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A Comparison of the Properties and Strengths of Adhesives

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Abstract

This investigator teaches a course in junior high industrial arts in which students are exposed to a number of different adhesives. The text used in the industrial arts course classifies the types of adhesives and gives the procedure for using each one, but does not identify the properties of the adhesive or the safety knowledge essential for using them. The several kinds of adhesives used in this course have special properties which determine how and when to use them. To supplement the text and to provide more hands-on activity, a unit could be developed which would help students determine why some adhesives are more practical than others for certain job applications. Such a unit would give students the opportunity to perform practical testing and gain technical information in this field.

Chairman

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A Comparison of the Properties and Strengths of Adhesives

A Research Proposal for Presentation
to the Graduate Committee
of the Department of Industrial Technology
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In Partial Fulfillment of the Requirements for
the Non-Thesis Master of Arts Degree

by
Merwin Foster

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Chapter 1

INTRODUCTION

The use of adhesives has long been a common practice in industrial arts laboratories. Industrial arts teachers are frequently asked which adhesive is the strongest or which adhesive is the best for a given application. The answers to these questions are usually based on the teachers experience. Insufficient thought has been given to the real reason why an adhesive is dependent on the conditions under which it is used. Each type has individual characteristics that make it most suitable for use under specific conditions.

Adhesives used in industrial arts laboratories are frequently purchased in small quantities from local dealers or school supply houses. They are often identified by certain trade names rather than by type. Adhesives are often thought of as a substance to fasten materials together with little regard given to their limitations, characteristics and intended use.

It was felt, that in order to clarify some of the thinking and help solve some of the problems encountered in using them, a study of the adhesives most commonly used in industrial arts laboratories would be valuable to industrial arts teachers and students.

The objectives of the study were:

1. To research relevant information on the properties of adhesives and the safe use of said adhesives in industrial arts laboratories.
2. To construct test apparatus to determine the tensile strength and shear strength of said adhesives and the effects of temperature and humidity upon their strength.
3. To develop a unit of study for junior high students on identifying the properties of adhesives used in industrial arts laboratories.

Statement of the Problem

This investigator teaches a course in junior high industrial arts in which students are exposed to a number of different adhesives. The text used in the industrial arts course classifies the types of adhesives and gives the procedure for using each one, but does not identify the properties of the adhesive or the safety knowledge essential for using them. The several kinds of adhesives used in this course have special properties which determine how and when to use them. To supplement the text and to provide more hands-on activity, a unit could be developed which would help students determine why some adhesives are more practical than others for certain job applications. Such a unit would give students the opportunity to perform practical testing and gain technical information in this field.

Importance of the Study

The adhesive industry has grown at a tremendous rate. Amazingly, there are more than 15,000 adhesives of 103 distinct chemical types with 1,080 brand names. Most are spin-offs from sophisticated industrial products that hold together many of the products we buy. Students in the industrial arts program are, or will be the adhesive industry consumers. Their knowledge of the various types of adhesives and their characteristics is one phase of the industrial arts program. A program of practical testing is one way to instruct the future consumer of adhesives. This enables the students to work with the materials and acquaint themselves with the procedural application of the adhesive.

Limitations of the Study

This study is not meant to be a research of all types of adhesives. Only the following will be researched: contact cement, casein glue, resorcinol glue, epoxy glue, animal hide glue, and polyvinal resin glue. Accepted testing methods and standards will be adhered to and will be altered only as needed to adapt to the level of intended application. Test apparatus will be constructed within the limitations of cost incurred and time involved. It should be noted, that for the purposes of this study, the terms adhesive and glue are interchangable.

DEFINITION OF TERMS

Adhesion. The state in which two surfaces are held together at an interface by forces or interlocking action or both (Gagle, 1968, p. 4).

Adhesive. A substance used to hold materials together by surface attachment. It is a general term that includes cements, glue, paste, or mucilage (Wagner, 1970, p. 26-1).

Assembly Time. The time interval between the spreading of the adhesive on the adherent and the application of pressure or heat, or both, to the assembly (Gagle, 1968, p. 310).

Glue. An adhesive prepared from hides, tendons, cartilages, bones, etc., of animals by heating with water. Through general usage, this term is now synonymous with the term adhesive (Gagle, 1968, p. 323).

Glue Line. The adhesive layer between two adherends (Gagle, 1968, p. 324).

Pot Life. The rating in hours of the time interval following the addition of accelerator before a chemically curing material will become too viscous to pass predetermined viscosity requirements (Gagle, 1968, p. 49).

Shear Test. A method of separating two materials by forcing the interface to slide over each other. The force exerted is distributed over the entire bonded area at the same time. Strengths are recorded in pounds per square inch (Gagle, 1968, p. 53).

Storage Life. The period of time during which a packaged adhesive can be used. Sometimes called shelf life (Meese, 1974, p. 204).

Tensile Test. A test in which specimens are subjected to an increasing pull until they fracture (Gagle, 1968, p. 342).

Wood Failure. The rupturing of wood fibers in strength tests on bonded specimens, usually expressed as the percentage of the total area involved which shows such failure (Gagle, 1968, p. 344).

Working Life. The period of time during which a two-part adhesive, after mixing with a catalyst, solvent, or other compounding ingredients, remains usable (Gagle, 1968, p. 62).

Chapter 2

HISTORICAL INFORMATION

The origin of adhesives goes back to the unrecorded periods of history. The earliest adhesives were natural products and, undoubtedly, were first discovered when man began to learn to cook his food. Anyone familiar with kitchen routines knows that pots and pans are hard to clean after hot cereals, puddings, or meat juices and gravy have been cooked in them and they are allowed to cool and dry. Even considerable soaking and scrubbing may not remove such food residues. Such substances certainly have good adhesive properties and often a fair degree of water resistance and durability (Blomquist, 1963, p. 2).

It is difficult to trace the history of adhesives into modern times. There are scattered references to the bonding of papyrus with some sort of adhesive in the days of the ancient Egyptians. More recently, veneered furniture and cases have been discovered in the tombs of the early Pharoahs of Egypt. The adhesives used were believed to have either a starch or animal protein base. These same types of adhesives have been used more recently for sealing envelopes, coating postage stamps, and for veneering furniture. (Blomquist, 1964, p. 3).

Elijah Upton established the first glue factory in the

United States in 1808, and in 1814 the first patent on adhesives was issued for the production of glue from animal bones.

In 1909 F. G. Perkins found that tapioca could be made into glue with lye and this made plywood production economical. Then, around the time of World War I, proteins regained their prominence as wood adhesives. Casein, obtained from milk, was found to make a glue with a better water resistance than those from tapioca starches. Scientists at the U. S. Forest Products Laboratory found that the albumin in blood made an adhesive with even better water resistance (Forest Products Laboratory Annual Report, 1976, p. 8).

Casein glues were used structurally during World War I to construct the wooden main-frames of aircraft but were found to have limited resistance to moisture and to mould growth. These limitations of adhesives of natural origin have provided the stimulus responsible for the great expansion since the 1930's in the development of new adhesives which are based upon synthetic resins and other materials. The outstanding advantage of the new adhesives over the earlier types is their excellent resistance to moisture, mould growth and a variety of other hazardous service conditions (Shields, 1970, p. 4).

Phenol formaldehyde was the first synthetic resin of importance to adhesive bonding, being mainly used for wood assembly and plywood manufacture. Later demands of the aircraft industry for materials suitable for metal bonding led to the employment of modified phenolic resins. The 1950s saw the introduction of epoxy resin-based adhesives offering equal strength properties and the processing advantages associated with 100% reactive solids systems (Shields, 1970, p. 4).

