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## EXPERIMENTAL STUDIES ON COMPRESSION AND VIBRATION CHARACTERISTICS OF GRANITE EPOXY- AN ALTERNATIVE MATERIAL FOR PRECISION MACHINE TOOL BEDS

SUBRAHMANYA SWAMY. S<sup>1</sup>, B. R. SREEDHAR<sup>2</sup>, VINAYAK J KALAS<sup>3</sup>, CHANDAN K. M<sup>3</sup>

1. Professor and Head, PG Program in Machine Design, Bapuji Institute of Engineering and Technology, Davangere, India.
2. Associate Professor, Department of Mechanical Engineering, G.M. Institute of Technology, Davangere, India.
3. Undergraduate Student, Department of Mechanical Engineering, Bapuji Institute of Engineering and Technology, Davangere, India.

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**Abstract:** Granite epoxy composite is a novel material being developed as an alternative material for precision machine tool beds. The role of four important factors that affect compression strength of Granite epoxy - Granite aggregate mix composition, Granite aggregate to epoxy ratio, hardener to epoxy ratio and Vibration of mould during compaction, were investigated. The grading of the aggregates should be such that voids between larger aggregates are filled with smaller fractions and epoxy resin so as to achieve maximum density and strength. Five different graded compositions of granite aggregate were selected for compression testing based on void ratio analysis and by calculating the "total surface index" of these mixes. 50% coarse composition achieved a modulus in compression of around 30GPa and compression strength of 120 MPa. To study the vibration characteristics, 50x50x480 mm specimens were cast making use of same five compositions of granite aggregate, which were used for compression testing, with 12% resin content and tested for resonant frequency and damping ratio. Influence of resin content on vibration behaviour was also studied by changing the percentage of resin to 10% and 14% in the optimised 50% coarse composition of granite aggregate. The results of these investigations are given in this paper.

**Keywords:** Granite Epoxy, Compressive Strength, Modulus in Compression, Damping Ratio, Resonant Frequency.

Corresponding Author: MR. SUBRAHMANYA SWAMY S.



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## INTRODUCTION

There is a need to build machines capable of delivering versatile functions with higher and consistent accuracy in operation coupled with high productivity. To meet the stringent demands of precision machining, alternative materials for machine tool structures in place of conventionally used cast iron must be employed. These alternative materials should have better specific stiffness, excellent damping properties to sustain high speeds of operation and should be thermally less sensitive. The highest amount of damping is provided by interface friction in machine tools. However, damping provided by this method is usually at the expense of structural stiffness<sup>1</sup>. The research now is therefore towards developing materials that have high internal damping and high specific stiffness. In this respect, materials such as hydraulic concrete, welded steel structures filled with sand have been tried, but these materials have poor shear properties and low loss factors and therefore provide very less damping. There have been many attempts to develop alternate materials for machine tool structures that have better dynamic performance and take lesser time for manufacture. Salje<sup>2</sup> studied the static, dynamic and thermal behaviour of polymer composites and compared their mechanical properties with those of cast iron. There was an attempt<sup>3</sup> to use cementitious materials such as ferro-cement and polymer impregnated ferro-cement for machine tool structures. A three-axis CNC grinding machine tool has been designed for the ultra-precision mirror surface grinding of advanced materials such as ceramics and other hard and brittle materials<sup>4</sup>. The bed of a machine tool contributes much to overall dynamic stiffness and a polymer concrete bed was designed and manufactured to improve the dynamic performance of the above machine. The performances of grinding machine were evaluated both by vibration test and by grinding of hard and brittle materials. Polymer concretes are highly filled synthetic resins, which cure when mixed with catalyst. No volatile substances are produced during the curing reaction. Curing may take the form of polymerization (as in case of unsaturated polyester resin and methyl methacrylate), or polyaddition (as in case of epoxy resin and polyurethane). The fillers used perform very much the same function as the aggregate in cement concrete. Epoxy resins have a great advantage that their characteristics can be varied considerably by using different formulations. Although these resins are costlier compared to polyester and polymethyl methacrylate, their performance is superior compared to both the other resins mentioned. Internal stresses are not developed in the composite because of the nature of curing and this is one of the most important advantages of epoxy composites. Epoxy resins cure by polyaddition and their adhesion to all kinds of materials is excellent. The absence of ester groups means that epoxy resin has particularly good water resistance.

