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Analysis of wear properties of granite dust filled polymer composite for wind turbine blade

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ABSTRACT

Efficient usage of wind energy by establishing a suitable material for wind turbine blade is considered in this paper. Aluminium alloys and coated timber were used as blade material in the early stage and are discarded for various reasons including their life time and their efficiency. New polymer based materials such as Carbon fiber, Glass fiber, and Aramid fiber with different kinds of resins are being used as wind turbine blade material these days. As a new trend, granite dust is filled with the polymer material to improve its qualities like hardness and durability. It is tested for wear properties in Air jet erosion tester by varying the angle of impingement keeping other factors constant. Its mechanical properties like tensile stress, hardness and density values are calculated and plotted in graphs. The obtained results demonstrate how the wear properties of these samples changed with the impingement angle.

1. Introduction

Wind energy was used for various purposes in ancient times including transportation of ships, fishing in sail boats, and natural ventilation in palaces. Similarly Wind mill also served various purposes like grind corn, pump water in sugarcane industry and salt industry etc. But usage of wind mill to produce electricity is implemented first in America in 1887 [1]. Then onwards the era of wind power is started and the researches towards the improvements on this field started taking place. The shape of the blade, the material used to make rotor and blade, the optimum length of the blade and coatings used on blades are some of the dominant features considered presently by the researchers [2]. With the improvement in technology, different materials have been tested for wind turbine blade material considering its supreme expected qualities like high stiffness, high strength, long fatigue life, low weight, long durability and electrical and thermal resistance [3]. At the early stage, aluminium alloys and coated timber were used as blade material but now most of the blades are manufactured by Carbon fiber, Glass fiber, and Aramid fiber Figs. 1–5[1–9]

2. Research background

Wind turbine blades were made up of alloys of aluminium at the early stage of this revolutionary idea. But thermal damage because of lightning strike [4], less fatigue level, low tensile strength and less stiffness became hindrance for their expected performance and resulted in less efficiency. Poor corrosion resistance and Vibration of blade when it rotating were negative outcomes of that idea and resulted in the failure of above mentioned material [5]. Then the idea of coated timber arose, which was mainly for developing countries because of their economic conditions. But here the problem accompanied was the blade material was limited for certain kinds of timbers and the length of the blade was small [6]. Still it served small level requirements. It can’t be used for large commercial needs. Nowadays Carbon fiber, Glass fiber, and Aramid fiber are used for this purpose [7]. According to the studies by the researchers, glass fiber has good electrical and mechanical properties and high heat resistance. Carbon fibers have an excellent combination of very high stiffness, high strength, light weight and low density [1]. Carbon fibers are thrice as stiffer as glass fiber and about two times stronger. But five times costlier than glass fibers. Aramid fibers (aromatic polyamides) have excellent environmental and thermal stability, static and dynamic fatigue resistance, and impact resistance. These fibers have the highest specific tensile strength (strength/density ratio) of any commercially available continuous-filament yarn. Aramid reinforced thermoplastic composites have excellent wear resistance. Aramid fibers have low or very low densities. But all of them (carbon fiber for long blade and glass and

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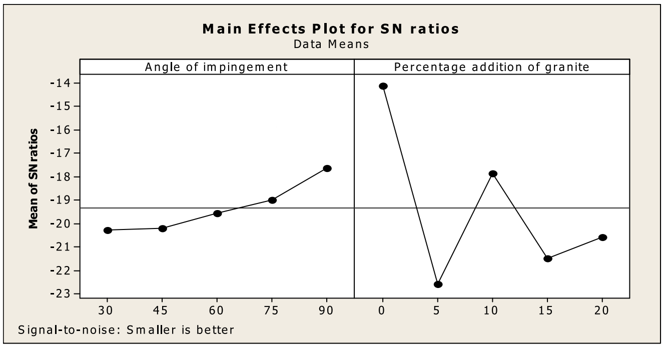

Fig. 1. Results of erosion analysis.

