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Failure load prediction of single lap adhesive joints based on a new linear elastic criterion

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ABSTRACT

In this study a new failure criterion has been proposed to predict the static strength of single lap adhesive joints under tensile loading. The criterion is based on a simple 2D linear elastic finite element analysis and two material and geometry parameters. According to this method, the longitudinal strain magnitude along the adhesive layer is used as a failure parameter. The criterion suggests that fracture occurs when the failure parameter along the adhesive mid-plane reaches a critical value at a critical distance. Failure loads are also determined experimentally for a series of single lap adhesive joints of different bonding lengths. It is shown that the predictions based on the proposed criterion have good agreements with the experimental data.

1. Introduction

Applications of adhesive joints as an alternative to welding, riveting and other traditional fasteners have been greatly increased in structures and industries such as aircraft and automobile. Compared with conventional methods, the adhesive joints have certain advantages such as more efficient and uniform stress distribution along the bonding plane, rather lower weight, joining thin and dissimilar materials and also improving corrosion resistance.

Considering the extensive use of adhesive joints, understanding the failure mechanisms is important for this type of bonding. The prediction of failure load in adhesive joints depends on several factors such as the joint geometry and the phenomena related to bi-material interface. Researchers have developed numerous failure criteria to estimate the fracture loads for a variety of adhesive bonding configurations. Among different joint configurations, single lap joint (SLJ) has received more attention by researchers because of its simplicity and efficiency. But singularity in the shear and peel stress/strain distribution at the ends of the overlap has made the analysis of SLJs difficult. Some of the classical articles on single lap joints were published by Volkersen [1], Goland and Reissner [2] and Hart-Smith [3]. They proposed analytical solutions for stress fields in single lap adhesive joints which were later used in some failure criteria. Tong [4] used Goland and Reissner method [2] and proposed a failure criterion based on nonlinear adhesive material properties and a global/local analysis procedure. He used shear and peel strain energy rate and studied single lap joints and lap shear joints. Fraisse [5] also used Goland and Reissner [2] stress distribution to apply *J* integral as a failure criterion. Some other researchers proposed a critical stress as failure parameter. For example Rahman et al. [6] employed peel stress and crack tip opening angle technique to predict failure strength of adhesive joints. Martiny et al. [7] made use of maximum stress at a point to evaluate the failure loads in the joints. In some other studies, shear strain along the adhesive layer was proposed for estimating failure loads in adhesive bondings (see for example Tong [4], Morais et al. [8] and Karachalios et al. [9]). For short overlap SLJs, Karachalios et al. [9] and Crocombe [10], recommended global yielding as a failure estimation criterion. As another failure parameter, critical energy was used by Fernlund et al. [11], Baziard et al. [12], Chen et al. [13] and Hell et al. [14]. Stress singularity at the overlap ends of SLJ prompted some other researchers to study failure in adhesive joints based on generalized stress intensity factor and within the framework of linear elastic fracture mechanics (see, for instance, Barroso et al. [15] and Groth [16]). *J*-integral and similar fracture mechanic based models were also used in some studies [5,17,18] to estimate failure load in cracked single lap adhesive joints.

As described above, various parameters have been proposed to predict failure loads in SLJs. Each method has its own advantages and disadvantages. However, those methods which are both simple and accurate in estimation of the failure load are more favorite for engineers and researchers. Such methods enable the engineers

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Table 1
Mechanical properties of the adherent and the adhesive.

Material	E (GPa)	υ
Al 7075-T6	72.3	0.3
Epoxy-Minute [20]	2.5	0.3

Table 2
Dimensions of the single lap joints (mm).

Joint no.	Bonding length, L	Adhesive thickness, t	Width of joint, w	Adherent thickness, T
A	108	0.35	12.55	3
B	71			
C	50			
D	35			

to estimate the dimensions of the joints in the early stages of design without complicated calculations.

In this paper a new strain based criterion has been introduced which could predict the failure load in single lap adhesive joints very well. The proposed criterion is based on the longitudinal strain along the adhesive layer. The criterion is also applied to some experiments performed on SLJs with similar geometry but different overlap lengths.

