Adhesively Bonded Single Lap Joints With Hole & Pillar Interface.

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ABSTRACT

. A continuous investigation and experimentation are carried out to study the behavior of single-lap adhesive bonded joint by proposing different ideas with geometrical perspective to improve the performance. For example, wavy sinusoid, reverse bent, a pattern generated, non-flat zigzag adherend generated, by introducing micromachining, etc. This work is an attempt to present a new design concept for single lap joint with hole and pillar arrangement at the interface of a thick adherend to improve joint strength by reducing peel stress at overlap end. The performance of pillar and hole generated single lap joint has been investigated numerically and experimentally. A parametric study was carried out by varying diameter of hole/pillar and distance from the centre of the overlapping area. Single lap joint was manufactured by using ductile (2015) and brittle adhesive (AV138).The experimental results showed that the interface hole and pillar can considerably influence the adhesive joint strength and this was in correlation with the numerical results obtained from finite element analysis.

KEYWORDS Single lap adhesive Joint, Hole pillar interface, Dissimilar adhesive, FEA

I.Introduction:

Adhesive bonding technology is acting as dominant solution compared to traditional joining methods such as welding, bolting, riveting etc. in various industries such as automobile, aerospace and marine. The adhesive has potential in various type of construction, for example, bonding hybrid thick aluminium, steel and composite joints, typically 5-10mm. Structural metal sheet strength mainly depends on the connection between them and process parameters. For the enhancements of lap joint strength engineers and scientist are continually working by proposing different macroscopic and geometrical interface arrangements. Due to a simple and easy manufacturing process, the single lap joint is mostly studied and capable of joining different material properties with geometry compared to other joining methods [1-4]. Overall stresses of the structural sheet are concentrated at overlapping area, in most of the cases bonded end of overlap area act as weakest link then structure. Several studies were done in last few decades and proposed many ideas for improving strength and stress distribution in a single lap joint [5-7]. Improving joint strength and reducing peel stresses is mainly achieved by two methods, by modifying condition of the substrate surface and by geometrical modification at interface area [8-9]. Macroscopic modification focused by many scholars combining macro, fibers, micro and Nanoparticles, into the arranged adhesive to reduce the peel stresses [14-16]. Different methods were suggested by researchers for geometry modification on the substrate surface, for example, surface angular patterning, hole drilling, chamfering, grooving, reverse bent, wavy, sinusoid interface, micromachining operation etc. [10-13]. Surface patterning was done by using a vertical milling machine to improve interlocking between adhesive and adherend [17]. In some cases, non-flat adhesive joint design demonstrates a noticeable improvement in joint strength by reducing peel stresses at overlap end. Several studies show potential by modifying macroscopic state on the strength of single lap joint [18].

Won-Seock Kim.et al. [19] investigated the effect of periodic surface patterns on the adhesion performance of polymer-metal bond and contribution by varying micro pattern on mechanical interlocking was determined, dissipation energy, adhesion, cohesion on strength was also examined. E.G. Baburaj.et al. [20] worked by modifying the titanium plate surface using laser ablation process that produces micro columnar arrangements that improve the bond strength by many ways, it was found that as a result, the failure of a joint strength moves from interfaces into the bulk of the adhesive layer. Dongkai Xu.et al. [21] suggested new economic and environmental-friendly surface modification techniques, produce different surface texturing pattern, i.e. Channel arrays and grid pattern by using forming based micro-rolling system.

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Edward Peter Arul and Animangsu Ghatak [22] worked by fixing monolithic pillar of micro channels on the surface of silicon elastomers, those patterns of pillar improve the adhesion by crack arrest and initiation'' mechanism. Pinto et al. [23] experimentally investigate the effect of hole drilling on the strength of single lap joint, by varying process parameters, i.e. whole diameter, adherend thickness, type of adhesive and design layout. It was found that joint strength never affects by unmodified design parameters, results show decline failure load concerning to process parameters. Volkan Arikanet al. [24] presented effect of hole drilling at depth half of adherend thickness and found a rise in failure load also conclude its never benefits at ambient temperature. Yadong Zhou et al. [25] suggested pin profile connected composite single lap joint and examined it load-carry capacity, Non-circular profiles, various round-corner squares and pin of the racetrack-like profile were investigated to determine its pick stresses. Results were compared to circular one; an orthotropic effect of a proposed interface was also discussed. From the results in the literature, this interface might increase the joint strength by mechanical interlocking.

