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Dynamic strength of single lap joints with similar and dissimilar adherends

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ABSTRACT

The increased use of adhesives for joining structural parts demands a thorough understanding of their load carrying capacity. The strength of the adhesive joints depends on several factors such as the joint geometry, adhesive type, adherend properties and also on the loading conditions. Particularly polymer based adhesives exhibit sensitivity to loading rate and therefore it is important to understand their behavior under impact like situations. The effect of similar versus dissimilar adherends on the dynamic strength of adhesive lap joints is addressed in this study. The dynamic strength is evaluated using the split-cylinder lap joint geometry in a split Hopkinson pressure bar setup. The commercial adhesive Araldite 2014 is used for preparing the joints. The adherend materials considered included steel and aluminum. The results of the study indicated that the dynamic strength of the lap joint is influenced by the adherend material and also by the adherent combination. Even in the case of joints with similar adherends, the strength was affected by the adherend type. The strength of steel–steel joints was higher than that for aluminum–aluminum joints. In the case of dissimilar adherends, the strength was lower than that of the case of similar adherends. The results of this study indicate that the combination of adherend material should also be accounted for while designing lap joints.

1. Introduction

Compared to riveted and welded joints, adhesive joints require minimal changes in the geometry of adherends and also do not alter the basic properties of the adherends. Further, the load transfer is more uniform and to a large extent the joint is leak proof. Because of these advantages the use of adhesive joints in commercial products, automobiles and even in sectors like aerospace is significantly on the rise [1]. One of the important concerns from a designer's perspective is evaluation of the joint strength. The strength of the joint could depend on the type of adhesive, the surface preparation of the adherends, adherend material, operating temperature and the loading conditions. Adhesive joints can also be subjected to impact type loading where the rate of loading is higher. Typical examples are automotive crash, bird impact in aircrafts, sudden loads as in landing of aircraft etc. to mention a few. Polymer based adhesives are known to exhibit sensitivity to loading rate and therefore evaluating the joint strength under dynamic loading conditions becomes important. One of the major advantages of adhesive bonding is the capability to join dissimilar materials. Typical examples could be joining metals to plastics and composites in secondary structural elements of automobiles and aircrafts. Adhesive manufacturers invariably provide the lap strength of adhesives obtained with a particular adherend material at slow loading rates. The effect of dissimilar adherends on the strength also should be understood to garner the full potential of adhesive joints successfully in commercial applications.

There are several reported studies addressing the effect of adherend stiffness on the strength of adhesive joints with similar and dissimilar adherends subjected to static loading. Cheng et al. [2] studied the stress distribution in single lap joints having different adherend thicknesses and adherends made of different materials. They reported that the ratio of the elastic moduli of the adherends has a significant effect on the maximum shear and normal stresses in the adhesive layer. Sawa et al. [3] investigated the effect of adherend elastic modulus on the stress at the interface between the adhesive and the adherend and reported that the peak interface stress increases with a decrease in the elastic modulus of the adherend. For dissimilar lap joints, Sawa et al. [4] investigated the effect of the adherend elastic modulus ratio on the stress distribution at the interface between the adhesive layer and the adherends using analytical and numerical techniques. They observed that, as the elastic modulus of one of the adherends decreases, the stress singularity near the edge of

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the adhesive at the interface with adherend having lower elastic modulus increases. It should be noted here that the adhesive thickness in the joints considered in [3,4] is comparable to the adherend thickness, which is not common in lap joints. Silva and Adams [5] reported that for joints involving dissimilar adherends, use of a dual adhesive proves to be advantageous. Recently, Reis et al. [6] investigated the effect of adherend rigidity on the strength of single lap joints subject to quasi-static loads. They observed that the joint strength was higher with stiffer adherends in the case of similar adherends. In the case of dissimilar adherends, the joint strength was in between the joint strength corresponding to each adherend material in a similar adherend configuration. Afendi et al. [7] also investigated the strength of adhesively bonded scarf joints with dissimilar adherends. These investigations clearly indicate that the stiffness of the adherend for both similar and dissimilar adherends is one of the factors that can affect the stress distribution and therefore the strength of single lap joints.

The behavior of adhesive lap joints when subject to dynamic loading has been addressed by many researchers. There are a number of different approaches to determine the dynamic strength. These include the instrumented impact technique [8], drop weight testing [9] and the set up described by Kilhara et al. [10]. Recent years have seen the use of the split Hopkinson pressure bar (SHPB) to evaluate the lap strength and butt strength of adhesive joints [11–15]. Various specimen geometries have been proposed for evaluating the dynamic lap strength using the SHPB technique. These include the split-cylinder specimen suggested by Srivastava et al. [11], the pin-collar specimen proposed by Yokoyama and Shimizu [12] and the simple lap joint specimen used by Adamvalli and Parameswaran [13]. These investigations report that the dynamic strength of the lap joints can be 2 to 3 times higher than the static strength.

