International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue III, March 2018- Available at www.ijraset.com

Adhesive Bonding in Aircraft Structures

Harshada M. Ahire [1], Sumit R. Singh [2]
[1, 2]*Department of Mechanical Engineering, Lokmanya Tilak College of Engineering, Kopar Khairane, Navi-Mumbai.*

Abstract: Adhesive bonding is a process of joining similar or dissimilar material. Adhesive bonding of aircraft has been in use for over 70 years and still in use on current aircraft projects as a direct alternative to riveting. The cost of different shapes and the size of rivets, screws, bolts and washer are more. To overcome this, adhesive can be used. Bonding of metallic honeycomb to skins for elevators, ailerons, tabs and spoilers and of stringers to skins for both fuselage and wing construction are the main uses for adhesives. This paper introduces the use of adhesive bonding on commercial aircraft and how the adhesive materials developed.
Keywords: Animal Glue; Synthetic Glue; Epoxy glue; Phenolic glue; Redux 775; Aluminum Alloys

I. INTRODUCTION

Adhesive bonding has been used in the manufacturing of aircraft wing structures and fuselage for over 70 years. It is used as an alternative to riveting for aircraft structures. The problem with rivets is that it does not get load transfer from one part to another evenly. It gets a relatively few number of points that move all the load. These rivet (holes) are where most fatigue cracks start. So when one makes a new design or repairs a design, make sure there is enough distance between the fasteners and that the metal doesn't tear out and also that there is enough distance between the fasteners and the edge of the metal. Adhesive Bonding is an excellent way to reduce the peak loads because loads are spread over large area instead of left fasteners. Adhesives eliminate the weight of thousands of rivets normally used in aircraft construction and did away with the risk of the holes through which air could leak while the cabin was pressurized at high altitudes. This is the reason why bonding was found to be superior in most situations. Adhesive bonding is used extensively in the fabrication of aircraft internal structures and providing the smooth surface for supersonic planes. It is widely applicable in fastening of stiffness to the aircraft skin and in assembling honeycomb structures in aircraft. Adhesives are applied on the surface of work piece by hand brushing, spraying, roller casting. Almost all solid material can be joined with adhesive bonding.

II. TYPES OF DIFFERENT ADHESIVE USED IN AIRCRAFT STRUCTURE

A. Animal Glue

Early aircraft were built almost entirely of wood with some steel cable to provide diagonal bracing. The glues used for bonding wood were based on proteins extracted from animal products such as bone, fish skins, blood or milk. These adhesives classified into two types:

1) *Assembly (or laminating)*- The more solid structures, such as propellers and curved frame members were prepared by laminating the solid pieces of timber between 3.0 and 15.0 mm thick, with all grain directions parallel to each other. Such structures are defined as "layers" [2] or “glued laminated structures”.
2) *Glues for plywood manufacture.*

a) *Collagen Glue;* The word Collagen is derived from Greek word Collapse means “Glue" and Gen means “Creator". They are also known as “Hot” glues. It is created by prolonged boiling/steam of animal connective tissue. These glues are formed through the process of hydrolysis of collagen from. It is similar to gelatin. These gelatin solution are the concentrated and dried to produced Jelly-

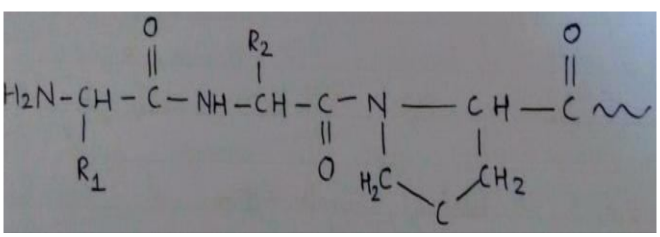

Fig 1. Structure attributed to gelatin

Like product from which constituent majorly as amino acid /polypeptide referred as Gelatin in Fig 1.The main disadvantage of this glues was the "Working time" was so short.

b) *Blood glues:* These glues are based on globular protein, albumen which are extracted from blood of animals. The glue is made either from fresh blood of slaughtered animal or from black soluble blood albumen obtained by processing the fresh blood. Albumen has molecular weight in the range of 20000-70000, is soluble both in water and dilute salts. Blood albumen glue is highly water resistant. Due to this, blood albumen glue becomes the primary adhesive system for the preparation of plywood until ousted by the Togo phenol-formaldehyde (P/F) system on the early to mind-1930s.

