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Adhesively Bonded Single Lap Joint(SLJ): A Review

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Abstract. The utilization of adhesive joints has expanded quickly in past decades. Driven by the developing interest for light weight structures, composite adherends have expanded in prominence, profiting by their high explicit mechanical properties and design tailorability. Adhesive bonded joints have been generally utilized for composite materials as a fundamental option in contrast to regular mechanical joint structures. The Essential goal of this survey is, to research the impact of contrasting parameters like adherent thickness, thickness of the adhesive and overlap length at the breakdown mode of connection with dissimilar components. To inspect the stresses in the adhesive and to anticipate the quality of the joints, Lap joint speculations for adhesive bonded single lap joints have made. Single lap adhesive joint offers numerous focal points, for example, efficient, cost sparing, great damping attributes, high quality when contrasted with other regular joining process.

Keywords: Adhesive joints, Single Lap Joint(SLJ), Cohesive zone models, Stress distributions.

1. Introduction

Adhesives have been utilized for a huge number of years, yet until century back, the tremendous dominant part was from natural items, for example, flora, milk, cartilage, fish and membrane. In consideration around 1900, engineered polymers which are dependent on adhesives is represented. The numerous modern employments of sealants and adhesives came into existence. It is difficult to imagine an item in the industry, in the home, or anyplace.

Over traditional mechanical fasteners, reinforced adhesively joints is spreading option in contrast to mechanical joints in construction of applications along with give numerous points of interest. It will give progressively invariable stress diffusion by the side of reinforced region whichever empowers to undergo greater stiffness and transmission of load, lessening the mass what's more, in this way the expense.

Without any unfavorable clash on the limit of heap bearing, bonded joints are much of the time expected to support steady or periodic loads for magnificent periods of time. Tendency to overdesign the structures of composite took place in the absence of appropriate material selection and failure criteria. Security contemplations regularly need that adhesively bonded structures, the particularly utilized in fundamental load-bearing operations, incorporate mechanical latches as a bonus of wellbeing insurance.

The above habits bring about bulky and all the additional lavish parts. An improvement of solid idea and visionary procedures needed for outcome in progressively proficient utilization of composites and adhesives. In order to ground plan structural joints in building framework, it’s important to have the option for investigating them. It implies us to decide strains as well as stress for a given loading, to anticipate the likely purposes of lack of success. Essential numerical methodologies, considering examinations of adhesively bonded joints are numerical as well as analytical method.

2. Materials, Testing and Results:

Anyfantis et al. (1), conducted the experimental studies on the thick varying adherents of adhesively bonded single lap joint (SLJ). With reference to the varying materials he studied the numerous factors which causing the breakdown of joints due to failure load and mode of failure for the different conditions as varying the thickness of the adhesive, varying the thickness of the adherents and also varying the overlap length. He considered the structural adherent materials as mild steel and carbon fiber reinforced polymer (CFRP). Took seven SLJ specimens for the manufacturing as well as for trials. Conducted testing and inference were made based on the force displacement and force strain readings concerning with robustness of joints and firmness of the joints.

Sahoo. P.K. et al. (2), Mathematical and quantifiable non-linear finite element analysis antiquated done for composite-metal adhesively reinforced joint after assessment example mathematical as well as survey. Composite-to-metal joint with two dimensional ennoblement of plane stress has done with Redux 319 A as adhesive. Materials used for metal is Al - 2024 - T 3 and composite CFRP T 300 / 914 C utilized in the analysis. The laminate of composite is made out of 10 layers having width 0.15 mm succeeding stacking sequence $[+45/-45/0/90/0]_S$. Utilizing two dimensional plane stress Quad four elements the finite element models have been generated. Due to failure load of adhesively bonded lap joint between metal-composite adherends is anticipated utilizing material nonlinear finite element and mathematical approach. The joint of indistinguishable design failure loads was accessible with exploratory application. The arithmetical forecast is inside 7 percentage of the exploratory outcomes in addition to be viewed as good. The capacity to anticipate the failure loads to a level of exactness altogether lessens the requirement for over the top costliest testing exercises. It's prescribed that the metallic holding surface be coarseness impacted in the course of surface readiness so as to have more quality just as inability to happen in adhesive material.