Today, the number of applications for adhesives is large and ranges from industrial processes, to assembly jobs which require the use of varying quantities of adhesives. Paper, packaging, footware and woodworking still remain the major outlet for adhesives; but usage has increased significantly in industrial equipment, building and construction, vehicle manufacture, instrumentation, electrical and optical assemblies, and military and space applications. The last decade has seen the advent of many new synthetic resins and other components which have made possible the development of stronger, more durable and versitile adhesives for bonding surfaces, which were previously difficult or impossible to bond before.

Chapter 3

TECHNICAL INFORMATION

The basic function of adhesives is to hold materials together by surface attachment. A few of the more important advantages of adhesive bonding include: (1) rapid, economical joining, (2) a means of providing a new structural or composite unit, (3) more uniform distribution of stress, (4) a means for obtaining surfaces free of holes, (5) a method of forming joints sealed against moisture, and (6) an important means for minimizing potential points of corrosion so often evident in mechanical joining.

Adhesive Selection

Generally, the first consideration in making a selection is the choice between the various types of adhesives which will adhere to the materials to be bonded.

Each adhesive manufacturer publishes detailed technical data sheets as well as elaborate charts which describe the physical specifications of the various types of adhesives. In addition, one or another of the industrial magazines frequently publishes a "selector chart" with complex groupings of chemical families, design considerations, viscosity ranges, and technical information necessary for the selection of an adhesive (Adhesives Age, 1973, p. 20).

Most adhesive suppliers emphasize the pitfalls involved in using such printed material as a final guide to selecting adhesives. Regardless of the industry involved, the selection of the proper adhesive depends basically upon the answers to three questions.

1. Which materials are being joined?
2. How is the completed assembly expected to perform in end use?
3. What method of adhesive application is most suitable (Adhesives Age, 1973, p.20)?

Of the three, the greatest amount of detail is necessary in specifying the end-use properties required of the completed assembly. Within limits, it is then possible to select the desired from of adhesive (liquid, paste, powder, film); the method of application (by trowel, brush, spray,) and to determine its adaptability to the production equip--ment available (Adhesives Age, 1973, p. 20). Table 1 is an example of adhesives classified by form.

Since no universal adhesive exists which will fulfill all the bonding requirements for all materials in every possible application, it is often necessary to compromise, bearing in mind the desired bond properties.

Properties of Adhesive Materials

There are many varieties of trade names and grades

Table 1---Adhesives Classified by Form.
(Materials Engineering, 1975, p. 25).

Type ↓	Remarks	Advantages
Liquid	Most common form; practically every formulation available. Principally solvent-dispersed	Easy to apply. Viscosity often under control of user. Major form for hand application
Paste	Wide range of consistencies. Limited formulations; principally 100% solids modified epoxies	Lends itself to high production set-ups because of less time wait. High shear and creep strengths
Powder	Requires mixing or heating to activate curing	Longer shelf life; mixed in quantities needed
Mastic	Applied with trowel	Void-filling, nonflowing
Film, tape	Limited to flat surfaces, wide range of curing ease	Quick and easy application. No waste or runover; uniform thickness
Other	Rods, supported tapes, precoated copper for printed circuits, etc.	Ease of application and cure for particular use

of adhesives marketed in several forms and in various size containers. The criteria used for selecting the adhesives for this study were:

1. Adhesives commonly used in junior high industrial arts laboratories.
2. Adhesives that could be readily obtained from local stores or from school supply houses.

This study was limited to the six different types of adhesives discussed below.

Contact cement (usually applied on both surfaces to be glued and air dried tacky before joining) adhere instantly. The use of contacts creates quick bonds on materials such as hardboard and high pressure laminates. The trick in using contact cement is to be certain to line up the work perfectly. Adjustments cannot be made once the edges are stuck. Contact cements develop 50 to 75 percent of their full bond strength immediately when laid down (Popular Science, 1971, p. 92). The relatively low strength of contact cements make them inadequate for highly stressed joints (Wood Handbook #72, 1974, p. 9-7). It can be used to join any combination of wood, cloth, leather, rubber, plastic, and thin metal. It loses its strength when exposed to high moisture conditions. Contact cement contains volatile, flammable solvents and the work area where it is applied must be well-ventilated with no open flames or pilot lights. Prolonged inhalation of vapors should be avoided.

Polyvinal-resin glue, a synthetic, is a rather thick, white, milky liquid that comes ready to use in plastic squeeze bottles. This glue is an emulsion of vinal resins finely dispersed in its liquid state until exposed to drying action of the air or wood.

Polyvinal-resin glue is not waterproof and should not be used in assemblies that will be subjected to high humidities or moisture. The vinal-acetate materials used in the glue are thermoplastic, which means that under heat they will soften; therefore, it should not be used in the construction of such articles as radios or T V cabinets where the temperature may rise above 165 degrees (Wagner

1970, p. 7-1).

The principal advantages of polyvinal-resin glue are the elimination of mixing for use; long pot life; easy application to small pieces with squeeze bottles, pressure guns, or hand brushes; and rapid development at normal shop temperatures (Gagle, 1973, p. 17-10).

Liquid hide glue, sometimes called cold hide glue, is a clear, light amber colored liquid of medium viscosity. Liquid hide glues are formulated from the hot animal glue solutions by dissolving a jell-depressant in the hot solution. The jell-depressant, usually thiourea salts, retards the jelling or setting of the glue. The glue remains in liquid form until exposed to drying by air or by loss of moisture to wood. Hide glues are generally resistant to organic solvents but do not withstand exposure to water, weather, heat, or bacterial growth in humid conditions. Resistance to water and mould growth is improved by the use of additives. Hide glue has good gap-filling properties where a close fit is not feasible (Shields, 1970, p. 34).

Hide glue is still available today, but is not widely used. It is sold in sheet, flake, pearl, and ground forms. The dry forms of glue are soaked in water for several hours and are then melted and used at temperatures of not over 150 degrees. Hide glue is also available in liquid form and is packaged in plastic squeeze bottles (Wagner, 1970, p. 7-3).

Casein glues were developed about the time of World War I when somewhat better moisture resistance was needed than achieved with the older hide glues. Casein glue is packaged in a dry powder form and requires mixing with cold water. The powder is composed of dry ground casein, hydrated lime and sodium salt. When water is added to the dry glue, the lime reacts, forming a strong caustic alkali which dissolves the casein. As the glue sets, the lime reacts again with the soluable casein to form a bond.

Casein glues have better moisture resistance than other natural glues, but are not suitable for actual water-immersion applications, or those where high-relative-humidity conditions are to be encountered (Gagle, 1973, p. 17-8).

Woods with oily films and pitches can be bonded with casein glue. By using a heavy mix, this glue has good gap-filling properties on rough surfaces and poorly fitted joints. The two limitations of casein glue are that it stains the wood and it is abrasive.

Resorcinol resins, and combinations of these, have been used since World War II to provide durable glue lines. Their principal use has been in laminating heavy structural timbers for exterior and other severe exposures, including the bonding of preservative-treated woods (Gagle, 1973, p. 17-8).

