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The role of adhesives in building design is discussed. Three major areas are as follows--(1) lamination of structural timber beams, (2) bonding of cementitious materials, and (3) bonding of gypsum drywall construction. Topical coverage includes--(1) structural lamination today, (2) adhesives in use today, (3) new adhesives needed, (4) production testing problems, (5) selection, use, and performance data for bonding agents, (6) bonding materials for interior finishes, (7) bonding of structural materials, (8) current practices in bonding gypsum drywall, (9) attachment of gypsum drywall boards to studs, (10) lamination of drywall gypsum, and (11) joint finishing and nail setting. (RH)

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# ADHESIVES IN BUILDING

- Lamination of Structural Timber Beams
- Bonding of Cementitious Materials
- Bonding of Gypsum Drywall Construction



National Academy of Sciences—
National Research Council
publication 830

## BUILDING RESEARCH INSTITUTE
### Officers and Board of Governors

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Proceedings of a conference held as part of
the 1960 Spring Conferences of the
Building Research Institute
Division of Engineering and Industrial Research

Publication 830
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Washington, D. C.
1960

The Building Research Institute gratefully acknowledges the contributions to building science made by the participants in this conference.

Milton C. Coon, Jr.
MILTON C. COON, JR.
BRI Executive Director

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# Abstracts of Conference Papers

STRUCTURAL LAMINATION TODAY
By Ward Mayer, Timber Structures, Inc.

A general orientation on the materials and methods used in present-day structural timber laminating is given, and the author then discusses the future potential of the industry, in terms of the need for standard quality control. The difference between lumber laminating and timber laminating is pointed out and some of the new techniques under experiment and development are briefly described.

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ADHESIVES IN USE TODAY
By R.H. Bescher, Koppers Company, Inc.

The three types of adhesives in use most widely are described in terms of their usage. Other adhesives such as the melamines are mentioned, and types of joints and edge gluing are discussed.

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NEW ADHESIVE NEEDS FOR STRUCTURAL TIMBER LAMINATING
By Maurice J. Rhude, Unit Structures, Inc.

The relationship of the cellular structure of wood to the type of material necessary to achieve good lamination is outlined. Types of joints are detailed, as are methods of design for the fabrication process, with stress laid on the importance of the time-temperature relationship in achieving a successful job. Four different methods of bringing elevated temperatures to the glue line are listed, as are the advantages of curing the adhesive at room temperature in some instances. Design of adhesives for condition of service, for level of initial joint strength, to meet laboratory tests, and for considerations of cost are detailed, followed by description of the types of adhesives that may be developed for future use.

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PRODUCTION TESTING PROBLEMS WITH PRESENT MATERIALS
By R. E. Wirth, Rilco Laminated Products

Testing programs are divided into three categories: evaluation of product and process capability, testing and control of raw materials, and surveillance of process and production control. Each of these types is described in detail. Methods used to test the various types of joints and the glue line are discussed, and the author points out that the most serious problem facing the industry today is enforcing continuous and conscientious use of methods which will result in a uniform product of top quality.

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SELECTION, USE AND PERFORMANCE DATA FOR BONDING AGENTS
By John Hans Graham, John Hans Graham & Associates

Case studies of use of bonding agents by the author's firm in various types of buildings are discussed, and frequently, actual specifications quoted. Methods of surface preparation are detailed, and the performance resulting from the use of different techniques is described. The process of spraying on a plaster bonding agent, and then applying a coat of lime-putty plaster directly to the bonding agent is noted as being cleaner, faster and more economical than conventional methods previously used. Techniques to be used in projects now in the planning stages are also discussed, and the performance data requirements contained in a new Military Specification for concrete bonding compounds are listed.

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BONDING MATERIALS FOR INTERIOR FINISHES: THEIR PROPERTIES, APPLICATIONS AND FUTURE
By Phyllis H. Larsen, Larsen Products Corp.

The role of synthetic resins in the development of the modern bonding materials is noted in tracing the history of these compounds and their widening use in construction. Three steps essential to successful bonding operations are set forth and illustrated. Various present-day applications of bonding agents in both construction and renovation of buildings are detailed, and attention is called to the cost saving possible. A heavy-duty type of bonding with PVA emulsion type material for use in supporting 75-ton milling machines, and in the construction of underground ballistic missile launching pads are cited as trends toward future uses.

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THE USE AND ECONOMICS OF BONDING AGENTS FOR STRUCTURAL APPLICATIONS
By John W. Davis, Lacy, Atherton & Davis

The author names the two most common uses of bonding agents in building construction today as: 1) lamination of metals, concrete, wood, insulation and other materials for panel construction; and 2) bonding of various cementitious finishes to concrete or masonry structures for interior design. The uses of structural bonding agents in building construction, he finds, are either for repair and restoration, or for research and experimentation. Cases of such are then detailed and the degree of success achieved in each is noted. Limitations imposed by temperature variations are mentioned, and it is pointed out that the economics of each application must be studied in terms of the individual job, acceptance by building codes and underwriters, etc.

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CHARACTERISTICS AND PROPERTIES OF STRUCTURAL BONDING AGENTS FOR CEMENTITIOUS MATERIALS
By Raymond J. Schutz, Sika Chemical Corp.

Bonding agents for cementitious materials are analyzed in terms of two types: those for bonding plastic materials to hardened materials, and those for bonding hardened materials to hardened materials. Formulation and mixing of the two-part compounds are discussed, along with the effect of temperature on curing time. Typical application procedure is detailed and illustrated and four different types of applications are listed.

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CURRENT PRACTICES IN BONDING OF GYPSUM DRYWALL
By C.E. Kallem, Hollenbeck Drywall Associates, Inc.

The size and scope of the gypsum drywall industry and its tremendous growth over the past few years are noted. The author then cites the need for development of more versatile adhesives to serve this industry, and also the need for specifications in this field. Four ways in which the adhesive industry could contribute to further progress are enumerated, all of which would help to save time and labor.

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ATTACHMENT OF GYPSUM DRYWALL BOARDS TO STUDS
By Alex O'Hare, Miracle Adhesives Corp.

While research has shown that better nails, properly dried studs and careful workmanship will help overcome the problem of nail popping in gypsum drywall construction, it is felt that all of these precautions still will not offer a positive cure. It is the industry's goal to eliminate all nails from the face of the wallboard, but currently the author points out that the "adhesive-nail-on" system is the best practical answer. This system is described, as well as various successful methods for applying the adhesive, and its role in reducing substantially the number of nails necessary for the average job is noted.

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LAMINATION OF GYPSUM DRYWALL
By Rodney G. Buergin, National Gypsum Co.

Three systems using multiple layers of gypsum wallboard are described, and three types of adhesives for this purpose now in common use are discussed: the tape joint adhesive, the mastic type, and the contact bond adhesive. Limitations of these are cited, leading to recommendation of nine separate properties required in an adhesive which would be considered ideal for the purposes.

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JOINT FINISHING AND NAIL SPOTTING
By Granville G. Waggoner, Drywall Company, Inc.

The operations involved in joint finishing for drywall construction are detailed and the process of nail spotting described. The desired characteristics of adhesives used for joint finishing are enumerated, and the present waste of time and money involved with achieving a perfect job are cited. The author urges further research in materials, methods, procedures and tools.

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FUTURE POSSIBILITIES AND RESEARCH NEEDS
By Roger K. Humke, Minnesota Mining & Manufacturing Co.

Interpretation from the standpoint of the adhesives manufacturer of the long-range requirements for adhesives in the building industry in general, as well as for use in drywall construction is presented. Development of the new film type adhesives is discussed and some of the uses of the double-faced films are noted. New methods of effecting rapid curing of adhesives, and efforts being made by manufacturers to explore different types of curing agents such as heat, steam, ultrasonics, etc., are detailed. The highly reactive, two-part compounds, and the use of proportioning units and guns are indicated as leading to some revolutionary developments for the future. The author predicts that an acceptable adhesive which will eliminate any need for nails in drywall construction will be available in the very near future. Builders, contractors, board manufacturers and others in the field are urged to cooperate in field testing of new adhesive products to speed the development of a more perfect system that is also competitive in cost with conventional methods.

# Foreword

By George J. Schulte,*
Marketing Supervisor, Adhesives, Coatings and Sealers,
Minnesota Mining & Manufacturing Co.

This conference on "Adhesives in Building" should provide another link in the chain of better understanding between the adhesives industry and the building industry. This is the real purpose behind these conferences. They serve to encourage one industry to cooperate with another to advance the technology of the building industry as a whole.

Our BRI Planning Committee has organized a number of BRI conferences, but the one which laid the groundwork for this meeting, and possibly others, was the December 1957 conference on "Adhesives and Sealants in Building." That meeting touched on many of the applications for adhesives and sealants in the building industry. Among the subjects covered were laminated wood structural members, and bonding agents for cementitious materials. The Committee felt that these subjects were worthy of further BRI Conference time as they represented new and growing fields for adhesives. Sections of these proceedings dealing with "Lamination of Structural Timber Beams" and "Bonding of Cementitious Materials" provide some challenging targets for adhesive manufacturers.

The third subject of this conference, "Bonding of Gypsum Drywall Construction," promises to be a very important new area for adhesives and joint-filling sealers. In this section, gypsum drywall contractors, gypsum wallboard manufacturers, home builders and adhesive manufacturers outline the adhesive needs of the industry and plan future cooperation in developing adhesives for drywall.

*GEORGE J. SCHULTE is chairman of the BRI Planning Committee on Adhesives and Sealants in Building which developed the program for this conference; B.S. in Chemical Engineering, Michigan State University; M.A. in Marketing, Wayne State University; Member of American Chemical Society, American Marketing Association and Building Research Institute.

# LAMINATION OF STRUCTURAL TIMBER BEAMS

Chairman - Frank J. Hanrahan
Executive Vice President
American Institute of Timber Construction

# Introduction

By Frank J. Hanrahan,* Executive Vice-President,
American Institute of Timber Construction

The use of laminated structural timber in most types of building construction is growing very rapidly. As a new industry, we are continually searching for better and more economical ways of improving our present products.

Some of our problems and indications of possible solutions are here discussed by experts in various phases of the field, particularly problems relating to adhesives and sealants.

We hope that by frank discussion and the presentation of new knowledge and ideas, those attending the conference and reading the proceedings will be stimulated to conduct research and assist in other ways in advancing the art of building construction—particularly in the structural laminated timber field.

*FRANK J. HANRAHAN graduated in engineering from Purdue University; registered Professional Engineer in two states; Member of more than 50 national societies and associations, including Building Officials Conference of America, Building Research Institute, National Fire Protection Association and National Lumber Manufacturers Association; formerly chief engineer for NLMA and author of national design specifications for stress-grade lumber and its fastenings.

# Structural Lamination Today

By Ward Mayer,* Chairman of the Board,
Timber Structures, Inc.

This paper will present a review of the current status of the structural timber laminating industry to provide a general orientation on the materials, methods, markets and future potentials of this industry. The accompanying figures illustrate the end product and its use in today's construction, and provide a reasonably accurate cross-section of what is being done in structural glue laminated timbers today. Obviously, this material, commonly called "glulam," is a medium of wide versatility and one which offers the architect many ways of expressing his conceptions.

Materials

In the United States the wood used for this purpose, with the exception of some shipwork and specialties, is in general from the softwood forests, principally Douglas fir and Southern pine. These two species have, to date, provided the best measure of economy combined with strength and appearance.

Laminations are generally in lumber thicknesses of 1" and 2" nominal, as contrasted with the fractional thicknesses used to make plywood. Also, the grain of the successive laminations used to build up structural laminated timbers is parallel, rather than cross-banded as in plywood. This is to gain greatest strength in the long direction of use in service.

Glue, or rather adhesive, is the bonding material. Currently the workhorse is casein with mold inhibitor. From a service standpoint, the standard brands of this material have proved very satisfactory for interior locations. This adhesive also possesses moisture resistant quality in considerable degree, but for members which are to be permanently exposed to the weather in service, or for other conditions imposing high humidity, or in case of uncertainty as to end use, certain resin glues are employed so as to insure permanence of bond.

Neither the casein nor the resin adhesives are as yet ideal from the structural timber laminator's viewpoint. Casein adhesives are, compared to the fully waterproof types, much the more reasonable in cost. They also afford a reasonable length of time for the laying up of extensive assemblies of laminations. Their fault lies in the long periods for which they must remain under clamp, and in their restriction to sheltered use of the product in service.

On the other hand, the resin glues used for waterproof bonding are very expensive and, with some exceptions, require as long or longer a time under clamp as casein. Properly cured, they do produce a permanent bond for service of the product under either wet or dry conditions, thus eliminating certain restrictions as to end use.

Without attempting to go into detail, may I suggest that the most needed improvements in adhesives lie in the reduction of cost of the fully waterproof types, and special

*WARD MAYER is President, American Institute of Timber Construction; Director, West Coast Lumbermen's Association; Member of Economic Council of the Lumber Industry and National Lumber Manufacturers Association.

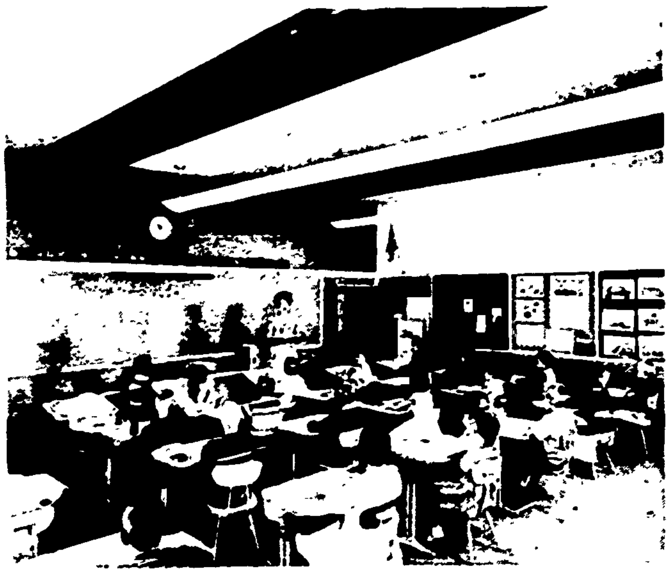

Fig. 1 - Laminated beams are used entensively in one-story school rooms.

Fig. 2 - Glulam arches and heavy timber construction in church structures.

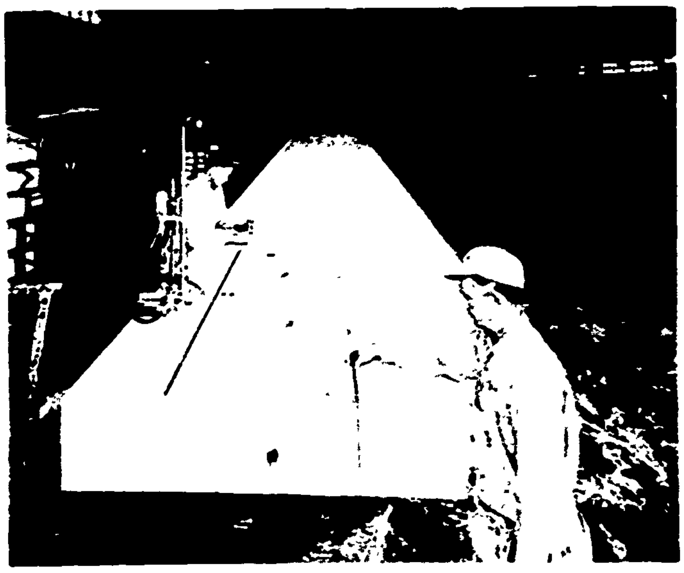

Fig. 3 - Glulam girder 12-1/2" x 71-1/2" x 103' going through 78" x 40" planer.

attention to contact or other formulations especially directed toward less wasteful structural end jointing of laminations. These are, in both instances, areas well worth exploring.

In such exploration it should be remembered that though plywood uses more adhesive per thousand board feet of lumber and thus affords a greater volume market to the adhesive manufacturer, the two products are similar only in the fact that both are made of wood and glue.

In general, though frequently used in conjunction with each other, they serve differing purposes. Methods of manufacture and marketing are radically different. The point I desire to make is that exploration and research for the adhesive best suited to structural timber laminating should be performed solely with that particular end product in mind, rather than plywood or other uses as well.

## Methods

In a discussion of methods, it is essential to include some consideration of markets and of selling. Structural timber laminating today is almost exclusively a custom business. As a matter of fact, the very basis of the wide acceptance and use of the material by architects has been the ability of the laminators to make it available in whatever form or size the architect may conceive. For the first time, architects have had wood which could be made to flow into contours and still achieve their three cardinal purposes, strength, beauty and economy, all in the one piece. Architects are individualists and they welcome materials which do not restrict their freedom of expression.

This is not to say that production-line methods are not, or cannot, be used. They can be, and are used, but they are only possible to the extent that they can be applied to a custom order file of wide variety. Orders run from a few to many pieces, and in great diversity as to size, shape, capacity and appearance. Methods must therefore be versatile. The basic requirements of production are space, shelter, suitable materials, pressures, temperatures and humidities, skilled labor and, above all, experienced, competent and conscientious supervision plus integrity of the laminator himself.

Most structural laminators today buy their materials, including lumber, on the open market. Some are departments of, or closely associated with, producers of lumber and owners of forests. However, structural laminating is a specialty business, involving engineering and sales problems, as well as problems of production which differ from those of the basic lumber producer.

## Potential

We come now to the oft-abused phrase, "future potential." Any remarks along these lines are purely conjectural. The glulam industry does not yet have reliable statistics upon which to base dependable projections into the future. It does seem apparent that there is currently a decided renaissance in the use of wood and that it has, in good part, been sparked by the development of structural glued laminated timber. The National Wood Promotion Program of the National Lumber Manufacturers Association is carrying the message of wood with increasing force through national advertising and by other means. The forests are being more intelligently harvested and renewed, and more completely utilized. These things are certainly favorable to future development.

Any attempted projection must take into consideration methods as well as markets. Today's methods of structural laminating on a custom basis are reasonably efficient, varying in some degree, according to the individual plant. There are, of course, areas for improvement and, with the keen competition already existing in this industry, solutions to problems will evolve, and should facilitate, growth of the industry. However, in the custom laminating business, the total of such areas does not bear sufficient proportion to the whole cost to justify any expectation of startling growth from that factor alone.

Constant promotion, dissemination of knowledge, and educated selling of the product are the things which will insure stability and growth. That the laminators themselves have faith in the future is evidenced by their formation and support of the American Institute of Timber Construction, to which they devote very substantial financial support, and much technical skill and knowledge from their engineering and administrative staffs.

This organization, in existence now some eight years, has been and will continue to be a force for progress in wise use of wood for structural purposes. Through it, essential standards have been provided and, under Mr. Frank Hanrahan, executive vice-president, the AITC in cooperation with other interested organizations is continuously advancing the cause of wood, stressing particularly the wise use of the material.

Currently, one of AITC's major objectives is a commercial standard for glued laminated structural timber. Writing has proceeded through some twelve drafts and two years' time, and is now approaching the stage of being circulated to the industry for comment. We hope to have the Department of Commerce printing of the standard completed within the current year, thus establishing basic minimums for design and manufacturing which will provide the architect and/or other specifier with additional assurance and authority when he calls for the material.

Standard quality control will be required of each individual plant, and further insured by an impartial surveillance system. The establishment of this commercial standard should have a favorable effect on the stability and growth of the industry.

Though I have stressed the fact that today's structural timber laminating is a custom business, and have indicated a belief that for the architect's requirements it will so continue, I by no means intend any assumption that other developments may not occur which can increase the scope and growth of lumber and timber laminating as a whole, irrespective of the custom feature.

Incidentally, lumber and timber laminating, are two very different things, though frequently confused one with the other. Lumber laminating, namely edge and/or end gluing to produce wider and/or longer lumber, for the purpose of salvage, raising values, or meeting special market requirements, has been with us a long time. Machines with which to accomplish this work have been improved and the usage will probably increase.

Lumber laminating also includes more recent developments such as studs made by laminating two 1 x 4's, heavy decking by laminating two 2 x 6's, and other specialties. There is good reason to anticipate growth in these and similar areas, wherever a profitable market is found to justify the cost of the specialized machinery and techniques required to assure production at prices competitive with other materials. Volume and automatic machine processes are essential to this avenue of development.

Structural timber laminating, on the other hand, is the laminating of lumber into timbers. Nothing less than four laminations is considered structural. This work may be straight or curved, long or short, four laminations or a hundred, glued for wet service conditions or dry—all in the same day's work. A given order may be for very few pieces or for a considerable quantity. Of one thing we may be sure—variety. Currently at least, this is, in very major degree, a material which is first sold and then made, therefore the applied term, "custom business."

Obviously, the mere existence of today's customs does not in itself say that tomorrow's will be the same. Research and experimentation are under way on machine laminating in the structural field, as well as in lumber preparation. At least one company has for years produced curved barn rafters by a continuous press method, which exudes a finished product in continuous flow, requiring only cutting to length as desired. Machines are employed for gluing laminations end to end. Recent experiments at Washington State University have produced a pilot machine using glue film and wood surface preheating to laminate beams.

Whether the future will see these or other machines developed to a point of versatility in keeping with the needs of the comprehensive timber laminator is perhaps debatable. Certainly they may be developed for some part of the job. The point I wish to make is that differing adhesives, as well as methods and the requisite supporting economics, are and will be required for both custom and machine production. Research in both is highly desirable.

Experimentation is also under way as to potential sales justification for inventories or pilot stocks of basic sizes of residential beams. One of the principal difficulties, from the investment, profit and loss side, is forecasting the sizes and lengths which this highly individualistic field may call for. Here again, the custom built feature is a factor, in that it does provide for more architectural flexibility and retains the attractive sales feature of providing whatever shape, size, or appearance the individual user may desire. In all probability there will evolve a place for both methods of marketing.

In the industrial field, there is also progress and experimentation in lines where there is sufficient demand for quantities of identical size and other requirements to justify the requisite plant investment to produce such items, within limits competitive with other materials. The same may prove true as to some sizes of lumber which are currently supplied in the form of sawn timbers. Currently, the price gap is wide, but a combination of growing demand and changes in utilization of the log may eventually reduce this gap to manageable proportions.

In the plywood field there is promotion of hollow beams, arches and other primary construction members utilizing both plywood and glued laminated timber. In the wood treating field there is also progress in protection of wood against its natural enemies. Where economically feasible to "make a good product better," or essential to the wise use of wood, this progress points to promise for the future.

Rather than attempt any estimate of future potential of the industry, I present these facts as being indicative of probable growth. The industry is alive, conscious of its problems and its responsibilities. The material has proved its rightful place among front-line building materials and, in my opinion, it will hold and probably improve that position.

Finally, I would like to convey to the Building Research Institute the thanks of our industry for its interest in some of our technical problems. The very fact of that interest is additional warranty of future progress.

# Adhesives in Use Today

By R.H. Bescher,* Assistant to the Vice-President and General Manager, Wood Preserving Division, Koppers Company, Inc.

The selection of an adhesive for structural laminating depends on the type of service the finished laminate will be expected to withstand. Consideration should be given to whether the finished laminate will be in the interior of a building or exposed to exterior conditions. The adhesive should not damage or weaken the wood. It should produce adhesive joints that are equal to, or greater than, the strength of the wood.

Other important considerations in the selection of an adhesive are: the species of wood, working or application characteristics of the adhesive, and the production facilities. Location of plant, type of production equipment, handling methods and present assembly variables all must be balanced against the use characteristics of the selected adhesive.

In structural laminating today three adhesives are the most widely used: casein, phenol-resorcinol and resorcinol adhesives.

Casein adhesive is classed as a water-resistant adhesive because of its relatively high moisture resistance compared to that of vegetable and animal glues. Its basic ingredient is milk protein which, when combined with alkaline chemicals, constitutes an adhesive. Prepared casein adhesive is supplied in the form of powder and, when mixed with water in the correct proportion, is ready for use. It sets as a result of chemical reaction and the loss of water to the wood and the air. If joints are well made, casein adhesive will develop the full strength of the wood, especially in the softwood species, and will retain a considerable portion of its strength even when submerged in water for a few days. Where continued exposure to outdoor conditions is involved, casein adhesives are not recommended.

Casein adhesives in general have a storage life of one year or more when kept dry. Their working life varies with the different formulations, but it is usually at least five hours at 70° to 75°.

Phenol-resorcinol and resorcinol adhesives are made from phenol, resorcinol, formaldehyde and some type of filler. They are supplied in liquid form, with a liquid or powdered hardener supplied separately. The two components are mixed prior to use. On most species of wood, the joint strength is as great or greater than that of the wood. The cured glue joint is not affected by fresh or salt water, most acids, organic solvents, lubricating oils, or greases. Heat sufficient to char the wood will not degrade the bond to any greater degree than it does the wood itself.

Where maximum durability is required, as in outdoor exposure under the extremes of high and low humidity, and high and low temperatures, the choice would be resorcinol or phenol-modified resorcinol adhesives. Work over the past few years has shown that these adhesives perform very well in the bonding of treated woods. The

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bonding of the more recently developed fire retardant woods is more difficult but recent studies indicate progress in this application.

In general, the resorcinol and phenol-modified resorcinol adhesives have a storage life of one year or more when stored at room temperature. Working life of these adhesives varies between two and six hours depending on the adhesive temperature.

Melamine adhesives are used in structural laminating, but to a lesser extent than the three adhesives previously mentioned. Most melamine adhesives are supplied as powders and are prepared for use by adding water. Adhesive joints that are well made have excellent resistance to weathering, high temperatures, and high humidities. Higher temperatures are required for cure of the melamine adhesive than the previously mentioned adhesives. Working life of melamine adhesives range from two to 36 hours depending on the formulation. The storage life of melamine adhesives is six months to a year or more.

With the increasing shortage of timber of the necessary widths and lengths to produce these large laminates, a considerable amount of edge gluing and end gluing has been done in the past few years. The use of edge glued lumber and the placement of end glued joints in large structural laminates is regulated by design strength requirements. Plain scarf joints have been the most commonly accepted type of end joint.

Considerable work is being done by the industry on better methods for producing end joints, with the objectives of further savings in lumber, faster production cycles, and effecting a stronger scarf joint. The adhesives currently used and mentioned earlier can be used in the production of the end and edge joints, but faster curing, waterproof adhesives at low temperatures would be desirable from the laminator's viewpoint. Development work is currently underway to produce waterproof adhesives to meet this rapidly increasing demand for faster production of end and edge glued lumber at normal temperatures.