Granite and other rocks have been used for manufacture of surface plates due to their superior wear resistance quality and more particularly non-denting property<sup>5</sup>. Fine-grained rocks have relatively high density and hardness. They have higher scratch resistance and are less porous. Granite has low thermal conductivity and high specific heat in addition to good compression strength. This stone has a thermal expansion as low as  $8 \times 10^{-6}$  and a proven dimensional stability.

Mixing and bonding together carefully selected mix of correctly graded granite aggregate, epoxy resin and curing or hardening agent forms epoxy composite. In this work, Araldite based epoxy system is utilized which has excellent properties for casting machine tool structures. The inorganic filler used in this work is crushed particles of black granite (Dolerite) with an average compressive strength of around 180 MPa and a tensile strength of around 25 MPa. Black Granite has excellent dimensional stability, abrasion resistance and very less porosity. The specific gravity of Black Granite is around 2.8 to 2.9.

The primary requirement of granite epoxy composite for machine tool structural applications is a satisfactory compressive strength in its hardened state. Many of the desirable properties like durability, impermeability, abrasion resistance, Young's modulus and resistance to creep are highly influenced by the magnitude of compressive strength of epoxy concrete. Maximizing the compression strength of granite epoxy is therefore an important requirement and the focus in this work is to optimize the composition of granite epoxy from the compression strength point of view.

## **FACTORS INFLUENCING COMPRESSIVE STRENGTH**

### **(a) Composition of Granite Aggregate**

The composition of the granite aggregate in the composite plays very important role in minimizing the voids in the material. It is therefore necessary to identify the correct grade of granite aggregates so as to reduce the void content as well as the epoxy content leading to reduction of production costs of the material. This can be achieved by a proper combination of coarse and fine aggregates of granite by utilizing grading curve<sup>6</sup>. The standard grading curves were developed in such a way that each succeeding particle would have  $\frac{1}{2}$  the diameter of preceding particle. The maximum size of the aggregate used in this work is 10mm.

The coarser and finer fractions of the aggregates can be suitably combined to obtain the desired standard grading. The grading or particle size distribution of aggregates is a major factor determining the workability, segregation, and handling and finishing characteristics of

the concrete. The workability of the mix is influenced more by finer fractions than due to the coarser fractions of the aggregate. Graded Granite aggregates when mixed with epoxy resin, results in lesser voids leading to increased compressive strength of the composite. As the void content is less, the amount of epoxy utilized to produce the composite would also be reduced.

Crushed granite aggregate mixture is taken and mechanical sieving is done using standard Taylor screens of different sizes. Particle distribution curve (grading curve) is established on semi-log graph sheet. The following five different compositions of granite aggregate mix were selected:

**A. 25% coarse aggregate + 75% fine aggregate**

**B. 40% coarse aggregate + 60% fine aggregate**

**C. 50% coarse aggregate + 50% fine aggregate**

**D. 70% coarse aggregate + 30% fine aggregate**

**E. 90% coarse aggregate + 10% fine aggregate**

The grading curve of granite aggregate is analyzed to determine composition of the mixture. Uniformity coefficient ( $U_u$ ) is the ratio of diameter of particle at which 60% of the mix is finer ( $D_{60}$ ) to the diameter of particle at which 10% of the mix is finer ( $D_{10}$ ).

$$U_u = D_{60} / D_{10} \quad (I)$$

Coefficient of curvature ( $C_c$ ) is defined as the ratio of the square of  $D_{30}$  size to the product of  $D_{60}$  and  $D_{10}$ .

