CONDITIONS AFFECTING THE MAKING OF GLUED JOINTS

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It is unfortunately true that the term "glued joint" does not correlate in the average mind the ideas of strength, durability, and all-around high quality that rightly apply to such joints when properly made. The notion of inferiority of glued joints in general has doubtless been formed from the all too common experience of furniture pulling apart and veneers peeling away in actual service. Carelessness and abuse on the part of the consumer are of course responsible for a part of the failures, but a considerable part of the trouble lies farther back.

Glued products, if properly made, possess decided advantages for certain purposes over articles of solid wood construction. A cross-banded plywood or veneered panel, for example, is far more constant in dimension with changes of moisture content, and, especially in the case of thick-core panels, is less liable to warp and change shape than solid wood of the same dimensions. These advantages are of great importance where flat, close-fitting parts are a prime essential, as in furniture, cabinet work, and doors. Furthermore, by crossbanding, i.e., building up alternate layers of wood
at right angles to each other, a construction can be obtained which is approximately equal in strength in all directions, whereas the strength properties of solid wood, with and across the grain, are fundamentally different. The quality of wood used in a built-up product can also be more exactly selected than is possible in solid construction.

All the foregoing are benefits which the consumer enjoys or at least shares; but there are others accruing particularly to the manufacturer, chief of which are that the wood in smaller dimensions can be dried more quickly and cheaply and that it can be more economically used. But, one and all, the advantages of glued construction will go for nothing if the joints are not made to withstand service conditions. The glued product must, first of all, give satisfaction under reasonable service; on top of that, sooner or later it has got to withstand unreasonable service - the slam, the drenching, the punishment.

An undetermined but undoubtedl y very large part of the failures of glued joints are due to improper gluing conditions and methods. This, the actual gluing process, is the aspect of the matter which will be principally considered here; but it is only one of five factors determining the final result, each one of which demands at least passing mention in the present connection.
The Five Problems of the Manufacturer

In general, then, the problems of the manufacturer of glued products may be classified as: (1) Selection of suitable materials; (2) preparation of the materials for use; (3) proper construction; (4) gluing conditions and methods; and (5) drying and conditioning the glued stock.

Selection of Materials

Glue and wood are, of course, the two major products in glued wood construction. The different species of wood vary among themselves to a marked degree, and the several kinds of glue, also, are surprisingly unlike in most characteristics. It is obvious that the manufacturer should have an accurate and rather complete knowledge of the properties of different woods and glues if he is to make the best product for a particular service. Of late years there has become available a great deal of practical information as to our native commercial woods; Bulletins 552 and 556 and other publications of the U. S. Department of Agriculture will be found of interest in this regard. As to the various glues used in woodworking, the Forest Products Laboratory has issued several publications describing and comparing their more important characteristics.
A selection of the best glue or wood for a particular use cannot be made until the service conditions are understood. With that information available, it is then necessary to determine what properties and characteristics of wood and glue are essential and from that what particular wood or glue most nearly meets the requirements. For example, in an exterior veneered door, because of the severe moisture conditions to which it is subjected, water-resistance and durability are the most important characteristics in selecting a glue. Other characteristics should, of course, be considered, but they are of less importance. On the other hand, in gluing such a material as white bird's-eye maple veneer, the staining characteristics of the glue are relatively more important than water-resistance or maximum strength, though good strength is, of course, required. In a similar manner, the important requirements of the wood for different uses must be taken into account.

**Preparation of Materials for Gluing**

Both glue and wood may be of the highest quality and still the glued joints be inferior, owing to the improper preparation of either or both for gluing.

The exact technique of glue mixing varies with the different kinds and brands. In mixing a prepared glue it is
usually advisable to follow the instructions furnished by the manufacturer, though it is sometimes necessary to vary details so as to obtain the best mixture for a particular purpose. The more important points of variation are (1) proportion of dry materials and water, (2) manner of putting the materials together, (3) method, speed, and time of stirring, and (4) in the case of animal and most vegetable glues, temperature of the mixture.

The preparation of wood for gluing involves cutting to size, elimination of defects, drying, and surfacing. Most of the wood that is to be glued is first cut either into veneer or into inch lumber which is later dressed down. Although some stock thicker than an inch is glued up, such as is used in doors, chair seats, thick table tops, framing for auto bodies, and airplane parts, the fact remains that the great bulk of the wood for gluing is cut from the log into veneer or inch boards. Lumber is first dried and then surfaced for gluing, whereas with veneer the gluing surface is produced as it is cut from the log or flitch and the drying is done afterwards.

