Retrofitting of Aluminum Structures with CFRP Patch

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***Abstract*--The present work deals with the retrofitting of the aluminium structures with CFRP Patch using adhesive bonding. Three parameters have been considered for bond strength evaluation. bond length, surface preparation and epoxy based structural and non-structural adhesive combination. The experiments have been performed to observe the effect of above parameters on bond strength formed between Aluminium and CFRP Patch. Different surfaces were prepared by sand blasting, abrasive paper and surface texturing by chemical etching. Tensile test was conducted to find the load capability of the CFRP Patched samples. It was observed that the 40% structural with 60% Non-Structural Adhesive resin combination at 100 mm bond length with circular cavity textured at 10 % fractional area produced a better retrofit of the structure.**

Keywords— Retrofitting; surface preparation; CFRP Patch; surface bonding; load capability.

I. INTRODUCTION

Carbon fiber reinforced polymer composites (CFRP) are used in many aerospace applications as it has high strength to weight ratio. In reality, most structural applications require to bond CFRP with metal frames to retrofit the damaged structures or to a form complete structure [1]. Nowadays CFRP patches are considered for repairing the weaker section.

Adhesive bonding is the process of joining similar or dissimilar components with the application of a thin layer of adhesive. An adhesive joint can be a reversible or irreversible based on the selected adhesive and joint configuration. The main advantage of this adhesive bonding is that it can be used to join thin components (similar or dissimilar) and components with different thickness.

The main problem with adhesive bonding of metal plates with CFRP is its low strength. Adhesion mechanisms that occur between CFRP and Metals are categorized as, a) chemical bonding such as Van der Waals forces and b) mechanical Interlocking between adhesive and substrate [4]. In order to vary the mechanical interlocking of surfaces, pre-surface preparation is needed, which includes grit blasting, sand blasting and etching etc. The mechanical interlocking provides by allowing adhesive to wet the cavities and asperities of adherent surfaces and curing it to full solidification. In most cases, rough surface is good for better mechanical interlocking between the adhesive and adherend. However, the surface asperity dimension must be controlled in such way that the avoid the formation should be minimized. the voids at the bottom of the surface irregularities may generates regions of stress concentrations which are not desirable [2].

The strength of a component may decrease as it undergoes for many damaging conditions during its service like corrosion, erosion, hydrogen cracks, earth quake, structures continues to age and deteriorate, etc. it leads to failure of the component, in order to ensure the safe working condition, it must be repaired or replaced. The traditional repairing technics like welding, riveting, nuts and bolts etc. may induce residual stresses in the material, may increases the weight of the components and may not provide a better seal. Hence, these factors may affect the working efficiency. In order to avoid such difficulties, nowadays bonding CFRP patches to the weaker sections are considered to be an alternative and cost-effective strengthening method. The damaged sites which are fixed by the composite patch are 50% cheaper than metallic wraps and replacement methods [3].

The aim of the present study is to enhance the bond strength by optimizing the structural and non-structural adhesives, bond length and the surface texture of the adherend.

II. MATERIALS:

In this work the following materials were used 1) Aluminium Plates (AA 6082 T6) of 125 x 25 x 6 mm, 2) Unidirectional carbon fiber (12KUD-300 Gsm), 3) Two parts non-structural epoxy adhesive system (Araldite- LY 1564 & Aradur-22962) and 4) two parts structural epoxy adhesive system (Araldite AW106-Hardener HV953U).

Note:

Al=Aluminium Plates (AA 6082 T6), SA=Structural Epoxy adhesive, NS=Non-Structural Epoxy adhesive, SB=Sand Blasted, E-80= 80 grit size emery paper abraded surface, C-2 and C-10= Circular cavity with 2% and 10 % fractional area, S-2 and S-10 Square cavity with 2% and 10 % fractional area.

Specimen Labelling: First and second positions represents the materials to be joined, third position represents bond length, fourth position shows surface preparation and fifth position shows SA-NS epoxy mixer.

