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Investigation of Environmental Degradation on Joint Properties of Polymer Adhesive Joints in Salt Water Environment

Shirish Kerur*, Shivakumar S.#
* Jain College of Engineering, Belagavi, India
\# Department of Mechanical Engineering, GIT Belagavi, India

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Abstract

The objective of research work is to establish the influence of environmental factors such as moisture and temperature on the shear properties of metal and polymer joints. The specimens of metal and polymer joints were prepared with aluminium plate and glass fibre reinforced plastics. Here three types of resins were used for joining the metal and polymer composites viz. epoxy vinyl ester and polyester. The joint specimens were exposed to 80 °C temperature and relative humidity of 90% for 25 days in environmental chamber. The single and double shear strength of the joints for ascast and hygrothermal exposed specimens are investigated. The results showed that the strength of hydrothermal specimens decreased about 25%, 18% and 33% for epoxy, vinyl ester and polymer adhesive joints respectively. The result also shows that vinyl ester joints exhibit lower water absorption and property degradation of the joints.

Keywords: Polymer adhesive, ascast, saline water, degradation, joint properties

1. Introduction

Polymeric adhesive joints are finding applications in automotive, marine, aerospace and space structures. On the other hand, unlike conventional joining techniques such as bolting, welding, brazing and riveting polymer joints provide many benefits such as uniform distribution of load, reduction in stress intensity, air tight seal and lighter weight. Polymer joints promote strong and durable bonds to the surfaces of metal or polymer or composite, but needs mechanical or chemical modifications. The modifications enhance their wettability, projected bonding space and protect the joints from environmental contaminates. Previous work proved that carbon fiber reinforced plastic could be effectively used in steel metal joints [1-5]. But the same author showed the limitation of joints during corrosive environment. It might be attributed to lack of robust methodologies, which can efficiently incorporate the high durability of polymer adhesive joints[6].

Generally, polymer adhesives degrade both physically and mechanically properties over time especially in a corrosive environment such as marine, humid, hot and cold conditions. Kanerva et. al. [7] showed that polymer joints create a weak bonding between polymer composites and steel. They showed that the polymer binding strength depends on the quality, integrity and durability of the polymer adhesive. Many researchers [8-12] developed several theories of degradation of polymer adhesives. One of the most important theory says that the degradation of polymer adhesive occurs due to the permeability of joining materials, which is mainly caused because of moisture diffusion in to the polymer adhesives [13]. Another important property influencing the quality of joint is wettability, which in turn enhances adhesion between the joints with modification of mating surfaces[14]. The mechanical treatment would introduce physiochemical changes, which results wet surface to modify the surface topography [20]. Moreover, the degradation data on the polymer adhesive materials will be used to

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*Corresponding author
Email address: smkerur@jainbgm.in (Shirish Kerur)
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design the components for many applications. Hence the focus of this research work was to investigate the effect of temperature and humidity on the mechanical properties of single and double lap joints.

2. Experimental Study

The materials used in the present works are Aluminium 6061 T4 Sheet, Epoxy resin(LY 556), Organic modifier Araldite (HY 951) and Glass fiber (GSM 400) woven roving. Other two resins *viz.* vinyl ester and polyester were selected for comparison. These resins are used as structural adhesives to bear high loads and in adhesive joints where the joint is subjected to critical conditions. Surface treatment was carried out as per ASTM D2651 standard. For cleaning and degreasing the surface of the adherend, methyl ethyl ketone (MEK) was used. The degreasing process started with the cleaning of the surfaces of each adherend with absorbent paper, wetted with MEK to eliminate the dirt and grease. The specimens were performed upon by mechanical abrasion in order to remove weak adhering and contaminated outer layers on the adherend surface, thereby, exposing freshly non-oxidized surface directly to the adhesive. The surface of each adherend was prepared using two different grinding papers identified as P40 and P120. Following mechanical abrasion, adherends were cleaned again using MEK and rinsed thoroughly using water. A water break test was used to analyze surface cleanliness. This test depends on the observation that a clean surface will hold a continuous film of water, rather than a series of isolated droplets. A break in film indicates contaminated area. Distilled water was used in the test and a drainage time of 15 s was allowed. Then, each adherend surface was dried by passing hot stream of air from the drier. A surface profiler, Talysurf was used to determine the surface roughness both before and after the surface treatment. The profiler moves in a single direction with a scanning length of 2.5mm.

