INVESTIGATING THE EFFECT OF PATTERN AND MIX ADHESIVE ON STRENGTH OF ADHESIVELY BONDED JOINTS

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Abstract

Due to the demand for lightweight constructions to reduce fuel consumption especially in the aerospace and automotive industries aluminium alloys stand out as the conventional choice for light weight structures. The main objective of present work is to study the effect of several patterns and mix adhesive on mechanical strength of adhesive joints. The recognition of a stronger joint depends not only on the joint design and type of adhesive used, but also on the preparation of the adhering surfaces. Patterns were treated by cleaned with acetone. Substrates were then bonded by mix adhesive alternately by brittle (AV138) and ductile (Araldite 2015) one and static tests will be carried out. In the present paper finite element analysis results were presented by considering 0°, 90°, 90°cross, 30° and 30°cross pattern generated on aluminium alloy (6082-T6) proposed for mixed-adhesive joints. Results compared with or without pattern mixed-adhesive joints only, 90°cross and 30°cross pattern shows appreciable improvement in joint strength as compared to 0° and without surface patterns, with mix adhesives do not have a significant influence on the joint strength of joint as compared to without pattern joint.

Keywords: Surface pattering; Surface preparation; Epoxy/epoxides; Aluminium and alloys; Static stress analysis.

I. INTRODUCTION

Joining technology with adhesive raise in the field of manufacturing especially for low weight application as compared to other technology in this regards surface finish or surface treatment play a major role for securing good adhesion. It has been mentioned that surface roughness of joining parts is very important to control the state of adhesion [1]. Review show the various methods of surface pre-treatment on titanium alloy to improve the adhesion also identify the surface pre-treatment, surface chemistry and properties of bond durability in adhesion studies. Particular emphasis is made on the modification of metal oxide surface [2]. Different surface pre-treatment methods have been used from long time in light weight application such as Chromic Acid Anodisation (CCA), Sot gel treatment or phosphate-fluoride; empower the remodeling of surface chemistry and morphology [3-4]. In recent studies emphasize the great potential understanding the use of modern laser beams, laser irradiation leads to the formation of thin oxide [5-6]. There are multiple aluminum pre-treatment procedures, which are mostly multistage procedures. The most common treatment is mechanical abrasion; vapor degreasing and alkaline cleaning [7]. Also some like as Grit-blasting or scotch-brittle abrasion [8-9]. In most of result the literature is for mechanical treatment such as shot-blasting [10-11]. Chemical etching, flame treatment, plasma etching, UV irradiation corona discharge is widely accepted [12-13]. Shear strength and fatigue life was investigated as a function of surface preparation both by dry and wet methods [14-15]. Similar investigation was carried out by author and found that surface treatment had minor effects on the strength of lap joint [17]. Roughness is an important factor which affects the strength of bonded joint and increase the contact area between the two interface connections. For metal roughness may increase the resistance of the joints but for substrates with low surface energy the increase of roughness does not have the similar effect [18]. Author found that increase of stress concentration and rational decrease in the resistance of the lap joint because the adhesive does not penetrate fully into the cavities [19]. Thus it is consider that many surface treatment applied in order to generate roughness induce physical and chemical changes that can affect the surface energy of subtract and wettability the result from the literature show that a rough surface increases the joint strength up to certain point [20]. There are various studies in literature on effect of roughness on a macro scale [21] and subtract topography has also been studied [22].