III. SAMPLE PREPARATION AND EXPERIMENTATION:

Aluminium AA 6082-T6 plates have been taken with following dimensions 125 x 25 x 6 mm. the surfaces with different surface morphologies have been created before the application of patch. The surface preparation considered as 1) abraded using 80 grit SiC paper 2) Sand Blasted with 0.35-micron size particles and 3) circler and square cavities made with chemical etching on sanded surface. the fig.1 shows the adherend surface prepared with different surface treatments and the fig.2 shows the schematic representation of different cavities created with etching. Structural epoxy adhesive was mixed in 0, 10, 40, 70 and 100 percentages in the structural and non-structural mixer. The carbon fiber has been taken in the following dimensions 30 x 25, 40 x 25, 50 x 25, 80 x 25, 100 x 25, 130 x 25 and 140 x 25 mm.

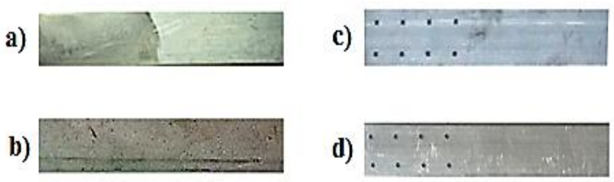

Fig.1. a) Abraded surface, b) Sand blasted surface, c) Square cavity by chemical etching d) Circular cavity chemical etching.

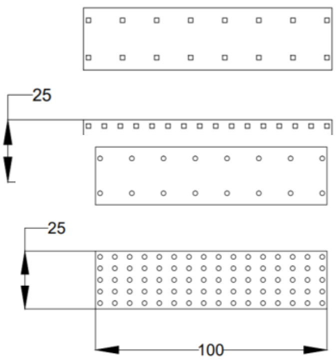

Fig.2. schematic representation of square and circler cavities with 2% and 10% fractional area spread over the 100mm bond length.

A. Preparation of Al-CFRP-Al bond:

The surfaces to be joined have been cleaned with acetone to remove oil, dust and scales from the surfaces. Kept them perfectly horizontal with a gap less than 2mm in a jig to minimize the edge effect. The structural and non-structural epoxy adhesives were blended homogeneously then applied in the gap between the plates and a thin layer over the adhered surface. A carbon fiber layer has been kept over the mixed epoxy layer in the bond length location as shown in the fig. 3 (a). The alternative layers of epoxy and carbon fiber has been laid until 3 layers of carbon fiber impregnates with epoxy. All the samples were prepared in the atmospheric curing condition.

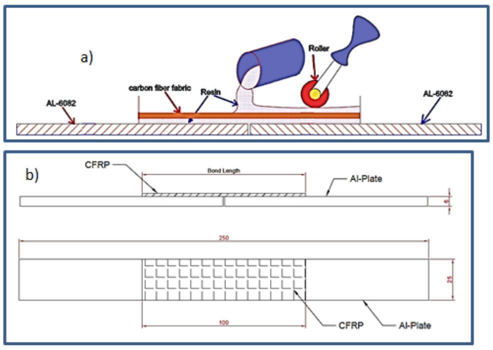

Fig. 3. a) Fabrication process of Al-CFRP-Al adhesive joint, b) Dimensions of Al-CFRP-Al adhesive joint.

IV. RESULTS AND DISCUSSION:

The specimens were mechanically tested with Universal testing machine with a 100 kN load cell [monotonic tensile loading using M/s.Jin Ahn Testing, China]. The loading rate was 0.5 mm/min, and all tests were performed at room temperature.

