Experimental study to increase the strength of the adhesive bond by increasing the surface area arrangement

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Abstract. This research represents an experimental and numerical tensile study to investigate the effect of adding epoxy and both sides of two specimens on the shear stress at which the failure of the bond occurs. Also, the effect of the of epoxy bond arrangements on the toughness and the area of contact were investigated. Fifteen specimens in three arrangements are used for the tensile test. In the first arrangement (case 1) the epoxy bond is placed in between the steel specimens. In the second arrangement (case 2), the epoxy bond is placed between the steel specimens and it extended 5 cm outward from both sides. In the third arrangement, the epoxy bond is placed between the steel specimens and it extended 10 cm outward from both sides. These arrangements used to increase the contact area of the bond. The single Lap – Simple bond type is used for this study. The experimental and numerical results show a good agreement. The arrangement of the epoxy bond is found to have a strong impact on the mechanical behavior. The shear stress increase by 500% in case of arrangement 3.

Keywords: increasing strength, Adhesive bond, Epoxy, surface area

1. Introduction

Over the last decades, composite materials have been used significantly in all engineering and became a dominant class of materials for wide range of applications, like spacecrafts and building structure. Also the military industries have been using composite material widely for high performance applications where the cost is secondary. Technological developments in composite materials have been accompanied with development in adhesive bonds. The bonded joints have become a complementary of the traditional mechanical fasteners in composite materials and metallic structure. The use of adhesively bonded joints are very common in such structures due to the longer service life, improved load distribution, lower machining cost and less complexity. In addition to that, the recent
advances in the filed of epoxies and adhesives lead to higher temperature sustainable adhesives which increases the integrity of the structure under severe operating environment.

There are many types of the adhesive bonds. Focusing on our study, the adhesive bonds can be classified according to their configurations into four groups

1.1 Single Lap
This configuration is very simple and active. There are three types of it (Simple, Beveled and Radlused) as shown in figure (1-1a). The single Lap – Simple type is chosen for this study.

1.2 Double Lap
This configuration has three types (Simple, Beveled and Radlused) as shown n figure (1-1b).

1.3 Scarf
(Single Taper, Double Taper and Increased Thickness) as shown in figure (1-1c),

1.4 Strip
This configuration has three types (Single Strip, Double strip and Beveled Strip). as shown in figure (1- 1d).

Figure 1. Configurations of adhesive bonds
2. Literature Review

In recent years, more attention has been paid to the use of adhesive–bonded joints. The use of adhesive bonding offers additional advantages over the traditional jointing methods. These advantages are fatigue and corrosion resistance, lighter weight, crack retardation, good damping, and cost saving [1]. Mechanical performance of adhesive bonded joints depends on a number of parameters such as: material properties and joint geometry (adhesive thickness, adherend thickness), surface roughness etc.

Many experiments have been conducted to investigate the relation between the adhesive layer thickness and its shear strength [2]. Numerous experiments have been conducted to determine the strength and the fracture behavior of material pieces adhesively jointed for different bond geometries. These experiments investigated the effect of bond geometry on the crack path propagation and the assessment of fracture initiation criteria [3]. In another work, a simplified model has been developed to evaluate the stress distribution in the adhesive layer of double-lap joint (DLJ) under a cyclic tensile lap-shear load. The adhesive material was assumed to follow the constitutive relation of elastic perfectly shear stress-strain [4]. The effect of adhesive bond thickness on the mechanical behavior of polyurethane adhesive for automotive applications [5]. The effect of adhesive bond thickness on the fracture toughness was tested for thickness range from 0.2 to 2 mm. Specimens were fabricated from hard tool steel. The fracture toughness was found to increase with thickness of the adhesive bond. It increases by 20% for thickness between 1 and 2 mm and linearly between 0.2 and 1 mm. Another experimental work was conducted to investigate the effect of surface roughness of different adhered sheets on the strength of the adhesive bond [6]. The adhered sheets were from wood and Aluminum. Sand papers and emery papers were used to obtain different degree of roughness sheets. The results revealed that there is a direct effect of roughness on the strength of the adhesive bond. For the wood, the adhesive bond strength was found to decrease with the increase of the roughness. For the Aluminum the roughness has an optimum value because the strength of adhesive bond increase first and then tend to decrease with the roughness increase. Measurements were conducted to investigate the effect of specimen geometry on strength of single lap adhesive bond. The effects of adhesive bond length and thickness on the failure load were investigated. The failure load was found to increase linearly with the increase of bond length for bond thickness of 1.5 mm. The bond thickness was found to have a variant effect on the failure load. The optimum thickness was 0.5 mm.