3) Casein Glues: Casein glue is made from milk protein. They are also known as to be very strong over a long period of time. It is water resistant

.During the First World War, due to lack of improving in engine power, the weight of aircraft had to be reduced to improve their speed and performance, adhesive bonding was key in being able to achieve this. It was used extensively in assembling of early wooden aircraft (World War 2 Fighter Aircraft) Casein has a micelle structure, which consists of sub-micelles linked through Ca9(PO4)6 moieties as is shown in Fig 2. The main disadvantages were that the pressing times were long but this situation could be alleviated by submitting them to a hot cure. Further, the glue lines in the bonded structures were readily attacked by acidic-, alkaline-

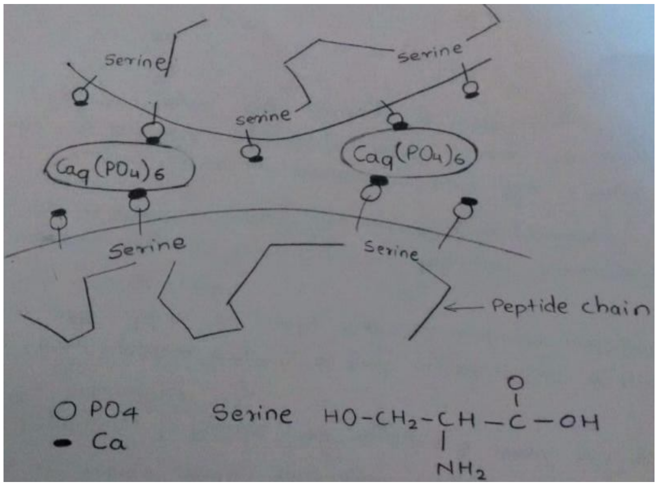

Fig 2. Structure attributed to casein micelles

or enzymatic-hydration. This occurrence led to many observations of fungi spores being seen in early aircraft. If the pilots could detect the smell of sour milk it means aircraft structure was about to fail.

B. *Synthetic Glue*

Synthetic Adhesives have been successfully used in aircraft industry. The use of this glue become almost universal in early 1940s in aero plane construction.

1) *Urea-Formaldehyde:* Urea-Formaldehyde is a non-transparent thermosetting resin/ polymer. It is a two-component system consisting of resin and hardener which were applied to different substrates. Hardeners mostly being acids or compounds, which would react with resin and release acidic species. Thus lowering the pH and initiating cross linking reaction. Upon closing or heating the joint, curing was accelerated producing infusible hard solid providing excellent esistance to cold and humid conditions. However it succumbs to warm and acidic conditions undergoing hydrolysis. Also it lacked gap filling properties thus thick film of adhesive was extremely brittle and crazed easily. Use of fillers solved the crazing to some extent but it still persisted. Formic acid being used as a hardener, add cellulosic fillers and an aliphatic or alicyclic alcohol to the resin and cure with thiocyanic acid released from the ammoniumthiocyanate hardener. Aerolite is still the used due to its ability to repair successfully structures that were previously bonded with casein glues. After the war the use of U/F adhesives persisted, particularly with gliders, jets age in the production of air intakes, having multi-curvature design, was only possible through bonded wooden laminates and the trailing edges and control surfaces of wing.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue III, March 2018- Available at www.ijraset.com

