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Experimental and numerical analysis on the adhesive T-joint using high temperature adhesive

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Abstract. The adhesive T-joint is most widely used in automotive, aircraft and fluidization bed system. In order to determine the effect of the temperature and adhesive thickness on the joint strength, a series of a tensile test and numerical analysis were conducted in this study. The T-joint specimens were fabricated using 304 stainless steel plate (SS 304), 304 stainless steel perforated plate and high-temperature epoxy adhesive. The series of adhesive T-joints with different adhesive thicknesses (0.5, 1.0, 1.5 and 2.0 mm) were tested in tension loading at room temperature (RT) and elevated temperature (55 °C, 75 °C, 100 °C and 125 °C). Additionally, the T-joint structure was modelled, simulated and analysed for stress assessment to predict the strength of adhesive T-joint at the various temperature and adhesive thicknesses. The average failure stress decreases with the increasing of the temperature. Nevertheless, the failure stress of the T-joint decreased with the increasing of the adhesive thickness. The finite element prediction for T-joint strength is in a good agreement with the experimental failure stress results.

Keywords. T-joint, temperature, adhesive thickness, finite element prediction.

1. Introduction

Historically, mechanical joining techniques were involved nails, screws, bolts and rivets. The adhesive bonding is inadequate compared to normal adhesive for binding the book, paper, woodworking, and packaging process [1]. The adhesive was based on the animals, rubber from the wood and tree resins. In 19th-century, due to the technical and systematic interest, the researchers improved the adhesion properties. Sometimes, materials or parts were operated in high-temperatures, high-pressures, high speeds or highly- erosive environment. Thus, the adhesive behaviour towards the applied situation needs to be characterized in order to get a properly designed joint. Another important parameter that needs to be emphasized is the effect of the adhesive thickness at the different temperatures on the joint strength [2].

Adhesive property is one of the basic processes in adhesion where it heavily influencing the strength of the joint [1]. Joint performance (operating environment, load), adhesive type, substrates type, cost, aesthetics, health necessities, application, manufacturing process and pre-treatments are several important aspects in selecting the adhesives in the fabrication process. Other than that, testing and validation are required in order to verify process quality [3].

Numerous studies on the effect of temperature on the adhesive behaviour have been conducted. The tensile test experiment on a urethane structural adhesive at different temperature i.e (50 °C, 60 °C and 70 °C) was investigated by [4]. The experimental results have demonstrated that stress-strain behaviour is dependent on the temperature. Apart from that, [5] investigated the effect of temperature on the

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cohesive properties of an epoxy adhesive. It was reported that the fracture toughness is fairly unaffected by the temperature from -40 °C to 80 °C. The glass transition of the epoxy adhesive investigated is 90 °C meanwhile the peak stress in peeling loading decreased monotonically with increasing temperature within this temperature range. At glass transition temperature, Tg there is a rapid reduction in both modulus and strength when the temperature increases, and leads the adhesive to no longer carry a substantial load.

2. Experimental detail

2.1. Materials

The adhesives used in this study was E 214 HP, which is one of the component structural Hysol line by Henkel. The adhesives recommended to be used with metals for high temperatures application. The glass transition temperature, Tg was provided for E 214 HP: 120 °C. The curing schedule for two hour at 120 °C was follow for adhesive. The properties for material used to fabricate the adhesive T-joint presented in Table 1.

Table 1: Material properties of adhesive and adherent

Material properties	Elastic modulus (MPa)	Poisson's ratio
304 Stainless steel	193000	0.31
Hysol Adhesive	1887	0.39

2.2. Specimen Fabrication

2.2.1. Adhesive T-joint Fabrication

In this research, a jig was prepared for the T-joint fabrication process. The jig was used to assist the alignment of the base plate and perforated plate with respect to each other during curing process and functions as a fixture to control the adhesive thickness such as shown in Figure 1. The thicknesses of T-joint adhesive are 0.5, 1.0, 1.5 and 2.0 mm respectively. All fabricated adhesive T-joint specimens were cured at 120 °C using a furnace for two hours as illustrated in Figure 2.

