A glue failure in South Africa

by Pat Beatty

On Saturday, 19th April, 1958 a Kranich built in Czechoslovakia in 1943, broke up in the air during aerobatics, the port mainplane fracturing at the extreme root immediately outboard of the main fittings.

The machine was flying at about the all-up weight limit, and at the time of the failure was (according to both pilot and passenger) under heavy positive G loading at the commencement of a loop at a speed of about 160 km/h. The air was comparatively smooth at the time.

Examination of the fractured main spar showed large areas of almost complete glue failure between the plywood webs and laminated booms, particularly near the root, and in one place a length of approximately 27 inches was completely clean, the boom being covered with the filled Urea Formaldehyde glue whilst the ply web was merely stained with hardener and otherwise clean.

From these facts, and from a careful examination of the fractures itself it was concluded that glue failure was the cause of the accident. There is no way of finding out the load that was imposed at the time of the failure and it is not therefore impossible that this load exceeded the safe limits. The stick force per G is so low, and the potential lift force so high, that it is felt that pilots often put on far more G than they intend for very short periods. The machine had been well maintained recently and (apart from the glue failure) was in good condition at the time of the accident. Examination other than by extensive stripping could not have revealed the state of the glue.

The machine had been in South West Africa from 1953 to 1955 and was probably subjected to high temperatures over this period. To try and find out how far the glue had deteriorated, test pieces were cut from the root end of the undamaged main plane and shear tests were carried out by the Forest Products Research Institute, Pretoria.

Method of Test

To make up the test specimens, a piece of wood (clean kiln dried sapele mahogany) was glued to the outer face of the plywood, thus forming a sandwich, with the plywood between portions of the laminated span boom and the freshly glued piece of wood. The specimens were then prepared and tested so that the stress was concentrated along the glue line between the plywood and laminated boom. As the outer ply grain direction was at right angles to the grain direction in the span boom, half the specimens were prepared and loaded each way.

Tests were also made of new glue lines made with Aerolite U. F. glue (unfilled) using original span booms and new birch plywood in order to get a «control figure» and of Casein glue in a 20-year-old Grunau Baby main former.

Analysis of Results

The results show that the strength of the original glue line had decreased to an average value of only 33 % of the probable new strength and the minimum value to only 21 % of the original minimum.

The strength of the 10-year-old Casein glue line was reasonably high, and indicated very little, if any, strength decrease from new. These results are even more remarkable considering the state this former was in. The original varnish had deteriorated away almost completely; there were unmistakable signs of water soakage; in parts, the timber had been severely crushed by over tightened bolts. Examination of the fractures after test also showed some abnormally thick glue lines. There was no significant decrease in strength of the U. F. glue used in this repair in 4 years.

Reasons for Deterioration of Glue Line Strength

The dangerous weakness of the original glue lines tested, could be due to any or a combination of several of the following:

(1) Poor original gluing. Unserviceable glue or hardened glue. Incorrect temperatures, insufficient time under pressure, etc., or the use of difficult to glue ("case hardened") ply.
(2) Decrease in strength due to shrinkage causing excessive stress in the actual glue line.
(3) Deterioration due to prolonged exposure to high temperatures.

Dealing with these possibilities in order:

(1) The possibility of poor original gluing is thought to be remote as the general standard of workmanship was very high. That case hardened or difficult to glue plywood was used is thought to be a possibility. One authority puts the percentage of aircraft plywood afflicted with this disease as high as 30 %. The causes of case hardened plywood do not appear to be completely understood but are thought to be partly caused by mechanical damage to the surface of the veneer during peeling; this damaged surface then impedes the elimination of water from the glue joint and prevents the glue reaching the inner walls of the wood cells, and so weakens any subsequent glue bond. Also a hydrophobic surface can be produced on the ply by the action of heat and pressure during manufacture. The existence of case hardened plywood was discovered in England in late 1937 or early 1938 and the sanding of all aircraft plywood as a cure was made obligatory by the British Air Ministry in 1942. It is interesting and perhaps significant to note that this "disease" was never noticed when Casein glues were used, before the advent of the large scale use of U. F. resins.

