Water ageing effect on the strength of adhesively bonded joints

M. Mariam, M. Afendi, M. S. Abdul Majid, and M. J. M. Ridzuan

Citation: AIP Conference Proceedings **2030**, 020039 (2018); doi: 10.1063/1.5066680
View online: https://doi.org/10.1063/1.5066680
View Table of Contents: http://aip.scitation.org/toc/apc/2030/1
Published by the American Institute of Physics

Water Ageing Effect on the Strength of Adhesively Bonded Joints

M Mariam[1,a)], M Afendi[1,b)], M S Abdul Majid[1,c)] and M J M Ridzuan[1,d)]

[1]School of Mechatronic Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia,

[a)]Corresponding author: mariam.bt.majid@gmail.com
[b)] afendirojan@unimap.edu.my
[c)] shukry@unimap.edu.my
[d)]ridzuanjamir@unimap.edu.my

Abstract. Moisture absorption and behaviour in water environment are major concerns for materials as reinforcement in composites. This paper presents a study on the influence of water ageing on mechanical properties and damage locations of the adhesively bonded joint. To this goal, three combinations of adherends were investigated: similar aluminium/aluminium, similar composite/composite and dissimilar aluminium/composite. All joints were bonded using two parts paste of Araldite epoxy adhesive. The vacuum bagging was used to produce composite adherends. The joints were aged in tap water at a temperature of 50 °C for several days of exposure (20, 40, 60 and 80 days). The effect of the immersion treatment on the tensile properties and water absorption were investigated through experiment. Overall, three replicates of joints were characterized by performing single lap joint (SLJs) tests. The moisture absorption results showed that percentage of water absorption increases with increasing of immersion exposure for each materials combination with unsaturation. The reduction of joint tensile strength was observed for each joint materials with the increasing of immersion periods. The huge reduction gap or percentage of dry and wet specimens were detected on similar composite/composite with nearly 50% at the first 20 days of immersion. The damage location and failure of the joint have been observed with cohesive and adhesive failure.

INTRODUCTION

In the automobile industry, the necessities of lightweight materials in automobile parts such as roof, door and engine covers have growth demanding. The challenging have led the industry replacing the commonly used steel to light materials aluminium alloy, fibre reinforced plastic and other types of alloy. Several methods have been introducing in application to joining the materials, such as riveting, bolting, and welding. However, some of the methods are not suitable to be applied to dissimilar materials, especially composite which attributes to high-stress concentration. The joint method has been used as a bonded joint which is require adhesive in the bonding. The choices of adhesive based were important as it can affect the joint strength.

The durability of adhesively bonded joints was examined in a recent research study concerning the environmental effect. Thus, there is some interest highlighted in the study to understand the mechanism degradation and long-term performance of moisture [1-4]. There are several factors that affect the durability and strength of adhesive joints; adhesive thickness, adherend thickness, surface treatment and geometry effect. Meanwhile, environmental factors have been investigated as influential on adhesively bonded joint strength and other mechanical properties. The water absorption can greatly influence the physical and mechanical properties of adhesive which is water diffuse through cracks. Hence, the water may alter the properties of a material in a reversible or irreversible manner [5]. This is leading to a reduction of modulus and strength with a consequent low load-bearing capacity. The epoxies adhesive use in engineering application commonly takes as a saver from the presence of humidity in the harmful environment. The interface and interphase are designated to surface between adhesive and adherend and volume adjacent to the interface, respectively [6]. The adhesive was

Green Design and Manufacture: Advanced and Emerging Applications
AIP Conf. Proc. 2030, 020039-1–020039-6; https://doi.org/10.1063/1.5066680
Published by AIP Publishing. 978-0-7354-1752-6/$30.00