Wood for gluing should be dried free of casehardening and other stresses and conditioned to a uniform moisture content. Unequal moisture in the pieces before gluing is the source of much trouble afterwards. The proper
moisture content varies over quite a wide range and depends upon a number of factors, of which the service conditions the product is to meet and the amount of moisture to be added in gluing are most important.

After drying, the next important step is machining, with the three objects of (1) reducing the lumber to the proper dimension, (2) eliminating defects, and (3) preparing the surfaces for the glue. Wood properly surfaced for gluing is smooth, even, and flat. For panel work it is also of uniform thickness. When placed together the surfaces should make complete contact under relatively light pressures.

Proper Construction

Warping, weakness, and lack of durability in glued products are commonly due to the use of unbalanced or other improper construction. The rules governing the construction of most glued products have been pretty well established through long usage and by experiment. Consciously or unconsciously, they have been built around the principle of avoiding internal stresses so far as possible, or, when such stresses are necessarily present, balancing them by a symmetrical arrangement of similar plies, laminations, or parts. These rules, empirical though they may be, have their basis in the shrinkage, density, and strength properties of the
various woods and the gluing characteristics of various surfaces. Research has already furnished a considerable body of basic information along these lines, the use of which would help to solve many problems of the craftsman.

**Conditions and Methods of Gluing**

As previously stated, however, this discussion will deal principally with the problems of the gluing process itself, which takes high rank as a source of trouble and expense to the manufacturer. It involves putting together the glue and wood, which have been properly prepared, in such a way as to form satisfactory joints. A quantity of glue is spread on one or both wood surfaces, and sufficient pressure is applied to bring the pieces together. If the work is properly done, the joint which is made will consist of a continuous film of solid glue firmly adhering to both wood surfaces.

The principal conditions determining the success or failure of the gluing process are: (1) Consistency of the glue mixture; (2) method of spreading glue and quantity spread; (3) manner of assembling the laminations, and time elapsing between spreading of glue and pressing; (4) amount of joining pressure applied; (5) duration of joining pressure; (6) kind of wood; and for animal glue, (7) the temperature of the room and the wood.
Experimental work has been under way for some time at the Forest Products Laboratory to determine the relative importance of these various conditions or factors in the making of glued joints. The work was started with the purpose of finding out the best methods to use in gluing airplane propellers, and the early work, which was done mostly with animal glue, covered a wide range of conditions within the limitations stated. Since then the scope of the investigation has been enlarged to cover other glued wood products and other conditions of factory practice; and the work now in progress includes all the various glues and woods commonly used together. The present discussion will be confined largely to the work with animal glues, since this adhesive offers the best illustration of the various points involved in practice.

The tests have shown that there are three major types of weak joints which may occur on account of poor gluing conditions or methods, or both. These types are illustrated in Figure 1. The three sets of ten tested specimens each represent three blocks glued under different conditions. The photograph exhibits the character of failure and the appearance of the broken joints. The "starved" type of joint is clean in appearance and shows no distinct film or layer of glue. It results from the glue being forced into the wood
Chilled joint - glue formed into a firm jelly and the pressure applied was insufficient to bring complete contact. White spots are areas of no contact.

Starved joint resulted from the application of pressure while the glue was too liquid. Occurs frequently on certain woods.

Dried joint - glue dried on the wood before pressure was applied. Poor adhesion throughout.

Fig. 1 - Common types of weak joints.

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or out over the edges and is likely to occur with glue mix-
tures of low viscosity and with porous woods. The "chilled" type of joint is due to the glue jellying without sufficient pressure to give complete contact. It occurs only with ani-
mal (hide or bone) glues. The "dried" joint occurs with all glues and arises from the fact that a dried film of glue will not adhere even under a very high pressure.

Consistency of Glue Highly Important Consideration

In making a glued joint it is of the highest im-
portance to have the glue at the proper consistency when the pressure is applied. If it is excessively thick or exces-
sively thin, there is danger of getting weak joints. Some variation in consistency may be compensated for by the use of a high or a low pressure. Spreading, assembling, kind of wood, and temperature are of importance chiefly in relation to the consistency of the glue at the exact time of applying pressure.

