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STUDY OF STRENGTH DEGRADATION DUE TO STRESS AND ENVIRONMENTAL EFFECT IN FIBER REINFORCED METAL MATRIX COMPOSITE – BASALT/ ALUMINIUM

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Abstract: The combination of environment effect and internal stress due to various forms of loads on stiffened structures like fuselage, wing and empennage of air vehicles, hull of a ship, and structural components of automobiles diminishes its design fatigue life. In fact, due to this effect the elongation and restoration of the material deviate from its elastic curve day by day. After a period of time, the repeated usage of these vehicle components in the changing environment with continues reaction to external loads causes crack formation in the weaker section of the material. The aim of this study is to limit the elongation of material and maintain the required strength and stiffness by introducing fibre reinforcement in metal matrix composite. Also it helps us to evaluate the strength degradation due to the environmental effect. For the analysis, a metal matrix composite was fabricated with 30% basalt as fibre reinforcement with 70% aluminium GRADE 6061-T6 as matrix. An experimental setup was fabricated to provide an artificial environment for the combined effect of stress and corrosion. The specimens were prepared according to the ASTM standard and fixed in the experimental setup for testing. The ultimate tensile strength of the specimens was determined initially and then after 30days, 60days and 90days interval using Universal Testing Machine (UTM). Also, the deflection due to a static load of 5 kg in 90 days duration was recorded and its slow strain rate was observed using the fabricated experimental setup. The maximum displacement of the material for 3 intervals using UTM and deflection curve due to static load in 90days using the experimental setup were compared, and hence the strength degradation rate was estimated.

***Index Terms*:** **Slow Strain Rate Stress Corrosion, Fibre Reinforced Metal Matrix composite, Crack Propagation Control, Basalt / Aluminium Hybrid Composite.**

1. Introduction

In aircraft industries Aluminium alloys are widely used because of its high strength to weight ratio and good corrosive resistance. With the statistical data of environmental attacks on materials, manufacturers keep on investigating alternative long lasting materials for various applications; also they are trying to manipulating the existing constituent materials' composition to achieve the desired material properties. The idea behind this work was adapted from various research outcomes, some of those works were highlighted here for the evaluation and motivation of the work. Outcomes from previous studies in hybrid composites recommended one of the effective approaches, that is by optimizing the mechanical properties of the material the damages and failures in materials could be controlled within the limit. In his study, the control is brought out by modifying with material coating or surface treatment of reinforcements. The work was succeeded with the expected results of mechanical properties [3]. In another study of Al-Si composition for the requirement of aerospace and automobile applications, rolling and T6 treatments effect on A6061/Al2O3 metal-matrix composites was investigated. Here the metal-matrix composites with different amounts of reinforcing Al2O3 particles were examined in the aspects of wear resistance and hardness. Finally, in T6 treatment, the hardness is enhanced considerably [4]. In another case, the abrasive wear rate of as-cast and heat-treated Al (6061) alloy reinforced with 9% by weight of SiC particulate and 0, 1, 3 and 5% by weight of E-glass fibre subjected to different aging durations were tested. In each test, the wear rates of the hybrid composites were found to decrease with increase in aging durations. In both as-cast and heat-treated hybrid composites, the wear rate increased with an increase in the sliding distance [5]. Based on these observations and results, the work is done by manipulating the constituent materials. In this work, Aluminium 6061 is selected as matrix and basalt as reinforcement, since aluminium has high strength to weight ratio and good corrosive resistance. In aircraft industries, weight reduction is one of the key areas, materials with high strength to weight ratio is added advantage. Normally, the material used for maritime and aerospace applications must have good corrosion resistant and thermal resistance. Another factor which affects the fatigue life of the vehicle is crack formation due to deterioration and repeated usage of components .So, in order to control crack propagation in materials and maintain the required strength, following ideas were taken into consideration. We are familiar with some of the following cases and solutions for them. Usually crack propagation in materials are stopped by drilling holes at the end of the crack path, and partially separated materials strengthened by rejoining them with metal pastes or glues or tightly packing with fibers. Some of these ideas were considered here for the fabrication of composite material.

II. Materials and Fabrications

2.1. Materials

The constituent materials are Aluminium 6061-T6 and fibre. Aluminium 6061-T6 is used in aircraft because of its high corrosive resistance than other aluminium basalt grades. Basalt fibre is fabricated from molten rock, so by nature, it has high resistivity to corrosion, thermal and also it has relatively good mechanical properties, so that these two materials were chosen in the ratio of 70:30 for the fabrication.