In addition to selecting the proper glue to withstand the service requirements of the finished laminate, we should remember that the quality of a glued laminate depends not only on the adhesive but on good control of the production process used to assemble the laminated member.

# New Adhesive Needs for Structural Timber Laminating

By Maurice J. Rhude,* Chief Engineer,
Unit Structures, Inc.

The combination of wood and adhesive has advanced greatly, the last 25 years, the returning of heavy timber construction to the building industry. Wood is the greatest renewable resource in the building materials field and is continually being improved and refined for particular needs. Adhesives exist for thousands of uses, but the ideal adhesive for a specific wood-bonding job has not yet been developed. If we can define that specific job, and then clearly state what we expect of an adhesive, there are somewhere the research funds and the talent to design that ideal adhesive for us.

## Design for Materials to be Bonded

"Laying the keel" for any discussion of adhesive needs by our industry requires, first, a look at the wood itself. In fact, whether we are choosing an adhesive from the adhesive manufacturer's present list, searching for modifications to them, or for new adhesives, consideration must be given to the material to be bonded.

The cellular structure of wood is responsible to a considerable degree for its characteristic differences as a structural material. This fact should be considered when searching for the right adhesive. Most structural materials are essentially isotropic, with approximately equal properties in all directions. Wood is not isotropic. There are three recognized wood grain directions, longitudinal, radial and tangential. High strength and stiffness exist parallel to the grain, with the strength across the grain being considerably lower. Wood strength in tension parallel to grain is 25-40 times the tension perpendicular to grain strength, and the strength in compression parallel to grain is 6-10 times the compression perpendicular to strain strength. Wood has not a single modulus of elasticity, but three, varying as much as 150 to one.

Wood is also unlike most structural materials in regard to the reason for its dimensional changes. The thermal expansion of wood is so small as to be unimportant in ordinary usage. Changes in dimension are from gain or loss of moisture. Dimensional stability, then, refers to the ability of the wood to withstand swelling and shrinking caused by moisture changes. The total swelling and shrinking of wood also varies in the three structural directions, being about 6-16% tangentially, 3-7% radially, and only 0.1-0.3% longitudinally.

Parallel to grain, wood is strong, stiff and very dimensionally stable. Across the grain it has its lowest strength, it is not stiff, and there can be problems with dimensional stability.

Would it be possible to develop an adhesive with directional properties? Structural designs in wood must be both strong and stiff. A rigid adhesive is needed to bond the laminations together, as deflection frequently will govern in a design. Both strength and stiffness of the adhesive are factors that will affect the performance of a glued joint.

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Wood has well known and excellent impact resisting properties. Very rigid adhesives may fail under impact; a rubbery adhesive may be objectionable from the standpoint of creep and low strength. Ideally, the modulus of elasticity of the adhesive should be the same as that of the wood. Obviously, some compromise between the two extremes would be the most suitable adhesive.

## Design for Type of Joint

Joints should be designed so that all of the bonded area carries load at the same time. The stress distributing ability of the adhesive can then impart flexibility to the joint and provide good fatigue properties. Adhesive properties desirable during fabrication vary with the type of gluing to be done. Bonding side grain to side grain is the most common and simplest gluing operation. The gluing area may be but a few square inches, or it may be hundreds of square feet, depending on the length of the member to be glued and the number of glue lines.

Edge gluing to make wider boards of narrow lumber is a similar operation to bonding side grain to side grain.

The gluing of end grain to end grain to make longer boards of short ones presents the greatest problem, because it is the most difficult surface to machine, and the most difficult gluing task for the adhesive. The production of a strong and durable bond upon surfaces containing the cut-off ends of thousands of small, hollow wood fibers is a real challenge.

These end joints are not large surfaces, varying from the long plane scarf to the short finger joint. Good strength ratios are possible with plane scarf joints; much work is being done to improve the design and fabrication of the finger joint, since it is so much less wasteful of material.

The end joint, while the most difficult gluing problem, fortunately holds the best promise for early adhesive improvements. The need for an adhesive with a long pot life, with appreciable assembly time, does not exist. A fast-curing, room-temperature setting adhesive for end joints is needed and the possibility of having it soon is excellent.

## Design for Fabrication Process

When designing an adhesive for the fabrication process, we must consider the surface preparation of the materials to be bonded, the method of adhesive application, and the heat and pressure to be used in curing. Furthermore, the adhesive must not damage or weaken the wood and it should permit machining of the finished product without serious damage to surfacing equipment.

Materials to be bonded must be clean. The adhesive must stick to the bonding surfaces, with the liquid adhesive having the physical property of wetting the surface under the proposed method of application.

Time and temperature play vital roles in almost all gluing work. Setting of the synthetic resin adhesives is faster at the higher temperatures; a rule of thumb exists that a rise in temperature of 18°F doubles the rate at which the chemical action of setting takes place. This temperature sensitivity is a two-way factor. We want a long pot life and a short setting time. A low temperature helps the first and hinders the second. Temperature is therefore both ally and enemy of the laminator. One procedure is to keep the adhesive cool in storage, apply it to the mating surfaces at temperatures consistent with the assembly times required or desired, and then later heat the glue lines when the member is in the clamps under pressure. The spread adhesive film is small indeed compared to the large volume of wood, and cool adhesive placed on warm wood will quickly reach the temperature of the wood and have a decreased setting time. Conversely, cold wood slows down the reactivity of the adhesive. A lengthened clamping time will be required to allow any elevated ambient air temperatures to penetrate the wood, reach the glue line, and cause it to set. Application of heat to a laminated member is only to set the adhesive, and temperature effects take place only when the temperature reaches the glue line.

Gluing equipment must consider this time-temperature relationship if it is to approach perfection. Any rapid method of laminating must reduce the time under pressure; heat is often utilized to accelerate the adhesive cure. The adhesive selected, and the time and temperature for curing, determine the automation possible in laminating.

One way of classifying adhesives is the bonding temperature required. Wood is an excellent insulator. This means that heat being brought to the wood surface will require some period of time to reach the innermost glue line. Is a room temperature ($68^{\circ}$-$86^{\circ}$F) or an elevated temperature best for curing?

Several methods are used in structural laminating to bring elevated temperatures to the glue line:

1) Heat is applied to the surface of the member with the thermal conductivity of the wood being relied upon to take the heat to the glue line. Special curing chambers with steam or hot water pipes, dry kilns, electric infra-red radiant heating, and hot press platens have been used.

2) Radio frequency is used where voltage is applied across the material and heat is generated in the wood or glue line itself due to the excitation of the molecules at this very high frequency.

3) Low voltage resistance heating is employed where a high current is passed through a strip of thin metal. The temperature of the wood is raised, and also the temperature of the glue line, if the metal is in close contact with it.

4) Wood is preheated to increase the reactivity of the adhesive when applied. This requires rapid handling of multiple laminations and adhesive application, as a wet or dry film, simultaneously to all laminations. This method has not proven satisfactory with present adhesives because laminations preheated to a high temperature level result in very critical assembly times.

Curing the adhesive at room temperature has several advantages:

1) The good insulating properties of wood need not be working against us.

2) The equipment mentioned previously for bringing elevated temperatures to the glue line are not required.

3) There are no elevated temperatures to consider, as far as possible injury to the wood is concerned.

The combined efforts of the laminator, adhesive manufacturer and equipment manufacturer are going to develop fast-setting, room-temperature curing adhesives and the required facilities and production procedures.

Design for Condition of Service

The correct adhesive for structural glued laminated timber is one that maintains an adequate bond between the laminations for the conditions of exposure to which the joint will be subjected.

"Water-resistant" and "waterproof" have been used in the past to describe respectively the casein and the modified phenol-resorcinols, the two workhorses of the laminating industry. Waterproof adhesives are those required for wet use service conditions where the glue line is subjected to exposure to free water, or where the relative humidity of the air is such that the adjacent wood can go to the 16% moisture content level or more.

This means a relative humidity about 80% or above for repeated or prolonged periods. Water-resistant adhesives for dry use service conditions perform adequately when the wood has a moisture content less than 16%.

These conditions of service must be sufficiently well known to be specifiable. Then the most suitable adhesive can be selected. Stating that "all beams with all or part exposed to the weather shall be laminated of waterproof adhesive" is an inadequate description of a condition of service. Reference to the condition of use as "interior" or "exterior" is also certainly not adequate.

An adhesive should have only those properties which are required for the particular job. It is needless to specify resistance to water, when water or moisture will never touch the adhesive. A high strength adhesive is not necessary to adhere a weak material to a strong material when a lower strength and lower cost adhesive will do the job.

In most cases, the adhesive must be durable under changing relative humidities, as well as high and low wood moisture contents. It must be resistant to bacteria, molds, other decay organisms, heat and cold, and be compatible with various preservatives and fire-retardant chemicals.

Wood can be a permanent material for all construction purposes. The adhesive must be equally as resistant to deterioration as the wood itself. Any superior resistance on the part of the adhesive will not extend the life of the wood.

We will continue to search for better adhesives for wood. When these are found, we will look to improvement of the wood, because the adhesive may now be more resistant than the wood. Preservative chemicals are the answer and, when these are used, better adhesives will be required so that they will be compatible with these chemicals.

## Design for Level of Initial Joint Strength

Initial joint strength must be of such a level that it allows handling of the assembly when removed from clamp pressure. This initial strength at time of removal from the clamps may be but a fraction of the ultimate strength. Prior to machining or other rough handling, there could well be an extended time for bond strength development. In other cases, good bond strength may be required when the assembly is removed from the clamps because the assembly is going to be placed in service immediately. Since different levels of initial joint strength are required for various laminated products, it does not appear proper to design all adhesives alike in this respect.

## Design to Meet Laboratory Tests

In most cases, the bonding strength of the adhesive must be as great as that of the wood in shear parallel to the grain, or tension perpendicular to grain. Block shear, parallel to grain, is the usual physical test used to evaluate this bond. Such a strength test should not be basically a tension perpendicular to grain test, as it will be testing the wood rather than the adhesive. Tension perpendicular is the property of wood in which it has its lowest strength. Laboratory test procedures have been devised to test the adhesive and the wood, acting together, to withstand stress due to dimensional changes. Such procedures involve subjecting the glue lines to a series of differing temperatures, humidities and moisture conditions, usually on a cyclic basis. The test is a cyclic delamination test.

Tests should not be so severe that they are beyond performance requirements. They would then result in the selection of an adhesive much too expensive for the job to be done. Undertesting could be equally ineffective.

## Design for Cost

Cost is a factor in choosing any adhesive. The right adhesive is the one that will do the job, with an adequate margin of safety, at the lowest possible cost. A borderline adhesive that causes a lot of rejects is expensive regardless of its price. Adhesives must be capable of withstanding certain abuse by the contractor and the building owner. While an adhesive may be satisfactory under favorable conditions, it may have nothing in reserve to handle variations in bonding techniques, excessive humidity or unusual service conditions.

A cost of $10-$15 per pound may not be unreasonable if the job can not be done with other fastening methods. Such is the case in the aircraft and missile fields, where the standard joke is "We'd use gold if it would stick."

What price adhesives does the laminating industry require? Too often we state that new adhesives cannot be tried because of the high cost. On the other hand, the adhesive manufacturer states that he cannot afford to give consideration to new wood adhesives unless we pay higher prices. Most of his adhesives start out being expensive and, as the volume goes up, the price goes down. Every new chemical must pay its way.

Present adhesives used by the laminating industry cost from less than 1¢ per sq. ft. for casein, to approximately 3¢ for the phenol-resorcinols and 5¢ for the straight resorcinols.

Although not used to any extent, the ureas and phenolics run as low in cost as the casein. Contact cements are in the 3-5¢ per sq ft class. There are still other adhesives that might be considered, also not presently used, which cost well over $1.00 per sq ft.

## Future Design Considerations

A perfect adhesive would glue wood end grain to end grain; glue equally well all the species; produce strong, stiff and durable joints; have considerable gap-filling properties; cure upon contact with little or no pressure; allow long pot life and assembly time but set instantly after being clamped; be tolerant of temperatures over a wide range; come ready-mixed from the adhesive manufacturer; and be compatible with wood preservative chemicals. Utopia is still a long journey down the road.

At present we must sacrifice some desirable properties to obtain other essential properties in an adhesive. The material to be bonded, the type of joint, the fabrication process, the condition of service, the level of initial joint strength, the laboratory tests to meet, and the cost must all be considered in selecting an adhesive for a particular use. There is no perfect adhesive which will do all the gluing jobs with equal effectiveness. The final choice of adhesive for a specific job will usually be a compromise of the several factors involved.

Adhesives should be tailor-made to the specific job, or even to the individual plant and its facilities and procedures. Processing techniques, skill of workers and local temperature and humidity conditions may well mean that an adhesive which performs to our satisfaction under the conditions of one plant may be totally inadequate for another. This can be true even though the two plants are manufacturing the same product in what may outwardly appear to be the same manner.

The ability of an adhesive manufacturer to help solve a particular plant's bonding problems depends upon his understanding of the facts in the problem. High strength may mean 5 psi to one industry, 5,000 psi to another. Even the word strength means little unless the type of strength is indicated. High heat resistance may mean the boiling point of water to one person, and the 500°F range to the aircraft or missile manufacturer. Room temperature may mean many things to different people. The laminator must adequately define these performance requirements for the adhesive manufacturer.

We can say that there are two approaches to this problem of new adhesives. Shall the approach be short-range, where present adhesives are used in combination with each other to obtain the best characteristics of each, or shall the approach be long-range, where we search for a new chemical?

Today there is a definite movement in the direction of the thermosetting resin adhesives which maintain high bond strengths under extremes of service. These are two-part adhesives with the chemical activator added at the time of use.

Some of the "blue-sky" thinking in adhesive research envisions:

1) One-part adhesives with a latent catalyst that calls for heat to trigger the chemical reaction.

2) Two-part systems where one part is placed on each piece to be joined and the pieces are then brought together.

3) A thermosetting compound in a contact cement, using the contact cement to hold the surfaces in position until the adhesive sets.

4) A compounding of high molecular weight elastomeric materials with low molecular weight phenolics.

5) Encapsulated materials where clamping pressure triggers the chemical reaction.

6) Spraying the adhesive as a two-part system, with mixing taking place in the air just before contact with the wood.

7) Spraying the two parts separately onto the two pieces to be joined and then assembling the two pieces.

8) An adhesive with directional properties, rigid in one direction, flexible in the other.

9) Materials which are stable in a mass but are unstable and chemically reactive when spread as thin films.

10) Adhesive in mastic form squeezed from a tube like toothpaste.

The performance of an adhesive for structural glued laminated timber must be a lot more than just "sticking things together." The adhesive must be strong and rigid, able to resist stress and creep, durable so as to withstand weather, moisture, temperature changes, mold and chemical action over a long period, and be compatible with wood and its preservative and fire retardant treatment chemicals.

# Production Testing Problems with Present Materials

By R. E. Wirth,* Executive Staff,
Rilco Laminated Products

The structural wood laminating industry is gradually developing uniform product qualification methods and establishing performance standards. For most operators, this will eventually lead to complete quality control by continuous surveillance over design, raw materials, process capability and control, production control, and finished product inspection. The products, generally, become the basic structural frames for all types of buildings and therefore perform primarily in the protection of life and property. Since no practical non-destructive tests exist for evaluating the finished members, it is essential to provide continuous evaluation and control of individual components and procedures within the limits of proven standards.

For the purpose of this discussion, the usual testing program maintained by a laminator might be divided into three categories: evaluation of product and process capability, testing and control of raw materials, and surveillance of process and production control. Although the subject concerns, primarily, testing for production control, it is essential to consider briefly some of those tests made intermittently on production sampling to assure that the product itself is uniformly in conformance with the standards.

## Evaluation of Product and Process Capability

In order to evaluate the product and process capability, it is necessary to provide in the standards numerical values required by design, to which test results of production sampling can be compared. Testing in this category requires controlled procedures to develop actual values, and is ordinarily done intermittently or as required by changes in materials or processes. Allowable working stresses are established for the wood, and adherence to grading rules accomplishes a specific comparison to the standard. Strength and durability criteria for adhesives are established by the industry and these data also provide means of measurement and comparison to performance standards. Products in which varied and different methods of face and end gluing have been used are tested under uniform procedures, and the results are compared to values set forth in established standards. Checking by statistical methods then proves or disproves for the capability of a process to achieve uniformly the values specified. The laminator generally accepts industry data regarding wood and adhesives but he must test to qualify the bonds produced in his own process of face and end joint gluing and to determine conformance with design standards.

Tests used universally in the industry for evaluation of face gluing are the standard ASTM block shear test (Fig. 1) and ASTM D1101-58 for accelerated aging (Fig. 2). Since there are many different methods in use for processing end joints, basic research should first establish the value of a specific scarf or end joint and determine that the process is capable of consistently producing the joint as tested. For scarfed end joints, these tests may be used except that for nonwaterproof bonds, the aging test would not apply. The problem involved here is that in neither of these tests is the stress applied

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Fig. 1 - Standard block shear test specimens indicate value of bond in terms of percent wood failure and shear strength of joint in psi.

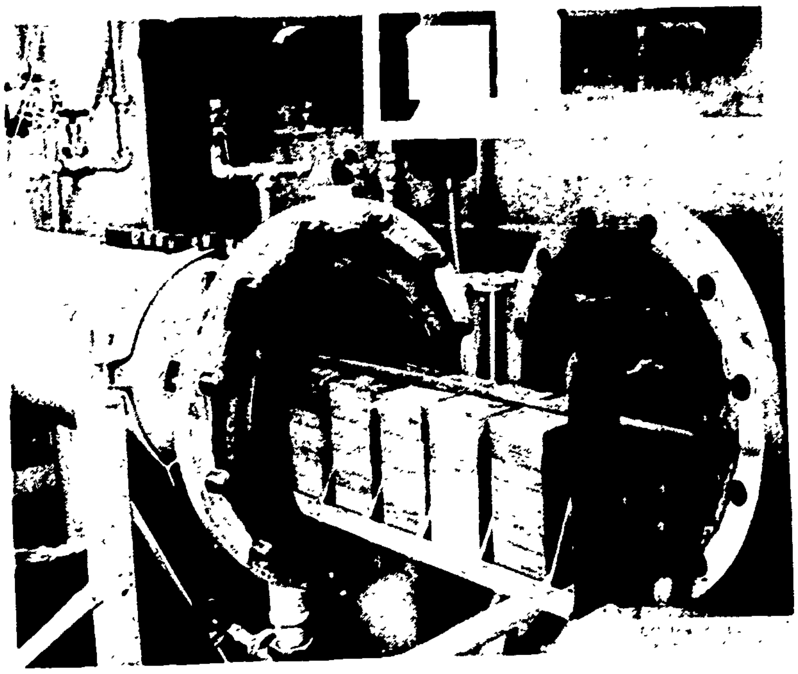

Fig. 2 - Laminated specimens are inserted in autoclave for ASTM D1101-58 delamination test.

to the glue line in the same manner as will result from design loads. Finger joints and others present special problems.

There is a need existing today in the industry for a uniform method of testing and evaluating end joints. One solution might be found in using a tension test, similar to ASTM D143-52, which is used for testing lumber in tension parallel to grain. This method is successfully used for testing scarfs in nominal 1" x 3" specimens, which were necked down to 1/4" x 3/4" section size in the area of the scarf joint. By using 1" x 3" control pieces cut from the same original board, the results compare the value of the joint with both the value of the solid wood and the design strength. A similar method for testing in direct tension parallel to grain has been used with promising results by L.M. Selbo at the Forest Products Laboratory in Madison, Wis. The samples cut from the scarf area are 3/32" x 3/4" x 4" and have uniform cross sectional shape throughout the length. The test load is tension parallel to grain. Other methods have been proposed and used to a limited extent but have not developed a considerable amount of interest for this purpose.

In some cases, the finished product is checked by examination of 5/32" diameter cores extracted by an increment borer driven into the member in a direction perpendicular to the plane of the glue line. Some indication as to the quality of glue lines can be observed from these cores; however, the size of the area observed is small and this test would constitute supporting information but not conclusive data.

In the category of testing the finished product, there is definite need for further procedures that might be adopted as uniform for the industry. Perhaps of considerable value would be increment cores of larger size, that would not exceed the size of allowable defects but would be large enough to allow measuring the shear value of the glue line. In the search for more comprehensive, nondestructive structural tests, there might be some possibility in supersonic flaw detection, or perhaps an adhesive additive that would provide selective influence on some activating medium.

Testing and Control of Raw Materials

The first requirement for attaining structural adequacy in a laminated member is lumber which has the strength to satisfy the design. The testing of lumber is not a normal procedure in the production of laminated members, but proper selection accomplished by visual inspection and grading is necessary to assure that all lumber meets the structural standards represented by the grading rules. Each piece must have the necessary percentage of good wood in any cross-sectional area. Defects are considered equally effective throughout the piece, and there is no tolerance permitting a percentage of pieces not meeting the strength requirements of the grade.

When the lumber is ready to enter the production process, the first actual testing is the determination of moisture content. This is ordinarily accomplished by instruments that indicate the amount of moisture present by its effect on electrical resistance or on an electro-magnetic field, and measured electronically. The problem is to control the lumber going into the product at the required average moisture content, and the control should be such that the gradient throughout the finished member does not exceed 5%. In this area, there is a need for a universal method of selecting lumber to control both the average moisture content and the gradient.

Two other problems facing the industry in lumber selection are worthy of considerable search for dependable solutions. One is involved in the grading of lumber to be used where working stresses require a certain density determination. It can be demonstrated that visual inspection and current grading procedures are ineffective for adequate control. As long as density within a specie has an influence in establishing working stresses, there is a definite need for more accurate determination of grading procedures. The second problem is finding a method for quickly and positively identifying timber breaks or areas in the wood where the wood fiber has been damaged by compression or tension failures that apparently occur when the tree falls. The occurrence of these defects is quite frequent, and it is easy to miss them in ordinary grading practices.

Equally as important as lumber selection is the evaluation of adhesives received from the supplier. Industry standards for structural adhesives presently require conformance to the military specifications MMM-A-125 for casein and MIL-A-397 for waterproof resin glues. Performance requirements in these specifications are based on use with white oak, hard maple and veneers. A number of problems are thus created, as the lumber used in the structural laminating industry is predominantly soft wood. The laminator, therefore, tends to accept the certification of the supplier for conformance to adhesive requirements and makes his own examination by testing the species he is using under actual plant conditions. This situation points out a need for the development of complete adhesive specifications for the commercial laminating industry that will not be affected by changes and specialized needs of military procurement. It would seem that this would encourage the adhesive manufacturers to direct more of their development work on adhesives toward this market.

When a fresh shipment of casein glue is received, a record is initiated to record performance data and maintain its identification with the manufacturer's batch number. A check is made on the working life in accordance with procedures set forth in specification MMM-A-125. Block shear tests are made in accordance with this specification or ASTM-D905-49 except that the hard woods specified are replaced with the specie of lumber that will be used in production. Minimum performance data for these tests may be found in the standards of the American Institute of Timber Construction, or in Bulletin 1069 published by the Forest Products Laboratory. Viscosity is checked and the batch record marked with any desirable change in the amount of water used in the mixture to bring the consistency of the mix to that which is best suited to the process. One of the problems inherent in the use of casein glue is the variability in viscosity from batch to batch, which necessitates some means of control to assure proper glue spread. In general, these procedures are adequate and create no serious problems for the laminator. There is a need, however, for a soak test to use with regular shear blocks to determine water resistance. The standard veneer specimens do not represent the conditions involved in structural lamination.

Waterproof resin adhesives are examined for conformance to MIL-A-397 and to any specific requirements of the laminator's process. A pot life test of each batch is made with controlled temperature for comparison with the specified requirement of the adhesive. Also, a pot life test is ordinarily made without any control of exotherm temperatures, which indicates the adhesive's adaptability to the specific process and is useful in scheduling the gluing operations. Samples from each batch are also submitted to accelerated aging tests for evaluation of durability. The procedure most commonly used is ASTM D1101-58. However, there are several modifications of this procedure which can be accomplished in much shorter time and appear to give equally dependable results. There is a definite need for a uniform procedure that might be completed within a period of 24 to 48 hours with accurate results.

All of the above procedures result in data expressed by numerical values, which may be compared to standards of performance and therefore are essential to the industry for establishing uniformity in standards.

## Process and Production Control

Production testing, sometimes termed "in-line testing of production" is the most important category as far as the laminating operation is concerned. The purpose is to compare representative samplings of daily production to specified standards. This must be done quickly and economically, so as not to interfere with production processes, and of more importance, to give results which can be interpreted and applied immediately to production and quality control. These tests are generally designed to indicate a minimum of performance that equals or exceeds the value specified in the standards. Since evaluation in terms of specific figures is not required, the tests have become somewhat empirical, as they are based on experience, and the effectiveness of their use is dependent largely on the skill and judgment of the operator.

Tests are included in routine procedures for the measurement of glue spread. Accurate determinations are made by weighing a sample piece of the lumber being used, before and after spreading with adhesive, and computing the results in terms of pounds per thousand square feet of glue line area. Another method accomplishes the same purpose by weighing the adhesive deposited on a piece of paper of known area that goes through the glue spreading operation on the face of the member and is subsequently weighed, with adjustments made to account for the thickness of the paper.

In most cases, pressure is applied by clamping systems that operate by means of threaded, screw-type bolts or rods, with nuts and pressure plates. The test for adequate pressure is ordinarily accomplished by placing a compressometer in a typical package and, with a torque wrench, determining the actual amount of torque necessary to produce the required pressure on the compressometer gage. When the clamps are tightened on the glued assemblies, the final turn or two is done with a torque wrench so the actual pressure under the clamp is known. The accuracy of this method is dependent upon the general condition of the screws and clamping paraphernalia. It is essential that the test set-up be actually representative of the clamped package when the requirements are determined. A much needed improvement in the gluing operation might be found in the development of an air operated impact wrench that would automatically cut out when the desired torque is reached.

In a typical laminating operation, there are certain procedures required which are closely related to in-line production testing, but are most often considered functions of production control. Several of these should be mentioned, since they are highly critical to a satisfactory product.