Varity of surface pretreatments have been used with various degree of success to increase surface tension, increase surface roughness, change surface chemistry, increase bond strength and durability of polymer composite adhesive joint. The researchers have used many different titanium alloys as substrates in past, however Ti-6Al-4V is most widely used one in aerospace industries [2]. Surface preparation used for polymeric and materials are highly varied and can be conveniently classified such as i) Mechanical, ii) Chemical, iii) Electrochemical, iv) Thermal, v) Photochemical and vi) Plasma. Following are surface treatment used for polymeric material a) Abrasion/Solvent cleaning, b) grit blasting, c) peel-ply, d) tear-ply, e) acid etching, f) corona discharge treatment, g) plasma treatment, h) flame treatment, i) laser treatment and j) silver electrolytic pretreatment process resent work on Ti-6Al-4V alloy, investigation by laser texturing aim to improve surface bonding different surface texturing are developed and concluded that 30% higher shear strength as compared to plain and sand blasted surface. Another uses large laminar spots to modify the surface roughness which, they have observed to reduce glycerin contact angle. On pure aluminum sample they have improve adhesion strength by 70% as compared to plain samples [23].

In single lap joints, the edges of the joint are the areas that have the highest stress concentration. The average stress is lower than the stress on the edges of the joint, and this unequal distribution of stress along the adhesive layer leads to failure normally for loads of inferior value than the adhesive can support [24]. Fig. 1 shows the difference in joint strength for ductile and brittle adhesives, depending on the length of overlap. The joint strength increases initially, being higher for brittle adhesives. But for big overlaps, it appears that the ductile adhesives have joint strength much higher than the brittle adhesives [25]. Mixed modulus joints have been proposed in the past [26–30] to improve the stress distribution and increase the joint strength of high-modulus adhesives. The stiff, brittle adhesive should be in the middle of the overlap, while the low-modulus adhesive is applied at the edges prone to stress concentrations. Pires et al. [31] and Fitton and Broughton [32] also proved with a finite element analysis and experiments with two different adhesives that the mixed-adhesive method gives an improvement in joint performance. The latter study refers to composite adherend and various adhesive moduli for the ductile adhesive and a 50 mm overlap. Temiz [33] used finite element analysis to study the influence of two adhesives in double-lap joints under bending and found that the technique greatly decreases the stresses at the ends of the overlap. Bouiadjra et al. [34] used the mixed modulus technique for the repair of an aluminium structure with a composite patch. The use of a more flexible adhesive at the edge of the patch increases the strength performance of the repair. The technique of using multi-modulus adhesives has been extended to solve the problem of adhesive joints that need to withstand low and high temperatures by da Silva and Adams [35].

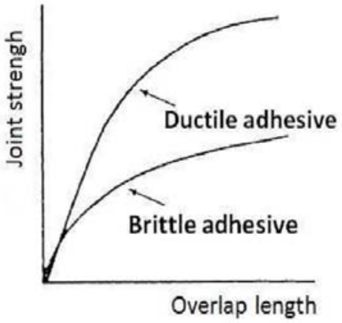

Fig. 1: Effect of overlap length on strength for ductile and brittle adhesives.

II. MATERIAL AND SPECIMEN GEOMETRY.

Due to the demand for light weight construction and structure in aerospace and automotive, aluminum alloy and Aluminium alloy has wide scope for making variety of accessories. Therefore, commercial available 6082-T6 with a thickness of 2 mm was selected for adhesive bonding. The physical and chemical properties of selected aluminum magnesium alloy are given in table 1and table 2 [16].

Table 1

Chemical composition of specimen 6082-T6

Element	*Si*	*Fe*	*Cu*	*Mn*	*Mg*	*Cr*
Weight (%)	1.02	0.26	0.022	0.672	0.761	<0.002

Table 2

Mechanical properties of aluminum specimen 6082-T6

Tensile strength (σt) mpa	305.6
Yield stress (σy) mpa	245.10
Elongation at failure (Єt) %	16.50
Young's modulus, E (GPa)	69.5
Shear modulus, G (GPa)	25.34
Poisson's ratio(µ)	0.346

Epoxy adhesive are found in many application in aerospace and automobile industries. In this work, two adhesive are selected alternately out of which one is brittle adhesive (AV 138) and other is ductile adhesive (Araldite 2015) [16].