This study is an attempt to present new design configuration of hole and pillar interface single lap joint, the effects of interface morphologies on the distribution of shear stresses. Particularly their maximum values and joint strength of adhesively bonded joints through experimental investigations and finite element analysis.

II.Experiment Material:

Ductile adhesive (Araldite®2015 from Huntsman) and brittle two-component epoxy adhesive (Araldite ®AV 138/HV 998 from Huntsman) was used for experimentation. The mechanical properties of the selected adhesive are taken the form [17] shown in table 1. Aluminium alloy (6082-T6) was selected as adherend because of it lightweight application in aerospace and automotive industries. Also has sufficient load bearing capacity, cheaper and accessible to machining. The properties were determined using the thick adherend shear test, both adhesives were cured at 100 °C for 15 min in table 2[17].

Mechanical Properties	AV138/ HV998
Mechanical Properties	
Tensile strength (σt) MPa	305.6
Yield stress (σy) MPa	245.10
Elongation at failure (Єt) %	16.50
Young's modulus, E (GPa)	69.50
Shear modulus, G (GPa)	25.34
Poisson's ratio (μ)	0.346

Table 1. Mechanical Properties of Aluminium specimen 6082-T6

Mechanical Properties	
Young's modulus E (GPa)	4.59± 0.81
Yield strength σy (MPa)	36.49±2.47
Tensile strength σt (MPa)	41.01±7.28
Failure strain Єt (%)	1.3±0.44
Poisson's ratio (μ)	0.35

Table 2. Properties of epoxy adhesive AV138/ HV998

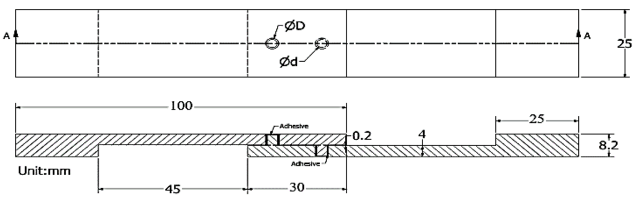

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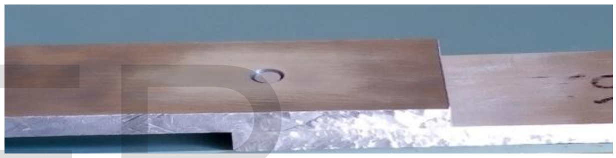
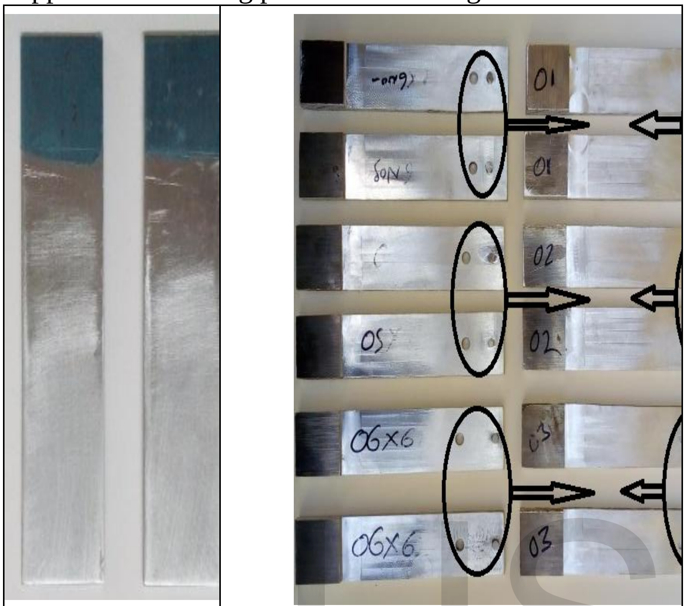
Fig 1. The geometry and dimensions of Single Lap Joint.



