WOOD AND ADHESIVES PROBLEMS—A LOOK AT THE FUTURE[1]

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ABSTRACT

Problems of current concern to the producers and users of wood products involving the use of adhesives are discussed, with some of the economic factors identified. Similar problems that might be encountered in the next five to ten years are discussed, with an attempt to anticipate the impact on the forest products industry if successful solutions are realized.

Possible solutions to the problems identified are discussed, with particular emphasis on the type of investigations that should be undertaken at research establishments to provide the highest probability of success in solutions.

Additional keywords: Adhesive evaluation, adhesive testing, pollution control, research and development, standards, applied research, economic analysis, properties.

The title of this paper is self-explanatory and we propose to look at the problems in several major categories: viz., adhesive uses and applications; desired adhesive properties; environmental and resource implications; adhesives testing and evaluation; application of new technology, and responsibility of researchers and users. Following consideration of the problems, we will suggest some possible avenues to solutions.

BACKGROUND

Unfortunately, the use of adhesives is largely an art rather than a science, an art that dates back to the Egyptian dynasties. The adhesives themselves, particularly those now in use, are highly complex chemical substances, whose intricate molecular composition makes difficult basic studies of interfacial bonding phenomena (Blomquist 1963). More and more is asked of adhesives, yet too little is known of the newer ones, particularly of their long-term durability and performance. Adhesives are expected to perform consistently in environments that would not have been considered a short time ago. In the "Golden Age" of animal glue, it was all so simple: if a problem arose in connection with high water resistance, we knew we couldn't, so we didn't (Dosker 1958).

Adhesives have a major function of holding and are always an integral part of a structure or composite. Thus, they do not function as separate entities, but as constituents that influence and, in turn, are influenced by the materials they contact.

As skilled construction labor becomes scarcer, as competitive pressure from substitute building materials intensifies, as increasing costs or scarcity of high-grade timber leads to more sophisticated and efficient designs, and as more and more wood fiber is used in some reconstituted form, there will be a greater and greater need for better adhesives. Although it may be too much to expect that we will see the demise of hammers and common nails, nails have long been obsolete, and they never have been first-class fasteners for wood.

Before answers can be found, the problems—and problems are really opportunities—must be properly identified, and this should be a joint effort of the producers and the users of adhesives. To date, there really has been too little communication between these two vitally concerned groups.

The approach to research and development in adhesives should not be too cautious or conservative. The possibility of achieving something significant—something really worthwhile—is so much greater if

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the original objectives are ambitious, that it would probably be a strategic error to start out with only modest goals.

ADHESIVE USES AND APPLICATIONS

There are three general classifications for adhesives used by the wood products industry—structural, quasi-structural, and nonstructural—all vitally important to wood products acceptance and utilization.

The structural uses include glued-laminated members, end-jointed dimension lumber, trusses of varying types, glued and nail-glued stressed-skin panels, treated-wood components, composite products of both all-wood and wood/nonwood combinations, and connections between structural members of light-frame structures.

Quasi-structural adhesives, generally those classed as elastomeric, are used where their limitations with respect to creep can be overcome by combination with other fastening methods. Typical applications are in bonding panel products, such as floor sheathing to the supporting joists, or in providing increased racking resistance to large diaphragms made from tongue-and-groove decking. Although use of these adhesives undoubtedly improves the load-carrying capability of the structures, no stress increases are claimed because of lack of sufficient data concerning creep and durability of the adhesives. They are used, however, because it is accepted that, in addition to strength, overall performance is improved and a better structure results.

Nonstructural adhesives (often rubber-based contact adhesives) are used in furniture, plastic overlaying, and some composite products. Other types of nonstructural adhesives may be used for manufacturing shelving, panelling, end-jointed joinery stock and, in some cases, studs.

Most of the adhesives mentioned above are shop-applied, where precise control over gluing conditions can be achieved, yet one of the greatest potentials for expanded use of adhesives with wood is in field application. Ideally, for field application, adhesives require wide tolerance to moisture content, temperature, surface conditions, and ability of applicators. The adhesive systems should not require elaborate application equipment, and should have long pot life, yet they should, ideally, be capable of accelerated cure by simple adjustments of bonding conditions or techniques.

ADHESIVE STANDARDS AND EVALUATION

The transfer of technology from country to country depends in part on participation by people directly involved in that technology. One of the greatest aids in seeing that new technology is usefully applied is the drafting of appropriate standards and specifications. Presently, most international standards bodies are constituted by representatives from industry, rather than from the scientific community, and industry representatives are usually less communicative than are scientists. This situation frequently hampers the transfer of applied technology from country to country.