$$C_c = (D_{30})^2 / (D_{10} \times D_{60}) \quad (II)$$

$D_{30}$  is the particle diameter at which 30% of the aggregate mixture is finer. By controlling the magnitude of  $U_u$  of a mix, it is possible to reduce the voids in the aggregate mix leading to improvement in compressive strength. The aggregate mixture becomes well graded if  $U_u$  is greater than 6 and  $C_c$  is between 1 and 3. A suitable workable grading of aggregates is required to produce satisfactory epoxy concrete. This depends upon the shape, surface texture and type of aggregate and the amount of flaky or elongated material. The granite aggregates can be rounded, sub rounded, angular or sub angular. The specific surface varies with different types of aggregates due to variation in angularity. Crushed stones have a higher angularity index than the irregular and rounded aggregates. A typical grading curve is given in Fig.1.

The quantity of epoxy resin required to produce given workability depends to a larger extent on the surface area of the aggregates. The “total surface index” of a mixture of aggregates is calculated by multiplying the percentage weight of material retained on each sieve and the corresponding surface index. The sum total of the above is added to a constant 330 and the result is divided by 1000 giving the surface index value. The details of surface index calculations are available in Table I for 40% coarse + 60% fine sample. For 10 mm maximum aggregate size used in this composite, an optimum surface index value of 0.7 to 0.8 is suggested.

Void ratio is the ratio of the volume of the voids within the aggregate mix to the total volume occupied by the aggregate mix. From each grading curve, required percentage of different particle sizes in the aggregate mix is identified and weighed. The above aggregate mixture is taken in a beaker of known volume and compacted. Water is slowly filled into this beaker to a designated level. This covers the voids in the mixture. The volume of water added is a measure of the voids in mixture. Volume fraction of the aggregate is the ratio of the net volume of the aggregate to the total volume occupied by aggregate mixture. Higher the volume fraction of the aggregate, higher would be the weight content of granite in the composite leading to better mechanical properties of the composite. The results of coefficient of uniformity, coefficient of curvature, void ratio analysis and surface index for various samples are available in Table II.

#### **(b) Epoxy Resin / Granite Aggregate Ratio**

Varying the proportion of granite aggregate in the mixture can alter the compressive strength of epoxy concrete. Increase in granite aggregate portion in the mixture within practical limits minimizes the epoxy content and production cost can be reduced. Epoxy content in the mix depends on the absorption capability of the aggregate, grain size of the aggregate and the shape of the casting. Epoxy content has to be controlled in the mix as most of the mechanical and thermal properties of granite epoxy are highly influenced by its magnitude. Based on practical considerations, resin content of 12% by weight was employed in this experimentation.

#### **(c) Frequency of Vibration**

The extent to which an aggregate can be compacted to produce a minimum void content is dependent on the particle size distribution and the frequency of vibration during compaction. Due to the controlled forces applied to the aggregate during compaction, tight stone-to-stone contact of the grains is possible, thus minimizing the influence of epoxy resin on the coefficient of thermal expansion of granite epoxy. Also because of the tighter grain contact, deformation and creeping characteristics of the component can be minimized. Vibrations can vary from 1000 cycles per minute to 5000 cycles per minute and it is economical to use a compaction device

that can vibrate at the natural frequency of well-graded granite aggregate. Natural frequency of well-graded granite particles is around 35 to 40 Hz. In this study, a frequency of 40 Hz was maintained during compaction.

#### **(d) Hardener / Epoxy Ratio**

Generally the manufacturers of epoxy system recommend the formulation of hardener / epoxy ratio for the epoxy system chosen. In this work, a ratio of 1:10 (hardener to resin ratio) is utilized as per the recommendations of the manufacturer. Excess hardener does not take part in the reaction.

