International Journal of Adhesion and Adhesives 80 (2018) 128–132

Contents lists available at ScienceDirect

International Journal of Adhesion and Adhesives

journal homepage: www.elsevier.com/locate/ijadhadh

Experimental investigation of the effects of adhesive defects on the single lap joint strength

F. Heidarpour, M. Farahani*, P. Ghabezi

School of Mechanical Engineering, College of Engineering, University of Tehran, Iran

A R T I C L E I N F O

Keywords:
Adhesive joint
Single lap joint
2D Defect
3D Defect
Joint strength

A B S T R A C T

For robust design of the joints in the engineering structures, it is necessary to determine the stress and strain under a certain load and predict the failure potential. Adhesive joints are susceptible to defect and separation, especially the joints with high overlap area. The aim of this study is the experimental investigation on the influences of the size and shape of 2D and 3D defects on the ultimate shear strength of the adhesive single lap joints. So, square, triangular and circular defects with different sizes are artificially embedded into the Araldite 2015 adhesive layer of the Aluminum 2024-T3 joints. The artificially defective samples are examined under the axial tensile tests according to ASTM D1002-01 standard. In the case of the single lap joints with 3D defects, there is an approximately linear decrease in the joint strength as the defect area increases. However, when 2D defects are applied in adhesive joint, a non-linear decrease in the joint strength is observed. Actually, the joint strength decreases gradually when the defect area/overlap area is smaller than 30%. The decline rate in the joint strength for bigger defect is more sever, indicating that the edges of the overlap area become more important as the local strains exceeding the limiting values in this zone. The survey about the defect shape show that the least decline in the strength of single lap joints occurs with circular defects. The greatest disparity in reducing the strength compared to the other 2D and 3D defects is approximately 11% and 8%, respectively. Based on the experimental results, functions are proposed to estimate the ultimate strength in defected samples with respect to defect-free samples.

1. Introduction

The use of adhesive joints is growing in engineering applications due to their many advantages compared to mechanical joints. The reasons why adhesive bonding is so desirable compared to other conventional joining methods are listed below [1,2]:

- Often, thinner gage materials can be used with attendant weight and cost savings.
- The number of production parts can be reduced, whereas the design is more simplified.
- The need for milling, machining and forming operation of details is reduced.
- Large area bonds can be made with a minimum work force without special skills.
- Adhesive bonding provides a high strength to weight ratio with three times higher the shearing force of riveted joints.
- Improved aerodynamic/hydrodynamic smoothness and visual appearance.
- Use as a seal, and/or corrosion preventer when joining incompatible materials.
- Excellent electrical and thermal insulation.
- Superior fatigue resistance. Adhesively bonded assemblies have shown a fatigue life twenty times better than riveted structures of identical parts.
- Often, the adhesive is sufficiently flexible to allow for the variations in coefficients of thermal expansion when joining dissimilar materials.

In the recent years, such joints have been extensively used in the composite fiber reinforced structures. Classic joints often required to cut the fibers which consequently reduce the structural integrity. Adhesive joints are used for a wide variety of applications from traditional industries, such as construction, sporting goods and packaging to advanced industries such as aircraft, aerospace, electronics and automotive.

The joint strength can be largely improved by surface treatment. Forming an adequate surface chemistry is the most important step in

* Corresponding author.
E-mail address: mrfarahani@ut.ac.ir (M. Farahani).

http://dx.doi.org/10.1016/j.ijadhadh.2017.08.005
Accepted 1 August 2017
Available online 24 August 2017

Table 1
Mechanical properties of Al 2024-T3 (manufacturer data sheet[a]).

Poisson's ratio	Elastic modulus	Ultimate strength	Yield strength
0.33	73.1 (GPa)	480 (MPa)	345 (MPa)

[a] CRP MECCANICA S.r.l.

Table 2
Mechanical properties of Araldite 2015.[a]

Tensile strength at 23 °C	Shear modulus	Elastic modulus	Elongation at break
30 (MPa)	711.5 (MPa)	1850 (MPa)	4.4%

[a] According to manufacturer data sheet (Huntsman company).