The single lap joints were subjected to hygrothermal conditioning in a climatic chamber in order to evaluate the influence of moisture combined with the cyclic variation of temperature. This hygrothermal conditioning was based on ASTM D 5229 M-04 for composites undergoing mechanical tests in humid conditions. Single lap joints were exposed to 80°C and relative humidity of 90%. The average period of conditioning was of four weeks, long enough for the material to reach the saturation with moisture. The effects of moisture present in the atmosphere should always be considered in the design of structural joints. Therefore, moisture can penetrate into the polymer matrix by means of the diffusion process.

The single lap and double joints are dipped in water for moisture diffusion at room temperature and initially specimens were withdrawn at interval of 1 hour, wiped dry by tissue paper to remove surface water and then weighed in an electronic balance to monitor the change in mass due to moisture absorption for a week then the time interval was changed to 24 hours and same procedure was carried out for week, then again time interval was changed and reading was taken on weekly basis. This procedure was repeated for 25 days the percentage moisture uptake (M) of the fiber metal laminate specimens are then computed by using the equation

$$M = \frac{(m_s - m_d)}{m_d} X\,100$$

Where, m_d and m_s are the mass of the specimen before and after moisture exposure.

A Universal Testing Machine (UTM) was used to determine the shear load associated the single lap joint specimen after hygro-thermal effect. Load cells and extensometer measures the key parameters *viz.* force and deformation when sample is examined.

3. Results and Discussion

3.1 Moisture absorption

Figure 1 and 2 show the percentage of moisture absorption after 25 days of conditioning, the specimens Epoxy (E), vinyl ester (V) and polyester (P) with single lap joint and double lap joint respectively. Single lap joints absorb moisture at an average of 0.11% of weight, whereas the specimens with double lap joints absorb moisture of 0.14% of weight. Also it can be observed that for the first 15 days the absorption was linear irrespective of the shape of the specimens. After 15 days of exposure there is no significant increase of moisture absorption, indicating that the saturation was reached. This is similar for all types of specimens having different adhesive orders [15].

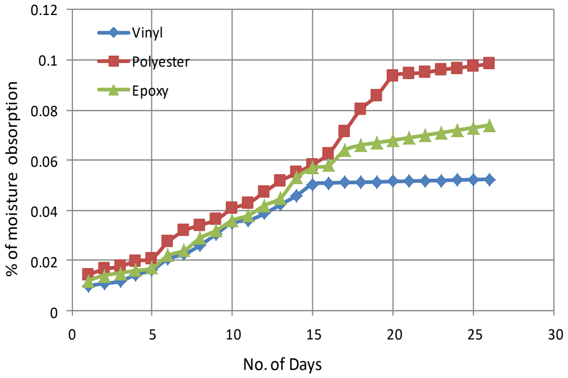

Figure 1: Moisture absorption of Single lap joint specimens

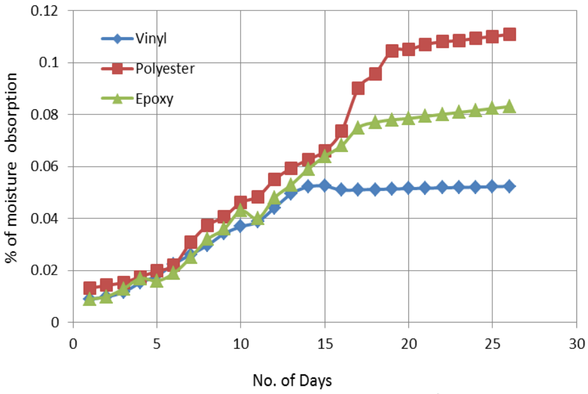

Figure 2: Moisture absorption of double lap

This stabilization occurred after about 15 days of exposure to hygrothermal conditioning. The moisture absorption for polymer adhesive specimens with single lap joint is lower than that of adhesive joint specimens having double lap joints. The difference in moisture absorption is due to cross sectional area of specimens exposed to moisture. The specimens with single lap joint order has less cross sectional area of expose to moisture compared to the specimens with double lap joints as shown in Fig. 3. It can also be seen that the moisture absorption in vinyl ester adhesive joints specimens is lower than those of epoxy and polyester adhesive joints since the literature report values in these cases are from 1 to 3.5wt% [15].

