required.

The final decision to begin work on the concept was made by Blomquist, the Project Leader, with the approval of the Southeastern Forest Experiment Station.

The scope of the RWU's original mission was quite limited. Our goal was to produce a vertical framing member—a stud—92-5/8 inches long that would be capable of supporting both vertical building loads and bending loads due to wind in the same manner as sawed studs made from species such as Douglas-fir, southern pine, spruce, or fir. There were no restrictions on size or shape, but the new stud was supposed to be made from wood-based materials. A stud was chosen as the framing member because it was considered to be the least critical structural member in residential construction.

Research on structural composite panels, an integral part of the total research effort, was the responsibility of the American Plywood Association. It was given a research grant from FHA-HUD funds received by the Forest Service. This research proceeded concurrently with the work on studs.

Once the decision to undertake the research had been made, the problem was analyzed and a research direction developed in a series of meetings between the Housing Research staff and Koenigshof. Personnel from FHA-HUD were also involved both in person and in telephone conferences. It was decided that the new stud would be the same size (1.5 by 3.5 inches) as existing sawed studs and that dimensional stability would have to be comparable to sawed studs, at least in the 3.5-inch dimension.

The term "COM-PLY" was not coined until a year later. Initially, we referred to the stud as "the new stud" or "the synthetic stud." These terms became a problem because we did not want to develop a bad image for the product before it had a chance to prove itself. The term "COM-PLY" was developed in a brainstorming session with all of the research staff participating. The term "COM-PLY" was later copyrighted by the American Plywood Association—with no objection from the Forest Service—since we felt that it could better regulate the use of the term.

Another decision made at this time was that the major objective would be the development of the COM-PLY stud and that results of the research would be published in some sort of manual rather than as individual reports scattered through the literature. The major effect of this approach was that studies were planned to answer specific questions related to the eventual manufacture of the product. In many studies, the number of samples and the statistical design were inadequate for publication of the results. We did make rapid progress, but there was very little optimization and some questions were bypassed once a workable solution was found.

At the start of the research we made a list of all of the problems that we recognized and the approximate order in which answers were needed. This exercise was valuable, but we were fortunate in finding as we went along that many of the anticipated problems either did not exist or had already been solved. This phenomenon is sometimes referred to as "luck."

From the start, we needed and got a team effort. We realized that all parts of the problem had to be solved at about the same time. The research assignments were very loose and were made principally on the basis of previous work in a particular area. Work on the veneer resource, the particleboard core, the fastener and end use problems, and the gluing of veneer to the particleboard core was conducted at the same time. We got together regularly to discuss the progress of the work. Everyone knew what everyone else was doing. This constant cross-fertilization of ideas and approaches to problems made the work go a lot faster. Plus, we could always count on help.

This report presents some results of the unpublished studies to prevent their loss and to show the sequence of progress. An understanding of the sequence is important because a perfectly acceptable composite stud was developed, produced in a pilot-plant operation, and extensively tested in demonstration houses with involvement of the major building codes about 2 years after the research began.

At the outset, there were no real standards for the strength and stiffness of sawed studs. Studs were being produced and sold from species as diverse as Douglas-fir with an average MOE of 1,700,000 PSI and lodgepole pine with an average MOE of 950,000 PSI. Grading rules for Stud grade 2 by 4's were quite specific on such matters as size, moisture content, warp, crook, bow and wane; there was not a word about minimum strength or stiffness.

The ultimate marketability of the COM-PLY stud was a constant concern. We knew that particleboard

had a reputation for poor durability and quality. By adopting the ASTM D-1037 6-cycle, accelerated aging test, we went out of our way to ensure that there was no question of the durability of the COM-PLY stud.

Initially, it appeared that there were five major areas of research required.

1. **The quantity and quality of veneer available from trees in typical stands.** As part of this problem, some decision needed to be made about the quality and quantity of veneer required to produce a stud with the required strength and stiffness. We wanted to be sure that the veneer and the material for particleboard were in reasonable balance so that additional residues would not be produced. This problem was assigned to McAlister.

2. **The physical characteristics of the particleboard core of the composite.** In 1972, particleboard made with phenolic binders was a rarity and no one was producing a particleboard 1-1/2 inches thick. The characteristics of the particleboard would determine the quality and thickness of the veneer required and would affect the dimensional stability of the composite stud. Dimensional stability was deemed to be critical so that sawed studs and the new studs could be used interchangeably in the same wall system. This problem was assigned to Duff.

3. **The fastening characteristics of the new studs.** We wanted the new studs to be completely compatible with nails, screws, and other devices and with traditional practices of construction. This problem was assigned to Zornig.

4. **The adhesive bond between the veneer edges and the particleboard core.** This problem was assigned to Vick.

5. **The economics of the manufacture of COM-PLY studs.** This area included resource availability, plant design and layout, cost of raw materials, labor costs, etc. This problem was assigned to Koenigshof.

Blomquist was responsible for the overall planning and direction of the research effort. Koenigshof, after his transfer from the Washington Office to Athens, was assigned as a team leader for structural considerations and testing procedures.

**Resource Studies**

Several simplifying assumptions were made at the start of these studies. We assumed that grade C and better veneer would be required for the edges of the COM-PLY studs. The maximum open defect allowed for C grade veneer is 1-1/2 inches, and any larger defect seemed excessive for 1-1/2-inch-wide structural lumber. We also assumed that three layers of veneer would be required to sufficiently randomize the defects to produce a uniform strength and stiffness of the COM-PLY studs. The first resource studies were limited to southern pine because veneer yields by grade were available by 1-inch diameter classes for loblolly and slash pines (Clark and Schroeder 1971; Phillips and others 1979; Schroeder and Clark 1970). Data had been collected on veneer yields by block and by tree. The objective of these studies had been the development of yield equations related to tree diameter and height. It was necessary to analyze the data from a different perspective to obtain the information that we needed for the composite stud work. Clark, Phillips, Taras, and Saucier from the Utilization of Southern Timber RWU in Athens, GA, were quite generous in sharing the raw data, even to the extent of giving us a complete set of data cards.

These data were combined with data from the Southeastern Station's Forest Inventory and Analysis RWU on the number of trees in each diameter class by stand type. The results showed that almost all of the C grade veneer in southern pine comes from the first three blocks in the stem. This analysis also showed that there was enough C and better grade veneer in the first three blocks of trees in average stands of southern pine to completely utilize the entire stem (to a 2-inch-diameter top) in the production of the COM-PLY studs. In fact, a small surplus was available to provide veneer edges for particleboard made from some of the trees classified as "culls" in typical stands.