#### **(e) Compression Testing**

Well-graded granite aggregate mixture required for casting test specimen is weighed and oven dried to remove moisture content, if any. Epoxy resin and Hardener are mixed after weighing. The oven dried aggregate mixture is slowly added to this epoxy resin and hardener solution and continuous stirring is maintained for 10 minutes in order to achieve good wetting of aggregates. The inside surface of the mould is smeared with releasing agent. The aggregate mixture is poured into mould and compacted by keeping the mould on vibrating table for 4 minutes duration at 40 Hz frequency. The cast specimens were kept for curing for a period of 24 hours at room temperature. Compression test was conducted on specimens of  $\phi 38 \times 58$  mm-size cast using different compositions of granite mix. The end faces of the specimen were machined using a carbide turning tool to obtain flat surfaces to ensure proper contact of the end plates of the testing machine with the specimen. Each specimen was weighed using an electronic balance and its density was determined after recording the dimensions of the specimen. Loading was done using a UTM fitted with a 200 kN load cell for detecting the load applied on the cast specimen. A dial gauge with a least count of 0.010 mm was used to measure the deflection of the sample. Five samples in each composition were tested and the results are given in Table III. A typical stress strain diagram for one of the samples tested with 50% coarse aggregate composition is shown in Fig.2. Variation of compression strength with respect to aggregate composition is shown in Fig.3.

It is clear from the tests that aggregate mix containing more than 50% coarser fraction yields lesser compression strength. 50% coarse sample has achieved compression strength of 125 MPa. It is obviously due to the fact that this sample has the highest density (low void ratio) coupled with good coefficient of uniformity leading to well graded condition. 40% coarse composition has also performed equally well compared to 50% coarse composition both in terms of strength and modulus.

## VIBRATION CHARACTERISTICS OF GRANITE EPOXY

The objective of this study was to investigate experimentally the effect of granite aggregate mix composition on vibration characteristics of granite epoxy. 50x50x480 mm specimens were cast by making use of five different compositions which were utilised in compression testing and tested for resonant frequencies and damping ratio by conducting modal analysis using FFT analyser. A resin content of 12% by weight was utilized to cast the specimens. A cast iron (FG 200) specimen of the same size was also tested to obtain resonant frequency and damping ratio. The experimental setup is shown in Fig.4. Young's modulus for various compositions was also estimated using this vibration impulse response method by measuring the resonant frequency. Typical frequency response functions (FRF) were obtained for various compositions of granite epoxy and cast iron. A FRF obtained for 50% coarse composition is shown in Fig.5 and the amplitude response in time domain is shown in Fig.6. The FRF and the amplitude response of cast iron are shown in Fig.7 and 8 respectively. The damping ratios of the specimens were calculated using the logarithmic decrement approach and also by measuring the frequency interval of 3dB where the magnitude of the vibration dropped 3dB from that of the fundamental frequency. The results of the experiment are available in Table IV. The relations for computing the damping ratio are given in equations (III) and (IV).

$$\text{Logarithmic decrement } \delta = \ln \frac{X_n}{X_{n+1}} \quad (\text{III})$$

$$\text{Logarithmic decrement } \delta = \frac{2\pi\xi}{\sqrt{1-\xi^2}} \quad (\text{IV})$$

Modal damping was estimated by using relation (V).

$$\text{Modal damping} = \frac{f_2 - f_1}{f} = \Delta f / f \quad (\text{V})$$

Where 'f' is the resonant frequency,  $f_1$  &  $f_2$  are frequencies at half power bandwidth and  $\xi$  is the damping ratio.

This relation is valid only for small damping ( $\delta \ll 1$ ). Larger the damping, broader is the resonance peak. Young's modulus 'E' was calculated after measuring the fundamental natural frequency and using the relation (VI) of the beam with free-free end.

$$E = \frac{\rho \cdot S}{I} \left[ \frac{2\pi f L^2}{22.4} \right]^2 \times 10^{-9}, \text{ GPa} \quad (VI)$$

Where  $\rho$  = density in  $\text{kg/m}^3$ ,  $S$  = cross sectional area in  $\text{m}^2$ ,  $L$  = length of beam in  $\text{m}$  and  $I$  = moment of inertia in  $\text{m}^4$ .