The dimension of hole and pillar generated single lap joint is shown in figure 1.The substrates were cut from 10.5 mm thick sheets using wire cut CNC machine. Fig. 1 shows the geometrical dimensions of adhesive joints. The overlap length, thickness of bond line, the substrate thickness and the substrate free length were 30, 0.2, 4 and 45 mm, respectively. ØD and Ød are diameter hole and pillar. While designing the geometry of hole and pillar joint, the arrangement is made in such a way that the pillar and hole form a between interlocking. 4mm thick adherend was selected. Hole diameter was chosen 1mm more than that of pillar. Adhesive thickness of 0.2mm was selected as it show best results [17], while interlocking, pillar comes at other side of lap joint due to hole, the area is field by adhesive at other end as shown in fig1(a).

B. Substrate and Surface preparation:

The Manufacturing of hole and pillar interface specimen was done CNC-vertical milling machine (Mannford VL12004000 rpm capacity), which was previously fitted with 12, 3size end mill tool in the tool holder (Fig. 2). Controlled parameters with the tool feed rate 2500 rpm. Side step and depth of cut was 5 and 0.1 mm with servo68lubrication was used. The profile geometry and motion of tool along the profile were fed to the machine programming system as two-dimensional drawings. The entered profile geometry was verified on a graphic computer screen. After the successful profile definition was recorded by the computer the program is executed (Figure 2).After machining operation only acetone was applied for cleaning process to obtain good adhesion.



Configuration0
2(a)

Configuration3,6
Configuration 2,5
Configuration 1,4
2(b)

Figure 2(a,b). CNC-Vertical milling machine used for creating hole and pillar on the surface

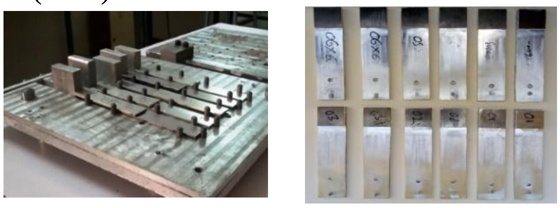
Configuration0-Single lap joint without hole and pillar arrangement.
Configuration 1-10mm distance between hole and pillar with 4mm Hole and 3mm pillar diameter.
Configuration 2-15mm distance between hole and pillarwith 4mm Hole and 3mm pillar diameter.
Configuration 3-20 mm distance between hole and pillarwith 4mm Hole and 3mm pillar diameter.
Configuration 4-10mm distance between hole and pillarwith 5mm Hole and 4mm pillar diameter.
Configuration 5-15mm distance between hole and pillarwith 5mm Hole and 4mm pillar diameter.
Configuration 6-20mm distance between hole and pillarwith 5mm Hole and 4mm pillar diameter.

In order to determine the effect of pillar and hole on adhesive bonded joint, two geometric parameters were chosen to investigate failure shear strength of the joint. First, hole and pillar were generated at a distance of 10mm, 15mm and 20mm with respect to centre of overlap length with varying diameter of Ø4mm Hole-Ø3mm Pillar, Ø5mm Hole-Ø4 Pillar with constant 30mm overlap length. The resulting experiment matrix is presented in Fig 3.

Fig:3 Joint geometric parameters selected for experimentation

C. Joint Preparation and Testing:

Joint preparation is done using aluminium fixture to maintain thickness and proper alignment of hole and pillar with 1mm clearance. 0.2 mm adhesive thickness selected since believed to be the best performing thickness. Spacers with a thickness of $thickness_{specimen} + thickness_{adhesive} = 4.2$ mm were used in order to assurance a constant thickness of the adhesive layer. Five joints can be prepared at a time in a fixture as shown in figure 3. Joint cured for 3 hour in fixture and 15minites in furnace for 100°C [17] before testing. All the joints were tested for ductile (2015) and brittle adhesive.



(a) (b)

Figure 4(a, b). Fixture for SLJ maintaining thickness and overlap length.

D. Results and Discussion:-

5.1Influence of brittle adhesive (AV138)

Tensile tests were performed in order to see the influence of hole and pillar interface with different configuration of brittle adhesive. The tests show that the interface surface leads to a higher joint strength compared to ductile adhesive as shown in fig 5. Configuration 1, 2, 3, 4, 5, and 6 give highest strength with respect to configuration 0. The results are presented in Fig. 5. Clear conclusion can be made in relation to joint strength increased. Configuration 3 gives 50.5% increase in average shear strength compared to flat configuration 0. Configuration 1, 2, 4, 5 and 6 give 33.69%, 35.36%, 50.5%, 42.75% and 45.32% increase in joint strength compared to flat configuration 0. Fig. 7 the fracture surfaces show that the specimens without interface had adhesive failures, while the interfaced ones had mixed/ cohesive. Careful analysis showed that a thin layer of adhesive was present on the aluminium surface. The fracture surfaces show that all the specimens had mixed/cohesive failures without any special surface treatment. Configuration 4 show that (fig:6) the pillar remain unbroken condition for two sample, still joint show applicable increase in joint strength, this type of failure was also observed in few sample. This may be because of in proper spreading of adhesive in between pillar and hole. Configuration 3 i.e. 20 mm distance between hole and pillar with 4mm Hole and 3mm pillar diameter give higher strength, it can be conclude that as distance between hole and pillar increased the strength is increasing