Table 3

Mechanical properties of brittle and ductile adhesive [25-31]

	Brittle adhesive	*Ductile adhesive*
Young's modulus E (GPa)	4.59± 0.81	1.85±0.20
Yield strength σy (MPa)	36.49±2.47	12.63±0.61
Tensile strength σt (MPa)	41.01±7.28	22.67±1.82
Failure strain Єt (%)	1.3±0.44	4.85±0.07
Poisson's ratio (µ)	0.35	0.33

III. TREATMENTS

The effect of the patterns can be evaluated in two conditions with and without surface treatment. The impression was to form if the patterns would be sufficient to have static shear strength without additional treatment. For the case of 'no treatment' simply acetone was used to clean the substrates after the patterns were done.

IV. SURFACE PATTERNING

The surface preparation surface of the substrate is of importance in the operation of a bonded joint, as its resistance depends deeply on the value of this operation. In an ideal bond, the substrate must be the puniest link, however in most of the bonded joints it is the adhesive that behaves as the weakest link. Different surface patterns and depths will be tested in tensile tests for both adhesives and the best pattern and depth can be exam.

The patterns formed to the specimens consisted of a series of channels, which were applied with 0°, 90°, 90°cross, 30° and 30°cross pattern angles with depths of 0.1 mm. The distance between the channels is 2 mm and 4 mm adherend thickness. Figure 2 shows specimens with a pattern
0°, 90°, 90°cross, 30° and 30°cross pattern angles and depths of 0.1 mm compared with a specimen with without pattern.

The manufacturing of the patterned specimens will done on a vertical milling machine, which fitted with a lathe cutting bit with a 30º angle in the tool holder.

V. BONDING

The adhesive joints will be manufactured using a mould. The adhesive thickness used is 0.2 mm, since this is believed to be the best performing thickness. This is achieved by the curing setup shown in Fig. 3.

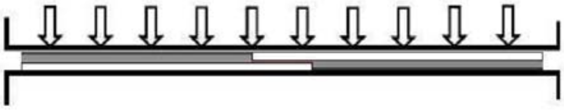

Fig. 3: Setup used to constant adhesive thickness.

To guarantee a constant thickness of the adhesive layer hot-plate hydraulic press will be used to secure the parts in place during the curing process. The hot-plate hydraulic press uses heat and pressure in order to cure the adhesive.

VI. STATIC TESTING

Determining the tensile test of single lap joint is one of the most common methods to characterize an adhesive joint. The test is carried out by applying load in longitudinal direction. The shear strength of adhesive joint will exam by using a hydraulic testing machine able to provide load up to 100 N The strength will be influenced by pattern joint after different surface pretreatment. Each specimen will be tested for shear stress. Each joint prepared by after surface pretreatment will be tested and compared to the non-treated single lap joint. Fig. 4 show basic arrangement of single lap joint.

Fig. 4: Representation of a single lap joint

VII. FINITE ELEMENT ANALYSIS

To conduct the experiment ten geometric models are created in Creo Parametric software. Static shear test is performed in order to see the influence of the depth of the patterns. In these tests the patterns were produced at 90º 30°cross and 0° with depths of 0.1 mm. Four two-part paste adhesives were selected, bonded by mix adhesive alternately brittle (AV138) and ductile (Araldite 2015).

A. Geomatric Modealing

Creo Parametric 2.1 is very powerful tool. An overlap area of 25 x 25 was prepared with the various patterns. A very rough approximation for the yield strength can be calculated from the overlapping region. As shown in Fig. 5

For the experiments, a specimen with a simple geometry was chosen (Fig. 4). An estimate for the failure load can be calculated following a simple methodology proposed by Adamset al. [17].