Resorcinol glue is available only in a two-part form: a dark reddish liquid resin, and a powdered or liquid hardener or catalyst. Resorcinol glue is strong, durable, and waterproof. Its chief disadvantages are that it is quite expensive and leaves a dark glue line. It sets up at room temperature in 8 to 10 hours. This glue is well suited for water skis, boats, and other structures that will be exposed for long periods to high humidity or water (Wagner, 1970, p. 7-2).

Chemical reaction between the resin and hardener is the key to epoxy's tough plastic bond. Equal amounts of resin and hardener are squeezed out and blended together for use.

Because of the wide variety of epoxy-resin formulations, it is difficult to generalize on their applicability for wood bonding. Some that have been studied gave quite strong dry joints initially, but their long term performance under high humidity and exterior exposure was poor. Their higher cost limited use in woodworking. Therefore, they must be considered primarily as a type of specialty adhesive for woodbonding. They are useful for bonding metals and certain plastics to wood for special uses.

Curing times for epoxies depend on the hardener used and the temperature. Curing can be hurried by increasing the temperature. Low temperatures slow curing; at zero degrees Fahrenheit, curing stops (Popular Science, 1971, p. 92).

Pot Life

The working life of an adhesive is the time elapsing between the moment an adhesive is ready for use and the time when the adhesive is no longer usable. Pot life is another term commonly used for working life (Skeist, 1965, p. 62).

Some adhesives, like polyvinal-resin, are ready to use when received and have a relatively long pot life. Other adhesives, like epoxy, require mixing some catalyst on curing agent with the resin at the time of use in order to provide the necessary chemical reaction of curing. This reaction starts at the time of mixing, with a gradual thickening of the mixture with increasing time. This reaction continues whether the adhesive mixture is in the mixing pot, or on the wood before the joint is assembled and under pressure.

Storage Life

The storage life of an adhesive is the time during which an adhesive can be stored, preferably under controlled conditions, and remain suitable for use.

Some adhesives seem to be impaired by exposure to low temperature but can be restored to satisfactory service by slight warming and agitation. Some solvent-based adhesives separate at temperatures of 30 to 40 degrees Fahrenheit, but can be reconstituted by stirring at room temperature. The undesirable effects of low temperature are not limited to water-based adhesives. Although adhesives may be apparently unaffected by being frozen and thawed once, they may be affected by repeated cycling (Skeist, 1965, p. 62).

Storage life of an adhesive may be determined by conducting a viscosity test or a lap shear test. The test results may be compared to a known fresh value, utilizing a minimum pounds per square inch value for qualification. The timing of these tests is established from information obtained from vendors, military specifications, or practical experience.

Theory of Adhesion

Theories of adhesion are relatively few in number, but the lack of numbers has not necessarily simplified understanding or encouraged agreement. Quite often, in fact, disagreement has been more the rule than the exception. One of the principal reasons for disagreement has been that the proponents of a particular theory try to explain all adhesion on the basis of one concept, rather than admit to a certain degree of truth in each theory (Gagle, 1973, p. 2-1).

For many years, it was felt that glue held wood together through mechanical attachment. This concept proposed that the liquid glue flowed into pores and cavities of the wood and then hardened to form an interlocking solid material. Today, a more acceptable explanation is called specific adhesion. Briefly, this theory states that the molecular forces that cause certain molecules of different materials to be attracted to each other are the ones that operate in the gluing process. It is also believed that, in some cases, a kind of chemical reaction takes place that forms different molecules that add to these adhesive forces (Wagner, 1970, p. 7-4).

Chapter 4

INDUSTRIAL GEOGRAPHICAL INFORMATION

The manufacturers of adhesives are primarily located in heavily industrialized states because that encompasses the industries main marketing area. The Thomas Register lists 366 adhesive manufacturers in the United States. Figure 1 on page 20 shows the geographical location of adhesive manufacturers in the United States.

Many factors have contributed to the growth of the adhesives industry. Adhesives were not seriously considered as structural bonding agents until the 1940's, when the aircraft industry promoted their usage, primarily, out of sheer necessity. In the last two decades, various forms of adhesives have replaced the use of screws, rivets, welds, nails, pegs, bolts, thread, clamping, soldering, and brazing in many fields. Some idea of the rapid growth in adhesive formulations is evident from the fact that there are more than 15,000 glues of 103 distinct chemical types with 1,080 brand names. The number of manufacturers of adhesives is another indication of the size of the industry. Modern Plastics Encyclopedia lists the names of manufacturers or suppliers of resins and adhesives. All types of adhesives are included in the list and the reader should consult this book for data on specific products, trade

Figure 1. Geographical Location of Adhesives Manufacturers

names, as well as bonding classifications.

The future of the adhesive industry is predicted in a study conducted by DuPont. DuPont's Interindustry Delphi Study on the Future of the Adhesives Industry in the United States suggests that the adhesives industry will experience perhaps serious problems from the government restrictions on use of certain materials or from supply shortages. The study could foresee no significant shifts occurring in the industry's structure with respect to the types of companies which develop, manufacture, distribute and use adhesive products. Figure 2 shows adhesive consumption and expected growth in the United States.

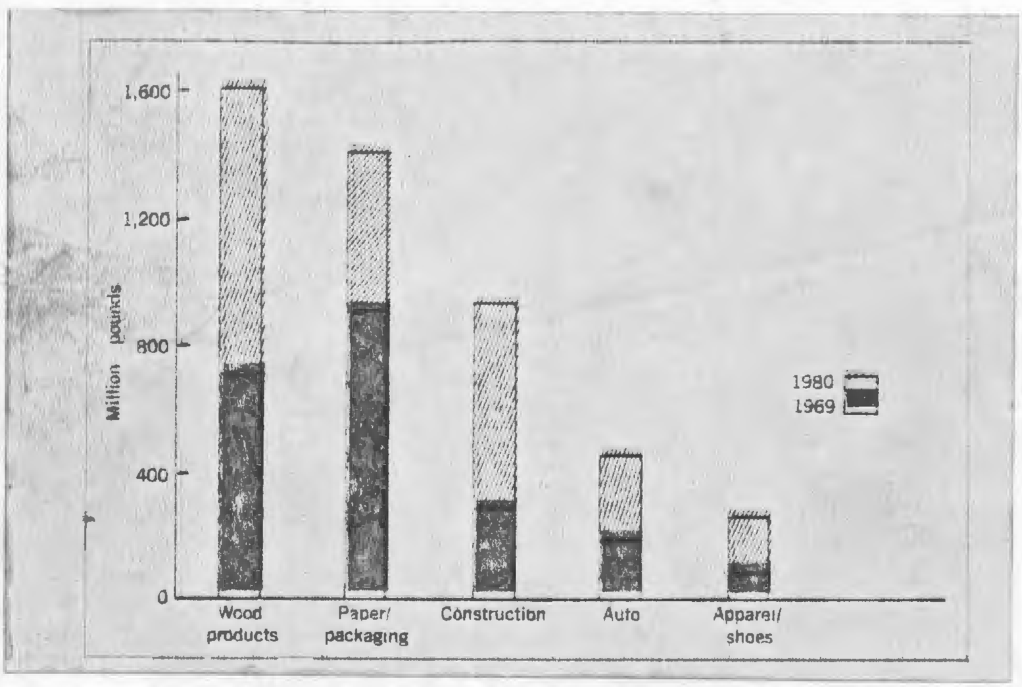

Figure 2. Adhesives Consumption and Expected Growth in the United States. (Adhesives Age, 1974, p. 18).

Chapter 5

THE PROJECT

One of the objectives of this study was to construct a test apparatus to determine the tensile strength and shear strength of five commonly used adhesives in industrial arts laboratories and the effects of temperature and humidity upon the strength of those adhesives.