3.2 Influence of ductile adhesive (2015)

Single-lap adhesively bonded joints with hole-pillar configurations (0, 1, 2, 3, 4, 5 and 6) were tested for ductile (2015) and brittle (AV138) adhesive. Figure 4 summarizes the static testing performed. The lap-shear strengths as function holes configurations are shown in Fig. 8. This figure represents the average ultimate failure load for the different configurations of ductile (2015) and brittle adhesive. Average lap shear for brittle adhesive is higher than ductile adhesive for all configurations. The lap-shear strength is decreased in configurations 1, 2,3,4,5 and 6 with respect to configurations 0(flat) for ductile adhesive, The tests show that the pillar interface surface leads to a lower resistance of the joint, but no conclusion can be made in relation to the different configurations since the results are very similar between them and the variations in the failure load are within the experimental error (standard deviation).Fig6 Shows the fracture surfaces of specimens with different configurations(one sets of specimens are shown). The fracture surfaces show that the specimen with configurations0had mixed /cohesive failures lead to the best result. The next higher failure load was observed for configurations 4 with mixed /cohesive failures surfaces as shown in Fig. failures surfaces show that pillar is broken and fixed into hole at ultimate load. Due to ductile nature of adhesive 2015 in some cases pillar remain unbroken conditions this may be because of improper spreading of adhesive or air entrapped.

1 Finite Element Analysis:

In this work commercial software ANSYS 14.5.7 workbench is used for the finite element analysis. Meshing is a very important part of pre-processing in FEA software. In ANSYS workbench there are many tools and options available to help creating an effective mesh. The finite element model is composed; tetrahedrons method is to use when all the elements required are tetrahedral for the interface area, which needs cohesive elements. But the accuracy of results of an analysis depends a lot on the mesh quality of the model. Ideally, the results obtained from a finite element analysis get more accurate with increased number of elements following figure shows mesh result. However, increased number of elements also increases the process time required to run an analysis.

The total number of elements 2396520 and nodes 3431804 are created after generation of mesh for single lap adhesive joint and it can increases step by step using advance option available in ANSYS workbench shows in figure 8-13.

In previous work proved surface patterns influence the joint strength of SLJ. In case of brittle adhesive (AV138) the specimen with 90° pattern without chemical etch shown better result than chemically treated patterned specimen(2).The same specimen is consider for FEA analysis without considering UV effect and comparing result with few new design of pattern formed by non conventional machining and press working operation. In this analysis Brittle adhesive (AV 138) is considered for static structural analysis on room temperature 22° C with a failure load of 10000N and snap shot from ANSYS software is shown in figure 14-15.

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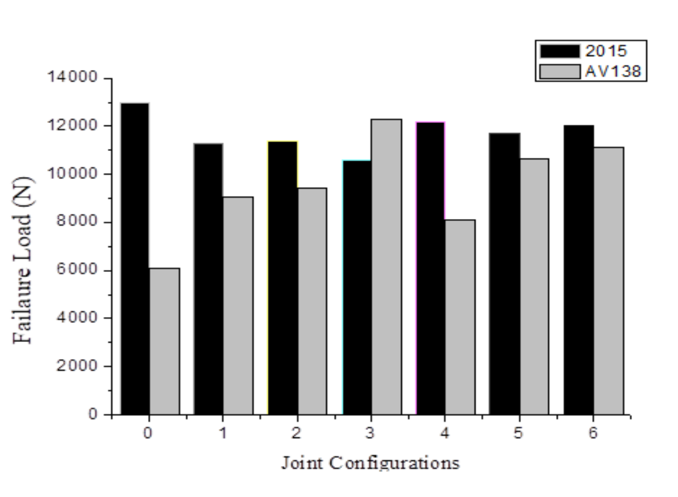
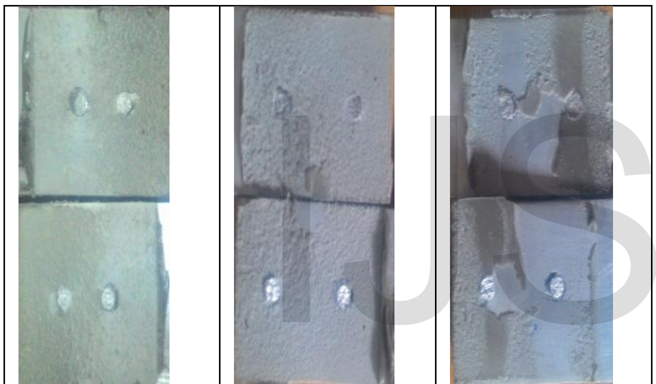