Toshiyuki Sawa et al. (3), Tensile load is applied to single-lap adhesive joints of dissimilar adherends which are broke down as a three body connection issue utilizing the two dimensional hypothesis of elasticity. In the numerical estimations, the impacts of modulus of elasticity proportion in the middle of various adherends, the proportion of thickness of adherend, the proportion of the adherend lengths, as well as thickness of adhesive on the proximity stress disseminations at the coherence are analyzed. Therefore, it's discovered that 1. The singularity of the stress happens close to the corners of blend as well as it increments at the border of the interface of an adherend with little tensile modulus 2. Pressure uniqueness increments at the border of the assemblage of an adherend with more slender width. 3. Solitary tension increment at the border of the two coherences as the proportion of the top adherend magnitude to the reduced one declines and 4. Particular tension raise at the borders of the two assemblages as the thickness of adhesive diminishes when the adhesive is sufficiently dainty, and they additionally increment as the adhesive thickness increments when the adhesive is heavy enough. Furthermore, particular burdens got from the investigation is contrasted. Pressure estimation and Finite element analysis (FEA) was completed. The systematic outcomes are in genuinely acceptable concurrence was deliberate along with FEA outcomes.

L.D.R. Grant et al. (4), For the manufacturing of car body shells mainly mild steel will be the adherend and toughened epoxy will be the adhesive. A series of experiments were conducted based on different loadings and finite element analysis was done to determine the effect of structural adhesive rather than spot welding. Different parameters were inspected like bondline thickness, overlap length and spew fillet. Pure bending, three-point loading and tension test was conducted on the lap joint. They came to conclusion that three-point bending and tension loading are the same in which they affect the adhesive whereas four-point bend test does not cause failure since the steel yields before the joint fails.

Lucas F. M. et al. (5), evaluated the effect of different thickness of adhesives like 0.2mm, 0.5mm and 1mm, on the strength of single lap joints by selecting different types of adhesives like AV138, EA9361, and EA 9321. The experimental results show that as the adhesive thickness decreases lap shear strength increases, and as the toughness of adhesive increases the lap shear strength also increases. For predicting the lap shear strength, they used Taguchi method and for the effect of adhesive thickness on the lap shear strength is elaborated by the stresses of adhesive and adherend interface. In order to determine the failure load, they used progressive damage model with respect to the interface elements.

Xiaocong He et al. (6), Investigated the development in finite element analysis of adhesively bonded joints and mentioned about the recent development in the application. Finite element analysis has the capability to choose different parameters and helps to find suitable one for the joint manufacturers. It will help the manufacturers to choose suitable properties of material or geometry by performing man test simulation that would reduce the cost in practical.

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Phil Yarrington et al. (7), Conducted experiments and analyzed using Hypersizer software which has the compatibility of finding the stresses and size optimization of composite as well as metallic structures. It has the ability of computing the adhesive stresses detailed about in-plane stress and out of plane stresses in the adherends. They investigated the cause of failure of bonded joints and also validated their predictions. In order to get accuracy against the test data they compared the results against many failures bonded joint theories. Fourteen test instances were taken with respect to three non-similar joint configurations and the ratio of failure load predicted to the average test failure load which ranges from 0.77 to 0.95 and they concluded that the Hypersizer software is relatively accurate and agreeing for the initial failure prediction.

