Effect of Multi Walled Carbon Nanotubes On Strength of Single Lap Joint.

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ABSTRACT -The average shear strength and elongation at failure of adhesively bonded single lap joints (SLJs) were studied when different weight percentage of nanoparticles i.e. multi walled carbon nanotubes (MWCNTs) were added to the adhesive. The overlap length of the SLJ is varied to further study the effect on strength. This study takes in consideration Aluminium 6082 T6 with adhesive AV 138.

KEYWORDS -Adhesive and Cohesive Failure Nanoparticles Mechanical Properties Single Lap Joint

I. Introduction:

A promising joining technique in contemporary aerospace industry is adhesive bonding which joins dissimilar as well as similar materials in a light-weight connection. However, available adhesives are neither durable nor have near comparable strength as traditional techniques. Pertaining to this fact, reinforcing adhesives with nanoparticle can be potential solution which can lead the way for universal adaptation in adhesive joining techniques in slew of other industries and solve the issues mentioned above.

Adhesively bonded joints are increasingly being used in aerospace and automotive industries.

Using adhesive bonding weight and cost of the joint can be reduced. The single lap joint with metallic flat plates offer elegant join formation with added efficiency, therefore they are used more commonly.

There are many factors which influences the strength of the joint namely adherend, overlap length, adhesive thickness, surface preparation, etc. In any case the failure must occur inside the adhesive i.e. cohesive in nature so that adhesive can be used to full capacity. Multiple factors mentioned above affect various properties of the single lap joint e.g. surface preparation must be improved if failure is adhesive in nature.

Adhesive bonding has many advantages over welding and bolting namely excellent resistance to mechanical vibrations and failure loads, weight and cost saving, sealing ability, minimum stress concentration. But along with advantages this technique has several disadvantages such as long curing time, poor temperature resistance, careful surface preparation before bonding. Fereidoon et al. used functionalized and non-functionalized MWCNTs to improve the shear strength of SLJs according to ASTM-D5868-01. The results revealed that the average shear strength increased up to 40.5% by adding 1.5 wt.% of MWCNTs into the epoxy adhesive. Also, they showed that the bonding surface of aluminium substrates was not chemically affected by MWCNTs. Tutunchi et al. used silica nanoparticles into an acrylic adhesive to enhance the shear strength of steel-glass/epoxy composite joints. They showed that addition of silica nanoparticles up to the weight percentage of 1.5 led to increase the shear strength by about 29%. A significant decrease in water contact angle and consequently increase in interfacial wettability of the acrylic adhesive with steel and glass/epoxy substrate was also reported and therefore, the shear strength of adhesive joints was increased. May et al. added inorganic nanoparticles including MWCNTs and $\gamma - Al2O3$ as reinforcements into the epoxy/sol-gel adhesive to improve the adhesive joint strength. They showed that incorporation of $\gamma - Al2O3$ and MWCNTs with weight percentages of 0.71% and 0.05%, respectively, resulted higher lap shear strength compared to the corresponding single phase-reinforced and unreinforced adhesives. The increase of lap shear strength was attributed to the improvement of adhesion between the adhesive and substrates and adhesive cross-linking (cohesive strength). Cui et al. used second phase nanoparticles namely nano-hexagonal boron nitride (BN) into a mixture of adhesive resin and micro silver particles to improve the shear strength and electrical conductivity. The results showed that addition of 3 wt.% of BN considerably increased the electrical conductivity and shear strength of the adhesive.Zhai et al. investigated the effect of adding nano alumina particles into an epoxy adhesive on improving the adhesive strength using pull-off adhesion test. By increasing the nano alumina content, the adhesive strength gradually increased and reached to a maximum value at a weight percentage of 2. Improvement of adhesive strength caused the failure locus to change from interfacial to combination of interfacial and cohesive.

The shear strength at failure of single lap joint is main focus of this study. The adhesively bonded single lap joint reinforced with multi walled carbon nanotubes is tested for shear strength.