The next questions were concerned with the MOE of veneer cut from southern pine trees of various diameters. MOE is a measure of stiffness of materials and permits calculation of deflection of structural members under load. We needed to know the average MOE of the veneer and also whether the MOE was normally distributed. Measuring the MOE in bending of veneer proved to be difficult. We adapted the techniques developed by Koch and Woodson (1968) to estimate the dynamic MOE of veneer by measuring the transit time of a stresswave through a veneer strip. Koch and Woodson gave us a great deal of veneer that had been stresswave tested for the lamination study and had not been used. This

pretested veneer speeded up our work considerably in preparing studs for testing. A study was designed in cooperation with the Utilization of Southern Timber RWU in Athens to collect loblolly pine veneer from a previously planned study of veneer yield by grade. Veneer was collected from each block just after roundup, in the middle of the peel, and just before the core was dropped. Over 600 veneer strips 1.5 by 100 by 0.167 inches thick were tested for dynamic MOE at the Forest Products Laboratory in Madison, WI (McAlister 1976). We found that the MOE of the loblolly pine veneer averaged about 1.8 million PSI, that the stiffest veneer came from the second block in the tree, and that the distribution appeared to be normal. Normal distribution simplified subsequent projections and analysis of the resource.

We did a short study to determine whether we needed three plies of veneer or if two plies on each edge were sufficient. We found that differences in strength and stiffness between studs made with two plies or three plies of veneer were not of practical significance. These results meant that we could use thicker veneer and fewer gluelines to produce the studs.

The effects of using lower grade veneers and of different methods for laminating plies on the strength and stiffness of the studs were studied intensively. Results indicated that at least half of the D grade veneer from loblolly pine could be used if care was taken that one of the plies was of C grade veneer. This finding meant that suitable veneer could be taken from more of the low-grade pine and hardwood trees in typical stands and that utilization of timber for COM-PLY studs could approach 100 percent of stand volume. It also became apparent that short grain in the veneer was the limiting factor in the strength of the composite. Short grain was as likely to occur in clear veneer as in veneer of the lower grades.

The effects of variations in the MOE of the particleboard core on the strength and stiffness of COM-PLY studs were also studied. The particleboard that we were using as a core material at that time had an MOE of between 250,000 and 450,000 PSI. Results indicated that variations in the MOE of the particleboard did not significantly affect the MOE of the composite. The only significant factor was variation in the MOE of the veneer component.

**Particleboard Research**

There were several immediate problems with the particleboard core. From the start, the COM-PLY studs were intended to be fully weatherproof. One of the initial requirements was that the studs retain at least 50 percent of their strength and stiffness after 1 year of outdoor exposure. We needed a particleboard with a phenolic binder. The only phenolic particleboard available was a special II-B-2 mobile-home decking 5/8 inch thick with a density of about 60 PCF. To match the thickness of sawed studs, we needed a particleboard that was 1.5 inches thick. Initial steps involved gluing together three thicknesses of 1/2-inch particleboard or using two plies of 5/8 inch and one ply of 3/8 inch in the center. The thickness swelling of the laminated particleboard was close to 30 percent. We found one company in the East that was making an extruded board 1.5 inches thick. This board disintegrated when soaked in water. We were told that a phenolic particleboard 1.5 inches thick would be impossible to produce economically because the cure time would be at least 25 minutes.

One company on the west coast was making particleboard 1.5 inches thick for door core stock using a urea binder. This material was produced in two densities, 28 PCF and 42 PCF. Tests of this material were encouraging. Thickness swell was only about 20 percent—way too much but closer to acceptable than previously tested materials. We made up several studs with this core material and even exposed some to outdoor weathering on a test fence. The COM-PLY studs made with the urea binder particleboard cores lost only about 20 percent of their initial strength and stiffness after 1 year of outdoor exposure.

We continued to negotiate with particleboard plants to produce some 1.5-inch-thick phenolic binder board. No plant was willing to guarantee the level of internal bond, MOE, modulus of rupture, or thickness swell. Blomquist finally contracted with a major particleboard producer for a one-shift production run. The plant operators would try their best to meet our specifications with the phenolic binder, but we would have to take what we got and the price was $10,000. It worked out very well in the end, but we were pretty worried. The problem was that urea binders have a lot of "tack" (stickiness) and phenolic binders have very little tack. After the mat was formed and before it went to the prepress, it had to be transferred from one conveyor belt to another. Since there was so little tack and the mat for a 1.5-inch-thick board was so thick and heavy, the mat cracked and

broke during transfer. For a couple of hours all the mats were run back into the surge bins and there were no boards going into the hot press. Eventually the percentage of phenolic resin binder was raised to 8 or 9 percent rather than the 6-percent target value. The mats held together and particleboard started coming out of the presses. The press time was rather long—20 minutes—but it was expected. We ended up with two flatbed truckloads of particleboard. Thickness swell of this board was about 10 percent; the MOE was about 450,000 PSI with an internal bond of 80 to 100 PSI. Density of the board was about 42 PCF, which turned out to be ideal. Our gamble had paid off handsomely; this core material was used in the pilot-plant production run. We knew for the first time that we were likely to be successful in producing a COM-PLY stud that would meet all of the standards that we had set. This milestone was very important.

**Compatibility With Traditional Construction**

The residential construction industry is highly traditional. New products are accepted reluctantly, especially if they require new and special techniques, tools, or fastening procedures. We wanted the COM-PLY stud to be as close to sawed studs as possible in appearance, performance, and use. The COM-PLY stud should require no special fastenings. In practice, this meant that it had to be nailable with conventional nails.

We had predicted that a major fastening problem would be splitting when nailing through the veneer edges and into the particleboard core with 6d and 8d common nails. It turned out that the most serious problem was splitting of the ends when the studs were end-nailed to the plates with 16d common or 16d sinker nails. The 60 PCF particleboard we had laminated together to make 1.5-inch-thick core material split so severely that there was no nail withdrawal resistance.