Scarf joints are examined for accuracy of form and machining by measurement with square and micrometer in addition to visual inspection of the surfaces. Checks are made with mating pieces assembled to assure intimate contact of the surfaces to be adhered, with no interference to full pressure over the glue area.

Control of glue line temperature for the curing cycle is an important function of production control when resin glues are being used. Ordinarily a heated chamber or other type of heating system is utilized to maintain ambient conditions about the clamped assemblies to induce elevated temperatures in the glue lines for proper polymerization. Expendable thermocouples are inserted at strategic points in innermost lines for determining temperature with a potentiometer. These readings are recorded at regular intervals throughout the curing cycle and become a permanent quality control record.

Fig. 3 - A potentiometer is connected to thermocouples inserted in glue lines to provide temperature readings indicating progress of cure.

The working life of both resin and casein adhesives is affected by temperature and relative humidity in the gluing room, and also by temperature and moisture content of the lumber. Measurement of these conditions is made for the purpose of adjusting time and to remain within effective working life of the glue.

After curing of the assemblies is completed, a number of different tests are used for determining the integrity of the glue bonds. There are two methods for gluing end joints. One method is to apply the glue, position the joint, and clamp it integrally for curing with the whole clamped assembly of full length laminations. The other is to glue the end joint separately and, after the glue has cured, surface the lamination full length, with the face gluing then being a separate operation. The problem in testing completed end joints is to get samples that are representative of a production run. While this is relatively simple when the end joints are preglued, it presents many difficulties when the joints are glued integrally. It is rarely possible to get an end joint for testing from the end trim of a completed member. Therefore, the method generally used is to make a sample assembly at the same time the main member is being put together. The glue spread, timing and cure can be controlled to represent conditions in the product quite closely. However, the pressure is influenced by variables surrounding each individual joint, and therefore might be questionable, as far as its representation of all other joints is concerned. The thickness of the lamination in the area of the end joint is critical and must be precisely controlled to assure pressure.

Several methods are in use for testing end joints. They are all designed to stress the glue joint area in some manner until it has completely failed, and evaluation of the glue joint is then made on the basis of how much failure occurred in the wood or glue. One method of accomplishing this task is commonly known as the torsion method (Figs. 4 and 5). Test pieces are sections of full size laminations, long enough to have a full size scarf joint in the center, with enough material left on either end to allow clamping outside of the scarfed area. One end is clamped in a fixed position and a lever is applied on the other end in such a manner that it may be twisted and the scarf opened up or the wood broken. Another method uses approximately the same test piece except that it is positioned to function as a simple beam in a device that loads it at third points until complete failure occurs. Evaluation of the glue bond is the same as above. Occasionally the standard ASTM block shear test is applied to end joints but, due to the difficulty in preparing representative samples, it is not often used for production testing.

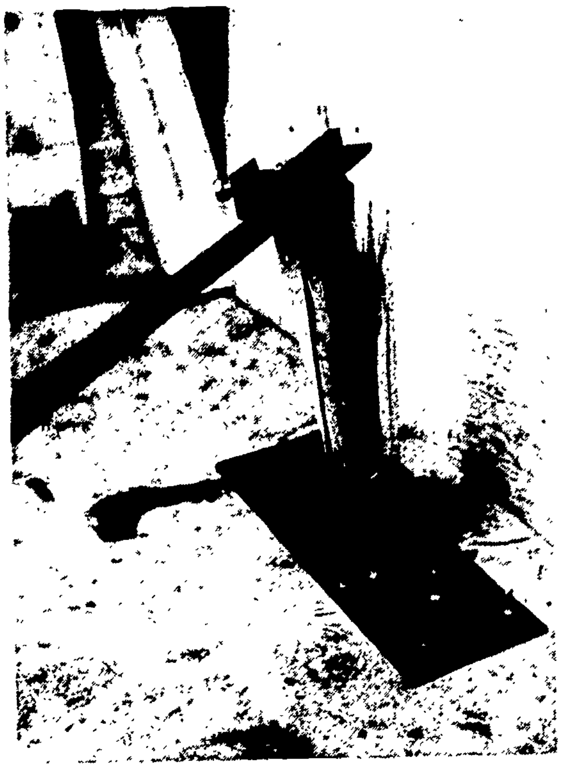

Fig. 4 - Breaking a scarf joint in a torsion test for determining amount of wood or glue failure.

Fig. 5 - A broken scarf joint showing practically all wood failure which indicated a good bond.

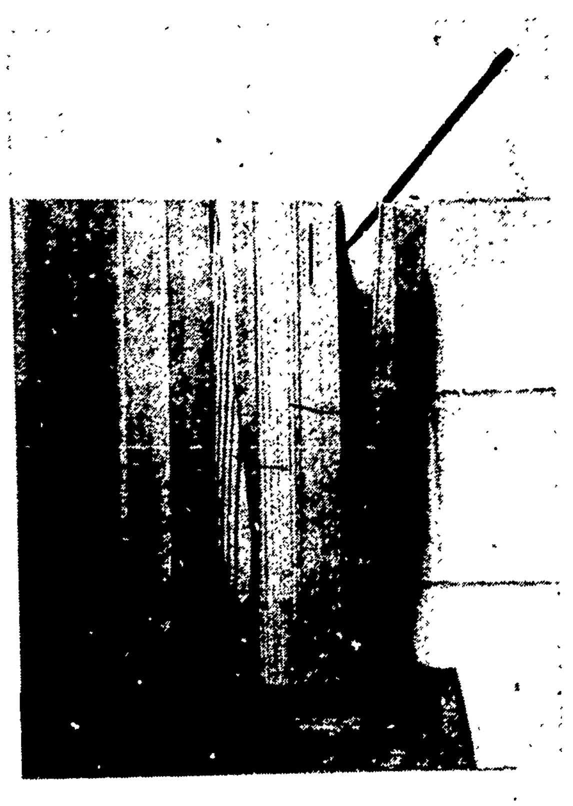

Fig. 6 - A wedge or chisel is driven into the glue line of a beam section to cause separation.

Fig. 7 - The surfaces exposed by wedging open a beam glue line show practically all wood failure indicating an adequate bond.

The major problem in end joint testing is to secure representative sampling for statistical controls. A second problem is involved in applying the destructive load to the test samples. It must be done in a manner which places the major portion of the stress at the glue line, and the load must be of sufficient magnitude to assure that the amount of wood failure is actually indicative of glue line strength. The usefulness of these procedures is dependent on operator skill and experience, and a technical background is essential to interpretation of the test results.

Testing of the glue line strength in the face bonding of the member is accomplished by ASTM block shear test in most plants. In some cases laminators use only a hammer and chisel for separating a piece of end trim at the glue line (Figs. 6 and 7). The value of this as the only test used is questionable, since the end trim is liable not to be representative of the rest of the member. The chisel test provides, however, a good indication of the strength of the glue line being tested and is a valuable supplement to other testing in most operations.

After a member is completely assembled and fabricated, visual inspection discloses evidence concerning integrity of the process, and should be a routine quality control procedure. In a laminated member properly produced, the glue lines will have a thickness within the range of 0.003" to 0.009". Openings in glue lines will be infrequent and extend only slightly into the piece. Seasoning checks in the wood will be slight and any occurring adjacent to glue lines will disclose separation of wood fiber as well as glue. Deviation from these conditions is not conclusive in the matter of structural adequacy, but should initiate a study of the production record of the member to determine that all processing requirements were met before certifying its conformance to standards.

Routine testing is also essential on certain items of equipment and instruments used in production controls. Torque wrenches accomplish a critical job in the laminating process and, at best, they are rather fragile and need constant care. Testing facilities should be provided for routinely verifying their calibration, or they should be sent to a laboratory for testing and adjustment. There is need for the establishment of a uniform procedure in the industry for wrench calibration.

The electrical resistance type moisture meters quite often lose their accurate calibration, or become erratic in their operation without giving any warning that readings are improper. Therefore, it is essential that routine testing be done by comparing meter readings with oven dry tests to assure proper calibration. There is considerable room for improvement in the measuring and control of moisture in lumber and in laminated beams. The instruments which indicate the amount of moisture by measuring the electrical resistance between needles inserted into the wood are not practical for continuous production line checking, and readings are limited to relatively small sections of the piece. These instruments, when equipped with insulated needles and properly used, will, however, indicate quite accurately the over-all moisture content and the gradient. Electronic meters generally indicate an average moisture condition in an area, but do not indicate the nature of a gradient that might exist in the moisture distribution within the piece. In many cases, the evaluation of moisture meter readings is influenced by the operator's knowledge of the drying procedures used on the lumber and his experience with materials previously received from the same source. It is obvious, therefore, that there is a need for standardization of procedures throughout the industry with a method that measures moisture conditions uniformly and with accuracy requisite to the needs of the product.

Probably the most serious problem facing the industry today is enforcing continuous and conscientious usage of the methods currently available which will result in a uniform product of top quality. Raw materials are not specifically designed and graded for individual operations and must be continuously qualified, especially the lumber for strength and the glue for quality and working characteristics. The variables inherent in both make mandatory an adequate system of quality control in all phases of a laminating operation. Adherence to established standards, and measurement of conformance by these procedures, performed by skilled operators, will assure a product of superior integrity.

# Open Forum Discussion

Moderator - Alan D. Freas, Assistant to the Director, Forest Products Laboratory, U.S. Dept. of Agriculture

Panel Members - Elmer Bergey, National Casein Company
R.H. Bescher, Koppers Company, Inc.
Gordon Brown, Monsanto Chemical Company
F.J. Hanrahan, American Institute of Timber Construction
Ward Mayer, Timber Structures, Inc.
M.J. Rhude, Unit Structures, Inc.
R.E. Wirth, Rilco Laminated Products, Inc.

Mr. Freas: Mr. Rhude would you like to open this discussion period by giving us a few words on sealers for laminated timbers?

Mr. Rhude: The basic reason for a coating is a simple one. A single material rarely has all the properties necessary to do a job or, if it does, it costs too much. Coatings perform some function for the materials which the material can not handle adequately alone. Wood coatings are used to: 1) protect, resist wear, resist soiling, repel water or moisture in the air, and reduce the deteriorating effects of ultraviolet light; 2) decorate, increase lustre and impart or preserve color. Finishes may be penetrating or surface coatings. Those which penetrate into the pores of the wood are low in effectiveness. They enter only the large pores and cell cavities and do not swell the wood. Moisture that causes wood to swell enters and moves through the cell walls and merely filling the cell cavities with oils or resins does not keep moisture out as the cell walls at the surface remain exposed. What we need is a substantial, continuous coating for the wood. Coatings are not impermeable to moisture, but they do prevent rapid changes in moisture content in the surface layers of the wood. Wood kept for a long period under damp or dry conditions will reach a natural equilibrium of moisture content, finish or no finish. The moisture-excluding effectiveness of a sealer lies in its ability to retard the exchange of moisture between wood and air.

Moisture-excluding effectiveness values vary from 3% for a single coat of raw linseed oil to 95% for three coats of aluminum flake in a phenolic formaldehyde resin varnish of high quality. In the order of effectiveness we have the penetrating stains, fillers, sealers and water repellent preservatives, followed by the surface coatings such as lacquers, varnishes, paints and enamels. Under ordinary usage, to withstand swelling and shrinking caused by moisture changes, wood need not be stabilized 100%. For most uses, it can change dimensions almost constantly within a limited moisture content range and still perform to complete satisfaction.

We need finish coatings for structural glued laminated timber that:

1) Adhere to the wood when the moisture content is 7 to 16%, and then prevent moisture from going in or out through the surface.

2) Do not damage the strength of the wood.
3) Have the same coefficient of expansion due to temperature and moisture content as wood.
4) Give a dull finish in most cases; a glossy finish is acceptable less often.
5) Do not darken or have yellowish tendencies.
6) Have a low cost. (A pound of wood costs only 3 to 4¢, and coatings for wood stabilization cannot cost several times the cost of the wood.)
7) Dry rapidly even when subjected to a wide variation in temperature, relative humidity and air movement.
8) Have elastic properties consistent with the wood movement for a particular service condition.
9) Resist deterioration from free water and sunlight.
10) Can be shop prefinished within the requirements of the production processes of our industry.
11) Can be applied by brush, roller or spray to a wide variety of shapes and sizes of members.
12) Wear well in transit and during erection.
13) Serve as insulation and acoustical treatment of the member surfaces in certain usages.
14) Can be stained in the field even though the sealer has been shop applied.

We are not apt to develop a perfect finish immediately, any more than we are apt to develop a perfect adhesive for all jobs. Undoubtedly, we must sacrifice some desirable property for another which we cannot do without, for a particular job. Frequently, some degree of durability must be sacrificed for increased drying time and reduction of dust damage. An increasing number of customers want shop prefinished members, yet maximum protection is impossible during subsequent shipment, storage and erection. Members to be steamed at the job site can have nothing more than a temporary moisture seal shop applied.

Alan D. Freas: The various speakers have raised problems and set forth ideals related to adhesives, but the adhesive manufacturers did not have an opportunity to talk in the first go-round. Therefore, I am going to ask Mr. Brown to comment on the problems that the laminators have described.

Mr. Brown: All I could say right now is that we will have to back-order that request. We recognize, of course, the need for improvement in adhesives. Whether this will come about through the evolutionary development of present products or through a revolutionary new type of adhesive, no one can say.

Mr. Freas: Mr. Bescher, do you have any comments from the standpoint of the manufacturer?

Mr. Bescher: I think everyone in the room realizes that today's adhesive is a compromise. If it has a long pot life, that means it is not very sensitive to temperature. If you want a quick cure, the adhesive must be quite sensitive to temperature. As we change our operations, we can modify our adhesives to do a particular job better and that, I think, is going to be the way adhesives will advance. We will have a more specialized adhesive for each special job, rather than one adhesive that will do every job.

Robert A. Wilson, Ellerbe and Company: If a glulam member extends from inside dry conditions to outside wet conditions, should the phenol or phenol-resorcinol type adhesive be used in the entire assembly of the member? Or are two adhesives used in a single member?

Mr. Rhude: First of all, you cannot spread half of a long lamination with a dry adhesive and the other half with a wet adhesive. There are many ways to get around this. There is a possibility of using moment splices to allow two members to be joined. If you cannot do this, then I would say to select wet use adhesives for the most critical of the two conditions.

L. G. Derbyshire, General Electric Co.: What adhesives are used in the fireproof plywood now available?

Mr. Bescher: Most fireproof plywood on the market now is processed after it is made. In other words, they make the plywood, put it in large retorts and impregnate it, and then re-dry it. There is a little plywood used here in New York, for example, in which an untreated, fancy veneer is glued with a rubber-base type of adhesive onto fire retardant, treated Douglas fir plywood.

Mr. Freas: Isn't plywood intended for fireproofing treatment usually glued with a vinyl?

Mr. Bescher: Yes, it's always glued with a vinyl. It has to be a fully waterproof glue, because the treating process is as good a testing procedure as anything yet devised for ascertaining whether the glue makes a good bond or not.

Mr. Derbyshire: Are these adhesives considered good enough?

Mr. Bescher: As far as the treating industry is concerned, those adhesives are entirely satisfactory. They hold the plywood together and, if there is any delamination, you can always cut the plywood apart and see if it was a failure of workmanship in applying the glue, or whether some other thing went wrong. But, where the glue has been properly applied and properly cured, these adhesives are entirely satisfactory.

Mr. Derbyshire: What adhesive do you recommend for fireproof lamination?

Mr. Bescher: In many cases laminators have used casein glues, and they are perfectly satisfactory if you have dry conditions. Most treated wood, though, is also exposed to decay, termites and moisture, and if that is the case, then you have to use a resorcinol or modified resorcinol type glue. Some of the glue laminators might be able to state better than I can the percentages of the two glues that have been used.

Mr. Freas: Either in a fire retardant treated or a nontreated member, do the glue types have any effect on the fire resistance of the member?

Mr. Bescher: I am not sure of that. The casein glue, as I recall, is quite susceptible to high temperatures. Therefore, if you glue plywood with a casein glue, it will delaminate and each layer will burn as an individual layer. This is probably not true of structural laminators as the heat resistance of the 2" lamina probably gives you considerable protection. To my knowledge, almost all structural laminates are glued with a modified resorcinol and not with any other type of adhesive, if they are sent to a treating plant and fireproofed.

It has to be water resistant glue; nothing else will go through the treating process.

Unsigned question: Have radioactive isotopes and X-ray been considered for examination of finished glue lines?

Mr. Wirth: I don't have sufficient information to give a complete answer to this question. I understand that radioactive isotopes have been used in polymerizing phenolic resins, but as to their use in the laminating industry, I believe it has been nil.

Mr. Freas: I think what the question refers to is a magic method, x-ray or radioactive emissions, or something of the sort, which will tell you the quality of a finish glue line throughout. Perhaps the best answer to that is that we don't have it yet, but that is what we would like to have.

S.R. Miller, Jr., E.L. Bruce Company: How do you prepare and test a lamination to prove that the glue line is stronger than the wood?

Mr. Wirth: A few methods are in common use; probably the most dependable one is the accelerated aging test where the specimens are subjected to racking and pressure in an autoclave. That is an ASTM test. Other than that, the chisel test is used, but that does not numerically evaluate the amount of strength of the glue line. It merely indicates that there is failure of the wood adjacent to the glue in the particular glue line being tested.

W.W. Weichelt, F.P. Wiedersum Associates: Are there any particular requirements for adhesives in connection with factory finished or field finished materials?

Mr. Rhude: The choice of adhesives is really determined by the service condition. The break point is where the wood has a 16% moisture content. If you were going to place finished coatings on the member, as long as it has a substantial continuous coating it will tend to hold the moisture content of the wood within a narrower range when subjected to changing relative humidities or contact with moisture. If it were a very severe wet use condition in the field, one where a man sets the laminate out in the mud, for instance, of course the waterproof adhesive would be the better one to use.

Mr. Freas: Some of the adhesives are colorless and some are not. However, the glue line is a very thin line. We talk in terms of .005" and when you have something that thin, the amount of coloring imparted to the over-all member is not great. There was a time when the color of the waterproof adhesives was objectionable, but we find this not to be true today. In fact, we find that the fine adhesive line actually tends to accent the difference in the grain between the individual laminations and often this is a desirable characteristic. There is little possibility of the adhesive ever coming through or spoiling a finish.

T.E. Werkema, Dow Chemical Co.: Can you give, quantitatively, some measure of the present size of the glulam business—board feet of lumber used, or pounds of glue used?

Mr. Mayer: Our industry has probably been negligent in not keeping statistics. It has a wide range of products and statistics have always been a problem. I can't give you any exact figures, but I can tell you that the industry is growing very rapidly and the use of the products is growing very rapidly.

E. J. Mills, Jr., Union Carbide Chemical Co.: What is the ratio of use in laminating timbers for the adhesives: casein, phenolics, resorcinols, melamines?

Mr. Mayer: I'll give a wild guess and say 20% waterproof, 80% casein. Perhaps the two other laminators represented here would like to guess also.

Mr. Wirth: I would go along with Mr. Mayer. Apparently the figure would be very close to 20% waterproof, 80% casein. Melamines are not widely used because of the extremely high temperature required for curing. They are used to some extent to provide a colorless glue line in scarfing operations.

Mr. Rhude: I will also agree. Definitely, the waterproof phenolics and resorcinols are on the increase. In our own operation, just in terms of tons of adhesives, the phenol resorcinols have doubled in each of the last two years.

Mr. Mills: Is there a trend toward universal use of exterior service adhesives exclusively, as is now occurring in the plywood industry?

Mr. Bescher: There is definitely a trend toward use of more waterproof adhesives. Certainly, they should be used for all exterior exposures. Another area where it has been proved important to use waterproof adhesives is in cases where we do not know the end use of the product. If it is used in an interior location, the casein glue would have been perfectly satisfactory. If, however, it ends up somewhere out in weather, or exposed to alternate sun and rain over a period of years, it very definitely should have been waterproof glue. I might add that the American Institute of Timber Construction has specifications and recommendations on the use of different glues available, if anyone wants more specific information.

M.H. Johnson, University of Florida: Do a series of glue lines appreciably assist in stabilizing the moisture content in glulam timbers used in areas of widely varying humidity?

Mr. Rhude: I would say no. Wood is quite different from many materials in regard to its reasons for dimensional change. In the case of wood its changes in moisture content are due primarily to changes in the relative humidity of the air. This is a law of nature and there is nothing you can do about it. The waterproof adhesive, if it is very rigid, may help to prevent the change in dimension, but the glue line is a very small area, and I would say that it cannot act materially to cut down dimensional changes.

Mr. Johnson: In your opinion is there feasability in the idea of precutting and clamping the lumber and then pressure treating the glue into the assembly similar to what is done with salts or creosote treatment?

Mr. Bescher: Actually, something similar to that is being done today. You can impregnate wood with phenol formaldehyde resin, which is essentially the same chemical as the glue, and then set that resin inside the wood, but the cost is terrific. We are making some wood for the automobile industry, called die model lumber, which is made essentially that way, and it sells at $3.00 a board foot. It doesn't change dimensions, but stays exactly as it is. They model the automobile part out of it, put it in a Keller machine and shape a piece of steel that will punch out the fenders, bodies and tops to make an automobile. They can't have those things change size, because if they change size the automobile parts won't fit when they start to assemble them. There is nothing else that they can mould as readily as this wood.

John S. Best, Dow Chemical Co.: What is the average selling price per pound of laminated structural components, and what is their average delivery cost per pound?

Mr. Bescher: We do not estimate by the pound. We do not even estimate by the board foot, as is common in lumber. Each piece is priced according to the material it takes to make it, the shape it's in, the difficulties in making it, etc. In laminated timber construction, we have to price according to the piece; there is no one common denominator.

Mr. Rhude: I previously mentioned a figure of 3 to 4¢ a pound for wood. After using adhesives to bind some pieces of wood together, plus all the other operations, I would say that around 10¢ per pound might be a cost figure for laminated wood. However, you must realize that the size of the member and the number of pieces that go to make up 10,000 board feet will certainly influence the end result. We have straight members, and we have curved members. We have members that are curved in several directions, and they have twists, in addition to curves. So when I mention a figure of 10¢ a pound, please don't be alarmed if you want to order some material that costs much more.

Mr. Hanrahan: To comment further on that, I think you will have to change your concept. You shouldn't discuss glue laminated lumber and lumber in the same terms; they are entirely different things. Take our industry, for instance. We not only manufacture structural glue laminated lumber, but we assist the architect and engineer in the design. With proper advice on structural distribution of loads and stresses, and combinations of types of construction, you can provide a very economical building. What you are really concerned with is the total cost of your finished structure; you are not concerned exactly with the cost per pound. One of the common things that is being done today is to use 3" to 4" decking with laminated arches or other laminated members. This provides good insulation, an interior finish, and a solid base on which to place your roofing. When you put all those things together and compare them with other methods, you have an entirely different cost picture than if you talk in terms of cost per pound. Furthermore, you are talking about a premium product, not about a material that is like any other construction material. This is a finished product, a well manufactured, quality product. Naturally, you expect to pay more for that kind of product than you would for ordinary construction materials in which no pains have been taken to assure proper appearance, etc.

Mr. Freas: The matter of preservative treatment has been mentioned very briefly. Is this practical for laminated members? Are there any particular difficulties encountered, any special steps that have to be taken?

Mr. Bescher: Let's put it this way—preservative chemicals on the surface of the wood might be called a contaminant, something on the surface through which we must allow the glue to penetrate and provide a bond. Therefore, in one respect, we might say that the glue temperature or the time should be somewhat longer for treated lumber or untreated lumber. There are many preservatives which can be satisfactorily glued after the lamina have been treated, and then there is also the case of gluing the member first and treating it afterward. The industry also has a specification, a standard, on the gluing of treated lumber and the treating of solid sawn and glued laminated lumber which, if you are interested, is also available from American Institute of Timber Construction.

Mr. Freas: Mr. Rhude, you mentioned a while ago a case where somebody was storing completed laminated members in mud. Do you want to expand on problems of handling completed laminated members on the job site?

Mr. Rhude: This is quite a long subject, and an important one. I think all manufacturers send certain instructions for handling laminated wood with their shipments. For instance, it is not a good idea to put a chain around a member and drag it across the ground in the process of putting it in place. When the members leave the plant they usually are wrapped in waterproof paper. This protects them from scuffing, or from dirt and water, in transit. Once they arrived at the job, however, most laminators take the position that the protection of the members is the responsibility of the buyer. We give instructions that if the members are going to be stored for some time before erection, they be blocked up off the ground, that there be some space between the various members so that air can circulate around them, and that they be covered and protected from water. As far as erection is concerned, techniques can vary a great deal, depending upon the size of the members. Some of these members weigh a few pounds and others weigh tons. This, or course, requires different methods of handling. Some require blocking around the four corners of the member and some type of a sling that will support it. It is important that caution be used so you do not damage the wood fibers. By saying this I do not mean you have to handle these members with kid gloves. This is a structural material, it is strong, it is stiff, but nevertheless it must be handled carefully, if you want it to do your structural job and also be the beautiful member you expect it to be.

Mr. Mayer: I would like to remark that casein glue, as used by structural laminators, is used with a mold inhibitor and it has ample moisture resistance to meet the normal construction exposures. I don't want to put the idea forward that waterproof glue necessarily has to be used just because of casual exposure of the completed member to the weather. I stated that waterproof glue should be used for exterior exposures or high humidity situations. I meant instances where those conditions obtain over a period of years. Casein does very well for our normal interior uses and does possess sufficient moisture resistance for exterior exposures during construction.

Mr. Brown: I understand that in Europe urea formaldehyde adhesives are widely used in structural laminating. Why are they not used in this country?

Mr. Mayer: Urea resin adhesives are not waterproof. Furthermore, they are not as resistant to simple high temperature under dry conditions as casein. They are very versatile and very fast, and they are very good for many uses, but in laminating they are not as foolproof, and they are not the gap-filler that casein is. I don't believe there is a future for urea in laminating, due to the fact that they are not sufficiently water-resistant to be considered for exterior use.

Mr. Hanrahan: I might comment a little further on that. There is no urea resin used in the laminating industry in this country at all. It is used rather extensively for covering material where the structural strength is not so important; where, if you get a minor amount of deterioration, it doesn't seriously affect the use of the product. You must remember that we are trying to develop the full strength of the wood and maintain it that way over 50 or a 100 years, or whatever the service of the structure is. So, for that reason, we just don't use the ureas.