II. Experiment:

A. Material:

For experimentation the brittle epoxy adhesive Araldite AV138 was used. As shown in table 1 the mechanical properties of the given adhesive area taken. In this experiment for the adherend i.e. aluminium alloy (6082-T6) was chosen because of its light nature, wide appeal to aerospace industry and availability. It also has a property to hold the meatal or in better terms high load bearing capacity. It has a low cost adding to it's favourability. After the adherend shear test the properties were taken. In test of adhesive it was cured at 100^0C for 15 minutes. The properties are shown in table 2. Fig 1 shows the geometrical dimensions of aluminium alloy having thickness of 6 mm and 110 mm total length. For the first factor i.e. for overlapping length, two different bond length 47 mm and 25 mm were taken for study. The uniform thickness of adhesive is taken to be 1 mm. The second factor for this experiment is nanoparticles incorporates in adhesive with 3 different weight percentage. The weight percentages are 0.2, 0.5 and 0.8 percentage which is added to the selected adhesive. At first, during mechanical stirring at 100 rpm nanoparticle of different weight percent were added for 15 minutes. This mixture is also placed in a sonicatorhaving power of 70W and pulse for 45, 50 and 60 minutes respectively.

To increase the dispersion of nanoparticles in the mixture, mechanical stirring with rotation speed of 1500 rpm for the 20, 25, and 30 minutes duration was undertaken for 0.2, 0.5 and 0.8 wt.% of nanoparticle respectively. After that sonication process is repeated i.e. power of 70W for 30 min and pulse of (1:1). Later once again mechanical stirring is done at 100 rpm. In order to remove the bubbles,the mixture was placed in vacuum degassing oven for 20 minutes having a pressure of 0.2 bar and temperature of 25^0 C. To prevent the temperature of mixture from rising too high during sonication, this process is conducted in the container having ice and water. Also, the uniformity of mixture the process of sonication was stopped after 10-15 minutes and this mixture was stirred by a small spoon.

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)	69.5
Shear modulus, G (GPa)	25.34
Poisson's ratio (μ)	0.346

Table 1. Mechanical Properties of Aluminium specimen 6082-T6

Mechanical Properties	AV138/ HV998
Young's modulus E (GPa)	4.59± 0.81
Yield strength	36.49±2.47
σy (MPa)	41.01±7.28
Tensile strength	1.3±0.44
σt (MPa)	0.35
Failure strain Єt (%)	
Poisson's ratio (µ)	

Table 2. Properties of epoxy adhesive AV138/ HV998.

B. Substrate and Surface preparation:

In the single lap joint, the prototype is made by twoSheets of given dimensions were bonded with each other by using adhesive on the bare surfaces of both. As adhesive gets in contact with unclad surface of adherend surface preparation the surfaces of aluminium alloy were polished by using 1000 grit sand paper after that roughing of that bond area is carried out by using 200 grit sand paper this result in the increase in roughing between adhesive and adherend. Then by using detergent, substate was cleaned also with acetone by using cotton. For acid etching the ingredients shown in the table 3 was used. After that adherends were placed for hot water bath at 60-65^{0}C for 30 minutes. At last the joints were removed from the solution and washed with deionized water and dried by placing them in an air recirculating oven having temperature of about 30-40^{0}C.

Sulfuric acid	27.5
Sodium dichromate	7.5
Deionized water	65

Table 3. Composition of etching solution (wt. %) for aluminium alloys

C. Joint Preparation and Testing:

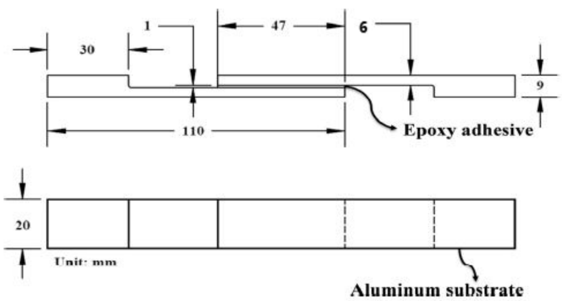
The single lap joints were manufactured by mixing nanoparticles in the selected adhesive with 3 different weight percentages. This gives the idea about average shear strength. In this experiment two factors are taken into consideration.

1) Weight percentage of nanoparticles.

