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Research Paper

EXPERIMENTAL STUDY ON MECHANICAL PROPERTIES OF RED GRANITE-EPOXY PARTICULATE COMPOSITES

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This paper presents a study on the red granite powder reinforced epoxy composite. The composites have been fabricated by varying the granite-epoxy ratio on weight percentage basis. The compressive strength of the composite is studied by varying the epoxy content and the grain size ratio by weight percentage using Taguchi's orthogonal array L-27 and Analysis of Variance (ANOVA) by assistance of Minitab 16 software. The damping behaviour is studied using experimental setup interfaced to LabVIEW software. The Mechanical properties are investigated by conducting tensile, flexural, impact, hardness and water absorption tests. The compression test results recorded a very good strength of 110 MPa for granite-epoxy ratio 75:25 with grain size ratio 50:50. The composite shows high damping for granite-epoxy ratio 80:20. The tensile, flexural and impact strengths are found to be maximum for granite-epoxy ratio 50:50. Rockwell hardness test indicates highest hardness for granite-epoxy ratio 80:20.

Keywords: ANOVA, Compressive strength, Damping ratio, Epoxy, Red granite

INTRODUCTION

The structural materials used in precision machines need to possess high strength as well as good static and dynamic stiffness. Studies on the mechanical properties of granite-epoxy composites are reported in the literature (Rama Krishna *et al.*, 2005; Ramakrishna *et al.*, 2005; Shetty Ravindra Rama and Rai, 2008; and Deepak *et al.*, 2013). These composites have been reported to be used as structural materials of precision machines due to its high strength, stiffness and most importantly high vibration damping characteristics (Selvakumar and Mohanram, 2012). The materials specified for machine structures must exhibit better modulus of elasticity, yield strength, good mechanical properties such as high compressive, flexural, tensile strength, toughness and wear resistance (Antonio Piratelli-Filho and

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Flaminio Levy-Neto, 2010). The traditional materials used for machine tool structures like cast iron and steel have high stiffness and good mechanical properties, but at high speeds they tend to produce positional errors which may affect the accuracy and surface finish of the manufactured products (Antonio Piratelli Filho and Flaminio Levy -Neto, 2010; and Selvakumar *et al.*, 2012). Recent research suggests the use of composite materials for precision machine structures. The studies on damping of epoxy-granite composite are reported (Deepak *et al.*, 2013; Antonio Piratelli-Filho and Flaminio Levy-Neto, 2010; Syath Abuthakeer *et al.*, 2011; Selvakumar and Mohanram, 2012; and Selvakumar *et al.*, 2012). Damping of materials for machine structures is studied using half power bandwidth method (Dai Gil Lee *et al.*, 2004; Jung Do Suh and Dai Gil Lee, 2008; Sung-Kyum Cho *et al.*, 2011; Syath Abuthakeer *et al.*, 2011; Niehues *et al.*, 2012; and Selvakumar *et al.*, 2012). Rama Krishna *et al.* (2005) carried out study on mechanical properties of granite-epoxy composites. Antonio Piratelli-Filho and Flaminio Levy-Neto (2010) presented study concerning the behaviour of particulate composite beams based on granite powder and epoxy and carried out damping test. Antonio Piratelli-Filho and Frank Shimabukuro (2008) conducted compression strength characterization on granite-epoxy composites using design of experiments.

The present study on the red granite powder reinforced epoxy composites is an attempt to understand the static and dynamic behaviour. The composite is been developed with varying granite-epoxy ratio by weight percentage according to ASTM. A detailed study on the compressive strength of composite is carried out by varying the epoxy content and grain size ratio by weight percentage using Analysis of Variance and Taguchi's orthogonal array (Philip Ross, 1996). The damping capacity of the composite is studied using experimental setup and LabVIEW software. The mechanical properties are studied by conducting tensile, flexural, impact, hardness and water absorption tests by varying the granite-epoxy ratio by weight percentage.