Mr. Freas: In mentioning adhesives there has been something of a brush-off, just a bare mention, of resorcinol and phenol resorcinol materials. I wonder if someone would like to comment about the differences between these two products in use.

Mr. Brown: Well, the first and foremost difference is about 25¢ a pound. The resorcinol formaldehyde glues are made with a component that is added just before use, which is the hardener. It is actually a missing component in the resin structure that allows it to thermoset completely. The phenolic glues used in plywood are strictly hot set; they will not set cold. Phenol resorcinol glue for laminating is something of a compromise, wherein the phenol and formaldehyde are reacted for part of the glue, and we attempt to so design the glue that we get the advantage of the cold setting properties of resorcinol and the low cost of the phenol, and strike the most happy balance between the two of them. Phenol resorcinol glues tend to have more elasticity of flow and can sometimes be used when longer assembly times are necessary. I don't mean to run them down as a compromise between quality and cost. They are high quality adhesives, but they need a little higher temperature to set.

# BONDING OF CEMENTITIOUS MATERIALS

Chairman - Julian Panek
Manager, Technical Services Dept.
Thiokol Chemical Corporation

# Selection, Use, and Performance Data for Bonding Agents

By John Hans Graham,* AIA
John Hans Graham & Associates, Architects-Engineers-Planners

Many thoughts and questions arise in an architect's mind when he considers the bonding of interior finishes, such as:

1) It is difficult to obtain data free of exaggerated sales claims as to performance of adhesives?
2) Is sales literature too general, beamed to the layman?
3) There is a need for technical data on how products perform in a structure.
4) What is the coefficient of expansion of adhesives?
5) What is the strength of cementitious materials and bonding agents under heat conditions?
6) What is their resistance under extreme cold conditions?
7) What about water solubility?
8) What data are available on permanent performance?
9) There is a prime need for a manual or reference outline of families of bonding agents for cementitious materials with chemical names simplified and easily remembered.
10) Properties and characteristics must be set down fearlessly.
11) More job testing is desirable before product is applied.
12) Materials manufacturers must experience an increasing degree of control over the finished product on the job.

Fortunately, answers to some of the questions mentioned are now available and, while I will not be able to answer them all, I shall attempt to discuss some of them from a certain amount of experience.

Our firm was one of the first to utilize modern bonding materials to accomplish the finishing of interior surfaces on large-scale construction. Back in 1950, we were prevailed upon to use a bonding material to finish the ceilings, walls and columns of a 12-story concrete structure, now known as Skyline Apartments, in Syracuse, N.Y. This building was constructed by the Turner Construction Company under an FHA-insured loan, with a total of 365 so-called semi-luxury type apartments. The floor area was approximately 250,000 sq. ft. Originally, in our specification, we provided under the lathing and plastering section the following provision, which was standard:

> "Plaster bond finish obtained by removing surface of concrete to depth of approximately 1/16". Treatment may be mechanical, such as hacking, or chipping; or may be accomplished by applying cement retarder compound to inside of forms. When a retarder compound is used, and upon removal of forms, all loose surface material shall be removed by wire brushing, until rough bonding surface of exposed aggregate is obtained. Use plaster bond finish for all vertical or overhead concrete surfaces that are to receive an applied finish of mortar or plaster after forms are removed."

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As can be seen from the provision, much preparation was required to insure an adequately rough surface for application of the finish surfacing materials. Needless to say, when a new method of bonding finish plaster to poured concrete surfaces was presented to us, we were definitely interested. The saving, including time and labor, would obviously be considerable. Laboratory data were furnished to us which indicated that the new bonding material was much stronger than actually required to hold up a finish thin coat of plaster.

Before making our decision to try these new, revolutionary adhesives, we were taken to an existing job where ceilings and walls in an old hotel had been renovated using this material. Discussing the performance of the material with the building owner, the contractor, and the plasterer who actually used the material, we obtained full assurances that the bonding product would perform satisfactorily.

On the Skyline Apartments project in Syracuse, we therefore made a change in specification allowing the contractor to apply the bonding material directly to the concrete surfaces, and apply the finish coat of plaster to the bonding material. Some difficulty was experienced on this job—not necessarily with the performance of the material, but as a result of the lack of experience of the plastering mechanics in this type of application. In normal plastering, the plasterer depends on mechanical keying and suction developed to hold the succeeding coats of plaster. With the new bonding method, very little suction is developed. The adhesion of the finish plaster is accomplished by reason of a mechanical keying that results when the wet plaster re-emulsifies the bond film, and by chemical-adhesive bond that is established after plaster and bond film dry.

Since that time, our firm has designed many buildings. In those projects which our design studies indicated would be most economically constructed by using reinforced portland cement concrete, frame and flat plate construction, we have specified bonding agents. We have also gained considerable economic advantage, through savings in labor and materials, by specifying the use of bonding agents to bond finish coat of plaster to the structural walls, columns and ceiling members.

In most areas, reinforced concrete construction has an economic advantage in the lower multi-story buildings. It is economically desirable, of course, to design and build concrete buildings up to 22 stories and even higher under certain conditions. Surfaces produced in the structural frame of a concrete building require a minimum of finishing, and are most pleasing to the eye.

A number of years ago, as reinforced concrete buildings came more and more into prominence, we learned to chip, grind and polish these surfaces, and use them as the completed room finish. This proved to be much more economical than using the traditional metal lath, and two- or three-coat plaster application. It also eliminated much plaster material and labor. However, there was much to be desired in the appearance of such finish surfaces.

Then, with the introduction of the modern method of bonding plaster directly to the poured concrete walls, a rebirth in demand for plaster finished surfaces took place. This was due primarily to the unsurpassed beauty of plaster, but it has also proved to be more economical to finish the poured concrete surfaces with a bonding agent and a thin coat of finish plaster than it is to grind down, rub, dress up and paint the exposed concrete.

More recently, our firm and associates designed the Park Towne Place Apartments, a $17-1/2 million group of 19-story apartment buildings, totaling some 1,000 living units. Flat plate reinforced concrete construction was determined to be most economical for this FHA-insured redevelopment project in downtown Philadelphia, Pa. We elected to use bonding agents to apply a thin coat of white lime-putty plaster directly to the concrete. This is one of the largest urban renewal projects in the United States, and allows for estate living in the heart of the city. Buildings are fully air conditioned, and the grounds boast an outdoor swimming pool and cabana club. There is also an underground parking garage for 760 cars and surface area parking for 300.

In the construction of this project, the general contractor utilized plywood forming for the concrete columns and floor pours. His variation in surface tolerances was limited to 1/4" in 4' in ceilings. This tolerance was deemed necessary in order to allow finishing the concrete surface by applying a minimum thickness of plaster directly to the concrete by means of a plaster bonding material.

This tolerance did not work a hardship on the general contractor. On the contrary, it was felt that having a specification for forming in the construction program assures neater and more ably supervised building, whereas a loose specification often allows a lower quality of workmanship. A tight performance specification keeps everyone on his toes, and the over-all appearance of the project, while construction is underway and also at the completion of the job, is much more satisfactory.

Concrete surfaces were turned over to the plastering contractor in such condition that he only needed to spray, using a plaster bonding agent, and apply lime-putty plaster directly to the bonded surfaces. This operation is immeasureably cleaner, faster and more economical. Figures 1 through 6 show the various steps taken in this method.

In this day of large-scale construction projects involving large mortgages, especially on speculative housing, control of construction time becomes an all-important factor. Interest rates on large loans make it imperative that the project be completed and opened for occupancy as rapidly as possible. We feel the use of this modern method of bonding results in a saving of time unequalled by any other means of surfacing.

As far as individual decoration is concerned, again this method is most efficient. The very thin coat of plaster takes a minimum of time to dry and to reach condition for painting or papering.

In this flat plate construction, we finish all exposed concrete columns, ceilings and walls with a skim coat of plaster bonded to the surface by liquid bonding agents. Exceptions are the top floors of each building and the ceilings in the ground floor where commercial establishments are installed. At these two levels suspended ceilings are required to handle additional insulation, air conditioning and lighting equipment. Incidentally, we have found no problem in utilizing concrete surfaces as finish surfaces where electrical conduits are installed in the concrete. The heating and air conditioning can be installed in the walls below the windows or in the interior walls next to the partitions. In some instances, we have utilized space in corridor ceilings to handle additional mechanical duct work.

Turning now to several projects which we have on the drawing board, I would like to discuss a project which we designed for the United States Air Force at Kindley Air Force Base in Bermuda. This consists of 180 dwelling units for surplus commodity family housing and includes group housing, single detached houses, and multi-story apartments and is to be constructed under the supervision of the United States Corps of Engineers. In our specifications, Section 16-E, bonding agent, reads as follows:

> "Bonding Agent—shall be a resinous water emulsion adhesive that will permanently bond plaster material to wet or dry concrete surfaces. Such material shall have a viscosity about equal to that of ordinary paint and shall be suitable for brushing or spraying. It shall be inert to oxygen and perfectly stable when water has dried out. It shall lose none of its flexibility or adhesive strength and shall be completely free from any tendency to harden or crazecrack. It shall be vermin-proof, nontoxic, nondeteriorating and incapable of supporting flame. Certificate of compliance with these requirements must be supplied by the manufacturer, together with copy of approved testing laboratory report and samples for tests and shall be subject to the approval of the Contracting Officer."

Another project now in the design stage, which will utilize flat slab concrete

Fig. 1 - Spraying equipment used in application of bonding agent.

Fig. 2 - Plasterer spraying bonding agent on exposed concrete slab ceiling.

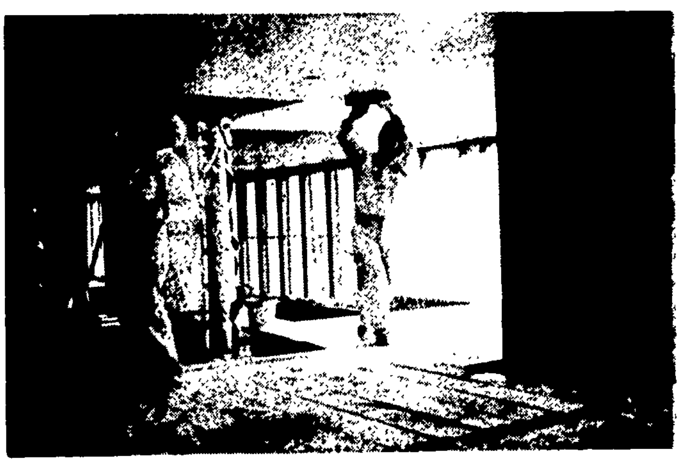

Fig. 3 - Plasterers troweling on and brush troweling lime putty and gaging plaster white coat.

Fig. 4 - Plasterers white coating ceiling over bonding agent.

Fig. 5 - Plasterer filling voids and cracks of ceiling.

Fig. 6 - Completed white coat ceiling.

construction with surfaces to be finished using bonding agents, is the Brookline "Farm" Redevelopment Project in metropolitan Boston, Mass. It will entail construction of four buildings, nine stories high, and will furnish apartments for 944 families.

Our office has also designed the Gregory Park Redevelopment Project in Jersey City, N.J., which will furnish quarters for 800 families. It will include two buildings of 21 stories each. A proposed office building in the Charles Center in Baltimore, Md., will utilize the same type of construction in portions of the building. An apartment project in Cleveland, Ohio, will have a similar type of construction, as will the Harrisburg Redevelopment Project, under construction across from the Bureau of Labor and Industry in Harrisburg, Pa. (Fig. 7).

Fig. 7 - Towne House Redevelopment Project, Harrisburg, Pa.

As to use and performance data, the architect specifying liquid bonding agents must familiarize himself with the over-all physical properties of such materials. Recognized manufacturers of such materials are able to furnish performance data which indicate bond strengths for various types of surfacing materials. As an example, I have performance data furnished by one of the manufacturers of bonding agents, which lists various strengths for bonding plaster materials to concrete surfaces, as follows:

| | |
|---|---|
| 1 : 3 Ottawa Sand Mortar | -367 si |
| 1 : 3 Brown Coat (Gypsum) | -138 psi |
| Acoustical Plaster | - 68 psi |
| 1 : 3 Perlite Plaster | -167 psi |
| Finish Plaster | -120 psi |

In addition, test data on the variation of strengths for bonding various surfaces and surface materials have been established by independent laboratories. These test data are available, and it will perhaps be of interest to include some of them in this discussion.

A Military Specification has been established for "Bonding Compound, Concrete." This very detailed specification sets forth performance data requirements as follows:

| Property | |
|---|---|
| TENSILE STRENGTH | |
| 1 : 3 Brown Coat | 60 |
| Acoustical Plaster | 65 |
| Finish Plaster (30% gaging Plaster) (70% lime Plaster) | 120 |
| 1 : 3 Perlite Plaster | 150 |

| | |
|---|---|
| 1 : 3 Ottawa Sand Mortar | 200 |
| 1 : 3 Cowbay Sand Mortar | 200 |
| Neat Molding Plaster | 250 |
| Neat Portland Cement | 250 |
| Shear Strength Neat Portland Cement | 300 |

In addition, several large cities have, through their building standards board, approved certain manufacturers' bonding agents for specified uses. I am referring to the City of New York and the City of Los Angeles, which I know have tested and approved for installation these bonding materials. I am informed by one of the large manufacturers in one metropolitan area that 21 million sq. ft. of plaster have been programmed for installation within the next 18 months.

These few facts will give you an idea of the extensive use that architects, contractors and developers have made of bonding agents in their construction of new buildings. We know that many will still continue to design buildings as they have in the past, and of course many owners will continue to specify types of construction for which they have a preference. However, we believe all architects, contractors, buildings owners or potential owners should be made aware of the considerable economic advantage that may be obtained by using such modern construction methods as bonding agents in the planning, design and construction of their buildings.

TENSILE STRENGTH OF CEMENTITIOUS MATERIALS

| Bonding - Agent | | Polyvinyl Acetate | Tensile Strength—(Average of 3 Briquets) | | |
|---|---|---|---|---|---|
| Test # | Cementitious Material | Surfaces | 7-day Breaks (psi) | 1-yr Breaks (psi) | 2-yr Breaks (psi) |
| 1 | Gypsum plaster | Portland cement | 205 in bond | 267 in plaster | 267 in bond |
| 3 | Portland cement | Portland cement | 213 in cement | 168 in cement | 267 in cement |
| 5 | Gypsum plaster | Oil-base paint quick drying enamel | 170 in bond | 198 in bond | 197 in paint |
| 7 | Portland cement | Oil-base paint quick drying enamel | 50 in cement | 47 in cement | 67 in paint |
| 9 | Gypsum plaster | Rubber-base paint | 218 in plaster | 253 in plaster | 223 in plaster |
| 11 | Portland cement | Rubber-base paint | 363 in cement | 250 in cement | 277 in cement |
| 13 | Gypsum plaster | Vinyl-base paint | 87 in plaster | 145 in plaster | 162 in plaster |
| 15 | Portland cement | Vinyl-base paint | 242 in cement | 178 in cement | 150 in cement |
| 17 | Gypsum plaster | Asphalt emulsion | 93 in plaster | 142 in bond | 148 in asphalt |
| 19 | Portland cement | Asphalt emulsion | 140 in asphalt | 122 in asphalt | 100 in asphalt |
| 21 | Gypsum cement | Silicone water repellent compound | 120 in plaster | 163 in plaster | 173 in plaster |
| 23 | Portland cement | Silicone water repellent compound | 168 in cement | 183 in cement | 153 in cement |

# Bonding Materials for Interior Finishes: Their Properties, Applications and Future

By Phyllis H. Larsen,* President
Larsen Products Corporation

As little as 10 or 12 years ago, there were no means to bond gypsum plaster securely and successfully to a poured concrete structure—beams, walls, ceilings. Bituminous materials, for example, which had been tried for this purpose for some years, were disapproved in the 1946 ASTM Manual. This is what was stated at that time in the American Standard Specifications for Gypsum Plastering and Interior Lathing and Furring under the heading of Preparations for Plastering - Masonry Surfaces (Note 2.): "Because bituminous compounds do not provide ideal bases for plaster, the application of plaster to masonry or concrete which has been coated with such compounds should be discouraged."

The need for a reliable method for bonding was urgent. Buildings of flat plate construction were being more widely designed, and ceilings, especially, were often left unfinished. Costly attempts were made with imitative plasters; lathing was prohibitively expensive; cement slurries had proved inadequate. It was not until the development of synthetic resins that the formulation of a reliable bonding material was realized. At this point a new industry was born, destined to revolutionize many construction techniques.

The first and original (now patented) product of this nature, which has been used successfully for nearly 10 years, is a scientifically compounded bonding material utilizing the unique properties of emulsified polyvinyl acetate resin with no less than eight essential components, each contributing a vital function to the adherence of wet mixtures of plaster, cement, mortar, etc., to substrates such as monolithic concrete, old painted plaster, stone, glass, ceramics and metals. To the polyvinyl acetate must be added: plasticizers to impart permanent flexibility to the resin, a requirement for maintaining permanent adhesion of the bond and protection against vibrations and stresses which would otherwise loosen the plaster: solvents for softening of the resin to facilitate strong initial adhesion at the time of application; gums to improve flow and add to the adhesion; coupling agents to balance and stabilize the emulsion; coalescing agents for enhancing film formation; a color for identification and means for rapid inspection; and fire-retardant chemicals for compliance with fire regulations, where required by local codes.

The success of this bonding operation involves the careful execution of the following steps:

1) Secure firm adhesion of a film of the bonding agent to the substrate by brush, spray or roller coating.
2) Obtain intimate contact of the resin particles with the cementitious material at time it is troweled on, by the remoistening or re-emulsifying action of the water in the wet plaster or Portland cement with the resinous film.
3) Provide adequate curing of the topping material for stucco and other cement work,

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Fig. 1 - Mechanical bond.


Fig. 2 - Adhesive bond.


Fig. 3 - Chemical bond.

and thorough drying of the bonding agent, in order to obtain a strong bond and avoid an unsatisfactory job such as would be evidenced by cracking, buckling and ultimate loosening of the topping.

To illustrate the three-way bond, in Figure 1, mechanical bond, arrows show the liquid bonding agent penetrating the pores of the substrate forming a mechanical interlock or bond. This is the first step in the bonding process. Figure 2, adhesive bond, shows that as moisture evaporates from the bonding agent adhesion develops within and on the surface of the substrate, forming both mechanical and adhesive bonds between the two elements. In Figure 3, chemical bond, we see how the bonding agent penetrates the voids of new material and forms a strong mechanical and adhesive bond. Then the crystalline structure of the new material establishes a chemical bond between itself and the bonding agent.

Laboratory tests now show no loss in bonding strength when wet plaster is bonded to the resinous film which had been brushed onto concrete one year previously.

A bonding agent of this type produces a film which is ageless, nontoxic and verminproof. It is unaffected by the alkalinity of gypsum lime-putty or Portland cement mixes. Its viscosity is about that of a good paint. It is resistant to most acids and will not burn or deteriorate. Its lasting flexibility correlates with its ability to re-emulsify upon contact with the wet cementitious finish covering. A dried film of this type is impossible to break or snap, whereas in contrast, a dried film of a differently formulated polyvinyl acetate emulsion is hard and brittle in nature—to use a hard and brittle dried film, without permanent flexibility, as a bonding agent, would seem to invite trouble, since the essential components for a permanent bond are lacking.

Applications of Bonding Agents

In our modern buildings, especially multi-story buildings of reinforced concrete, bonding agents play a most important role. The concrete surfaces of the columns, beams, walls and ceilings are all relatively smooth and can be utilized with a plaster finish at a minimum of cost. Applying a bonding agent to such areas and bonding a thin (1/8" or even less) coating of white lime-putty plaster produces an excellently finished surface.

A few years ago, I visited the office of one of the largest architectural firms in Los Angeles. I had been particularly impressed with the imaginative style of the numerous buildings designed by this organization, but I asked, in particular, why one architectural firm would choose the medium of flat plate construction, while others seemed to prefer the suspension ceiling system. I have always remembered the answer: poured concrete slab design is unlimited in its direction. It may be curved, angular, or geometric and is not limited to fabricated shapes using structural steel of specific dimensions that have to be set at right angles one to another. As contemporary architects, these people were interested in the most unhampered style of design. Cost was also a major factor, for extra floors could be obtained within a limited number of feet in height, by utilizing the space wasted in the suspension ceiling system.

A case in point is the beautiful, new Imperial House in New York City. In this 33-story luxury type apartment plaster bonding materials were utilized to simplify and economize on the plastering. The contractors used concrete frame construction and flat plate ceilings, and finished these surfaces by using plaster bonding agents to bond a finish white lime-putty plaster directly to the concrete. The Imperial House is the largest reinforced concrete building in New York City, and it occupies a whole city block.

A well-known slogan among plasterers is, "It costs less to plaster than to paint." In terms of dollar value, the most important aspect of the advent of liquid bonding materials has been the fact that their use permits a direct application of finish plaster to concrete. This enables a plastering contractor to bid against two separate contracts for flat slab work—the cement finishers who would quote on the cost of honing and grinding the concrete ceilings, and the painter. In a Nashville, Tenn., public housing project, 60,000 yards of concrete ceilings were sprayed over a film of bonding agent on the underside of concrete slabs, prior to receiving a white skim coat of plaster. The original specification had called for grinding the joints and painting at this PHA project. The specifications were changed, when it was proved that a sand float ceiling could be applied over the concrete at 20% less cost, using the modern bonding method. This work was done back in 1952. Similar savings have been reported from many parts of the United States. More recently, the New York City Housing Authority allowed an option in their specifications for use of a bonding agent on concrete surfaces in lieu of the specified finish.

Another quite different use of a bonding agent is illustrated by a spectacular ceramic tile mural, 30' x34-1/2'designed for the Buildorama Exhibit of the Dupont Plaza Center, Miami, Fla., sponsored by the American-Olean Company. It contains 34,000 pieces of ceramic tile, and required a year to plan and design. In this unusual assignment for a bonding agent, the bonding material was used to bond the fresh cement mortar bed to the old wall surface prior to setting the ceramic tile. Bonding agents were also used in the construction of the Dupont Plaza Center, which houses the Architects' International Bureau of Building Products.

A heavy duty type of bonding with the PVA emulsion type material was installed at the Eaton Manufacturing Company's Cleveland, Ohio, plant. The Eaton Company had to install two 75-ton milling and drilling machines, 25' by 67', on the concrete floor of this plant. Machines had to rest on piers, rather than on the floor itself, and forms required for single pour of these mounts were extremely expensive. A heavy duty, resinous bonding material was brushed on the 36" thick base floor at spots where the 80 piers were to be located. With the simplest of forms, these 8" thick piers were then poured, with every assurance of a permanent bond to the base. Simple bonding replaced complicated forming, and resulted in appreciable savings in the installation of these 75-ton machines.

In the construction of the Nation's first underground ballistic missile silo, a deep concrete nest for the 110-ton Titan ICBM, located at Vandenberg Air Force Base, Lompoc, Calif., a bonding agent of the type heretofore described was used to permanently bond fire resistant concrete to base concrete used for the blast pad at the rocket launching site.

The fact that a bonding agent would bond in this location had been proved earlier at a rocket test installation where temperatures reached 5000° F, and thrust at rocket nozzle was in excess of 300,000 lbs. per sq. in. To give you a further idea of the tremendous forces with which the bonding product was involved, in one experiment the pressure moved a 1" thick steel plate, 24' x 24', a distance of over 300 yds. in the first 10 seconds of firing. This is dramatic testimony to the almost incredible standards required and successfully met by today's bonding materials.

## Future Uses of Bonding Agents

Bonding materials of the vinyl acetate emulsion category are relatively new products. The rapid growth in their use by the building industry has kept manufacturers on their toes, adapting to new requirements for these materials. The future can bring, as evidenced by our description of the Vandenberg Air Force Base ballistic missile silo, new applications of many kinds, so that bonding materials will more and more become an indispensable ally of the plastering and Portland cement concrete industry. To say the least, liquid bonding materials have arrived. Today they are given a major consideration in specifications for new construction, renovation or maintenance of industrial, institutional, municipal, governmental and residential structures.

# Open Forum Discussion

Moderator - Julian Panek, Manager, Technical Service Dept.
Thiokol Chemical Corporation

Panel Members - John Hans Graham, Architect
Phyllis Larsen, Larsen Products Corp.

Mr. Panek: With respect to the use of the bonding agents on concrete, is there a minimum film thickness for satisfactory performance?

Mr. Graham: We recommend that the film be at least 2 mils (.002") when applied on a dry surface, and 4 mils when applied on a wet surface.

Mr. Panek: Has there been any failure due to the fact that films less than 2 mils have been applied?

Mr. Graham: We have not experienced any failure which we could attribute to films being less than 2 mils in thickness.

Mr. Panek: What are your recommendations for applying the bonding agent to insure a minimum film thickness of 2 mils?

Mrs. Larsen: The manufacturer's recommendations on the can will insure this thickness. It is conceivable that someone could carelessly dilute the bonding agent, in which case the control is lost. Moreover, it is also conceivable that the air pressure in the gun could be too high, in which case, again, the manufacturer's directions are not being followed.

Floor Question: What are the recommendations for preparing concrete prior to the application of the bonding agent?

Mrs. Larsen: The concrete has to be structurally sound, all loose flake has to be brushed off and any oil, grease, or dirt properly removed. We do not recommend the application of a bonding agent over any oily surface.

Floor question: How do you treat rough surfaces prior to application of the bonding agent?

Mr. Graham: Any protrusion over 1/4" must be knocked off. Such protrusions mainly occur at the joints.

Mr. Panek: In your paper, you stated that from an architect's viewpoint, it would be desirable to know the water solubility of bonding agents. Where and how would this information be helpful to you?

Mr. Graham: While we are concerned with the use of bonding agents for interior finishes, we are concerned with the sensitivity of these films to moisture. In one case, the water or moisture may be minimized by design. In a second case, if insufficient time is allowed for drying of the concrete, the evaporation could cause a problem with the film. Third, if we were alerted to the resistance of the agent to moisture, we could better time the individual operations. Lastly, if there were conditions of moisture on the job, and we knew that the films were unsatisfactory for this specific condition, then we could use other materials such as epoxy which are satisfactory in such an environment.

Mr. Panek: What are your recommendations for applying plaster over applied bonding agent films?