2) Surface area for bonding (Overlapping length) and of prototypes of three weight percentage and of pure adhesive also with two different overlapping length of 47 mm and 25 mm. 8 prototypes were formed. For the average values we took 3 prototypes for each of above. Therefore, 24 prototypes were formed.

At first 3 prototypes of different weight percentage were tested under the quasi-static loading having displacement rate of 0.3 mm/min. To provide the uniform thickness of adhesive a fixture is used. At the end of 5 days and end of curing time those prototypes were removed and remaining spewed out adhesive is removed by polishing. At last the prototypes are ready for testing on UTM up to the failure.

Multi walled carbon nanotubes (MWCNTs)	
Average diameter size	10–20 (nm)
Specific surface area (SSA)	200 (m2/g)
Average length	10–30 (µm)
Purity	95%



(a)

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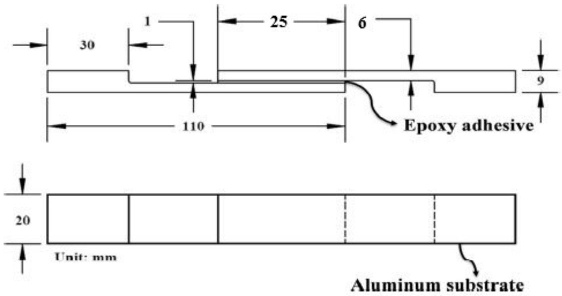


(b) Fig 1. The geometry and dimensions of Single Lap Joint.

Results and Discussion:

In this experimental study, the effect of nanoparticles (MWCNTs) with weight percentages 0.2, 0.5, 0.8 and overlap length 47mm, 25mm was investigated on mechanical shear strength property. The shear strength value for single lap joint is found maximum at 05 wt.% of MWCNTs compared to 0.2 and 0.8%. The average shear strength increased by 14.8% compared to the pure adhesive. However, it is observed that the average shear strength reduced by 5.5% compared to pure adhesive pure adhesive when the % of MWCNTs in the adhesive was 0.8%.

Now, regarding the material toughness i.e. ability of material to absorb energy and plastically deform without fracturing. It is also found that due to reinforcement of MWCNTs the single lap joint toughness was significantly increased as a result of increased strength and elongation at failure. The fracture surface of the joint is shown in fig as it is clearly seen that the failure of unreinforced SLJ is interfacial according to fig (b) for SLJs reinforced with MWCNTs no change between adhesion of substrate and adhesive was observed. Thus, the failure of SLJs reinforced with MWCNTs remained predominantly adhesive.

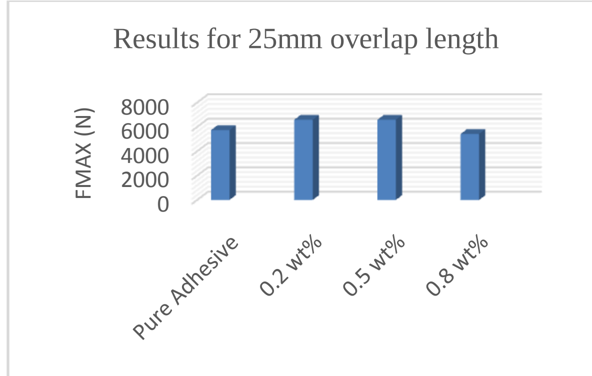
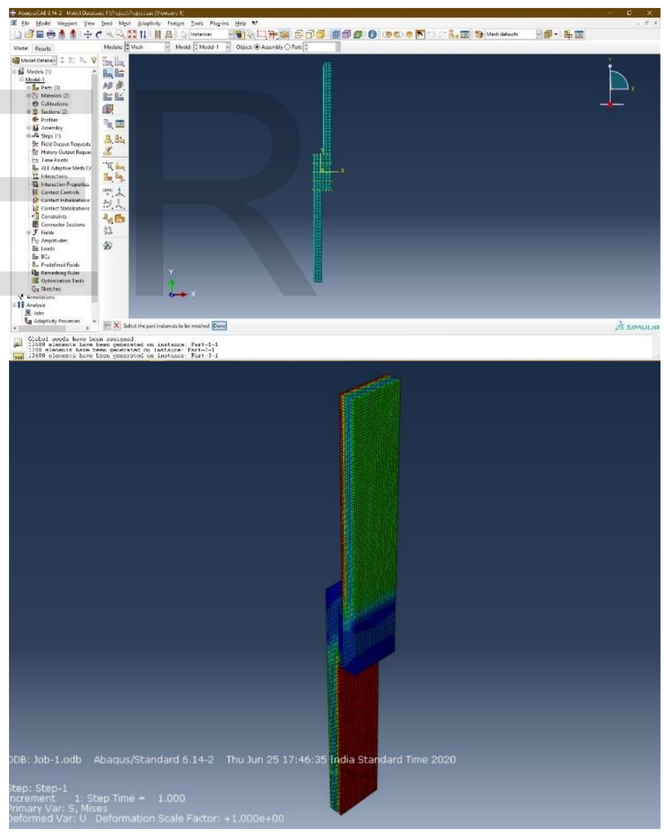