If the scientific community becomes more involved in the testing and evaluation of adhesives, particularly in the drafting of the required specifications, then the chances will be improved for wider international acceptance of wood products that utilize adhesives in their manufacture.

Two adhesives areas need specific attention—methods of testing and evaluation, and philosophy of testing and evaluation. The first is essentially measurement of properties and the second is predictive and is based on certain observations or measurements.

Since application of a given product is essentially the same in any country, it seems logical that specific information about a sample should mean the same thing in any country. In other words, the same test, if it is valid, should satisfy DIN in Germany, JAS in Japan, CSA in Canada, and ASTM in the United States. At the present time, tests acceptable in one of these jurisdictions are often meaningless or are not accepted in another. This situation is a great hindrance to the wider acceptance and use of wood products. Internationally used and accepted test criteria would do much to correct it. Such criteria should relate to actual performance in service. Engineers and designers—indeed, the users of the products—are most concerned with adequate levels of performance, and are really unconcerned that a given adhesive may provide a shear strength several times that required for adequate safe performance. They are concerned, however, about impact strength, effect of temperature and moisture, resistance to chemical reagents, and effects of species.

If a new adhesive system is developed, it is unrealistic to make up test panels and wait for 25 years, while they weather on a test fence, to see if they perform satisfactorily. It is now accepted (in North America at least) that phenol-formaldhyde (p-f) adhesives, such as those used in the manufacture of exterior-grade plywood, are satisfactory, durable adhesives for this purpose—in other words, a suitable yardstick for comparison. Therefore, if a new adhesive system is to be evaluated for exterior-type performance, we need adequate methods of relating its ultimate performance to that of p-f adhesives. These tests do not need to be quantitative; they can be simple *go* or *no-go* evaluations. In other words, if they will perform as well as or better than p-f, they are rated *go*. In this instance, how much better is not material to approval. Current trends are toward objective, scientifically based methods, rather than relying on subjective judgment from some kind of accelerated-aging process. The present state of adhesives technology suggests that rational comparison methods can be developed and, thus, the burden of critical decisions can be removed from subjective evaluators.

Nondestructive testing should not be overlooked as a possibility for evaluating the long-term performance capabilities of adhesives. Proof loading, ultrasonic testing, X-ray scanning, or other techniques may be as good as or better than any now in use or contemplated; but their development must come from the scientific community rather than from users of adhesives.

Quality control is one aspect of testing and evaluation that is frequently overlooked (Blomquist 1972). Quality control should not be confused with quality inspection; the latter is but part of a quality control program, which should begin as the raw materials enter the plant, not part way through the process, or in the shipping area. Since adhesives systems are becoming more sophisticated, codes and regulations are becoming more stringent and, since applications of adhesive-bonded products are becoming more demanding, assurance of quality of product becomes increasingly important. Even though quality control is essentially a routine manufacturing function, the scientific community has a large part to play in the formulation of adequate quality control programs and procedures. To date, scientific input has generally been at a less-than-desirable level.

TESTING METHODS

Because of the need to make more effective and efficient use of the forest resource and because of current pressures on price and availability of traditional adhesives, it is inevitable that the forest products industry will develop and use alternative adhesives. Therefore, new and acceptable short-term methods for testing durability of the new adhesives on a short-time basis will be urgently needed. How long should a bonded product survive a given exposure environment so that it can be called durable? It would probably be difficult to obtain a consensus for such a definition among adhesive researchers and users. Because of this difficulty, an analogy can be drawn to the application of British common law in the administration of justice where practice is based on precedent. Phenol-formaldehyde resin has been used for more than 20 years and it is generally agreed that it is a durable adhesive for exterior use. The p-f resin may thus be considered as our precedent for example, and thus any new adhesive that has performance properties and chemical resistance similar or superior to that of an exterior p-f resin should be considered a durable exterior adhesive.

The finding of test methods for obtaining answers to establish the level of similarity to p-f resin for new adhesives is the most difficult task. The testing method must be economical, while the results should be able to predict the future performance of the product. The testing methods for adhesives might be separated into two categories—adhesion testing and adhesive testing.

Currently, the testing of adhesion between wood and glue in the bonded products can best be accomplished by methods that include the generally accepted boil-dry-boil, delamination, and creep-behavior tests. It seems likely that, with the current activity in Arctic regions, the addition of a low-temperature cyclic test may be advantageous. This would be particularly important in the case of construction adhesives.