2.2. Steps for the Fabrication Process

In order to fabricate fibre reinforced metal matrix composite, a rectangular dye frame using a steel rectangular pipe was selected. Sides of frame were drilled to feed basalt fibre through it; the depth of the dye frame is 6mm. The gap between the slots is 5mm. Basalt fibre was weaved through the slots in bidirectional with necessary tension and tied to the screws attached to the plates as shown fig.1. Then the aluminium 6061-T6 was melted and the liquefied aluminium was filled in the dye frame.

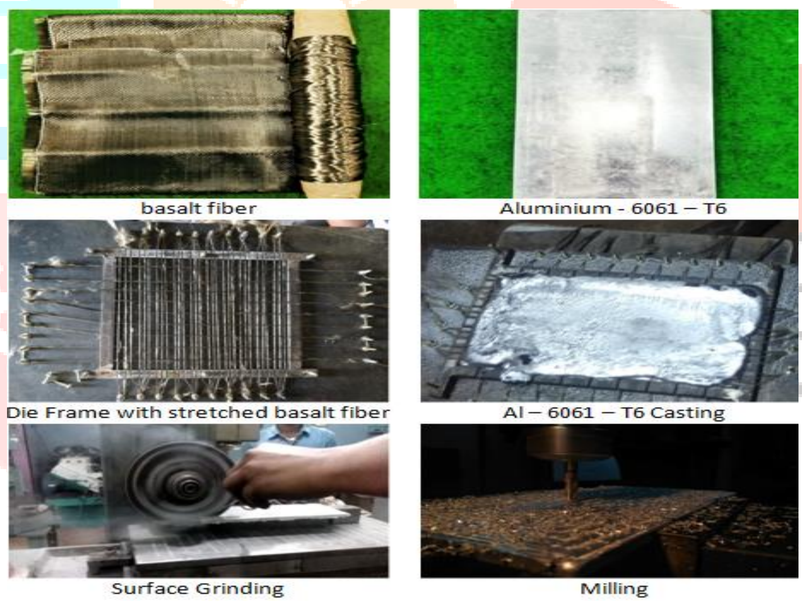


Figure.1. Fabrication of fiber reinforced metal matrix composite.

It was kept for natural curing for 24 hours, after curing; the composite was given for milling and surface grinding. The finished material was divided into specimens according to ASTM using water jet cutter.

III. Experimentation

3.1. Testing of Tensile Strengths using UTM

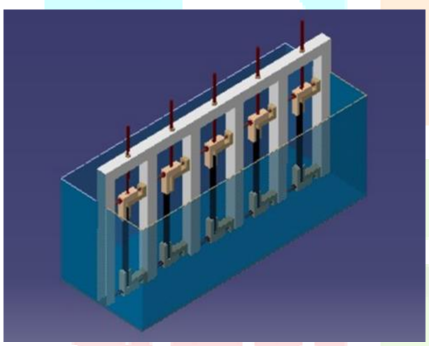
Initial mechanical strength of specimens was tested using universal testing machine as shown in figure.2. The stress-strain relation and load versus elongation behaviour of the materials were observed. UTM results shows the Strength and elongation of pure aluminium is lower compared to hybrid aluminium composite.

Fig .2: Testing of Metal Matrix Composite and Al- 6061 using UTM

The tensile strength of specimens after exposed to the environment with static load and without static load for 30-days, 60days and 90days duration were tested using universal testing machine and the values are recorded in tables 1.

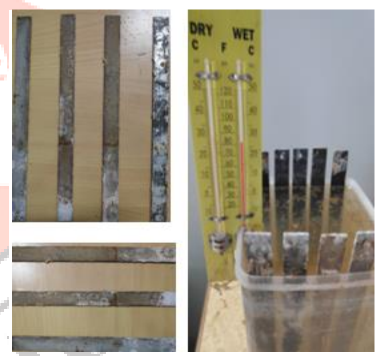
3.2. Testing of specimens in an Artificial Environment with static load and without static load

An artificial environmental setup was fabricated for the experimental study. The setup has the provision to suspend tensile load at one end of the specimen and the other end could be rigidly fixed on the top of the frame as shown in the following fig. 4.The NaCl solution of pH value 7.6 is filled in the container. The strain gauges of 350 Ohms were fixed to the middle of the specimens, and static load of 5kg was applied at the free end. Strain in each specimen was noticed with help of multi channel strain indicator as shown in fig.4.b.