Hai Huang et al. (8), A logical model was made to choose the anxiety transports of single-lap adhesive fortified composite joints under pressure. Both the adherend and the Adhesive were acknowledged direct flexible in the surmising's. The Laminated Plate Theory was used in describing the mechanical lead of the composite adherends, while the straight versatility hypothesis was applied to depict the material response of the Adhesive. Therefore, the worries in the Adhesive can change through the bondline thickness. After the general course of action of overseeing conditions was directed by vitality technique, it was disentangled by using an emblematic solver—Maple with reasonable limit conditions. Results from the systematic model were affirmed with limited component examination using business programming ABAQUS. Single-lap composite joint assessments were driven after ASTM D3165, Quality Properties of Adhesives in Shear by Tension Stacking of Single-Lap-Joint Laminated Congregations. In spite all of the three failure strategies for fortified joints, substrate, firm, and Adhesive failure, were accessible as the exploratory results, the substrate failure mode was the critical disappointment mode viewed. In this manner, just substrate failure mode was ruined down using the made model in the present paper. Four failure criteria, Tsai-Hill failure criteria, Von Mises failure standard, most extreme interlaminar tractable pressure basis, and greatest ordinary pressure foundation, were used to relate the anxieties and failure load. Nonlinear relapse was directed to choose the significant parameters in the failure criteria. Taking into account the preliminary outcomes, thicker bondline realize increasingly delicate joints. The assortment of the failure load for joints with various bondline thicknesses was consistent with the foreseen results.

Jose M Arenas et al. (9), the goal of this paper is to break down the impact of the adhesive thickness on the mechanical conduct of the joint and, by methods for a statistical analysis dependent on the Weibull distribution, propose the ideal thickness for the adhesive consolidating the best mechanical exhibition and high dependability. This methodology, which is material without a lot of trouble to other joints and adhesives, gives a general use to an increasingly solid utilization of adhesive bonding's and, therefore, for a superior and more extensive use in the mechanical manufacturing forms.

Ayatollahi M.R. et al. (10), To find the failure load they suggested the advanced strain based criterion on the single lap adhesive joints. They used Al 7075-T6 as adherent and adhesive as a 2-part epoxy-based paste. They have pre-treated the adherent surfaces using chronic acid. Continued by etching process with the help of solution of de ionized water, sulfuric acid and sodium dichromate. For the etching process they have dipped the adherents for 15 minute whereas the solution is maintained at 71°C. After this, they drizzled the tap water over the specimens and dried at 50 °C. Within two hours of surface preparation the adherents were bonded with the adhesive and cured at room temperature for about 72 hours. They described a new approach in which, when the adhesive midplane approaches a critical value of longitudinal strain at a particular critical distance then failure occurs. For different bonding lengths, number of experiments were conducted on single lap joints, and got good failure load result in accordance with the critical longitudinal strain criteria.

Murat Demir Aydin et al. (11), in this paper they took AA2024-T3 aluminum plate as adherent and FM 73 as adhesive. The adherend surfaces was treated with acetone and to remove the contaminants they used sand blasting process. Later etching is done to adherent using combination of sulphuric acid and Sodium dichromate along with heavy water at 60°C to 65°C for thirty minutes. Later, the adherent is washed with running tap water and dried for thirty minutes using oven which is kept at 60°C. Before bonding with the help of BR 127 priming is done. The adherent is bonded with the help of adhesive FM 73 and hot press is done for the specimens 0.28 MPa pressure at a temperature of 120°C for the duration of sixty minutes. They considered three different thickness and four overlap lengths. During the testing, they observed three different forms of failure in the single lap joint. In the first type they observed there was no plastic deformation and without any crack the specimens were fractured. Similar kind of fracture is seen in the second type and also in the adherends both plastic deformation and peel effect was noticed. In the last type they observed the crack initiation at the free ends and its inseminate to the centre of the overlap region and catastrophic failure occurs and also they observed a huge plastic deformation and peel effect at the free ends. SEM images were used to analyze the damage zone in the adhesive layer which causes due to initiation and propagation. By increasing the adherend thickness the strength of the joints and the effect of shear stresses also increases.