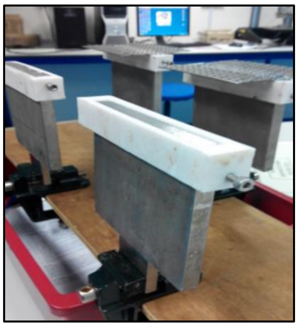

Figure 1. T-joint preparation

Figure 2. Curing of adhesive T-joint in furnace

2.3. Test Procedure

Tensile test for fabricated adhesive T-joint specimens was conducted by using Shimadzu AG-IS MS Universal Tensile Testing Machine (UTM) with a load capacity of 250 kN at temperature of RT, 55 °C,

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75 °C, 100 °C and 125 °C at a constant crosshead speed of 1 mm/min. The thermostatic chamber model of TC- N300 SHIMADZU was used to retain the surrounding temperature for applied temperature test. The test temperature was set at the chamber, and a thermocouple was applied to the specimen to obtain an equilibrium of the sample. The specimen was then kept in the chamber at a chosen constant temperature for 30 minutes before conducting the tensile test. Five specimen of the adhesive T-joint with difference adhesive thicknesses; 0.5, 1.0, 1.5, 2.0 mm were undergo the tensile test at this elevated temperature.

3. Finite element modelling of Adhesive T-joint

Similar T-joint geometry model with various adhesive thicknesses used in the experimental testing were modelled using a SolidWork simulation software. The drawings of the T-joint models with selected adhesive thicknesses imported to ANSYS 14.5 software. The linear elastic isotropic and Multi-linear Isotropic Hardening (MISO) was set for adherent and adhesive respectively. In finite element (FE) analysis, the part of the modelling was divided into adherent (304 stainless steel) and adhesive (E 214HP Hysol). The mechanical properties of the adherent is referring to the Table 1. For the meshing size, the maximum sizes of adhesive and perforated plate are 0.5 mm and 1.0 mm for base plate (as shown in Figure 3) respectively. All the boundary condition of the modelling was set same as the experimental condition before run the finite element simulation (as shown in the Figure 4). In order to predict the failure of the adhesive T-joint, the threshold of the stress concentration was identified by using FE model analysis. The maximum Von Misses Stress of the adhesive T-joint was obtain by referring to the technical data from the experiment. The distribution of Von Mises Stress and deformation were calculated.

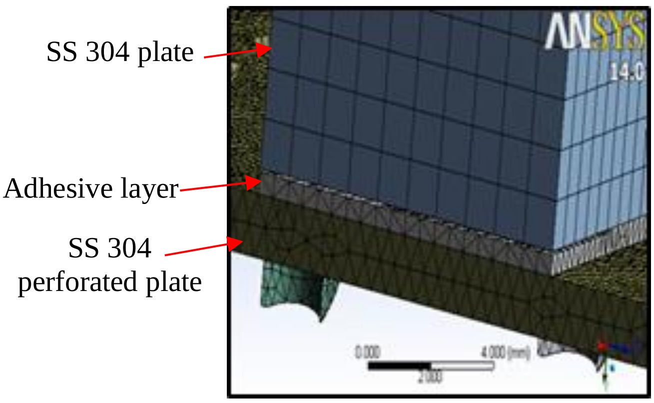

Figure 3. Meshing

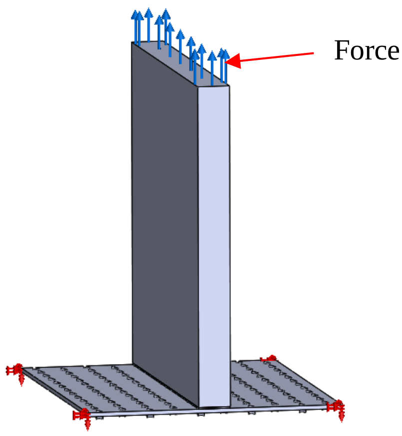

Figure 4. The loading condition force at T-joint

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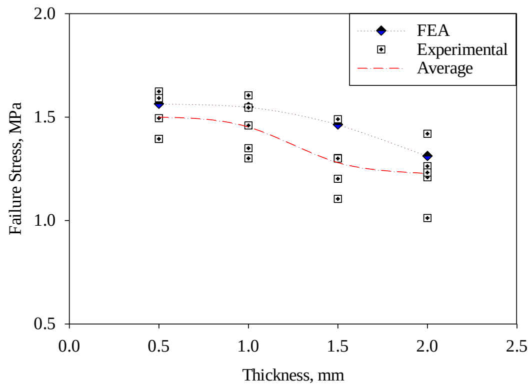
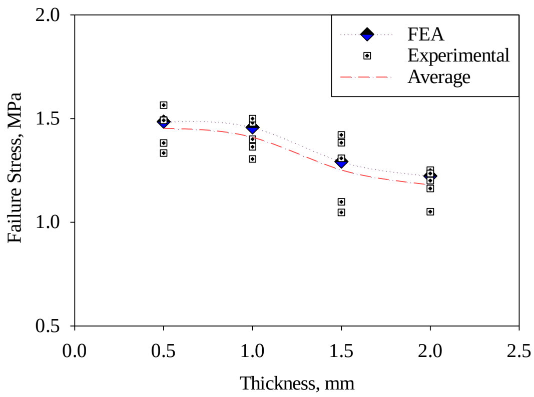
4. Result & Discussion

