A Review on Effect of Saline water on Adhesive joints of Composites

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Abstract: Fiber reinforced polymers (FRP's) have been mainly used as a replacement for metals because of their better strength, stiffness, low specific weight, and corrosion resistance. It is used in almost every industry, including automotive, aerospace, and structural engineering. In the present scenario, these FRP's adhesive joints are widely used because of their ease of fabrication, design flexibility, and uniform stress distribution in joints. Many environmental conditions affect these joints, like temperature, humidity, loading conditions, saline water, UV exposure, etc. Among these, saline water degrades the structural materials and adhesive joints used in its fabrication, leading to failure. In this paper, the effect of these environmental conditions and design parameters on adhesive joints used for FRP structures is studied. Many design parameters, like overlap length, adhesive thickness, and materials used as adhesives, have been reviewed. Research shows that joint behaviour mainly depends on optimal design parameters and environmental factors. The main focus of this article is a review of research on how the environment affects FRP adhesive joints and how they are used in marine and offshore applications.

Keywords: Adhesive bonding, Fiber Reinforced, Hydrothermal Aging, Single-lap joints.

1. Introduction

This Fiber reinforced polymer composites are widely used in structural engineering because of their better properties over metals. One of the major properties of FRP's is their high strength to weight ratio. These FRP's are also useful in huge engineering structures like building composite bridges, pedestrian footbridges, etc. Carbon fiber-reinforced composites are used in all of these heavy structures due to their higher flexural strength than glass fiber-reinforced composites. Composite materials also have better corrosion resistance, which makes them much more applicable in marine, i.e., seawater atmosphere, applications. Over the decades, they have been widely used in marine structures, boats, ships, water storage vessels, pipelines, the strengthening of concrete structures, etc. In the early 1990s, they were also used in offshore oil industries [1]. Glass fiber reinforced composites (GFRP) are more cost-effective than CFRP, which makes them highly applicable in regular marine structures. As it is well known for its corrosion resistance, many applications are found in civil engineering construction. Some of these include the protection of seashores and structures from the effects of tides [2].

The main problem of using GFRP in marine applications is that the resin used, which gives bounding strength, gets affected by seawater, where degradation occurs over the long term, affecting mechanical properties and interlaminar shear strength [3]. Many resins are commercially available that are used for marine applications, like polyurethane, phenolic, polyester, vinyl ester, and epoxy. Among these three, epoxy, vinyl ester, and polyester are commonly used and have undergone research.

Many marine applications, mainly ships, boats, etc., are facing challenges in fuel consumption and safety regulations. These demands have made composite materials useful in all these applications because of their better strength-to-weight ratio. For the fabrication of GFRP's, adhesives are widely used at different levels. In recent advances in adhesive technology, adhesive joints have become highly applicable in composite structure fabrication and assembly due to their cost effectiveness and design flexibility, making them highly suitable for composite material assembly. However, using these adhesive-bonded composite joints in marine applications is difficult. Adhesive bonded joints will be affected by high humidity, seawater, and high temperatures, which will reduce the joint strength of GFRP structures. When these adhesive joints are used in a marine environment, they absorb a large amount of water, weakening them [3]. Many parameters are considered while designing the joints, such as overlap length, the yielding of adherence, bond line thickness, and the plasticity of adhesive

2. Adhesive bonds

In the present scenario, there is a lot of demand for adhesive bonding in all industries because of its high strength-to-weight ratio, damage tolerance, design flexibility, and better fatigue strength. Even adhesive joints offer acoustic isolation, vibration attenuation, high corrosion resistance, and better uniform stress distribution. This makes them more significant than conventional joining processes. Overall, adhesive bonding is less expensive and offers greater joining strength, making it ideal for use in automotive, aerospace, electric, electronic, and marine structures [4,5]. These adhesive bonds are also increasingly being used in the repair of damaged structures.

In manufacturing, bonding can be done in three different types: co-curing, co-bonding, and secondary bonding. These methods of bonding are shown in Figure 1.