penetrated in the interphase and a little adhesive remains in the bondline for efficient load transfer region [7]. There are several hypotheses were made on adhesive joint durability. One of the assumptions was a decrease in joint strength with increasing exposure time. The behaviour was reported by Hua et al., (2008) when condition the aluminium-composite single lap joint with two-part epoxy adhesive at 50 °C, 95.8% RH [8]. The failure surface was primarily cohesive, in the adhesive layer and close to the interface. The decrease in joint strength may be owing to a combination of adhesive layer and interface strength degradation mechanisms. On the other hands, the observed failure location on the FRP/steel adhesive joint shows that it was initiated from the centre to the critical length of bonded assume as an adhesive failure. The transformation to cohesive failure developed during propagation stage. From the phenomenon, exposure duration significantly influences the joint strength which weakened the interface gap between adherends [1]. Moisture absorption is necessary to measure and characterise the uptake behaviour of an adhesive during environment degradation. An adhesively bonded joint has been manufactured using a variety of adherends, including; metals, composites and polymers, where each material has its own unique response to environmental factors. The water transport for metal adherend was subjected to the oxide layer of materials that attract water molecules due to its polar properties. Within the oxide layer, the mechanism of absorbed water of metals considerably stronger compared with the interaction between metal surface and adhesive in bonding specimen [3]. This can lead to severe and irreversible changes caused by weakening or disrupting adhesion forces, cathodic or galvanic corrosion of the metal substrate. The water transport classification for composite materials was depending on temperature, hygrometric rate and nature of materials. In general, moisture can potentially attack FRP composites by one or a combination of the following mechanisms: (i) altering the resin matrix; (ii) damaging the fibre/matrix interface; (iii) fibre-level degradation.

The purpose of this paper is to elucidate the effect of moisture absorption on joining materials of metal and non-metal. From experimental procedures, the water absorption characteristics and the effect of water absorption on the tensile properties of the adhesively bonded joint have been studied. Therefore, in the present study, mechanical behaviour of tensile loaded single lap joints (SLJs) under the environmental effect of hot water immersion are characterised as follows:

- Aluminium-aluminium (Type I)
- Composite-composite (Type II)
- Aluminium-composite (Type III)

EXPERIMENT METHODOLOGY

Specimen Manufacturing

Two adherend materials were considered in the study; i.e., aluminium alloy A7075 and 17-ply laminates of glass/epoxy composite which was produced using vacuum infusion method. The composite adherends were cut using diamond cutter from solid plate woven glass fibre laminates. Additionally, for adhesive bonding, a two-part paste Araldite epoxy adhesive with a dimension of 0.2 mm thickness was used as a bonding laminate between adherends. The mechanical properties of adherends were tabulated and shown in Table 1. Meanwhile, the mechanical properties of Araldite epoxy adhesive at room temperature was given in Table 2. Also, equilibrium moisture uptake and moisture dependent Young's modulus of the adhesive are given in the Table 2, as examined previously [9]. For the purpose of the study, the SLJs specimen; Type I, Type II and Type III were manufactured using a jig. A total of three joints for each type were tested with a dimension of (160 mm x 40 mm x 6.2 mm). Surface preparation was applied to the aluminium adherends by water-proof abrasive paper and degreased with acetone to remove surface oxide layer of aluminium before drying it with a microfiber cloth. The joint manufacturing was carried out in an environmentally controlled room to avoid excessive dust particles. The two adherends were bonded together using a jig and adhesive was applied on the overlap area. To maintain an adhesive thickness of 0.2 mm, the spacers were used. The dimension of adhesive SLJs was shown in Fig. 1.

TABLE 1. Mechanical properties of adherends.

Material	Ultimate Tensile Strength [MPa]	Yield Stress [MPa]	Elastic Modulus [GPa]	Poisson's ratio v
AA7075	220	95	70	0.33
GFRP	215	79	5.64	0.22

TABLE 2. Mechanical properties of Araldite adhesive at various temperature condition [9].

Environment condition (°C)	Young's modulus (GPa)
Dry (RT)	1.392
Saturation (50°C)	0.426

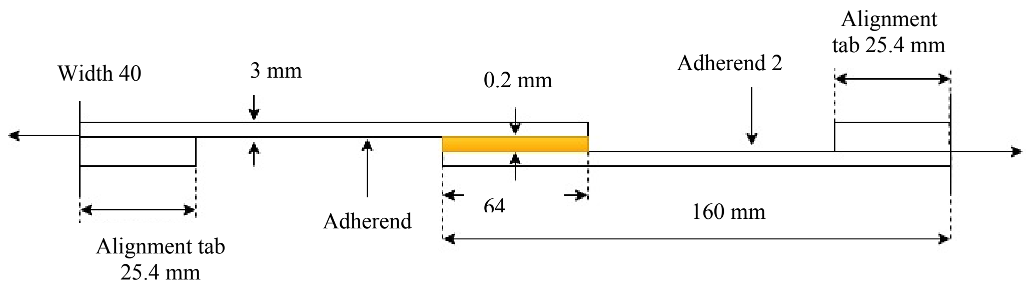


FIGURE 1. A Configuration of adhesive SLJs.