A great deal of ingenuity and effort went into developing special fastener systems to attach the studs to the plates. One method used a modified joist hanger arrangement. Another used a crimped, folded, toothed plate (like a small truss plate) that fit into a grooved plate. Later we noted that the 28-PCF-density and 42-PCF-density urea door core boards did not split when end-nailed with 16d common nails. The 28-PCF-density board had very low withdrawal resistance, but withdrawal resistance for the 42-PCF-density board was quite acceptable. Several other limited tests confirmed that particleboards in the 38 to 42-PCF-density range did not split when end-nailed and gave acceptable withdrawal values. Particleboards in this density range could also be toe-nailed into the plates with 8d common nails.

The 38 to 42-PCF-density range for the particleboard core material is a critical specification so that conventional fasteners can be used.

**Gluing Veneer to the Particleboard Core**

We anticipated trouble in laminating the veneer to the particleboard core because the two materials have completely different dimensional stability characteristics. The joint must resist the differential swelling of the veneer and particleboard and still be able to transfer horizontal shear forces from the veneer edges to the core. The cut edge of the particleboard is quite porous and not a good gluing surface. The flat grain southern pine veneer has wide bands of latewood, which is also a difficult gluing surface. It looked like an insoluble problem.

However, the first thing that we tried worked very well. We used a 100 lb/Mft$^2$ spread of a conventional phenol-resorcinol adhesive that cures at room temperature. Best results were obtained with a 5-minute open assembly time and a 15- to 20-minute closed assembly time. Applied pressure of 125 PSI and a curing temperature of 70 °F were also important. The curing time could be reduced if the bondlines were cured in a hot press at 300 °F.

The major disadvantage of the system was cost. Phenol-resorcinol adhesives are relatively expensive, compared with phenolic plywood adhesives and phenolic binders for particleboard. We used this adhesive system for the veneer to core bond throughout all subsequent research on the COM-PLY studs, including the pilot-plant run that produced over 3,200 studs (Vick 1977a).

We did experiment with an emulsified polyisocyanate adhesive designed for a very rapid curing at room temperature. This adhesive was quite effective but more expensive and more difficult to use than the phenol-resorcinol adhesive. We extensively tested melamine resins, melamine-urea resin blends, and phenolic resin molding adhesives that could be cured rapidly with radio-frequency energy. Nothing worked any better than the phenol-resorcinol adhesive that we started with. This adhesive system passed both the ASTM D-1037 6-cycle accelerated aging test and the 1 year of outdoor exposure with practically no delamination or loss of strength.

**Economics of Manufacture of COM-PLY Studs**

Research on the economics of manufacture included the development of detailed cost analyses of the production processes for several alternative methods of manufacture and plant layouts. Price trends for both raw materials and studs were studied. Detailed costs could not be estimated until the manufacturing process was known. The economic studies, therefore, lagged behind COM-PLY stud development. It appeared, however, that COM-PLY studs could be produced and sold at a profit in competition with conventional sawed studs. Since studs are one of the lowest priced commodities, it appeared desirable to be able to produce other types of structural lumber in the same plant to raise the average price of products.

**Summary of COM-PLY Stud Research**

The original mission of the research was completed in June 1975 with the construction of the third demonstration house using COM-PLY studs and COM-PLY panels. This demonstration house was built in Vancouver, WA, with the cooperation of the American Plywood Association. It was completed in time for the 1975 meeting of the Forest Products Research Society (FPRS) in Portland, OR. Our team's report on the development of the COM-PLY stud and a report of research on composite panels by the American Plywood Association were presented at the annual meeting (Blomquist and others 1975; Lyons and others 1975).

This achievement was remarkable. In less than 3 years we had taken a complex idea from concept to reality. At this point, there were no publications on the research. A great deal of what had been learned in the 3 years of concentrated effort was contained in the summary report delivered by Blomquist at the FPRS annual meeting. The format for the definitive report on COM-PLY was not determined until the following year when it was decided to publish a series of individual reports with a common format to be known as the COM-PLY series.

The decision was made at this time to extend the mission of the research to include joists and other structural members. The results of this research are detailed in the following section of the report.

## Joists

The decision to develop a COM-PLY joist was a logical outgrowth of the success of the stud program. In all development and analysis, we had considered the stud as an end-loaded and side-loaded beam rather than as a column with bending loads. Well-accepted standards for structural performance of joists existed, and we believed that we could develop COM-PLY members that met those standards. A problem analysis showed several areas that required research.

1. The MOE of a joist is critical because deflection under design load is limited to 1/240 of the span with an absolute limit of one-half inch, no matter what the span. A target MOE of 1.4 million PSI was set for COM-PLY (southern pine joists have an MOE of 1.6 million PSI) so that allowable span of COM-PLY joists would be comparable to that of sawed joists. There was a problem connected with joist length. Since studs are less than 8 feet long, they can be fabricated with full-length veneers on the edges. Joists are up to 32 feet long. This means that some method of joining sheets of veneer (scarfing or staggered butt joints) had to be developed and the effect on joist stiffness and strength determined. This area of research was assigned to McAlister.

2. Utilization of hardwoods for both veneer and particleboard components of the COM-PLY structural materials. Even in pine stands, there is a considerable volume of hardwood. The use of hardwoods was an integral part of the COM-PLY concept. There were no data on veneer yields by grade for hardwoods. Since most hardwoods other than oaks have lower MOE than southern pine, there was concern over possible performance problems of hardwood veneers in composites. This research area was assigned to McAlister.

3. Creep is the continued increase in the deflection of beams with no increase in load. This problem was potentially serious because particleboard was known to creep. Joists would be subject to long-term bending dead loads. This investigation was assigned to Wittenberg under the supervision of Koenigshof.

4. The fire resistance of joists. COM-PLY studs did not perform as well as sawed studs in fire tests. That problem is more serious in joists than in studs because the load-bearing requirements for floors are more critical than for walls. Fire performance for

walls is limited by burn-through and load carrying and has a 20-minute base for performance. Floors are required to carry full design load (live and dead) for 10 minutes. This research area was assigned to Duff. After Duff left the project in 1981, the research was carried on by Wittenberg under the supervision of Koenigshof.

5. Joists have different fastener requirements than studs. Many builders use joist hangers, others use ledger strips. Bearing, or compression resistance perpendicular to the joist, was seen to be a possible problem. This research was assigned to Wittenberg.

6. The termite and decay resistance of untreated COM-PLY joists was a matter of great concern. Preservative treatment of joists is desirable or required in some situations. Treatment of a structural member that consisted of over 50-percent particleboard was seen as a potential problem. This research was assigned to Gaby.

