Journal of Engineering and Emerging Technology
2024 Vol. 02, No. 01

www.jeet.unram.ac.id

eISSN: 2964-4178

Effect of Aggressive Environment on the Shear Strength of Hemp and Fiberglass Composite Joints

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(Received 17 February 2024; Accepted 20 March 2024; Available online 29 June 2024)

ABSTRACT

Natural fiber composites (NFC) are growing due to their low cost, lightweight and environmentally friendly. In using the NFC in a structure, NFC is often connected and bonded with other materials, such as fiberglass-reinforced polymer composites. Adhesively bonded composite joint is suitable for connecting dissimilar materials. The paper investigates the effect of ageing in different ageing media on the shear strength of hemp fiber reinforced unsaturated polyester composites bonded to glass fiber reinforced unsaturated polyester composites joints. The joints were immersed in an aggressive environment (distilled water, alkaline/NaOH solution, acid/vinegar solution, and salt solution) up to 15 days. The results showed that after ageing for 7 days, the shear strength increased by 16%, 16% and 18%, respectively, for aging media of distilled water, salt solution and acid solution, whereas aging in an alkali solution (NaOH) for 7 days, the shear strength decreased by 29%. After the aging time of 15 days in distilled water, salt solution alkaline solution (NaOH) the shear strength decreased by 21, 5 and 72%, while aging in acidic solution, the shear strength is still higher by about 15% than the unaged specimens.

Keywords:

Adhesive joints;
Aggressive environment;
Natural fiber;
Shear strength.

1. Introduction

Composite materials have attracted scientists and engineers to develop lightweight structures such as automobiles, boats, aerospace, etc. Most high-performance composites are made of synthetic fiber; however, due to environmental concern, natural fiber become a suitable alternative. Although natural fiber composites have lower strength than synthetic fiber composites, natural fiber composites are superior in specific strength. Therefore, a combination of synthetic and natural fibers composites is required in lightweight structures. To combine the synthetic and natural fiber composites, adhesive joining provides low-cost, lightweight, uniform stress distribution, and smooth joining (Campilho and Fernandes, 2015) Several researchers have reported the natural fiber composites joints. Campilho et al. (2013) studied the fracture properties of jute-reinforced polymer composites using bonded and co-cured composites both experimental and numerical. Melese and Singh (2020) investigated the sisal, jute dan sisal/jute hybrid adhesively bonded joints using three joint configurations (i.e. single lap, double-strap butt, and scarf) under tensile loading. The hybrid joint indicated the highest strength, where double strap joints gave the best performance compared to the others. Queiroz et al. (2021) investigated the joint of hybrid of glass and jute fibers reinforced composites with different lay-up, where jute and glass fibers were functioned as core and skin, respectively. The number of glass fiber layers were increased from 2 to 3 layers. The joint strength increased with the increase of the glass fiber layers number, due to more cohesive failure rather than delamination. Mittal et al. (2015) investigated various parameters including curing temperature, and overlap length of jute fiber reinforced unsaturated polyester composites bonded joints using epoxy adhesive. They found that high curing temperature (100^{o}C) improved the joints strength compared to the room temperature (23^{o}C) cured joints. Increasing overlap length from 10-30 mm decreased the mean of shear strengths.

In practice, adhesively bonded structures are often exposed in hostile environment. Sugiman et al. (2013) exposed aluminium bonded structures in deionized water at temperature of 50°C up to three years. A decrease of about 23% was observed after 3 years exposure. Further Sugiman et al. (2019) explored the residual strength of glass fibre reinforced unsaturated polyester composites bonded to steel adherend and exposed in distilled and salt water under stable and fluctuating conditions. They reported that aging in salt water under the fluctuating condition caused severer effects on the joints compared to those aged in distilled water under the stable and fluctuating conditions. Although numerous studies about ageing of composite to metal, and metal-to-metal joints have been reported, however, to the best author's knowledge, ageing of natural fiber composites joints is rarely reported. This preliminary study investigates the aging of hemp and glass fibers composites joints in the different ageing media such as distilled water, salt water, acid and base solution. A single lap joints was used to determine the residual strength of the exposed joints as well as the mode of failure.