To determine the influence of resin content on the damping ratio of granite epoxy, the optimized composition 50% coarse from the standpoint of compression strength was utilized to cast two more specimens with 14% and 10% epoxy by weight. The responses of these specimens are shown in Fig.9 and 10 respectively. Damping ratio was determined for these two samples by logarithmic decrement method. The consolidated results of the tests are available in Table V and the variation of the damping ratio with respect to resin content is shown in Fig.11.

There is an increase in damping ratio with an increase in resin content of the mix. The increase in damping ratio is not significant enough to utilize higher resin content. Higher resin content leads to higher material costs.

## CONCLUSION

Compression properties of Granite epoxy with different graded granite mix compositions have been determined. The compositions used in this work have attained compressive strengths ranging from 55 to 125 MPa. 50% coarse composition has a  $C_u$  of 40 and a  $C_c$  of 2.3 with the least void ratio among the selected specimens. Specimens having 50% coarse aggregates have shown higher values of modulus of elasticity of around 30 GPa and compression strength of 125 MPa. 60% fine aggregate composition has also shown good results both in strength and modulus. Tests have demonstrated that higher than 50% coarse content in the mix leads to reduction in compression strength of granite epoxy. As the finer content of granite in the mix increases, the flowability of the mix decreases due to the increase in viscosity of the mix. To overcome flowability problems in casting bigger structures, epoxy content needs to be increased resulting in higher costs. It would therefore be economical to select the composition containing 50% coarse + 50% fine aggregates as this has performed better in compression test.

The vibration tests indicate that the damping property could be tailored into the structure by a proper selection of the granite aggregate distribution. The ratio of the damping of granite epoxy to that of cast iron varied from a minimum of 4 to a maximum of 10 in various specimens. 90% coarse sample has shown the highest damping of about 10 times that of cast

iron, while 40% coarse has shown the least of about 4 times that of cast iron. 50% coarse sample, which has shown excellent results in compression strength, is having a damping 8 times higher than cast iron. 90% coarse sample has a maximum damping ratio of 0.025 which is about 10 times that of cast iron. This could be due to the presence of voids within the specimen as sufficient fine particles are not available to fill up the gap between the coarse particles. 90% coarse sample has very poor mechanical strength and hence is not recommended to be used for precision bases even though it has a very high damping. Tests have demonstrated that increasing the resin content for a given aggregate composition does not contribute significantly in increasing the damping ratio of the composite. It is therefore recommended to use 12% epoxy resin by weight.