There are also several numerical investigations addressing the stress distribution in the adhesive for lap joints subjected to dynamic loads. Sato et al. [16] studied the dynamic deformation of lap joints and scarf joints under impact loads. Higuchi et al. [17] investigated the stress distribution in adhesive lap joints with similar adherends subjected to impact loading. They observed that the peak stresses at the interface between the adherends and the adhesive increases as the adherend elastic modulus increases. This is contrary to what has been observed by the same authors [3] for static loading. Sawa et al. [18] investigated the effect of elastic modulus ratio on the stress distribution in lap joints having dissimilar adherends, subjected to impact loading. They observed that as the elastic modulus ratio increases, the peak stress also increases. These investigations [3,4,17,18] indicate that the effect of elastic modulus ratio on the stress distribution in the adhesive is not the same under static and dynamic loads. Very recently, Liao et al. [19] have performed an experimental and numerical investigation on the mechanical properties of single lap joints with dissimilar adherends subjected to impact tensile loading.

The present study focuses on understanding the effect of adherend material and adherend combination on the dynamic strength of single lap joints prepared using the commercial adhesive Araldite 2014 (manufactured by Huntsman) when subjected to high rates of loading. To the best of our knowledge, the effect of adherend combination on the strength and stress distribution in single lap joints subjected to very high rate of loading as obtained in the SHPB test is not reported in literature. Steel–steel (SS), aluminum–aluminum (AA) and steel–aluminum (SA) joints are considered. The split-cylinder lap joint geometry [10] is employed. The dynamic loading is achieved by using a split Hopkinson pressure bar (SHPB) apparatus. In order to understand the stress distribution in the joints, three-dimensional finite element (FE) simulations of the joints subject to impact loading is also carried out using the commercial FE software ABAQUS-explicit. The details of specimen preparation, testing, FE modeling and the results from experiments and FE simulations are discussed in the following sections.

2. Experimental details

2.1. Specimen preparation

The adherends used were SS304 steel and Aluminum 6106. Potential applications of Aluminum 6106 include marine applications, railway rolling stock, automotive structures etc. The SS304 and Al-6106 materials were procured commercially. The split-cylinder geometry shown in Fig. 1(a) was used. The surface preparation used is as follows. The bonding surfaces were cleaned with acetone to remove traces of previous adhesive if any. Then the surfaces were abraded with fine grit abrasive paper at $\pm 45^\circ$ to the loading direction and then cleaned with methanol. The adherends were then weighed and paired together. The thickness of the adherends at different locations along their length was measured for each pair of adherends and the average thickness was recorded.

Araldite 2014, manufactured by Hutsman is a two part epoxy based adhesive which cures at room temperature. This adhesive is recommended for bonding metallic and composite adherends as per the technical data provided by the manufactures. The properties of the adhesive are given in Table 1. Araldite 2014 has two parts, resin and hardener and the recommended ratio of resin to hardener is 100:50 by weight. Once mixed, the pot life of the adhesive is only 40 min. The premixed adhesive was applied to one of the adherends. Then the two adherends were assembled and smeared slightly so that the mixture spreads uniformly and then left in a fixture for curing as shown in Fig. 1(b). Care was exercised to ensure that the loading faces of the specimen remain parallel to each other. After curing, any excessive adhesive which spilled out of the joint was cleaned and the joint was weighed again. The net weight of the adhesive in the joint was calculated.

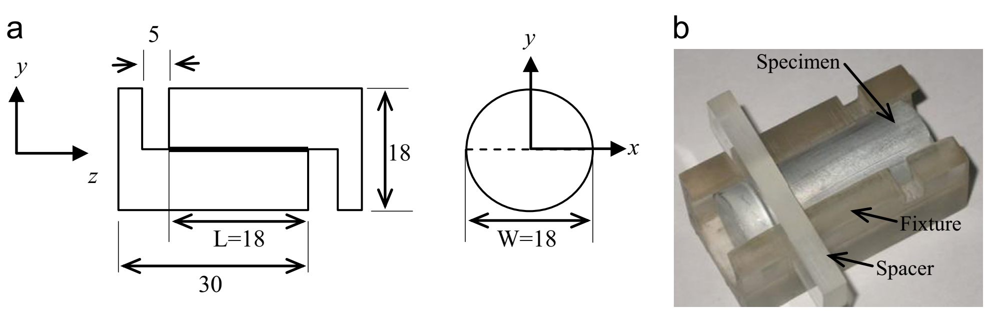

Fig. 1. (a) Specimen geometry (all dimensions in mm), (b) assembled specimen in fixture.