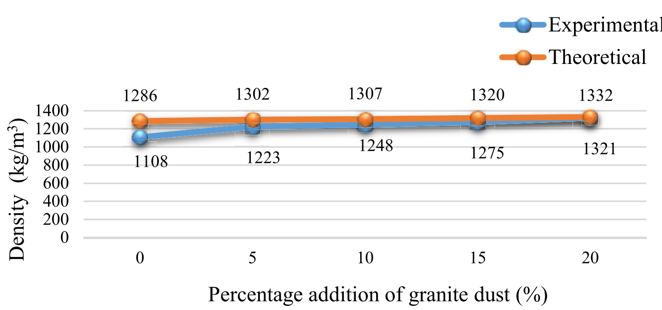

Fig. 2. Comparison of theoretical and experimental density of the samples.

aramid fiber for small blade) are used across the world today [8]. It is expected that the qualities for this application can be improved by adding some filler material with fibers. In this paper, granite dust is added with poly amide fiber in different percentage and tested for erosion under air jet erosion tester by varying the test conditions. The density of the granite is between 2.65 and 2.75 g/cm^3 and compressive strength is more than 200 MPa [9]. The addition of granite dust to hydraulic turbine blade material gave fantastic results while considering both stability and durability [10]. So here also granite dust is added in order to improve its mechanical properties with no cost because it is a waste material from granite industry and in other words this may be considered as utilization of waste material.

3. Experimental procedure

3.1. Preparation of the specimens

In this study, Polyamide needle fiber reinforced plastic was used as wind turbine blade material with varying the percentage of granite dust by 5%, while keeping the percentage of poly amide fiber constant and changing the percentage of resin. This data is shown in Table 1. Polyester resin is the adhesive material used in this work. Specimen of size 200 mm*100 mm*5 mm were developed by hand layup process. Hand layup process is an open moulding process. In this process, fiber reinforcements are placed in a mold by hand and resin mixed with granite dust (filler material) is applied with a roller or brush. The prepared specimens were then cut into small pieces of size 25 mm*25 mm*5 mm to test in air jet erosion tester.

3.2. Description about the tests

The specimens were tested in TR-871-400 Air Jet Erosion Tester abiding ASTM G76 international test procedure. The tests were conducted in a velocity of 60 m/s, because it is the normal survival speed of a wind turbine. Survival speed is the maximum speed of wind a wind turbine can withstand, above which it cannot survive [5]. Angle of impingement is varied in steps of 30^0, 45^0, 60^0, 75^0, and 90^0 with

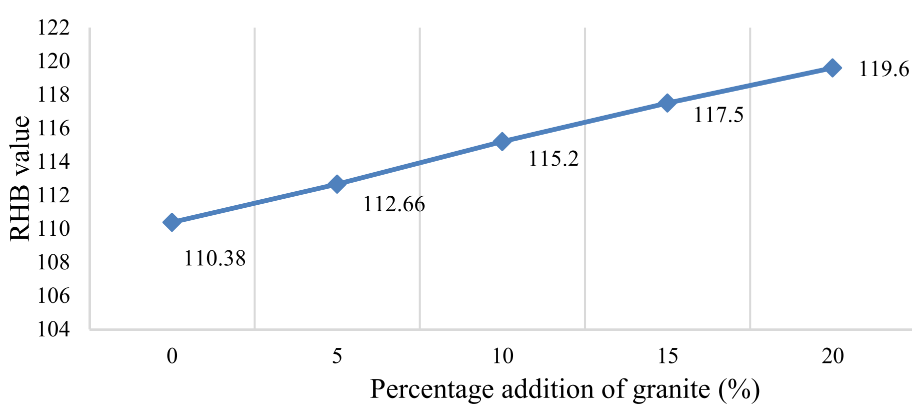

Fig. 3. Results of rock well hardness B test.

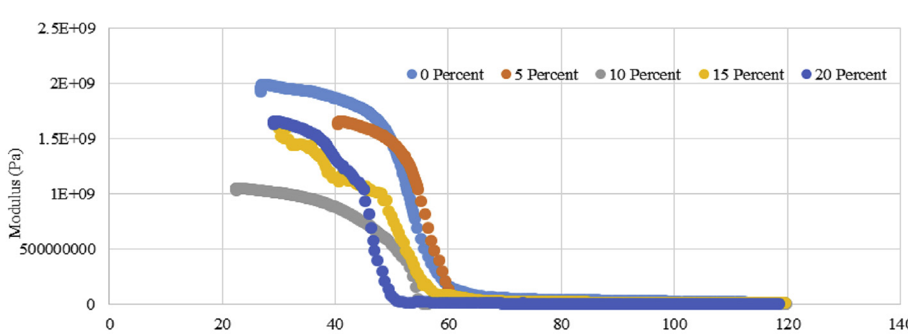

Fig. 4. Temperature Vs modulus.