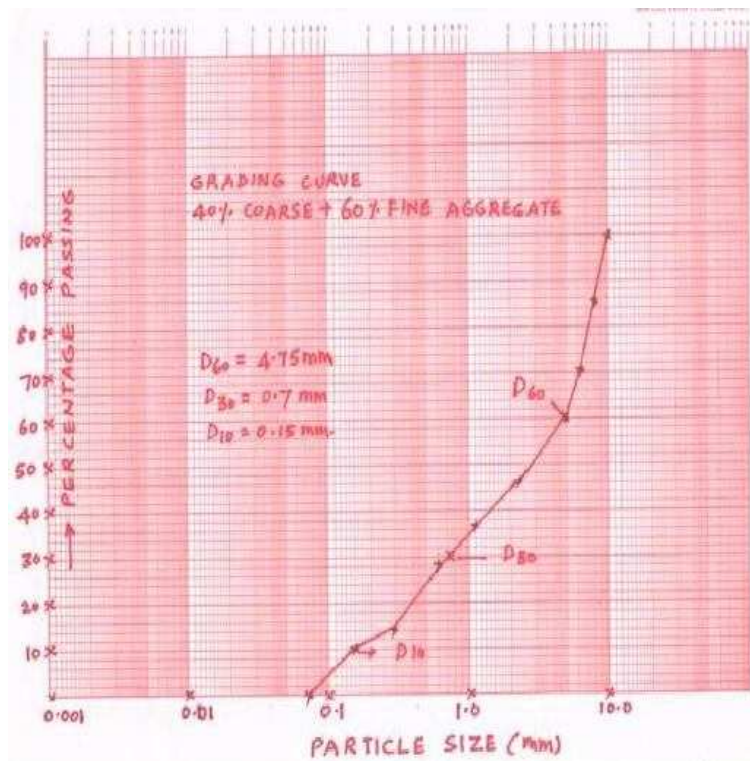


Fig.1. Grading curve for granite aggregate

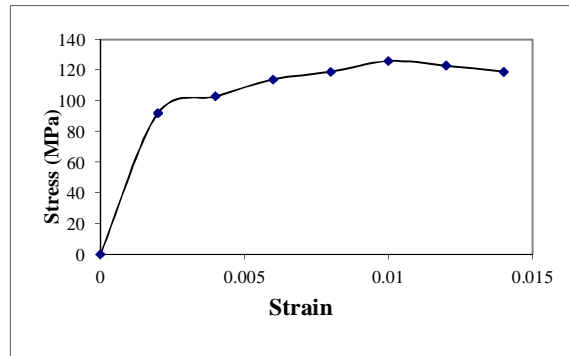


Fig.2. Stress-Strain diagram for a 50% coarse sample

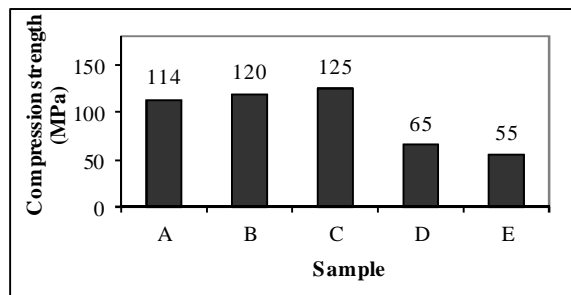


Fig.3. Variation of compressive strength with aggregate composition



