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DEVELOPMENT OF WOOD ADHESIVES AND GLUING TECHNIC

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Furniture and other relics of earlier civilizations attest the gluing of wood (9)[2] as an art of long standing, but they furnish little authentic information that is of practical value to the craftsman of today as to kinds and quality of adhesives used or of methods or processes. Because of mechanical and chemical progress, it is doubtful that even reliable and complete historical records would add much of practical value to present-day gluing operations. Consequently, this paper will discuss only the more recent developments in glues and in the technic of using them.

Development of Glues

It is a common assumption that the joints in chests and other articles recovered in recent times from ancient tombs were glued with adhesives that were superior to modern glues. The fact that the joints have endured for many centuries is, however, no positive evidence that the adhesives were superior to present glues. On the other hand, the fact that the wood in these particular articles was not damaged leads us to believe that the surrounding conditions were not extremely severe. In other articles recovered there has been more or less damage, presumably to both glue and wood. Adhesives are available today that might reasonably be expected to withstand permanent exposure to conditions where wood is not deteriorated.

Animal and fish glues were undoubtedly of ancient origin and may have been used by the craftsmen of 20 or 30 centuries ago. Certainly they were the best known and most extensively used a few

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[1]The author has spent 13 years in research and investigational work on glues and gluing problems at the Forest Products Laboratory.

[2]Numbers in parentheses apply to references cited at the end of the paper.

centuries ago. Blood-albumin glues are reputed by some to have had an early origin and perhaps casein glues were also known to the ancients. Large-scale production of glues under efficient and refined methods, however, is a development of modern times. Manufacturing under more precise, controlled methods has resulted in glues that are probably of higher and more uniform quality than the ancient glues from the same sources. Coincident with better manufacture, improvements have occurred in the testing and grading of adhesives and better technic has been developed in their use.

In the United States it has been only within the last 20 years that animal and fish glues have had serious competitors in the woodworking field. Starch glues, suitable for wood joints, were developed about 1912, and during the World War casein glues came into use on a commercial scale in the woodworking trade. Both starch and casein glues have grown in importance during intervening years. Vegetable-protein glues were developed commercially subsequent to the World War, and they, too, have grown rapidly in importance. Though the protein glues have a vegetable source, they are more analogous to the casein glues than to the starch glues in properties. Animal, casein, starch, and vegetable-protein glues have been quite fully discussed elsewhere; (13)[3], hence only adhesives that have not yet come into general use in woodworking will be discussed here.

Miscellaneous Adhesives

There are many kinds of adhesives, such as blood-albumin, phenol-condensation products, rubber cements, cellulose esters, silicate of soda, waxes, asphalts, and gums, which have been used to some extent or proposed as glues for wood. Blood glue has been used considerably, and others may eventually become important. So far as is known no extensive tests ever have been made on most of the foregoing miscellaneous adhesives. Samples of many of them, however, have been tested at the Forest Products Laboratory in order to obtain some idea of their value and suitability for making joints in wood. The results of these preliminary tests indicate that some have outstanding properties.

Blood-albumin glues are the best known of the miscellaneous group. They have been used more extensively in European and Asiatic countries than in the United States, but their use appears to be diminishing rather than increasing. They have been used principally in plywood, but casein glues at present appear to be taking their place in part, both here and abroad. High water resistance is the most

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[3] See also papers on these four classes of glues presented at the Sixth Annual Meeting of the Wood-Industries Division of The American Society of Mechanical Engineers.

valuable property of blood-albumin glues; the necessity for hot-pressing is the chief disadvantage. Because the cheaper cold-press method of gluing prevails in the United States, the blood-albumin glues have been used here only in a few plants. Attempts to produce a cold-press blood-albumin glue have met with only partial success.[4]

Phenol-Aldehyde Adhesives.--By heating a phenol with an aldehyde it is possible to produce hard, strong adhesive substances that appear to be unaffected by moisture in any form. Adhesives of this type that have been produced commercially have yielded joints in wood of high strength when tested both dry and wet. Phenol-aldehyde adhesives are apparently more water resistant than any of the glues now in common use. They are, however, several times as costly as the common woodworking glues, and the necessity for hot-pressing in order to produce the characteristic bakelite reaction is a disadvantage particularly under prevailing methods of manufacture in American factories. Unless the phenol-aldehyde adhesives can be produced more cheaply, they will be restricted to special uses. Tests made in Germany indicated that similar adhesives of this class (8) became brittle in wood joints when dry, but this characteristic was not found to be objectionalbe in the tests at the Forest Products Laboratory.