EXPERIMENTAL PROCEDURE

Materials

The composite material is prepared by reinforcing red granite particles in epoxy resin LAPOX-12. The red granite slabs obtained locally are crushed and sieved. The resin used is LAPOX-12 (3202) which is a liquid of medium viscosity along with hardener K-6. Hardener K-6 is a low-viscosity room temperature curing liquid. It gives a short pot life and rapid cure at normal ambient temperature. The mixing ratio of resin to hardener is 10:1. The granite powder obtained after crushing is sieved using Sieving Machine. Different grain sizes are obtained from sieving process. The obtained granite grain sizes were 53 µm to 74 µm, 75 µm to 105 µm, 106 µm to 149 µm, 150 µm to 211 µm, 212 µm to 299 µm, 300 µm to 424 µm meshes.

Sample Preparation

Teflon moulds were prepared for the fabrication of composite specimens. The cavities for compression, tension, bending, impact and hardness are engraved as per ASTM by various machining operations. The composite samples were fabricated in the moulds at room temperature by varying the granite-epoxy ratio by weight percentage. Small and large grain sizes of red granite particulates were mixed in different proportions to improve compactness and reduce porosity. The specimens were allowed to cure for 24 hours in the mould at room temperature. After removal from the mould the specimens were kept in electrically controlled oven at 60 ºC for 4 hours to accelerate the curing process and then left for 7 days at room temperature for complete curing.

Compression Test

For compression test ASTM D 695 is followed. The compression test was conducted on F.I.E make universal testing machine of 40 kN capacity, interfaced to FIE software to record the data. The influence of change in epoxy content and grain size ratio of granite on the compressive strength of composite is investigated using Taguchi's orthogonal array and Analysis of Variance (ANOVA). Table 1 shows the factors and the levels used for the study. Details of the grain size mix are highlighted in Table 2. Taguchi's orthogonal array L-27 is used for two factors with three levels and experiments are conducted. In each case 3 specimens were fabricated, tested and the results are reported.

Table 1: Control Factors and Levels Used

Control Factors	Level 1	Level 2	Level 3
Epoxy Content %	15	20	25
Grain Size Ratio %	50-50	60-40	70-30

Table 2: Grain Size Mix for Different Grain Size Ratios

Grain Size Ratio by Weight Percentage	Grain Size: 75 µm-105 µm	Grain Size: 300 µm-424 µm
50-50	50%	50%
60-40	60%	40%
70-30	70%	30%

