A Methodological Study for the Stress Analysis to Evaluate Single Lap Adhesive Joint

Sagarsingh Kushwah¹, Meet Bhatt¹, Chirag Desai¹, Shreyashkumar Parekh¹ and Poojan Joshi¹

¹ Department of Mechanical Engg, R. N. G. Patel Institute of Technology, Bardoli, Surat, Gujarat, India
sagarsinghkushwah123@gmail.com

Abstract. The use of adhesive bonding is increased in load-bearing applications in place of conventional joining techniques such as bolted or rivets joints. The high-stress concentration occurs at the end of an adhesive-bonded lap joint so all failures begin at the end of the overlap region and get fractured in the end. The single-lap adhesive-bonded joint was used in the current study to examine the peel stress and shear stress results along the overlap region. The comparison of the analytical and experimental result was made to validate the results along with it the load vs displacement curve was obtained from results. Also, stress vs strain curve and peel stress vs overlap length of the one mm thickness of testing specimen was obtained.

1. Introduction
In various applications such as the marine industry, aerospace, cars, trains and civil constructions, adhesive bonding is utilized as a load-carrying joint in structural jointing. Single lap adhesive joint offers many benefits, such as saving time, economizing costs, good damping properties and very high strength in comparison to other conventional joining processes. The load is transmitted smoothly from one plate to another through an adhesive in this joint. An adhesive is a material that binds two or more separate materials together and resists their separations when applied to one or both surfaces [1]. The use of adhesives offers many advantages like less stress concentration, uniform stress distribution, less weight, and ease of manufacture compared to mechanical fastening. It also improves the aesthetic design as well as ergonomic design. The adhesive joint is more widely used over mechanical joints to connect structural components due to more uniform interfacial stress distribution and resistance towards fatigue failure. In various types of joints, structural adhesives are used. The adhesive joint commonly used is illustrated in Figure 1. Among these is the simplicity of the single-lap adhesive joint. The adherent can be a composite with either metal or fibre. A single lap joint is the most common and diverse research is conducted to analyze its strength and characteristics.

Ahmed, E. and Tehami, A. showed that adhesive thickness, curing conditions, adherend thickness, bond length, and joint end geometry are the factors that affect the strength of the adhesive bond [2]. The sizes of the area to which the adhesive is applied and the adhesive used are factors that determine the applications of various adhesives. The adhesive can be applied to either one material or both of the materials being bonded. Shiuh-ChaunHer reveals that in adhesive bonding, the parts are aligned and pressure is applied to assist in adhesion and to eliminate the air bubbles. The applying tools for the adhesive are brushes, rollers, spray guns, applicator guns using pellets. These can be operated either manually or automatically [3].
The wide applications of composite materials are spacecraft, solar reflectors, satellite structures, radar, rocket engines, etc. A defined degree of anisotropy in the properties of the laminate varying fibre orientation. It is also used in bearing material, pressure vessels, electrical devices, truss members, etc. CRPF is used extensively in Formula one [4].

2. Literature Review

For the determination of the mechanical properties of various adhesives, the single-lap adhesive joint is used as a standard test model. The single-lap adhesive joint is also widely exploited in various applications due to its characteristic’s property of efficiency and simplicity.

In the past few years, many researchers investigated the stress analysis of a single lap joint. A variety of studies have been performed on mathematical modelling and stress analysis of adhesive lap joints. Nabil M. Chowdhury has shown that the difficulty of the mathematical model is high, so the solution is performed either numerical or analytical methods. In adhesively bonded joints, the calculation of the stress distribution can be done by various analytical methods [5]. X.Q. Zhang has shown that the analytical approach has been found difficult due to its geometry and complex nonlinear function of material property. Several simplifications and assumptions are made in a wide range of developed solutions [6].

Volkersen method was the first analytical method used to calculate the stress analysis of bonded joints which was introduced in 1938 by Volkersen. This approach describes the principle of differential shear. Volkersen didn’t consider the bonding effect because of the eccentric load path [7].