The viscosity of a layer of glue at any particular moment after being spread on the wood is determined by several contributing causes. First, there is the kind of glue and the proportion of dry material and water used in mixing it. Blood and animal glues, when properly mixed and used, are quite low in viscosity, i.e., fluid, while casein and
vegetable glues are normally high in viscosity; but any one of these will show a considerable variation with the proportions of dry glue and water used. In general, an animal or a blood albumin glue is thinner than a vegetable glue mixed with a larger proportion of water. After glue has been spread on wood, it begins at once to thicken, some kinds showing a much more rapid change than others. The total amount of change depends upon the conditions surrounding the gluing and the lapse of time between spreading and pressing.

In an animal glue solution, viscosity depends very largely upon temperature. Indeed, for the first few minutes after animal glue has been spread on the wood this effect is much more important than the drying; whereas with other glues temperature has relatively little effect. Investigators have shown that at 140°F., the approximate temperature usually recommended for heating the glue before using, the change in viscosity with one degree of temperature is very slight, but that in the region of 80°F. to 90°F. the change per degree becomes very great. In other words, an animal glue solution as it approaches room temperature changes in viscosity very rapidly. This temperature-viscosity relationship, although general for animal glue, shows a certain amount of variation with the grade and mixture of the solution.

In Figure 2 are shown a number of tested joints which were pressed while the glue on the wood was at different
consistencies, obtained by varying the temperature of the wood and the lapse of time between spreading the glue and pressing. The joints made were of yellow birch with a certified propeller glue about equivalent to Peter Cooper's standard No.1. The mixture chilled into a jelly at 89°F. The illustration shows the character of failure and the figures for strength in each case. Only one side of each joint was photographed, since the other side would show the same characteristics. Each ten half specimens are grouped together in their original block, and the blocks are arranged so as to show the more important gluing conditions. The gluing was done in a room at a temperature of 70°F. For half the specimens the birch wood was heated at 120°F for 20 minutes before gluing. The others were glued at room temperature. In each case pressures of both 150 and 400 pounds per square inch for approximately 18 hours and "assembly times," i.e., periods of preliminary contact without pressure, of 3, 5, 8, 12, 18, and 25 minutes, were used. The glue was at approximately 140°F., when spread on the wood, and both faces of the joint were coated. The coated surfaces were placed together as soon as spread, but pressure was not applied until the predetermined assembly time had elapsed.

The glue, as soon as it was spread on the wood, began to change in viscosity, and within from 1 to 2 minutes on the wood at 70°F. it had chilled into a jelly. On the heated wood
it changed much more slowly, and for the shorter assembly periods it was too fluid to give good joints on the birch.

The effect of all these conditions on the character of the joint is quite clearly shown in the figure. On the heated wood, with both pressures, the joint strength was low for the quickly pressed joints but showed a reasonably consistent increase in strength with assembly times up to 18 minutes. The quickly pressed joints of the heated wood are typical "starved" joints. At both the 18 and the 25 minute assembly times the joints were of good strength and a considerable percentage of wood failure occurred. The joints of the heated wood glued under 150 pounds pressure tested uniformly stronger than those glued under 400 pounds.

On the other hand, when the wood was not heated there was no indication of starved joints, and the 400 pounds pressure produced uniformly stronger joints than the 150 pounds pressure. Under the lighter pressure there were weak spots in the joints, as shown by the minimum strength values, caused by partial or incomplete contact over portions of the joint. The 400 pounds pressure, however, produced a complete contact and joints of uniformly high strength.

These and many other tests have shown that the best results are obtained with glues when they are of the proper viscosity at the time of pressing. Animal glues when mixed
and prepared for use are ordinarily much too thin for immediate pressure after spreading. They should be allowed to thicken considerably on the wood or should be mixed thicker originally. Animal glue is at the best viscosity for pressing just before it has formed a jelly, which may be judged by touch. If it is too thick to "string" but sufficiently sticky to follow the finger a short distance and then draw down into distinct scar-shaped impressions, it is at the safest consistency for pressing. Of course, if proper care is used, good joints may be made by pressing before or after the glue has reached this condition, but the chances of securing joints of maximum strength are not so favorable.

