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An investigation into the effects of fabric reinforcements in the bonding surface on failure response and transverse impact behavior of adhesively bonded dissimilar joints

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ABSTRACT

The purpose of the current study is to evaluate the failure response and transverse impact behavior of adhesively bonded dissimilar single-lap composite joints fabricated by using fiber-reinforced polymer. The adherend materials utilized for the experimental tests were AA6082-T6 and glass fiber reinforced polymer (GFRP) in the form of thin sheets. The adhesive used was a warm to hot curing epoxy system (Araldite LY 1564 SP/Aradur 3487 BD) manufactured by Huntsman. In this study, some modifications were provided to enhance the failure response of single-lap composite joints. These modifications comprise the addition of different type and number of fabric reinforcements in the bonding surface. Based upon the test results, an increase of 33.6% in the failure load at room temperature is obtained for the joint fabricated by the addition of double-layer glass fabric reinforcement in the bonding surface. However, the failure load of all types of joint modifications decreases with the increasing tensile test temperature from room temperature to 75 °C. Similarly, tensile tests of the same specimen also resulted in double failure displacement by comparison with the adhesively bonded joint through only epoxy without any fabric reinforcement. The effect of low velocity impact on the failure response of the joints at the impact energy level of 2.5 J is also evaluated. From the tensile tests subsequent to impact treatment, it was found that the transverse impact significantly reduced the failure load of all types of joint modifications. However, the adopted modifications provided tensile failure loads over 1875 N and 1270 N for the joint fabricated by using double-layer carbon and glass fabric reinforcements, respectively.

1. Introduction

AA6082 (Al-Mg-Si alloy), a medium strength aluminum alloy, is a precipitation hardenable material widely used in aircraft, automotive, aerospace and recreation industries. Its good resistance to corrosion, low cost, convenience of processing and high mechanical properties makes this alloy an ideal material for many structural applications [1–3]. Besides this alloy, composite materials have also been commonly used in turbine blades, automotive and aerospace industry and other engineering fields due to their low density and superior strength to weight ratio [4]. Owing to these attractive properties, aluminium alloys and composites can be used commonly as adherend materials in adhesively bonded single-lap and double-lap composite joints.

Joining of similar and dissimilar materials such as glass fiber reinforced polymer (GFRP) composite and aluminum alloy is quite important so as to provide good mechanical performance to structures and obtaining cost-effective and attractive assemblies. GFRP and aluminum alloy composite joints have widespread applications including the marine field such as the bonding of hull to deck, channels running through the deck, sea chests, exhaust system and the engine compartment [5–7]. Therefore, effectual joining of these materials is a prerequisite and a challenging procedure in several applications. Nowadays, adhesive bondings are continuously finding applications in the field of aerospace, automotive and electronics due to the process benefits [8–10]. Therefore, epoxy based adhesive bonding is considered as a promising candidate to join these materials. Adhesive bonding has gathered wide acceptance as a substitute for conventional mechanical connections in many engineering applications due to their higher fatigue life, better resistance to environment, design flexibility and superior weight performance [5,11]. In addition to aforementioned

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properties, many adhesive-bonded joints present cost reduction and short production times [12]. However, considerable environmental effects such as thermal cycles, moisture and UV radiation are known to affect the long-term durability of epoxy adhesives and reinforced polymers [13]. Adhesive joints also have low fracture toughness and the process sometimes requires complex and delicate preparation [14].

Over the last decade, several researchers carried out experimental and numerical studies regarding the application of adhesives and adhesive joints in various studies [15–18]. In a recent study, Yokoyama and Nakai [19] investigated the impact tensile strength of epoxy resin based adhesive butt joints with dissimilar adherends through a modified split Hopkinson pressure bar. The influences of loading rate, adherend material and adhesive thickness on the tensile strength of the joint were also evaluated. Zhao and Xu [20] studied the effect of bonding areas on strengths of polymer/polymer, metal/metal, and polymer/metal similar and dissimilar joints. Marami et al. [21], proposed to enhance the mechanical properties of adhesively bonded joints using different weight fractions of Reduced Graphene Oxide (RGO). They also described a finite element (FE) model to estimate the failure strength of RGO reinforced adhesive bonded single lap joints. Sayman et al. [22], reported the effects of previously applied axial impacts at different temperatures on tensile properties of single-lap adhesively bonded composite-to-composite joints. The influences of different temperatures and several hole configurations on the load-carrying capacity of adhesively bonded single lap joints were investigated by Arikan et al., [23]. Korayem et al. [24], evaluated the effect of carbon nanotube (CNT) modified epoxy adhesives on the bond behaviors such as bond strength, failure modes and effective bond lengths of double strap joints. Fatigue tests of adhesively-bonded steel lap joints under variable frequency were carried out to investigate the effect of loading frequency on fatigue life of the joints by Reis et al., [25]. Mori and Biwa [26] studied the interaction of Lamb waves with an adhesively-bonded imperfect joint comprised of aluminum alloy plates. Most of these papers are related to different fields of application, especially in the field of aeronautical and mechanical engineering. In addition to this, the new civil engineering applications about adhesive joints with epoxy resin and dissimilar adherends are also studied so as to evaluate the bond length, temperature, curing time, type of adhesives and so forth [27–30]. It can be seen that the above mentioned papers, many of whom focused on adhesively bonded single-lap joints have only dealt with the joint performance without any fabric reinforcement in the bonding surface. Hence, in the present study, single-lap joints manufactured through different fabric reinforcements in the bonding surface is being investigated.