The upper limit is given by the load corresponding to the total plastic deformation of the adhesive (global yielding):

PGY=tybl (1)

Where PGY is the failure load of the adhesive due to global yielding, ty is the shear yield strength of the adhesive bis the joint width and l is the overlap length. The direct tensile stress (st) acting in the adherend due to the applied load P is

бt= P/bts (2)

Where ts is the adherend thickness. The stress at the inner adherend surface (ss) due to the bending moment M is

бs=6M/bt^2 (3)

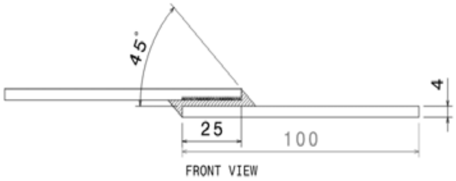

Fig. 5a: Joint geometry

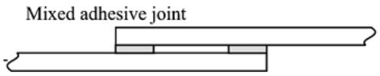

Fig. 5b: Joint geometry

Solid geometry diagram of Pattern with 30°cross, 0°, 90° is shown in figure 6, figure 7, figure 8.

30°cross pattern

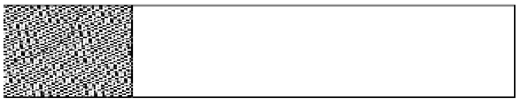

Fig. 6: 30° cross pattern.

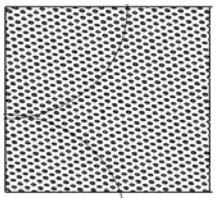

Fig. 7: Detail view of 30° cross pattern

Fig. 8: 0° pattern.

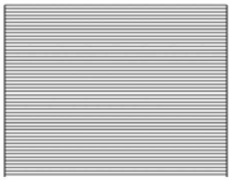

Fig. 9: Detail view 0° pattern.

Fig. 10: 90°cross pattern.

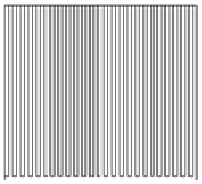

Fig. 11: Detail view of 90° pattern.

B. *About 'FEM'*

The Finite Element Method (FEM) has become a powerful tool for the numerical solution of a wide range of engineering problems. Applications range from deformation and stress analysis of automotive, aircraft, building, and bridge structures to field analysis of heat flux, fluid flow, magnetic flux, and other flow problems. With the advances in computer technology and Computer Aided Design (CAD) systems, complex problems can be tried out on a computer before the first prototype is built. In this method of analysis, a complex region defining a continuum is discretized into simple geometric shapes called finite elements. The material properties and the governing relationships are considered over these elements and expressed in terms of unknown values at element corners. An assembly process, duly considering the loading and constraints, results in a set of equations. Solution of these equations gives us the approximate behavior of the continuum. Use of computer is an essential part of the finite element analysis. Well-developed, well-maintained, and well-supported computer programs are necessary in solving engineering problems and interpreting results. Many available commercial finite element packages fulfill these needs.

Now a days, number of sophisticated FEM software's are available and are widely used in research and development centers. ANSYS is one of them. The ANSYS program has many finite element analysis capabilities, ranging from a simple, linear, static analysis to a complex, nonlinear, transient dynamic analysis.

A typical ANSYS analysis has three distinct steps:

- Build the model
- Apply the loads and obtain the solution
- Review the results.

VIII. FINITE ELEMENT ANALYSIS EXPERIMENTATION

Solid model was created in Creo Parametric 2.1 and commercial software 14.5.7 workbench is used for finite element analysis. FEM model of adhesive-bonded joint with a 30° cross pattern (Fig.6) is created. Model have overall dimension equal to the specimens, with 4 mm thickness and 100 mm length with 25 mm overlap length. 0.2 mm thick adhesive layer was added along the overlap length. Bonded by mix adhesive alternately, brittle (AV138) and ductile (Araldite 2015) for static structural analysis at room temperature 22° C. The finite element model is composed; tetrahedrons method is used 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 figures shows mesh result. However, increased number of elements also increases the process time required to run an analysis. Adhesive bonded joint with a patterns 0° is modeled without considering surface preparation. Only adhesive bonded and pattern generated lap joint is considered for mesh generation using 0.1 mm; tetrahedrons elements.

Table 4
Meshing results.