Fig.4. Experimental setup for vibration analysis

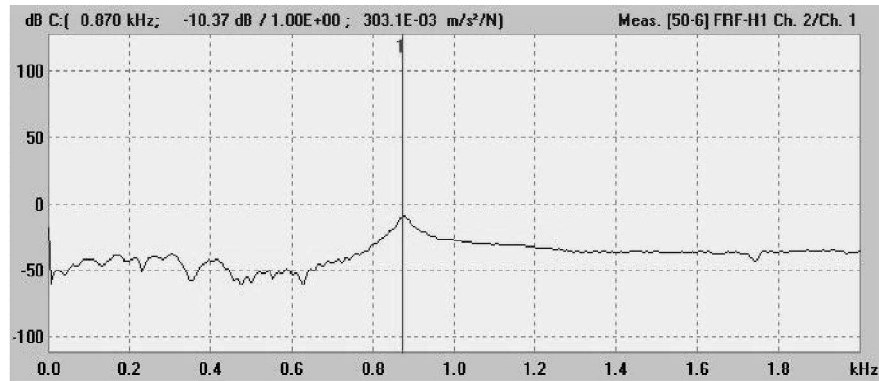


Fig.5. FRF of 50%coarse sample with 12.5%resin

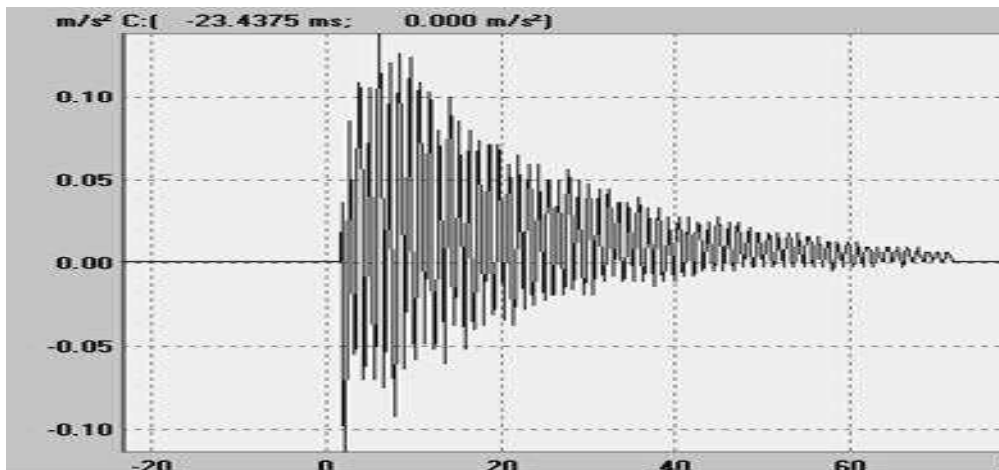


Fig.6. Response of 50%coarse sample

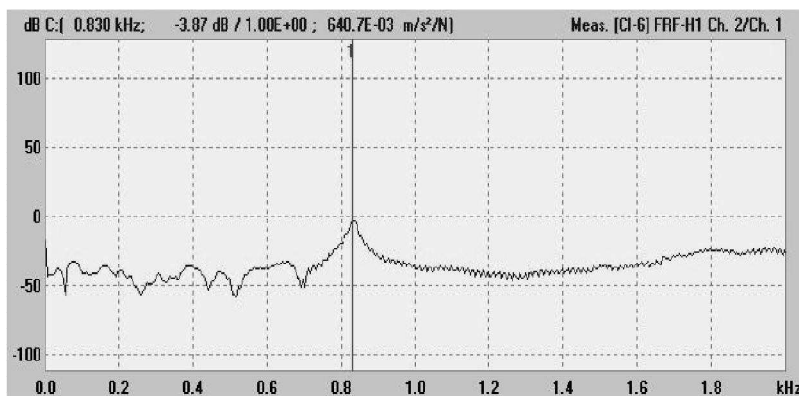


Fig.7. FRF of Cast iron