Fig 2. Result for 25mm overlap length prototypes

The increase in overlap length also effected the shear strength of SLJs. It is found that the shear strength increased by 172% by increasing the overlap length from 25 mm to 47 mm at 0.5% of MWCNTs.



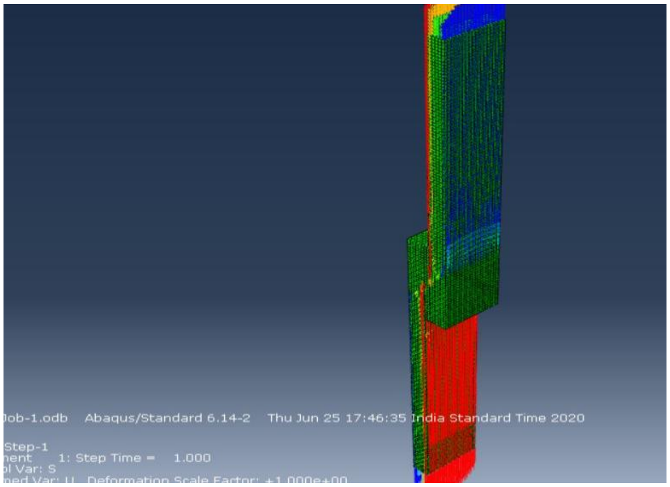


Fig 3. Abaqus analysis of Single Lap Joint.

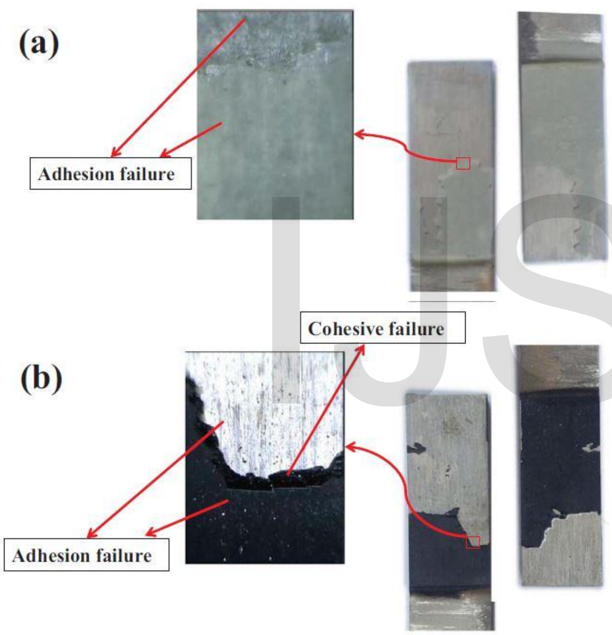


Fig 4.Fracture surfaces of a) unreinforced SLJs b) SLJs reinforced with 0.5 wt% MWCNTs

D. Conclusion:

In this paper, the study of effect of nanoparticles i.e. multi walled carbon nanotubes on the mechanical behaviour of adhesively bonded single lap joint was completed. The experimental results showed that the addition of nanoparticles improved the mechanical properties including shear strength. It is also found that the incorporation of MWCNTs in the adhesive have no degrading effect on the mechanical properties in the studied three wt.% of nanoparticles.

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