4.1. Results of the numerical analysis and the comparison between experimental results

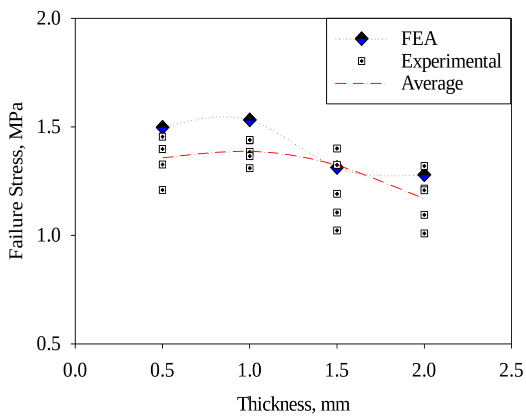
There was a general trend of decrease in T-joint strength with increasing adhesive thickness. Meanwhile, the strength of the T-joint also significantly decreased with the increasing temperature. The optimum thickness is 0.5 mm while the T-joint being the least strong at 2.0 mm adhesive thickness. Hence, 0.5 and 1.0 mm adhesive thickness only have a small difference of failure load. Despites, larger flaws probability as thicker adhesive means potentially more defect in joint such as entrapped air, a gap at edges due to difficulty to apply adhesive at that area, not consistent mixing and many more flaws can possibly reduce overall strength of the joint seating [6]. In Figure 5, the results for the average experimental for the T-joint specimens at RT, 55 °C, 75 °C, 100 °C and 125 °C are depicted. The parameter attained it maximum failure stress at RT and the lowest is at 125 °C. It should be mentioned that at 125 °C, is exceeded the Tg values of the adhesive, which is the factor to explains the clear drastic drop in tensile strength of the T-joint. The results from the numerical analysis showed almost similar pattern with the experimental results.



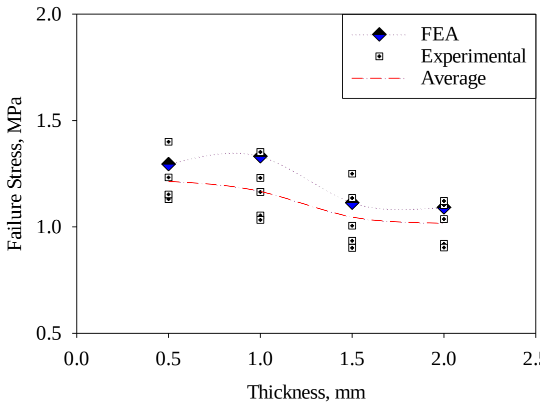
(a) RT



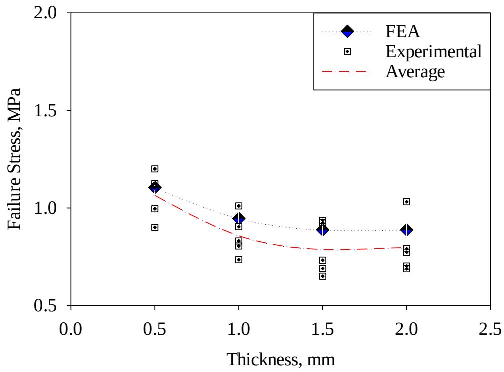
(b) 55 °C



(c) 75 °C



(d) 100 °C



(e) 125 °C

Figure 5: Comparison of failure stress against adhesive thicknesses at a) RT, b) 55 °C, c) 75 °C, d) 100 °C and e) 125 °C

5. Conclusions

As a conclusion, the failure stress was found to be greatly related to the temperature and adhesive thickness. There are only small reductions of T-joint failure stress at RT until 100 °C. However, the failure stress of adhesive T-joint decreases significantly at temperature 100 °C due to the testing temperature already overpasses the Tg of the adhesive. Besides, the adhesive T-joint with adhesive thickness of 0.5 mm to 1.0 mm revealed the optimum value of adhesive T-joint strength for entire bond-line thickness. The FE analysis results for adhesive T-joint shows good agreement by having the same pattern in terms of failure stress in experimental results.

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