Mrs. Larsen: Our experience is that the plaster may be applied as soon as the film has dried. The time interval could be as short as 5 minutes. In several cases, the plastering was not done for at least 3 months after the film was applied.

Unsigned question: What is the expected performance of the bonding agent in areas where high relative humidity would prevail?

Mr. Graham: Here again, we must know the sensitivity of the bonding agents to moisture before we apply them. It may be that in such an environment, we might want to use epoxy base adhesives.

W.S. Elliott, Vermiculite Assn., Inc.: Would the use of form oil on concrete leave an unsatisfactory surface for the application of the bonding agent?

Mrs. Larsen: Normally, form oil does not transfer to concrete. The thin residual amount of form oil that may transfer to concrete has not posed any problems to date. Ordinarily any form oil that may transfer to the concrete is absorbed into the concrete.

William Lukacs, YMCA Natl. Headquarters: Would excessive moisture from a leaking water pipe or excessive heat from steam pipes affect the bond?

Mrs. Larsen: Both conditions could cause a deterioration of the bond. Both conditions should be corrected as soon as possible. It may be possible that the wet walls could be dried out before any damage has occurred to the bond.

Mr. Panek: Do you recommend bonding agents for exterior application where water could be absorbed through the concrete?

Mrs. Larsen: The bonding agents have been used in constructing swimming pools.

Unsigned question: You mentioned the need for data on the coefficient of expansion of the adhesive. Actually, isn't this more a problem of relative rates of movement of the substrate and the overcoat of plaster?

Mr. Graham: The point is well taken. We have run into problems and failures. In one case, the plaster was applied too thickly and it pulled away and buckled. This may have been due to excessive weight. We feel that flexibility of the film is desirable, and we are aware of the different rates of expansion of the dissimilar surfaces. The bonding agent must be able to adhere in spite of all inherent movement, otherwise failure must occur.

G.R. Keane, Eggers & Higgins, Architects: Can the bonding agent be applied over bituminous dampproofing as, for instance, on exterior walls or columns?

Mrs. Larsen: I can refer you to some tests made on a city block in Los Angeles. The City required tests to be performed over a two-year period, before they would permanently approve the bonding agent, and those tests involved various surface finishes such as silicone, paint, asphalt, and many others. In that two-year test, the bonding agents gave extremely good performance. However, the asphalt must be free of any loose particles which might have accumulated if it had been weathered outdoors for some time. It must be scraped down to a structurally sound base. Actually, in the Times-Mirror Building in Los Angeles they had an asphaltic roof and they wanted to add two more floors to the building, so they scraped it down, put a bonding agent on, and then put concrete floors over that.

H.R. Young, E.I. duPont de Nemours: Are there any reliable accelerated tests that can be used to gage or estimate reliability or durability of any given bonding agent?

Mrs. Larsen: We do testing in our laboratory at 100°C for 72 hours and run comparative tests. Our bonding agents perform satisfactorily in these tests, which indicate that the bonding agents will perform satisfactorily in the field.

Mr. Panek: My own feeling is that there are no truly reliable accelerated tests. All accelerated programs permit one to make a calculated guess, at best. The only answer to the question, "How do you know that the performance will be satisfactory for a period of time?", is to wait this period of time. Then and only then, can you predict performance with certainty, and of course, only under the exact same conditions.

Unsigned question: In union work, what trade would command jurisdiction for applying the bonding agent?

Mrs. Larsen: When this material first entered the construction field, the Plasterers and Cement Finishers International Association took over the jurisdiction for their mechanics, and it was declared a plasterer's accessory in that capacity. Mr. Martin may be able to add to this statement.

T.T. Martin, Natl. Bureau for Lathing and Plastering: What Mrs. Larsen said is true. This union still provides the man to operate the machines that apply the plaster immediately after application of the bonding agent. There is another International Union known as the Bricklayers, Masons, and Plasters International Union which claims jurisdiction over the application of the bonding agent.

Editor's note: (It has been subsequently established that the jurisdiction for the bonding agent is resolved by agreement between the painters, plasterers, bricklayers, and masons. In the New York City area, the bonding agent is applied by the plasterer.).

W.S. Elliott, Vermiculite Assn., Inc.: Will the plasterer's union also apply the plaster by spray guns? Some unions in New York have refused to do this.

Editor's note: (It was established during subsequent discussion that certain unions do allow the practice in New York City.).

# The Use and Economics of Bonding Agents for Structural Applications

By John W. Davis,* Partner
Lacy, Atherton & Davis, Architects and Engineers

In this paper we have endeavored to confine the term "structural" to the building construction field, and to pursue the uses of bonding agents as substitutes for direct mechanical connections taking the same stresses as bolts, rivets and welds. To date, the most common and accepted use of bonding agents in building design has been in: 1) lamination of metals, concrete, wood, insulation and other filler materials for panel construction; and 2) bonding of various cementitious finishes to concrete or masonry structures for interior design.

The structural uses of bonding agents, as defined, has been limited in this country to maintenance and repair of concrete frames, and the application of cement base finishes to existing masonry construction. However, due to the apparent success of the epoxy resins in the fields mentioned, together with a backlog of tests and experiments performed on highway, bridge and airstrip design, where the bonding agents have been used in basic design for the addition or extension of slabs, it seems only reasonable that there can be and will be many applications which will be acceptable and practical in the building structure.

While our firm's uses of bonding agents in the nonbearing and nonstructural applications have been many and varied for a period of 15 years of new construction, our experiences in the purely structural applications have been limited to the bonding of joints in wearing surfaces where the bonding agent is acting as a combination adhesive and sealant. For this particular use, there is much to be said for both the epoxy and thiokol base materials. From our experience it is found that while the epoxy materials have tremendous adhesive qualities in bonding to concrete, their extensibility is definitely limited. On the other hand, polysulfide base materials show greater extensibility, but demand far more protection and perfection of field workmanship in order to produce satisfactory adhesive results.

Therefore, in an effort to stay within the confines of my subject, "Structural Applications," it has been necessary for me to depend on a research of publications in order to highlight what is felt to be the use of bonding agents which eliminate mechanical fasteners to transfer stresses in a building design. While this research furnished me with a wealth of material pertaining to the aircraft industry extending over a period of 15 years, and more recent uses in the highway and paving industries in general, structural use of bonding agent by the building industry falls into two categories, repair and restoration, and research and experimentation.

Under the first heading, the use of a bonding agent by the Hydroelectric Power Commission of Ontario, Canada, is quite interesting. It evidently became necessary to reface the exterior of a power plant and, in a search for practical means of accomplishing this, their engineers investigated a project performed at West Point 18 or 20 years ago, where anchors for a brick veneer wall were bonded by means of an adhesive or bonding agent to an existing retaining wall. Due to apparently successful performance on this project, they experimented with a pronged anchor bonded to the existing brick

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wall of the power plant. These anchors were turned down into the cells of a glazed brick veneer, to be used as the facing. Upon testing a large panel of this veneer, they failed to weaken or fracture the adhesive bond to the existing brick. The anchors were bonded to the existing brick wall horizontally on 4' centers and every five courses vertically. The project consisted of approximately 20,000 sq. ft. of wall veneer. The alternative to the use of the adhesive in this case would have been the accepted design of drilling and setting anchors or ties into the existing wall by means of lead or mortar, which apparently would be a far more costly method.

The use of the bonding agent in this case brings to the designer's mind many possible adaptations for new construction: attaching lintels and girt systems to concrete structures or fireproofed steel frames; the application of various panel systems to the girt system or directly to the structure; attaining wood blocking or nailers to structural frames, angle nosings for concrete steps, etc. This list could go on forever, and no doubt many of these ideas have been used, but have not achieved general acceptance.

Under the heading of research and experimentation, a recent use of an epoxy adhesive in new structures has been the fastening of insulated concrete panels, to act as spandrels, to a concrete frame girder. In this case the panels were precast on the ground, erected in place, and fastened by use of adhesive. By means of shoring they were kept in place until the adhesive had cured and set. This eliminated the need for anchor bolts or any direct metal connection. This application, I feel, is quite recent and is being watched and studied as an experiment, rather than as an accepted detail at present.

While the applications mentioned are probably very minor in scope, and there are no doubt numerous similar or more outstanding examples, there has been no pattern of general structural application or acceptance, either by architects or engineers in general, or by the various codes that govern their designs. The accepted applications of adhesives have been in floor, wall and ceiling construction, that is, as fasteners for plaster, wallboard or other interior finishes, for the application of insulation and the application of various wearing surfaces to concrete slabs or other structural floor systems. The testing of these applications, where reputable and proper adhesives have been used, has proved in most cases that they will withstand more stress than the materials they are bonding.

The bonding of fresh concrete to cured concrete is now accepted and has been successfully accomplished by use of an epoxy-nylon compound. The only requirement in the use of these compounds is that the cured surface be reasonably free of oil, grease and loose particles. The usual chipping and roughening, and the introduction of dowels, anchors and other devices, is eliminated. A thin coating of the adhesive is applied to the existing surface, and it is ready for the fresh concrete in about 15 minutes. While this method has been used in the repair and maintenance of existing walls and floors, in new construction it will allow the designer to vary floor finish thickness on a structural slab, and avoid the usual problem of filling recesses or depressed areas.

The economics of adhesives in some fields have been proven, principally in their use with laminated materials and in applications that do not require the extreme in tensile and fiber stress, and can thus take advantage of the adhesives using neoprene and reclaimed rubber as a base. The use of epoxy based materials will no doubt enable the building industry to discover many more beneficial applications, but a great deal of further work will be required in order to arrive at positive cost comparisons. In general, adhesives will tend to eliminate both shop and field fabrication of many items in building construction. From the architect's standpoint, I feel that any elimination of shop drawing and fabricating drawing in his office would bring us closer to Utopia. However, before this transpires, there will be many difficulties to overcome.

The use of the more commonly known adhesive bases is limited by a temperature rise of about 300 degrees; at 300 degress they will start to disintegrate and reach failure at 400 degrees. Therefore, it seems that for any great structural use involving exposed shear connections in the buildings, development will have to come by way of the silicone bases, in order to cover the temperature ranges of our standard structural materials and the requirements of the underwriters and building codes. But, in the case of fire-proofed steel, tests made in Europe on the "preflex technique" showed that bonding of shear connectors with epoxy resins gave superior results to the welded shear connectors (especially where fatigue tests were carried out). The results of these tests show that four 1-1/2" x 1" steel angles bonded to 1" steel plate with epoxy adhesives imbedded in concrete will support 26-28,000 lbs.

In conclusion, we feel, as architects, that in the future the use of adhesives can accomplish much in eliminating short circuits due to faulty insulation, water and leakage problems, where it is necessary to fasten girt systems, angle lintels, wall ties, etc., to curtain walls, whether they be of metal, lumber, glass or masonry. The economics of these applications, in all cases, will have to be studied for each individual use, and their acceptance by building codes, underwriters, etc., will have to be accomplished by the industry itself. For success, bonding agents must be accepted as structural materials, not as an additive to known structural materials.

# Characteristics and Properties of Structural Bonding Agents for Cementitious Materials

By Raymond J. Schutz,* Vice President
Research and Development, Sika Chemical Corp.

Bonding agents for cementitious materials may be classified into two types: 1) those suitable for bonding plastic concrete or mortar to hardened concrete, mortar or other structural materials; 2) those designed to bond hardened concrete or mortar to hardened concrete, mortar or other rigid materials. Compounds have been developed which will fulfill both functions. The characteristics required of both types would be:

1) High bond strength.
2) Ability to bond a variety of materials to concrete or mortar.
3) Usable pot life and reasonably fast cure.
4) Good aging qualities and resistance to alkaline environment.
5) Simple mixing and application procedure to permit use by ordinary job labor.

These bonding agents are formulated as two-component systems, consisting of a base resin or resins and a curing agent. The base material may be a straight epoxy resin or an epoxy-polysulfide blend. The curing agents will vary according to the base formula used, but are usually amines. Since these bonding agents usually will be used on construction sites, mixing procedure and the ratio between the two components should be kept as simple as possible. The optimum ratio of the two components would be 1:1. Such a ratio is easily measured in the field, but not always obtainable with the particular chemical system employed. Experience has shown that measuring even a 1:1 ratio in the field cannot be reliably done by job labor. It is best to package these systems in units so that full units are mixed rather than measured from the can.

To facilitate thorough mixing, which is necessary to obtain optimum cure, the components should be manufactured in different colors so that improper mixing is evidenced by streaks or nonuniformity of color. The pot life of the mixed component should be long enough to permit using all of the adhesive before stiffening begins. After stiffening, curing time should be as short as possible to permit fast removal of shores or temporary fastenings. Where plastic concrete or mortar is to be bonded, curing time should approximate that of the setting of the concrete or mortar.

Curing time will be affected by temperature, becoming longer as temperature decreases. It is not recommended that these compounds be used below 60°F, as curing time will be excessively long and, depending on the chemical system, might be erratic.

The flexural strength of regular high grade concrete will be in the area of 600-800 psi. The bond strength of these adhesive systems is far in excess of that figure. Bonds obtained will be stronger than the concrete or mortar itself. If failure occurs in such a bonded system, it will not be through the glue line but usually through the new concrete, as this will be slightly weaker than the old concrete. When bonding a broken section of concrete together, an adhesive with good gap-filling characteristics is required. Since

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concrete or mortar does not break clean, pieces of aggregate, sand, and cement paste will powder off. The adhesive will have to be viscous enough to fill the gaps left by these lost pieces. Where the bonding agent is to be used only with plastic concrete or mortar, a low viscosity is desirable to permit economies in application and coverage.

Portland cement paste is highly alkaline, having an average pH between 11 and 13. The adhesive used to bond cementitious material will have to be resistant to this alkaline environment. In many instances, the sections bonded will be exposed to other chemicals such as cleaning solutions, food acids, etc. The bonding agent must also be resistant to such injurious solutions.

## Typical Application Procedure

As with all bonded assemblies, the bond strength obtained will only be as good as the bonded surfaces. Surface preparation is extremely important. Hardened concrete and mortar usually has a layer of weak surface laitance and scum. The tensile strength of this surface laitance will be only 75-150 psi, and it must be removed by sand blasting, acid washing, or chipping if bond strengths in excess of this figure are desired. Where steel is to be bonded to concrete, mill scale should be removed from the steel. The bond strength of mill scale is only about 75 psi in tension. When bonding aluminum, the aluminum should be cleaned by sandblasting, steel wool, or alkaline etches. The importance of surface preparation cannot be over-emphasized.

The adhesive will usually be available as a two-component unit, with the proper weight of each component preweighed by the manufacturer. To insure complete emptying of the containers, the cans are usually opened with a can opener. In this manner, the complete contents can be emptied from the cans (Fig. 1). The two components are then thoroughly mixed, either by hand or by use of a slow speed electric drill equipped with a paddle. Such paddles are available commercially or can be made on the job by the average contractor (Fig. 2).

The adhesive can then be spread by brush. When bonding to a hardened cementitious material, brushing has proved the best form of application since any dust which might be left on the surface is combined into the adhesive and acts as a filler rather than a bond breaker, which would be the case if the adhesive were sprayed. (Figure 3 illustrates an adhesive being applied to a concrete highway using ordinary fiber brooms.)

If the particular adhesive formulation does not contain any solvents, fresh concrete or mortar can be applied immediately. If the adhesive formulation contains a solvent, the solvent must be allowed to evaporate before application of the plastic mortar or concrete. Concrete or mortar is then applied, using standard concreting techniques (Fig. 4).

When bonding broken pieces of concrete together, or bonding steel or other metal shapes to concrete, an adhesive with good gap-filling properties is required. Figure 5 shows a standard concrete beam broken in a flexural test. Notice that sand, concrete dust, and pieces of aggregate have been lost and the pieces no longer mate exactly. Figure 6 shows a standard beam which has been bonded together and broken in a standard third point loading test.

## Conclusion

Adhesive systems such as those described have been used over the last five years for many structural purposes in bonding cementitious materials. Some of these applications are:

1) Bonding of thin concrete or mortar overlays to base concrete.
2) Bonding additional concrete to structural members, for such purposes as lengthening or widening slabs, beams, or stair treads.
3) Bonding load transfer devices and shear connectors to concrete.
4) Bonding of broken sections together and the fastening of wood, metal, plastic,

and concrete signs and decorative devices to concrete and masonry.

The service life of such installations indicates that the adhesive should last as long as the economic life of the structure.

Figure 1

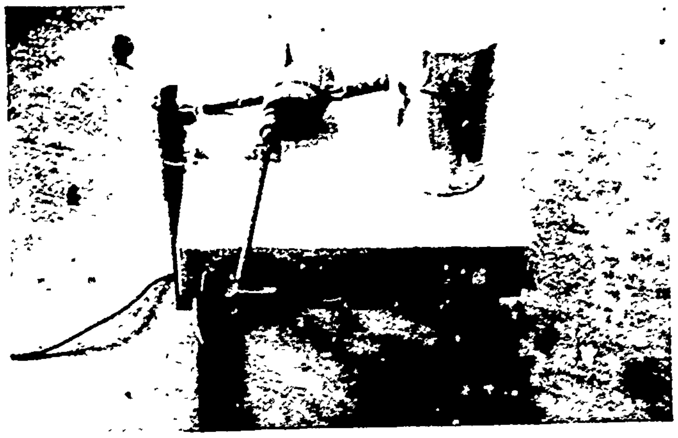

Figure 2

Figure 3

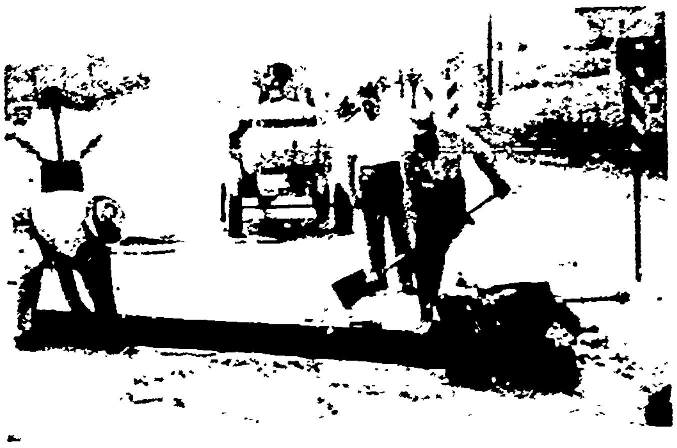

Figure 4

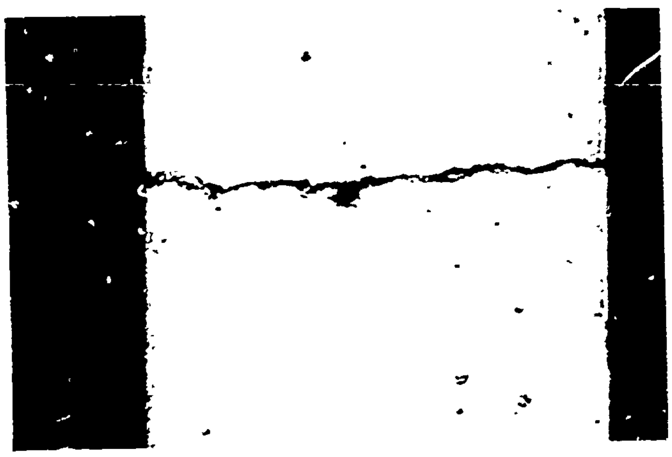

Figure 5

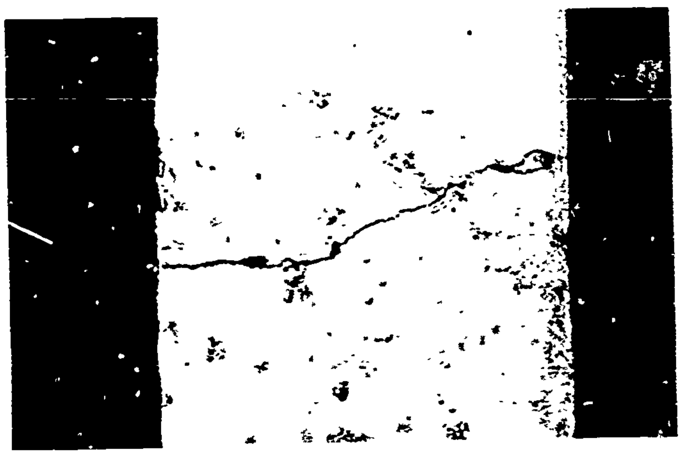

Figure 6

# Open Forum Discussion

Moderator - Julian Panek, Manager
Technical Service Dept., Thiokol Chemical Corp.

Panel Members - John W. Davis, Lacy, Atherton & Davis, Architects and Engineers
Raymond J. Schutz, Sika Chemical Corp.

Unsigned question: At how low a temperature can the adhesive be applied and cured in one or two hours?

Mr. Schutz: Within a fair range the curing time of these adhesives systems can be varied. However, at a temperature of 55 or 60$^{o}$, if you accelerated the adhesive to a point where it would set in two hours you would have insufficient pot life.

Unsigned question: Will the epoxy adhesives allow you to pour new floors over poor finishes, or is the poor floor surface due to excessive wear or poor material?

Mr. Davis: You have lots of wear on concrete floors in manufacturing plants, but whatever was left would have to be pretty structurally sound. Of course that is one thing the adhesives industry will have to watch out for, because it will end up as a cure-all. People will put it down and then it will get a bad name if it doesn't stand up over deteriorated material.

Unsigned question: Insofar as toxicity is concerned, what special precautions have to be observed by workmen using the bonding agents?

Mr. Schutz: In most cases the curing agents used in these systems will be toxic; however, the percentage of active curing agents in any system would be rather small. All that would be required would be good hygiene. Have workmen wash their hands once in a while or better yet, wear gloves. They are not quite as bad as they sound, but there is a toxic ingredient to which some people's skin will be highly sensitive and others' will not. Good hygiene is the answer. There is no real trouble experienced in the field. In fact, in one case I know of, the trouble was the man washing his hands too often in toluene solvent. It dried his skin out and caused more trouble than the curing compound itself.

H.R. Young, E.I. duPont de Nemours: Numerous references have been made to epoxy resin adhesives. Are epoxies preferred over all other types? If so, why?

Mr. Schutz: It depends on what particular area of application we are talking about.

Mr. Davis: There are two different qualities of the polysulfide materials as opposed to the epoxy. I do not pretend to be a chemist, but from my own information the epoxies are far better adhesive-wise and require less care in the installation. Polysulfide bases need more attention to the application and more care during construction; however, they have far greater extensibility or elasticity.

Mr. Schutz: Are these systems, whether they be straight epoxy or epoxy polysulfide systems, superior to other systems such as polyvinyl acrylics?

Mr. Davis: The advantages of these systems, whether they be straight epoxy or the epoxy polysulfide, would be their water resistance, resistance to alkalis, and their extremely high bond strength.

Ardis White, University of Houston: Regarding the bonding of shear connectors to steel, to what extent has this been done and with what types of shear connectors?

Mr. Schutz: The pre-flexed system which Mr. Davis referred to used both steel angles and also a rather odd, horseshoe-shaped steel connector which is apparently popular in Europe. There is some work being done right now at Rensselaer Polytechnic Institute on the bonding of standard American shear connectors to steel for composite bridge construction, under sponsorship of the New York Department of Public Works. That work is not complete.

Wesley A. Wieting, Perkins & Will: In bonding precast concrete elements together, what type of failure has developed? What should we watch for in supervising this kind of work?

Mr. Schutz: The things to watch for would start all the way back in the design stage. If you were putting these precast elements together in a conventional manner, you would use some form of load transfer that carries the load into the concrete. When you are bonding two precast elements together, the transfer must go through the bond and the surface of the concrete. There will be no load transfer into the interior other than the load transfer through the concrete or aggregate itself. So, in the design, especially where shear is concerned, you will have to be thinking of surface area rather than a load transfer into the center of the beams. There will have to be some thought devoted to this in the design stage and careful surface preparation.

E.S. Wormser, The Gibson-Homans Co.: In applying fasteners to concrete walls, what holds the fasteners in place until the epoxy adhesive has cured? Do not the fasteners have a tendency to slide unless mechanically held in place until the epoxy adhesive has cured?

Mr. Davis: My knowledge of this particular use has been through the research I described. The question came to me at the same time, and I endeavored to find out. The only thing I have been able to find out is that they use a type of material that sets almost immediately on application.

Mr. Schutz: There are adhesives that set so fast the workmen can hold it while it cures, but there is quite a bit of waste there, because you leave some in the pot to harden. The State of Maryland has used nothing more than plain scotch tape to hold the fasteners until the cured adhesive can hold the device by itself.

Unsigned question: What are the allowable design stresses?

Mr. Schutz: The design stress, to be practical, would be the stresses that the concrete itself could hold. If you have a relatively poor concrete, say with a flexural strength of 300 psi, you can't hope to have any more load-bearing capacity. At the present time the only statement of allowable stresses I have seen has been that of the Corps of Engineers for extending airport pavement. Their allowable stresses are 400 psi in flexure in the bonding agent.

Unsigned question: What is your experience with the freeze-thaw performance of these bonding agents?

Mr. Schutz: The bonding agents themselves absorb practically no water and would take alternate cycles of freezing and thawing very well, in fact much better than concrete, as all concrete will absorb some water and be affected by freeze-thaw.

Unsigned question: Have you any idea of relative costs of laying new concrete over old, using the modified adhesive, versus the preparation by use of the tenon machine?

Mr. Schutz: The concrete surface itself, the "old" concrete we'll call it, has to be sound and in some cases, even using adhesives, you have to go over the surface with a tenon machine if your concrete surface is deteriorated. When you bond a thin overlay to that deteriorated surface, in all probability the deteriorated surface will pull off when load or stress is applied to the topping. These methods do not obviate the need for good surface preparation. The tenon machine is an excellent way to prepare a surface for overlay whether you use this method or any other method.

Mr. Panek: Assuming that you do not use the tenon machine, and if you have a fairly good surface to adhere to, is there any difference in the cost?

Mr. Schutz: The conventional method would be to scrub in an ordinary cement grout. Now, an ordinary grout costs very little, maybe $1.00 for four gallons, whereas the adhesive costs perhaps $20.00 a gallon. Using an adhesive, then, rather than a cement grout to apply a topping would be more expensive. However, the bond would be sure and extremely strong.

William Lukacs, National Council of the YMCA: Has there been any experience with the application of non-skid nosings to concrete, and/or metal pan type stair treads with bonding agents in lieu of bolts, etc., as now done?