Moisture Absorption of Single Lap Joint

The SLJs specimen (Type I, Type II and Type III) were immersed into tape water at 50 °C for several days of 20, 40, 60 and 80 to investigate the moisture diffusion and the effect of stress on the joint ageing response. A water bath tub was shown in Fig. 2 used for specimen immersion. The weight of the specimens was measured over a period of time until saturation was achieved.

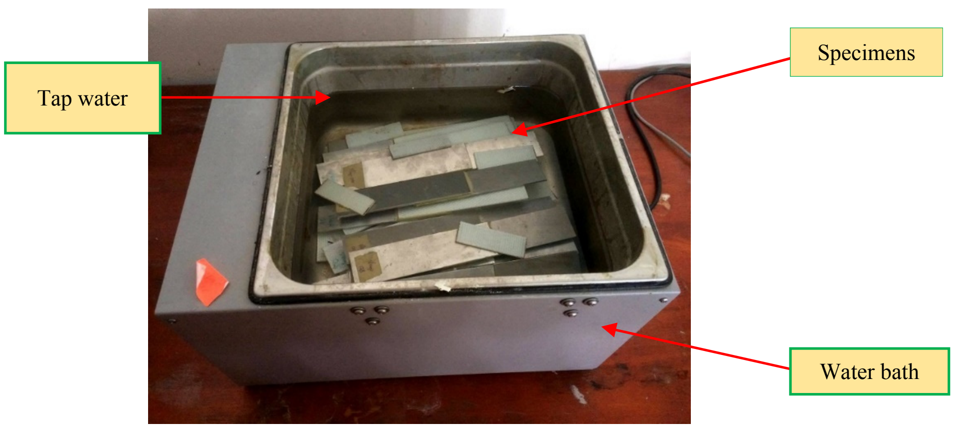


FIGURE 2. Water immersion method.

Mechanical Testing

The SLJs specimen for all types of exposure treatments were tested on a 100 kN load cell universal testing machine at room temperature. In order to minimise the influence of bending stresses inherent in the testing of the SLJ specimens, two alignment tabs with an equal thickness of the substrate were attached to both fixed ends of the specimen. Load-displacement curves were obtained as the specimens were tested at a crosshead speed of 1 mm/min. A total of three replicates were tested for each experimental set and the average peak loads and failure displacements were reported.

RESULTS AN DISCUSSION

The influence of moisture absorption and diffusion of the aluminium and composite single adhesive bonded joints were analysed. Three different adherend combinations (Type I, II and III) were developed through the experiment.

Moisture Absorption Percentage

The percentage of absorbed water for each adhesive single lap joint specimen was determined with the differences weight between dry and wet samples. Thus, the gain weight was calculated using Eq. (1):

$$\mathrm{M(t)} = \frac{Mf - Mi}{Mi} \times 100 \tag{1}$$

where M(t) is the percentage of absorbed moisture, and Mf and Mi represent the mass of the specimen prior to wet and dry, respectively. Figure 3 below represents the percentage weight gain as a function of the square root of time (in hour) for bonded joint specimens. The immersion was observed under a hot temperature of 50 °C at 20, 40, 60 and 80 days. Form the Fig. 3, the water absorption curves were shown into a linear path for specimens of composite-composite and aluminium-composite by following the extended time. However, the pattern was exceptional for a specimen of aluminium-aluminium as it reached the lowest absorption. The water absorption was not reached saturation rate for all joint specimen as it speedily increases the weight gain as the period was extended. The maximum water absorption percentages of the composite-composite, aluminium-composite and aluminium-aluminium were 3.31%, 2.60% and 1.90%, respectively. The composites were attacked and absorb more water because of the penetration process between adhesive and fibre-matrix.