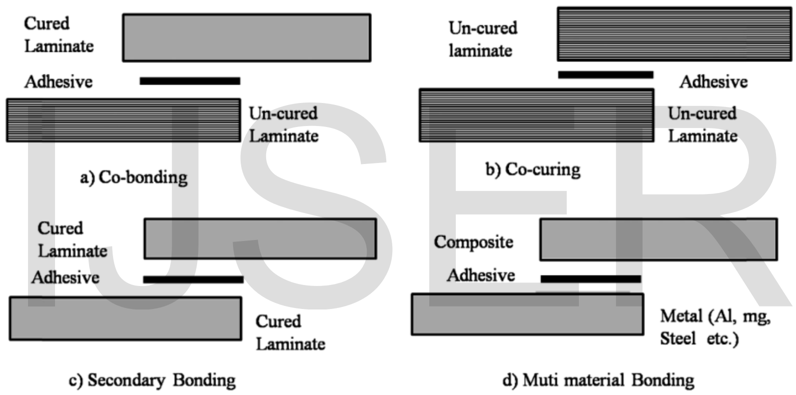

Figure.1. Different bonding process used in manufacturing of composite materials. [6]

In co-bonding, one adherent is cured along with the adhesive. Co-curing occurs when both parts are allowed to simultaneously cure. When an adhesive layer is being cured in between two already cured composite panels, this process is called secondary bonding. The combination of metal with the secondary bonding process itself defines multi material bonding. For huge structures, the commonly used secondary bonded joint method is used, and for repairs of structures and components, the multi-material bonding method is used [7, 8]. These two methods are more commonly used than co-cured joints. The moisture released by the prepreg spread into the adhesive layer, resulting in a weaker joint and lower strength [7-9]. As a result, moisture plays a significant role in GFRP adhesively bonded joints.

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3. Parameters influencing adhesive joints

To achieve a proper design of a composite structure, geometric configurations presenting higher strength, durability, and rigidity play an important role. Overall, for low cost, better properties need to be achieved, along with reducing the weight. In the current situation, it's important to both cut costs and worry about how natural resources are being used up and damaged [10]. FRP structures play an important role in marine and offshore applications. And during fabrication, adhesive joints have made the process simpler and more dependable because of their better strength and less effort. But the study of the properties of these adhesive joints is important. The flow chart below depicts the properties that influence the adhesive joints of FRPs.

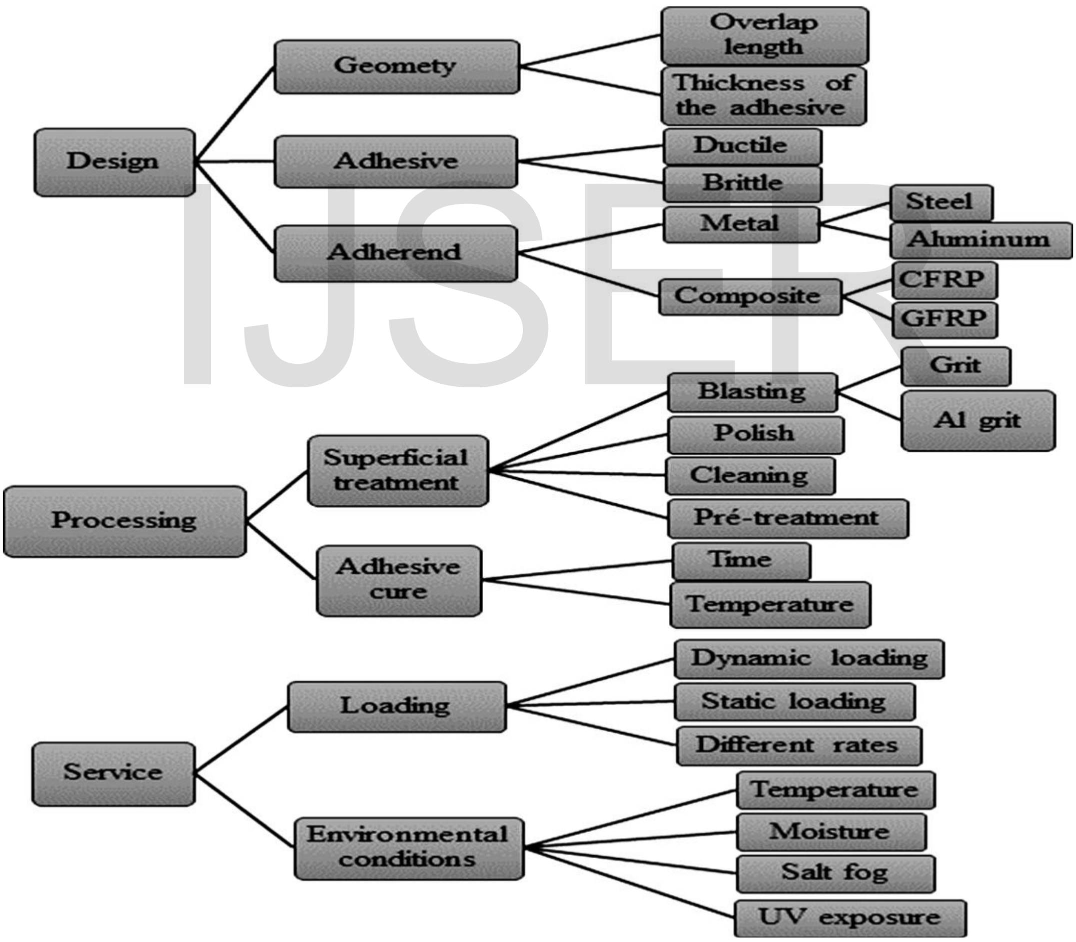

Figure. 2.Parameters influencing adhesive joints. [6]