7. Manufacturing COM-PLY joists economically was a potential problem because joists require more veneer, probably thicker veneers and more gluelines than COM-PLY studs. A manufacturing process had to be developed to bring particleboard, veneer cutting and drying, and laminating technologies together to produce a new product. This problem area was assigned to Koenigshof.

8. The use of COM-PLY structural lumber for light-frame wood trusses. This use was conceived because of the large amount of structural lumber used annually in trusses. The general properties of COM-PLY structural lumber (dry and straight with uniform strength and stiffness) made it desirable for use in a highly engineered product like a truss. Initially, the major problem was seen as the lateral-load resistance of truss plates in the composite structural lumber. This problem area was assigned to McAlister.

As with stud development, the major objective was considered to be the development of the COM-PLY joists and trusses rather than the production of publications. The technology transfer effort was to be concentrated on the commercialization of the COM-PLY joist; that is, to persuade a manufacturer to build a plant to produce COM-PLY structural lumber. Some publications about the veneer resource studies were in the works, but no decision had been reached on a format for publishing the compendium of work on the COM-PLY project. Much of the research was interrelated. For example, decisions about the veneer thickness required to increase joist MOE would affect fastener performance, creep, fire resistance, treatability, and economics. Therefore all research efforts had to be closely coordinated. Individual researchers had to exchange information frequently.

**Joist Stiffness**

The first development work was concentrated on 2 by 10 (1.5 by 9.25 inch) joists. A direct scale-up with the same proportion of veneer as on the COM-PLY stud failed. The MOE of this joist was about 0.9 million PSI, while the target MOE was 1.4 million PSI. Since the MOE of the particleboard core averaged about 0.45 million PSI, the only solution was to increase the amount of veneer on the edges of the joist. Calculations indicated that we needed between 1.25 and 1.50 inches of veneer on each edge of a 2 by 10 to meet the stiffness requirement. Veneer would make up 27 to 32 percent of the total volume. A quick check of the resource data on veneer grade yields indicated that some D grade veneer would have to be utilized. Another problem was with the number of gluelines. With 1/8- to 1/6-inch veneer, 8 to 10 gluelines would be required for each edge lamination. These gluelines are quite expensive. One solution was to use 1/4-inch-thick veneer. The use of 1/4-inch veneer on all composite lumber would result in a nearly constant ratio of veneer to particleboard of 27 percent for everything from 2 by 4's to 2 by 12's. However, the number of gluelines would be minimized, which would tend to minimize costs.

We could not find a veneer mill willing to peel and dry 1/4-inch southern pine veneer. The consensus was that peeling 1/4-inch veneer would tear up equipment. It was a bit frustrating since for years veneer mills on the west coast had peeled 5/16-inch Douglas-fir veneer for core stock without tearing up any equipment. Finally we found a small veneer mill in Murphy, NC, that agreed to peel and dry some southern pine 1/4-inch veneer for us. We had to take mill-run veneer. They would clip the material to 12 inches wide, and we would pay for the square feet of veneer actually cut. This veneer was the basis for most of the development work on the COM-PLY joists.

We soon realized that the target value for MOE of 1.4 million PSI was a bit unrealistic with the particleboard core that we were using. An MOE of 1.1 to 1.2 million PSI was practical and within the same stiffness range as spruce pine-fir joists that residential builders were using in many areas. Mechanical testing of many joists showed that if

joints in adjacent plies of veneer were staggered or offset at least 12 inches, there was no effect on the MOE of the joists and the strength (MOR) was reduced very little. We found short grain was the most serious veneer defect, reducing both strength and stiffness. A great deal of otherwise clear veneer has extremely short grain. Much of the time, the severity of the short grain is not evident from the surface appearance of the veneer. The dynamic MOE of the veneer determined by stresswave techniques was an excellent predictor of joist MOE. However, even the stresswave technique would not detect areas of short grain in a long strip of veneer. We looked at many alternative systems of grading veneer for use in COM-PLY products, but we never found any system that did a better job than the standard American Plywood Association panel grading rules.

Many tests of COM-PLY joists indicated that, with the number of plies of 1/4-inch-thick veneer being used in the composite beams, the grade of the veneer did not have to be very good. We found that we could use all of the D grade veneer if the outside ply was of C or better grade. Since all of the veneer that could be peeled would be usable, some source of additional particleboard would be needed to use all of the veneer. This development was of major importance to the economics of manufacture for COM-PLY.

**Utilization of Hardwoods**

Major questions about the utilization of hardwoods concerned the characteristics of the hardwood veneers—their yield by grade and their strength and stiffness. We assumed that the particleboard furnish for COM-PLY could be made of a mixture of softwood and hardwood. (This was a trifle optimistic.) As nearly as we could tell from the literature, very little research had been done on structural characteristics of hardwood veneers. We initiated a hardwood veneer study in cooperation with the Utilization of Southern Timber RWU in Athens as part of its hardwood biomass research. Veneer yields by grade and stiffness characteristics were determined for sweetgum, yellow-poplar, and white oak from the Georgia Piedmont; for yellow-poplar, white oak, and soft maple from the North Carolina mountains; and for yellow-poplar, blackgum, and sweetgum from the South Carolina Coastal Plain.

Each study followed the same procedure. Sites were selected in each area as being representative of the timber. Three trees in each 1-inch diameter class from 10 to 22 inches d.b.h. were selected from each site. Only dominants and codominants with no visible decay were considered. The trees were felled, measured, and bucked into 1- or 2-block sections (a block was considered to be 8.4 feet long). A 1-inch disk was taken at the top of each block. The trees were weighed in the woods and then trucked to a cooperating softwood plywood mill (the same mill was used for all three studies). One-sixth-inch veneer was peeled from the blocks after conditioning. A color-code spray system was used so that the veneer from each block could be identified when tallied for size and grade. Each block was measured at each end and at the center immediately before being chucked in the lathe. Each core was measured at each end and at the center after it was dropped. A similar procedure had been used to determine the yield by grade for southern pine veneer.

Veneer was taken from each block to be used for strength and stiffness tests. The tests and the results are fully described in published reports (McAlister 1980; McAlister 1982; McAlister and Clark 1983).

Generally, the results of the studies were quite favorable. The yield of veneer from the hardwoods was somewhat less than from southern pine, but the quality of veneer was comparable. The strength and stiffness of the hardwood veneer were excellent. Yellow-poplar in particular was found to have an MOE equal to that of southern pine (McAlister 1982). Yellow-poplar and sweetgum were found to be completely suitable for use in structural composites. This finding opened up the possibility of complete stand utilization for production of COM-PLY by using pine and mixed hardwood stands.