A number of articles on testing materials and designing test apparatus were reviewed. This led to the conclusion that the testing apparatus should be designed to test tensile, shear strength, and measure the pressure applied to adhesive joints. A testing apparatus so designed would reduce construction costs and eliminate the duplication that is inherent with three separate sets of testing apparatus. As finally designed, the testing apparatus was constructed with materials and equipment available in most industrial arts laboratories. Figure 3 shows the completed testing apparatus.

The frame of the testing apparatus was constructed with 4" metal channel. The corners of the channel were mitered and welded together to form the rectangular frame. The moveable channel located between the top and bottom of the apparatus is attached to ¼" steel plate with a 3/4" diameter metal rod.

Figure 3. Testing Apparatus.

The grips (Figure 4) were constructed from 2½" square tube. The shearing jig (Figure 5) was constructed from 2½" square tube with 1 1/8" square tube used to hold the test specimen. The 1 1/8" square tube was held in place by plastic steel. The punch for the shearing jig was made from ½" steel plate.

The five ton hydraulic jack was attached to the 3000 lbs. pressure gauge by a hydraulic hose. 1" pine was used to elevate the testing frame and provide a base to mount the pressure gauge.

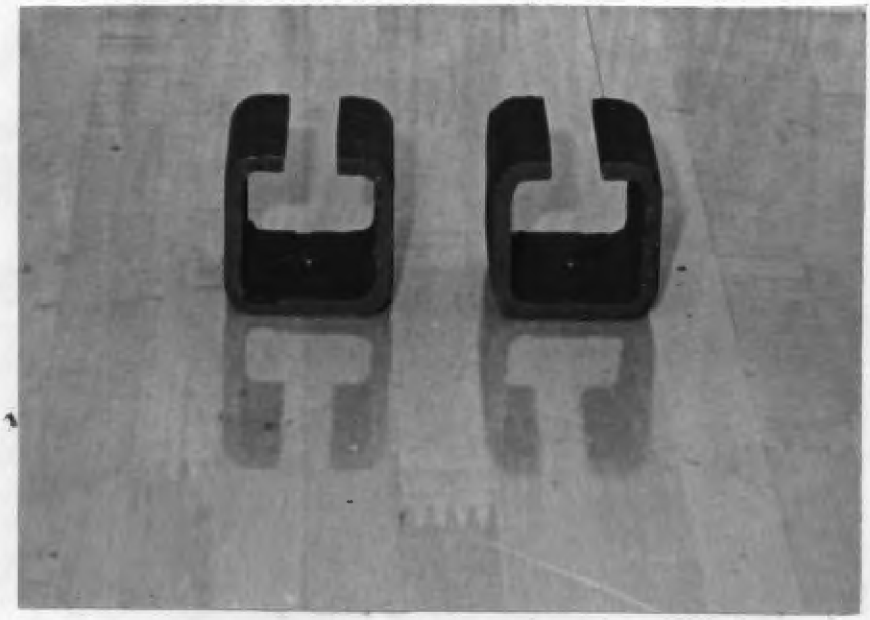

Figure 4. Grips For Testing Apparatus

Figure 5. Shearing Jig For Testing Apparatus

Chapter 6

THE TECHNIQUE OF PREPARATION AND PROCEDURE

The preparation of the material to be glued and the procedure for gluing are as important as the selection of the correct adhesive. The manufacturers recommendations for preparation and procedure should be reviewed before attempting to glue.

Preparation of Wood

Wood pieces that are to be assembled with glue should all have the same moisture content. This will take place automatically if all pieces of wood are stored in the same area for a period of time. The moisture content at the time of gluing should be about equal to that which the article will attain when it is placed in service. The average moisture content for interior woodwork in the United States is about 8 percent, but varies widely for different parts of the country. Exterior woodwork varies from 12 to 18 percent. High moisture contents (15 percent and above) will retard the curing time and may require the use of special glues (Wagner, 1970, p. 7-4).

Sanded surfaces do not always produce glue joints of high strength, since the surface imperfections are filled with wood dust which may prevent good contact between wood and adhesive. Planed surfaces bonded with thin glue-lines produce the highest strength joints.

A variety of species of wood are used in industrial arts laboratories, however, this study was limited to the use of oak. All oak used in this study was kiln dried. The woods were stored under the same average conditions for at least six weeks before any samples were prepared.

Standard woodworking machines were used to process the wood. All wood was surfaced and cut to standard dimension on the table saw. The surface area for bonding the shear specimen and tensile specimen was one square inch. Figures 6 and 7 show a drawing of the shear specimen and tensile specimen respectively.

Preparation of Adhesive

Adhesive preparation requires careful attention. After storage, the adhesive must be warmed to the correct temperature for application. Where component mixing is concerned, it may be important to measure the proportions correctly if optimum results are to be obtained.

Polyvinal, liquid glue, and contact cement are ready to use when purchased, while many of the other glues need to be mixed and prepared. When preparing powdered glues, mix just the amount you will need for each job. These glues have a working life of only a few hours and then must be discarded. A paper cup makes a good container for mixing small quantities of glue (Wagner, 1970, p. 7-5).