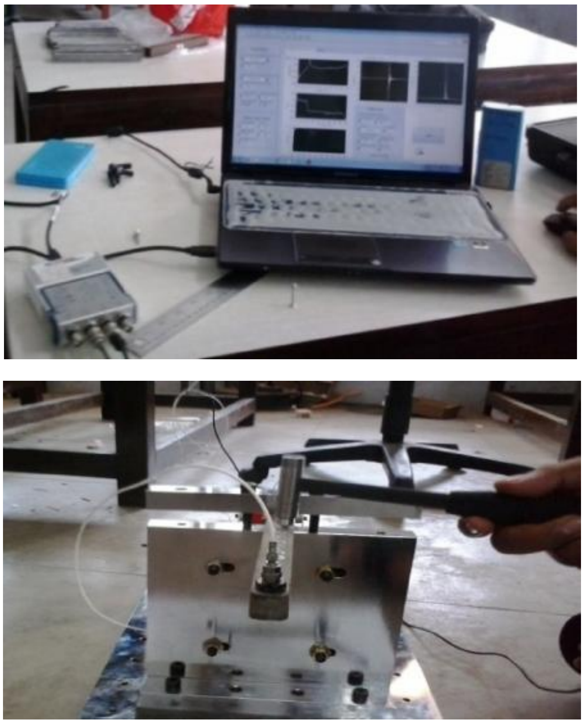
Damping Test

The damping test is conducted using experimental setup interfaced to LabVIEW software on fabricated beam type specimens of dimensions 200 mm x 20 mm x 20 mm. 50% of the grain sizes of 53 µm-74 µm, 75 µm-105 µm, 106 µm-149 µm and 50% of 425 µm-599 µm were used by weight to achieve compactness. The vibration response of the specimens was obtained using impact testing, where an impact hammer was used to slightly knock the specimen which is fixed on one end in cantilever manner. The resulting vibration was measured using a an accelerometer of sensitivity 101.9 mv/g. The experimental setup consisted of an impact hammer, an accelerometer; signal conditioner, LabVIEW software and data acquisition. The vibration signals are conditioned and displayed as a frequency spectrum through LabVIEW software. The frequency spectrum is used to analyze the fundamental frequencies and to determine the damping ratio and logarithmic decrement.

Flexural, Tensile, Impact, Hardness and Water Absorption Tests

The flexural, tensile, impact and hardness tests are carried out on granite-epoxy specimens prepared of ratio's 50:50, 60:40, 70:30 and 80:20 by weight percentage to investigate the mechanical properties of the composite. The grain sizes 53 µm-74 µm, 75 µm-105 µm and 106 µm-149 µm were used in equal proportions for the fabrication of composites. In each case 3 specimens were fabricated, tested and the results are reported.

Figure 1: Experimental Setup for Damping Test



Flexural Test

ASTM D 790 is followed for flexural test. The three point bending test was conducted on Instron 3366 machine of capacity 10 KN, in which data was recorded with computer interface. The strain rate of 1.5 mm/min was set.

Tensile Test

ASTM D 638 is followed for tension test. The test was conducted on Instron 3366 machine of capacity 10 KN, in which data was recorded with computer interface. The strain rate of 1.5 mm/min was set.

Impact Test

Impact strength was determined using the Izod-Charpy pendulum impact tester. The notched specimens according to ASTM E 23 were prepared and Charpy test is conducted.

Hardness Test

The hardness of the composite was measured using Rockwell hardness testing machine referring B-scale. The major and minor loads applied were 100 Kgf and 10 Kgf respectively.

Water Absorption Test

The composites were fabricated according to ASTM D 570-99. The composite specimens were weighed before immersing in water. The specimens are immersed in water for 15 days at room temperature to measure water absorption. Then specimens were removed, cleaned with a cloth and weighed again. In each case 3 specimens were fabricated. The percentage change in weight is determined as:

$$\%\ Change\ in\ Weight = \frac{Final\ Weight - Initial\ Weight}{Initial\ Weight} \times 100$$

RESULTS AND DISCUSSION

Compressive Test

The obtained compression test results are shown in Table 3.Taguchi method stresses on the importance of studying the response variable using the signal-to-noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. The compressive strength was considered as the quality characteristic with the concept of “the larger-the-better”. The S/N ratio is given by Equation (1).

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum\frac{1}{y^2}\right) \quad ...(1)$$

where n is the number of measurements in a trial/row, in this case, n = 1 and y is the measured value in a run/row. A higher S/N ratio indicates better performance of the response variable. The high S/N ratio of 40.82 for 25% epoxy content with 50-50 grain ratio in Table 3 indicates highest compressive strength.

Main effects plot for SN ratios shown in Figure 2a highlights that compressive strength increases with increase in epoxy content. High compressive strength is obtained for 25% epoxy content with 50-50 grain size ratio. Main effects plot also shows that 50-50 grain size ratio gives high compressive strength compared to grain size ratios 60-40 and 70-30. The interaction plot in Figure 2b shows that, grain size ratio 50-50 produces high compressive strength for all epoxy content. There is a uniform mixture of fine and coarse grains in 50-50 grain ratio which results in high