Other studies on the use of mixed hardwood furnish in the particleboard core of composite structural members were done in cooperation with the University of Georgia and Washington State University. The results of these studies were not published, but they were generally favorable. Particleboard made from mixed hardwood furnish had adequate strength and stiffness for use in composites.

However, the thickness swell of the hardwood furnish particleboards was somewhat greater than for particleboards made from southern pine furnish. This problem was left at this stage since we did not have facilities for this type of particleboard research. We felt that our resources were better used on other research.

**Creep of Structural Composites**

Creep—increasing deflection with no increase in structural load—was seen as a possible problem with COM-PLY joists. The problem is not unique to composites. Solid sawed joists are known to creep because of the visco-elastic nature of wood, and particleboards used as flat panels have serious creep problems. Creep in particleboard may be caused by the density gradient that is a consequence of the reactions to temperature, moisture, and pressure gradients during the press cycle. Whatever the mechanism, the perception was that particleboards (and products made from them) would creep.

This problem was discussed at great length. Two or three possible approaches to measuring creep in COM-PLY joists resulted in study plans. In a preliminary study, joists under load were cycled through several cycles of high temperature and relative humidity. The conclusion was that COM-PLY joists were no more creepy than southern pine joists. Data from this preliminary study were not sufficient to warrant publication. No detailed study of creep in composite joists was installed because (1) a final specification for the particleboard core material had not been developed, (2) sufficient temperature-humidity-controlled space for a large number of specimens was not available, and (3) both money and manpower were in short supply and had to be used for studies of higher priority.

One limited study was installed as the result of a deflection problem that surfaced at the EER-II test house in Damascus, MD, during 1982. During construction, it was noted that the outboard end of a joist with a 2-foot cantilever had deflected almost three-fourths of an inch after a heavy rain. The engineer in charge of the design of the EER-II house brought up the question of creep. A study was initiated in haste. Two floor sections were fabricated using 2 by 10 joists spanning 14 feet and loaded to 125 percent of design load. Deflection measurements were taken almost continually for the first couple of hours after the load was applied, then daily for several weeks, then weekly for a year, and finally monthly until the study was terminated some 5 years later. Both floor sections survived the 125 percent of design load for over 2 years. Finally, the joists in one of the floor sections buckled and failed because lateral bracing was lacking. Lateral bracing was added to the other floor section without removing the load and the test continued. When the load was removed, the floor section was allowed to recover for 6 weeks. The final deflection, after full recovery, was about equal to the initial deflection under load. This movement was termed "irrecoverable creep." The joists were then removed from the floor section and tested under static bending to failure. There was no change in stiffness and, as nearly as could be determined, no change in strength of the COM-PLY joists due to the 5 years of loading at 125 percent of design load.

Due to the limited nature of the study, the results were not submitted for publication.

**Fire Resistance of Joists**

Fire resistance of building components, especially naturally combustible wood-building components, is very important. Insurance rates and the danger to human life are major considerations. Tests of COM-PLY studs for fire resistance at the Forest Products Laboratory in Madison, WI, uncovered a problem. Generally, the composite materials were not as fire resistant as solid sawed materials. Most of the strength of the composites came from the veneer on the edges of the members. When the veneer burned through, the member failed. The best that could be said for the composites was that they were almost as good as the sawed members.

This problem was especially acute for COM-PLY joists. The fire resistance of joists is measured by building a complete floor system over a large furnace. The floor is loaded to design load with vats filled with water. When the fire is started in the furnace, the temperature rise must follow a standard curve. Failure is measured by collapse or excessive deflection of the floor system. In initial ASTM and Underwriter tests, COM-PLY joists failed in 7 minutes. The unofficial benchmark failure time for joists was 10 minutes as established by FHA-HUD.

Obviously, these tests of complete floor systems are quite expensive. Very few laboratories in the United States are capable of performing them, and a great deal of material must be shipped. We needed

