Analysis of Erosion Properties of Polymer Composite Filled with Granite Dust for Hydraulic Turbine Blade Material

J. Joy Mathavan, Sugandha Shrestha, Rehan Kaifi and Amar Patnaik

Abstract The main objective of this research work is to introduce a new material for hydraulic turbine blade for efficient usage of hydraulic energy. Instead of the usual alloys used for hydraulic turbine blades, composite material has been tested in this paper. Polyamide needle fibre (aramid fibre) has been used here; due to its high resistivity to erosion by water, it is cheap among other fibres while polyester resin was used as the matrix. The samples were prepared by hand lay-up process. As a new trend and considering waste matter utilization, granite dust was added to the above composite as a filler material, because it is considered as an industrial waste. It belongs to the igneous rock family and is found to have good mechanical properties. In different percentages, granite dust was added to the composite to test the improvement in the erosion resistance and other mechanical properties. The velocity of jet, the feed rate of erodent (silica sand), the size of erodent, and the angle of impingement were changed, and the tests were done in Taguchi standard L25 table with five variables and five factors. The results are analysed and plotted in graphs. Hardness number was calculated in Rockwell hardness tester. Theoretical and experimental densities were also calculated.

Keywords Polyamide needle fibre · Slurry jet erosion · Granite dust

1 Introduction

Sediment erosion in hydraulic turbine blade is being as the main hindrance in the advancement of projects based on hydraulic power. Solid abrasive particles found in waterfall, or river water is the source for fast wear down of turbine blades and other parts, which causes reduction in the performance of turbines. It leads to the drop-off in reliability and efficiency of turbine and also operating life of turbine blades. M. Pandhy and P. Senapati stated in their studies that silt erosion in hydro

J. J. Mathavan (✉) · S. Shrestha · R. Kaifi · A. Patnaik
Malaviya National Institute of Technology, Jaipur 302017, India
e-mail: 2012ume1777@gmail.com

S. K. Ghosh (ed.), *Waste Management and Resource Efficiency*,
https://doi.org/10.1007/978-981-10-7290-1_51

turbines cannot be avoided totally, but excellent materials and surface coating can be used to raise the life of the runner. So they worked and found that NiCrFeSiB alloys are resistant to abrasive wear [1]. From this, it can be noticed that there is requirement for new materials to be developed for the purpose of turbine blades, and they should be able to stand firm in erosion situation due to excess sediment. The primary action on the way to such progress is to explore different possibilities in material selection in laboratory. It should be noticed that a standard methodology has to be followed to perform sediment erosion experiments in controlled atmosphere.

Wear on the blade of the turbine due to erosion is a complex occurrence which is caused by (i) the hardness, size and shape of the erodent particles, and their concentration (ii) elastic properties, substrates, surface hardness, chemistry and surface morphology and (iii) operating conditions such as impingement angle and velocity. 13Cr–4Ni steels are the usual material for the application of water pumps and hydro-turbines. They are preferred because they have outstanding mechanical properties. Though these alloys have noticeably poor resistance to erosive wear and scratched-off because of high content of silt in water, B. Rajkarnikar et al. numerically obtained erosion pattern for Francis turbine components. Their information may serve as an input for turbine design method to recognize the regions where distinct surface treatment is needed in order to enhance the durability of the components which are exposed to sediment erosion [2].

Composites are made from two or more constituent materials which have significantly dissimilar physical/chemical properties which when combined produce a material having properties altered from its individual components where the individual components remain separate as well as distinct within the finished structure. Composite material structure possesses two components: the fibre and the matrix. The fibres which generally possesses a high modulus of elasticity and ultimate strength are the part of the composite material which contributes to the strength. Examples of commonly used fibres are carbon, glass and aramid fibres. The matrix in a composite is to bind the fibres together as well as protect the fibres from damage by the transfer of stresses to the fibres. Examples of common structural resin systems are vinylester, polyester and epoxy. This paper includes our findings of a composite material of polyamide fibre and epoxy resin with various percentage addition of granite dust.