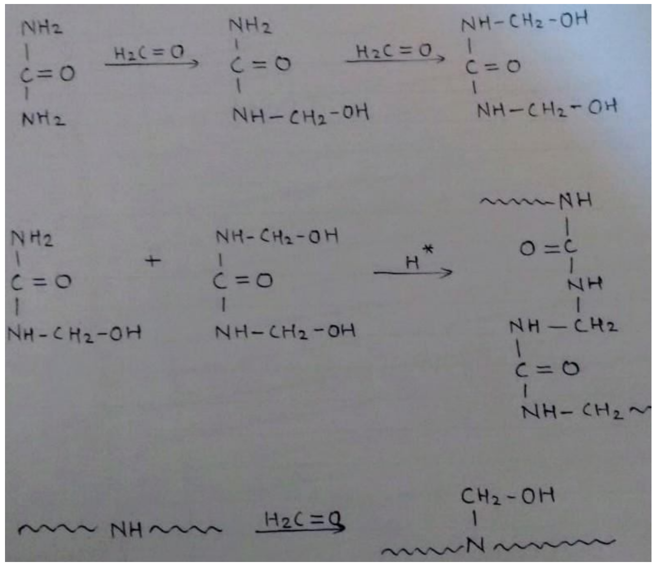

Fig 3. Reaction of urea-formaldehyde resin

2) *Phenol Formaldehyde:* Phenol formaldehyde resin (PF) is a synthetic polymer produced by the reaction of phenol and formaldehyde.PF is highly cross-linked and this makes the cured resin, hard, thermally stable and highly chemically resistant and waterproof. It reacts with natural phenol-like lignin found in wood to improve glue to wood bond to make superior wood adhesives. It has been around for long enough to have proved itself over the long term. The uncured resin is toxic and needs pressure and heat to cure. It's expensive and not a very good gap filling material.
3) *Resorcinol Formaldehyde:* Resorcinol-Formaldehyde is produced by natural resin with potassium hydroxide, or by synthetic methods. It is waterproof, chemically stable, has wide range of working temperatures and humidity conditions. It meets necessary strength, reliability and durability requirements for aviation industry. It is used as adhesive for oak and oily woods. However, joints and laminations must be tightly clamped. It has poor gap filling capacity. It has a short shelf life of about one year and is sensitive to temperature when uncured. Curing process takes about 10 hours and it's toxic and irate skin and eyes when uncured.

C. Epoxy Glue

Epoxies are formed by polymerization of the hardener and resin. Here, the resin when combined with a specified catalyst initiates curing (exothermic reaction). Epoxide groups of the resin and the amine groups of the hardener form covalent bonds resulting in cross-linkage of the polymer thus providing rigidity and strength. It is used to join both metals and non-metals. They suit a range of different applications, materials and operating conditions. Their properties are based upon the specific chemistry of the system and the type of cross-linking. Varying temperature and pressure while curing and choice of resin and hardener compounds varies mechanical strength, thermal, electrical and chemical resistance.

D. Phenolic Glue

Phenolic resins are produced by condensation of phenol and formaldehyde as liquid compositions and films. They can with stand high temperatures under load and severe environments and can resist deformation and creep thereby maintaining structural integrity and dimensional stability. Phenolic resins are of two types:
1) *Novolacs:* They need a cross linking agent to polymerize as they are not reactive.
2) *Resoles:* These resins contain reactive side group and are self-curing.

The curing process requires heat and pressure. Also, adhesive releases water during curing which would be present as vapor and pressure prevents foaming. Hexcel Composites Redux Film 775 is metal-to-metal adhesives used for major structural build applications. It is prepared from a thermosetting liquid phenolic resin and a thermoplastic powder, polyvinyl formal (PVF). The PVF acts as a toughening agent. Liquid and powder technique is used where, phenolic resin is coated onto the surfaces and the PVF powder is sprinkled upon them, followed by bonding in a hot press.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue III, March 2018- Available at www.ijraset.com