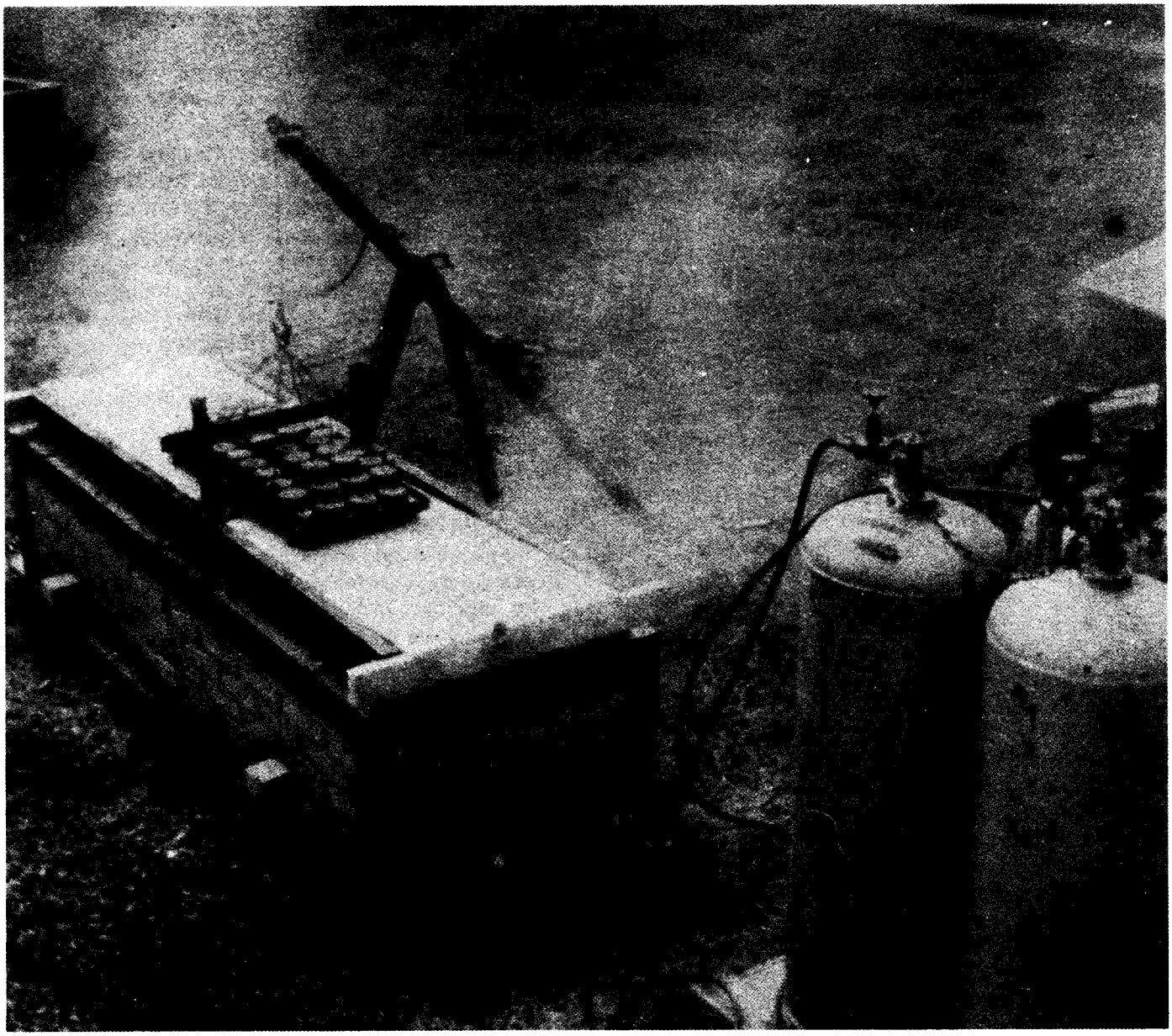

Figure 10.—Comparative fire performance of sawn lumber and many types of composite structural materials was evaluated in the "coffin fire test."

some method of evaluating the fire resistance of structural members that would be faster and less costly than the full-scale tests. This was the basis for the development of the "coffin fire test."

The "coffin" was a small furnace made of fire brick. The heat source was a large two-arm pipe burner using propane gas. The test consisted of making up a panel 32 inches wide and 96 inches long from 2 by 4's covered with 1/2-inch gypsum board. This panel acted as the cover to the coffin furnace. Design load was applied at third points with lead weights set in place with a small derrick made from a length of pipe and a boat-trailer winch. The initial deflection was measured with a transit using a reference point on the panel (fig. 10). The burner was ignited and the temperature rise was controlled by regulating the gas-flow according to output from quick-acting thermocouples in the furnace. Failure was determined from transit-based deflection readings. The burner was extinguished, the panel was removed, and the flames were doused with a garden hose. The procedure was not a standard test, but it did provide comparative values with known materials and their performance in the standard test. Since the test was quick and inexpensive, we were able to

determine the probable effects of many variables in the construction of composite structural materials.

Some of the knowledge gained from the "coffin" test helped during design of composite joists that did meet the standard fire test value of 10 minutes. We found that (1) the stiffer the veneer used in the composite, the longer the time to failure; (2) the higher the density of the core material, the longer the time to failure; (3) the higher the MOE of the core material, the longer the time to failure. It was this last conclusion, coupled with the development of the fully aligned particleboard core, that led to the development of a composite joist that exceeded the 10-minute benchmark time in a standard test.

None of the data developed from the fire tests (the "coffin" test or the standard ASTM fire tests) were published.

**Fastener Interactions**

Joists have some unique fastener problems compared with studs. End-nailing must support both shear and moment loads (for example, around stairwell openings) for the life of the structure. If joist hangers are used, several small nails near the end of the joist must support large shear loads in a very small area of the core. Some joists act as header beams where ledger strips nailed into the particleboard core support heavy lateral loads.

These problems were studied by Wittenberg and Walker for several years. Results were reported in COM-PLY Report 20 (Wittenberg 1981).

**Decay and Termite Resistance**

Generally, framing materials are used in protected environments where resistance to decay and termites is not a major factor. However, some natural resistance to decay and termites is desirable for any structural material, and preservative treatment of framing lumber is either desirable or required in some applications. Several studies were initiated in cooperation with the Wood Products Insect RWU, Gulfport, MS, to check termite resistance of untreated composite floor joists. Some natural termite resistance of the composites was found (Gaby and Carter 1981).

The treatability of composite structural lumber was tested. Results indicated that composite structural lumber was easy to treat to any desired retention with waterborne preservatives. Full penetration of the members was achieved in less than half the time required for southern pine lumber. Some of the thickness swell that occurred during treatment of composite lumber was irrecoverable on redrying, but the swelling was not sufficient to be considered a defect. Decay and termite resistance of the treated composites was outstanding. Composite structural lumber was treated with chromated copper arsenate to a retention level of 0.6-pound PCF and used in an All-Weather Wood Foundation System for the EER-II research house in Damascus, MD. There were no publications on this phase of the work.

**Economics of Manufacture**

The costs of manufacturing composite structural materials were a constant concern. The overall research objective was to develop a product that could compete on a performance and price basis against No. 2 KD southern pine dimension lumber. This objective guided our research from the beginning, and there were some positive benefits to this approach. Since hardwood stumpage prices are generally lower than softwood stumpage prices, economic considerations made research on hardwood components more attractive. Also, costs were considered when we evaluated resin binders for particleboard; times and temperatures for curing particleboard; the peeling, drying, and laminating of veneer; the amount and type of waste produced at each processing step; the amount of electrical and heat energy required for each processing step; and the amount of labor required for each step.

These factors, together with data on the basic forest resource and yield factors, were incorporated into a computer program that yielded estimates of required inputs, amount and type of waste generated, fixed costs, variable costs, assumed cash-flows, and profitability. The program was developed and refined over a period of years by Koenigshof. Results of the detailed analysis of joist manufacture under specific assumptions were published as COM-PLY Reports 15, 17, and 26 (Koenigshof 1978, 1979, 1983). Seminars on the feasibility of manufacturing COM-PLY panels in converted plywood plants were presented in cooperation with the American Plywood Association. Koenigshof also prepared detailed economic analyses for several major forest products manufacturers who were considering the feasibility of producing composite structural products.

Generally, the economic projections for composite structural product manufacture were favorable. The basic assumption was that composite structural products could be sold at a price at least equal to the average price of No. 2 southern pine dimension lumber.

### An Intermediate Product

A workable composite joist was developed and tested by early 1978. Enough joists and studs were made in the laboratory to construct a demonstration house in Atlanta, GA, in conjunction with the 1978 Forest Products Research Society annual meeting (fig. 11). The demonstration house incorporated composite floor joists that were 32 feet long and continuous over a center support. There were also composite studs and composite panels that had been commercially manufactured in a North Carolina plant.