Granite dust has been mixed in different percentages to test the improvement in required properties. The density of the granite is between 2.65 and 2.75 g/cm^3 (but for granite dust/powder, it decreases to 1.65 g/cm^3) and its compressive strength is greater than 200 MPa. The reason behind the selection of granite dust to be added is that it contains SiO_2 (Silica)—72.04% and Al_2O_3 (Alumina)—14.42%. So it is expected that the erosion resistance and hardness values will satisfy the requirements.

2 Methodology

There are a lot of methods for fabrication of composite materials. Some of the methods developed which meet specific manufacturing or design challenges are injection moulding, hand lay-up process, etc. Selection of a method for a particular part depends on the materials used, the design of the part and application of that particular model or end-use of it. Composite production procedure engages some kind of casting to strengthen the resin/fibre mixture and its shape. A casting apparatus is essential to provide the shapeless fibre/resin arrangement its shape prior to and all through its cure.

2.1 Specimen Preparation

The most popular type of open moulding process is hand lay-up process. The hand lay-up is done manually and is a slow and labour consuming method. In this process, polyamide fibre gets added layer by layer and polyester resin mixed with granite dust used as the matrix to adjoin and strengthen the composite. Different percentage of granite dust mixed to form the composite is given in Table 1.

2.2 Slurry Jet Erosion Test

Slurry Jet Erosion Testers facilitate the detection of excellent material in particular working environment. The wear rates found by experiments may be referred to calculate the service life and cost of life cycle. In this experiment, the test variables considered are velocity of water jet (8, 16, 24, 32 and 40 m/s), angle of impingement (30°, 45°, 60°, 75° and 90°), erodent size (150, 200, 250, 300 and 355 μm) and erodent feed rate (160, 195, 230, 265 and 300 g/min). The slurry jet erosion tester required the test material to be of the exact size of the die of the tester (25 mm $\times$ 25 mm) and silica sand of less than 400 μm to act because an abrasive sand particles or impurities larger than 400 μm would get stuck in the nozzle of slurry jet erosion tester through which the jet water with erodent impinges on the test material. Average reading of five tests of

Table 1 Percentage addition of individual materials to form the composite

S. no.	Sample	Polyamide fibre (%)	Polyester resin (%)	Granite dust (%)
1	Sample 1	10	90	0
2	Sample 2	10	85	5
3	Sample 3	10	80	10
4	Sample 4	10	75	15
5	Sample 5	10	70	20

each having a test duration of 10 min has been taken to finalize the erosion loss. The weight before and after the tests was measured with a balance of least count 100 μg. The obtained results are analysed and compared by Taguchi L25 table (five factors and five variables), and the optimum results have been identified.

2.3 Rockwell Hardness Test

The Rockwell hardness test method, as defined in ASTM E-18, is the most commonly used hardness test method. Unlike Brinell hardness test, it can also be performed to the specimens which do not have a reflective surface. The Rockwell test is generally very easier to perform, and more accurate than other types of hardness testing methods. In Rockwell hardness tester, variety of indenters may be used. In this study, conical hard steel with a round tip for composite materials with indenter size 1/16″ was used. The load applied is 100 kgf according to machine standards. Average of 5 readings for each sample has been taken to conclude the hardness of the sample.

2.4 Tensile Test

Tensile test has been done through dynamic mechanical analysis. The graphs drawn for modulus vs temperature and tan delta vs temperature are compared for different percentage addition of granite dust. For this purpose, sample has been cut in a size of 2 mm × 3 mm × 12 mm. The highest temperature assigned as 120 °C and increment per minute fixed at 3 °C per minute.

