Combining high and low density laminations of the same species, provided they are otherwise alike, into the same laminated construction does not appear to cause internal stresses of large magnitude. Laminated specimens under test have shown little weakening or tendency to warp from this cause (*14*).

There is a difference in shrinkage between quartered and flat-sawn material of the same species. Although this difference is greater in some woods than in others, an average of 150 species of wood shows a tangential shrinkage of about 8 per cent and a radial shrinkage of about 4½ per cent between the oven-dry and saturated conditions (*16*). Combining quartered and flat-sawn material is a disturbing factor in certain classes of laminated construction, such as propellers, but may be relatively unimportant in others.

The direction of the grain of adjacent laminations affects the strength and shape of glued members. Cross grain in a lamination results in a certain amount of longitudinal shrinkage of that particular lamination, whereas the longitudinal shrinkage of straight-grained material is very small or negligible. Consequently a construction made of cross-grained and straight-grained laminations is very likely to warp.

Stresses in laminated members resulting from differences of moisture content in the laminations have been found to disappear gradually and without danger of later recurrence if the glued block is kept for a long time in the same atmospheric condition, because the member checks or changes shape more or less to relieve the stressed condition of the fibers. If, however, the original stresses are the result of combining quartered and flat-sawn material they may die out during a long conditioning, but as soon as the atmospheric conditions change the stresses will be set up anew.

In general, then, it should be apparent that for laminated-wood articles in which high strength and accurate shape are required all plain-sawed or all quarter-sawed material of the same wood or similar woods should be used, and all pieces should be at a uniform moisture content when glued. For the manufacture of articles where slight changes in form are of no consequence, these precautions are of the United States:

GLUE FORMULAS FOR USE IN AIRCRAFT

The following water-resistant glue formulas, with directions for mixing, were developed at the Forest Products Laboratory by the laboratory personnel and are available for the free use of the people of the United States.

CASEIN GLUE FORMULA NO. 11 [23]

Ingredients	Parts by weight
Casein	100
Water	220–230
Hydrated lime	20– 30
Water	100
Silicate of soda (water glass)	70
Copper chloride	2– 3
Water	30– 50

[23] This formula, developed at the Forest Products Laboratory, is covered by U. S. Patent No. 1,456,842, which is available for the free use of the people of the United States. BUTTERMAN, S., and COOPERRIDER, C. K. PROCESS OF MANUFACTURING WATERPROOF ADHESIVES. (U. S. Patent No. 1,456,842.) U. S. Patent Office, Off. Gaz. 310: 1129. 1923.

The 220 to 230 parts of water added to the casein is approximately the right amount to use with Argentine (naturally soured) casein; but if a different casein is used, the water requirement will lie somewhere between 150 and 250 parts by weight.

The formula presupposes that a high-calcium lime will be used. A lime of lower grade may be used, but a proportionately larger amount of it will have to be added unless one is willing to sacrifice the water resistance of the glue. It is suggested that the user try 25 parts of lime to begin with. If this does not give good results, the amount can be varied within the limits specified.

The density of the silicate of soda used should be about 40° Baumé with a silica-soda ratio of from 1 to 3.25. Copper sulphate can be substituted for copper chloride.

The casein and water are placed in the bowl of the mixing machine, and the paddle is made to rotate, stirring the mixture until all the water has been absorbed and all the casein moistened. By allowing the casein to soak beforehand for a while it is more readily dissolved in the mixing process. In a separate container the hydrated lime is mixed with water. This mixture is stirred vigorously at first, but just before it is added to the casein it should be stirred with a gentle rotary motion, just enough to keep the finest particles of lime in suspension. Pour this milk of lime quickly into the casein.

When casein and lime are first combined they form large lumps, which are balls of casein coated with the partly dissolved casein. These balls break up readily under the action of the mixer, becoming smaller and smaller and finally disappearing. The solution, in the meantime, is becoming thin and fluid. Within the first minute after adding the lime it is well to stop the paddle and scrape the sides and bottom of the can, and then stir again. If a deposit of casein remains unacted on, it may cause more lumps later.

When about two minutes have elapsed since the lime and casein were first put together, it will be noticed that the glue has begun to thicken a little. The sodium silicate must be added now, or else the glue will become too thick. Disregarding lumps in the casein, if they are but few, pour in the sodium silicate. The glue will become even thicker momentarily, but it will soon change to a thin, smooth, and fluid consistency.

The stirring should continue until the glue is free from all lumps. This should not take more than 15 or 20 minutes, counting from the time the lime was added. If the glue is now a little too thick, a small amount of water may be added. If the glue is too thin, however, it will be necessary to discard the entire batch and start over again, using a smaller proportion of water.

The copper salt may be added at different times during the mixing process with apparently the same final results. If added as a powder or a solution to the casein before soaking, it is likely to have a corrosive action on the metal container, and for this reason it is advisable to add it later during the mixing process. If added at first, however, it should be thoroughly mixed with the casein before the addition of the lime. It may be placed in solution and conveniently stirred into the moistened casein immediately before adding the lime or after all the other ingredients have been combined and the mixture rendered smooth and uniform in consistency. When added at the end of the mixing period, it should be poured into the glue in a thin stream and the mixture stirred vigorously. Stirring should be continued until any lumps that may have formed at first by coagulation, when glue and copper solution mix, are broken up and a smooth, violet-colored glue is obtained.

Glue prepared by formula No. 11 has proved to be exceptionally strong and durable in aircraft construction, even under wet or damp conditions.