2. Methods

2.1. Materials

Woven hemp and woven glass fibers were used to fabricate the laminate composites for the adherend of a single lap joint. The adhesive used was Demp-X two-part epoxy component. The ageing media were distilled water (pH 7.13), 3.5 wt% salt solution (pH 7.94), 3.5 wt% NaOH solution (pH 12.44), 0.12 wt% vinegar acid solution (pH 3.35). The matrix of laminate composites was Yukalac unsaturated polyester resin with a hardener of methyl ethyl ketone.

2.2 Alkalization Treatment

Before the fabrication of hemp composite laminate, the hemp was treated using sodium hydroxide solution with a concentration of 0.5 wt%. The hemp fiber was soaked in 5-liter solution for 24 hours at room temperature. Then, the treated hemp fiber was rinsed using tap water to remove the sodium hydroxide. After that, the hemp fiber was dried under the sun for several days and then dried in an oven at a temperature of 70°C for 60 min. The dried hemp fiber was kept in a sealed plastic bag.

2.3 Fabrication of Hemp and Fiberglass reinforced unsaturated polyester Composites

Hand lay-up and compression moulding was used to fabricate the composites. Before the mixture was poured into the mould, the mould was first smeared with mirror glaze to make it easier to release the composites from the mould. Then, the polyester resin and MEKPO catalyst were mixed with the resin to hardener ratio of 100:1 (by weight). After that, the mixture was poured into the mold which already contained 3 layers of hemp woven fiber or 5 layers of fiberglass woven fiber. The composite was then compressed using a male mould and left for 24 hours for curing. The thickness of the composite was 3 mm, maintained by putting two spacers, at both edges of the mould (see Figure 1). After the composite was cured, the mould was opened, and the composite was cut according to the dimensions of the single lap test specimen. The above stages are carried out successively with woven hemp fibre and glass fiber. The woven hemp and glass fibers/unsaturated polyester composites were then called HFUPC and GFUPC, respectively.

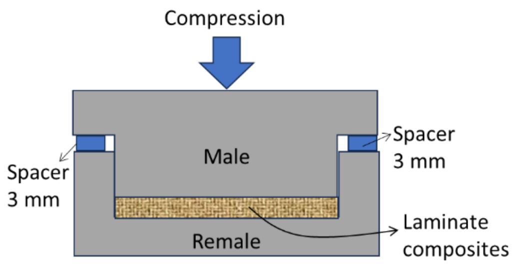

Figure 1. Moulding of laminate composites.

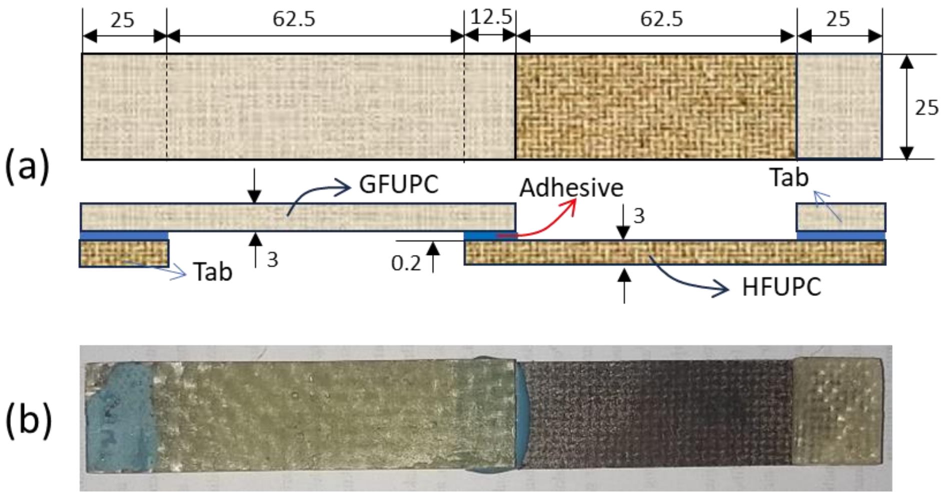

Figure 2. (a) The dimension of single lap joint (not to scale), (b) The photograph of the specimen. Unit is in mm.