In the following sections, the geometry of test specimens and experimental details are discussed. Then after introducing the proposed criterion, some finite element analyses (FEA) are performed using the concepts of the new failure model. A comparison between the experimental and predicted failure loads is presented later. Finally, for further validation of the new method, it is applied to some test results which have been published previously in the literature [8,19].

2. Experiments

2.1. Specimen and material

Al 7075-T6 was used as adherent and "Epoxy-Minute", a two-part epoxy-based paste (produced by Weicon-WEICON GmbH & Co. KG), was used as adhesive in the experiments. The adhesive and adherent mechanical properties are given in Table 1. The mechanical properties of the adherent were obtained experimentally from a standard tensile test, and the adhesive properties were taken from the Weicon technical data sheets [20].

Single lap joints were made with similar configurations but in various bonding lengths. Fig. 1 shows a schematic picture of the joint and the test specimen. Two tabs were attached to the end of the joints to ensure alignment between the load and the mid-plane of the adhesive. Different dimensions of the joints are given in Table 2.

2.2. Joint preparation and test results

For surface preparation, the adherent surfaces were pre-treated by chromic acid. The etching process was performed with a solution of sulfuric acid, sodium dichromate, and the de-ionized water. The etching solution was maintained at about 71 °C and the aluminum parts were allowed to stay in that for about 15 min. Then the test specimens were taken out and were sprayed in tap water for another 5 min. Finally the test specimens were dried thoroughly at about 50 °C.

The adherents were bonded with the adhesive within 2 h after the surface preparation and then the joints cured at room temperature for about 72 h.

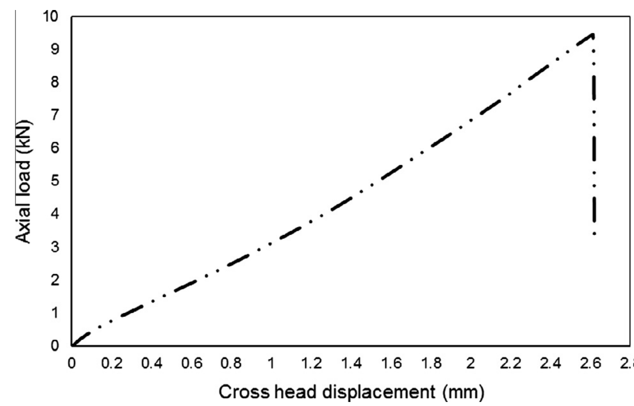

Fig. 2. Load–displacement diagram for joint series D.

Two or three specimens for each configuration were fabricated and tested in a tensile test machine under displacement control conditions with a displacement rate of 1 mm/min. During the tests, the load was increased up to complete debonding of the joints. The maximum load which resulted in complete debonding was recorded in each test. Fig. 2 shows a typical load–displacement diagram for joint D which is almost linear.

Fig. 3a shows the joint D in clamped condition in the test machine after debonding and Fig. 3b displays a sample fracture surface in the joint A.

3. Proposed failure criterion

A new distance based method has been proposed for failure load prediction of single lap adhesive joints as a popular configuration in adhesive bonding. The proposed method is based on a specific longitudinal strain along the adhesive mid-plane. According to this method, failure occurs when the longitudinal strain along the adhesive mid-plane reaches a critical value at a specified critical distance. The critical longitudinal strain and the critical distance are two major parameters of the proposed criterion which are obtained experimentally. Since the critical longitudinal strain is the main parameter in failure load prediction, the method is called CLS (Critical Longitudinal Strain) criterion.

To determine the CLS constants, two different single lap adhesive joints with similar geometry and material but different in bonding lengths should be tested under tensile static loading up

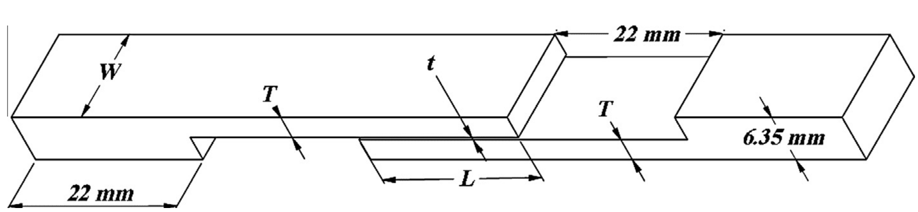

Fig. 1. Schematic picture of the specimen.