3 Results and Discussion

3.1 Results of Taguchi Analysis

Figure 1 shows the graph obtained by Taguchi analysis after obtaining the average of five set of experiments for each. It can be noticed that the velocity of the water jet plays a vital role than all the other factors. With increment in velocity of water jet, the erosion rate also increasing. It can be observed that 75° angle emerged as the best angle with least erosion, and it is followed by 90° angle. 10% addition of granite dust gives minimum erosion. 200 μm size erodent particles give less amount of erosion and minimum feed rate of 160 g/min causes least erosion.

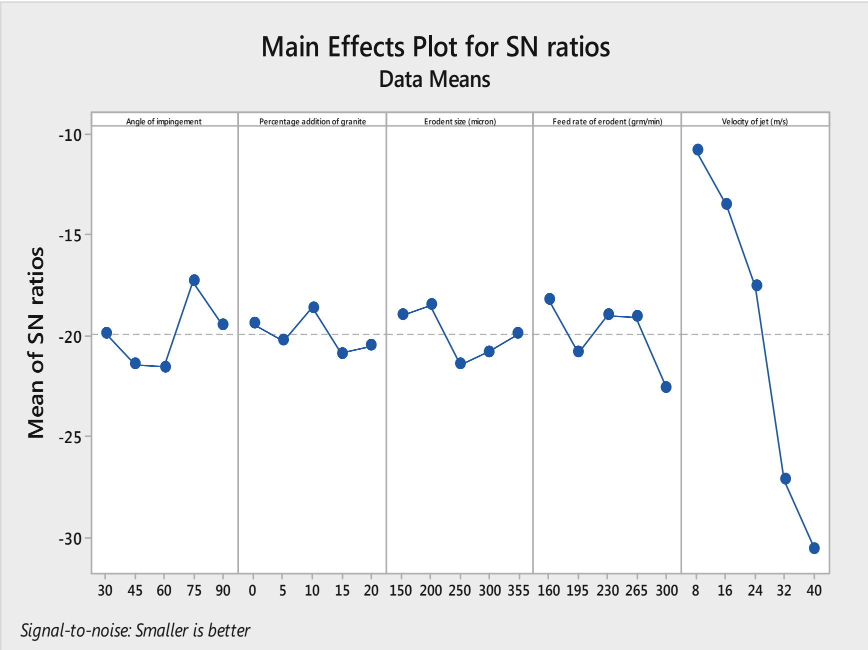

Fig. 1 Graphical representation of results of Taguchi table

3.2 Density Comparison of the Samples

In composite materials, the theoretical density in terms of weight fraction can simply be found by using the formula [3, 4, 5]

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

This formula has already been used by Agarwal and Broutman [3] in their work, where w represent the weight fraction and ρ represent the density. The suffix g stands for granite, m stands for matrix, f stands for fibre and ct stands for composite material (Table 2).

The prepared composites in this study contain three elements namely fibre, matrix and particulate filler. The actual density (ρ_{cm}) of the composite can be found out experimentally by usual water immersion method. The volume fraction of voids (V_v) in the composites is calculated using the following equation [3, 4, 5]:

$$\text{Vv} = (\rho_{ct} - \rho_{cm})/\rho_{ct} \tag{2}$$

Table 2 Density comparison of the samples

Sample	Percentage addition of granite dust	Experimental density (kg/m^3)	Theoretical density (Kg/m^3)	Volume fraction of voids (%)
Sample 1	0	1108	1286	13.8
Sample 2	5	1223	1302	6.0
Sample 3	10	1248	1307	4.5
Sample 4	15	1275	1320	3.4
Sample 5	20	1321	1332	0.8

3.3 Rockwell Hardness B Test Results

See Table 3.