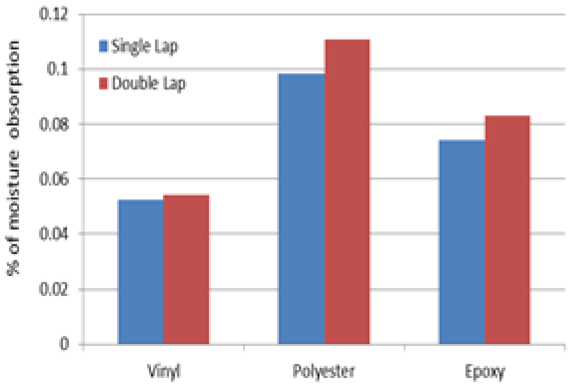

Fig. 3. Comparison of moisture absorption between single and double lap joint after 25 days

This phenomenon is due to presence of the outer layers of aluminium which acts as barriers to the diffusion of moisture in the laminate. Moisture is absorbed only through the side ways of the laminate and not at the top and bottom faces.

3.2 Shear strength of lap joints

Results are obtained by conducting tests and the values recorded and shear strength is obtained by means of stress-strain values are determined. Fig.4, (a) and (b) shows the stress-strain curve for the specimen ascast and 25 days exposed specimens respectively.

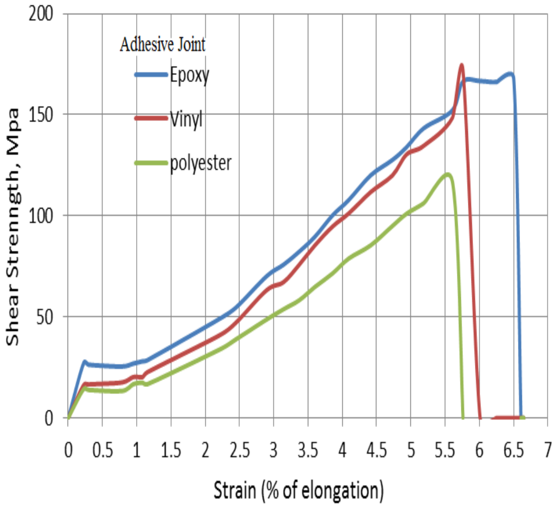

Figure 4(a): Stress strain diagram of double lap joint

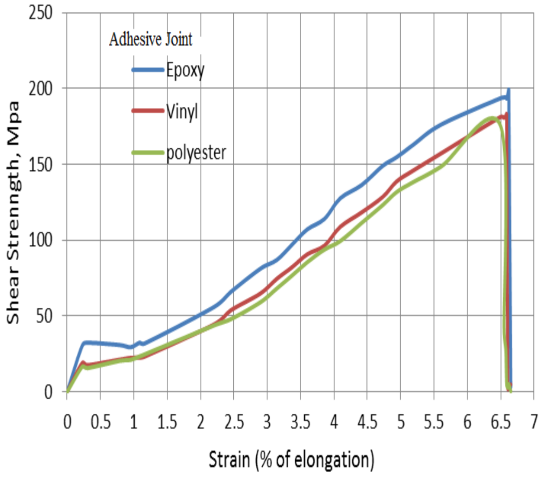

Figure 4(b): Stress strain diagram of double lap joint specimen 25 days

It is seen from the experiment results that specimen epoxy adhesive show maximum shear strength of 193.56 MPa and the polyester shows lowest value of 156 MPa. The vinyl ester adhesive joint shows almost same as epoxy but it fails lower strain rate. Both polyester and vinyl ester shows high brittle in nature hence they failed prematurely.