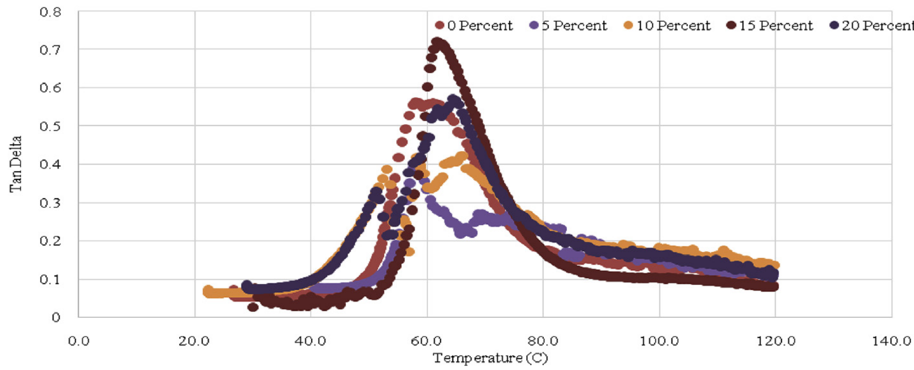

Fig. 5. Temperature Vs Tan Delta.

Table 1
Percentage addition of individual material.

Number	Specimen	Poly amide Fiber (%)	Poly ester Resin (%)	Granite Dust (%)
1	Specimen 1	10	90	0
2	Specimen 2	10	85	5
3	Specimen 3	10	80	10
4	Specimen 4	10	75	15
5	Specimen 5	10	70	20

independent specimen holders. The erodent feed rate was 5 g/min and the erodent used here was normal sand (SiO_2) with 50 μm size because these are the particles strike the wind turbine blades mostly mixed with wind. There is a facility to change the temperature of the specimen under experimentation up to 800 °C. But more than 60 °C is not practically identified anywhere in earth. Since the tests are conducted in 40^0 Celsius average temperature. Erodent feed rate and velocity of the air jet in Air jet erosion tester kept constant. 10 samples were used for each test and average of it was taken to analyze the erosion. Weights of the specimens were measured by Precisa 125 A precision balance, has a least count of 1 mg and an upper limit of 450 g can be measured on it. Before and after the experiments the specimens were cleaned and weighed to calculate the weight loss. The three point bending test is conducted in DMA 8000 dynamic mechanical analyzer. According to machine standards, the thickness of the specimen should not exceed 3 mm and length can be in between 10 and 20 mm. The width is kept around 5 mm because increase in width may result in an uneven holding of the specimen in the clamp.

4. Results and discussion

4.1. Erosion analysis

The results obtained from Taguchi analysis of L25 orthogonal array is shown in Fig. 1. It has 5 factors and 2 variables. The percentage addition of granite dust and the impingement angle are the 2 variables here. 30^0, 45^0, 60^0, 75^0, and 90^0 on impingement angle and 0%, 5%, 10%, 15% and 20% on percentage addition of granite dust are the 5 factors for those 2 variables. The SN ratio was chosen based on smaller is better criteria. The reason behind the selection of these criteria is, if the erosion rate reduced, it is better to be used in wind turbine blade application. SN ratio means the signal to noise ratio i.e. a measure of robustness used to identify control factors that reduce variability in a process by minimizing the effects of uncontrollable factors (noise factors). The SN ratio for angle of impingement shows 90^0 is the best (and 75^0 is the next) applicable angle to minimize erosion. Both these angles stand above the mean line in the graph.

Here, the erosion rate is decreasing with the increase of impingement angle. While considering the percentage addition of granite dust, pure polyamide fiber without adding any filler material is being the best and 10% granite dust added fiber is also good for use. It can be noticed that both these values are above the mean line in the graph.

4.2. Density analysis

Wind turbine blades were made up of timber (density = 408 g/cm^3 – 624 g/cm^3) [6] and aluminium (density = 2.7 g/cm^3) in the early stages and carbon fiber (density = 1.75 g/cm^3), e-glass fiber (density = 2.54 g/cm^3) and aramid fiber (density = 1.45 g/cm^3) [1] at present. But a wind turbine blade must possess low density with high stiffness [1]. Density can be calculated theoretically and experimentally. Usually the theoretical density can be obtained in terms of weight fraction for any composite material by the equation given below.

$$\rho_{ct} = 1/[(w_f/\rho_f) + (w_m/\rho_m) + (w_g/\rho_g)] \quad (1)$$

Here, w represents weight fraction and ρ represents density.