The test of durability of the adhesive itself may be complicated by the presence of fillers and extenders. The complex composition of these materials used in modern adhesives limits the direct application of chemical methods for testing. Tests of filler and extender influences could be conveniently incorporated into performance tests. The test of durability of the resin itself can be done with physical and chemical methods, using p-f resin as a reference. Testing methods could include acid and alkaline hydrolysis, ozone degradation, heat resistance (thermal softening test), dry and moist heat aging, differential thermal analysis of the curing process and, possibly, some other physical-chemical methods. Tests for decay and fire resistance of adhesives should also be included. In developing their new methods and tests, adhesives scientists should not overlook the opportunities offered by the development of very sophisticated and exotic technological methods that are currently being developed, particularly in the aerospace industry.

ECONOMIC IMPLICATIONS

In many instances, adhesives are the most effective, efficient, and economic means of joining wood for useful applications—glued-laminated structures and plywood come to mind immediately. What is important, and perhaps not well understood, is that adhesives can play a very important part in the structural assembly of products, such as houses, ladders, and other high-volume items. While the technique of adhesive bonding plywood or particleboard floor sheathing to the supporting joists has been known for several years, and some builders would not consider building without it, it is still not used by the bulk of the housing industry, even though it has been demonstrated that it can be of economic benefit to builders. If the use of this technique had been aggressively promoted by adhesive manufacturers, it might have been in wider use by now. What is probably not realized by the adhesives industry is that the quantity of resin solids involved, if the entire housing industry could be persuaded to use the technique, would equal or exceed the quantity of resin solids used in the softwood plywood industry and the dollar volume involved would be considerably greater, as these are more expensive resin solids. Similarly, adoption of adhesive-bonding techniques on a widespread basis by the light-frame structural industry should be of considerable interest to the adhesives industry. However, as already stated, this business is not self-generating—an enterprising group must go after it.

Other economic considerations are the potential saving of material and money, if joint or connector efficiency can be improved through the use of adhesives. Wider use of adhesives of the right type suggests potential for substantial savings in labor costs, particularly for factory-built housing components.

ENVIRONMENTAL AND RESOURCE CONSIDERATIONS

If we continue to utilize current adhesives and current adhesives technology, there are environmental quality considerations to be met. Wash-down water from phenolic adhesives kills fish and other aquatic life, even in low concentrations. More and more attention is being directed to the environment in which people work and some presently operating plants may have problems in meeting proposed health and safety standards. Some storage and manufacturing areas have concentrations of fumes that are uncomfortable to work in, even if they are not at hazardous levels. These conditions will not be tolerated much longer, yet they are probably soluble by application of appropriate existing adhesives technology. The alternative is to use expensive and elaborate ventilating systems that do little to solve the problem—they just remove the symptom, or lessen it to acceptable levels.

Currently, popular wood-adhesive systems are based largely on products of the petrochemical industry and thus have fluctuated wildly in price with the current world "shortage" of petroleum products. Additional pressure has come from environmental legislation requiring lower levels of emissions from automobile engines. This has led to an increased demand for low-lead and no-lead gasolines. Unfortunately, the aromatic fractions of petroleum, the key basic chemicals for manufacture of these motor fuels are also the basic chemicals for phenol, the principal chemical in waterproof wood adhesives, and prices have escalated accordingly.

It seems unlikely that the petrochemical supply situation will improve in the foreseeable future, and attention should be directed to discovering alternative sources of chemicals for adhesives—sources that are not so sensitive to outside pressures and that exhibit some stability of supply and price. If such sources could be found within the forest products industry, utilizing unused residue from a renewable resource, it would make the forest products industry much more independent.

Since future supply and price prospects for adhesives based on petrochemicals are rather bleak, we should devote more attention to adhesive raw materials from different sources. For instance, by-products of coal refining or gasification may be economically attractive for adhesive synthesis. Perhaps petroleum refining residues, which are currently considered of little value or a waste for disposal, can be economically utilized in adhesive formulation.

The use of abundant renewable natural resources for adhesives should be a most attractive prospect for research. It is probable that the high cost of petroleum derivatives will accelerate research into maximum utilization of every element of a tree, including its wood and bark, for adhesive formulation. In wood, nature has demonstrated that she is one of the most knowledgeable adhesive experts. The lignin distribution in wood and the lignin bonding of cellulose to form a rigid and strong wooden structure is a prime example. This natural bond is so durable that, in chemical pulping, unless the fiber structure is damaged to some extent, the complete breakdown of the lignin (adhesive bond) is difficult.