The works from literature reveal that there is not enough contribution in the field of studying the effect of the epoxy bond arrangements on the mechanical behavior. The present work represents an experimental and numerical investigation to examine the effect of adhesive bond length and arrangement in term of the contact area on the shear stress and toughness.
3. Experimental Method

In the current study, specimens used for the tests are made from Steel and with one type of epoxy. The chemical composition for steel used in this study as in the table (1).

| Symbol | Element   | Concentration (%) | Symbol  | Element   | Concentration (%) |
|--------|-----------|-------------------|--------|-----------|-------------------|
| Mg     | Magnesium | 0.023             | Cu     | Copper    | 0.4061            |
| Al     | Aluminum  | 0.0053            | Zn     | Zinc      | 0.0063            |
| Si     | Silicon   | 0.0019            | As     | Arsenic   | 0.01143           |
| P      | Phosphorus| 0.0012            | Zr     | Zirconium | 0.05              |
| S      | Sulfur    | 0.002             | Nb     | Niobium   | 0.0013            |
| Ti     | Titanium  | 0.0019            | Mo     | Molybdenum| 0.124             |
| V      | Vanadium  | 0.0016            | Ag     | Sliver    | 0.001             |
| Cr     | Chromium  | 0.1776            | Cd     | Cadmium   | 0.00069           |
| Mn     | Manganese | 0.678             | Sn     | Tin       | 0.001             |
| Fe     | Iron      | 97.13             | Sb     | Antimony  | 0.0012            |
| Co     | Cobalt    | 0.296             | W      | Tungsten  | 0.0075            |
| Ni     | Nickel    | 0.1639            | Pb     | Lead      | 0.0014            |
| C      | Carbon    | 1                 |        |           |                   |

The Epoxy used in this study is a low strength adhesive paste. When fully cured, the adhesive has good chemical resistance and good sustainability at high temperatures. It is suitable for bonding a wide variety of metals, ceramics, glass rubbers, rigid plastics and other materials and is widely used in many industrial applications where resistance normal environments.

The properties of the materials used in this study are shown in table (2). The properties of Steel and adhesive were obtained with web material databases.

| Material Properties                  | Adhreends Steel | Adhesives Epoxy |
|--------------------------------------|-----------------|-----------------|
| (Ultimate tensile strength (MPa)     | 1000*690        | 60              |
| (Ultimate shear strength (MPa)       | 1000*80         | 50              |
| (Young's modulus (MPa)               | 1000*200        | 12              |
3.1. Specimen

Three specimens of different arrangements were used in this study for tensile test as shown in figure. The number of specimens used in this study (5) for each configuration as shown in figure 3. The test device used in this study is universal test device as shown in figure 4.

Figure 2. Specimens arrangements
Figure 3. Specimens used in this study

Figure 4. Universal test device
4. Numerical Work

The two dimension problem is analyzed by the finite element method using the APDL program ANSYS. In this study the specimens is represented by plane element (Plane182), this element used for planes stress structure model. As shown in Figure (5). The element has two degree of freedom, all of them translations (u and v). After defining the element type, the material properties must be defined. The material properties used are listed in Table (2) for Steel and Epoxy.

![Plane182 element](image)

Figure 5. Plane182 element

After limited the element type and the material properties, used the rectangular element and mesh the all areas of specimen (the steel and epoxy) as shown in Figure (6). For two case.

![Meshing of the Specimens](image)

Figure 6. Meshing of the Specimens

5. Result and discussions

Results from experimental and numerical investigation of the effect of epoxy bond arrangement on the shear stress, toughness and elastic region are presented.

Figure 7 represent a comparison of the shear stress from experimental and numerical results from ANSYS. A god agreement can be seen between the numerical and experimental results since the average
error is less than 17%. The shear stress increases as the contact area of the epoxy increases due to different arrangements. Figures 8 and 9 show the contours of stress distribution for arrangement 1 and 2.

Also, the contact area was found to play a dominant role in toughness. The toughness increases with the area of contact as shown in Figure 10. The toughness increased by 5.7 times in case of arrangement 3 as compared with arrangement 1. The relation between the elastic region and area of contact is shown in Figure 11. The elastic region changes non-linearly with the area of contact.

![Figure 7. The Comparison between the Experimental and numerical results](image1)

![Figure 8. The Shear Stress Dis. On the resin (arrangement 1)](image2)
Figure 9. The Shear Stress Dis. On the resin (arrangement 2)

Figure 10. The relation between the Toughness and contact area
6. CONCLUSIONS

The present work is an experimental tensile study of the effect of epoxy bond contact area on the shear stress of the failure, the toughness and the elastic region of the bond. Fifteen specimens of three arrangements were used of tests. It was found that the contact region has a significant influence on the shear stress, toughness and elastic region.

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