Adhesives from Rubber.--Joints can also be made in wood by hot-pressing with adhesives made from rubber. Two commercial products of this type have been tested at the Forest Products Laboratory. The joints were strong both dry and wet, but the adhesives are expensive. They may find limited uses for special purposes.

Cellulose Esters.--Cellulose cements have been suggested at various times as adhesives for wood, and tests have been made on several products. Most of them are too thin and require more than one application to make good joints in wood. When so used, they are slow drying, and they are also relatively expensive. It is reported that joints of good strength and high water resistance have been made with them in Germany (8). Cellulose cements can be cold-pressed, but their cost and difficulty of use appear to make them impractical at present for general woodworking purposes.

Silicate of Soda.--Silicate of soda makes joints in wood of fairly high dry strength. It is cheap, easy to apply, and finds a large use in fiber containers, but the joints are weak when wet. Silicate of soda changes in properties with age and is therefore not considered a permanent binder.

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[4] A blood-albumin glue, which can be cold pressed and which is recommended only for light-weight woods, has been developed at the Forest Products Laboratory. See U. S. Department of Agriculture Technical Bulletin No. 205, page 54.

Waxes, Gums, and Asphalts.--Waxes, gums, and asphalts have been proposed as adhesives for wood. So far none of them has proved to be satisfactory.

Dry Glue Films

Attempts have been made from time to time to produce a dry film of glue that could be used in place of a liquid adhesive. The advantages of such a process are obvious, especially in laying thin veneer, but as yet a material of this kind has not come into commercial production in the United States. Some work was done in 1918 at the Forest Products Laboratory on a dry-glue process, and a film was produced experimentally using blood albumin as a base (1, 11). So far as is known, this material is not being produced commercially. Recently published accounts of tests in Germany indicate that attempts are being made in the same direction abroad (8). Films made from cresol-formaldehyde and from cellulose esters are reported to give good results. The dry-glue films, so far produced, require the use of a hot press. No information is available as to cost, but the dry films of these materials are undoubtedly more expensive than common glue mixtures.

Testing Glues

Progress and development in the manufacture of glue are necessarily related to its testing. Some means of measuring quality is essential to determine the value of new products and the improvement of old ones. Not only is glue testing necessary to the manufacturer, but it is also important to the user. It is his means of determining whether he gets value received for his money, and still more important, it helps to insure the value and quality of his own products. A table, a chair, a door, or an airplane wing beam is no better than the joints it contains.

Manufacturers commonly have their own methods of checking the quality of their raw materials and their manufactured glues. Consumers and others, likewise, use one form or another of test in an effort to check the quality of glues and to determine their suitability for a particular job. This has led to many forms and kinds of tests, all of which are aimed at essentially the same purpose. Standardization of tests and testing methods is therefore important to a common understanding. A considerable amount of work has been done upon standardization, but much remains yet to be done.

The testing of animal glues has reached a higher degree of perfection than the testing of other types of adhesives. A number of workers have investigated the physical and chemical properties of animal glues and methods of measuring them, and, as a result, clearly

defined and reasonably accurate tests of the glues themselves are available. The National Association of Glue Manufacturers, comprising a considerable number of animal-glue makers, has adopted uniform testing methods (4), and the U. S. Federal Specifications Board has recently incorporated these methods in a specification for Government use in the purchase of animal glue for woodworking (6). In Germany a committee on glue testing of the (German) Society for Testing Materials has recently carried out investigations with the object of setting up a uniform procedure in that country for testing animal glues (7). Investigators in Russia and other countries are also studying the testing of animal glue.