Fig 5: Average failure load of different joint configurations for ductile (2015) and brittle adhesive (AV138).



Configuration 1 | Configuration 2 | Configuration 3

Configuration 4 | Configuration 5 | Configuration 6

Fig 6: Specimen failure modes for brittle adhesive.

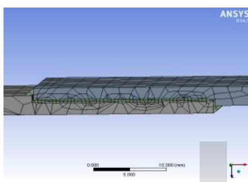
Configuration 1 | Configuration 2 | Configuration 3

Configuration 4 | Configuration 5 | Configuration 6

Fig 6: Specimen failure modes for ductile adhesive.

Table 6. Generation of mesh for single lap adhesive joint. (ANSYS WORKBENCH)

Fig. N	Node s	Eleme nts	Meshing
	3141		
8	2	5342	Map
	3911		
9	2	6650	Map
1	6713	12433	
0	61	5	Map
1	1939	39649	
1	865	8	Map
1	2206		Tetrahed
2	8	11110	rons
1	3431	23965	Tetrahed
3	804	20	rons



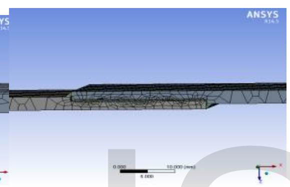
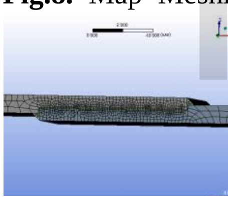


Fig.8. Map Meshing **Fig.9.** Map Meshing



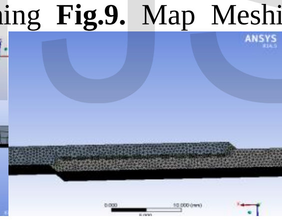


Fig.10. Map Meshing **Fig.11.** Map Meshing

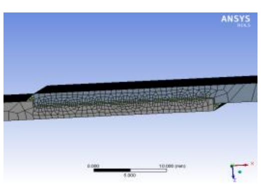


Fig.12. TetrahedronMeshing

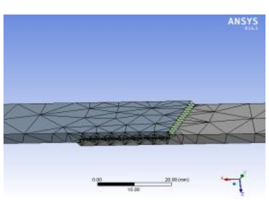


Fig.13. Tetrahedrons Meshing

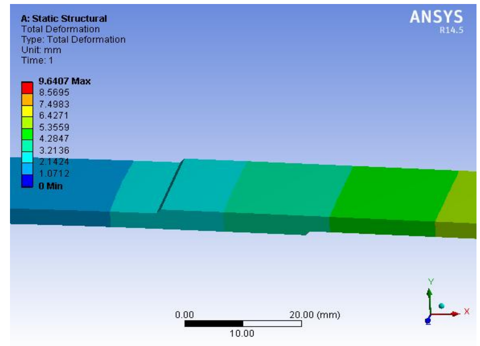


Fig.14. A specimen without interface patterned.

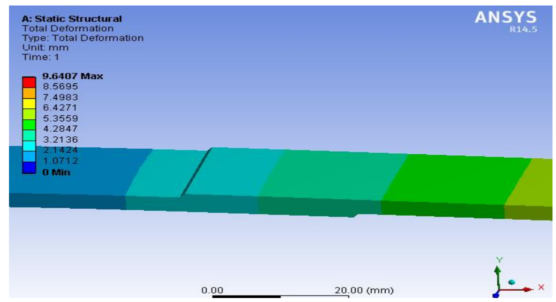


Fig.15. A specimen without interface array.