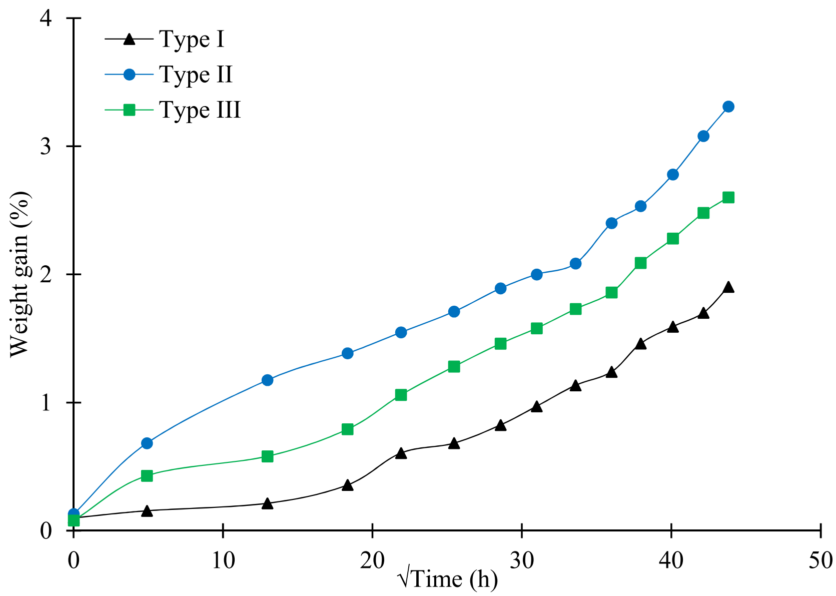


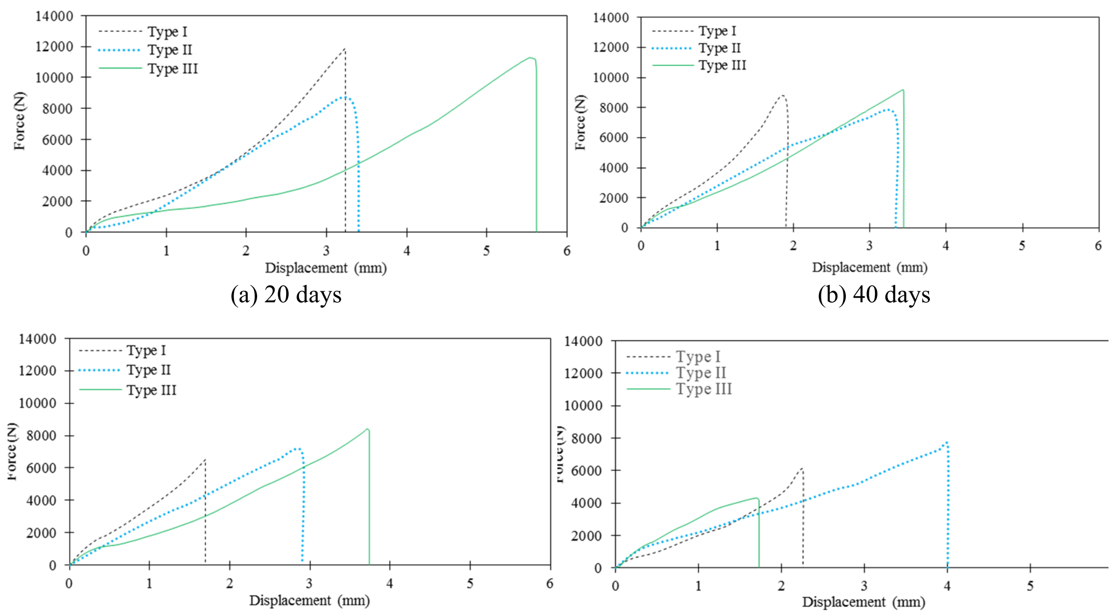
FIGURE 3. Weight gain as a function of the square root of time for bonded joint specimens.

Effect of Ageing on Joint Strength

Load-displacement of adhesively bonded joint for Type I, Type II and Type III were shown in Fig. 4 (a)-(d) at several immersion periods. The ageing of the specimens was performed using condition tank filled with tap water at 50 °C. The reduction of maximum failure load is approximately 24.7% and 35% for Type I which is for each 20 days immersion. The less reduction was detected on specimen Type II and III compared to Type I, less than 20% when glass fibre was used as a joint specimen. This was observed that less reduction is occurring in the composite as it penetrates the water diffusion on the interface between adhesive and adherend. The peak load shows most clearly the degradation of the adhesive layer due to moisture uptake. The displacement of joint materials was decreased as water exposure was increased. The longest displacement was observed on Type III followed by Type II and Type I for each water absorption cycles, 20 days. The value is approximately a total displacement of Type I and II.