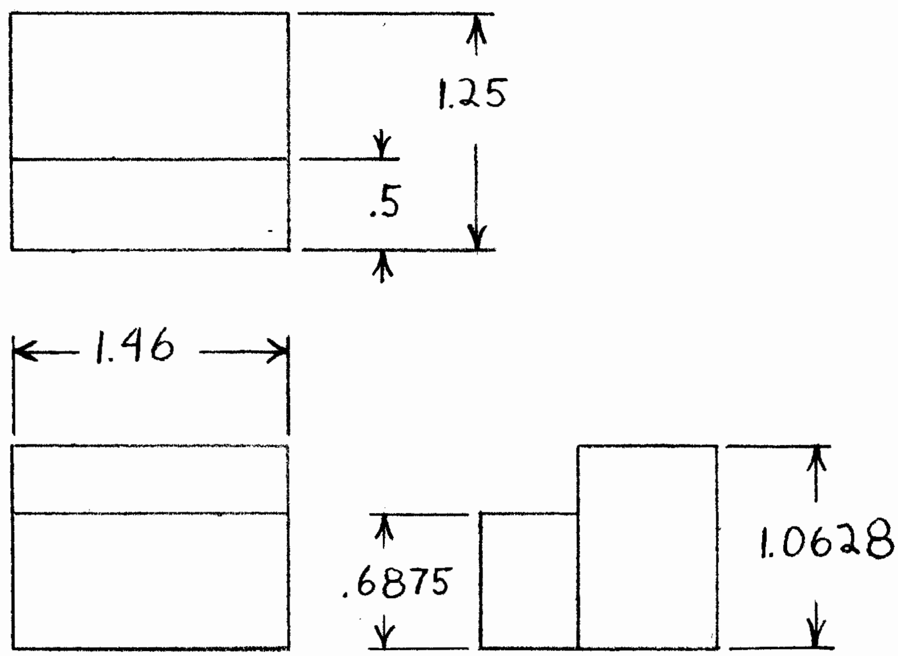

Figure 6. 3 View Drawing of Shear Specimen

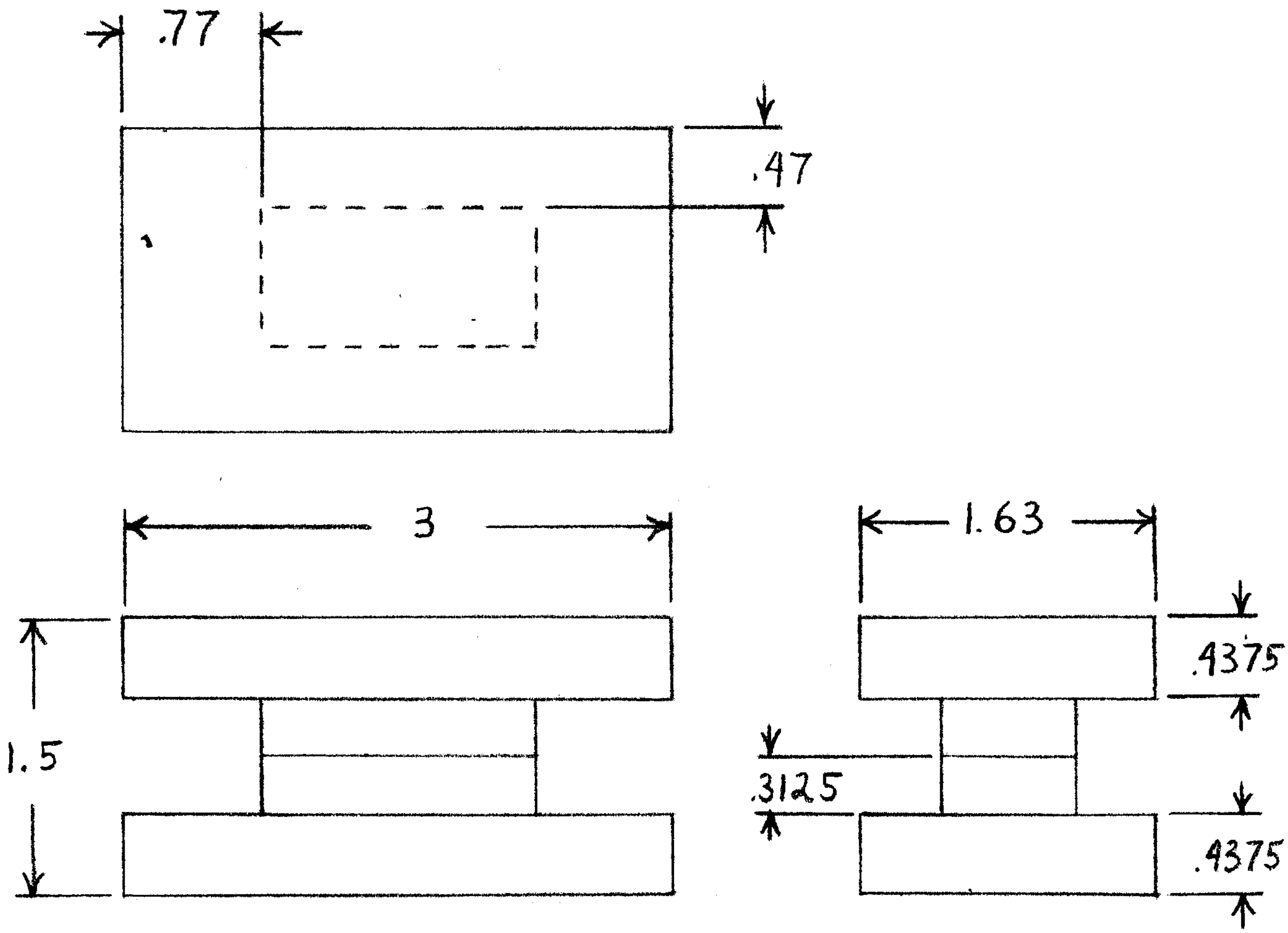

Figure 7. 3 View Drawing of Tensile Specimen.

Spreading the Adhesive

Applying the glue to the wood surface is called spreading. When the glue is applied to both wood surfaces to be joined, it is called a double spread, when it is applied to only one surface, it is called a single spread. A double spread was used on the wood samples in this study.

Glue can be spread with a brush, knife, roller, or a mechanical spreader. On production work, glue is sometimes applied with a brush.

A good glue film is about 5 mils thick, however, for the purpose of study, a proper glue film should yield a small amount of squeeze-out on the compressed wood samples. The surface of the wood should be coated, but not so heavy that an excessive amount of glue is wasted. The thickness of the film will vary with the kind of glue and the material being joined.

Consistency of the glue mixture, once it is spread on wood, may vary appreciably. It depends on such factors as the kind of glue; glue-water proportion of the mixture; age of the mixed glue; quantity of glue spread; moisture content and species of wood; temperature of the glue, room, and wood; time elapsed after spreading; and the extent to which the glue-coated surfaces are exposed to the air. Room-temperature-setting glues usually thicken and harden steadily after spreading until they are fully cured (Handbook # 72, 1974, p. 9-10).

Assembly Time

The time elapsed between the spreading of adhesive on the first wood pieces and the application of final pressure is called assembly time. Open assembly time is the period between glue spreading and the moment when the two surfaces are placed together. Closed assembly time is the time the pieces remain in contact before pressure is applied. Because glues are generally formulated for a variety of species, longer assembly periods are usually required with dense than with light woods to allow the glue to thicken before pressure is applied.

Polyvinal glues have an assembly time of about five minutes. Casein glue has an assembly time of about twenty minutes. Hide, resorcinol and epoxy glues all have relatively long assembly times, while contact cement should be allowed to dry completely before assembling the work. The film drying time will depend on the adhesive, rate and method of spreading, temperature, humidity, and circulation. A comparison of the assembly times is provided on Table 2.

Manufacturers of industrial woodworking adhesives generally indicate the permissible assembly time limitations for their adhesives in both open and closed assembly conditions. Since the adhesive will thicken both from evaporation and from chemical reaction as a function of rising temperature, these assembly conditions are usually cited for two or three different shop temperatures. Table 3 is an example of the directions for assembly time pro-

Table 2

Comparison of the Characteristics of the Types of Glue Used in This Study

Type of	Temp. range for use	Water resistance	Convenience of use	Working life Hrs.-Temp.	Type of assembly	Assembly time at 75° Minutes	Clamping pressures p.s.i.	Clamping time in hours Minimums
Cold hide	Above freezing	Low	Ready to use	Indefinite	Open or closed	Until tacky to touch	100 to 200	12
Casein	40 on up	High	Mix with cold water	6-8 70	Open	Max. 20 Min. 5	50 to 250	4-5 at 70°F.
Contact	70 on up	Low	Ready to use	30- 1 hr. 75	En.	Max. 1 hr. Min. -	25 - 100	30 min.
Polyvinyl resin	50 to 110	Very low	Ready to use	Indefinite	Open	Max. 10 Min. -	25 - 200	20 - 30 (minutes
Resorcinol resin	70 on up	Water proof	Mix with catalyst	3-4 75 3/4-1 90	Closed	Max. 30 Min. -	100 - 250	10 at70° 6 at80° 3½ at90°
Epoxy	60 on up	High	Mix with catalyst	50 - 60	Closed	Max. 60 Min.	25	1 hour

provided by Borden Chemical Co. for resorcinol glue.

Table 3. Assembly Times For Resorcinol Glue. (Borden Chemical Co., 1976, p. 2).

Maximum Permissible Assembly Time (time from spreading first surface to application of pressure):

A delayed assembly of about 1/3 the times shown in the table below is recommended for best results, especially for dense woods or for curing at high temperatures.