St no.	Detail description (Mix adhesive)	Nodes	Elements	Meshing
1	Adhesive lap joint Without pattern	31412	5342	Map
2	Adhesive lap joint With 0° pattern	39112	6650	Map
3	Adhesive lap joint With 90° pattern	3521804	2486520	Tetrahedrons
5	Adhesive lap joint With 90°cross pattern	3541913	2586321	Tetrahedrons
6	Adhesive lap joint With 30° pattern	3532825	2696831	Tetrahedrons
7	Adhesive lap joint With 30°cross pattern	3561804	2496664	Tetrahedrons

The total number of elements is 2496520 and nodes 3531804 are created after generation of mesh for single lap adhesive joint and it can be increased step by step using advance options available in ANSYS workbench as shown in fig (12a, 12b, and 12c). A similar specimen is considered for FEA analysis without considering surface preparation. In this analysis alternately Brittle adhesive (AV 138) and ductile adhesive (Araldite 2015) is considered for shear stress analysis.

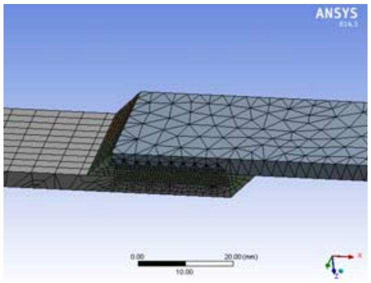

Fig 12a. Mashing of 0° pattern

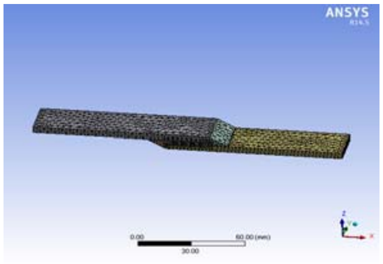

Fig 12b. Mashing of 90° pattern

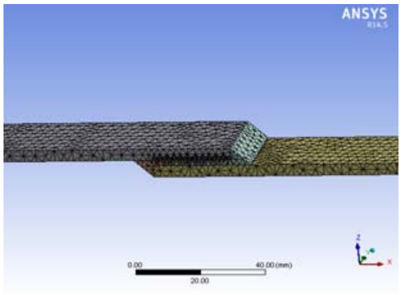

Fig 12c. Mashing of 30° pattern

Structural analysis is perform on 0° 90° 30° and 30° cross pattern generated analysis results of Mises stress and total deformation for on 0°, 90°, 90°cross, 30° cross, 30° and 30° cross pattern are shown in figures (13 to 26)