3.4 Variation of Modulus with Temperature

Loss modulus means being proportional to the energy dissipated during one loading cycle. For example, it can be said that energy lost as heat and is a degree of vibration energy that has been converted during vibration. It cannot be recovered. Figure 2 represents the variation of storage modulus with temperature. We can see that there are three significant regions in this graph. A high modulus zone from 20 °C to 50 °C is the first region. A transition region, where a significant reduction in the storage modulus values occur with rise of temperature (50 °C – 80 °C) is the second region. An elastic region where a severe deterioration in the modulus occur with rise of temperature (80 °C –120 °C) is the third region. It can also be noticed from the graph that 10 and 15% granite dust added samples have a high modulus of 900 Mpa and pure polyamide fibre–resin combination have minimum of 500 MPa. All the samples show above 800 MPa for which the granite dust has been added.

Table 3 Rockwell hardness B Test results

Sample	Percentage addition of granite	RHB value
Sample 1	0	108.5
Sample 2	5	110.5
Sample 3	10	115.6
Sample 4	15	117.4
Sample 5	20	119.6

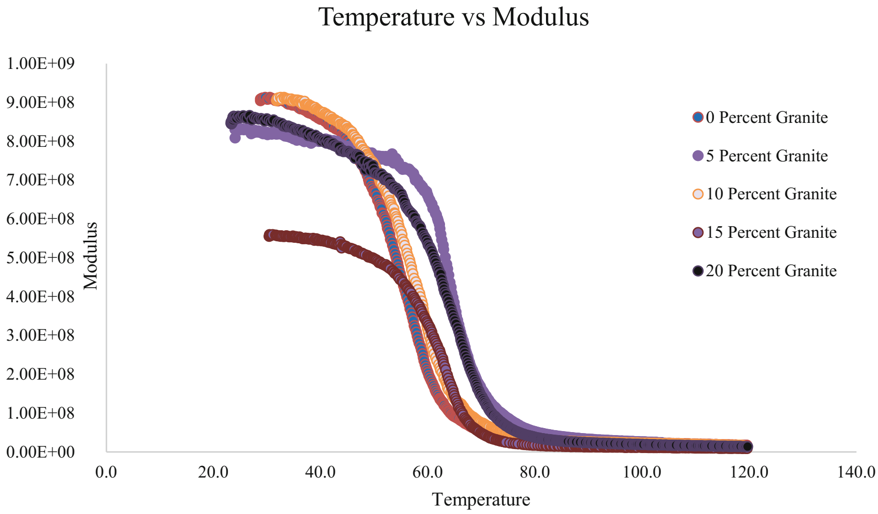

Fig. 2 Variation of modulus with temperature

3.5 Variation of Damping Factor (Tan Delta) with Temperature

Figure 3 displays the variation of damping factor (tan delta) with temperature. The loss factor tan delta considered as the ratio of loss modulus to storage modulus. It is the amount of the energy lost, which can be recovered, and characterizes internal