Temperature of room, wood, glue:	70°F.	80°F.	90°F.	100°F.
Open Assembly (surfaces exposed), mins.	30	20	15	10
Closed Assembly (surfaces together), mins.	75	45	30	20

Applying Load Pressure

Pressure is used to squeeze the glue into a thin continuous film between the wood layers, to force air from the joint, to bring the wood surfaces into intimate contact with the glue, and to hold them in this position during the setting or curing of the glue. Conversion of a liquid to a strong solid film is achieved by physical action, by drying out of the solvent, or by chemical action. During chemical action, the individual molecules in the glue film become larger and more completely joined together. Chemical action is accelerated by increases in glueline temperature.

The principal purpose of pressure is to distribute adhesive uniformly over the joint area, then to hold the woodpieces in intimate contact until the adhesive has developed sufficient strength to hold the joint together. Uniformity of bonding pressure is probably even more important than the actual magnitude of the pressure (Gagle, 1973, p. 17-14).

Light pressure should be used with a low viscosity glue that becomes thin during curing, heavy pressure with a thick glue, and corresponding variations in pressure with glues of intermediate consistency. The strongest joints usually result when the consistency of the glue permits the use of moderately high pressures (100 to 250 p. s. i.) to bring mating surfaces into close contact. Small areas with flat, well-planed surfaces can be conded satisfactorily at much lower pressures (Handbook # 72, 1974, p. 9-10).

Much has been written about the so-called gap-filling adhesives for wood. The implication is that gap-filling adhesives can be used in glue lines with less pressure than with conventional wood adhesives. The principal advantage of gap-filling adhesives is actually their ability to tolerate variable-thickness glue-line areas in the same joint, such as between two pieces of wood with wavy or irregular surfaces. External bonding pressure can only force the two pieces together tightly enough to mate the high spots on each piece. This leaves areas of thick glue lines over the lower spots. To be an effective gap-filling adhesive, the bulk of the adhesive in the thick areas must retain its expanded condition without shrinkage and pulling away from the surfaces, and without opening voids in the glue film. A more practical solution to the gap-filling problem is to machine the two surfaces for a closer fit so that thin glue lines are possible. Table 2 shows the gap-filling properties of the adhesives used in this study.

The testing apparatus is used as the medium for applying pressure to the wood samples in this study. Figure 8 shows the tensile specimen placed in the testing apparatus. The specific clamping pressures for the adhesives used in this study are listed on Table 2.

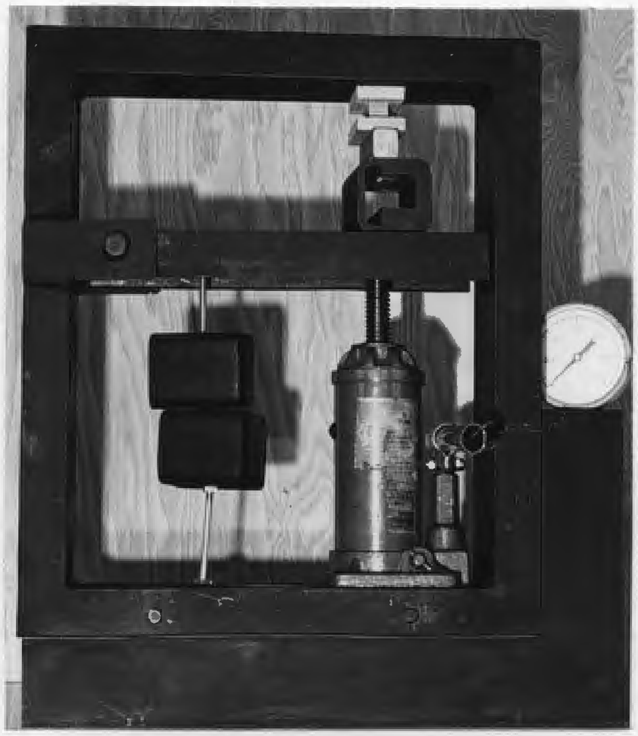

Figure 8. Applying Pressure to the Glued Wood Samples

Pressing Period

In addition to the amount of pressure used with an adhesive, the length of time that the joint must be under pressure before it develops sufficient strength to allow removal, is an important practical consideration in selecting the adhesive. The more reactive the adhesive, the shorter the required pressure period for a given application. Manufacturer's instructions should be followed on the pressing periods for each type of adhesive.

Wood samples in this study were left under load pressure for a period of twenty-four hours. This was done as a matter of convenience and also to parallel school shop conditions. All of the glues used have shorter pressing periods. Minimums that can be used are shown in Table 2. Figures 9 and 10 show the bonded specimens.

Testing Specimens

All specimens were tested for shear strength and tensile strength using the equipment shown in Figure 3. Test values for each type of wood with each type of glue were summed and the average values recorded.

The shear test is by far the most common and useful type of adhesive test. Not only is it quite simple to conduct, but it duplicates and evaluates the type of loading which adhesives are most often subjected to in service. Shear stresses are produced by forces which set in the plane of the adhesive layer and resist the movement of the adherent in opposite directions.

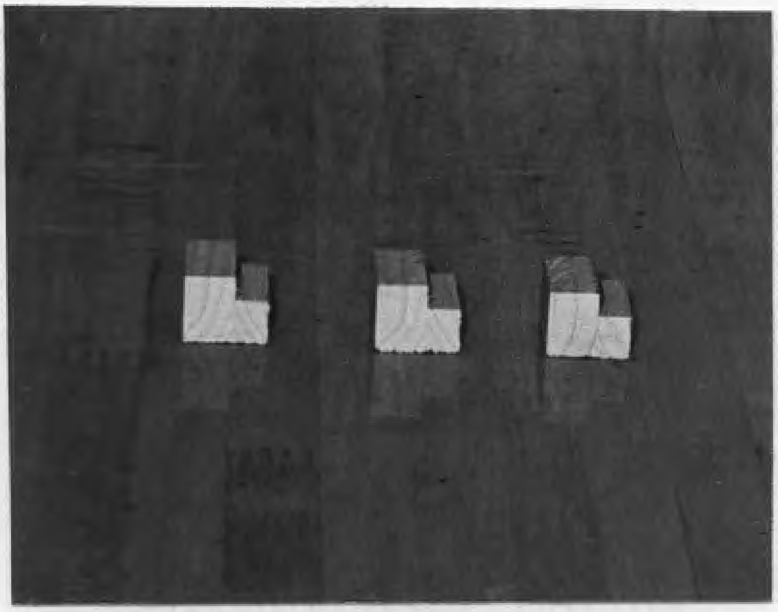

Figure 9. Bonded Specimen For Shear Test

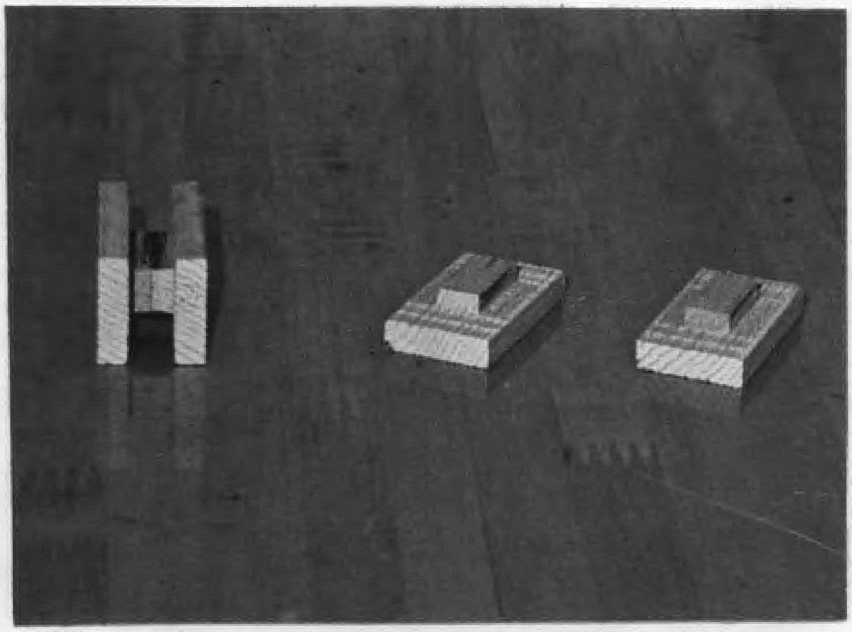

Figure 10. Bonded Specimen For Tensile Test

Figure 11. Wood Sample Placed in the Shearing Block.