Mr. Schutz: Some telephone companies in Iowa have applied metal nosings to travertine marble stair treads with these adhesives, in that case requiring an adhesive with good gap-filling qualities. That's the only installation of this type that I know about, but there is no reason why it couldn't be done.

Unsigned question: Are the techniques the same for bonding concrete to concrete, or concrete to other structural materials such as steel or plastic?

Mr. Schutz: Basically the techniques would be the same for bonding rigid materials such as steel or rigid plastic. The adhesive would have to have good gap-filling qualities; both surfaces would have to be clean. About the same rules would apply for concrete to concrete, or concrete to steel or wood. A clean surface is necessary so the material can fill gaps properly and achieve a 100% bond. The only difference would be that where plastic concrete is concerned you don't need the gap filling qualities.

Mr. Panek: How about something like teak and oily wood?

Mr. Schutz: I am glad you brought that up. These materials do not react well on oily surfaces. If the wood were oily, or if it were creosoted, I don't think you would get much of a bond, if any.

H.R. Young, E.I. duPont de Nemours: You described the use of adhesives with twice the strength of the concrete. What is the merit of this? An adhesive with equal and adequate strength could perhaps be developed at much lower cost.

Mr. Schutz: The epoxy adhesives have this high strength inherently. You are working with materials with a tensile strength of 7,000 or 8,000 psi. Of course, you can degrade them by adding fillers etc. However, what we are trying to attain here is a bonded assembly that can be trusted as a structural material. Workmen are going to apply it in the field, under field conditions, and therefore you must have a very good safety factor. Otherwise, in bonding two pieces of hard concrete together, you might not fill all of the gaps, or you might only have a 50% bond area. In this case, to attain sufficient structural strength, the adhesive would have to be twice as strong as the concrete because it is only covering half of the area. It's a safety factor and I think it is a necessary one, considering that we are working in the field with these materials, not in the laboratory.

Mr. Davis: I think, also, that if you tested these things at a considerably slow rate of movement it might become apparent that these adhesives with lower adhesive strength might give considerably poorer performance. Even though we are talking in relative terms, it really boils down to making an application to prove whether or not these lower strength adhesives will work.

G.G. Kubo, New York University: Can you test adhesion capacity non-destructively?

Mr. Schutz: No, I wish we could. To test an adhesive bond you have to test it until it breaks, then you know how strong it is.

Floor question: Do you have any knowledge of the application of epoxies or polysulfide modified epoxies added to improve mortar? If so do you think this is economically feasible? What percentage can you add to mortar to give it added properties of strength and flexibility, and still make is possible to use?

Mr. Schutz: I don't know of any work in that area. You would have to have a mortar which could be emulsified in some manner with the curing compound. There is no reason why we can't just incorporate sand into the adhesive without the use of water and use this as a mortar. This has been done. You can put a considerable amount of sand into the composition.

Floor question: Do you know of any use of these materials to improve gunite used on structures that are subject to cracking, peeling, etc?

Mr. Schutz: In gunite mortar itself? No, I don't. These bonding compounds have been used on repair work as the bonding medium between the gunite mortar and the base concrete, but just as a bonding layer similar to applying a thin overlay on a horizontal surface, not in the mortar itself.

Floor question: Has there been any test made on the life expectancy of epoxies; in other words, do they lose any strength over the years with weathering? If so, do they lose a great deal?

Mr. Schutz: I don't have any figures in my head; however, the Army is using an aluminum-to-aluminum bond which it has been testing in the Canal Zone since 1945. Those figures are available but I don't have them here.

Mr. Davis: Some tests we have run, where we have bonded new concrete to old, have been through freeze-thaw cycles. In other words, the job has been done about four years and it's gone through four winters and it seems tc be holding up.

Floor question: In bonding new concrete to old concrete, do you find that you get a much better bond if you have a low-slump concrete for your overlay?

Mr. Schutz: We have tried some work in that area and our results have been a little better with the higher slumps and with the more gap-filling type of material.

# BONDING OF GYPSUM DRYWALL CONSTRUCTION

Chairman - Thomas F. Neblett
Executive Director
Gypsum Drywall Contractors International

# Current Practices in Bonding of Gypsum Drywall

By C.E. Kallem,* President
Hollenbeck Drywall Associates, Inc.

A few years ago gypsum drywall was a relatively new product. Today it is used around the world. It represents a business that is not only big, it is overwhelming. Gypsum drywall has grown into a billion dollar business in the United States alone in the last 12 months. This material can be adapted to all the latest modern requirements for walls and ceilings of which the builder can be proud. It is interesting to note that there are 48,000 journeymen gainfully employed in the drywall industry. Twenty thousand of these are classified as taper-finishers. A taper-finisher is a man who embeds the tape, thereby sealing the joints and puts a finish coat over the tape preparing the surface for painting. There are 28,000 carpenter-mechanics employed who cut and fit the sheets of gypsum drywall preparatory to the taping.

Drywall construction has not achieved its wide acceptance by accident. For nearly a half century, gradual and fundamental progress has been made by the major segments of the gypsum industry. The precipitous rise in prefabricated wallboard consumption is the result of communication between contractors, the Gypsum Association and manufacturers. The manufacturers of gypsum wallboard have provided the users with constantly improved products through research and modern plant equipment. This represents huge investments of money, time and labor. We in the construction end of the business are singularly grateful to the gypsum manufacturers. We could not have attained over 75% of the residential market without the support of the Gypsum Association. The necessary promotional and technical activities have been carried, to a great degree, by the Gypsum Association.

The Gypsum Drywall Contractors International realized that we needed a handbook containing specifications for drywall construction. The Gypsum Association worked with us for two years on this document; it was completed last January, and is already out of date. This is just one illustration of the tremendous amount of work needed to keep up-to-date with our fast-moving industry.

As evidence that gypsum drywall has been accepted, it is gratifying to see how the opportunities presenting themselves through the use of our product have not gone unnoticed by the major proponents of quality construction. Figure 1 illustrates the eight-year rise in consumption of this material. However, in the midst of the many opportunities already presented, we find a serious challenge that may thwart further progress. Each day we find more and more adhesives replacing present methods of fastening. Where are the methods of fastening drywall to studs without mechanical devices? Where is the tested adhesive that can bond two pieces of gypsum board together in a moment of time?

Nail-on adhesives, laminated adhesives and taping adhesives are being modified constandly. For these we need specifications.

There are 2-1/2 billion lin. ft. of joints to be taped in 1960 on residential construction

*C.E. KALLEM is a member of Gypsum Drywall Contractors International, and Vice Chairman of its Technical Committee.

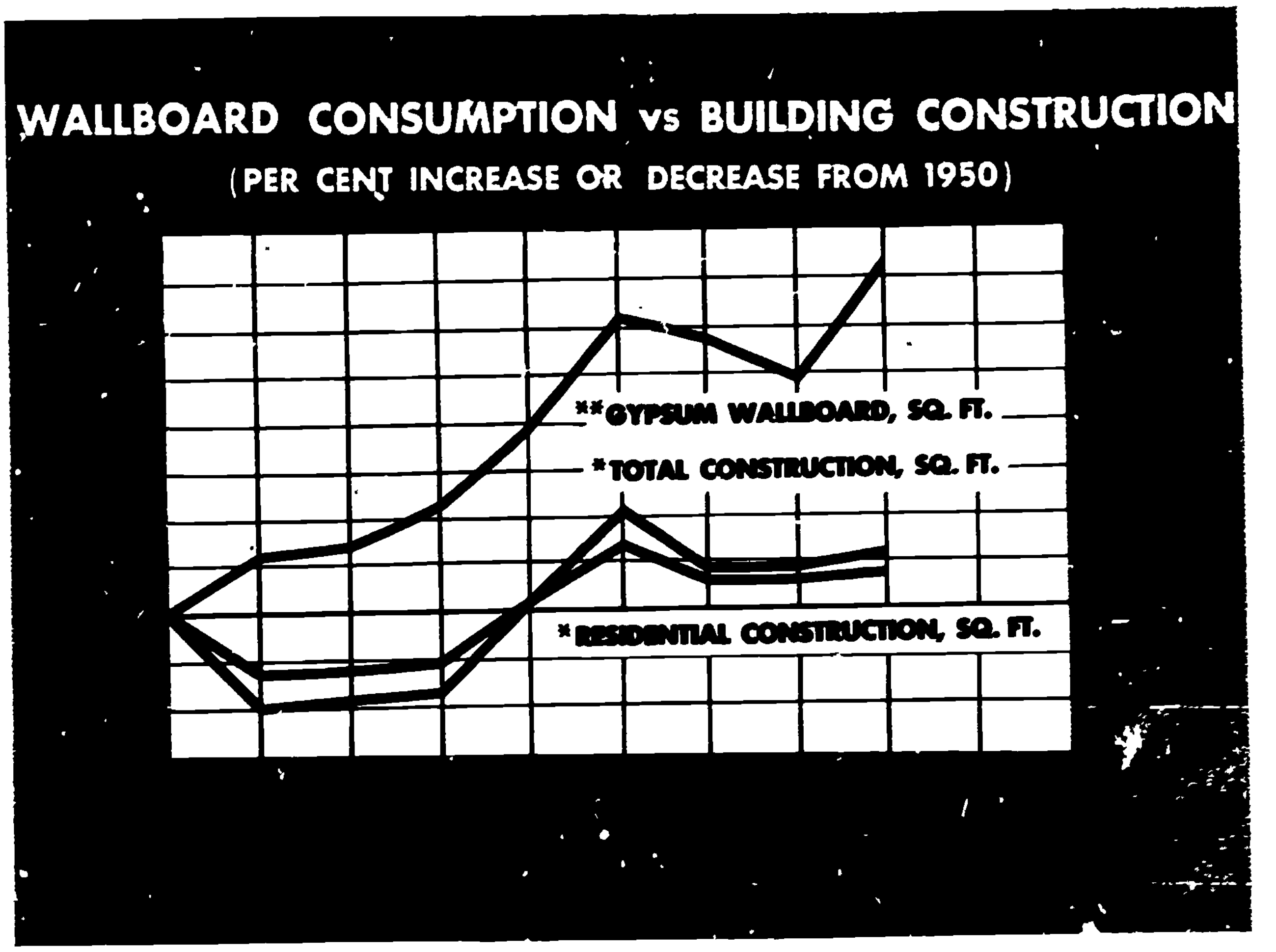


Figure 1.

alone. We must speed up the taping of these joints by as much as one or two days per house. The interest and concerted efforts of the adhesives industry to solve any of the foregoing problems will help materially. As we analyze today's problems the adhesives manufacturers could contribute in the following areas:

1) Provide a material to permit nails to be spotted one time only, rather than three or four times.
2) Provide a taping material that is not water soluble, or at least one that would set in damp weather, allowing work on the job to continue. These two materials would give the contractor one or two days less time on the job, give the manufacturers more research dollars and save the builder two days per house on 1,200,000 homes in 1960.
3) Provide a contact bond adhesive which could be used under all conditions.
4) Provide a tested bond adhesive that could be applied to one surface only.

Of course, this predisposes a considerable investment on the part of the adhesives industry. There are four areas that demand attention:

1) An ambitious development program implemented by job testing of materials. Materials tested in the lab are not subject to field conditions. Here is an area where we, the drywall contractors, are willing to cooperate for the mutual benefit of all. In certain cases, new materials or methods have been tested on the job and because the contractors conducted the actual test, it was either not an official test, or the project was abandoned for lack of time to work with it. In another case, an experiment was run on several hundred houses and a report has never been written on it. Obviously, there must be further communication developed between the lab and the actual job site.
2) Industry must be prepared to devote top technical men to these problems. More formulas must be produced, and old formulas re-evaluated. But more important, the responsibility for developing specifications for new materials must be faced realistically.

3) A constant flow of research dollars must be available to keep pace with this rapidly moving industry.
4) Brain-storming sessions such as this one must be held, however and wherever possible. Perhaps the Technical Committee of GDCI could be host to such sessions at its Directors' Meetings. We could very profitably spend time in small groups and later meet in general session to consolidate our gains.

In conclusion, I recommend that special attention be given to re-evaluating cooperatively present methods, and to exploring new fields of accomplishment. We must initiate development programs with first-line technicians and research workers and work systematically toward perfecting tomorrow's walls and ceilings.

# Attachment of Gypsum Drywall Boards to Studs

By Alex O'Hare,* Vice President
Miracle Adhesives Corporation

Gypsum wallboard or drywall, as it is now generally known, was first produced commercially and used in quantity during World War I. By 1950, more than 30 years later, this product was used in only 30% of new home interiors. In 1960, it is reported that 75% of all new home interiors will be built with Gypsum Drywall. This amazing jump from 30% to 75% in just one decade proves the importance of this fast-growing wall system to the building industry.

Improved installation techniques, developed during the last 10 years, are the basic reason for drywall's rapid advance in both the home building field and the commercial market. Joints are no longer covered with batten strips as of old. Present-day joint systems become an integral part of the wall. There are still several problems to overcome in these joint systems , the major one being nail-popping or nail-sucking, that slight protrusion or dimpling at the point of nailing in the face of the wallboard.

For years the cry has been, "Stop the pops than ruin a beautiful drywall job three months after installation." This situation still "hangs by the nail." Either the nails or the studs must be made stable after installation, or the nails must be completely eliminated from the face of the wallboard.

Research projects by Forest Products Laboratories, Virginia Polytechnic Institute and Purdue University all agree that better nails, properly dried studs and careful workmanship will help overcome this problem, but all of these precautions do not offer a positive cure. Even using a good nail, such as the new GWB-54 threaded nail, as approved by both the Gypsum Drywall Contractors International, will not eliminate popping if green studs are used in the construction. Drywall applied to properly kiln-dried lumber with plain nails or even with the approved nails may fail at a later date, if there is a constant moisture change in the wood structure because of wide humidity variations.

The obvious answer, therefore, is to eliminate all nails from the wallboard's face. This is the industry's goal. Single-layer gypsum wallboard, bonded directly to studs without the use of any nails, was demonstrated at the recent GDCI convention in Miami, but this method was not approved by that Association. This idea must first be proven by many field tests in various sections of the country with wide climatic differences before it can be generally recommended.

Currently the best practical answer to the problem of single-layer applications is the now generally accepted "adhesive-nail-on" system. It was originally developed to reduce the number of nails used, while at the same time building a stronger wall section. To determine how far nail reduction might go, racking tests on full-size panels were made at Ohio State University. They proved that the combination of adhesive and 50% less nails than previously specified by industry practice produced a wall twice as strong as that produced by the conventional method. A further reduction in the number of nails

*ALEX O'HARE is treasurer of Products and Process Development Laboratories; Member of Building Research Institute and Producers' Council; associated with Miracle Adhesives since 1935.

Figure 1.

Figure 2.

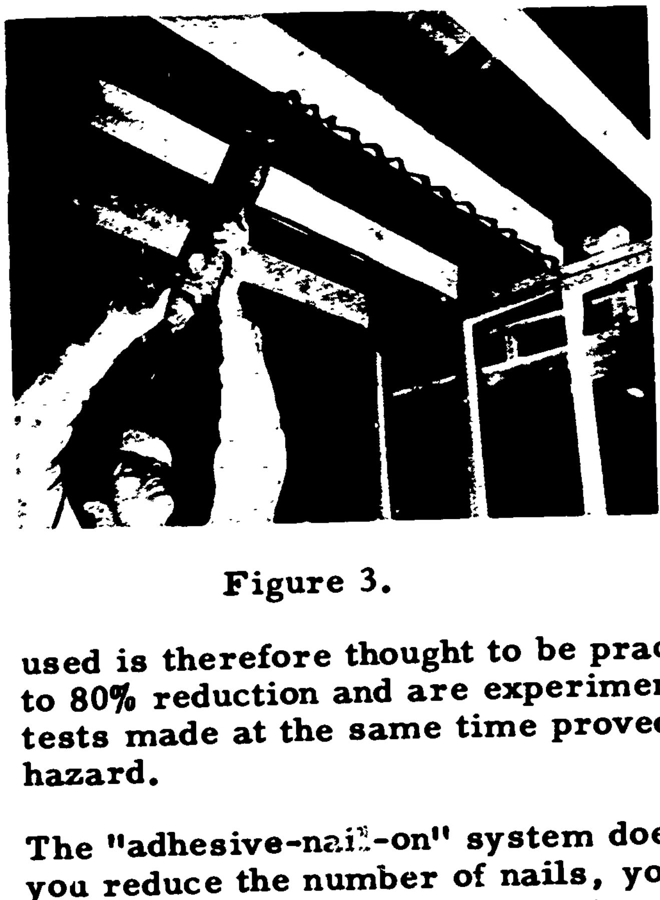

Figure 3.

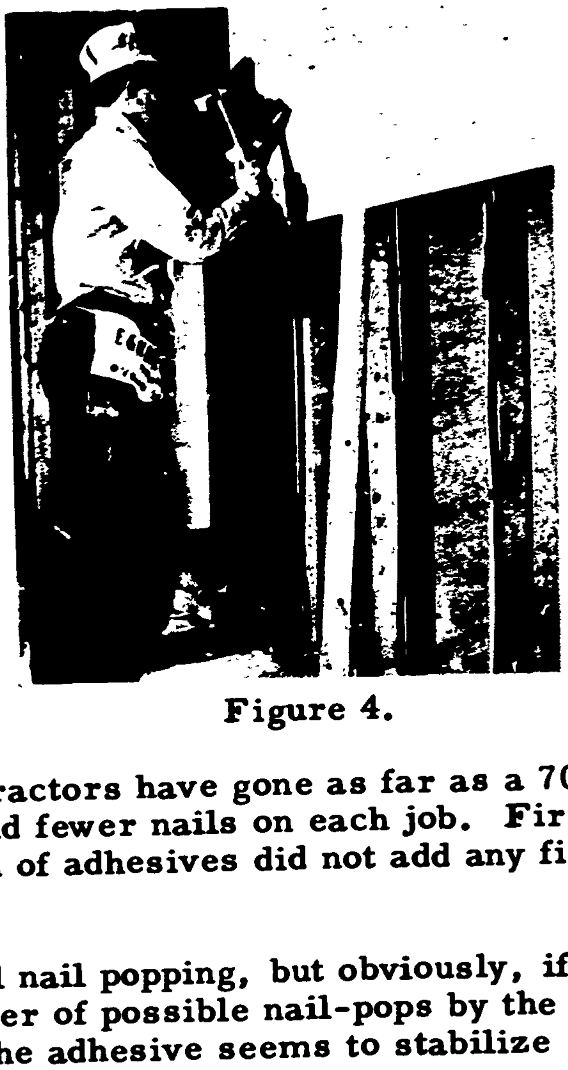

Figure 4.

used is therefore thought to be practical. Some contractors have gone as far as a 70% to 80% reduction and are experimenting with fewer and fewer nails on each job. Fire tests made at the same time proved that the inclusion of adhesives did not add any fire hazard.

The "adhesive-nail-on" system does not eliminate all nail popping, but obviously, if you reduce the number of nails, you reduce the number of possible nail-pops by the same amount. For reasons not as yet determined, the adhesive seems to stabilize the wall to such an extent that the few nails left do not pop.

The "adhesive-nail-on" method (Figs. 1 through 4), now used in every section of the country, is easy to use and requires very little in the way of special or costly equipment. A standard caulking gun of approximately one quart capacity, and a gun filler pump to fit directly onto a five gallon pail, are the only extra tools required. Adhesive is also available in cartridge form so that even the filler pump can be eliminated if so desired. The nozzle used is a standard 3/8" size with an angle tip to provide easy application.

A continuous bead of adhesive is applied to the center of the face of all framing members. On framing members where joining of two adjacent pieces of wallboard will occur, a serpentine or zig-zag bead is applied. A properly formed bead should extend out from the face of the stud a minimum of 1/4", and should contain sufficient material to spread over the entire surface of the stud when the adhesive is flattened to approximately 1/16" thickness by the nail pressure. This method of applying drywall to studs is simple, not expensive, needs no heavy outlay for tools, and has proved effective for many contractors.

Better tools for the application of the adhesive are asked for by one well-known drywall applicator. He claims that the pumps presently used to transfer adhesive from drum to caulking gun only empty two-thirds of the drum. This means extra labor time to transfer remaining adhesive to the new drum.

Current models of caulking guns and mastic applicators tend to clog at times, causing lost labor time for cleaning. There is obviously room for some improvement in both of these items used by the trade.

Although the "adhesive-nail-on" method of applying wallboard was designed mainly to provide for nail quantity reduction, a very important side effect has been observed. Completely filling the space between the stud and the wallboard, at all points, with a resilient rubber adhesive has produced a very marked reduction of impact sound transmission through the wall. This is a "plus" selling item for the builder.

Many drywall contractors claim there is no extra expense involved in using the "adhesive-nail-on" system, because there are fewer nails to buy and drive, it requires less labor installation time, and the quality of the work results in far less customer complaint about nail-pops.

Another method used to eliminate disfigurement of wallboard face involves a variety of floating-type clips, all difficult to cover in single-layer applications. A complete covering of nail heads can be achieved by a double-layer lamination, using two sheets of gypsum board, a method described elsewhere in these proceedings.

# Lamination of Gypsum Drywall

By Rodney G. Buergin,* Director of Technical Services
National Gypsum Company

When we speak of laminated gypsum wallboards in this paper, we are referring to two or more sheets of wallboard fastened together with some type of adhesive. A second concept in the use of gypsum wallboard in a laminated system is the adhesive application of a single layer of gypsum wallboard over a substrate such as exposed masonry walls or plastered ceilings and walls.

In considering the use of multiple layers of gypsum wallboard, we find several excellent systems available for a variety of uses. The most commonly used system is the one in which a base layer is first nailed or stapled to wall and ceiling wood framing members, and a second, finish layer, is laminated to the base layer. This system is used primarily in residential construction, but may also be used in certain classes of commercial buildings.

A second system, closely allied to the first, is one in which the base layer is either nailed, stapled or clipped to metal studs and metal ceiling channels, followed by the adhesive application of the finish layer. This type of construction is used primarily in commercial and institutional buildings where fire protection is a major factor and where only incombustible materials are desired.

A third type of system involves the use of several layers of gypsum wallboards laminated in various combinations to form nonload-bearing partitions ranging in thickness from 1-1/2" to 5".

These three types of laminated gypsum wallboard constructions encompass a wide range of details, but all have two components in common: gypsum wallboard and some type of adhesive. Several types of adhesives are now available for laminating gypsum wallboard and others are in the development and/or field testing stage.

The most commonly used type of adhesive, and one which has performed successfully for years, is tape joint adhesive. This is a dry powder material to which water is added on the job to form a paste. Tape joint adhesive, mixed to a somewhat higher consistency, is used for embedding paper tape over the wallboard joints. Special topping cements for finish coating tape joints are not suitable for laminating purposes. The adhesive must be mixed in accordance with the manufacturer's instructions.

When laminating, the tape joint adhesive is spread on the back surface of the finish layer of gypsum wallboard with a notched trowel, forming ridges ranging from 1/4" x 1/4" to 1/2" x 5/8", spaced from 2" to 8" apart, depending on the method employed in fastening the base layer and on the type of system involved. The wallboard can then be applied immediately and should be pressed tightly against the base layer. This type of adhesive has very little tack, therefore the wallboard must be held in place by temporary nailing or shoring until the adhesive sets or hardens, usually in 24 hours. The nails are then set below the surface of the wallboard or may be withdrawn if double-headed nails or plastic washers are used.

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A second type of adhesive is the mastic type which arrives at the job ready for use. Some of these adhesives have a reclaimed rubber base containing a solvent. The adhesive is applied to one surface, either to the back of the finish layer or to the face of the base layer, with a notched trowel forming ridges of a size and spacing complying with the adhesive manufacturer's specifications. The face layer should be applied immediately after application of the adhesive. Open time is usually quite short, which is a disadvantage. This type of adhesive is very flammable. Care must be exercised to avoid prolonged or repeated contact with the skin and inhalation of the vapors. The adhesive is easily troweled, allows adjustment of the board during placement and, like the tape joint adhesive, provides a means of leveling the finish layer over a base layer which may contain uneven spots or areas. The use of this adhesive also requires temporary nailing or shoring for several hours until the adhesive is set.

A third major type of adhesive, the use of which appears to be spreading rapidly, is the contact bond type. This adhesive also comes ready for immediate use on the job. Generally speaking, it consists of a neoprene rubber base with resins added for adhesion. It must be applied to both the face of the base layer and to the back of the finish layer. Normally it is applied with a roller or brush in a uniform, thin coating covering the entire surface. The adhesive must be dry before joining the two sheets of wallboard. Drying time varies with temperature and humidity conditions, but is usually from 15 to 30 minutes. When the two adhesive surfaces are placed together the gypsum wallboard cannot be shifted. The adhesive is easily applied, develops very quick bond strength and eliminates the need for temporary nails or shoring.

Relatively heavy pressure must be applied to every inch of the finish layer of board to insure maximum contact with the base layer. Because the adhesive film is thin and uniformly applied, comparable to a film of paint, the finish layer of wallboard must follow the general contour of the base layer. The finish layer, being somewhat rigid, will not conform to small dips and hollows in the base layer. There may, therefore, be areas where no contact is made between sheets. This type of adhesive is extremely flammable and, again, care must be exercised to avoid prolonged or repeated contact with the skin and inhalation of the vapors.

Future development of adhesives offers a challenge to the adhesive manufacturers which, if met, would be beneficial to the building industry, and particularly to those segments involved in laminated drywall construction. What is required is an adhesive containing as many of the following characteristics as possible:

1) Ready to use with little or no preparation required on the job.
2) Easily applied by roller, brush or notched trowel. (The latter would require a heavier consistency material and is needed where the substrate is slightly uneven.)
3) Open time of at least 45 minutes.
4) Permit immediate lamination or a maximum 5-minute waiting period after application of the adhesive.
5) Allow limited adjustment of the face wallboard after contact is made with the base layer.
6) Creep or cold flow resistance—no temporary nails or shoring required.
7) Permanence (heat resistance, good bond and shear strength, long-term performance).
8) Not flammable.
9) Nontoxic.

In addition, the building industry needs a specification, such as an ASTM specification, governing the adhesive to be used for the laminating of gypsum wallboard. This specification should be prepared by the adhesive industry in cooperation with the gypsum wallboard manufacturers and the drywall applicators.