(2) It is obvious from an examination of the spar that shrinkage caused partial fracture of the glue line or timber adjacent to it. In a study of temperature and moisture content in wood aircraft wings, carried out by the Forest Product Research, Pretoria, over a period of a year, the maximum and minimum moisture content at the root end of a Miles Master Wing was 16.3 % and 2 % respectively. This moisture content change of 14.3 % would cause a volumetic shrinkage of approximately 5 % with a radial shrinkage of 2 % and tangential shrinkage of 3.5 % (these are very rough approximations, but are probably on the conservative side). The root end of the spar boom is approximately 3″ × 3″ in section, so the shrinkage across the face would be approximately 0.080″. In addition to this shrinkage, the separate laminations each shrunk a different amount depending on whether they are predominantly radically or tangentially cut, and this causes the surface to which the webs are glued, to change shape until it is like a series of spanwise hills and valleys.

When these facts are borne in mind it is remarkable that designers expect large wooden beams of this type to give satisfactory service.

(3) US Forest Service Report No. 1597, February 1944 (Study of temperature and moisture content in wood aircraft wings in different climates) gives details of temperature measurements in an Anson Wing exposed in the open at Tucson, Arizona.

The highest observed temperature was 215° F (on and under the top skin of the leading edge); a temperature of over 189° F was observed 10 times between July 23rd and September 20th, and a temperature of over 160° F on 6 out of 10 days in June. Similar researches carried out in Pretoria, South Africa, recorded a maximum temperature of 174° F. Now it seems generally agreed by the authorities on the subject that the U. F. resins will not stand up to prolonged exposures to high temperatures but the author of this paper has not been able to find any references to specific tests aimed at discovering what this limiting temperature is. In the USA where laminated timber beams are extensively used for barn roofs, etc., Casein is the commonly used glue and U. F. resins are seldom used, amongst other reasons, because of their suspected inability to stand up to the high temperatures experienced. It seems fairly certain therefore that the U. F. resins will not stand up to prolonged exposure to the temperatures it is possible to find in the hotter areas of the world, although they might be satisfactory in England or similar climates.

Brief Comparison of Casein and U. F. Resin Glues

The limitations of Casein glues are well known. Casein is not completely waterproof and is subject to deterioration when exposed to mould and fungus growths. But apart from these limitations Casein has many advantages:

(1) Casein glues have stood the test of time.

(2) The glue is strong and has good gap filling properties.

(3) It is simple to use and can be mixed and used in any temperature in which men work (providing it is above freezing point).

(4) It appears to be very reliable in use and to stand shock better than U. F. glues.

Summary

It is realised that these tests by no means prove the case against U. F. glues but it is felt that the arguments do cause a very disquieting doubt, and it is hoped that some institute equipped to undertake the work will thoroughly investigate the suitability of U. F. glues for service in all parts of the world. It seems most probable that such investigations have already been carried out because such world wide researches were made to ascertain moisture content and temperature in wood aircraft structures. It is also believed that some countries are still using Casein glues and it would be interesting to know if this is by choice or for some other reason. The matter seems to the author to be extremely important as the majority of the world's sailplanes are still being assembled with U. F. glues. Since both U. F. and Casein glues seem to have serious deficiencies it seems peculiar that some of the later developed glues are not being used. Resorcinol Formaldehyde, in particular, would appear to be exceptionally good in all respects. The Forest Products Research Institute, Pretoria, recently carried out tests over a 4 year period to find a glue suitable for the manufacture of laminated telephone pole cross-arms. In service these cross-arms are completely exposed and U. F. glues were not even tested as previous experience showed that this would be a waste of time. Even Phenol Formaldehyde glues were found to deteriorate very quickly and proved inadequate for the job. Resorcinol Formaldehyde was found satisfactory. These tests did not, of course, investigate the glue's gap filling properties or its shock resistance.