Figure 11 shows the wood sample placed in the shear block. A load is applied to the test specimen by applying pressure with the hydraulic jack. The pressure required to break the adhesive bond is recorded on the pressure gauge on the right of the testing apparatus.

The test specimens were then examined for wood failure of the glued area. Wood failure values were estimated in percentage of the glue-line area in which the wood splintered. A careful estimate was made on each specimen and the percentage of wood failure recorded opposite the shear strength value. The results of the shear test are shown on Table 4. An adhesive is in tensile loading when the acting forces are applied perpendicularly to the plane of the adhesive. The tensile strength of an adhesive is the maximum tensile load required to break the joint. Figure 12 shows an example of the wood sample placed in the grips for the tensile test. The hydraulic jack is used to apply pressure to force the separation of the adhesive joint. The amount of pressure required to break the joint is measured on the pressure gauge on the right of the testing apparatus.

Figure 12. Wood Sample Placed in the Test Grips.

Table 4

Results of the Shear Test

Type of Glue	Species of wood	Average shear strength in lbs. p.s.i.	Average percentage of wood failure
Hide glue	Oak	1736	36.5
Casein	Oak	1981	34.9
Contact	Oak	750	0
Polyvinal	Oak	2025	26.9
Resorcinol	Oak	2561	48.9
Epoxy	Oak	1874	32.6

Table 5

Results of the Tensile Test

Type of Glue	Species of wood	Average tensile pressure in lbs. p.s.i.	Average percentage of wood failure
Hide glue	Oak	350	5%
Casein	Oak	684	85%
Contact	Oak	50	0%
Polyvinal	Oak	722	96%
Resorcinol	Oak	709	94%
Epoxy	Oak	700	89%

The test specimens were then examined for wood failure in the glue area. Wood failure values were estimated in percentage of the glue-line area in which the wood splintered. A careful estimate was made on each specimen and the percentage of wood failure recorded opposite the tensile strength value. The results of the tensile test are shown on Table 5.

The effects of temperature upon the strength of adhesive joints is measured by heating the glued wood samples in an oven at 150 degrees Fahrenheit for two hours, then subjecting the test samples to shear and tensile tests as previously mentioned. The effects of cold temperature upon the strength of adhesive joints was measured by placing wood samples in a freezer for twenty four hours, then subjecting the test samples to shear and tensile tests. The results of the tests for the effects of temperature upon adhesive joints are shown on Table 6.

The effects of high humidity upon the strength of the adhesive joint are measured by immersing wood samples in water for twenty four hours, then subjecting the test samples to shear and tensile tests as mentioned previously. The results of the tests for the effects of humidity upon adhesive joints are shown on Table 7.

Table 6

Effects of Temperature Upon the Strength of Adhesive Joints.

Type of Glue	Species of wood	Average shear strength in lbs. p.s.i.	Average tensile pressure in lbs. p.s.i.
Hide glue	Oak	150	too low to record
Casein	Oak	980	350
Contact	Oak	100	too low to record
Polyvinal	Oak	225	50
Resorcinol	Oak	1530	445
Epoxy	Oak	1210	540

Table 7

Results of the Tests for the Effects of High Humidity Upon the Strength of Adhesive Joints.

Type of Glue	Species of wood	Average shear strength in lbs. p.s.i.	Average tensile pressure in lbs. p.s.i.
Hide glue	Oak	210	75
Casein	Oak	450	175
Contact	Oak	150	too low to record
Polyvinal	Oak	525	210
Resorcinol	Oak	1860	670
Epoxy	Oak	710	250

Chapter 7

INSTRUCTIONAL UNIT

Testing the strengths of adhesives proved to be a very interesting subject. This writer believes that students in the industrial arts program could benefit from the opportunity to perform practical testing. They would gain technical information about the properties of various adhesives and acquire the safety knowledge for using the adhesive. For these reasons, the writer believes that a unit on adhesives would be of value to the student in industrial arts.

Objectives

The student will be able to:

1. describe the technical properties of the adhesives used in this study.
2. list safety precautions in using adhesives.
3. list two advantages and two disadvantages of each of the kinds of glues used in the study.
4. identify the correct procedure for gluing wood together.
5. demonstrate skill in performing shear and tensile tests.
6. interpret data and prepare a technical report.

Lesson Plan Outline

I. Introduction

A. Objectives of the unit

B. Definition of adhesive terms

C. History of adhesives

II. Technical information

A. Factors to consider in selecting an adhesive

B. Adhesive materials and properties

Safety Precautions

IV. Procedure for testing adhesives

A. Preparation of wood

B. Preparing the glue

C. Spreading the glue

D. Assembly time

E. Applying load pressures

F. Pressing period

G. Testing specimens

V. Student evaluation

Student Activity

I. Objectives

The objectives of this study are: (1) to study, observe, and experiment with the tensile and shear testing of adhesive bonds; (2) to interpret data and prepare a technical report; (3) describe the technical properties of the adhesives used in this activity; and (4) describe the safety precautions in using adhesives.

II. Specific References:

Groneman, Chris H., General Woodworking, Unit 25

Wagner, Willis H., Modern Woodworking, Unit 7

III. Background Information

An adhesive is any glue or cement product that is used to bond materials together. Modern adhesives exhibit a great deal of strength and are used as a principal means of joining materials in various industries. With many adhesives for wood, if the joining has been properly made and the adhesive used as prescribed, the joint will be stronger than the wood itself.

Testing the adhesive bond may take the form of a shear test, breaking test, or a tensile test. The tensile test is important because of the type of loading to which the bonded part may be subjected. It is a relatively easy test to perform and serves as a standard means of comparing the tensile properties of adhesive bonds. The tensile strength of a bond, expressed in pounds per square inch, is the maximum tensile load per unit area of the area bonded by the adhesive.

A simplified definition of shear stress is that it is an action caused by forces which act parallel to a given area and in opposite directions, tending to produce sliding of one portion past another.

It is the kind of stress developed when a material is sheared or punched.

Shear strength is an important consideration in the design and performance of many machine parts and elements. Rivets, bolts, and pins are often loaded partly, if not entirely, in shear. Bending forces applied to beams produce primarily tensile and compressive stress, but some shear stress is always produced. Such operations as shear cutting, blanking, and punching require forces which are dependent on the shear strength of a material.