There is general agreement among research workers that viscosity and jelly strength are the most reliable criteria for judging the quality of an animal glue, and one or the other or both are usually the basis for grading. In Germany viscosity is regarded as the more reliable of the two properties (7), while in the United States both are considered essential for defining the grade of a glue (4). Other characteristics commonly considered of some importance in an animal glue for woodworking are moisture content, reaction (acidity or alkalinity), tendency to foam, and odor or keeping quality. Joint tests in glued wood blocks have been a part of most all glue-testing investigations, but they are less accurate and less satisfactory for testing the quality of animal glues than are the physical properties of the glues themselves (14).

There are at present no generally accepted physical and chemical tests for blood-albumin, casein, starch, and vegetable-protein glues. In the absence of more refined testing methods, the strength of joints of all of these adhesives and the water resistance of joints of blood-albumin, casein, and vegetable-protein glues are the properties most often tested. Joint tests, therefore, constitute the principal means thus far available for determining the suitability of these glues for woodworking.

Forest Products Laboratory Joint Tests.--The Forest Products Laboratory during the World War developed two types of joint tests for aircraft glues (1). The tests were later used on starch and other kinds of adhesives. They are known as the block-shear and plywood-shear tests and have been described in several publications (13). The block-shear test is adapted to thick pieces and the plywood-shear test to veneer. Both tests have since been used in the same or slightly modified forms in several other countries (2, 5, 9, 10, 15). Both tests are simple, and with proper equipment and care can be quickly made with a moderate degree of accuracy.

All forms of joint tests involve a gluing operation, and this may have a most important effect upon the results. Poor gluing may result in weak joints with high-quality adhesives, while careful gluing may result in fairly strong joints with medium- to low-quality

glues. In addition to the gluing operation, the variable properties of the wood are factors that may lead to erroneous conclusions unless careful selection of material is made. With proper care in selecting and making joints, however, the block and plywood tests will show fairly consistent differences between weak and strong glues and will enable the selection of a glue or glues satisfactory for a particular job. Other tests on blood-albumin, casein, starch, vegetable glues, such as the viscosity and working life of the mixed glue, may give supplementary information of much value. It is to be hoped, however, that in the course of time complete tests will be developed for each of these glues that can be made directly upon the glue rather than upon glued joints.

Development in Gluing Technic

The third phase of the development of glues involves the details of their use and the technic of joint making. Only the principles of handling glues and making joints that have undergone important changes will be described here.

Preparation of Glue for Use.--In preparing glue for use the necessity of producing a glue mixture of uniform and proper consistency, in which the raw materials are completely dissolved or dispersed is of primary importance. The animal glue must be all softened and melted, the starch all "converted," the casein, vegetable protein, or albumin all dissolved in order to produce a uniform mixture. It is also important that the mixing or conversion be done without the inclusion of large amounts of air. Outside the character of the glue itself, the speed of stirring and the type of mixer govern the amount of air, or foam, included. Suitable types of equipment are available for preparing the different kinds of glues, and with reasonable care in the operation good glue mixes can readily be prepared.

An old tradition has been that an animal glue must be boiled to prepare it for use. Furthermore, it has been common practice to keep prepared animal glue boiling or near the boiling point during use. The injury to the glue and the wastefulness of such practice have been clearly shown by many investigators (13). It is unnecessary to go any further into this subject than to point out that the most desirable temperature conditions are known and that commercial practice has been largely changed to conform to improved practice. Equipment manufacturers have been very helpful in bringing about this change by providing glue converters and pots in which the temperature is easily or automatically controlled.

Temperature control is somewhat less imperative for blood-albumin, casein, starch, and vegetable glues than for animal glue,

but is nevertheless important. The quality of a starch glue and the working life of casein and vegetable-protein glues depend to some extent upon temperature. Manufacturers of starch adhesives usually recommend the temperature conditions most satisfactory in mixing, and temperature recommendations are also made by some manufacturers of casein and vegetable-protein glues. Heating blood-albumin glues and certain other adhesives during preparation above their coagulating temperatures alters their adhesive properties.