2.4 Joining Hemp and Fiberglass Composite

Single lap joints specimens were made of hemp and fiberglass composites. The adherend size was 100 mm in length, 25 mm in width and 3 mm in thickness. Before being bonded, the bonded area was lightly abraded using emery paper of 300 mesh and then was cleaned using acetone. The next step was mixing the epoxy adhesive and the hardener with mixing ratio of 1:1 (by weight), as suggested by the manufacturer. The adhesives were pasted into both adherend surfaces and then pressed using a fixture to maintain the alignment of the adherends. The adhesive thickness was 0.2 mm, which was maintained by using spacers with the same thickness of adhesives, as shown in Figure 2.

2.5 Specimens ageing

The specimens were grouped into two groups: unaged and aged specimens. The aged specimens were conditioned by immersing the specimens in four ageing media: distilled water, salt water (3.5wt%), acetic acid solution (2.5wt%) and sodium hydroxide solution (3.5wt%), with pH of 7.13, 7.94, 3.35 and 12.44, respectively, measured using a digital pH meter. The ageing temperature was room temperature. The soaking process was carried out in a closed container for varying times, namely 7 days and 15 days.

2.6 Shear Testing

The specimens were tested using a universal testing machine with a load capacity of 10 kN at a displacement rate of 2 mm/min. For aged specimens, the test was carried out just after the specimen was withdrawn from the ageing medium to avoid loss of the absorbed water. The mode of failure of each specimen was seen using the naked eye and also using a macro photograph. At least three specimens for each variation were tested.

3. Results and Discussion

3.1 Shear Strength Analysis

Figure 3 shows a graph of the shear strength of joints exposed to various ageing media. It can be seen that the unaged specimen has an average shear strength of 4.41 MPa. Surprisingly, compared to the unaged conditions, after being soaked for 7 days, the average shear strength of the specimens aged in distilled water, salt water, and acetic acid increased by 16%, 16% and 18%, respectively, whereas for the sodium hydroxide-aged specimens, the average shear strength decreased by 19%. Further ageing to 30 days, only the specimens aged in acetic acid showed a higher shear strength (15%) than that of unaged specimens, while those

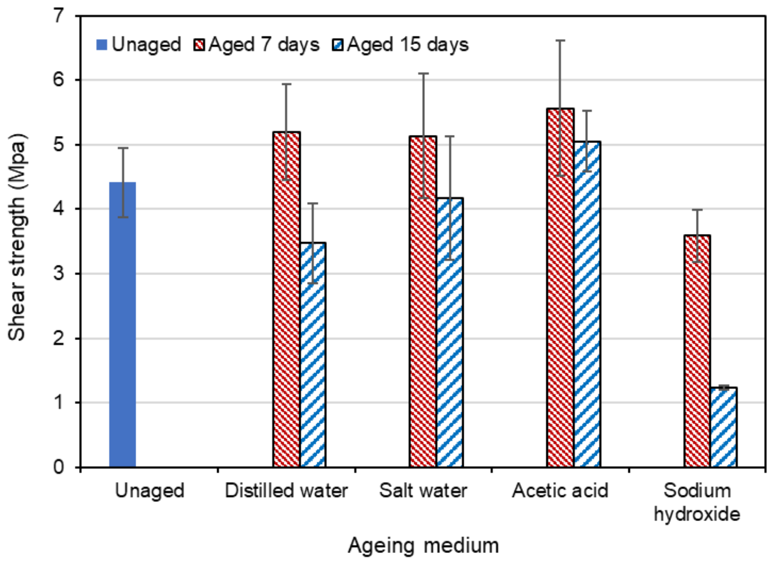

Figure 3. Graph of the avarage shear strength of all specimens

aged in distilled water, salt water and sodium hydroxide were lower than that of unaged specimens by 21, 5 dan 72%, respectively. It has been known that adhesive and polymeric matric composite absorb water when they are exposed in humid environments. A small amount of water has a positive effect on the fracture toughness of adhesive, as reported by Sugiman et al. (2016). Thus, the increase of shear strength at the ageing time of 7 days might be attributed to the increase of the toughness of epoxy adhesive. The same level of increase in shear strength of distilled and salt water-aged specimens is due to the same level of absorbed water, but the higher increase in acetic acid-aged specimens might be due to the toughness of adhesive in an acid environment. In contrast, the shear strength of the alkali-aged specimen decreased as the alkali is a corrosive media that induced damage on the composite and adhesive. Similar results of this phenomenon were also reported by Amaro et al. (2013) and Stenamenovic et al. (2011), when they studied the ageing of fiberglass-reinforced composite materials in various acid and alkali solution. With increasing ageing time, the absorbed water increases and then affects the decreasing mechanical properties, including the fracture toughness. This is manifested by the decrease of shear strength at the ageing time of 30 days as compared to the 7 days aged specimens. The shear strength of all aged specimens at an ageing time of 30 days was lower than the unaged specimens unless the acetic acid aged specimens and the worst decrease belonged to the alkali-aged specimens.