Shear strength of a material is equal to the maximum resisting force divided by the area under shear. Shear test results are generally less precise than tensile tests, for in shear testing a small amount of bending stress and friction is usually present.

IV. Equipment and Supplies:

1. Shear and tensile testing machine.
2. Grips for holding the testing specimen. Shearing block for testing machine.
3. Tensile and shear specimens.
4. Polyvinal resin glue, Resorcinol glue, Hide glue.

V. Procedure:

1. Glue the specimens in accordance with the procedure outlined by your instructor

Note: Glue 5 tensile specimens and 5 shear specimens with each type of adhesive. Glue the specimens together with the grain of the wood parallel in each piece. Let the glued specimens dry for 24 hours.

2. Place the specimen in the grips of the testing machine.
3. Apply the load at a rate of 1200 to 1400 lbs. per minute.
4. Record the maximum load carried by the specimen at failure. Record the percentage of glue failures, and contact failures as based on visual inspection.

VI. Results:

The report of this activity should include:

1. A description of the types of adhesives tested.
2. The data suggested in the above procedure.
3. A brief comparison of the different classifications of adhesives.
4. Answers to the questions included in this activity.

VII. Applications:

This test covers the determination of comparative tensile and shear properties of the adhesive bonds tested on standard specimens under specified conditions. The method compares the adhesives using the application prescribed by the instructor.

VIII. Questions:

1. In reference to wood to wood testing, explain what is meant by:
   A. Adhesive failure
   B. Wood failure
   C. Contact failure
2. Give the characteristics of the adhesive used in this experiment.
3. What are the advantages and disadvantages of each type of adhesive used in this activity?
4. Does a knife cutting an apple create shear stress? Explain.
5. Why are shear tests less exact than tensile tests?
6. Compare the shear test results with the tensile test results.

Chapter 8

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A summary of a comparison of the properties and strengths of adhesives is presented in this chapter. Conclusions reached after analysis of the facts are then enumerated. Finally, the recommendations for further research are presented.

Summary.

Adhesives are often thought of as a substance to fasten materials together with little regard given to their limitations, characteristics or intended use. The purpose of the study was to clarify some of the thinking and help solve some of the problems encountered in using adhesives.

The objectives of the study were:

1. To research relevant information on properties of adhesives and the safe use of said adhesives in industrial arts laboratories.
2. To construct test apparatus to determine the tensile strength and shear strength of said adhesives and the effects of temperature and humidity upon their strength.
3. To develop a unit of study for junior high students on identifying the properties of adhesives used in industrial arts laboratories.

The study was limited to researching the following adhesives: contact cement, casein glue, resorcinol glue, epoxy glue, animal hide glue, and polyvinal resin glue. Glues were selected for their availability and adaptability to the industrial arts laboratory. Information was obtained from industry on the characteristics of all the glues tested.

White oak was selected as the wood to be used in the testing. It was stored in the industrial arts laboratory to insure uniform moisture content in the wood. The oak was surfaced and cut to standard size.

A testing apparatus was designed to test tensile strength, shear strength, and measure the pressure applied to adhesive joints. The testing apparatus was constructed with materials and equipment available in most industrial arts laboratories. The testing apparatus was used as the medium for applying to the adhesive joints. Load pressure on the joints was measured by a hydraulic jack. Joints remained under pressure for twenty-four hours. A total of 72 specimens were tested in the study.

Conclusions.

A close relationship was found among the shear strengths and tensile strengths of resorcinol, polyvinal, casein, and epoxy. The results indicated that resorcinol glue had the highest shear test values of all the adhesives tested. The performance was based on the average strengths of joints in pounds per square inch.

Contact cement produced the lowest results of all adhesives tested. The average tensile strength values of contact cement were too low to record. A close relationship was found between test values and the percentage of wood failures in testing contact cement.

The results of the tests for the effects of temperature upon the strength of adhesive joints indicated that resorcinol glue produced the highest shear strengths of all the adhesives tested. Epoxy glue yielded the highest tensile strengths of all the adhesives tested for the effects of high temperature. A close relationship was found between the tensile and shear strengths of hide glue and contact cement.

Resorcinol glue yielded the highest shear and tensile strengths of all the glues tested for the effects of high humidity. A close relationship was found between the tensile strengths of casein an polyvinal glue.

Having completed the in-depth study, the writer will be more competent to instruct a unit on testing adhesives. The testing apparatus developed will assist in relating to the student the importance of selecting the correct adhesive for each application. Information learned through this study will enable the writer to better advise students on problems related to the use of adhesives.

Recommendations.

If this type of study should be undertaken at another time, the author recommends the following statements be considered:

1. The study could include several varieties of wood in the testing. Since the strength of a glue joint has a bearing on the type of wood used for the joint, the relationship between joint strength and the type of wood used for the joint could be observed by students.

2. The study could have been limited to the testing of tensile and shear strengths of adhesives. The effects of temperature and humidity could have been researched in a separate study.
3. The clamping pressure on the joints could have been varied to explore the relationship between clamping pressure and joint strength.
4. A comparison test could have been made between the adhesives used in industrial arts and the new super glues on the market.
5. A comparison test could have been made to test the strength of joints of non-porous materials.

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APPENDIXES

APPENDIX A

Sheldon, Iowa 51201
July 23, 1976

Dear Sir:

I am a graduate student at the University of Northern Iowa majoring in industrial education. I am enrolled in a projects research course which requires correspondence with industrial firms associated with the project area selected. My research is a comparison of the properties and strengths of adhesives.

I am seeking information on the properties and strengths of the following adhesives:

1. Contact cement
2. Casein glue
3. Resorcinol glue
4. Epoxy glue
5. Animal hide glue
6. Polyvinal resin glue

I would appreciate information on the properties and strengths of any of the above adhesives that your firm produces. I would also appreciate any samples of the above adhesives that your firm produces. Thank you for any help you might be able to give me.

Sincerely,

Merwin C. Foster

APPENDIX B

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
Forest Products Laboratory
P. O. Box 5130
Madison, WI 53705

1600
November 24, 1976

Mr. Merwin Foster
Sheldon Community Junior High School
Sheldon, IA 51201

Dear Mr. Foster:

This is a follow-up to your telephone request for information on the testing of adhesives.

Our Laboratory does not have this type of visual aid available but the following organizations should be able to help you -- The Franklin Glue Company, 2020 Bruck Street, Columbus, OH 43207, The Borden Chemical Company, 350 Madison Avenue, New York, NY 10017, the American Plywood Association, 1119 A Street, Tacoma, WA 98401, and the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

A complementary copy of our annual report is enclosed for your reference.

Sincerely,

MICHAEL C. CONTEZAC
Information Specialist

Enclosure

6200-11 (1/69)

BORDEN CHEMICAL
DIVISION OF BORDEN INC

BORDEN

October 27, 1976

Mr. Merwin Foster
c/o Sheldon Jr. High
Sheldon, Iowa 51201

Dear Mr. Foster:

Answering your recent request, I am sending you a copy of our bulletin discussing adhesives for the Furniture Industry and other information.

Let me know if I can be of further assistance.

Very truly yours,

R. J. Bandekow
Eastern Regional Sales Manager
Adhesives & Chemicals - East

RJB/psl
enclosure

114 ESSEX STREET, ROCHELLE PARK, NEW JERSEY 07662 • TELEPHONE: (201) 843-8088

VITA

Name............................Merwin Foster

Date of Birth...................

Place of Birth..................   South Dakota

Wife............................Cheryl Ann

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Graduated, 1965

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