The stress behaviour of an adhesively bonded joint was shown in Fig. 5 with multiple types of joining combination. The joint static strength is equal to the failure load divided by the bonded area. The bonded area was calculated by the measured width and overlap length of the joint. Among the three different materials combination methods, the static strength decreases with increasing of water content up to 80 days exposure. As compared to the dry state loading, the Type I average strength is 34.5 MPa, 30.5 MPa, 25 MPa and 16.6 MPa for 20, 40, 60 and 80 days exposure, respectively. This is followed by the Type II with 27.024 MPa, 26.440 MPa, 23.024 MPa and 21.499 MPa strength. Meanwhile, the dissimilar material of Type III shows the highest average of moisture with 40.107 MPa, 32.464 MPa, 29.619 MPa and 27.571 MPa.

The typical failure modes of three joints were shown in Figure 6. The observed failure mode and locations in the experiments are reasonable for each similar and dissimilar materials joining. And, failure examination of the specimen Type I revealed similar failure surfaces for the similar aluminium. The remaining adhesive is on both aluminium interface and it was subjected to cohesive failure.



(a) 20 days (b) 40 days

(c) 60 days (d) 80 days

FIGURE 4. Load-displacement of adhesive bonded joint at several immersion periods (a) 20 days (b) 40 days (c) 60 days (d) 80 days.

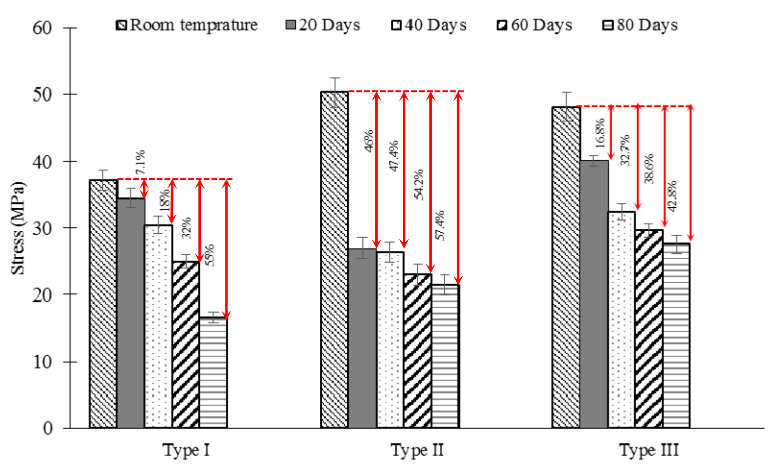


FIGURE 5. Stress behaviour of the joint specimen.