In this research, three-dimensional analyses of single lap jointswith different interface shapes were performed using the Abaqus FEM software. Applying the tensile load to the single lap joint causesboth tension and bending of the joint, resulting shear and peelstresses in the adhesive layer. Finite element simulations of simplifiedthree-dimensional models of self riveted adhesiveinterfaces with isotropicadherends were carried out to obtain the distribution ofshear and peel stresses along the bond line. Parametric variationswere studied via FEA to highlight the role of interface shape onthe distribution of stresses and inherently, the overall strength ofthe bonded joints. The stress analyses were investigated consideringthe isotropic nonlinear elastic properties of the adhesive andadherends. The geometric dimensions used for finite element simulationare provided in Fig. 1(a,b). To investigate the important ofthe hole and pillar arrangement on adherend interface which are interlock to each other in tensile load. Thus, for all six specimenswith specific centre distance and pillar diameter, two different conditions of adhesives of bond line were considered. Additionally, the effect of the hole and pillar interlocking, the adhesive thicknessand the elastic modulus of adhesive base and adherends wereassessed using finite element analysis.Three dimensional finite element analyses were carried out tosimulate the behavior of the adhesive joints.

The 3-node tetrahedralreduced integration elements were used for thispurpose. A mesh convergence study was also conducted to obtainthe appropriate element size for stress analyses. Tetrahedral elements with map meshwere considered in the adhesive thickness to obtain the distributionof stress in the adhesive layer. The element sizes used foradherents meshing were with a pattern that became coarser bygetting away from the bonding location. Fig.(Fig.7) shows a typical elementsize in finite element model. Themodels were collapsed atone end, while the other end of the joint was allowed to translateonly in axial direction without rotation. An axial tensile load equalto 12000N to 13000N, were applied at the end of the joints.In order to obtain the peel and shear stresses along the midplaneof bond line, Eq.1was employed [46].

$$\tau max = \frac{1}{2}[\sqrt{\sigma t^2 + 4\tau^2}$$

$$\tau max = \sqrt{\tau 1^2 + \tau 2^2 + 2\tau 1 \tau 2 Cos\Theta}$$

Where τmaxMaximum shear stress,σt Bending stress due to peeling, τ1Primary shear stress and τ2 secondary shear stress etc. Numerousfinite element analyses with consideration of material and geometry nonlinearity's were conducted on the tested adhesive joints.The numerical results showed a negligible plastic strain near thebimaterial conjunction of adherends only in 2015 adhesiveSLJ specimen.The numerical part of this research aims to show only the benefitof different HP interface geometries by comparing like-for-like stressdistributions.

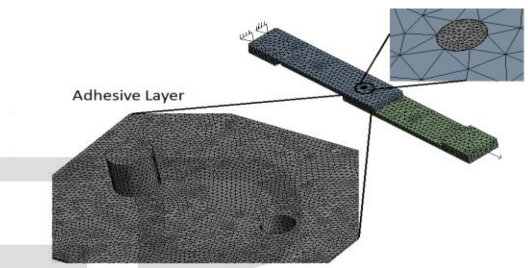


Fig.7: The finite element model meshing used for stress analysis.

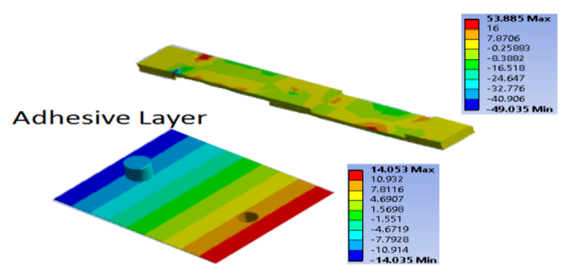


Figure 15 - Stress distribution (Shear stresses) in adherends and adhesive just before failure in tension