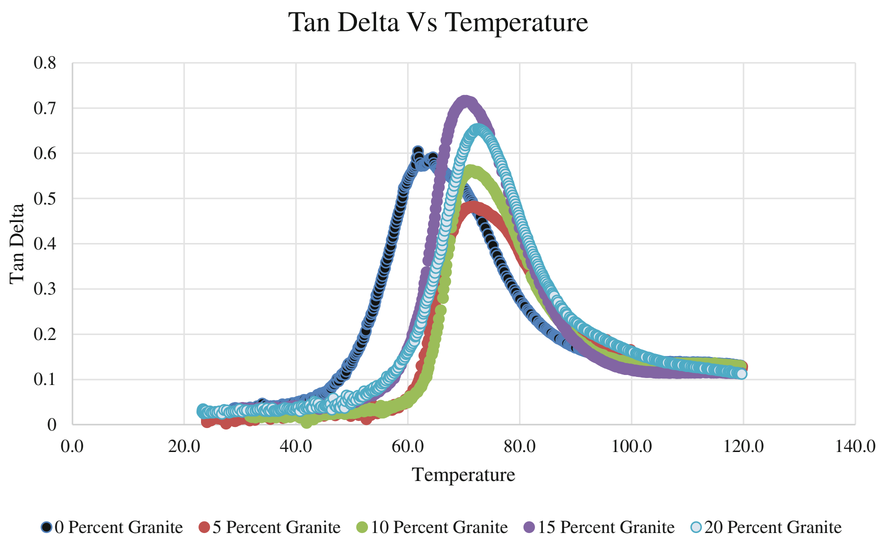

Fig. 3 Variation of damping factor (tan delta) with temperature

friction or mechanical damping in a viscoelastic system. The loss factor tan delta is a dimensionless number. A high tan delta value suggests that the material has a high, nonelastic strain component, whereas a low value shows that the material is more elastic.

4 Discussion

It can be observed that the overall erosion rate decreases with reduction in particle size, reduction in velocity and reduction in feed rate, whereas when using optimum angle of impingement and optimum filler material addition. It has been observed a slight deviation between the experimental and theoretical densities. It may be concluded due to the absorption of water particles by the sample when we immersed the material for experimental density calculation. If we consider the DMA analysis, significant reduction in storage modulus occurs in the range of 50–80 °C and a total decline beyond 80 °C. Almost the same pattern of results obtained in the study of thermo-mechanical characters for fibres by Amar Patnaik and SachinTejyan [4].

5 Conclusion

The velocity of water jet has great impact in the erosion. With the increase of velocity from 8 to 40 m/s, the rate of erosion also increases. Erosion rate is minimum when the velocity was 8 m/s and maximum when it was 40 m/s. In the same way, the highest erosion occurred when the feed rate was maximum and lowest erosion occurred when the feed rate was minimum; even though it is not showing a linear pattern, the size of erodent does not show a significant effect on erosion rate. But it showed that the minimum erosion occurred when the erodent size was 200 μm. While considering the angles of impingement, it showed highest erosion in the angles of 45° and 60° and showed lowest erosion in the angle of 75°. When considering the percentage addition of granite dust, lowest erosion observed on 10% addition of granite dust and highest erosion observed on 15% addition of it. So we can assume that 10% addition would be optimum.

Both hardness and density (theoretical and experimental) values are increasing with increment in addition of granite dust. If we pay attention on storage modulus, 10 and 15% granite dust added polyamide fibre samples have a high storage modulus of 900 MPa and pure polyamide fibre–resin added sample have minimum of 500 Mpa.

6 Future Scope

This paper has provided various conclusions and has brought into light various aspects that we can take into considerations about the material selection for hydraulic turbine blade. A waste product (granite dust) has been utilized as a constituent of our composite which is a prevalent by-product of stone cutting industries which are prevalent in Rajasthan. The analysis shows that 10% addition of granite dust to be optimum and a range of optimum results have been given. But in future, through further testing and analysis, an even more optimum addition percentage for granite dust can be obtained. Furthermore, in the future more advanced fibres may come for the purpose of turbine blades.

References

1. Padhy, M., & Senapati, P. (2015). Turbine blade materials used for the power plants exposed to high silt erosion—a review ICHPSD-2015.
2. Rajkarnikar, B., Neopane, H. P., & Thapa, B. S. (2013). Development of rotating disc apparatus for test of sediment-induced erosion in Francis runner blades. *Wear, 306,* 119–125.
3. Agarwal, B. D., & Broutman, L. J. (1990). *Analysis and performance of fiber composites*. NewYork: Wiley.
4. Patnaik, A., & Tejyan, S. (2014). Mechanical and visco-elastic analysis of viscose fiber based needle-punchednonwoven fabric mat reinforced polymer composites: Part I. *Journal of Industrial Textiles, 43*(3), 440–457.
5. Agrawal, P., Tiwari, A., & Tiwari, J. K. (2013). Tribological analysis of TiO2 filled polymer matrix composites. *International Research Journal of Engineering and Technology* (IRJET), *4* (6), e-ISSN: 2395-0056, p-ISSN: 2395-0072.