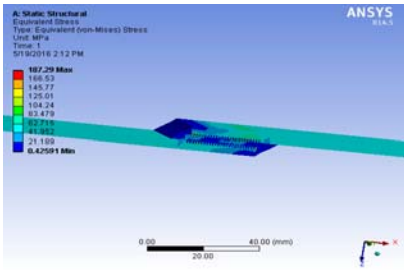

Fig 13. Von-mises stress of 0° pattern

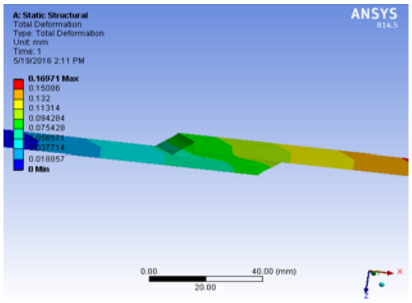

Fig 14. Total deformation 0° pattern

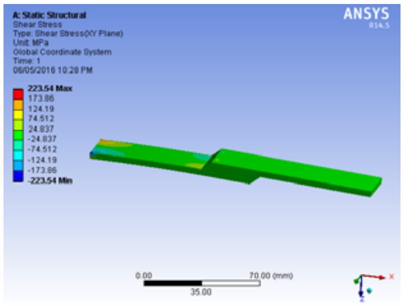

Fig 15. Von-mises stress of 90° pattern

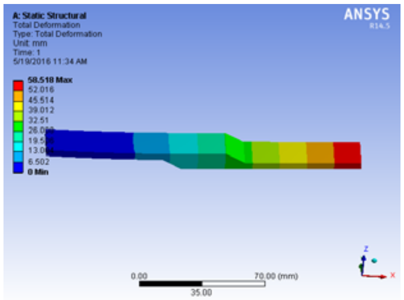

Fig 16. Total deformation 90° pattern

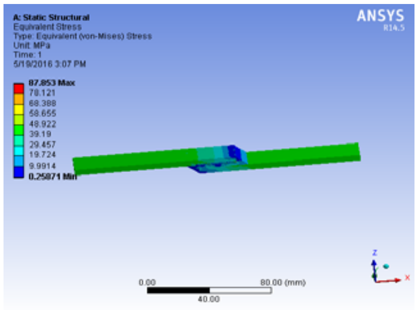

Fig 17. Von-mises stress of 90° cross pattern

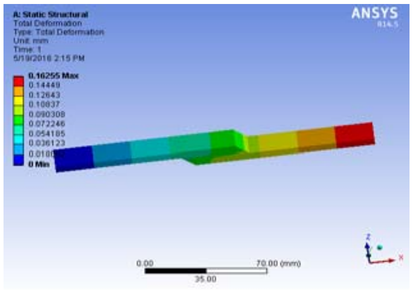

Fig 18. Total deformation 90° cross pattern

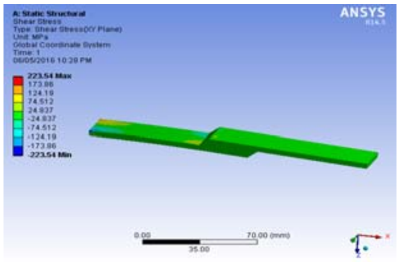

Fig 23. Von-mises stress of without pattern

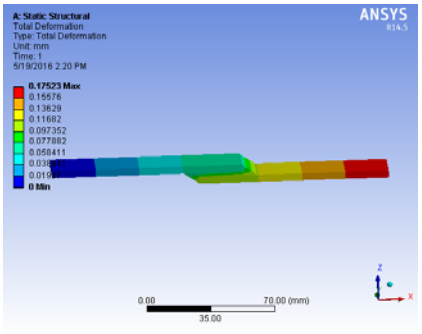

Fig 24. Total deformation without pattern

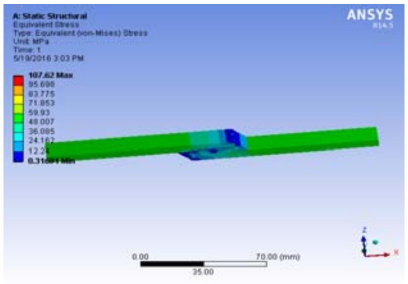

Fig 19. Von-mises stress of 30° pattern

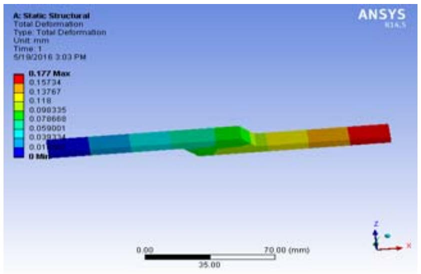

Fig 20. Total deformation 30° pattern

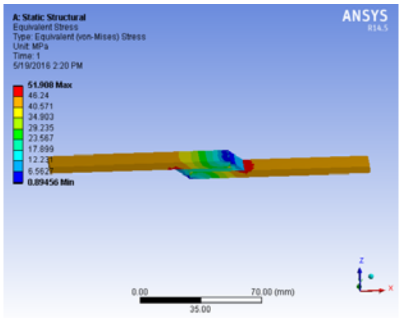

Fig 21. Von-mises stress of 30°cross pattern

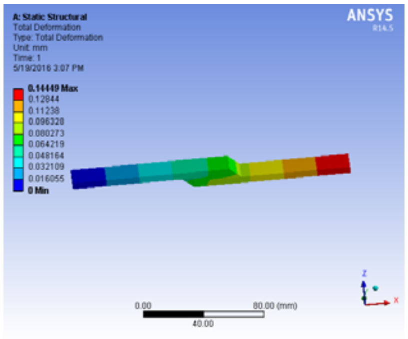

Fig 22. Total deformation 30°cross pattern

FEM models of all bonded joint with pattern and mix adhesive joints were created in FEA commercial software 14.5.7 workbench. Structural analysis is performed on aluminum alloy adherend in order to see the influence of pattern with mix adhesive strength on single lap adhesive joint. The first analysis is done without considering pattern effect using mix adhesive brittle adhesive (AV138) and ductile adhesive (Araldite 2015) comparing the results with without pattern joints.

A. *Load and boundry conditions*

Structural analysis is carried in FEA commercial software 14.5.7 workbench module. One by one all the geometric joints with pattern are imported, application of different material property to material (aluminium and adhesive) are given in table 2, 3. In second step mashing is done by considering Tetrahedrons element, because of lap joint is 3D geometry with adhesive and