Gypsum wallboard manufacturers are often asked whether or not a particular adhesive is satisfactory for laminating purposes. I'm certain that drywall applicators are also confronted with the same question. The existence of a controlling specification would permit a quick evaluation to determine the acceptance of the adhesive in question. Without this specification, it is difficult and time consuming to determine the acceptability of adhesives.

Laminated gypsum wallboard systems are the ultimate in drywall construction. They provide characteristics above and beyond the sum of the plies with respect to strength, fire resistance, sound deadening, etc. Many excellent adhesives are available for bonding together the plies of gypsum wallboard, and the future should bring even greater improvements both in adhesives and in laminating techniques.

# Joint Finishing and Nail Spotting

By Granville G. Waggoner,* President
Drywall Company, Inc.

Joint finishing in drywall construction is done in two distinct operations, taping and finishing. These operations may be done either by hand with scraper or trowel, or by so-called machine tools. In general, the adhesives used for each process are of different formulae.

Gypsum board is manufactured with a recess, or taper, on the long edge in which a fibrous reinforcing tape is embedded by means of an adhesive which bonds the tape and board together. After the joint is taped, the recess is then filled with a topping adhesive until it is smooth and level. This process takes two or three applications, with the width increased in each application. Lastly, the joint is sanded to leave a perfectly smooth surface for decoration.

In reference to nail spotting, it may be explained that a properly driven nail will leave a slight dimple in the face of the gypsum wallboard, with the head of the nail below the level of the board, and the face paper left unbroken. This dimple is filled with adhesive at the same time as the joints are filled, in order to leave an entirely level, smooth surface for decoration. This filling and smoothing also generally takes three separate applications.

The adhesives used in joint finishing today are water soluble, air-drying materials, and therefore are at the mercy of the elements, namely temperature and humidity. The strength and bond of the adhesive is only achieved upon drying. High humidity tends to defer this drying, and freezing can, in many cases, kill the bond before the adhesive has had time to dry.

The normal drying time is one day for each application—3 applications, 3 days, plus one more day to sand the surface smooth. This is about the minimum time in which a drywall joint can be finished, since one coat must be completely dry before the next one can be applied.

The desired characteristics of adhesives used in drywall joint finishing, therefore, are:

1) Ease of working (easy to mix, spread and sand).
2) Maximum bond or adhesion.
3) Fast drying with minimum shrinkage.
4) A permanently smooth finished surface.
5) Compatability with paint and other surface coatings or coverings.
6) Low cost (not necessarily in the bag or bucket, but on the finished wall).

The adhesive used in taping may have a higher casein content to give increased bond strength, whereas in the topping cement the casein content can be somewhat lower, since it is used to make the joint flush, and must be easy to sand to a smooth finished surface.

As to the matter of cost, these materials must be kept as low in cost as possible, and

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by that I mean not the cost of the adhesive in the bag, as it comes from the manufacturer, but the cost on the finished wall. A material that is difficult to mix is expensive, even at 4¢ per pound. If you have to fuss with it to get it properly applied, and make 8 or 10 trips back to the job instead of four, that is not low cost as far as the drywall contractor is concerned. The modern drywall contractor can tell you the exact amount of time it takes him to spot nail heads, tape, do all of his filling and sanding operations. In fact, using conservative figures, it costs $18,000,000 per trip for the drywall contractors of this country to finish all of the drywall installed each year. If each drywall contractor could save just one trip, some $18,000,000 could be released for more cooperative research between the manufacturer, contractor and builder.

The manufacturers have done a great deal over the past few years to produce an adhesive that would have the necessary working qualities and would produce an excellent finished job at a low price. We recognize that they deserve a lot of credit for those efforts. As an industry, we are more than willing to cooperate in research that will improve these products even further. We, as an industry, are available individually and collectively for field trials and testing work.

In addition, we feel that future research should be pointed in two directions:

1) Toward improving our present types of materials.
2) Toward developing materials, methods, procedures and tools to perform this job with entirely new and different techniques.

Only through continued cooperation in research and field testing of materials, methods, procedures and equipment can be continue the progress shown over the past years.

# Panel Discussion

Moderator - Thomas F. Neblett, Executive Director
Gypsum Drywall Contractors International

Panel Members - Chester E. Abbey, Merchandise Manager, Gypsum Products,
Bestwall-Certain-Teed Sales Corp.
John M. King, Director, Research Services
National Association of Home Builders
John A. Robertson, Manager, Research Dept.,
U.S. Gypsum Co.
A.T. Slosser, Manager, Industrial Adhesives Division,
Armstrong Cork Company
Fred Wehmer, Technical Director
General Adhesives Chemical Co.

Mr. Slosser: I am tremendously impressed with Mr. Kalem's presentation in which he mentioned that one of the prime objectives is this matter of improved communications between the manufacturer of the adhesives, the manufacturer of the gypsum drywall and the contractor. I agree heartily that this is the only way we are going to attain reasonable answers to our problems. From an adhesive manufacturer's viewpoint, I can say truthfully that we are quite in the dark as to exactly what is needed for the job. Many of us are working with products for this use, and we don't know whether we are offering a product too good for the job. We feel certain that we are offering what is adequate, but if economics are an important factor, we must be very careful that we don't over-sell the job. We should offer something that is entirely adequate, but the product shouldn't be one that is more costly than necessary, just to be safe. Therefore, this matter of communication between the drywall contractor and the gypsum wall manufacturer and the adhesive manufacturer is of tremendous importance.

Mr. King: This is the kind of approach that we at NAHB are trying to get across to the industry as a whole. We all recognize the tremendous need for further development of new products for home building. One of the basic principles we attach to product development is that of reducing construction time, both on the site and in the shop. This is particularly important when we get to the matter of finishing a house. So, I was pleased to hear that we can now reduce the number of nails used in fastening gypsum drywall by 50%. This is certainly a trend in the right direction. I think further development is needed in adhesives, both for site and for shop application. I am speaking now in terms of shop fabricated components for home manufacturers who have been interested in this area for a number of years. I hope that consideration will be given to shop fabrication as well as the field fabrication of components. This is particularly important with the greater degree of pre-finishing today of boards and panels before they are sent out to the site. If we can devise adhesive systems what will eliminate the nailing, it will certainly simplify the job of putting these panels up in the field. The home builder has a tremendous interest in new methods of joint finishing. This is an area that requires tremendous effort if we are going to reduce the total construction time at the site, not just the labor time but also the lost time, which is also important to the builder. For instance, Clayton Powell of Savannah, Ga. builds on a 14-day construction schedule. He finishes out a house from foundation to completion in 14 days, and he says that 3 to 4 days are taken up in the application and finishing, particularly, of the drywall. He has figured that, if he could eliminate 2 or 3 of these days from his schedule, he would save in construction overhead and expense at least $100.00 a day. So if he can go from 3- to 4-day drywall finishing schedule down to one day, certainly he will make a significant saving on his total costs.

He has been experimenting with a method to reduce the finishing time of his houses by using a system of steel channels nailed to the studs and to the ceiling joists. These steel channels accept the edges of the gypsum board, so you simply slide the gypsum board into the slots in these channels. There is a slight double line at the corner that is visible, but this eliminates the need for taping and finishing all of the corner joints in the house, and the intersections of the ceilings and walls. He has tried this out in several houses and estimates that he can save at least $20 a house, plus enabling him to finish out the house in one day. He hopes to use this system in combination with a wall finish which covers up the nail heads in one cost. I witnessed several of his attempts at a one-coat joint finishing system. There are a number of problems of which shrinking seems to be one of the greatest, but we feel that some day the breakthrough will come and through the manufacturer who comes up with this system of drywall joint finishing. The market, I can assure you, is tremendous and I am very pleased to see that the Gypsum Drywall Contractors International have the same goals and objectives that we have among ourselves.

Mr. Wehmer: I certainly agree that we need better communication. It's very difficult to develop something with your hands behind your back as it were. It's vitally necessary to get the information as to what is really needed in the field to the people in the laboratory in order to accomplish the things we are desirous of accomplishing. In this business of adhesives, we often get some rather peculiar requests. I was with a man one day who was talking to someone who wanted an adhesive. The adhesive he wanted was one that was very hard, but very soft and extensible; one that you couldn't dissolve in anything, but when you wanted to take it off it would come right off in water; and it had to be easy to apply. My friend listened patiently to all these opposites, and when he finally got through he chuckled and said, "Well, you'll have to wait until you get to heaven to get an adhesive like that—that's the one they use to put on angels' wings." Now, I think we would like to have an angel's wing adhesive for our laminating and finishing, but we are not quite there yet, and I don't think that we are likely to get there in one big jump. We are much more likely to do it by improving the things we have as time goes by. If someone makes a real technical breakthrough and brings out something completely different that does exactly what you want, I think it would be marvelous, but our best chance of getting the thing that is wanted in the field is by channeling information back to the people who develop these products in the laboratory. I am sure we will progress faster if we can do that.

Mr. Robertson: I am sure every manufacturer of materials whether it be adhesives or gypsum wallboard, faces more or less the same dilemma. In our field, it may be a gypsum wallboard which doesn't weigh anything, but which is still strong enough to spand 48 inches that the customer wants, so I sympathize with the problem. I am sure that we all try to find solutions to these problems and I agree with Mr. Slosser that they will come, but sometimes it takes patience as well as hope and optimism. There have been some subjects touched upon briefly on which I would like to elaborate. They touch upon the subject of wallboard lamination and wallboard adhesives. One is a question of how to attach gypsum wallboard to steel framing. In our discussions most of you probably have been thinking of wood framing, but the use of steel framing is an increasing factor in the market. The reference by Mr. King to the use of steel channels for attachment is an indication of that trend. We need a method of attaching gypsum wallboard properly to wood with "angel wing" adhesive if you wish to seal studs. A great deal of progress has been made, but a lot more needs to be made. Similarly, several references have been made to laminated free-standing constructions. These, of course, involve some sort of substrate in terms of framing and this subject is receiving a great deal of study at the present time. Beyond this, there is also the fact that mechanical fasteners are providing considerable competition for adhesives, as is the staple manufacturer with his methods of attaching to steel framing as well as to wood. Also, many drywall contractors, I am sure, are familiar with the efforts being made to promote the use of fasteners such as power driven screws, and these give an advantage to the use of mechanical fasteners which has not been apparent in others used today. I think that we have to realize, from the viewpoint of adhesives technology and adhesives development, that these materials must improve and must provide a means of doing a more effective job. It is a matter, in the end, of two things: the quality of the job and the dollars and cents required to do it. The economics must be considered as well as the quality.

Mr. Kallem spoke about some problems that arose from the fact that there wasn't water available, or there wasn't electricity available at the job site. We also had comments by Mr. Waggoner about the increasing use of ready mixed cement and ready mixed adhesives, supplied to the job ready to use. These are some of the ways in which the adhesive manufacturers today are proceeding along a line of advancement. We know there is a long way to go from the gypsum wallboard manufacturer's viewpoint and, by and large, the gypsum wallboard manufacturers are also the manufacturers of a substantial portion of the adhesives used today to fasten the tape, to flush the joints and to finish the joints. They realize, as well or probably better than most, that unless these things are prefected or brought closer to perfection, the business will reach a plateau, a situation which we insist must not occur. Of course, we will go ahead faster with the help of all concerned, but certainly in the gypsum wall-board manufacturing end, I am sure these problems will eventually be solved.

Mr. Abbey: I would like to point out certain things, in behalf of the gypsum wallboard manufacturers that may dispel any idea that the manufacturers are not interested in the problem either of laminating board to studs or of laminating one board to another. We are, in fact, very interested and I would like to present some of the things that have gone on in the industry in the development to this stage, to indicate what we have done and what we are doing. There has been some reference to the growth of this industry, but I don't know whether you realize that several manufacturers have been in this business for over 50 years. Reference was made to the fact that wallboard came into existence in World War I, but it was in existence for a considerable period before that, although not as much of a factor as it was during World War I, when a terrific amount was used in construction. There has been a great deal of development and improvement in the manufacturing process and an increase in the capacity. At the end of World War II, the capacity of the industry was roughly 3 billion sq. ft. of 3/8" material a year. That was the board capacity of the producers that were in the business then. This year, with the plants that are in existence or will come into existence, we will have a capacity of 14 billion sq. ft. of 3/8" board. Consider also, that this is produced by a limited number of companies, and that there are a few which produce a major portion of it. Not only do these plants produce the board, but they produce a major portion of the paper that is used to encase it. Take out of that 14 billion figure the fact that they make lath, sheeting, wood for wood deck construction and other board products as well as 1/2" board and 5/8" board, and the capacity is further reduced. It would appear from figures we have available that there is a capacity for 6 billion sq. ft. of board of different sizes available today.

After World War II, when there was such a terrific demand for housing, the board manufacturers were in no position to furnish anywhere near the amount of material required. In those days houses were small, with the gypsum wallboard used averaging only about 3,000 sq. ft. Today there is estimated to be some use of the product in 500,000 homes and the average amount of board per house is in the range of 5,000 sq. ft. In laminating construction, the average might go up to as high as 6500 to 7000 sq. ft. However, taking a total figure of 5,000 and considering that there may be 6 billion feet of board available, that's enough gypsum board to finish 1,200,000 houses. Now, we know very well from the great amount of competition from other types of wall materials, and from the fact that there are still several areas around the country where plaster is widely used, that nowhere near than many houses will be built with wallboard. Therefore, it appears obvious that we are approaching a stage when we have more board available than would be required for the conventional single layer application.

Now, lets talk about the dollars and cents represented by these houses. If the house used 5,000 sq. ft. and were built with 3/8" board, the board would cost the contractor in the range of $40 to $50 a thousand. Board is so priced that, depending on where the dealer and contractor are located, they may pay more for the same product if they are further away from the producing plant. That accounts for the difference in price. If you go up to a 5/8" board, it might cost $65 to $80 per thousand, and in this 5,000 sq. ft. house that means you have payed $250 to $400 for material. In the average selling price for such houses, the amount of gypsum board represents 2%, or possibly even less.

Another item of great interest to the wallboard manufacturers is the joint system material. Back at the end of World War II the type of system material used was selling at about $16 to $20 cwt. Today, that material is selling for $8 to $10 per cwt. That means that in a 5,000 sq. ft. home there may be $25 to $30 worth of joint system material. Those of you who have been in business for a long time know that the joint system material improved tremendously in its characteristics and its performance, yet the selling price of that material has been cut in half.

Tied in with all of these factors are the changes in the manufacturing process. I won't go into those in detail, but just point to one factor that will show you why. In the days right at the end of World War II, most of the manufacturers had trouble making board that was over 10' long. Today, with some of the latest machines, they make board more than

50' long at one strench. They can make three pieces of 16' board at one time, which illustrates some of the progress gypsum board manufacturers are making. Insofar as the joint system is concerned, we are working on many changes that we hope will eliminate the water problem. As to the lamination of the board product, one of the weaknesses that has not been discussed is that a paper surface being adhered to a paper surface, and it's that problem which has made some of us a little reluctant to move too rapidly in field lamination without mechanical fasteners. However, that is also being worked on and, in our paper processing, we are trying to develop better, stronger papers, thinner papers, that may ultimately solve that problem. At the moment, though, speaking for one phase of the industry, we do not think we are at the point where we can put up wallboard without any mechanical fasteners at all.

# Future Possibilities and Research Needs

By Roger K. Humke,* Marketing Supervisor, Adhesives, Coatings and Sealers Division, Minnesota Mining & Manufacturing Company

In this paper I will attempt to present, as a spokesman for the adhesives manufacturers, our interpretation of some of the fundamental, long-range requirements in drywall construction for improved bonding materials and techniques. It is also our intent to enumerate some of the revolutionary materials and technologies already developed, or being developed, which give us confidence that we can help solve these and other more difficult problems of the building construction industry.

Adhesives in themselves are not very glamorous-looking materials, but they are an essential part of the design of some very glamorous and exciting end products, as well as some which are very utilitarian by virtue of having been adhesive bonded. Among some of the most noteworthy products that have been made lighter, stronger, or more attractive looking, or have been more efficiently put together by the use of adhesives, are:

1) Aircraft—Our B-58 bombers could not have been build in their weight, design and power if high-performance adhesives such as we now have had not been made available for the purpose (Fig. 1).
2) Helicopter Rotor Blade—Complex shapes can be laminated from thin sheets of strong lightweight metals and provide durability and aerodynamically smooth surfaces that would not be possible with mechanical bonding methods. Aircraft engineers indicate that adhesive bonded rotor blades last an average of 1,200 hours in service on helicopters, where blades fabricated by other means last only 90 hours.
3) Scaffolding—One of the companies which supplies scaffolding to the construction industry found that, by properly designing the joints of their metal structures to take full advantage of the properties of new high strength adhesives, they can obtain lightweight scaffolding of more uniformly high strength and at a lower cost than was possible with welding techniques (Fig. 2).
4) Surface Vehicles—By the adhesive bonding of stiffening members to large, flat sheets of thin-gauge metal, manufacturers of truck bodies, diesel locomotive cabs and similar vehicles find they can obtain assemblies which are at least as strong as riveted ones, at a lower labor cost than necessary with riveting; and the resulting product is neater looking and easier to keep clean than riveted surfaces.
5) Corner Joints of Window and Door Frames—Several fabricators of aluminum windows and doors have found that they can use adhesives to form mitered corner joints by applying them to splines or metal inserts and assembling in such fashion that the stresses on the adhesive bond are placed in shear, which takes full advantage of the strength of the product. Some modified two-part epoxy compounds which cure at room temperature, and other more flexible higher strength one-part products which are cured for brief periods at high temperatures, can be successfully used for this purpose (Fig. 3).

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Fig. 1 - Structural film adhesive is applied to aircraft wing spar. Adhesive bonds and seals wing section to form integral fuel tank.

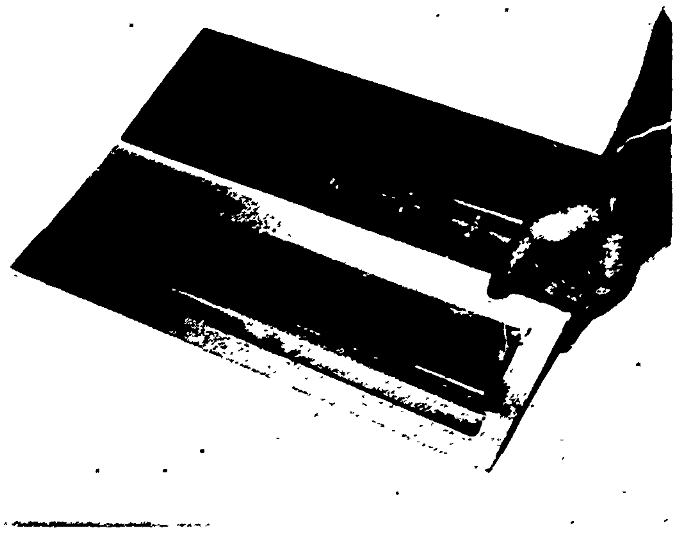

Fig. 2 - Comparison of adhesive bonded and riveted stiffening members. These can be bonded at a lower cost than riveting with resultant improvement in appearance.

Fig. 3 - Corner joints of window frames, storm doors, other building products are assembled with adhesives.

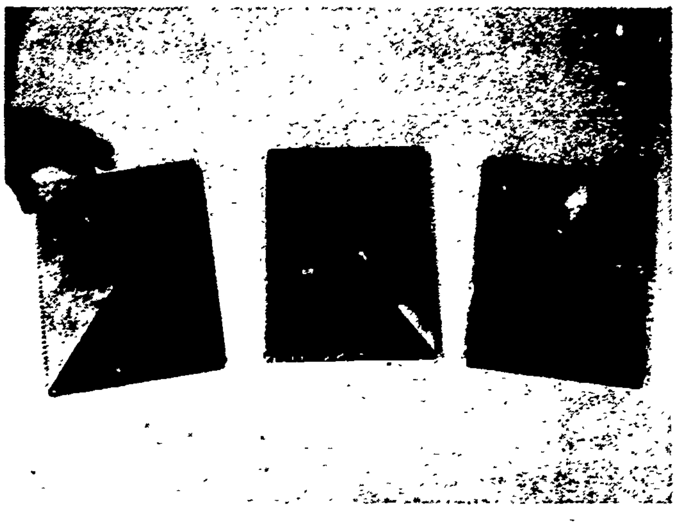

Fig. 4 - Three adhesive bonded sandwich panels constructed of aluminum honeycomb cores bonded to aluminum and glass facings with modified epoxy adhesives.

6) Curtain Wall Sandwich Panels—Here is perhaps one of the best examples in the construction industry of how adhesives have allowed fabrication of extremely strong, though lightweight, units. A variety of insulating core materials of relatively low inherent strength can be integrated with various thin facing materials to produce a composite assembly which has combined properties much superior to those of any of the individual components as far as producing a strong but light building panel is concerned (Fig. 4).

Types of Adhesives

There are many chemical and physical forms of adhesives, and a variety of application techniques for each, which make them wonderfully versatile tools of construction. First, let us consider the forms or types of adhesives which are available today.

There are liquids which are 100% solids (as paradoxical as that may sound); there are liquid adhesives that set when they are deprived of contact with oxygen; there are adhesives in film form which, upon the application of heat and pressure, transform themselves into powerful bonding agents with thermosetting or thermoplastic properties, depending on their composition. These are among the newer products of today. There are composite or double-faced adhesive films which have on one side an adhesive with a great affinity for certain surfaces and on the other side a different type of adhesive with affinity for other surfaces (metal vs. paper honeycomb, for example). There are contact bond adhesives which are applied to the bonding surfaces and allowed to set until they have passed the state when they would wet other surfaces, but which develop an instantaneous high-strength bond when the two coated surfaces are brought into contact with each other. There are other adhesives that react and set when exposed to light.

There are those that are elastic and those that are rigid, and there is a selection among all of these for resistance to a whole range of deteriorating influences, such as water, petroleum and ketone solvents, acids and alkalies, sunlight and temperature extremes. There are adhesives which swell or expand to fill a void, when exposed to heat. There are some that are deliberately conductive so that they can be welded through, or so that static electricity can be drained off through them.

Conversely, of course, there are those which have insulation characteristics that retard or completely block the galvanic action between dissimilar metals or that serve as a thermal-break between metals and other surfaces, to retard the passage of heat or cold.

The bonding of such relatively impervious materials as metal, glass, ceramics, or plastics to themselves or to each other is made possible through the use of liquid types that are 100% solids, or film adhesives which react in the presence of heat and pressure, for these eliminate the old problem of removing the liquid vehicle through evaporation or absorption.

## Application Methods

There has been a parallel rate of progress in the development of application techniques which make use of the new types of adhesives practical. For example, the film adhesives can be readily stamped or die-cut to a variety of shapes which match the faying surfaces of the objects to be bonded together. In some cases, the films are purposely made tacky to keep them in place until the surfaces are properly aligned for bonding. Most liquid products can be sprayed, troweled, brushed or roll-coated into place. Some are extruded from hand- or power-driven guns that offer a variety of bead shapes and diameters.

There are now available pumps and heating devices which make it possible to move even the heaviest of these products through pipe lines or hoses to the point of application. For the highly reactive, two-part chemical products, particularly those in which the ratio of components is extremely critical, there have been developed proportioning units and guns that will accurately and continuously mix the components in exactly the proper ratio.

## Future Potentials

This versatility of products and methods for applying and effecting cures of these "chemical welding" agents gives us basis for visualizing some exotic future products which may be made possible through their use:

1) Aircraft Industry—One of the most advanced industries, as far as the use of adhesives is concerned, is that of the air-frame producers and allied groups. As mentioned previously, design of the B-58 bomber was very much dependent upon use of high performance adhesives. There are even more challenging jobs to be done with adhesives in some of the aircraft, missiles and rockets now being designed. It seems reasonable that construction techniques pioneered in the development of modern-day aircraft will be translated into use in long-range, passenger-carrying space ships, manned satellites, and lunar stations, all of which seem to be possibilities within the lifetime of many of us. Structural adhesives that will withstand extremes of heat and cold, and that will ensure airtight joints between

metal alloys yet to be developed, are a must and will come to be.

2) Automotive Industry—One of the most logical places to look for future applications of adhesives is in the automotive industry. There are people in our industry who believe they will live to see the time when a substantial part of automobile bodies will be adhered or chemically welded with adhesives, regardless of whether the bodies are of plastic or metal or combinations of these materials. Some experimental work has already been done to substitute adhesives for welding in fabricating automobile frames. A major automotive manufacturer is utilizing adhesives to bond a stiffening section beneath the hood of his 1960 model. Also, there are several hundred well-known automobiles on the road today in which adhesives have been experimentally substituted for spot welding in holding of hinges.

3) Marine Industry—If there was ever an object that shouldn't have a hole punched in it, it's a boat! We think it is safe to forecast that screws, bolts and rivets will eventually be replaced with adhesives in the fabrication of boat hulls. Many wooden and plastic boats are already being adhered or laminated by means of adhesives or high-strength sealants. It seems rather logical to form a seamless boat of metal or plastic, one whose exterior surfaces would be entirely free of screw heads or rivet heads which impede its passage through the water. With no seams, there would be no need for caulking, and seat fastenings, stiffener ribs and keel assemblies could be adhered in place.

4) Appliance Industry—Printed circuitry for electronic equipment is dependent upon adhesives and is bound to progress into fields beyond the radio and television uses it has today. In other phases of the appliance industry, progressive manufacturers are experimenting with adhesives that will bond cooling coils to metal sheets and, in doing so, will eliminate the tedious process of soldering, brazing, or welding.

5) Furniture Industry—In the furniture industry, new opportunities for adhesives are also developing. Of course, makers of wooden furniture have been major users of glue for years, but countless yards of textiles and plastics are still being nailed to wooden frames. It is possible that this operation can be made more economical and efficient through use of fast-setting adhesives. As we see more and more furniture for homes and offices being made of metal and plastics, it would seem reasonable that markets will develop here for structural adhesives.

6) Apparel Industry—The day is probably not too far off when we will see shoes assembled without sewing or nails. Already some of us have seen advertisements for adhesives intended to mend socks, to repair sewn seams in clothing, to patch and repair fabric and carpets, and even to replace thread for the attachment of buttons.