The suffixes represent the individual components used here. (f-fiber, m-matrix, g-granite dust and ct-composite material). There are three main components in this composite, which are matrix-polyester resin, fiber and particulate filler-granite dust. Water immersion technique can be used to find the actual density (ρ_{cm}) of the composite experimentally. The specimens we tested here have a theoretical density range between 1.286 g/cm^3 to 1.332 g/cm^3 and experimental density ranging from 1.108 g/cm^3 to 1.321 g/cm^3. The density analysis shown in Fig. 2 gave a good output that the addition of granite dust is better than the usage of pure aramid fiber. While we increase the percentage addition of granite, the difference between theoretical and experimental densities is getting reduced.

4.3. Hardness test (RHB)

The hardness of the composite fiber relates the ability of wind turbine blade to withstand the impact from dust, rain and hail etc. The turbine blade need to be stiff enough to resist bending while rotating and avoid hitting the tower. The Rockwell hardness test is used here to find the hardness of the sample as defined in ASTM E−18. This is the most frequently used hardness testing method.

For this experiment, conical hard steel with a round tip with indenter size of 1/16" was used. The applied load is 100kgf. The graph illustrates that the RHB value is increasing with the increase in the percentage addition of granite dust to the composite. Average of the hardness of 10 samples were taken to finalize the hardness value. 20% granite dust added sample has the highest hardness value and pure sample without adding any granite dust has the least hardness value. As shown in Fig. 3, the hardness values are increasing gradually with the addition of granite dust.

4.4. Three Point bending test

Three point bending test is done through Dynamic Mechanical Analysis. Here a sinusoidal force is applied and the response of the sample is measured at a given temperature. For this purpose, sample was made in a size of 3*5*15 mm. The highest temperature assigned as 120^0 Celsius and increment per minute fixed at 3^0 Celsius per minute. The graphs are drawn for modulus vs. temperature and tan delta vs. temperature. They are compared for different percentage addition of granite dust. Tan delta denote the loss factor or damping factor, that is the tangent of the phase angle and the ratio of E"/E'. Where E' is the storage modulus, which is the measure of the elastic response of a material. It also called as in-phase element. E" is loss modulus. It is a measure of the viscous response of a material. It is commonly known as out of phase element.

The specimens exhibit a high modulus value in 20^0–50^0 Celsius region, followed by significant reduction in the region of 50^0 - 70^0 Celsius and total deterioration is observed in the region of 70^0 - 120^0 Celsius. And also all the specimens are showing a modulus above 1.5 Giga Pascal except 10% granite dust added specimen, which shows around 1 Giga Pascal. These details are clearly shown in Fig. 4 and 5.

5. Conclusion

The angle of impingement has some impact in the erosion rate. It shows the highest erosion in the angle of 30° and lowest erosion in the angle of 90° and erosion rate generally decreasing with increment in angle. Percentage additions of Granite dust also have influence in erosion rate. Lowest erosion observed when we do not add granite dust and it is followed by 10% granite dust added sample. Highest erosion is observed when we add 15% granite dust.

There was a slight deviation between the experimental and theoretical densities. It was assumed that the deviation occurred due to the absorption of water particles by the sample when we tested the composite material. It can be noticed that the volume fraction of voids getting reduce with the increment in the percentage addition of granite dust. But the exact reason for this behavior could not be identified.

The hardness values are increasing with the increment in the percentage addition of granite dust as expected.

The DMA analysis shows that 5% granite dust added specimen and pure poly amide fiber specimen withstand up to 60^0 Celsius but 20% granite dust added specimen tolerate only up to 50^0 Celsius. Anyhow 65^0 seem to be the maximum temperature acquired by them before they deteriorate.

6. Future scope

Normally wind turbine with all its components have a warranty period of 20 years. All the areas related to wind turbine such as structural design, material selection, sensors, and transmission lines are kept on being developed these days. Also special attention is focused on its individual parts like rotor, hub, generator, and control system. Moreover, in future we can expect more advanced materials may be discovered to serve this purpose.

Author contributions section

J. Joy Mathavan: Conceptualization; Data curation; Formal analysis; Funding acquisition; Methodology; Project administration; Resources; Software; Visualization; Roles/Writing - original draft; Writing - review & editing. Amar Patnaik: Investigation; Supervision; Validation; Writing - review & editing.

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