E. Redux 775

Redux 775 used in the manufacturing of aircraft was the words first metal-metal bonding process. Aircraft wings were expected to carry very high tensile stresses in flight and to ensure it is strong enough to with stand these loads without increasing weight, aluminum stiffeners were redux bonded to wooden components in the wing ribs, spar booms and stringers. Redux 775 was painted onto the substrate to be bonded and was then covered with polyvinyl acetyl, a high molecular weight polymer in powder form. Adhesives based, particularly, on phenolic, epoxy, polyimide and now cyanate ester chemistries which have been tailor made for the various applications within the aircraft industry and, in the last few years, for space applications. These adhesives impart, as required, a combination of toughness, thermal resistance and Durability to the bonded joint. The typical application process for Redux Liquid and Powder, which is still valid today.

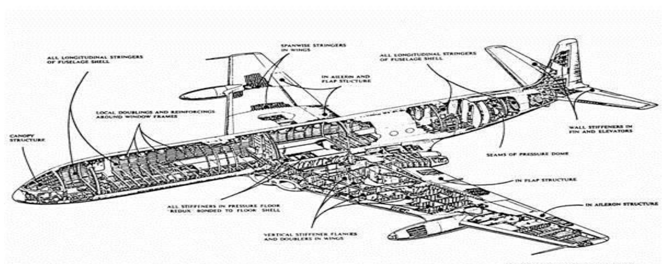

Fig 4. Adhesives used in the de Haviland Comet aeroplane [6]

III. WHY THIS BOND?

Rivet and bolt holes act as stress concentrators. Weight reduction

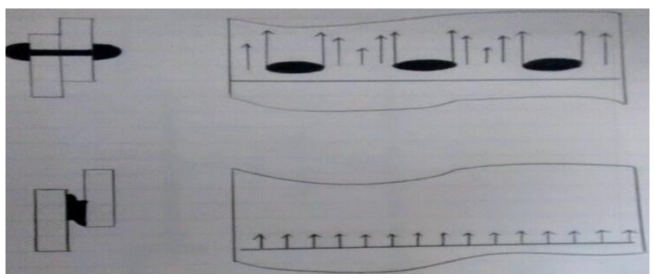

Fig. 5 Stress concentration in riveted and bonded joints

using "hollow", preformed stringers, honeycomb sandwich structures, using thinner gauge metal can be made possible through the use of adhesives. Also it increases in fatigue life and sonic damping. Bonded joint avoids areas of high stress concentration and provides a uniform stress distribution across the bond.

Absorbing acoustic energy thus reducing high frequency noise propagation. The bonded joint can be seen to withstand many orders of magnitude more cycles. Bonding also improves the overall stiffness of the final structure when compared with a riveted component of the same pitch between points of joining. Riveted joints are susceptible to a tearing failure. When rivets enter the skin, tensile load across the joint is maximum and can cause failure by tear/crack formation if the substrate is thin. Bonding eliminates the failures. Bonding technology within components eliminates the bearing stresses and minimizes the chance of premature failure.

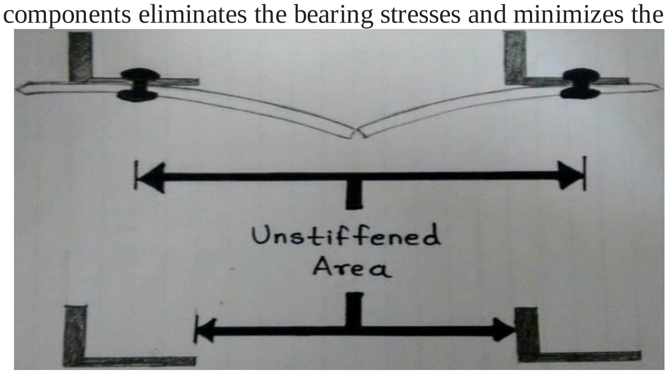

Fig 6.Effect of riveting and bonding on the aluminum skin.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue III, March 2018- Available at www.ijraset.com

Adhesive bonding reduces production costs and time as entire component can be assembled and bonded in one operation. Also, jigging required is often simpler, resulting in quicker assembly. The ability to join dissimilar materials.