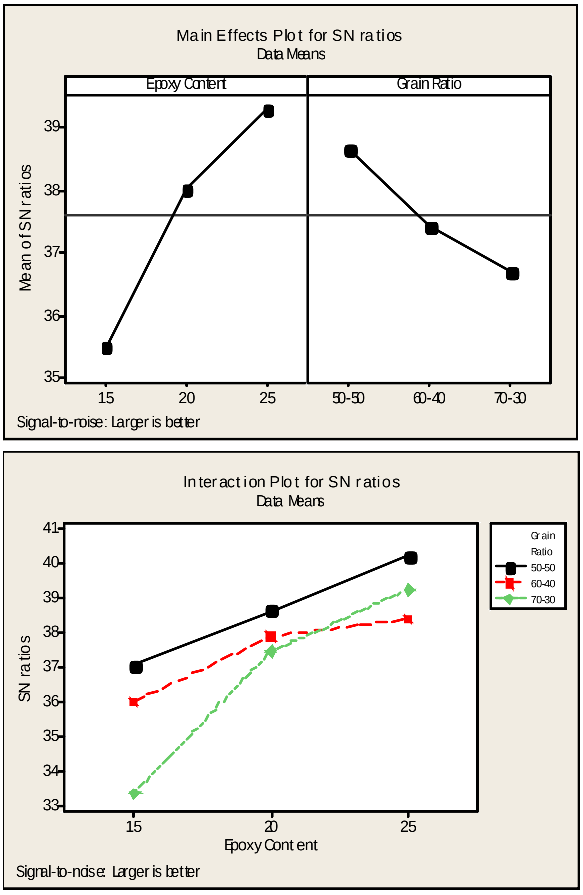
Table 3. Compression Test Results

S. No.	Epoxy Content by Weight Percentage	Granite Grain Size Ratio by Weight Percentage	Compressive Strength in MPa	Signal to Noise Ratio
1.	15	50-50	77	37.72
2.	15	50-50	68	36.65
3.	15	50-50	71	37.02
4.	15	60-40	64	36.12
5.	15	60-40	59	35.41
6.	15	60-40	67	36.52
7.	15	70-30	49	33.80
8.	15	70-30	45	33.06
9.	15	70-30	46	33.25
10.	20	50-50	85	38.58
11.	20	50-50	87	38.79
12.	20	50-50	85	38.58
13.	20	60-40	77	37.72
14.	20	60-40	78	37.84
15.	20	60-40	81	38.16
16.	20	70-30	81	38.16
17.	20	70-30	68	36.65
18.	20	70-30	77	37.72
19.	25	50-50	101	40.08
20.	25	50-50	110	40.82
21.	25	50-50	98	39.82
22.	25	60-40	81	38.16
23.	25	60-40	88	38.88
24.	25	60-40	81	38.16
25.	25	70-30	95	39.55
26.	25	70-30	89	38.98
27.	25	70-30	92	39.27

Table 4. ANOVA for Compressive Strength							
Source	**DOF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**Percentage (%)**
Epoxy Content	2	4700.22	4700.22	2350.11	135.58	0.000	69.56
Grain Ratio	2	1184.89	1184.89	592.44	34.18	0.000	17.53
Epoxy Content*Grain Ratio	4	559.56	559.56	139.89	8.07	0.001	8.28
Error	18	312.00	312.00	17.33			4.61
Total	26	6756.67					100

Note: DOF = Degrees of Freedom, Seq SS = Sequential Sum of Squares, Adj SS = Adjusted Sum of Squares, Adj MS = Adjusted Mean Squares, P = Percentage of Contribution.

Figure 2: (a) Main Effects Plot for SN Ratios, (b) Interaction Plot for SN Ratios



compressive strength and 25% epoxy content provides good wetting and bonding of granite particles.

