

Experimental Study on Failure Mechanism of Single Lap-shear Bond Joint with Dissimilar Materials

S H Chung¹, B C Park¹, H J Chun¹ and J C Park²

¹Department of Mechanical Engineering, Yonsei University, Seoul, Republic of Korea

²Commercial Vehicle CAE Team, Hyundai Motor Group, Hwaseong, Republic of Korea

E-mail: hjchun@yonsei.ac.kr

Abstract. The use of bond joints has increased recently, owing to a number of advantages they have over mechanical fasteners. However, most relevant studies have focused on bond joints with the same adherends. In this study, a quasi-static tensile test was conducted to investigate the failure mechanism of bond joints, considering different overlap lengths and dissimilar adherends. In the experiments, two modes of failure were observed: the interfacial and cohesive failure modes. The experiments showed that the length of separation of an overlap area through the interfacial failure was almost the same for different specimens.

1. Introduction

Adhesive joints are being increasingly used in the aerospace, automotive, and other industries where conventional fasteners, such as bolts, rivets, and welding are typically used. Although adhesive joints need extensive surface preparation and pre-treatment, they have a number of advantages over traditional fasteners, including savings in terms of time and cost, higher strength-to-weight ratio, corrosion and fatigue resistance, crack retardance, and damping characteristics, among others. [1, 2] Adhesive joints also allow the avoidance of machining the adherends and stress concentration in the vicinity of the resultant holes, which affect the overall load-carrying capacity of the joints. In other words, bond joints transfer loads more efficiently than mechanically fastened joints. In spite of these many advantages, it is difficult to predict the failure of bond. This is because the failure load and failure mode of bond joints are different from various other bonding methods and parameters. [3, 4] Many researchers have attempted to predict the failure load of bond joint and different models have been proposed. Sheppard et al. proposed a damage zone model based on a critical damage zone size and strain-based failure criteria to predict the failure load of bond joints. [5] In the damage zone model, joint failure regions appeared to be insensitive to finite element mesh refinement and the regions could be predicted. Apalak and Engin studied the initiation and propagation of damaged zones in the adherends and adhesive layer of adhesive single and double lap joints. [6] In their study, non-linearity of both the adhesive and adherends was considered. After interfacial failure was occurred, damaged zone growth was observed in the end of adhesive regions because of lateral straining. In the fracture mechanics approaches, a cohesive zone model was suggested to predict the failure load. Fracture mechanics uses an energy-based failure criterion, such as the J-integral or critical energy release rate. However, the cohesive zone model is appropriate for analyzing the fracture behavior of bond joints when the adherends considered only to have elastic deformation.



Hart-Smith first suggested the elasto-plasticity model. [7] The growth of the plastic deformation area in the elasto-plasticity adhesive layer of different types of adhesive bonded joints was examined, and the plastic deformation areas appearing at the free ends of the adhesive layer were shown. In the elasto-plasticity model, stress-strain curve of adhesive should be obtained through the coupon test. However, in the elasto-plasticity model, Hart-Smith neglected the normal stresses acting on the adhesive layer which might be the principal reason of joint failure.

There have been many studies on the failure mechanism and failure prediction of bond joints. However, most of them have focused on bond joints using the same adherends. Thus, in this study, a quasi-static tensile test was conducted to investigate the failure mechanism of single lap-shear bond joints with dissimilar adherends.

2. Material and methods

2.1. Material properties

Al6061-T6 aluminum and SS400 steel were used as adherends, while Araldite AV138/HV998 was used as the adhesive in the bond joints in this study. Metal adherends were tested to obtain mechanical properties and the test method was in accordance with ASTM E8/E8M-13, which is the standard test method for tension of metallic materials. Adhesive bulk tensile test specimens were manufactured and tested. The test method was in accordance with ASTM D638, which is the standard test method for tensile properties of plastics. A vacuum desiccator was used before the curing process to remove the air bubbles within the adhesive. Additionally, a vacuum bag was used to remove the air bubbles when the adhesive was cured at high temperature.