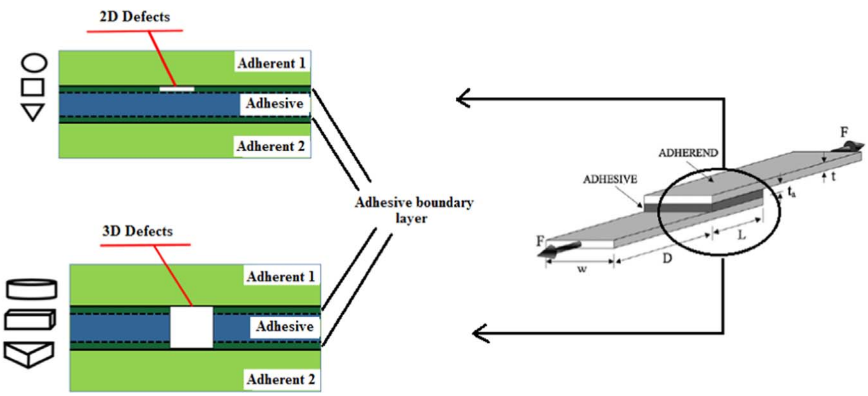

Fig. 1. Schematic representation of two-dimensional and three-dimensional defects in the adhesive joint [15].

surface preparation. As it is emphasized by Davis and Bond, surface integrity directly affects the joint continuity [3]. The surface plays an important role in adhesion process and is probably the most important parameter in evaluating the quality of an adhesive joint [4]. A suitable pre-treatment before applying adhesives can broadly improve the surface properties in order to reach the highest mechanical strength.

Schonhorn et al. [5] illustrated that the shear strength of a single lap joint, comprising a brittle adhesive (two-part epoxy), is governed essentially by the edge of the joint. In fact, creating a disbond at the middle of the overlap could not decrease the strength of the joint significantly. The single lap joint is the most common type of connection, because of its simplicity and efficiency; but one of the downsides of this joint is the fact that the stress distribution (shear and peel) is concentrated at the edge of the overlap area. Designers used different methods to improve the efficiency of single lap joints, including changing the geometry of the jointed parts [6,7] and changing the geometry of adhesive and overlap area [8,9].

Ribeiro et al. [10] have investigated the mechanical behavior of single-lap joints with defects centered in the adhesive layer for different overlap lengths and adhesives, experimentally and numerically. The numerical analysis by cohesive zone models (CZM) included the analysis of the peel and shear stress distributions in the adhesive layer, the CZM damage variable study and the strength prediction. The joints' behavior was accurately characterized by CZM and showed a distinct behavior as a function of the defect size, depending on the adhesive.

De Moura et al. [11] evaluated the influence of strip defects on the mechanical behavior of composite bonded joints. Experimental tests were performed using carbon-epoxy single-lap bonded joints. Numerical simulations included the interface finite elements with a mixed-mode damage model based on the indirect use of fracture mechanics. The interface finite elements allow the calculation of stresses at the adherent–adhesive interfaces and the damage model allows the simulation of damage initiation and growth. The application of this model for a single-lap joint is presented. The influence of a defect on the stress fields, joint strength and type of failure was evaluated. It was verified that specific strength of the joints was not affected by the size of the defect. The numerical results showed good agreement with the experimental ones.

Khoran et al. [12] used a full factorial experimental design to assess the importance of the manufacturing parameters. Digital photography technique was used to evaluate the induced damages. Ghabezi et al. [13] have investigated the bridging and the cohesive mechanism of adhesive bonded joints, including Nano-composite and nano-adhesive for mode I fracture. Nano-composite adherents with glass fibers and alumina nano-particle have been fabricated and underwent Double Cantilever Beam tests [18]. The concentration of this study is on the comparison of three different types of traction-separation laws and the effect of nanoparticle employment [19].

One of the problems that exist in adhesive joints, especially joints with high overlap area, is the poor adhesive distribution on the junction surface, which could be caused by human error or improper surface quality of the adherents [20]. Poor bonding can form 2D (planar) and 3D (volumetric) defects which can be detected by NDT[1] inspection. Karachaliosa et al. [14] examined circular and square defects in a single lap steel joint. Their results show that when a high strength piece is used for the joint, the strength decreases linearly as the size of the defect is increased, but the strength decreases non-linearly when medium or low strength steel is used.

The ability to predict the strength of the defective adhesive joint and evaluate the effects of defect parameters on the joint strength are necessary. The goal of this study is to experimentally examine the effect of the size and shape of 2D and 3D defects with square, triangular and circular geometries in the single lap adhesive joints on their ultimate strength, which is little addressed in the existing literatures.

2. Experimental detail

2.1. Materials and specimen preparation

Epoxy based Araldite 2015 adhesive is used to joint 2 mm thick 2024-T3 aluminum alloy sheets according to ASTM D1002-01 standard. The adhesive thickness and overlap length are 0.5 mm and 25.4 mm, respectively. The mechanical properties of the employed aluminum alloy are presented in Table 1.

Table 2 shows the mechanical properties of the Araldite 2015 adhesive that is used in the single lap joint.

PVC[2] sheets with 0.05 mm thickness and foams with 0.5 mm thickness in different shapes and sizes are used to create defects in the 2D and 3D form in the single lap adhesive joints. PVC sheets (foam sheet) are cut to the intended shape and dimension. They are covered

[1] Non-Destructive test.
[2] Polyvinyl chloride.