Table 4 highlights the results of ANOVA for Compression Strength, in order to find the significant factors which contribute to compressive strength and their interactions. The P and F values report the significance level. P-value of 0.000 indicates that both epoxy content and grain ratios are the significant factors as compared to the interaction term with P value of 0.001. The last column shows the percentage contribution of each of the terms. It can be seen that epoxy content has a contribution of 69.56%, whereas grain ratio has an influence of 17.53%, and the interaction has contribution of 8.28%. Therefore epoxy content is the most significant factor.

Damping Test

The magnitude versus frequency data is obtained from the damping test. The half-power bandwidth method is used to find out damping ratio (¸), which is given by the equation

Table 5: Damping Test Results			
Granite-Epoxy Ratio by Weight Percentage	**Damping Ratio ¸**	**Logarithmic Decrement ¢**	**Natural Frequency Hz**
85:15	0.02427	0.1525	200
80:20	0.0397	0.249	185
75:25	0.0171	0.10746	199
Pure Granite	0.0354	0.222	268
Neat Epoxy	0.03911	0.2459	114

$$\zeta = \frac{f_2 - f_1}{2f_n} \quad ...(2)$$

where ζ is the damping ratio, f_n represents the fundamental frequency and $\Delta f = f_2 - f_1$ is the bandwidth corresponding to half-power points. Logarithmic decrement (δ) is found out by using mathematical expression

$$\delta = \frac{2\pi\zeta}{\sqrt{1-\zeta^2}} \quad ...(3)$$

Table 5 shows the results of damping test. The red granite-epoxy ratio 80:20 shows highest damping ratio of 0.0397. The variation in damping with granite-epoxy ratio is shown in Figure 3.

Figure 3: Variation in Damping Ratio with Granite-Epoxy Ratio

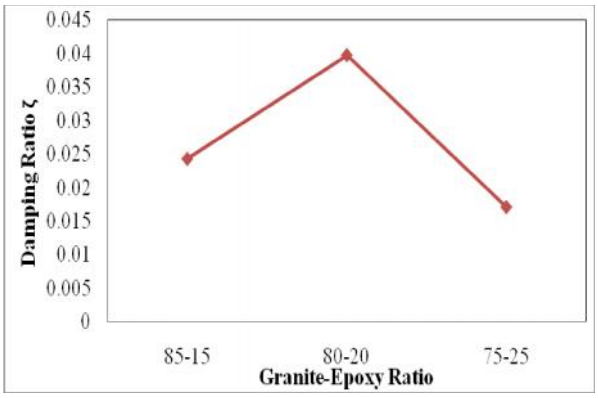


Figure 4: Variation in Flexural Strength with Granite-Epoxy Ratio

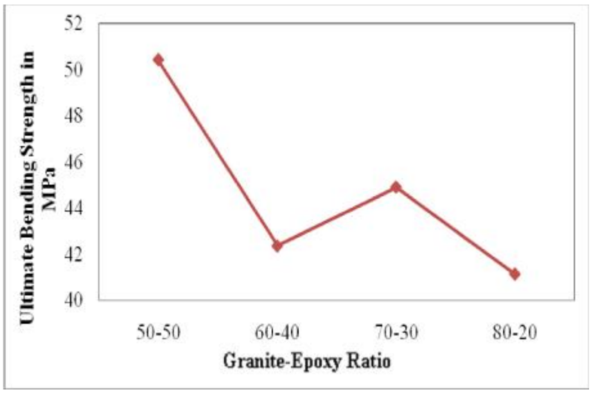
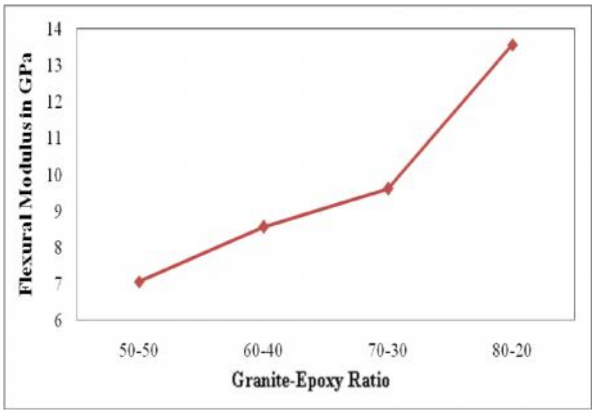