Even though a workable composite joist had been developed, there was still a great deal of work to be done to check alternative methods of manufacture and the effects of many process variables on the physical and mechanical properties of the material. The demonstration house was featured on an FPRS-sponsored tour at the annual meeting.

## Composite Truss Lumber

While research continued on the composite floor joists, the decision was made in 1979 to explore the development of composite truss lumber. There were two major factors considered in this decision: (1) the truss fabrication industry consumes about 2 billion board feet of dimension lumber every year, and (2) problems related to warped, twisted, and below-grade lumber could be reduced with composite structural lumber.

There were some immediate problems with the concept. To begin with, the standard method of fabricating light-frame trusses is with toothed metal plates made from 20-gauge or 16-gauge steel plate. The teeth are pressed into the wide face of the dimension lumber in the truss. With the standard configuration of composite structural lumber (i.e., the veneer on the narrow edges) the teeth are pressed into the flakeboard. Preliminary tests showed that the lateral load resistance of plates installed into the particleboard core did not yield useful design load values. Another potential problem was with the column buckling characteristics of the composite structural lumber. Studs are loaded as columns, but they are covered with sheathing or some type of panel material that braces the column. Truss components are

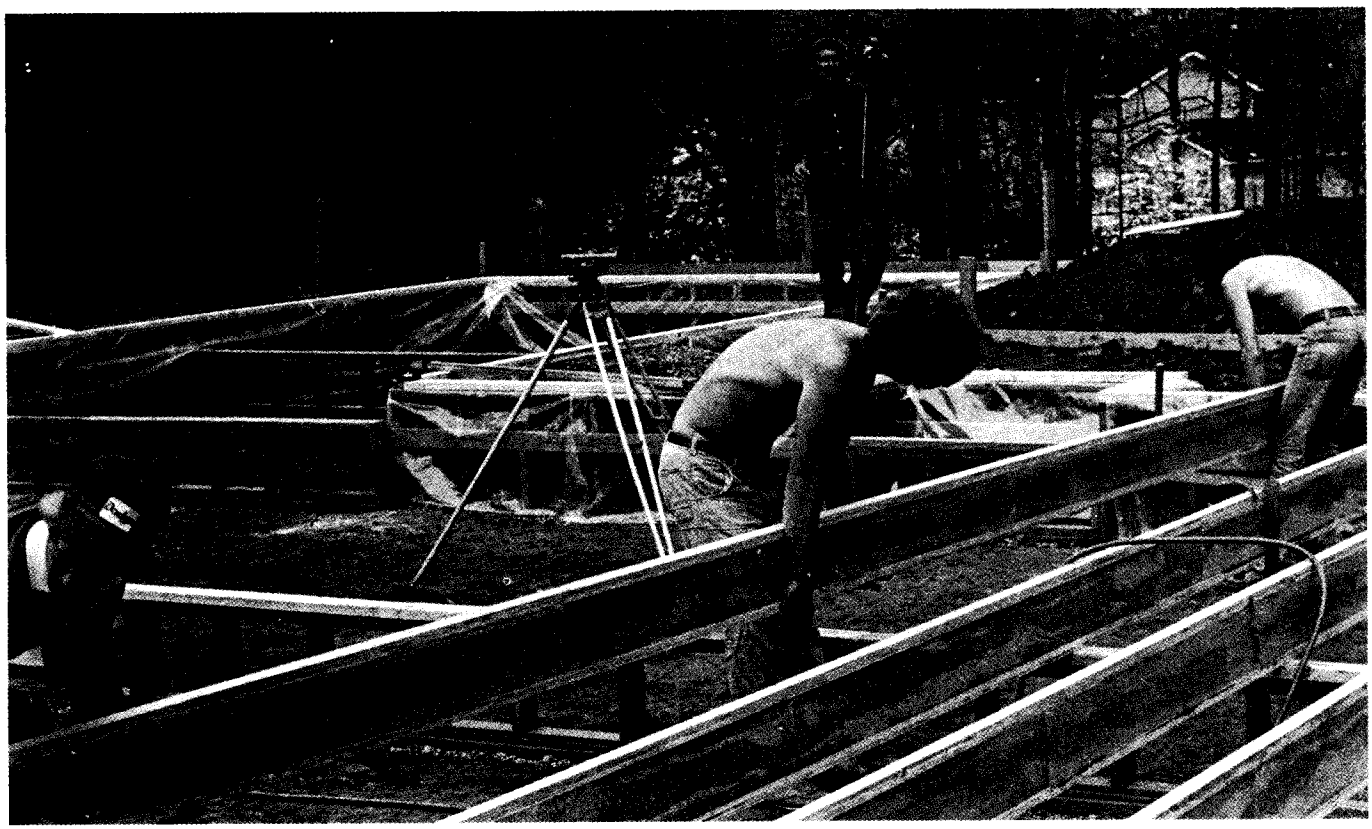

Figure 11.—Composite structural joists, 2 by 10 by 32 feet long, were used in a demonstration house in Atlanta, GA.

sometimes loaded in compression and, because of truss design, their ratio of length to radius of gyration falls into the intermediate or long column range. Preliminary tests had indicated a possible buckling problem with composites in the intermediate column range.

The quick fix was to redesign the composite specifically for use in trusses. Since the biggest perceived problem was with the lateral-load resistance of the truss plates, we moved the veneer from the edges of the composite to the faces so that the truss plates would be installed into the veneer. We hoped that moving the veneer to the wide face of the composite would also eliminate the column buckling problem. Moving the veneer to the wide face would greatly increase veneer use, but the veneer grade did not have to be as high because the stress level would be lower. Resource analysis indicated that if all of the D grade veneer could be used, there would still be enough veneer available to fully utilize the trees in a stand.

Extensive research was conducted. The lateral-load resistance of truss plates installed in the veneer-faced composite was more than adequate. In fact, it was almost equal to the values for truss plates installed in southern pine dimension lumber. The lower grade veneers did not lower the strength and stiffness of the composite if a few simple guidelines were followed. The results of this research were reported in COM-PLY Report 25 (McAlister 1983).

**Core Material for Composite Truss Lumber**

One of the requirements of the veneer-faced composite was a different type of core material. We needed a core that was 7/8 inch thick. In combination with two plies of 1/6-inch veneer on each face, the finished thickness would be 1.5 inches. Also, the dimensional stability properties of the core needed to be unique. With the wide face of veneer, a certain amount of linear expansion across machine direction of the particleboard would be desirable to reduce stresses induced by changes in moisture content.