Further research has been carried out by Goland M. and Reissner E. in 1944. The effect of rotation of adhered was initially considered by them. The problem was further divided into two main sections. (1) By applying the principle known as finite deflection principle, applied to bent plates which are cylindrical in geometry, the measurement of joint loads at the edges has been carried out, and (2) Due to the impact of the applied loads, the determination of joint stress has been carried out [8].

In 1973, adhesive plasticity was considered by Hart-Smith, L. J. The problem was further divided into four parts. The determination of bending moment $M$ was the first step. The effects of the bending stress on the strength of the adherents are considered in the second stage. In the third step, an analysis of the adhesive shear stress distribution can be carried out using the elastic-adhesive formulation. The problem of peel stress is addressed in the fourth final stage [9].

Ojalvo I.U and Eidino H.L. gave a new model based on the Reissner and Goland model. The modifications were made by them in the shear stress equations by modifying certain coefficients which considered the new boundary conditions for bonded peel stress calculation, together with the addition of new terms in the differential equation. The prediction of the variations in shear through the thickness of the bond was the main work done [10, 11].

According to the literature review, it reveals that the researchers have carried out most of their work on various lap joints, which are bonded to single adhesives. The overlapping area is the focus of the lap joint analysis. The prime factors for the failure of the lap joint are shear and peel stress. The adhesive is applied in different industries due to its favourable mechanical properties, resistance to chemical and atmospheric conditions, and low weight. The application of adhesive makes it possible to obtain construction materials with high stiffness and strength.
3. Problem Definition
A standard bonded single lap joint is taken into account for the initial study. This lap joint is made up of various analyses. Two identical adherents were taken which were of uniform thickness. They were bonded to the adhesive, which also had a standardized thickness. The thickness and is considered for upper and lower adherents. Figure 2 demonstrates the modelling of the overall geometry of the joint.

Figure 2 Geometry of Single lap Adhesive Joint

| Symbol | Single Lap Joint Parameter | Value |
|--------|-----------------------------|-------|
| $t_1$  | Upper Adherend thickness    | 1 mm  |
| $t_2$  | Lower Adherend thickness    | 1 mm  |
| $\eta$ | The Adhesive thickness of a single adhesive model | 1 mm |
| $\alpha$ | Length of adherend without overlap region | 100 mm |
| $2l$   | Length of Overlap           | 30 mm |
| $F$    | Applied load                | As per the result |

The aim of using adhesive is to maximize the strength and minimize the stress concentration of the joint. An attempt is made to provide simple as well as accurate solutions in the adhesive region to determine the peel stress and shear stress. For the particular lap joint, load values have been evaluated to study the behaviour of a single lap adhesive joint. After that, the value of shear and peel stress value can be obtained using numerical solutions through two-dimensional finite element analysis.

4. Material Selection & Methodology
Typically, aluminium, epoxy, FRP and steel, etc. are generally used for a single lap joint. In the present work, epoxy is selected as it has a wide variety of applications in the automobile industry and aerospace engineering. There is a range of thickness is available, but the thickness of 1mm with a length of 130 mm is taken at present work. The Laser cutting operation is carried out to prepare fibre epoxy. Two specimens of fibre epoxy having an identical dimension of thickness 1mm, width 25 mm, and length 130 mm used for making adhesive joints.

Table 2 Material property of composite material

| Adherend Material | Young Modulus (E) | Poisson Ratio (v) |
|-------------------|------------------|------------------|
| Fiber Epoxy       | 101.97 GPa       | 0.6              |

For adhesive work, both adhesives (epoxy) should be selected from each other. Araldite is selected as adhesive because it has wide application in the field of automobile and engineering components. Araldite gives a resilient bond. The key properties of Araldite are high shear strength and peel strength, good temperature resistance, and toughened paste.

Table 3 Materials properties of adhesive

| Adhesive Material | Young Modulus (E) | Poisson Ratio (v) |
|-------------------|------------------|------------------|
| Araldite          | 4.89 GPa         | 0.35             |
The specimen preparation involves the Epoxy sheet which is cut by performing the laser cutting operation. The dimensions should be as per requirement i.e., 130*25 mm as shown in figure 3. The Dogbone is prepared by the same sheet by laser cutting operation as shown in figure 4.