3.1 Surface Preparation

Surface preparation is an important part of the quality of adhesive-bonded joints made from composite materials. For a better adhesive joint, the surface must be well prepared well. In the surface treatment of adhesions, the following factors must be seriously considered:

- Cleaning of contaminants (dust, corrosion layers, lubricants, and so forth).
- Adhesive surface wet ability
- Better activation of material surfaces [11-16].

Primary and surface pre-treatment are required for higher-quality joints. A peel-ply technique or different mechanical treatment methods are adopted for cleaning the surfaces. The peel-ply technique is preferred over the other.[12, 17, 18]. Figure 3 depicts the morphology and texture of a composite material after peel-ply treatment.

Fig. 3. Laminate adhered surface after cleaning using peel ply technique [19].

3.2 Overlap Length

An example for FRP adhesive joints can be shown in Figure 3. The overlap length of the joint is given by the size of the bond, i.e., (L1 + L2). On review of previous research, the higher the overlap length, the greater the bonding strength. But this relationship holds good only to a certain length, beyond which overlap length has no effect on the strength of the joint [20].

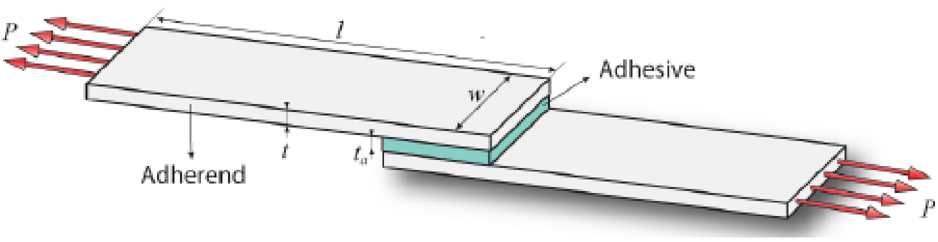

Fig. 4. Adhesive-joint composite panels

An example for FRP adhesive joints can be shown in Figure 3. The overlap length of the joint is given by the size of the bond, i.e., (L1 + L2). On review of previous research, the higher the overlap length, the greater the bonding strength. But this relationship holds good only to a certain length, beyond which overlap length has no effect on the strength of the joint [20].

Different configuration experiments have been conducted and analyzed. Referring to the work of Majidi and Razari [20], double strap joints with different overlap lengths are studied to determine the effective overlap length. They came to the conclusion that overlaps lengths greater than 30 mm did not result in a significant increase in strength. Researchers also studied that effective overlap length is very little influenced by loading rates, whereas it has a significant influence on the mode of failure of joints [21].

3.3 Adhesives and Adhesive thickness

The mechanical and chemical properties involved in an adhesive joint will define the joint's strength. Hence, the selection of the type of adhesive also plays a significant role. The failure mode of the joint depends on the adhesive material used with appropriate tensile strength [22]. Also, the type of loading that the joint experiences also varies the stiffness of the joint. According to research, when an impact load is applied to an adhesive material with a ductile property, it may exhibit rigid behaviour, even environmental conditions such as prolonged high temperatures [23]. Hence, the choice of adhesive solely depends on the application of the joint.

In adhesive joints, FRP’s adhesive thickness also plays an important role in the joint's performance. On review of some papers, it says that a thickness range of 0.1 to 0.5 mm provides higher resistance to loads considering most of the adhesives [24, 25]. It has also been observed that by increasing the thickness beyond a limit, rather than increasing the strength, it reduces [25, 26]. Hence, maintaining the optimum thickness gives the joint better strength.

3.4 Temperature

The operating temperature is critical for adhesive joints because temperature affects every component used in joints. According to research, joint strength is affected by the thermal expansion coefficient, adhesive cure shrinkage, and adhesive and adherent properties [27]. Another study also shows that the viscosity of adhesive also depends on operating temperature. [38]. It is also revealed that adhesive material shows brittle behaviour at lower temperatures and ductile behaviour at higher temperatures [29, 30]. Using polymeric adhesives at higher temperatures always reduces strength due to increased molecular mobility. Hence, it all depends on the glass transition temperature (Tg) of a given adhesive. Above this temperature, the viscoelastic property will respond irregularly, making material behaviour difficult to predict [31, 32]. As a result, the material's use is determined by the adhesive's Tg value. When the temperature is high, you need an adhesive with a higher Tg-value, and when the temperature is low, you need an adhesive with a lower Tg-value.