To the best of authors' knowledge, despite a great deal of work presented on the mechanical testing and durability to environmental effects of adhesively-bonded joints with various adherends, there is no study related to the investigation of single-lap joints between GFRP and AA6082-T6 fabricated by epoxy adhesive reinforced with woven E-glass and woven carbon fibers. Compared to the abovementioned papers, this study presents an innovative research with regards to the enhancement of the single-lap joint strength by adding fabric reinforcements in the bonding surface. The primary purpose of this study is to evaluate the combinability of GFRP and AA6082-T6 alloy using fiber-reinforced polymer with acceptable mechanical properties. Within this context, the single-lap joints were manufactured and investigated experimentally at different temperatures (25 °C, 50 °C and 75 °C). Besides, impact tests of the joints at an impact energy level of 2.5 J were conducted at room temperature so as to evaluate the influences of transverse impact on the load-carrying capacities of the joints. Moreover, the effects of number of fabric reinforcements on the bonding surface in terms of tensile properties and impact responses of the joints were also discussed through the load – displacement curves in detail.

2. Experimental study

2.1. Materials

Araldite LY 1564 epoxy resin and Aradur 3487 BD hardener supplied from Huntsman (Switzerland) were used as the adhesive material. The mixing ratio of the resin and the hardener in terms of weight was arranged to be 3:1. Curing temperature and curing time have a strong influence on the mechanical properties of thermosetting epoxies. In other words, there is a range for the curing time and also for the mechanical properties. Therefore, the curing process of the adhesive was performed for three days at room temperature so as to provide a sound bonding. The mechanical properties of the cured (neat formulation) epoxy resin and hardener can be found in Ref. [31] respectively.

Glass fiber reinforced polymer (GFRP) and aluminum alloy were used as the adherend materials. GFRPs were manufactured by vacuum assisted resin infusion method (VARIM). The lay-up configuration of the composite was considered as six layer [0°/90°] woven glass fibre fabrics having a density of 500 g/m^2. AA6082-T6 was also used as the secondary adherend material.

2.2. Mechanical properties of the adherends

Mechanical properties of the composite adherend were determined according to the standards (ASTM D3039-D3410-D7078) by a series of experiments including tensile, compressive, and rail-shear tests, respectively. At least five specimens were tested for each different type of experiments. Mean values and standard deviations of the results are given in Table 1. In the table, longitudinal modulus, transverse modulus, longitudinal tensile strength, transverse tensile strength, longitudinal compressive strength, transverse compressive strength, rail shear strength, and the Poisson's ratio were named as E_1, E_2, X_t, Y_t, X_c, Y_c, S, v_{12}, respectively. Final thicknesses of the composite adherends were measured as 2 mm. Hence, 2 mm aluminum alloy adherend were used to obtain the same thickness. Chemical composition and mechanical properties of the aluminum adherend can be found in Ref. [32], respectively.

2.3. Single lap joint preparation

Primarily, composite and aluminum alloy laminates were cut into a dimension of 25 × 100 mm in accordance with the standard test method of ASTM D5868 – 01 as shown in Fig. 1. Then, surfaces of the composite and aluminum adherends to be bonded to each other were cleaned and roughened with abrasive 60xsandpapers. Afterwards, mixing of the resin and hardener was spread by a small stick to form single-lap composite to aluminum joints. Secondary, to investigate the effects of number of different fabric reinforcements at the bonding surfaces, carbon and glass fabrics having a density of 500 g/m^2 prepared in the dimensions of 25 × 25 mm^2 were placed on the bonding surfaces. Epoxy resin was implemented again. Hence, the specimens were prepared through different number of various fabrics. All specimens were kept at room temperature for three days. It should be noted that the thickness of the bond line was arranged by using aluminum thicker plate with invariant dimensions under the free end of the upper adherend.

Samples without any reinforcement fabric were named as REF in the other subsections. Samples with single-layered and double-layer glass fabric reinforcements were coded as G1 and G2,