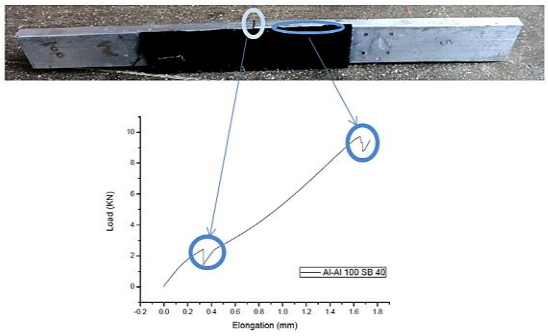

Fig.4. Load Vs Elongation of Al-Al 100 SB 40 Specimens

The tensile test of Al-CFRP-Al bonded samples were done. The test results were plotted between the load and elongation, the fig.4 shows the load vs elongation response of Al-Al 100 SB 40 specimen. From the fig.4 it is observed that the curve shows the hyperbolic exponential growth until about 20% of its ultimate load, it is because of the load distribution between Al-Al through epoxy mixer (tensile load) and Al-CFRP-Al bond (Shear Load), later a sudden drop of 5% load has been observed, it was because of the adhesive bond failure between Al- Al cross section. Further the load applied on the specimen was acted upon the bonded area between Al-CFRP-Al and shows an exponential growth until it reaches to its ultimate load and failed by de-bonding between CFRP and Al.

A. Selection of Epoxy Combination:

To get a strong bond between a metal and a polymer, the structural adhesive system must be used, and it should have good wettability (low viscosity), the structural adhesive (Araldite AW106-Hardener HV953U) that chosen for this research have high viscosity, hence the wettability was poor. An attempt has been made to increase the wettability of the adhesive by adding low viscous two parts non-structural epoxy resin (Araldite-LY 1564 & Aradur-22962 mixed as per manufacturer data) in 0, 10, 40, 70 and100 ratios. The fig: 5 (a) Shows the effect of adhesive percentage (Araldite-AW 106 & Hardener-HV 953 U) in SA-NS mixer on load capability of sand blasted joint with 100 mm bond length. As the percentage of adhesive increases from 0 to 40 the joint load capacity increases from 4.62 kN to 9.71 kN. Further increase in adhesive percentage from 40 to 100 the wettability of the epoxy mixer decreases (Viscosity increases) and the penetration ability through carbon fiber decreases hence become a poor joint.

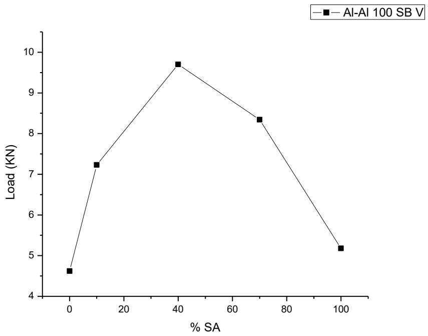

Fig. 5. (a) Effect of SA-NS combination on bond strength.

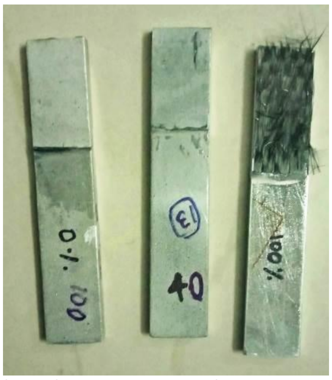

Fig. 5. (b) Surface after tensile test (Left side with 0%, Middle with 40% and Right side with 100% SA in epoxy mix).

From the fig.5 (b), it has been observed that, at 0% SA-NS epoxy adhesive sample fractured surface revealed that there was no adhesive residue on the metal surface that implies that the inter-laminar force is greater than adhesive force; hence there was no damage to the base material. The middle sample prepared with 40% SA-NS epoxy adhesive, the fractured surface showing a small amount of residue of the CFRP on de-bonded area that implies that the adhesion and inter-laminar forces are optimal in the epoxy mixer hence it was shown a good load capability. The right-side sample made with 100% SA-NS adhesive, the fractured surface shows rupture of the carbon fibers, it is because of the inter-laminar shear in the carbon fibers, where the adhesive force is very much higher than the inter-laminar shear force. Form the above set of experiments it has been concluded that joint with 40% SA-NS epoxy mixer exhibits the better joint strength.