patterns. All the results of mashing are represented in table 4. For stress analysis one end is keep fix and load of (12000 N) is applied at other end. Load applied is chosen from previous results [26] of mix adhesive without pattern. And results are plotted for shear stress and total deformation. Results show influence of pattern on shear stress is discuss in results.

As stress is the force per unit area, it depends on area of structure, while Strength is the resistance to maximum stress at the time of failure. As the stress is high the strength is low and vice versa.

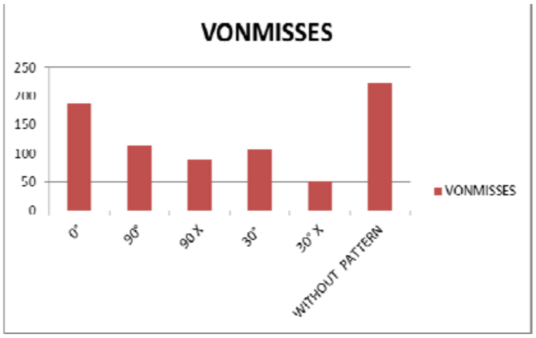

Fig.25 Effect of surface patterns with a depth of 0.1 mm on the shear stress of single lap joints with mix without surface preparation compared with no pattern joint.

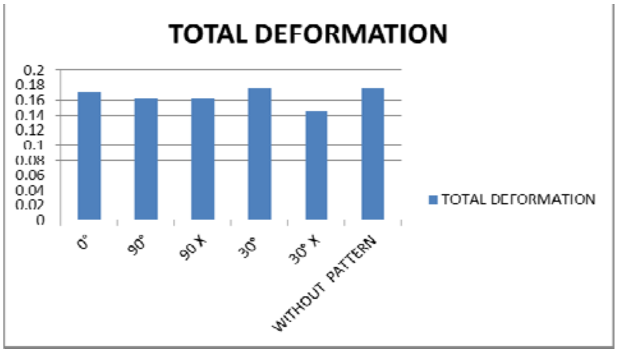

Fig.26 Total deformation of different patterns.

IX. CONCLUSIONS

Finite element analysis of single lap joints with patterns was studied without surface treatment and bonded by mix adhesive alternately i.e. brittle (AV138) and ductile (Araldite 2015) one. The conclusions that can be taken from the study are:

(1) Shear stress (von-misses) and total deformation analysis results are plotted with the mix adhesives i.e. brittle adhesive (AV138) and (Araldite 2015) and different pattern, show that the surface patterns influence the joint strength. This influence is most notable for specimens with 30° cross and 90° cross without considering surface treatment.

(2) 90° and 30° pattern also show appreciable improvement in joint strength as compared to 0° and without pattern joint.

(3) 0° surface patterns with mix adhesives do not have a significant influence on the joint strength of joint as compared to without pattern joint.

(4) Experimental analysis will be performing to validate the results for all joints.

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