Making an extra thick mixture or "cooking" the glue until it has thickened considerably from evaporation may make a further viscosity change unnecessary, but these practices are not economical of glue. Excessive heating or "cooking" of the glue also endangers its strength. Vegetable and casein glues are, ordinarily, much higher in viscosity than animal and blood glues, and do not need to undergo so large a change before pressing; in fact, "starved" joints do not commonly occur with these glues. But, even with them, it is best practice to avoid the immediate application of high pressures if the strongest possible joints are sought — especially with porous woods.
The rate at which any glue changes on the wood depends upon a number of conditions, such as the temperature and moisture content of the wood, the extent to which the glue-coated surfaces are exposed, the presence or absence of air currents, and the quantity of glue spread. Where the coated laminations or plies are laid together as soon as spread, the glue changes much more slowly than where left exposed to the air. Under closed assembly an average spread of glue may remain in good condition for from 15 to 20 minutes, or even longer. If exposed to air currents, the glue may dry within a few minutes until past the right stage, to a point where proper adhesion is impossible. With the wood heated, the drying proceeds much faster and dry spots may then occur within a very short time. While this is true more or less for all glues, casein glues in particular dry and set very quickly on hot wood, and there is much danger of poor joints. Heating the wood before gluing is liable, therefore, to cause "starved" joints with animal glue and "dried" joints with all glues. (See Fig. 1)

A small quantity of glue naturally changes more rapidly than a larger amount. For this reason a scanty spread of animal glue when applied to heated or warm wood has been found less liable to give "starved" joints than a
heavy spread, if pressed quickly; the quantity of glue spread
has less to do with producing a "starved" joint than the con-
sistency of the glue when the pressure is applied. For ex-
ample, a starved joint may be produced with a spread of glue
double that used to obtain a joint of maximum strength, pro-
vided the glue in the first case is pressed while thin and in
the second is allowed to come to the proper condition before
pressing. Note, however, that since a small quantity of glue
dries more quickly than a larger amount, the thin spread is
more liable to give poor joints where conditions are conduc-
tive to rapid drying or long exposure before pressing.

Relation of Pressure to Joint Strength

Pressing is an important part of the gluing opera-
tion. Pressure is applied in order to bring together the sur-
faces to be joined and to hold them firmly together while the
 glue sets. Without pressure the glue-coated pieces might warp
more or less from the effects of the added moisture. Pressure
forces the air from the glue line and also probably aids the
 glue in penetrating the cells of the wood, thus enabling it to
obtain a good hold.

The exact amount of pressure to use is of less im-
portance than is generally believed, and the necessity of ap-
plying a fixed amount is frequently overemphasized. For
example, pressure even as high as 1,000 pounds per square inch may produce joints of very high strength, whereas results equally good may be obtained by merely rubbing the surfaces together, provided the glue coatings are of the proper consistency and the wood surfaces are well machined and prepared. Under certain otherwise identical conditions pressures anywhere from 50 to 600 or more pounds may give satisfactory results. In fact, the effects of pressure are largely dependent upon the consistency of the glue. A glue which is thin and liquid at the time of pressing should be given a comparatively light pressure, whereas a thick one should receive a heavy pressure.

The effect of pressure on joint strength with both a thick and a thin glue is illustrated in Fig. 3. Here are shown the results of tests made with five different pressures, 25, 50, 150, 400, and 600 pounds per square inch, and under two different temperature conditions, 70° and 90°F. The joints made were of birch with certified propeller glue about equivalent to Peter Cooper's Standard No.1. The glue solution was heated to 140°F. when applied. When used under the 70° conditions it quickly chilled on the wood, usually within from 1 to 2 minutes, and at three minutes it had formed into a firm jelly. On the wood at 90° it changed slowly in
FIG. 3 - EFFECT OF JOINING PRESSURE ON THE STRENGTH OF GLUE JOINTS

Average strength values are based on from 32 to 62 tests. The average values are connected with heavy lines and the shaded portion of the points indicates the percentage of wood failure developed in test. The minimum values are connected with light lines.
consistency and did not form into a firm jelly even at the end of 25 minutes. The surfaces, both coated with glue, were placed together as soon as spread, and were left for periods of 3, 12, or 25 minutes before pressure was applied. The results of the 3, 12, and 25-minute periods were averaged together.

With the room and wood at 90°F, the 150-pound pressure gave the most dependable results. The 25, 50, and 150-pound pressures all gave about the same average strength values, but with the two lower pressures the joints were weaker in spots. A decided dropping off in strength occurred when the pressure was increased to 400 and 600 pounds per square inch.

The pressure-strength relationship was different, however, when the room and wood were at 70°F. Under these conditions the glue jellied before pressure was applied, and an increase in the pressure up to 400 pounds per square inch made a decided improvement in joint strength and was especially efficacious in overcoming weak spots. Both 400 and 600 pounds pressure per square inch gave very strong joints, as strong as the best of those glued in the warmer room. The placing of the pieces together without pressure as soon as coated and while the glue was still liquid resulted in adhesion over a part of the joint; then after the glue had jellied
(a rapid process at the lower temperature), the remaining portions were brought into full contact only by the use of very high pressures. This accounts for the low and high minimum strength values for the light and heavy pressures, respectively, in the 70° room.