Rene Quispe Rodriguez et al. (12), this paper deals with the analytical models and numerical result for single lap joint. For the comparison of analytical result, they used Abaqus software for finite element analysis and for the analysis they considered CPS8R an eight-node biquadratic element as an adherend (960 elements) and as adhesive (400 elements). As their analysis is static the three criteria is analyzed. In the first they considered the maximum stress or strain criteria for the bonded joints, in that they observed peel stresses should be minimized during design only. Since hydrostatic stress is not considered in the von mises this criterion becomes ineffective. Whereas in the second criteria is Finite zone criteria they found in the double lap joint maximum stress occurs down the fillet edge. Non-linear analysis was done which included residual thermal stresses and also observed when the strain reaches singularity the joint will fail. The main drawback of this criterion is its inevasible to find the strength of the joint as they use variety of adhesives and adherents. In the limit state criteria which is limited to range of adhesive joints, they found that before the failure in order to yield entire layer it requires ample ductility in the structural adhesives.

Ramazan Kahraman et al. (13), in this paper they considered aluminum sheets as adherend and two-part epoxy i.e. Fusor 309 as an adhesive. The aluminum sheets are degreased by dipping it in iso-propyl alcohol and trichloroethylene for short duration later it is washed using water and there by cleaning the rough surfaces using by 400 grit grinding paper which consists of silicon carbide. Again, they are degreasing the adherents in iso-propyl alcohol and trichloroethylene for each 30-minute duration, then immerse the aluminium sheets in the solution containing distilled water, sulphuric acid, sodium dichromate and after dipping wash with the distilled water and dry. For bonding, equal proportions of epoxy, hardener and alumina powder were added and mixed well and fixture is used to assemble the adhesive joints. The adhesive joint was tested according to ASTM D1002 and for mechanical characterization, Instron 5567 mechanical testing system is used. Adhesive thickness considered in the range from 0.03 to 1.3mm and observed that increase in the adhesive thickness resulted in decrease in shear strength of the adhesive joint. However, it was observed that it was not that much effective for the adhesive thickness upto 0.7mm and also, they noticed almost the joint failed in the cohesive zone only. They used ANSYS software package for the stress analysis, in order to find the mechanical strength of the joint for the different thickness and adhesive compositions they figure out the shear stress and von mises stress. Shear stress describes about the mode of failure whereas von mises stress determine the equivalent stress. Beam3 element is used for aluminum plates and for modelling the adhesive bond they used Plane 82 element. One end is kept free and for the other end they applied a load of 100N. The stress contours show that at the interface of the adhesive metal substrate, maximum von mises and maximum shear occurs. At the middle of the surface the shear and von misses stresses will vanish. Nonetheless, encouraging result is obtained in the experimental even though they used addition of 50 wt% alumina powder in the epoxy, and the adhesive retains its strength and last they concluded that with the comparison of both experimental and finite element analysis adhesive thickness has a negative effect on the shear strength of single lap joint.

Jinxin Ye et al. (14), for the tensile failure analysis of adhesive bonded joints they formulated an integrated 3D constitutive model. This integrated includes adhesive failure and delamination and to validate the result they compared the finite element method to experimental results. They have CFRP has an adherent and J116B as an adhesive. Four different overlap lengths were created for the single lap joint. The adherend consist of eight different oriented layers. To avoid the damage of the clamping ends during the testing, the adherend and the adhesive were cured at 175°C under 0.3 MPa for duration of 2 hours with the help of glass fiber reinforced plates. In an autoclave, the CFRP is treated at 0.5 MPa at two different temperatures and two different durations as follows 185°C for two hours and 195°C for three hours. The test was conducted under the quasi-static axial tension on an Instron 8801 hydraulic testing machine. They noticed that, the adhesive layer was completely damaged for the 2.5mm overlap length and for 5mm its partly damaged and they observed that the delamination failure and matrix failure occurred at the undamaged area. For the 10mm overlap length, the delamination is occurring at the upper plate corners, overlap area, lower plates and found adhesive is almost intact and for the 20mm overlap length at the edge of the overlap area minor failure of the fiber is observed which shows there is a fracture in the fibers. Adjacent to the adhesive, between the first two layers the delamination was occurred. They analyzed the failure morphology and load displacement curve and compared with the experimental results and also noticed that failure mode was significantly affected by the overlap length.