A universal testing machine (MTS 810) was used for the tensile test. Load was applied by stroke control at a rate of 2 mm/min for the adherends and 0.3 mm/min for the adhesive. A strain gage was attached to the center of the specimens to measure Young's modulus and Poisson's ratio. The strain signal was measured using a dynamic strain meter and the data was recorded on a PC through an A/D converter. The mechanical properties of the adhesive and adherends are shown in Table 1.

Table 1. Mechanical properties of adhesive and metals.

	Young's modulus (GPa)	Ultimate strength (MPa)	Poisson's ratio
AV138/HV998	4.5	41.04	0.35
Al6061-T6	68.9	310	0.33
SS400	190	400	0.26

2.2. Specimens and experimental procedures of bond joint

In this study, the bond joints were designed for single lap-shear testing according to ASTM D1002, which is the standard test method for apparent shear strength of single-lap-joint adhesively bonded metal specimens. The dimensions of the bond joints were changed when the joints were made to observe the change of failure mode and failure load. The geometry of the bond joint specimens is shown in Figure 1. The specimens of bond joint are shown in Figure 2.

A universal testing machine (MTS 810) was used and load was applied by stroke control at a rate of 0.5 mm/min, which is the standard for ASTM D1002. The experimental setup is shown in Figure 3. Three specimens were tested for each test condition and the mean value was taken.

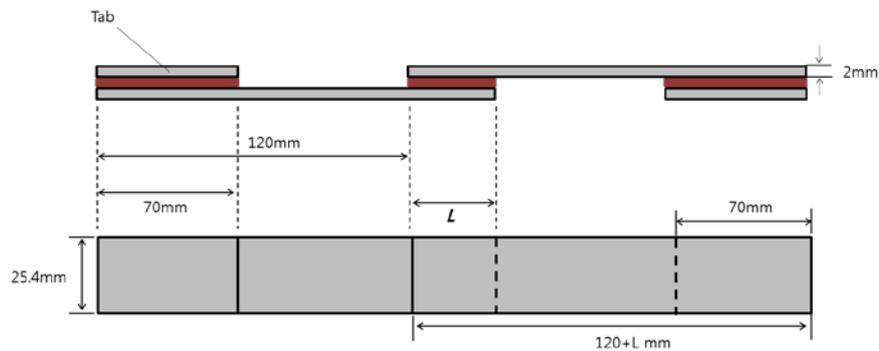


Figure 1. Specimen geometry of bond joint.

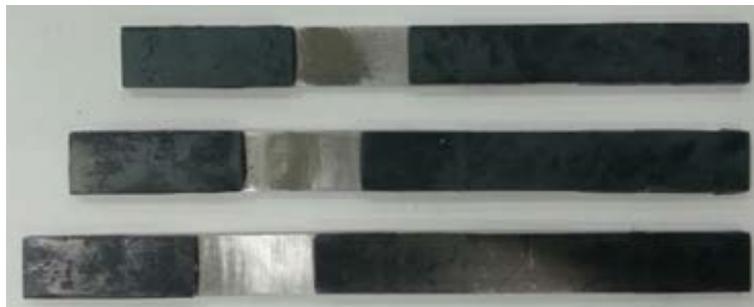


Figure 2. Specimen of dissimilar metal bond joint; overlap length: 20 mm, 40 mm, and 60 mm.



Figure 3. Experimental setup of single lap-shear test.

3. Results and discussion

3.1. Failure modes of single lap-shear bond joints

The failure modes of single-lap bond joints could be divided into cohesive failure and interfacial failure, as shown in Figure 4. The failure modes depend on the mechanical properties of the adhesive and adherends. The cohesive failure occurred when the adhesive is separated to both adherends. This failure mode was very radical and the crack initiation could not be observed. It can be inferred that the crack initiation and final failure occurred at the same time. Interfacial failure was a progressive damage occurring with plastic deformation of the adhesive along the bonded boundary. In this failure mode, the crack initiated in both ends of the overlap region and propagated along the interface

between adhesive and adherend. [8] However, in our experiment, cohesive and interfacial failure modes are usually observed together.