3.4 Shear Test Failure Mode

Figure 4 shows the failure mode of the unaged and aged specimens. For the unaged specimens, the failure mode seems to be interfacial, but after a close examination, the cohesive failure close to the interfacial of adhesive and HFUPC also occurred. The adhesive was well bonded at the GFUPC, which indicated that the bonding strength of adhesive and GFUPC was better than that of the adhesive and HFUPC. After being aged for 7 days in distilled and salt water, the failure mode of the joint was still similar to that of the unaged specimens, where the cohesive failure occurred close to the adhesive and HFUPC interface. However, the mixed cohesive failure occurred for the acetic acid-aged specimens, where the interfacial failure dominated. And for the alkali-aged specimens, cohesive failure was observed. With the increasing ageing time to 15 days, most of the aged specimens showed cohesive failure, indicating that the adhesive has been attacked by the absorbed water and decreased mechanical properties. As a result, the shear strength decreases and is even lower than that of the unaged specimens. For the alkali-aged specimens, the surface of the specimen became clean. This indicated that the alkali is corrosive media and must be avoided.

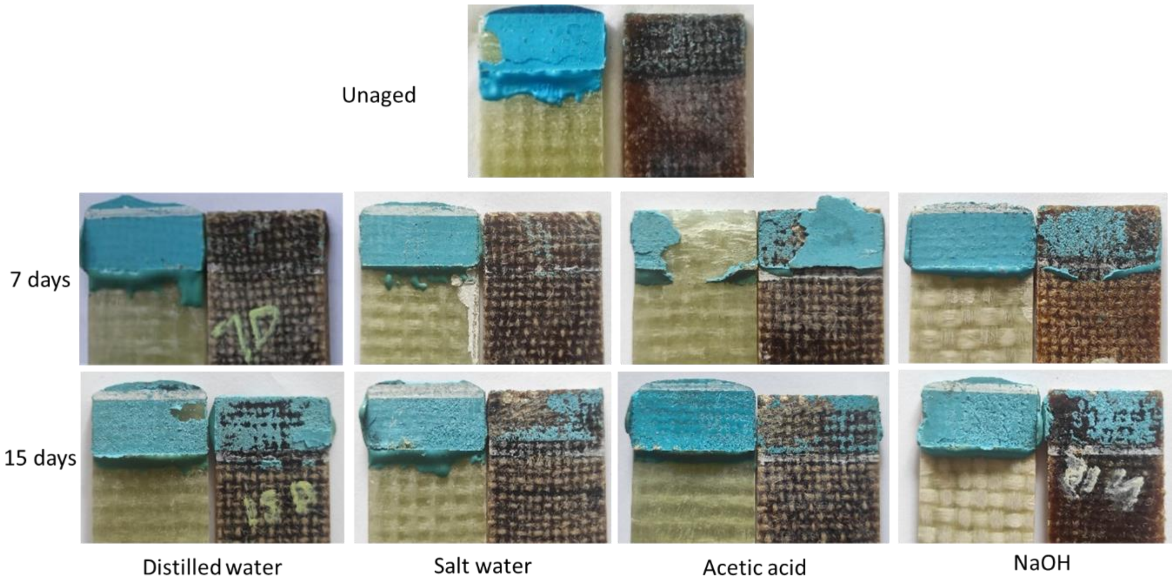

Figure 4. Failure mode of hemp and fiberglass composite joints of unaged and aged for 7 days and 15 days.

4. Conclusion

The effect of various ageing media on the shear strength of glass and hemp fibers-reinforced composite joints has been investigated. Some key points are summarized below:

- The aggressive environment influenced the shear strength in this study.
- The length of time immersion in an aggressive environment also affects the shear strength.
- Of the studied ageing media: distilled water, salt water, acetic acid and NaOH solutions, NaOH solution caused the most damaging effect on the joint strength, subsequently followed by distilled water, salt water and acetic acid. Ageing in acetic acid provides stability in joint strength.

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