Fig shows helicopter rotor blade sections where adhesive bonding is used to produce components from carbon and glass composites, aluminum and Nomex honeycombs and simple "plastic" foams.

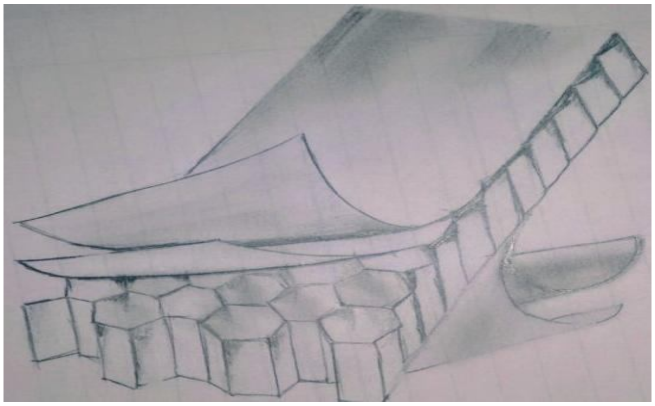

Fig. 7 Bonded honeycomb sandwich

IV. TYPES OF ADHESIVE JOINT

Adhesive joints are subjected to both tensile and shear loads Universal testing machine and computational analysis is used to determine Stress and strength of various joints. Structural adhesives when used properly, can replace welds, rivets and bolts providing better results.

A. Single Lap joint

It is a joint made by placing one member over another and bonding them together. Single lap joints are mostly used to study the lap shear strength of adhesive joints

B. Balanced Double Lap Joint

It is a joint made by placing two supporting members on the both faces of the joint, such that they overlap the faces of joint on both sides. Double lap joint offers more shear strength than single lap joint. Double lap joint is recommended to the structure where shear failure of the structural components occur.

C. Unbalanced double lap joint

It is a joint made by placing one supporting member on the either face of the joint. It provide low shear strength than double lap joint.

D. Scarf joint

Joining two members end to end. It is used when the material being joined is not available in the length required.

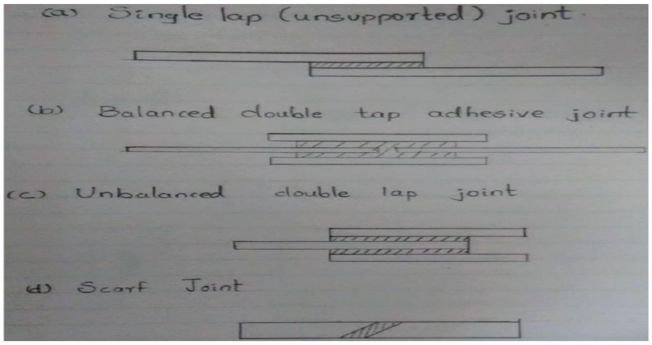

Fig. 8 Types of joints

V. SURFACE PREPARATION

For adhesive bonding, clean and dry surface is required as adhesives stick to surface which is to be bonded. Very few adhesives penetrate through contaminants to provide a bond. Dry porous materials are easy to bond whereas Non-porous surfaces should be degreased, dried, roughened, sandblasting, and etching if required. Prior to bonding, proper care must be taken like wearing cloves so as to avoid contamination due to fingerprints, body oils, or substandard degreasing or chemical solutions, etc. of the surfaces to be bonded. Bonding of surfaces should be done as soon as possible upon completion of any pre-treatment procedure. Depending upon the quality of bond required, three pre-treatment procedures are listed by increasing procedures:

A. Only degreasing
B. Degreasing, abrading and degreasing again
C. Degreasing and chemically pre-treat

Bonding surface should be perfectly clean, free of oil and grease. Degreasing should be performed on all surfaces. Abrading using sandblaster, wire brush, emery cloth, and or glass paper improves adhesion. Stripping of painted surfaces need to be done prior to pre-treatment for better adhesion. Chemical or electrolytic pre-treatment are used for superior adhesion.