**Gluing Conditions Interdependent**

The gluing process, therefore, involves a complex of factors of which the amount of gluing pressure, the temperature of room and wood, the kind, grade and mixture of glue, the manner and time of assembling laminations, and the quantity of glue spread, are all interdependent parts. Any one factor may be varied over a wide range and strong joints still result, provided the rest are controlled to compensate. Success depends upon getting one of many possible combinations of favorable conditions.

**Single and Double Spreading**

Under certain conditions the results obtained will depend somewhat upon whether single or double spreading is practiced; that is, whether one or both sides of the joint are coated with glue. This factor will make no appreciable difference in results, provided the glue is at the proper consistency when the pressure is applied. If, however, the
glue actually jellies before pressing, both sides of the joint must be coated for the best results, even though high pressures are used. If, on the other hand, the conditions surrounding the gluing result in excessively rapid drying, the same quantity of glue distributed over the two sides will dry more quickly and is more liable to cause weak joints than if spread on but one side. But as a rule, over a wide range of conditions, the double spreading is more reliable and will give the higher average joint strength.

Results Vary with the Kind of Wood

From what has been said it must not be concluded that a given set of gluing conditions will always produce the same results on all kinds of woods. Woods vary greatly in their properties. Some are light and porous, others heavy and dense; some are comparatively uniform in grain and texture, others are markedly nonuniform in these respects. Some are weak, others strong; some shrink or swell excessively with moisture changes, others vary but little. Some contain oils, or gums; others are comparatively free of such substances. Some cut and surface evenly and smoothly; others are difficult to machine at all. All these characteristics affect more or less the gluing properties of the various woods and the service they will give in glued construction.
Some woods glue satisfactorily under an extremely wide range of conditions. In Fig. 4 are shown four white oak blocks, representing half-size propeller blocks, all glued differently. Each consists of five laminations and four joints. The upper part of the illustration shows the blocks when removed from the press, the lower part the appearance of the joints after the blocks had been cut up and tested; the specimens are grouped together by joints (horizontal rows) and blocks (vertical columns). The time elapsing between spreading the glue and pressing was 3, 7, 11, and 15 minutes for the consecutively numbered joints of each block. Along the lower left margin of the diagram these are the numerals designated "assembly time". The temperature and pressure conditions for each block are noted at the head of each column. On block No. 4 the glue had chilled into a firm jelly at all joints before pressing. On the other blocks, when pressed, the glue was of various viscosities depending upon the temperature conditions and assembly times.

When removed from the press, the blocks showed a great variation in the amount of glue pressed from the various joints, although approximately the same amount of glue had been applied in each case. It is self-evident that where the wood had been heated before gluing there was much more glue squeezed out. A larger quantity of glue was also
**Fig. 4: Joints glued under different conditions showing the glued blocks and tested specimens**

Quartered white oak glued with animal glue (about equivalent to Peter Cooper's Standard No. 1) mixed 1:2.4
pressed out from the top joints, which had been coated and assembled last. On block No.4 the lines of drip shown on the sides flowed over the edges when the glue was spread, but a close inspection may show in places the lines of congealed or jellied glue which were forced out by the high pressure.

Notwithstanding the widely variant conditions under which the four blocks were glued, and the consequent great variation in viscosity of glue at the time of pressing, the joint strengths throughout were much the same. Such differences as did exist were due chiefly to differences in the quality of the wood. A high percentage of the failure in test occurred in the wood itself, and there was no one joint which tested low throughout. There is perhaps some indication of starved joints in block No.1 in the two spread last (3 and 7-minute assemblies), as shown by minimum strength values and per cent wood failures somewhat below the average. The tendency is slight, however, especially as compared to what would have appeared with certain other species.

The results here shown are quite typical of what occurs in gluing true white oak, a species in which the pores are more or less filled with tyloses. Other woods, including Central American mahogany and a number of conifers or softwoods, have also been found to give excellent joints throughout an extremely wide range of gluing conditions.
Yellow birch, on the other hand, has been found to give starved joints of low strength under conditions identical with certain of those applying to the white oak shown in Fig. 4. Hard maple, red oak, and ash appear to be similar to yellow birch in gluing characteristics. In general, the open-porous woods of high strength properties are the most difficult to glue and require the most precise conditions and methods in order to obtain satisfactory joints. Studies are now in progress at the Forest Products Laboratory as a result of which it is hoped that all woods now commonly glued may be grouped according to their gluing characteristics. For example, the woods in which starved joints are liable to occur would be grouped in one class, those which glue easily under a wide range of conditions in another, and the like; but as yet the studies have not progressed to a point where the lines can be drawn with exactness.