(a) **CAD Diagram**

(b) **Setup with static load**



(c) **without static load**

Figure.3. Artificial Environment with static load and without static load

Strain indicator was connected to the terminals of all strain gauge attached with specimens. The strains were noticed on the first day of all specimens to 90th day. The tensile strengths of the specimens after every 30 days were tested using UTM for comparison. Similarly, the specimens without static load were also studied. (See figure.3.c)

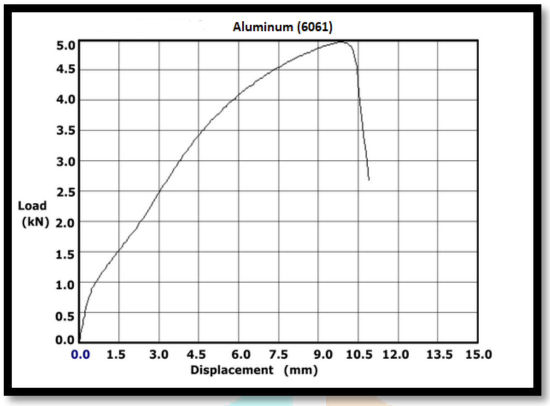
Tests were carried for two sets of samples (4 each set).

Sample type 1: aluminium/basalt hybrid composites
Mass = 83g
Volume = 250 x 25 x 5 = 31250 mm^3
Density = 2560 kg/m3

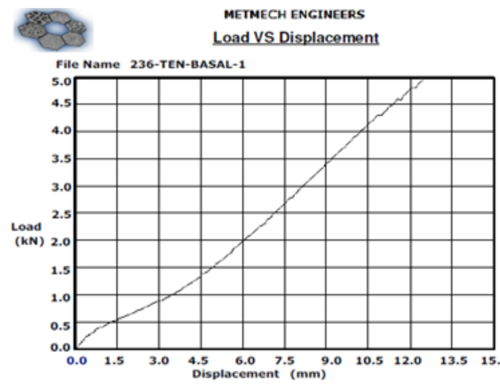
Sample type 2: aluminium 6061
Mass = 88g
Volume = 31250 mm^3
Density of 6061 Al = 2700 kg/m^3

IV. Result and Discussion

4.1 Test Results of Tensile Strengths using UTM

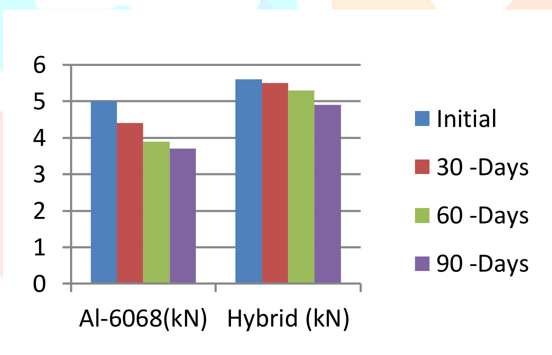


(a) Load Vs Displacement of Aluminium

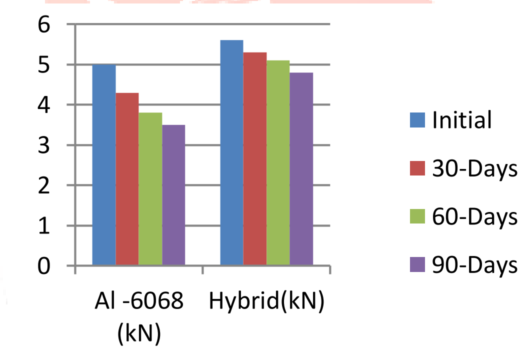


(b) Load Vs Displacement of Basalt/Aluminium

Figure.4.Load verses displacement curve of both samples



a. **With static load (kN)**



b. **With static load (kN)**

Figure.5. Comparison of strength degradation with number of days

The initial strengths of Al-sample and hybrid materials samples were studied from fig.4. The displacement of aluminium falls down after 5kN figure8.a where as the hybrid composite, still it is taking the load and displacement is linear to the applied load.