CASEIN GLUE FORMULA NO. 4B [24]

Formula No. 11, as above specified but without the copper-chloride solution, represents an earlier stage of development, known as formula 4B. The mixing is the same as for formula No. 11, except for the omission of the copper-chloride solution. The glue has a medium consistency, excellent working properties, and a good working life. It falls somewhat short of formula No. 11 in water-resisting properties, however.

BLOOD-ALBUMIN GLUE—HOT-PRESS FORMULA [25]

Ingredients	Parts by weight
Blood albumin (90 per cent solubility)	100
Water	170
Ammonium hydroxide (specific gravity 0.90)	4
Hydrated lime	3
Water	10

Cold water should be poured over the blood albumin and the mixture allowed to stand for an hour or two without stirring. The soaked blood albumin can then be put into solution with a small amount of stirring. After the blood albumin is in solution the ammonia is added while the mixture is being stirred slowly. Slow stirring is necessary to prevent foamy glue. The lime is then combined with the smaller amount of water to form milk of lime. The milk of lime is added and agitation should be continued for a few minutes. Care should be exercised in the use of the lime, inasmuch as a small excess will cause the mixture to thicken and become a jellylike mass. The glue should be of medium consistency when mixed and should remain suitable for use for several hours. The exact proportions of blood albumin and water may be varied as required to produce a glue of greater or less consistency or to suit a blood albumin of different solubility from that specified.

PARAFORMALDEHYDE-BLOOD-ALBUMIN GLUE FORMULA [26]

Ingredients	Parts by weight
Blood albumin (90 per cent solubility)	100
Water	140–200
Ammonium hydroxide (specific gravity 0.90)	5½
Paraformaldehyde	15

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[24] This formula, developed at the Forest Products Laboratory, is covered by U. S. Patent No. 1291396, which is available for the free use of the people of the United States. BUTTERMAN, S. PROCESS OF MANUFACTURING WATERPROOF ADHESIVES. (U. S. Patent No. 1291396.) U. S. Patent Office, Off. Gaz. 258: 354. 1919.

[25] This formula, developed at the Forest Products Laboratory, is covered by U. S. Patent No. 1329599, which is available for the free use of the people of the United States. HENNING, S. B. GLUE AND MANUFACTURING SAME. (U. S. Patent No. 1329599.) U. S. Patent Office, Off. Gaz. 271: 48. 1920.

[26] This formula, developed at the Forest Products Laboratory, is covered by U. S. Patent No. 1459541, which is available for the free use of the people of the United States. LINDAUER, A. C. BLOOD-ALBUMIN GLUE. (U. S. Patent No. 1459541.) U. S. Patent Office, Off. Gaz. 311: 669. 1923.

The blood albumin is covered with the water and the mixture is allowed to stand for an hour or two, them stirred slowly. The ammonium hydroxide is next added with more stirring. Then the paraformaldehyde is sifted in, and the mixture is stirred constantly at a fairly high speed. Paraformaldehyde should not be poured in so rapidly as to form lumps nor so slowly that the mixture will thicken and coagulate before the required amount has been added.

The mixture thickens considerably and usually reaches a consistency where stirring is difficult or impossible. However, the thickened mass will become fluid again in a short time at ordinary temperatures and will return to a good working consistency in about an hour. It will remain in this condition for 6 or 8 hours, but when the liquid finally sets and dries, as in a glue joint, it forms a hard and insoluble film.

This glue may be used in either hot or cold presses. When cold pressed, however, it has only moderate strength, and for that reason is not to be depended upon in aircraft construction where maximum strength is required. If hot pressed, it is high in strength and very water resistant.

WATER-RESISTANT ANIMAL GLUE FORMULA[27]

Ingredients	Parts by weight
Animal glue	100
Water	225
Oxalic acid	5.5
Paraformaldehyde	10

The glue is soaked in the water until the granules or flakes have been softened. It is then melted at about 140° F. after which the temperature is allowed to fall to between 105° and 115°. The oxalic acid, in small crystals, and the paraformaldehyde, ground to a fine white powder, are then mixed together and added to the glue. The mixture is stirred until all of the oxalic acid has gone into solution, after which it is ready for use. The paraformaldehyde does not readily dissolve in the glue, and much of it remains as a finely divided solid during the working life of the glue mixture. A certain amount of agitation is, therefore, necessary to keep it evenly distributed throughout the mixture. The paraformaldehyde should be fine enough to pass through a 50-mesh sieve.

The paraformaldehyde for use in this formula should be of the slow-reacting type. A fast-reacting paraformaldehyde appreciably shortens the working life of the glue mixture.

If kept at a temperature not exceeding 115° F., the glue will remain in a fluid condition for 8 to 10 hours from the time of incorporating the paraformaldehyde and oxalic acid, after which it will set to a tough, firm jelly which can not be melted again. It is important to avoid heating the glue mixture much above 115° if a long working life is required. Organic decomposition of the glue will not seriously affect the quality of the glue at this temperature, since the chemicals used in its preparation act as preservatives.

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[27] This formula, developed at the Forest Products Laboratory, is covered by U. S. Patent No. 1712077, which is available for the free use of the people of the United States. HRUBESKY, C. E., and BROWNE, F. L. WATER-RESISTANT ANIMAL GLUE. (U. S. Patent No. 1712077.) U. S. Patent Office, Off. Gaz. 382 : 201. 1929.

Both oxalic acid and paraformaldehyde are poisonous materials and should therefore be handled with care.

This glue combines the desirable characteristics of an animal glue with a relatively high-water resistance. However, the water resistance varies directly with the temperature of the water to which the glued article is subjected. At room temperatures the glue is highly water resistant, but at 140° F. it is very low in water resistance. The joints should be conditioned for about two weeks at room temperature to allow the glue to reach its maximum water resistance.

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