B. Selection of Bond Length:

The optimal bond length is the length beyond which there is no significant change in the bond strength. As the bond length increases, the adhesive surface increases which in turn increase the load capacity but it is limited to certain bond length later the increased bond has no significance. In order to find the optimal bond length, a series of experiments were performed by varying bond lengths of Al-CFRP-Al bonded joint at 40% SA-NS epoxy combination on sand blasted surface as shown in fig.6.(a), The results were plotted between load vs bond length as shown in fig.6.(b), the results revealed that the increased bond length from 30 to 50 mm may increase the load capacity by 100 % (from 4 to 8 kN), from 50 to 100 mm bond length the load capacity increase by 21 % (8 to 9.7 kN), from 100 to 140 mm bond length the load capacity increase by 3 % (9.7 to 10 kN). From the above analysis 100 mm bond length has been considered for further experimentation.

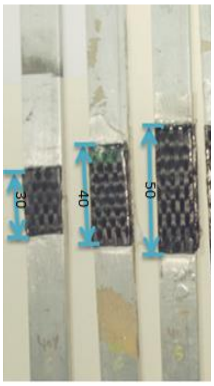

Fig.6. (a) Different bond lengths (mm)

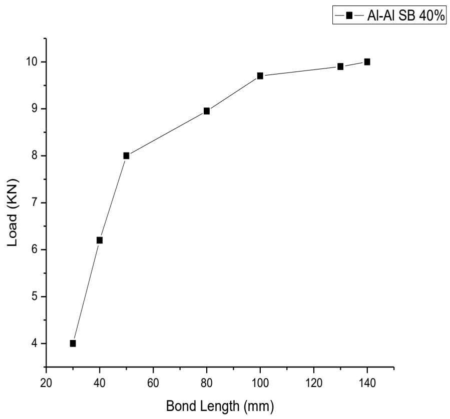

Fig.6. (b) Effect of bond length on load capacity

C. Selection of Surface Preparation:

A proper surface for the adhesive bonding is the one which provides good surface energy in order to have good wet out. From the above two experiments, the adhesive bond length and epoxy combinations were considered as 100mm and 40%. A series of experiments were performed to investigate the effect surface preparation on Al-CFRP-Al joint load capacity. The surface preparation considered for this work as 1) abraded using the SiC paper 2) sand blasted with 0.35-micron size particles and 3) cavities with chemical etching with 150 µm. The dimensions for chemical etching as shown in Table 1.

TABLE.1. CAVITY DIMENSIONS FOR CHEMICAL ETCHING

Cavities	**Dimensions (mm)**	**Fractional surface area (mm^2)**
Circular (Diameter)	2	2
Circular (Diameter)	2	10
Square (Side)	1.8	2
Square (Side)	1.8	10

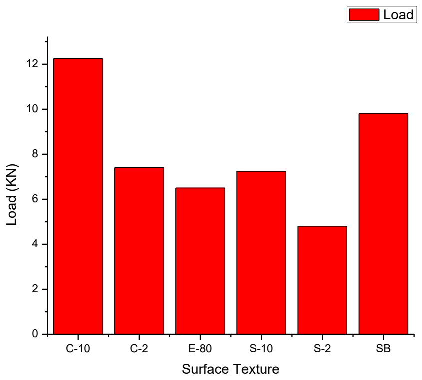

Fig.7. Surface texture effect on load capacity

The fig.7, shows tensile load capacity of joints made with various surfaces morphologies of adherents. It was concluded that the sample Al-Al 100 C-10 40 exhibits a better bond load capacity (12.25 kN). This may be because of the increased surface area (with in the designed bond length) and wettability texture.

V. CONCLUSIONS:

The present work mimics the retrofitting of the Aluminium structures using CFRP Patch and explores various parametric effects on bond strength. The load capacity of the joint is found to increase with 40 % epoxy combination. The optimum load capacity has been found at 100 mm bond. The surface preparation has also showed a significant effect on load capacity, the joint made with circular cavities of 2mm diameter and 150 microns deep spread over the bonded surface with the area fraction 10% was increased the bond load capacity by 25% over sand blasted surface.

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