Spreading.--To make a satisfactory joint it is important to spread an adequate amount of glue evenly and quickly over the surfaces to be joined. Machine spreading is quicker, more uniform, cheaper, and more economical of glue than hand spreading and is recommended on work adapted to it. Speed is essential in many operations in order to get uniform results. It is important to spread the right amount of glue — that is, a sufficient quantity to make a strong joint, but not enough to add excessive water to the glued members. The required amount of glue spread has been worked out experimentally (13) and is fairly well established in commercial practice. Spreading both sides of a joint uses more glue than single spreading and is ordinarily not justified.

An important development in gluing technic has to do with the consistency of the glue mixture at the time of pressing. Here again, with respect to animal glue, an old tradition has been inherited to the effect that the glue mixture must be relatively thin when pressed, that the wood must be hot, and that the solution must penetrate the cells to make a strong joint. Gluing methods and practices for several decades and perhaps centuries had been built upon this principle. It is not surprising, therefore, that the results of investigations showing that glue need not penetrate deeply into the wood cells, that relatively thick mixtures give better results than thin mixtures, and that strong joints can be made with animal glue on unheated wood should be regarded as revolutionary and accepted very slowly by the craftsmen. Although these principles have been checked and verified many times in commercial practice, there are still some who regard them with suspicion.

The Forest Products Laboratory undertook, somewhat more than a decade ago, a detailed study of the factors that affect the strength of a glued joint. Two general principles were formulated as a result of these investigations: First, that glue adheres tenaciously to wood substance and that mechanical adhesion, such as exhibited by the holding power of nails, is of secondary importance; second, that the making of strong joints involves a close correlation of the amount of pressure applied and the consistency (viscosity) of the glue mixture at the time of pressing (3, 12, 13). Since the publication of the results of these studies, similar investigations have been undertaken in other countries including Germany, England, and Russia, and the results recently appearing in foreign publications indicate that our conclusions are being verified by the workers of other countries (2, 8, 10, 15).

Working out the interrelation of factors for different gluing operations and different species of wood required the making of many thousands of tests and several years of work. The kind of glue and proportion of water in the mixture, the quantity of glue spread, the temperature of the glue and the room and the wood, the lapse of time between spreading and pressing, the amount of pressure, the length of the pressure period, and the species of wood were all investigated. The interrelation of these factors is complex, each depending upon the others, resulting in a large number of combinations of conditions that give good results and a like number that give poor results. However, from these investigations it is now possible to set up recommendations for gluing different species of wood with different kinds of glue that are applicable to different commercial gluing operations (13).

In general the most satisfactory joints are made by the use of relatively thick mixtures of glue and high gluing pressures. These two conditions are necessary to bring the contact surfaces of wood together, to force the air and excess glue from the joint, to spread the glue uniformly throughout the joint in a thin continuous film, to force the glue into intimate contact with the wood substance, but not excessively into the cell cavities, and to hold the joint in correct position while the glue sets. Excessive warming of the wood keeps an animal glue too thin for immediate pressing and favors starved joints, a condition in which there is not a continuous film of glue in the joint.

In quick clamping, such as in edge-joint gluing and certain assembly operations, the glue must be mixed relatively thick or, as in the case of animal glue, permitted to come to the proper consistency by cooling. Wood at 70° F. normally requires no further warming in operations where the pressure is applied within 1 minute after spreading. Gluing pressures of 100 to 200 pounds per square inch of joint are best; the lower pressures for lighter woods and the higher pressures for heavy woods. These recommended pressures are higher than those that still generally prevail in many operations.

Time-saving machinery and devices also have brought about important changes in the gluing room, as related to the technic of gluing. Mechanical spreaders, rotary clamp carriers, and hydraulic presses have had a marked effect on the time element in gluing — a most important factor in joint production. They have tended toward higher gluing pressures, have made it inadvisable in many operations to warm the wood, have brought about shorter clamping periods and the need for quick-setting glues, and have made it necessary to mix glues relatively thick. These developments have generally contributed to a more uniform and higher standard in glue joints, but to take full advantage of them the gluing operator must make certain that he controls the details of the operation in harmony with the changed conditions.

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