VI. BONDING OPERATION

For metal bonding, mostly welding and fastening with the help of rivets and nut-bolts are used. But, adhesives are also used now-a-days particularly for joining dissimilar material, avoid distortion, discoloration, drilling or weld worms. Bonding aids even stress load over bonded surface.
A small adhesive dispensing gun can be used for small operations and facilities that rely on manual processes. For, mass production, automated dispensing and for smaller operations, semiautomatic equipment is sufficient. Clamps, fixtures are also used in bonding operations.Hot bonding is carried out in large autoclaves although some hydraulic steam heated presses are still used.

VII. ASSESSMENT OF BOND QUALITY

Common tests used to assess individual bonded panels are lap shear test and peel test pieces.
Lap Shear helps in determining the shear strength of adhesives
for bonding materials when tested on a single-lap-joint specimen. It is applicable for determining strength of adhesive, parameters of surface preparation and environmental durability of adhesive. A peel test is used for substrates bonded using adhesive eg. T-peel, 90 degree peel, and the 180 degree peel. Adhesive strength may be defined as the stickiness of a material. It is a measure of the resistance to separation once after application of adhesive. The result thus obtained is then used to analyze the strength of bond for a particular application. The component tests are made from the same material used in the bonded structure and several different test configurations could be required to represent the variation in material thickness or bond lay-up. These are assessed by straight pull off and by tensile lap shear testing.

VIII. STRENGTH OF BOND

Gluing metals together with a strength which brings this method of joining materials into competition with riveting, at least in the thin gauges used in the aircraft and motor industries. This has already revolutionized the woodworking industries by providing superior quality of the resulting products and the increased rate of output made possible by the intrinsic high speed of setting of synthetic adhesives aided by such novel methods as heating with high frequency, infra□red, etc. Prior to gluing, sufficient data to compute the strength of the joints required should be available. According to Aero Research Ltd. in “the joint factor” which is defined as the square root of the thickness of the sheet divided by the length of the overlap.

IX. DURABILITY

A general objective of most durability tests is to provide confidence in the long-term performance of a bonded structure. Uncertainty over durability of adhesive bonded joints prevents the use of adhesive technology in many industries. Suitable NDT techniques should be used to correlate the results of systematic periodic inspection of existing bonded structures with accelerated laboratory tests. Information from such a program could then be used to assist in the design of structures having the optimum economic balance between performance and durability. Bonded assemblies whilst others are merely required to resist minor fluctuations in service environments for short lifetimes. With these factors in mind it may be appreciated that large numbers

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue III, March 2018- Available at www.ijraset.com

X. CONCLUSION

In Conclusion, adhesive bonding is now practiced on a larger scale some of it includes impact loading, aviation and marine industries. Modern adhesives are more durable and ductile thus working in impact loading conditions as well,
thus, the engineering of adhesives, its types methods of evaluation and preventive measures are becoming important.

REFERENCES

[1] Dixon D. Prediction of lap shear and peel strength adhesive bonds, and update on results of accelerated environmental testing BAe Sowerby Research Centre, Report No:JS 13729, May1997
[2] British Standards Institute, BS EN 312-2: 2000, Plywood ~ Classification and Terminology ~ Part 2: Terminology.
[3] “Glues used in airplane parts” by S.W. Allen and T.R. Truax Bonded Aircraft Structures, Papers given to a conference in Cambridge, UK. Bonded Structures Limited (1957)
[4] Hussey, B., & Wilson, J. (1996). Structural Adhesives Directory and Databook. Chapman and Hall, London.
[5] Hexcel Composites Limited (2000). Redux Bonding Technology
[6] Aero Research Technical Note, The structure of the DeHavilland
[7] Comet bulletin No. 165, Hexcel Composites Duxford
[8] Aero Research Technical Notes (1960). The Durability of Aerolite 300, Bulletin No. 205, January.