Table.1: Tensile Strengths with and without static load tested after 30 days, 60days and 90 days using UTM

Samples	Tensile Strengths after Number of Days with static load (kN)				Tensile Strengths after Number of Days without static load (kN)			
	1st day	30days	60days	90days	1st day	30days	60days	90days
Metal matrix	*5.6*	*5.3*	*5.1*	*4.8*	*5.6*	*5.5*	*5.3*	*4.9*
Aluminium	*5*	*4.3*	*3.8*	*3.5*	*5*	*4.4*	*3.9*	*3.7*

The percentages of strength degradation with static load and without static load were compared and the fatigue life of the material is estimated using bar chart shown figure.5

Table.2: Slow Strain due to static load and wet corrosion

Samples	Micro Strain in Number of Days			
	initial	30days	60days	90days
Metal matrix	*80*	*102*	*113*	*121*
Aluminium	*83*	*112*	*128*	*142*

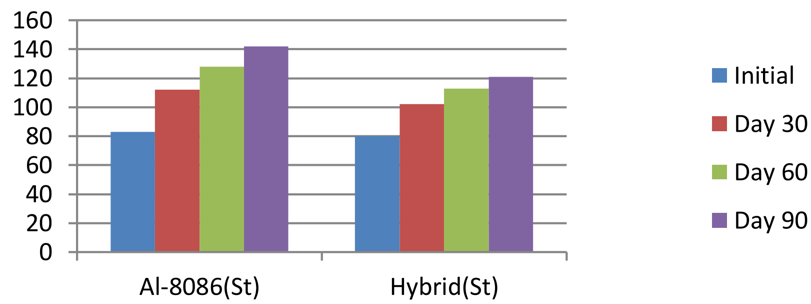
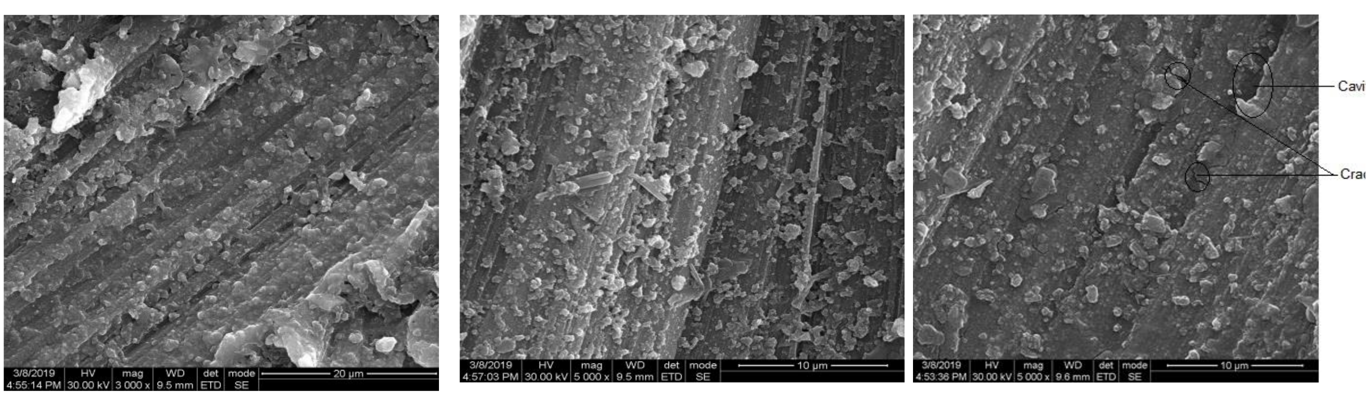


Figure.6: Micro Strain Rate using Stress Corrosion Setup

4.2. SEM Images of Metal matrix Composite

For SEM analysis, images of 30days, 60days and 90days metal matrix composite samples were taken (see, figure 12), the image we could see the external morphology, orientation of the material and few cracks and cavities. Due to the combined effect of stress and wet corrosion, some form of cracks could be seen in the images. When we compare these images, the crack growth is proportional to the number of days of interaction with the environmental factors and the internal stress in the material. The existence of the cavity is another parameter which accelerates the crack propagation in the metal matrix. This defect is marked in fig.7.c.
In figure 13 in 20-micrometer scale magnification, it could be seen that crack, the deposition of NaCl and irregularity on the surface due to corrosion.
The crack paths are intermittent within the material due to the presence of fiber that means it controls the crack propagation through the material from the starting point to the adjacent hole through which the fiber reinforced. As we know that the elongation of basalt fiber is comparatively less than aluminium, the crack in the metal matrix is resisted by the fiber reinforcement to a considerable percentage