Wood might be studied to determine how a tree glues itself so well, how lignin forms in wood, and why it is distributed in cell structure the way it is.

If these questions can be answered, the time required to find methods of effectively reutilizing the already available natural chemicals—especially the phenolic compounds—in wood and bark can be accelerated. This could shorten the time required for the forest products industry to become independent for raw material supply. Because of this, it may be justifiable to suggest that more fundamental research is urgently required to achieve the goal.

DESIRED ADHESIVE PROPERTIES

Although the "instant adhesive nail" may never come, the "ideal adhesive" for the forest products industry would be required to have the following properties:

- —quick setting time;
- —good gap-filling capability—say up to 1/16 inch;
- —wide range of temperature and moisture tolerances;
- —suitable range of open and closed assembly times;
- —ease of mixing;
- —long pot life;
- —compatibility with a wide range of adherends—wood and nonwood;
- —good physical strength—particularly in shear.

Of major importance in the light-frame structural market is adhesive durability—i.e., resistance to deterioration in service from heat, moisture, oxidation, fungi, bacteria, and other adverse environmental factors.

A matter of increasing concern is the need for adhesives that will provide suitable structural strength when bonding treated wood. Thus, adhesives are needed that are compatible with fire-retardant and preservative-treatment systems. This need will increase rapidly as more fire-retardant treated wood products are required to satisfy regulatory requirements and as more preservative-treated wood is employed in such building systems as all-weather wood foundations.

Color is of secondary importance for this structural adhesive. At the present time, structural adhesives that are "cost tolerable" are characterized by colors that are really unacceptable for application where appearance is a prime consideration. For nonstructural purposes, however, appearance is often of primary importance, particularly for decorative moulding, panelling, and similar products that are frequently treated with clear protective finishes.

In all cases, it is desirable that the adhesive, for whatever purpose, be capable of extremely rapid cure times in terms of present adhesive technology—on the order of seconds, and it should be reasonably "foolproof." More and more semi-skilled and unskilled labor will be used in the forest-products fabrication business, particularly as a greater proportion of components becomes factory made, and there will just not be an adequate level of technical expertise available to handle sophisticated or complicated adhesive systems.

LIMITATIONS OF CURRENT ADHESIVES

While it is too much to hope for the ideal adhesive with no problems or limitations, some of those inherent in currently used adhesives must be overcome if the utmost is to be realized from new adhesive systems.

Some of the problems that must be addressed include:

—compatibility with a wide range of adherends, so that wood can be bonded successfully to other structural materials;
—tolerance for variations in surface preparation with maintenance of desired levels of performance;
—recognition of the wood-products industry's needs for shear strength, toughness, gap-filling capability, creep resistance, water resistance, and thermal performance to ensure widest use;
—adequate quality control criteria for adhesive users' plants;
—establishment of adequate designs for adhesive-bonded connections in wood.

RESPONSIBILITIES OF RESEARCHERS AND USERS

It probably would be much better for all concerned if adhesive manufacturers, adhesive users, and adhesive scientists established closer communication than presently exists. Adhesive problems are not the exclusive property of any one of these groups and seeking solutions to problems in concert would probably provide better and quicker answers than if they addressed the same problems individually.

The users must make known their needs to the researchers in understandable language, and adhesives manufacturers should make efforts to determine users' needs and problems so that new products can be properly utilized.

Wood probably does not receive sufficient attention from adhesives researchers and manufacturers. The impact of wood-chemistry variables—particularly extractives—should be understood. The adhesive performance of tropical woods, which are becoming increasingly important in terms of quantities used, should be studied. The influence of surface preparation should be understood and adequate techniques should be developed to ensure the optimum surface is available for the adhesive being used.

Users should also obtain a broader understanding of how adhesives perform—particularly those types needed for their own purposes. Users have a responsibility for applying sound design principles to obtain the optimum performance form adhesive-bonded joints (Anon. 1971). Design is critically important, yet is often overlooked. The ideal geometry for a mechanically fastened joint is not necessarily ideal for an adhesive-bonded joint.

Users can offer considerable assistance in obtaining more rapid application of new technology by becoming more involved in the code-approval process and in discussions with regulatory agencies. This area is often overlooked, yet it can be one of the more serious obstacles to application.