![Figure 3 Fibre Epoxy Sheet](image1)

![Figure 4 Dogbone Specimen](image2)

The model typically used for tensile specimens is a dog bone form specimen in accordance with the EN ISO 527-2 standard, which is demonstrated in figure 4 [12, 13].

The Universal Testing Machine based on the present work is having a capacity of 100 tones. For the determination of the young’s modulus, the testing speed usually used is 1 mm/min but for failure testing higher-rated can be used. To determine the stress-strain curve, the load and displacements are measured. The procedure of testing is accompanied by grasping the specimen in the longitudinal direction until failure. A specialized fixture is used to grip the specimen in the longitudinal direction as the size of the specimen is too small and it is relatively easy to use for the measurement of adhesive displacement. However, if possible then it is recommended to use a non-contact device to avoid any kind of interference. Setting the appropriate requirement for the machine is necessary for further processes. After that, start the test after feeding all requirements until the specimen breaks. Remove the specimen from the gripper after completing the test. The output data like load-displacement values should be taken into account [14-16].

5. Experimental Result
The result for Dogbone, for the material Fiber epoxy peak load value, reaches up to 460N. This analysis would also use both an analytical and a numerical model to assess the effects of peel and shear stress.

![Figure 5 Stress vs Strain curve of a testing specimen](image3)
For testing specimen, the Stress vs Strain curve has been shown in figure 5. The specimen’s thickness was 1.0 mm. The Result of the specimen, as shown in figure 6, for the adhesive Araldite peak load value, reaches up to 5021.05 N, which is shown in the load vs displacement curve (Figure 7). This analysis would also use both an analytical and a numerical model to assess the effects of peel and shear stress.

![Figure 6 Tested specimen of single lap joint](Image)

![Figure 7 Load vs Displacement curve](Image)

From the above graph, the peak load value is 5021.05 N for 1.0 mm of thickness.

6. Validation of Shear Stress & Peel Stress Results:
In a single lap adhesive joint, the distribution of shear stress along the overlap joint is shown in figure 8. It has been found that the occurrence of shear stress is maximum at the free end of the adhesive region that is near to the adherend. The shear stress is maximum at both ends, whereas in the middle of the adhesive there is a decrement of the shear stress. In the case of finite product, the differential shear is more at the edges under loading conditions, such that the stress distribution is not symmetrical in both the right and the left interfaces.

![Figure 8 Shear stress vs overlap length (1 mm thick)](Image)
The experimental results are compared with the analytical results (Appendix A) in figure 9. The deviation between both curves occurs due to various errors caused by personal bias. The graph of Peel stress vs Overlap Length for 1.0 mm adhesive thickness is shown in figure 10.

7. **Conclusion**

It is noteworthy that the critical factor responsible for the design of the lap joint is shear stress. During the present work, analytical and experimental results indicate the accuracy of work has been compared. The thickness of the adhesive must be improved or optimized to enhance mechanical stability and increase the resistance to mechanical stresses. The increase in adhesive thickness allows the residual shear stress to decrease. Whenever the thickness of the adhesive increases the residual stress decreases.

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Appendix A

clear all
clc
%---------------------------------------------
% Input Data
%---------------------------------------------
ei = 101970;
e0 = 101970;
ti = 1;
t0 = 1;
l = input('Enter the value of overlap length: ');
x = -l:0.1:l;
P = 5021.05/19;
etal = 1;
E = 4890;
mu = 0.35;
G = E/(2*(1+mu));
%---------------------------------------------
y = sqrt((G/eta)*((1/(ei*ti))+(1/(e0*t0))));
a = (P*y)/2;
b = (ei*ti - e0*t0)/(ei*ti + e0*t0);
tau = a*((cosh(y*x)./(sinh(y*l)))-b*(sinh(y*x)./(cosh(y*l))));
figure(1)
plot(x,tau);
xlabel('Distance Along Overlap (mm)')
ylabel('Adhesive Shear Stress (MPa)')

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