The percentage difference of shear strength for specimens epoxy and polyester around is 20%. From the Fig. 4(b) the stress-strain curves for the degraded specimens (25 day exposure) it is seen that epoxy, vinyl ester and polyester adhesive shows 173, 174 and 108 MPa respectively. The percentage difference of shear strength for exposure specimens are around 25 % to 40%. The difference in strength is due to hygrothermal condition of test specimens i.e. when the specimens are subjected to conditioning the moisture diffuses into specimens leading to weakening of the bond between the aluminium and polymer. Weakening of bond in laminates results in degradation of the strength and hence de-lamination. This variation of shear strength may be function of some pores and voids where there is ingress of moisture generated during the environmental conditioning, degrading the interface and causing probable metal /polymer adhesives de-lamination.

It is also observed from the graphs that the shear strength of double lapped joint specimens (epoxy, vinyl ester and polyester) is almost same as single lapped joint but more load to required to break the specimen is needed [17].

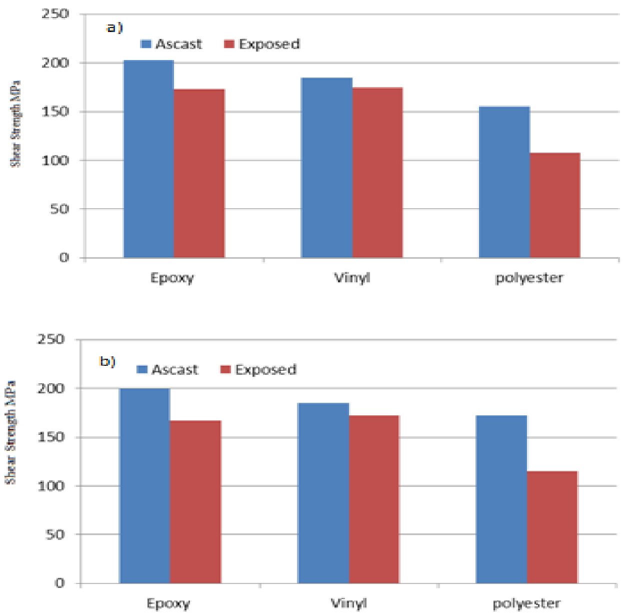

Figure 5: Comparison of shear strength for single and double lap joints for ascast specimen and 25 day moisture exposed specimen

This is due to thickness of double adhesive joints of specimens, as the specimens having double lapped joint in order to have 0.2 mm thickness and less shear strength, whereas the specimens having single lap joint in order have 0.1 mm thickness shown in Fig. 5. which Shows a detailed comparison between ascast and exposed specimens for single and double lap joints. It is seen that shear strength increases as the thickness of adhesive increases but the problem associated with this is that as the thickness increases the laminate de-lamination takes place.

From the graph stress- strain curve for epoxy specimens double lapped joint is linear up to 200 MPa stress for 1% strain in as cast condition, but after exposure to hydrothermal the curve shows non-linear character up to 155 MPa stress for 2.2% strain. This is due slipping of test specimen from setup, once the specimen is held firmly in the fixture of double shear set up again the curve shows the linear character and after certain load specimen breakdown takes place with an audible sound having stress value of 155 MPa for 6.3% of strain, which is indicated by sudden fall of curve in the graph. For the specimen vinyl ester and polyester show same trend of the stress- strain curve is linear up to 175 MPa and 165 Mpa stress for 1.5% strain respectively.

4. Conclusion

The influence of hydrothermal effect on single and double shear properties of ascast and exposed conditioned were investigated.

- After 25 days of exposure to hygrothermal effect, the test specimens with single lap joint absorb moisture at an average of 0.11% of weight and specimens with double lap joint absorbs moisture at an average of 0.14% of weight for all shapes of specimen.
- There is a decrease in shear strength from 200 Mpa to 175 MPa for epoxy single adhesive joint, from 175 MPa to 161 MPa for vinyl ester single adhesive joint and 150 to 105 MPa for polyester single lap joint with 5.47% deviation after 25 days hygrothermal exposure specimens.
- Whereas for double lapped joint specimens epoxy order the tensile strength decreases from 200 MPa to 1626 MPa contributing to an extent of 4.93 % deviation when exposed to hygrothermal condition, which is due to de-bonding of aluminium

and glass fiber leading to de-lamination. Vinyl ester and polyester degrade from 175 to 165 MPa and 165 to 110 MPa respectively.

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