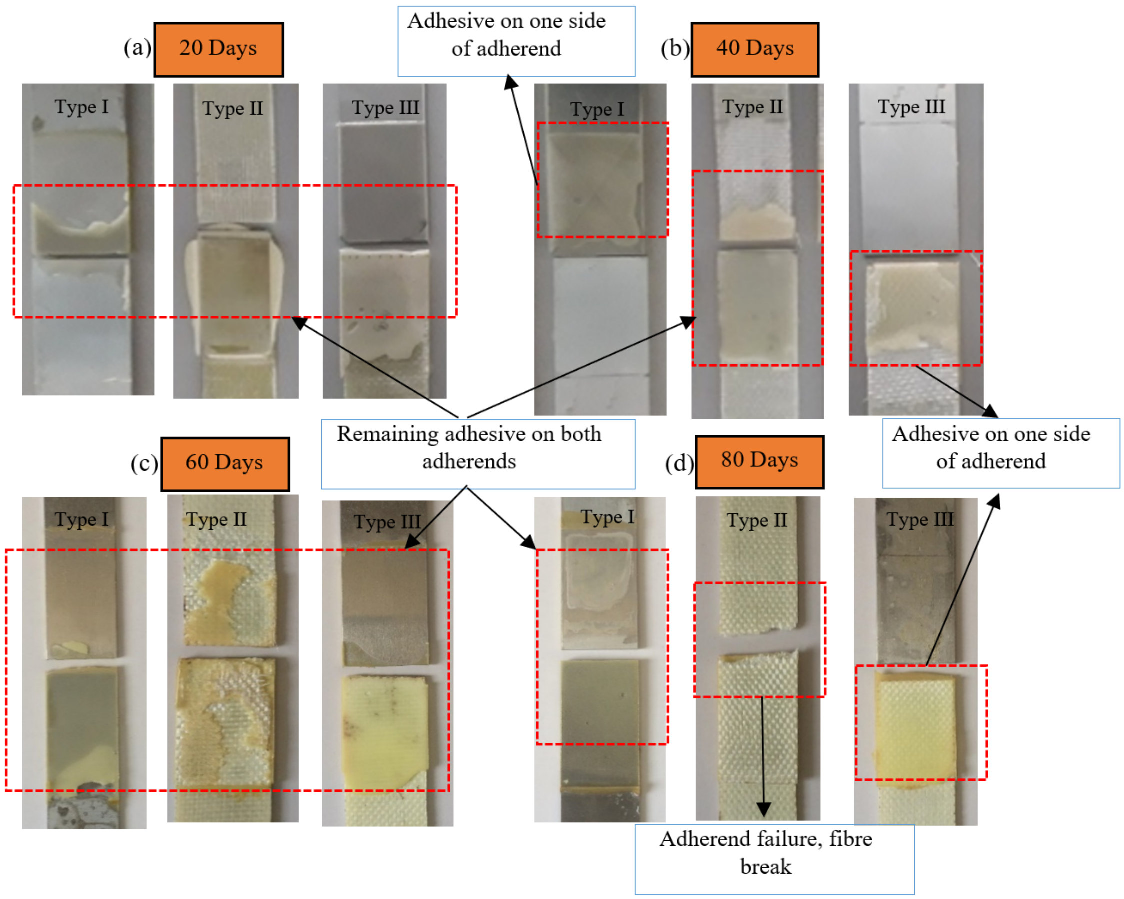


FIGURE 6. Typical failure modes (a) 20 days (b) 40 days (c) 60 days (d) 80 days immersion.

CONCLUSIONS

The effect of water ageing on mechanical properties of adhesive single lap joint has been investigated for multiple adherend materials combination. In order to analyse the interaction between water ageing and joint strength, the quasistatic test was conducted at room temperature for each combination. The results show that failure stress decreased with the increasing time of immersion. The adherend joint of composite typically shows the highest reduction percentage compared to metal. This was continually observed with the failure mechanisms of joint whereas, cohesive and adhesive failure was detected.

The damage mechanisms will be identified further by using scanning electron microscopy examination at different immersion time. Another extension will be to compare and validate the joint durability from an experiment into simulation analysis. This will be studied in future works.

REFERENCES

1. M. Heshmati, R. Haghani and M. Al-Emrani, Compos.Part B: Eng. 92, 447–462 (2016).
2. X. Han, A. D. Crocombe, S. N. R. Anwar and P. Hu, Int. J. Adhes. Adhes. 55, 1–11 (2014).
3. M. Heshmati, R. Haghani and M. Al-Emrani, Compos. Part B: Eng. 81, 259–275 (2015).
4. S. Sugiman, A. D. Crocombe, and I. A. Aschroft, Int. J. Adhes. Adhes. 40, 224–237 (2013).
5. M. Frigione, M. A. Aiello and C. Naddeo, Constr. Build. Mater. 20, 957–970 (2006).
6. J. L. Paris and F. A. Kamke, Int. J. Adhes. Adhes. 61, 71–80 (2015).
7. C. E. Frazier and J. Ni, Int. J. Adhes. Adhes. 18, 81–87 (1998).
8. Y. Hua, A. D. Crocombe, M. A. Wahab and I. A. Ashcroft, Int. J. Adhes. Adhes. 28, 302–313 (2008).
9. B. Izzawati, M. Afendi, S. Nurhashima, A. Nor , A.R. Abdullah, R. Daud and M.S. Abdul Majid, Mater. Sci. Forum 819, 443–448 (2015).