Figure 4. Failure modes of adhesive joints.

3.2. Single lap-shear bond joints with dissimilar metal adherends

In order to investigate the failure load and failure mode of the adhesive joints of dissimilar materials, Al6061-T6 aluminum and SS400 steel adherends, as well as AV138 / HV998 adhesive were used. From the experimental results, a boundary line was observed in the failure surface, as shown in the Figure 5. As mentioned before, the two modes of failure were observed with the interfacial mode occurring first. Additionally, experiments showed that the length of separation of an overlap area through the interfacial failure were almost the same for different specimens.

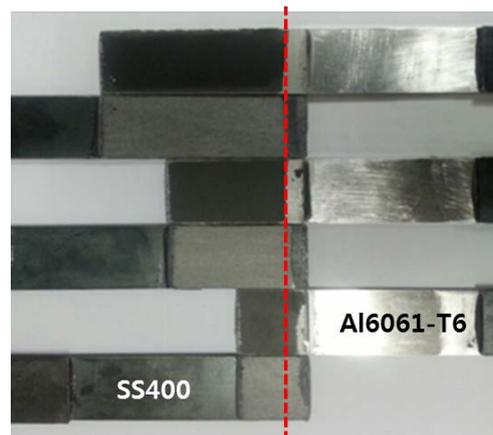


Figure 5. Surfaces of the failed specimens.

As P.N.B Reis et al. studied the effects of asymmetric properties of bond joints, the flexural rigidity of adherends played a major role in the performance of the bond joints. [8] In this study, SS400 steel adherend, which has approximately three times the elastic modulus of Al6061-T6 aluminum, was used and compared with joints between aluminum adherends. Compared to the same adherends joints, in this case Al6061-T6/Al6061-T6, using a stiffer material in a dissimilar joint, in our case SS400/Al6061-T6, resulted in larger overall flexural rigidity of the joint, which caused smaller bending rotation as well. Consequently, the smaller bending rotation of the joint causes the lower out of plane stress at the end of the adhesive joint. Thus, as shown in Figure 6, the failure loads of SS400/Al6061-T6 joints are larger than the failure loads of Al6061-T6/Al6061-T6 joints.

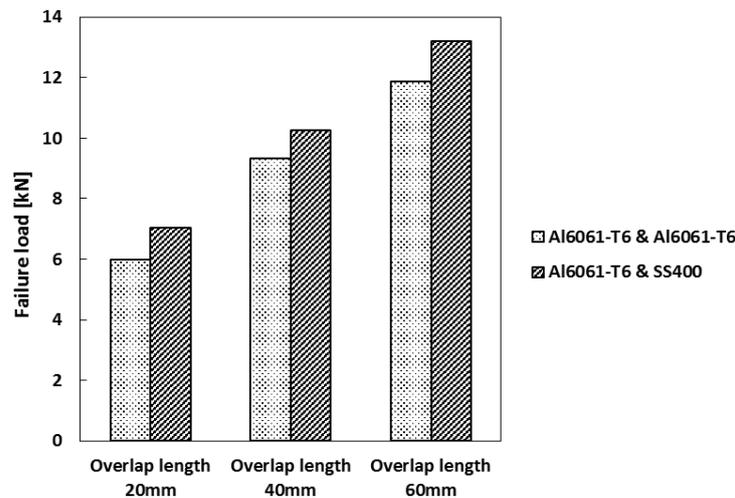


Figure 6. Failure loads of bond joints with same and dissimilar adherends.

4. Conclusion

The results of this study confirmed that the failure loads of bond joints with dissimilar adherends, in our case SS400/Al6061-T6, were larger than the failure loads of bond joints with same adherends, in this case Al6061-T6/Al6061-T6. Experimental investigations were conducted to elucidate the failure mechanism of single lap-shear bond joints, while taking into account the effects of the elastic modulus of adherends. From the experimental results, cohesive and interfacial failure modes of single lap-shear bond joint were observed together. The length of separation of an overlap area through the interfacial failure were almost the same for different specimens.

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