7) Plumbing Industry—The plumbing industry is a possible future market for some adhesives now on the shelf and others yet to be developed. Here, there is a growing demand for development of plastic piping for residences, commercial and industrial buildings. There are some builders who are even thinking in terms of threading flexible plastic tubes through a building in the same way that electrical or telephone wiring is threaded today. They would like to see all piping pass through one or more central panels so if replacement becomes necessary, it would simply be a matter of attaching a new plastic pipe section to the old one and pulling it through into position. How would these sections of flexible pipe be joined? We hope it would be done with adhesives.

8) Housing Industry—To get even closer to your direct interest, let us consider home construction, an area that is wide open for adhesive use. In the opinion of some observers of this industry, there is nothing quite so wasteful as the conventional way that houses are put together today. The idea of bulldozing a piece of land into a muddy morass and then depositing about 120,000 components into individual piles in the mud, with the expectation that a crew of men will cut, fit and pound these parts together in the rain or cold or heat, borders on the ridiculous. Yet, that is how it is being done. To this waste must be added excessively high labor costs.

One progressive designer and builder of quality homes has calculated that his job-site labor is costing him between 9¢ and 10¢ a minute per man, figuring wages, coffee breaks, getting a bet down on a horse, taking a smoke and watching a pretty girl hang up clothes in the yard next door. Just an asphalt shingle roof for an average house requires about 11,000 nails and 3500 shingles. Every nail has to be pounded into place. So, he and other progressive builders are asking that just as many components as possible be prepared or prefabricated under factory conditions, and with the most modern materials and techniques, in order that job-site labor can be reduced and modern homes produced at costs more people can afford to pay. These are some of the future trends we see for adhesives.

## The Future for Drywall

Now let us consider some of the more specific, perhaps closer, possibilities for solving the problems of the drywall industry with materials or techniques which depart somewhat from the conventional ones contractors are now using:

1) Attachment of Boards to Studs—It is well within the realm of possibility that compounds will shortly be available which will eliminate any need for nails and will provide a quickly assembled, durable bond between wall panels and framing members. Some products already available provide more than adequate strength and durability, but are not considered feasible because of material cost, difficulty of of application, or excessively long curing time at ambient temperatures. The ideal product toward which adhesives compounders are working, is a single-component mastic with good void-filling properties and the ability to cure almost instantaneously, on application of some form of energy which can be made readily available on the job site.
2) Lamination—Previous reports presented to this group have described use of casein type glues or joint cements in conventional two-ply construction, and others have mentioned the more recent use of contact bond adhesives in the type of installation where nails are eliminated from the finish ply. Although some drywall contractors appear to have been reasonably successful in the latter type of construction, we have been told that improvements are desired which would eliminate the present need for coating both surfaces and the difficulty of placing or repositioning of board when improperly aligned on the first attempt. There are some promising liquid compounds, both one-part and two-part types, which are under evaluation, and it appears that the final answer may be in a compromise between material cost and the labor factor, as well as between ease of application and rate of strength development. It goes without saying that use of nailless face plies will not reach full acceptability without definite improvements in the fiber strength of facings on the gypsum board itself, or a uniformly higher strength between such facings and the core of the board.
3) Joint Finishing—In the concealing of joints, there is an extremely urgent need, according to most drywall contractors, for a nonshrinking compound which can be applied in one operation, which will cure rapidly by itself or with applied energy, which can be easily sanded or smoothed to produce the same paintability and light reflective characteristics as adjoining wall surfaces. Many materials and technologies have been evaluated in an effort to solve this problem, both by the board manufacturers and the adhesive manufacturers. Many have been eliminated from consideration because of too high material cost, difficulty in mixing or application, or inability to sand or otherwise blend into surrounding wall surfaces. Some other promising technologies are under laboratory evaluation.
4) Prefabricated Structural Wall Panels—I am sure that both the users and manufacturers of gypsum board panels are well aware of some of the deficiencies in this building material itself: its relatively fragile skin and brittle cores, and the need for improving its acoustical properties. Some architects and builders who wish to design around these deficiencies visualize the ultimate in wall construction as a modular structural sandwich panel, prefabricated from skins of plastic or textured metal bonded to cores of strong, lightweight plastic form. Without regard for obvious economic factors and the problems of changing established building practices, we can indicate that there are already available chemical compounds capable of bonding them into complete structures.

## Summary

It is conceivable that almost any bonding requirement of the building industry, or its drywall construction operations, can be solved by the research staffs of the adhesives manufacturers, working with the virtually limitless combinations of new organic polymers which are continually being made available. To translate this potential into the reality of better buildings will require a willingness on the part of architects, builders, contractors and suppliers of the other building materials to cooperate in the fair trial of adhesive products which may have an initial material cost several times that of the conventional "glues" commonly used in this industry. Use of these high-performance products may require departures from the present building practices. However, their use should afford compensating, long-term advantages in providing buildings designed for better speed and economy of erection, better efficiency and comfort in service.

# Open Forum Discussion

Moderator - Thomas F. Neblett
Gypsum Drywall Contractors International

Unsigned question: How does the contact bond adhesive perform in a fire endurance test? If nails were completely eliminated would the board, in either single ply or laminated construction, remain in place as long as in nail-on construction?

Mr. O'Hare: Actually the contact bond type of adhesives will not appreciably add to the fire hazard. There is a possibility, however, that in high heat conditions you might get some delamination. Most of these adhesives have a heat resistance of between 250° and 300° F, so that where you run into actual burning temperatures, you might have some problems.

Mr. Abbey: The adhesives do not add to the fire hazard, but they certainly detract from the fire resistance of the construction. All of the gypsum board manufacturers, individually and collectively through the Association, have made tests on laminated construction and on single ply with adhesives. You cannot get the same fire resistance in a ceiling when you use adhesives. You need the mechanical fasteners to hold the board in place during the fire. If you don't have them, your paper will char at the point of lamination and allow the gypsum board to drop into the fire.

Unsigned question: Could further cooperation be considered between contractor and manufacturer with reference to job engineering of new systems and products?

Mr. Robertson: I am sure that fuller cooperation could be helpful. By and large most of the new products like gypsum wallboard, are developed by companies rather than by associations. I'm sure there's always some way of improving products through closer collective action.

John J. Turi, Plastering Institute: What is the difference cost-wise between a 1" laminated finish and a 1" plastered wall or ceiling?

Mr. Waggoner: It is very difficult to talk costs. We have relatively cheap labor in our area as opposed to many parts of the country. I'll use, as an example, 3/4" laminated wall which is the normal procedure. The best drywall job obtainable, as opposed to the best plaster job, will run between 60% and 75% of the cost of the plaster wall. We use the 3/4" because we have no experience with the 1" laminated wall.

Unsigned question: Can you or your Association provide reliable information on precisely what properties in an adhesive are of maximum importance? It was stated that a meaningful specification should embody tests to describe the important physical properties required in the adhesive with realistic numerical values applicable to each test. What numerical values should be assigned to each of the tests developed to describe these properties to assure satisfactory performance in service?

Mr. Kallem: As to the numerical value of properties, I feel that this is a manufacturer's responsibility. I would like to stress this. From a contractor's point of view, specification involves the individual manufacturer's product. There has been a tendency for a manufacturer to introduce a product and wait for his association or someone else to write the specification. Our contractors' association has a technical committee which is available for consultation to all manufacturers. For instance, we sat down with the nail manufacturers, and wrote specifications for nails that would pass FHA regulations. We are willing to do that with all manufacturers for all products. The individual cannot relieve himself of the responsibility of working with others on his specification.

Mr. Wehmer: Certainly there is no thought of a manufacturer not being willing to write a specification. Perhaps I am speaking only for myself, but we still have to do much work both in devising tests that are going to be meaningful and in assigning numerical values that do not penalize the adhesive manufacturer cost-wise. Also, we must devise testing methods that can be performed in a great variety of laboratories, because if you devise a test that can be done only in few laboratories, it is going to produce a meaningless specification. It is my feeling that we still have quite a way to go, because first, we will have to devise tests that are meaningful and second, we have to assign those numerical values which are going to make the tests mean something to the people who run them. There certainly is no desire on my part to try to duck any responsibility, and I think I speak for the rest of the industry, but it is going to require some work before we can actually come up with a specification.

Prof. E.G. Stern, Virginia Polytechnic Institute: As long as the wooden frame tends to adjust itself to changing moisture conditions, resulting in slight movements in joists, studs and plates—how can you apply the gypsum board rigidly to the framing by gluing? Nailing allows a certain movement of framing.

Mr. Slosser: It is possible to formulate an adhesive which, when it has set or attained its ultimate strength, will still retain sufficient elasticity to compensate for the difference in contraction and expansion between the two members. This is a factor being taken into consideration in the development of specifications. If a completely rigid adhesive was used, then it would not compensate, but we are trying to develop some elasticity in the cement to take care of that property.

J.S. Healy, Harrison & Abramovitz, Architects: In the laminating of gypsum wallboard, does the skin of the wallboard separate from the core material due to greater adhesion of skin to adhesive?

Mr. Buergin: No it does not.

M. Huntoon, American Builder Magazine: Would it be feasible in a double layer wall system to provide both layers with contact adhesive applied in the factory?

Mr. Robertson: There has been a lot of thought given to this and of course the use of temporary piling strips might be necessary, or it might not. Most of those in the building industry are familiar with the fact that something like this is done with asphalt roofing shingles, where the adhesive is vacuum applied and a piling strip of some sort is attached to the shingle, which is later stripped off at the job-site. This could be done. There are some technical, some shipping and some storage difficulties, but they are not insurmountable.

E. T. Hoffner, Drywall Contractor: What efforts are being made to induce builders to upgrade their thinking on the use of laminated raw construction in place of the 1/2" and 3/8" single layer now in general use?

Mr. King: There is a tremendous advertising effort being carried on by the industry to upgrade construction. The builder, in comparing a single 3/8" layer against a double laminated system, of course, thinks in terms of economics as well as the final quality of the job. In comparing these two systems, the builder is probably not completely sold on the fact that the laminated system may give a much better job than a single layer system. Now, you spoke of the 3/8" board. Most builders are using a 1/2" board and this in effect, is their way of upgrading the interior finish rather than using lamination. Certainly, in the higher cost houses—$25,000 and up—the laminated method has definite merchandising advantages.

Unsigned question: What is the Adhesives' Council doing to prepare a specification for adhesives for the adhesive nail-on system?

Mr. Humke: The Adhesives Council is a trade association of the major manufacturers of rubber and plastic base adhesives, its full name is the Rubber and Plastic Adhesive and Sealant Manufacturers Council. There is a technical committee of this group which has been active for a couple of years, trying to work out an industry standard for adhesives used in drywall applications, I would defer to the chairman of that Committee, Mr. Slosser, to describe the present status of that effort.

Mr. Slosser: Either the contractors or the gypsum board people can tell us exactly what values we have to establish, but we have taken as a basis for our specification a product which apparently has worked satisfactorily in practice. A specification has been drafted around the properties of that particular cement. We have run into difficulty in duplicating the laboratory test results in a variety of laboratories when we attempted to follow the test methodsand the descriptions that we have outlined in that specification. We have conducted several round-robin test sessions and the variation in the results from these different laboratories has been so great that we just aren't justified in offering that specification as a finished specification to the drywall people. We are now involved in another series of round-robin tests. We have some new leads as to where our troubles may be, and I am hopeful that after this testing is completed within the next 60 days, we will have a specification to offer the gypsum people within the next six to eight months.

Ray E. Cumrine, Ketchum & Sharp, Architects: Can adhesive for laminated construction be applied over existing painted finishes?

Mr. O'Hare: There are many types of adhesives that will not affect painted finishes, however those surfaces that are painted must be sound, just as in any other lamination job. If your paint is peeling, don't try to laminate.

Ray E. Cumrine, Ketchum & Sharp, Architects: Can laminated construction successfully bridge uneven base surfaces?

Mr. Buergin: It can if you use a mastic type or a joint-taping type of adhesive which can be applied in ridges. In some of our laminated constructions, for instance where we clip gypsum board to steel studs and the clip, of course, has a certain amount of thickness, we are forced to put on a bead of adhesive which is approximately 5/8". You can level with the mastic types of adhesives and the joint-taping types, but with the contact adhesives, you cannot.

R.W. Gaines, Union Carbide: Are the surfaces within the joint between the two drywall panels paper covered?

Mr. Abbey: The gypsum board is entirely paper enclosed, which includes the edges; the cut ends are not.

Salvatore A. Puglia, Raybestos: Any adhesive used for joint finishing and nail spotting that contains water will be slow drying. Are there any objections other than the common ones of flammability and toxicity to the use of a nonwater solvant base adhesive?

Mr. Kallem: Actually, there are no objections to this type of adhesive; in fact, I would rather encourage it. The point I would like to make, however, is that we should try to develop a type of adhesive, which would permit us to spot the nails only once. Even though we use the present system of joint treatment, this would again encourage the builder by speeding up the drywall work.

Mr. Waggoner: I would also say there would be no objections to a nonwater solvent base, but the solvent would have to be one that would provide the necessary characteristics. In other words, we still must clean up the tools, the equipment and the house and the material must then be one that could be readily removed. That is the reason we use the water based material, although in some instances it has definite disadvantages.

Allen E. Crapo, U.S. Rubber Co.: In using the adhesive nail-on method, do you have problems with nail pops in cold weather caused by the wood framing drying after heat is applied?

Mr. Waggoner: We have probably eliminated about 75% of the nails through using both nail and adhesive. One big reason why we have less nail pops is that we use less nails. Nail-on adhesives are not a true guarantee against nail pops.

Unsigned question: What is the attitude of unions toward new materials, new tools, and new methods?

Mr. Neblett: If I may, I would like to answer that one myself because the Gypsum Drywall contractors International has agreements both with the Brotherhood of Carpenters and Brotherhood of Painters. The contractors and the rest of the building industry, together with the AFL-CIO building trades jurisdictional procedures have recognized that the jurisdiction for the installation of drywall goes to the carpenters' union, including certain types of lamination and the use of certain adhesives. The agreements give the jurisdiction over taping and finishing to the painters' union. We have met with both the carpenters' union and with the painters' union and they have stated unqualifiedly that they will not interfere with any research, they will not interfere with any testing, they are cooperating with those who are field testing, they will not interfere with the introduction of any new tools, machinery or systems. S. Frank Raftery, representing the Brotherhood of Painters, Decorators and Wallpaper hangers has confirmed this to me, and Mr. Don Danielson of the carpenters' union will also confirm it.

Don Danielson: I am glad to confirm Mr. Neblett's statement on our cooperation. We recognize the contribution that the drywall industry has made to the construction industry as a whole. We have worked with them and we will continue to cooperate with them and make any contribution to the progress of this industry that we can.

R.S. Van Keuren, Syracuse University: Can a high tack neoprene or contact adhesive be used in conjunction with reclaimed rubber to entirely eliminate nailing? Do any difficulties result?

Mr. Humke: This, of course, is one of the approaches being considered, a heavy mastic type which will eliminate the need for even surfaces. Many raw material types are being considered but there's a long wait from laboratory evaluation to final acceptance of new materials. There are questions of strength of facing materials, shifting members, etc., to be resolved and no one has reached the point, as far as I know, where he is willing to go "all-out" with any type of mastic.

Arthur S. Tisch, Independent Nail & Parking Co.: How does the cost of the glue-nailed drywall system compare with all-nailed drywall and with wire lath and plaster? If green studs or ceiling joists are used, doesn't gluing in conjunction with nails make nailheads protrude more noticeably, since the gypsum board will follow the studs during shrinkage?

Mr. O'Hare: Actually, in the field, the adhesive nail-on method, for some unknown reason, gives the contractor less trouble, even with green lumber. Considering the fact that there are fewer nails to start with, they have less nail trouble with those that remain in the structure using the adhesive method. As to the variation in the cost, in some areas it does cost more money to use the adhesive, and in some areas, the saving on nails, and the saving of actual installation time offset the cost of the adhesive.

John A. Robertson, U.S. Gypsum Co.: What progress is being made in regard to adhesives to attach gypsum wallboard to steel framing members?

Mr. O'Hare: There is no doubt in my mind that adhesives available today can be used for bonding drywall to steel studs, provided the studs are properly designed for that application.

Mr. Neblett: Some field work has brought up a new way to implement the use of nails on metal channels. We found this out by accident. In nailing gypsum drywall to a metal channel, you put one nail in and then drive another one in the channel 8" away, and the first one will bounce out. The way to solve that is to put a bead of adhesive down the middle of the channel first, and you will have no more problem with nails bouncing around.

John S. Best, The Dow Chemical Co.: Would you give us a breakdown or cost analysis of the various operations required for installation of drywall, including materials, labor, etc.?

Mr. Waggoner: The cost to hang wallboard, on a footage basis, runs from 1-1/4¢ to 4¢ per sq. ft. The cost of material varies from 5 to 6¢, or 5 to 7¢, on 1/2" single layer material, which is your material predominantly used. To this you add the multitude of expenses for your four trips to the job, and the cost of nails, which is a relatively small amount. Add your overhead to that to make 100%. In our area the cost is much lower than it is in other parts of the country. I think 1/2" single layer work in the U.S. today costs from $1.00 to $1.35 a yard, there again, depending on where you are and what your relative costs are for labor and materials. Generally speaking, the cost breaks down into labor, board, incidental materials, such as nails, tape and cement, and your overhead and profit each representing a certain percentage of the total. Most manufacturers have tables available that will give you these percentages.

E.E. Wager, General Adhesives: Do you have specifications as to what an adhesive must do if mechanical fasteners are not used?

Mr. Abbey: One of the problems we have is the fire resistance. One of the places where we're actually getting more wallboard used is in commercial and institutional buildings and multi-story dwellings where fire safety is essential. In order to meet building code fire resistance requirements, we've had to use mechanical fasteners in addition to the adhesives.

John Ingersoll, American Home: What is the optimum thickness of drywall used in a double lamination, considering both quality and cost?

Mr. Robertson: It's difficult to answer that question, because of the many places it is used. Optimum thickness in a house that cost $250,000 might be quite different than in a multi-story apartment house. By and large, two 3/8" layers have been widely accepted as optimum for general use.

R.S. Van Keuren, Syracuse University: Various methods of gypsum board application are available, sheets horizontal, sheets vertical, double layer application, floating joints, etc., will you give a quick evaluation of the relative impact resistance of these methods?

Mr. King: There was an unpublished study done at Forest Products Laboratory on evaluation of board. If I recall correctly, they figured that, if you strike a partition or a wallboard surface with your fist, the impact energy is approximately 300 inch-pounds. By running an impact test on 1/2" board with a 10 lb. sand bag dropped from a certain height they found, the initial failure in a 1/2" board, nailed single layer to studs 16" on center, occurs at about 400 inch-pounds. The same test run on 3/8" board showed approximately 140 inch-pounds up to 180 inch-pounds. Two other figures quoted are the force of leaning against a wall with your back or with your shoulder, 10 inch-pounds, and kicking a wall, 960 inch-pounds. This isn't a direct answer to the question, but perhaps the figures for 1/2" board and for 3/8" board will give you some indication of the relative stiffness or resistance to impact of these two systems.

Unsigned question: Are there any specifications for laminating wallboard to concrete block or brick, preferably to outside walls?

Mr. Buergin: There are no industry specifications. Some of the individual manufacturers, I believe, have specifications for that purpose. We steer away from laminating gypsum wallboard directly to an outside masonry wall which is subgrade. You get into too many problems from moisture. You can waterproof the units, but again, the gypsum wallboard manufacturer has a tendency to steer away from that method because, if any trouble develops, it usually falls back into his lap.

# ATTENDANCE LIST

This Attendance List is for the entire BRI 1960 Spring Conferences. The persons listed attended one or more of the following conferences:

Paints and Coatings
Proposals for New Building Research
Current Research in Colleges and Universities
Adhesives in Building
Air Cleaning and Purification
Performance of Buildings
Insulated Masonry Cavity Walls
Open Session, Plastics Information Workshop

# Attendance at the Conferences

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| Abate, Frank | Supervisor, Olin Matheison, 39 Cooper Ave., New Brunswick, N.J. |
| Abbey, C.E. | Merchandise Mgr-Gupsum, Bestwall-Certain-Teed Sales Corp., 120 E. Lancaster Ave., Ardmore, Pa. |
| Adams, John F. | Ass't Vice-President, Temple University, Philadelphia 22, Pa. |
| Ahrens, Harry | Associate, Vincent G. Kling, Corinthian Ave., Philadelphia, Pa. |
| Akin, Russell B. | Ass't Director, Technical Services, Polychemicals Dept., E.I. duPont de Nemours and Co., Inc., Chestnut Run, Wilmington, Del. |
| Albright, Gifford H. | Program Director, Shelter Research and Study Program, Penn State University, 331 Sackett Building, University Park, Pa. |
| Aldridge, William F. | Building Engineer, New York Telephone Co., 140 West St., N.Y. |
| Aley, Jonathan | Building Editor, House Beautiful Magazine, 572 Madison Ave., New York 22, N.Y. |
| Allison, Dave | Architectural Forum, Time and Life Bldg., Rockefeller Center, New York 20, N.Y. |
| Allyn, Gerould | Rohm & Haas Co., 222 W. Washington Sq., Philadelphia, Pa. |
| Almy, Richard | Gen. Mgr., Floor Prod. Res., Armstrong Cork Co., Research and Development Center, 2500 Columbia Ave., Lancaster, Pa. |
| Anderson, H.E.B. | Construction Editor, "Plant Engineering," 308 E. James St., Barrington, Ill. |
| Atkinson, Paul W. | Mkt. Devel. Thiokol Chemical Corp., 780 N. Clinton, Trenton, N.J. |
| Attwood, James W. | Executive Vice-President, Unistrut Corp., 4118 S. Wayne Rd., Wayne, Mich. |
| Avery, Robert H. | Director, Application Engineering, Cambridge Filter Corp., P.O. Box 1255, Syracuse 1, N.Y. |
| Avery, W.C. | Service Engineer, Louisville Cement Co., 501 S. 2nd St., Louisville 2, Ky. |
| Bailey, George R. | G.R. Bailey Co., 141 W. Jackson St., Chicago 4, Ill. |
| Bailey, Roger | Head, Dept. of Architecture, Univ. of Utah, Salt Lake City, Utah |
| Bain, St. John | Manager, Product Application, Formica Corp., 4614 Spring Grove Ave., Cincinnati, Ohio |
| Barhite, John K. | Protective Coating Consultant, Eastman Kodak Co., Kodak Park, Engineering Division, Rochester 4, N.Y. |
| Barnebey, H.L. | Vice-President, Barnebey-Cheney Co., Cassady at 8th, Columbus 19, Ohio |
| Barnes, Charles A. | President, Barnes Bros. Inc., 2011 Aisquith St., Baltimore, Md. |
| Barnes, R.E. | Managing Dir., Perlite Institute, Inc., 45 W. 45th St., New York |
| Barradale, Stewart D. | Manager, Building Research, Southwest Research Institute, 8500 Culebra Rd., San Antonio 6, Texas |
| Barron, L.A. | Manager, Technical Service, Vermiculite Institute, 208 S. LaSalle St., Chicago 4, Ill. |
| Barth, Abe | Visitor with Government Rep., 329 Hillside Ave., Newark, N.J. |
| Barth, Max | Department of Defense, Pentagon, Washington 25, D.C. |
| Barton, R.H. | Tech. Dev. Rep., DuPont, 1750 N. Olden, Trenton, N.J. |
| Batchelder, Milton K. | Planning Engineer, New England Telephone & Telegraph Co., 185 Franklin St., Boston 7, Mass. |

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| Batchelor, Harry H. | Special Representative, Society of Residential Appraisers, 14 W. Saratoga St., Baltimore 1, Md. |
| Bates, A. Allan | Vice-President, Portland Cement Association, 33 W. Grand Ave., Chicago, Ill. |
| Baumann, John A. | Development Associate, Union Carbide Plastics Co., River Road, Bound Brook, N.J. |
| Beach, Robert S. | Executive Vice-President, Nat'l Ass'n of Building Owners & Managers, 134 South LaSalle St., Chicago 3, Ill. |
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| Bentz, Carl E. | State Architect, Ohio Dept. of Public Works, Columbus 15, Ohio |
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| Blakley, Thomas J. | Journal of Housing, Nat'l Ass'n of Housing and Redevelopment Officials, 1313 E. 60th, Chicago 37, Ill. |
| Blatz, Michael | Editor, Monsanto Magazine, Monsanto Chemical Co. |
| Bloomfield, Byron | Modular Bldg. Stds. Ass'n, 2029 K St., N.W., Washington, D.C. |
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| Boehme, Robert E. | Chief Engineer, Panelyte Division—St. Regis Paper Co., 2403 S. Burdick, Kalamazoo, Michigan |
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| Bourke, Art | Market Development, Structural Products Division, Nat'l Starch and Chemical Corp., 1700 W. Front St., Plainfield, N.J. |
| Boyd, Dr. Robert A. | Project Representative, Univ. of Michigan Research Institute, Ann Arbor, Mich. |
| Boyle, James J. | Resident Manager, Fresh Meadows (New York Life Insurance Co.), 61-25 190th St., Fresh Meadows 65, N.Y. |
| Brandt, John C. | New Products Division, Corning Glass Works, Corning, N.Y. |
| Breed, Arthur R. | Product Engineer, The Lamson & Sessions Co., 5000 Tiedeman Rd., Cleveland 9, Ohio |
| Bretscher, Carl E. | Supervisor of Planning, Office of the University Architect, Southern Illinois University, Carbondale, Ill. |
| Briggs, John F. | Carrier Corp., 385 Madison Ave., New York, N.Y. |
| Brock, J.W. | Tech. Planning Mgr., Canadian Industries Ltd., Paints Div., P.O. Box 10, Montreal, P.Q. Canada |
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| Brodsky, Lee S. | Vice-President, Hudson Painting & Decorating Co., Inc., 271 Madison Ave., New York, N.Y. |
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| Brooks, Gregory E. | Voorhees, Walker, Smith, Smith and Haines, 101 Park Ave., N.Y. |
| Brown, G.E. | Group Leader, Research, Monsanto Chemical Co., 911 Western Ave., Seattle, Wash. |
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| Brown, R.E. | Senior Technologist, Shell Chemical Co., 101 W. 51st St., New York, N.Y. |
| Brown, William S. | Architect, Federal Housing Administration, Washington, D.C. |
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