Figure 5: Variation in Flexural Modulus with Granite-Epoxy Ratio



Flexural Test

The variation in average ultimate flexural strength with granite-epoxy ratio is shown in Figure 4. The variation in flexural modulus with granite-epoxy ratio is shown in Figure 5. The three point bending test shows high average strength of 50.43 MPa for granite-epoxy ratio 50:50. The flexural strength decreases with increase in granite particle content beyond 50%. The flexural modulus increases with increase in granite particle content and maximum value of 13.57 GPa is obtained for ratio 80:20. The decrease in ultimate bending strength may be due to improper wetting of the granite particles as the granite content increases.

Tensile Test

The variation in average ultimate tensile strength with granite-epoxy ratio is shown in Figure 6. The variation in modulus of elasticity with granite-epoxy ratio is shown in Figure 7. The high average tensile strength of 28.22 MPa is observed for granite-epoxy ratio 50:50. The tensile strength decreases with increase in granite particle content beyond 50%. The modulus

Figure 6: Variation in Tensile Strength with Granite-Epoxy Ratio

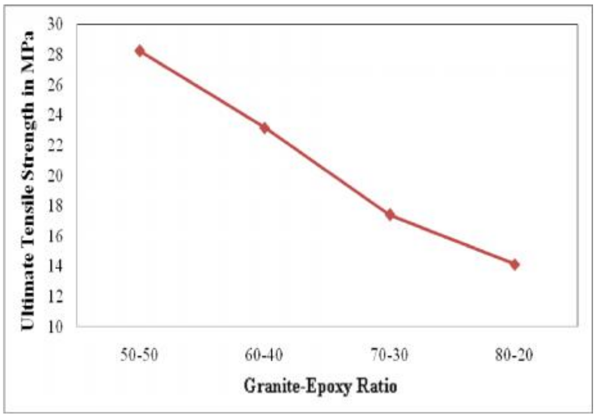
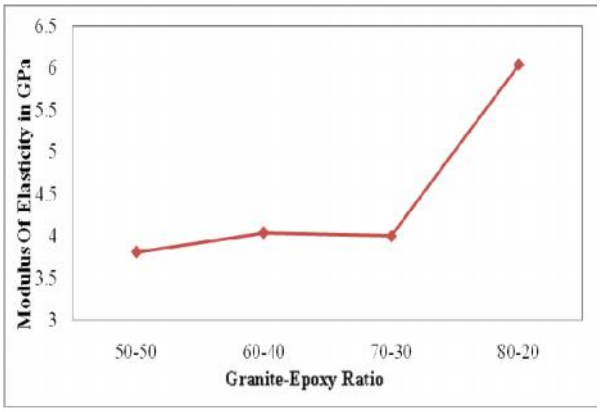


Figure 7: Variation in Modulus of Elasticity with Granite-Epoxy Ratio

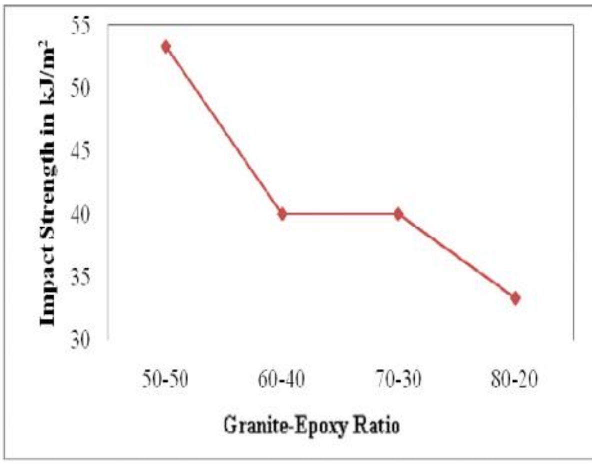


of elasticity increases with the increase in granite particle content and maximum value of 6.04 GPa is obtained for ratio 80:20. The decrease in ultimate tensile strength may be due to improper wetting of the granite particles at higher granite content.