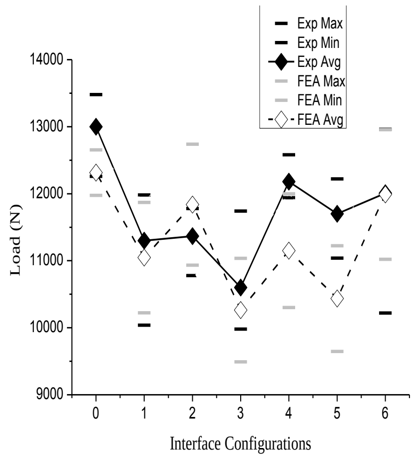


Fig: 9 Experimental and Numerical static shear strength of HP single lap joint for ductile adhesive(2015)

Fig: 9-9 show the experimental and numerical static load for ductile adhesive (2015) and brittle adhesive. Maximum minimum and average values of different interface geometries were compared. Brittle adhesive joint give higher shear strength compared to ductile adhesive,finite elements method (FEM) models developed for both adhesive lap joint showed some level of agreement. It can be said that the local movement of both end of adhesive layer peel and cleavage stresseswhich can lead to reduction of adhesive joints strength.These normal stresses usually lead to failure of the adhesive joints before the shear stress is fully developed so that the nominal maximum joint strength is not attained. Additionally, the local bending moments may result in yielding of the adherends, which may also limit the joint strength. Thus, the peel stress/strain should be considered as a key parameter in design of adhesively bonded joints. Adherend non-flatness can change the stress condition in the adhesive joint specially altering the values of peak stresses at both ends of bond line. According to Fig. 9-9, six configurations of HP-SLJs differ significantly in their mechanical behavior.For the configurations 3(AV138) and configurations 4 (2015) specimens, the highest value average final failure of the joints occurred at approximate loads of 12280 N and 12180 N.

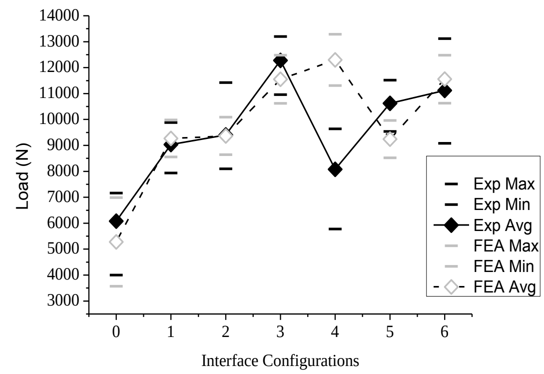


Fig: 9 Experimental and Numerical static shear strength of HP single lap joint for brittle adhesive(AV138)

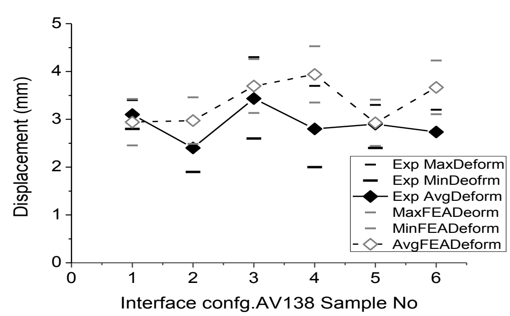


Fig: 9 Experimental and Numerical deformation of HP single lap joint for brittle adhesive(AV138).

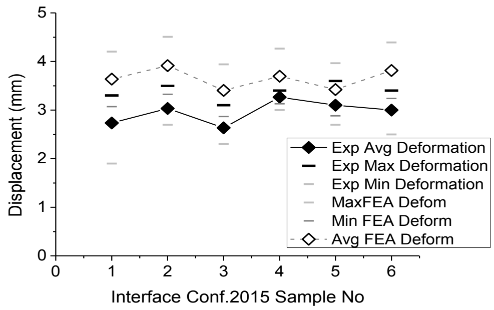


Fig: 9 Experimental and Numerical deformation of HP single lap joint for brittle adhesive (2015).

F.Conclusion :

Hole and pillar joints were manufactured and tested for static tensile test. FEM models of the joint configurations types were created in AbaqusFEM software package and related to experimental results.In the experimental part of the research, single lap joints with six different hole and pillar interface profiles were created from aluminum alloy 6082-T6. The experimental results revealed that there are considerable differences between the loadsbearing capacity of bonded joints with different interface profiles. For the best cases, the joint strength of configuration 3 for brittle adhesive was improved by 50% compared to the conventional single lap joint. As an important factor for investigating the strength of the adhesive joint studied for different morphologies of adherend interfaces, this was in correlation with the numerical results obtained from finite element analysis.

G.Reference

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