Valente J.P.A. et al. (15), in this they considered the three different adhesives, Araldite AV138, structural acrylic adhesive as 3M DP8005, and XNR6852 adhesive. With the help of End notched flexure and double cantilever beam tests they found out the fracture toughness with respect to tensile and shear. They conducted the cohesive zone model analysis and compared it with numerical and experimental data. In those three adhesives AV138 it gave them a worst result whereas the best result is obtained from XNR6852 adhesive followed by DP8005. Compared to steel adherend the major plastic deformation occurs for aluminium adherend. The CFRP material which has higher stiffness will reduce the maximum load during the load transfer.

Sontipee Aimmanee et al. (16), for the tubular coupler joint which is adhesively bonded, mathematical model with a variable stiffness is formulated. To predict the joint stresses for the tubular coupler joints which is adhesively bonded, composite adherends with variable stiffness under the torsion is formulated. The joint is believed to be axisymmetric, straightforwardly flexible, and abused to a uniform torsion. Due to adjust the joint is considered as two or three two indistinct rounded lap joints. Contrasting fiber direction is examined by discretizing a cylindrical lap joint into a limited number of enough little segments, all of which can be approximated to have consistent fiber point. Stresses made in the joint are directed by using flexibility conditions. This model is applied to search for the perfect variable-fiber direction in the coupler that actuates the base glue circle shear pressure. Finally, the effect of geometries of the perfect joints on the sum of the pressure parts in the adherends what's increasingly, adhesive stresses is pondered. A structure rule for the perfect coupler joint is given toward the finish of the paper.

L.D.C Ramalho et al. (17),in order to find the failure stresses, shear modulus and shear yield they have used Thick Adherend Shear Test, Napkin ring test and Arcan . They compared the results with different test and concluded that Arcan and Napkin Ring Test are better than the other alternatives. The tests are almost having constant shear stress with respect to the adhesive length and stress at the adhesive layer is zero i.e. it is having Pure Shear. In order to predict the strength of adhesive joints the tensile and shear tests are required. Many numerical method approaches are presented in this paper and they are coupled to finite element analysis. They have recommended to use Cohesive Zone Modelling (CZM) for the intrinsic formulation characteristics of the adhesive joints. CZM is the most effective and less time consuming calibration tool.

Melek Durmus et al. (18), Adhesive holding is one of the most used joining methodologies for holding composite or different sorts of materials. The joint kind for the most part used in Adhesive holding is the single lap joint (SLJ) type. In any case, in adhesively strengthened joints, strip pressure happens in view of the surprising stacking, which makes hurt the pieces of the deals district. Different sorts of joints are used to diminish these strip stresses. One of these joint sorts is the progression lap joint sort obtained by making steps in the cover an area. At this moment, properties of the single lap joint (SLJ), one-advance lap joint (OSLJ) and three-advance lap joint (TSLJ) with five unmistakable advance lengths presented to pliable stacking were investigated tentatively and numerically by keeping the holding an area same for all models broke down. AA2024-T3 aluminum composite was used as the adherend and DP460, an auxiliary glue with two segments, was used as the Adhesive. The progression of the break in the cover an area was seen with a quick camera. Consequently, the TSLJ type was found to pass on more burden than other joint sorts. Moreover, the change in the progression length in the three-advance lap joint sort essentially influenced the failure heap of the joint. Exactly when the failure loads got in the preliminaries and the numerical assessment were broke down, it was gathered that their results were generally excellent with each other when the firm zone model was used in the numerical examination. Another result got from the assessment is the perfect length of the underlying advance made at the pieces of the deals an area in the three-advance lap joint.