APPLICATION OF NEW TECHNOLOGY

Development of new technology is frequently less difficult than getting that technology put to use in a practical way. If a new adhesive is developed that can be produced at a reasonable cost, is based on raw materials readily available and with some continuity of supply, is not harmful to the environment or workers using it, and satisfies a multitude of performance and regulatory criteria, it is still not assured of acceptance and use unless someone takes the time to explain how to use it and to demonstrate that it is also sound economically.

Users do not communicate their needs too well to the scientific community, and the scientific community seems to have difficulty in communicating to potential users the practical significance of the new technology they develop. A little effort on both sides should yield tremendous mutual benefits.

Programs such as Operation Breakthrough brought to light many problems and shortcomings in the building process, many of them related to adhesives (Worth 1972), yet few adhesives technologists seem to be familiar with the information generated by Operation Breakthrough.

The Forest Products Research Society has recognized the need for vigorous activity in this area of technology transfer and now has an appropriate technical committee and has published papers on the subject (Tayelor 1973, 1975).

SOME DIRECTIONS FOR RESEARCH

As previously mentioned, a profitable area for adhesive research could be in the development of adhesive alternatives to the common nailing system for joining wood members. Although the contact force in the immediate area of nails is generally quite high, the overall contact area is far less than if the joint is made using adhesives. "Instant" adhesives, with acceptable creep and long-term durability cheracteristics, would be of tremendous benefit to the housing and light-frame structural industry. Conventional wood adhesives are generally too rigid for these purposes. Attention might usefully be directed to the copolymerization of existing adhesives, with moderately flexible polymers or the development of polymers typified by the copolymerization of resorcinol formaldehyde and epoxy resin, or systems of acetone-formaldhyde resin and/or some improved currently used construction adhesives. This area of research requires high-priority attention.

With the increasing trend to industrialization of components and utilization of composite materials formed from dissimilar elements, consideration must also be given to the development of techniques for the most effective bonding of wood to other materials. Metal bonding with adhesives generally involves acidic preparation of the surface. The residual acid could be detrimental to the durability of the wood itself and possibly to the adhesive.

The differential thermal expansion of two different substrates can cause great stress concentration at the interface, which can materially reduce bond durability. In this kind of bond, the durability criteria for wood/metal composites should be defined. Will the existing wood-failure technique of evaluation suffice? What magnitude of strength under what accelerated-aging systems is acceptable? Similarly, the bonding of wood to glass deserves suitable attention.

In bonding research of the type mentioned above, the adhesion theory that is generally used for wood must be thoroughly examined. Wood is a highly porous and absorbent material, whereas metal and glass are not significantly absorbent. To join such dissimilar materials, an adhesive should have equal facility in being able to accommodate each adherend. Such a gluing system would thus be greatly different from conventional wood adhesives. More systematic research endeavors, particularly in fundamental theory, is desirable if adhesives for satisfactory bonding of wood to metal, wood to glass, and even wood to cement are to be successfully developed.

Other than bonding wood to inorganic substrates, urgent study should be devoted to the bonding of "denatured wood" to itself or to normal wood. In this sense, "denatured wood" can be defined as wood that has received chemical or physical treatment, so that the original physical or chemical properties of the wood surface have been altered; e.g., fire-retardant and preservative-treated wood. In the bonding of such treated wood, conventional adhesives have generally not been suitable for developing joints with the required performance characteristics. Research into bonding wood of this type should, therefore, stress not only the development of suitable adhesives, but also surface improvement of the substrates.

In summary, there seem to be enough problems for wood and adhesives in the near future to provide many opportunities for improvements and advances in adhesives technology that will, in turn, enable wood to be utilized more effectively and efficiently.

New testing methods for adhesives must be developed and new raw-material sources should be sought for manufacture of wood adhesives, but adequate lines of communication must be established between researchers and users, so that newly developed technology can be effectively utilized.

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DISCUSSION

Helmuth Resch: I did not attend the conference on the use of elastomeric adhesives in the construction industry held a month ago at Madison. You touched on this area regarding present structures. Maybe you or someone who participated in the symposium might give us feedback.

Tayelor: I wasn't at the symposium. The example I thought of when that went into the paper was the work Jim Johnson did on diaphragms at your shop. I know that they got some very startling results—results that could be put to work. They are covered in one of your last OSU reports.

H. Resch: Kind of you to mention it. Recently such diaphragms have been constructed for the new Sheraton Hotel in Portland and a Safeway store in Corvallis.

Fred Brown: Would the speaker define "construction particleboard"? What is meant in terms of physical characteristics?

Tayelor: I'm not a particleboard expert but a mechanical engineer who's been hammered from time to time by wood technolo-