(a) Hybrid Composite after 30 Days **(b) Hybrid Composite after 60 Days** **(c) Hybrid Composite after 90 Days**

Figure.7: SEM Image of Hybrid Composites

V. Conclusion

From slow strain rate analysis the strength degradation of hybrid composite under stress corrosion environment after 90 days is 14%, where as in normal wet corrosion it is 12.5%. So, due to the combined effect of stress and corrosion the strength of the specimen decreased is 1.5% in 90days.
Similarly in the case of Al-6068 the percentage of strength degradation under stress corrosion is 30, whereas in normal wet corrosion the strength degradation is 26%, the difference in degradation due to stress is 4%.
So, When we compare the strength of both materials, Metal matrix composite has higher strength than pure aluminium, the reason is the fiber reinforcement gives additional strength to reduce overall elongation by sharing the load. The metal matrix elongation is resisted by the fiber and when the fiber fails the whole material fails. Table 4 gives the strength degradation of composite specimen and aluminium specimen in two environmental conditions.

Table.4: Strength degradation with and without static load after 90 days using UTM

Testing environment and specimen		Initial strength	strength after 90 Days	% of Strength Degradation
With Static Load	**Aluminium**	5	3.5	30
	Hybrid	5.6	4.8	14
Without Static Load	**Aluminium**	5	3.7	26
	Hybrid	5.6	4.9	12.5

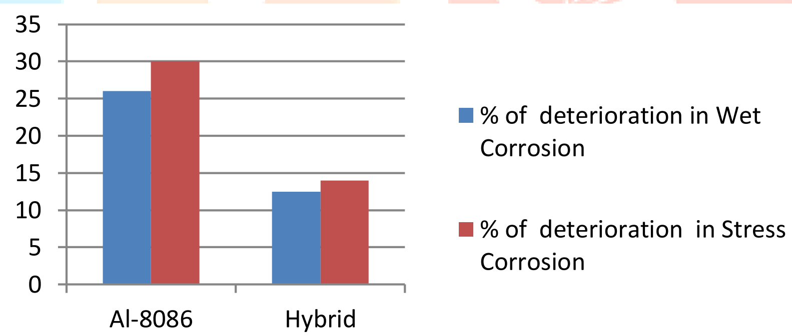


Figure.8: Strength Degradation with Environmental Effect

The slow stain rate under stress corrosion can be analyzed using table.5. The average strain rate per day of both the materials is compared in the following table.

Table.5: Average Slow Strain Rate per Day

Samples	Strain Rate per Day (10^{-6}/ day.)		
	After 30days	**After 60days**	**After 90days**
Metal matrix	0.73	0.37	0.27
Aluminium	0.97	0.53	0.47

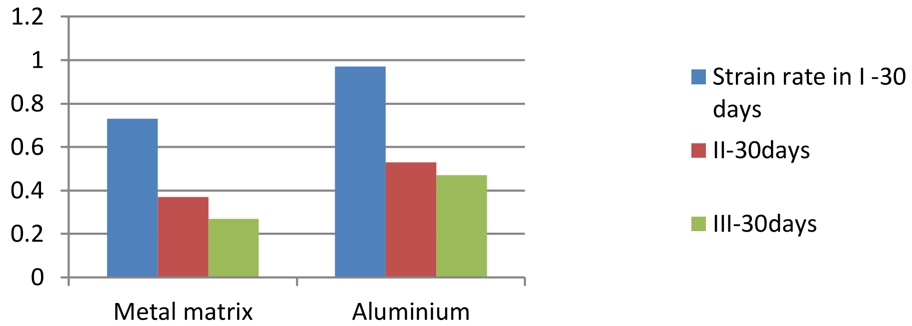


Figure.9: Strength Degradation with Environmental Effect

In fig.9 we see that the elongation reduces gradually due to degradation and there is a symptom of crack formation, as shown in fig 8.c.. So, by introducing fibre reinforcement in metal matrix composite could reduce the risk of crack growth and sudden structural failure, and save lives in all types of vehicles, especially in air transportation.

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