Xinkuo Ji et al. (19), In this paper, they have used intermediate temperature curing thermosetting epoxy based adhesive. It consists of epoxy resin, silver flakes, anhydride curing agent and other auxiliaries. They used Isotropic Conductive Adhesive (ICA) with a silver mass fraction of 60 Wt%, it is stored in -30°C in a test chamber which is maintained at low temperature. The dimension which they used is 50mm length, 25mm width and 2mm thick and the material is T2 copper plate. Before conducting the test, the copper plates were polished using abrasive paper and then wiped with alcohol and the thickness of conductive adhesive layer is 0.1mm. The curing temperature was gradually increased to 30°C per hour and maintained at 120°C for 3 hours and later cooled to room temperature in an oven. With the help of INSTRON 5544 universal material testing machine uniaxial tension shear test was conducted. They performed the tensile test at four different rates i.e., 0.05, 0.5, 5 and 10mm/min. While performing the tests, all tests were repeated for thrice and average values are taken. The results show that with increase in loading rate the fracture displacement and shear modulus increase.

Rouhollah H et al. (20), In this paper they have investigated the failure and fracture of aluminium and GFRP material as adherents using ductile adhesives in single lap joint (SLJ) and double butt lap joint (DBLJ). The length of the adherents was 125mm, width 25mm and overlap length 25mm. Due to limitation in the ductility of adhesive the failure load does not increase substantially as overlap length to width ratio was larger than 1. GFRP adherents were maintained at 4mm thickness. GFRP material was created with 11 layers of E-Glass and Epoxy as resin. For aluminium and GFRP material, Araldite 2015 is used as a resin as it is two part toughened epoxy structural adhesive. Araldite basically used for the joints which have dissimilar materials which has a high resistance to peel and shear stresses. Before conducting the test all the materials were cleaned with acetone and by P180 abrasive paper. Later, again it is cleaned with acetone and dried with cool blow air. The SLJ and DBLJ specimens were prepared by maintaining 0.3mm as the thickness of the adhesive layer. Then, specimens were cured for 72hours at room temperature. Using Zwick-Z1494 universal testing machine, test was conducted under quasi static tensile loading with a displacement rate of 1mm/min at room temperature. The average 33% increase in strength is found in SLJ compared to DBLJ during the experiments. 19% high numerical failure load for SLJ and 51% for DBLJ was obtained and the most common failure was Adhesive failure and light delamination failure.

Salih Akpinar (21), investigated experimentally as well as numerically the three different types of joints namely Single Lap Joint, One Step Joint and 3 Step Joint which was subjected to tensile loading. The specimens taken are AA204-T3 Aluminum alloy as adherent and two different adhesives namely DP460 and SBT9244. He examined the mechanical properties for six different samples experimentally and numerically. The same adherend thickness, width and overlap length were used but joints with different geometries. The materials were degreased with acetone, sandblasted, etched with Sulphuric acid, Sodium Dichromate and Oxyhydrogen then washed with tap water and dried in an oven for 15 minutes at 60°C. Later, experiments conducted with the help of Shimadzes-AG-I universal testing machine. From the experiments he got the results that one step lap joint and three step lap joint carried 11% and 60% more load than single lap joint. Machining at the overlap area decreased the peel stresses and it played a major role in the increase in joint strength.

3. Conclusion:

The overlap length has a significant effect on the strength of the joints despite of stiffness ratio and adhesive thickness. With 25mm overlap length, 70% increase of the adhesive thickness resulted in 5% maximum increase of the strength. Expensive Test activities can be reduced by predicting the failure loads to the accuracy. With the help of two dimensional elastic theory we can find the stresses in single lap joint of dissimilar adherends. At the edge of the interference of an adherend the singular stresses which is having smaller Young’s modulus and thin thickness was found to be greater than the edge at the interface of an adherend with greater Young’s modulus and having more thickness. When a lap joint is under tension the bending moment and longitudinal stress creates plastic strains at the edge of the overlap region and the steel becomes plastic this causes failure in the adhesive. The lap shear strength increases with adhesive toughness and decrease in adhesive thickness. While investigating the failure load at joints in Finite Element Method, it is necessary to use the bulk adhesive properties for a strain rate. In future applications, for the joint manufacturers Finite Element Analysis will help in a greater extent for the selection of various parameters and also to modify the geometry, which will help the analyst to simulate and obtain the results in a very less time and with a reduced cost.

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