**Conclusions**

The major part of the tests referred to in this paper were made with animal glue, but since their completion other tests have been made with blood albumin, casein and vegetable glues. It is believed that the following conclusions, while applying especially to animal glues, will hold true, within reasonable limits, for all:
1. The most important single factor in securing good joints is the viscosity or consistency of the glue at the time pressure is applied. Other factors are of importance in so far as they affect the glue viscosity at that moment, but of little moment otherwise.

2. If the glue is very viscous, such as a jellied animal glue, high pressures (400 to 600 pounds per square inch) are advisable in order to secure good contact and high joint strength. Under conditions where the glue jellifies before pressing, both sides of the joint should be coated with glue.

3. If the glue is very thin and liquid at the time the pressure is applied, starved or weak joints are very likely to result. The use of low pressures (25 to 50 pounds per square inch) may give successful results under these conditions, but is not to be depended upon, as a slight warp may easily prevent good contact.

4. The amount of joining pressure, the temperature of room and wood, the manner and time of assembling laminations, the glue mixture and quantity of glue spread required to give good joints are all interdependent. Any of these factors may be varied over a wide range and still permit strong joints, provided the other factors are controlled accordingly.

5. **Pressure.** Strong joints can be secured with joining pressures varying from 25 up to 600 pounds per square inch or even more. Low pressures are required if the glue is very liquid, and high pressures if the glue has chilled, or partially dried. Low pressures with chilled glue and high pressures with very liquid glue give weak joints.

6. **Temperature.** A low temperature (around 70°F) causes high grade animal glues to chill quickly upon the wood and necessitates relatively high pressures for good joints. A temperature of 90°F keeps the glue liquid longer; hence medium pressures and assembling times are desirable. If the wood is warmed for 20 minutes or more at 110°F or higher the glue remains liquid still longer.
and low pressures and long assembly periods are desirable. Less trouble is encountered in using heated wood in a 70° glue room than in a 90° room. In general, heated wood, keeping the glue liquid, favors the production of starved joints; heating also increases the likelihood of weak joints, because it favors warping of the wood and rapid drying of the glue, and makes it difficult to spread a sufficient quantity of the glue on the wood in the first place.

7. The assembly time, that is, the time which elapses between spreading the glue and applying the pressure has an important effect upon the consistency of the glue. With animal glue and heated wood in a warm room, relatively long assembly times are desirable. With the same heated wood in a 70° room, shorter assembly periods may be safely used. With both wood and room at 70°F., the glue chills immediately; and when it is in this condition good results can be obtained with either long or short assembly periods. "Open assembly", that is, allowing the spread glue to remain exposed to the air, induces rapid drying and is not desirable except where the assembly time is uniformly very short. Ordinarily the desired viscosity of the glue may be secured more advantageously through an adjustment of other conditions than assembly time and method.

8. Amount of glue spread. A spread of about 35 grams of glue mixture per square foot of joint area can be expected to give satisfactory results under most conditions. With conditions which tend to produce starved joints a light spread of glue gives stronger joints than a heavy spread; but with conditions under which the glue tends to dry excessively a heavy spread is better. Under conditions where the glue chills, the amount spread is not very important, so long as the wood is well covered.

9. Glue mixture. Joints of high strength may be made from glue solutions of different concentrations if the other gluing conditions are properly controlled. A medium mixture is to be preferred if
a wide range of pressure, temperature, and assembly conditions is likely to be encountered.

10. **Single and double spreading.** Spreading the glue on one or both sides of the joint gives about the same results, provided the glue reaches the proper consistency when pressed. If, however, it chills to a jelly, double spreading is preferable; if the conditions cause excessively rapid drying, single spreading, with the same quantity of glue, will be the more reliable. Under a wide range of conditions double spreading is more dependable.

11. **Species.** There is a considerable difference in the gluing properties of the different species. Open-porous woods are much more subject to starved joints than are the less porous. On the other hand, no marked differences can be detected among the species when glued under conditions where the glue is relatively thick when pressure is applied. Almost any species can be easily and satisfactorily glued under intelligently controlled conditions.