Impact Test

The variation in impact strength with granite-epoxy ratio is shown in Figure 8.The high impact strength of 50.33 kJ/m^2 is obtained for granite-epoxy ratio 50:50. The impact strength decreases with increase in granite particle content beyond 50%. The decrease

Figure 8: Variation in Impact Strength with Granite-Epoxy Ratio



in strength at higher percentage of granite may be due to improper wetting of granite particles.

Hardness Test

The hardness increases with increase in granite particle content as shown in Figure 9. The high value of hardness of 78 RHN is obtained for granite-epoxy Ratio 80:20. The increase in hardness is due to the rigid granite particles.

Figure 9: Variation in Hardness with Granite-Epoxy Ratio

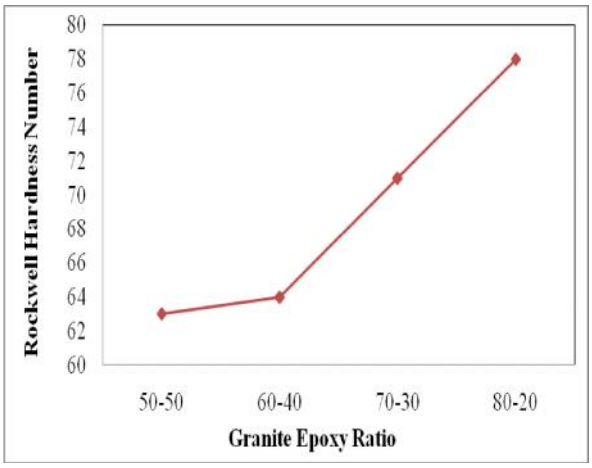
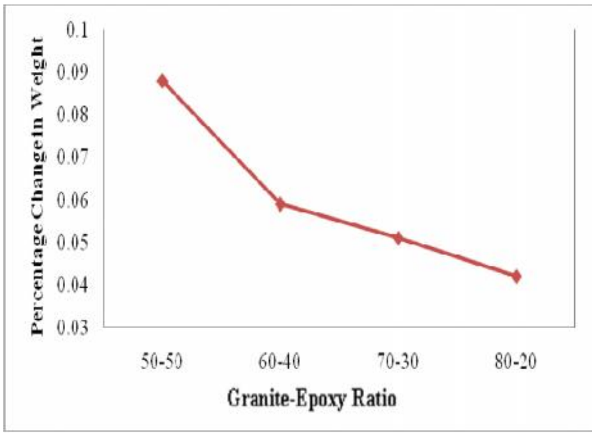


Figure 10: Variation in Percentage Change in Weight with Granite-Epoxy Ratio



Water Absorption Test

Variation in percentage change in weight with granite-epoxy ratio is shown in Figure 10. The maximum average change in weight of 0.088% is obtained for ratio 50:50.

CONCLUSION

The compressive strength is studied using ANOVA and found to be high for granite-epoxy ratio 75:25 with grain size ratio 50:50 by weight percentage. It was noted that for all epoxy content, the grain size ratio 50:50 shows high compressive strength. The analysis of variance shows that epoxy content is the most significant factor which contributes to compressive strength. The damping test results show that the composite has high vibrations damping capacity and is a promising material for precision machine tool structures. The results of mechanical tests on composite specimens with granite-epoxy ratio 50:50 by weight percentage shows highest flexural, tensile and impact strength. The hardness test indicates highest result for granite-epoxy ratio 80:20. The composite shows good resistance to water absorption and the change in weight is negligible.

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