3.5 Moisture (Humidity)

Moisture is a major influencing parameter that can come from liquid water, humidity, or salt solutions. It has a bigger effect on what sticks and how well it sticks, especially in the resin matrix of FRPs. Even in dissimilar joints, water affects the durability of the joint [33]. The absorption of the moisture occurs in many ways and depends on many factors, like temperature, which highly influences the diffusion, adhesive and adhering materials, time of exposure, surface treatment, etc.

In adhesive joints, moisture absorption may occur because of adhesive layer diffusion and adherends or absorption in pores present at adherends [33, 34]. Adhesive plasticization and, in turn, swelling of joints may occur because of water absorption. It also lowers the joint's Tg. These result in distortions and crack formation, reducing the mechanical strength of the adhesive joints [35–38]. The intensity of the effect of swelling also depends on the co-efficient of hygroscopic expansion between adhesives and adherends [39]. Many researchers have concluded from their experiments that moisture causes a reduction in the strength of an adhesive joint [40 - 44].

4. Saline Effect on Adhesive Joints

The structures present in the marine atmosphere face high humidity, salt water, and variations in temperature, which hamper their performance. Mechanical properties of adhesively bonded joints are primarily affected by the degradation of adhesives, adherends, and the interface between them [45].

Besides moisture, salinity also has a major effect on adhesive joints. Several authors have shown that prediction of the aging of adhesive joints because of the effect of saline water is very helpful to schedule regular repair and maintenance of the structures [2, 46, 9, 34]. D. Freitas et al. [47] studied FRP joints exposed to saline water for 30 days and 90 days. Results show that an increase in the time period of corrosion and deterioration of joints occurs. And also, the failure mode of joints changes from cohesive to adhesive. A similar investigation was carried out by Aroucehet et al. [48], in which the saltwater effect of adhesive joints was studied through floating roller shell tests. Another condition was added in which one set was completely immersed in salt water while the other was partially immersed. This helped in the evaluation of dry and wet conditions. It was discovered that joints that had not been aged and were 40 days old had mostly cohesive failures and had no effect on adhesive joints. After 150 days of corrosion, the effect of moisture increasing fracture surface was observed. Many other researchers demonstrated that the saltwater effect reduces the mechanical strength of adhesive joints. Even other environmental conditions have an effect, such as high temperatures, humidity, and cold conditions.

5. Discussion

As a lot of papers are revived in this study, research on FRP's adhesive joints plays an important role in the structural design for marine and offshore applications. Glass fiber-reinforced polymers are more cost-effective compared to carbon fiber-reinforced polymers in many applications. Adhesive joints outperform conventional joints in terms of strength-to-weight ratio, design flexibility, and aesthetic properties. It's even more significant because of better corrosion resistance and uniform stress distribution in joints.

As revived, many parameters are needed to be considered while analyzing an adhesive joint, like the design, processing, and application of joints. High temperature, humidity, and a marine atmosphere are all important performance characteristics. Many papers have shown that with better surface preparation, we can get better strength from an adhesive joint. Also, using good-quality, well-performing adhesives and maintaining optimum thickness in the joint makes the joint stronger. Environmental conditions like temperature, humidity, and salt water also hamper the performance of adhesive joints. When the temperature rises, molecular mobility rises, increasing the ductility of the joint while decreasing its strength. Humidity and salt water make the joints degrade and swell, further leading to crack formation. As a result, saline water has a significant impact on the resin bonding properties and reduces the life of structures.

6. Conclusion

On review of all papers considered, many factors influence the adhesive joints of FRP's. The mechanical, tribological, and morphological properties are directly related to the parameters based on the surrounding atmosphere. In other words, environmental factors directly or indirectly affect these properties.

Of all the parameters considered in this paper, there is very little information available on the influence of saline water on the overlap length of adhesive joints and even the adhesive thickness present in joints. The influence of this at high and low temperatures on joints also needs to be studied. Overall, saline water has an effect on the joints, causing them to lose strength and become distracting in structure. Still, there is a need for accurate information regarding how these parameters are affected by saline water. And also, remedies to overcome these and predict the aging of adhesive joints in fiber-reinforced composite structures are necessary.

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