A contract to produce a fully oriented particleboard 7/8 inch thick was negotiated with a west coast producer. It was assumed that the fully oriented particleboard core for which we contracted would have somewhat improved strength and stiffness parallel to machine direction due to the orientation of the particles. It was also assumed that linear expansion across the machine direction of the particleboard would be 4 or 5 percent after 24 hours of water soaking. Since the veneer moves about 6 to 8 percent under these conditions, such dimensional instability would be desirable.

We had worked closely with FHA-HUD since the beginning of the composite structural products research. The demonstration houses using composites had been insured under a special HUD program for innovative use of materials. In 1981 we were asked to take on a real challenge. FHA-HUD and the National Association of Homebuilders Research Foundation were cooperating in the design and construction of a showcase Energy Efficient Residence, EER-II, near Washington, DC. The construction was scheduled for late spring 1982. What composite structural materials could we supply? We agreed to produce the truss lumber, the joists, the studs, and the preservative treated framing for an All-Weather Wood Foundation for the EER-II project.

This was quite an undertaking. Our testing lab was converted to a pilot-plant operation with a layup and clamp table 34 feet long and 4 feet wide. Everyone in the project was involved in furious activity twice a day as the layups were made and the pressure was applied to the gluelines. Vick had tested extensively a special water-emulsion isocyanate laminating adhesive and found that a 4-hour cure time under pressure was sufficient to produce strong durable bonds between the veneer and the particleboard core. Special techniques were developed to laminate the veneer and spread the glue. The composite joists were made full length (32 feet). Each day's production was checked off the bill of materials.

We had to postpone producing the truss lumber until last because the special oriented core was not available. On the very last day in what could be called "good luck" or "just-in-time inventory management," the special core material arrived, but there was a problem. It was not what we had contracted for; the material was a three-layer board with the core oriented at right angles to the face orientation. A hurried test indicated that in other respects the core was acceptable. There was no time to reorder if we were to meet the deadline for the EER-II framing. So we accepted the order and used it. This was a wise decision.

Just as we started to fabricate the 2 by 4 truss lumber, we were asked to furnish some additional truss lumber for a two-car garage that had been added to the project. All the core material available from the original order was earmarked for necessary research projects. We ordered some special phenolic-bonded particleboard 7/8-inch thick with random orientation that otherwise met our specifications for internal bond and MOE. This material was used for the garage truss lumber.

The deadline was met, and we loaded all of the composite framing on an open flat-bed trailer for delivery to the truss fabricator and the building site. As the truck pulled away from the lab, it started to rain. There were no tarps covering the load, but we were not worried. This material had passed all of our durability tests. Murphy's Law applied in this situation – disaster. A week later we received a call from the truss fabricator. All of the garage trusses were coming apart. The truss lumber was splitting right throught the middle. What were we going to do about it?

We found that the garage trusses made with the random core material were splitting and coming apart. The trusses made with the oriented core material were fine. We needed to find out why, so we carefully tested the physical and mechanical properties of the two core materials. Every test recommended in ASTM D-1037 was performed on both core materials plus the 1-1/2-inch core used in the joists. There was very little difference in the test results between the particleboards except for thickness swell after a 24-hour water soak. The oriented core swelled about 5 percent; the thick core swelled about 10 percent; and the random core swelled almost 30 percent. We checked some other particleboards for thickness swell. In every case where the thickness swell after a 24-hour water soak exceeded 15 percent, we were able to reproduce the pattern of failure that had first been observed in the garage trusses for the EER-II project. Thickness swell became a major factor in the specifications for the core material for composite structural lumber.

**Oriented-Core Performance**

We also checked the performance of truss plates in the oriented particleboard. To our surprise, the lateral-load strength values for the particleboard were high enough for effective use in trusses. Another surprise was the low linear expansion (less than 0.5 percent) for the three-layer oriented particleboard core. We assumed that low linear expansion was due to the cross-oriented core layer. We also contracted with the same producer for some fully oriented flakeboard for core material; some 3/4-inch thick for lamination into 1-1/2-inch stock and some 7/8-inch stock for composite truss lumber.

The fully oriented core material was a real surprise. To begin with, the linear expansion across machine direction was about 0.3 percent after a 24-hour water soak. Thickness swelling was about 5 percent. MOE of particleboard is usually measured on a panel with the smooth surfaces top and bottom. The MOE of the flakeboard normal to panel surfaces (as a beam with the cut edges top and bottom) averaged about 1.2 million PSI with an MOR of over 6,000 PSI. The tension and compression values were also quite high. There was about a 3 to 1 differential in MOE parallel to and across machine direction. Thus, the MOE of the oriented flakeboard across machine direction was about the same as the MOE for random oriented flakeboard. The lateral load resistance of truss plates installed in the fully oriented core material was only 10 percent less than for the same plates installed in southern pine framing.

Actually, the fully oriented core material was a fully structural product as it was, without any veneer installed either on the edges or on the faces. This was a remarkable development. One problem surfaced. Since the core material was so dimensionally stable, when veneer was installed on members wider than 3.5 inches there was a serious problem with the faces swelling so much that the member took on a barrel shape. The problem was severe enough to cause splitting of the core at the center of the member after a couple of cycles of wetting and drying.

No further development work was done on the fully oriented flakeboard as a structural material because funding for the RWU was withdrawn and the project was terminated in 1986.

## Solid Accomplishments

Research on composite framing for studs started in 1974. Standards for the evaluation of performance characteristics of stud framing were developed, and a fully satisfactory composite stud was developed by 1975. Research on composite joists culminated in a fully satisfactory joist in 1978. Satisfactory composite truss lumber was produced by 1982. An experimental core material for composite truss lumber was found to be a fully structural material in its own right in 1985.

Economics of resource availability, market demand, and production feasibility were considered at every stage of the research. The RWU achieved all of its research objectives and goals well within the projected timeframes.

The RWU was terminated September 30, 1986. It was decided that further research and development of composite structural products would best be accomplished by industry.

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Between 1974 and 1986, a Southeastern Station Research Work Unit developed standards for composite studs, joists, and truss lumber and manufactured and demonstrated the materials. Economic feasibility was considered in every stage of research. Further development is left to industry.

Keywords: Construction lumber, composite lumber, truss lumber, joists, studs, performance standards.

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