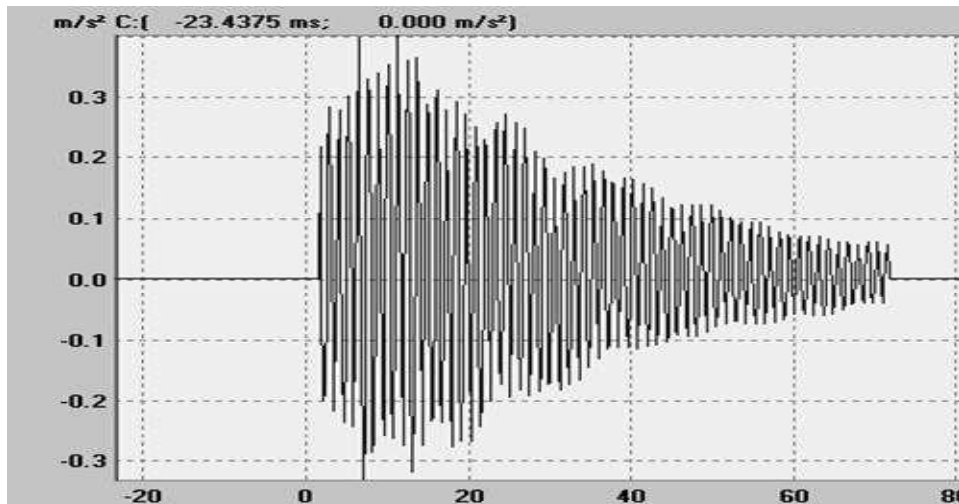


Fig.8. Response of Cast iron sample

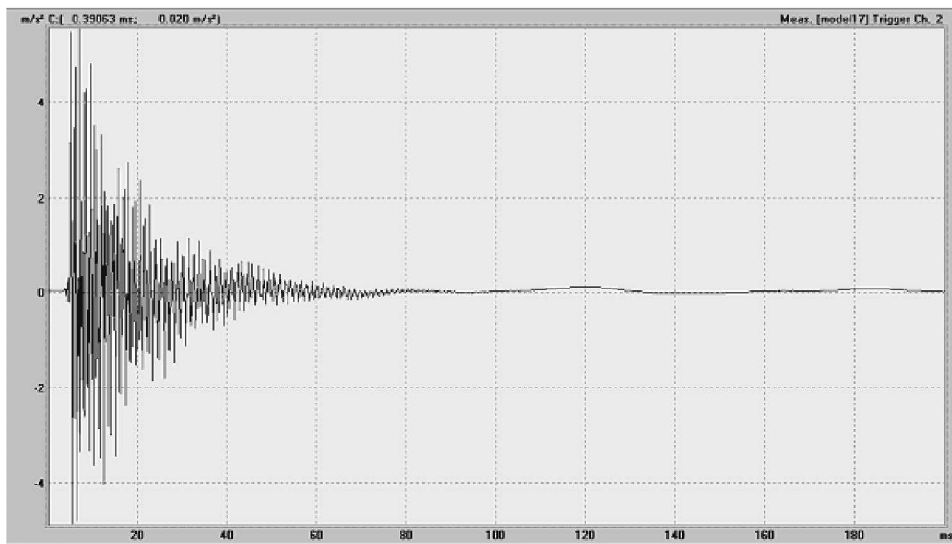


Fig.9. Response of granite epoxy specimen with 14% epoxy resin by weight

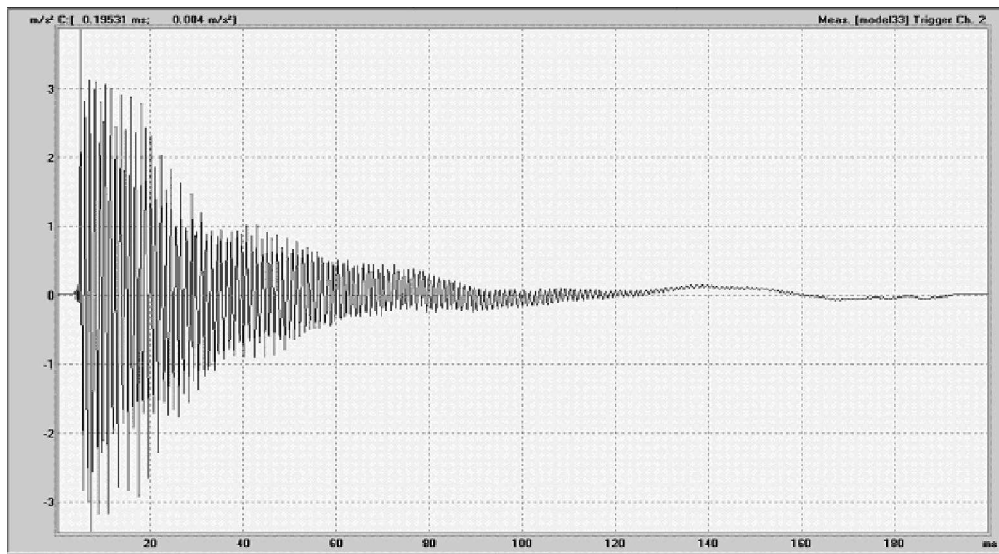


Fig.10. Response of granite epoxy specimen with 10% epoxy resin by weight

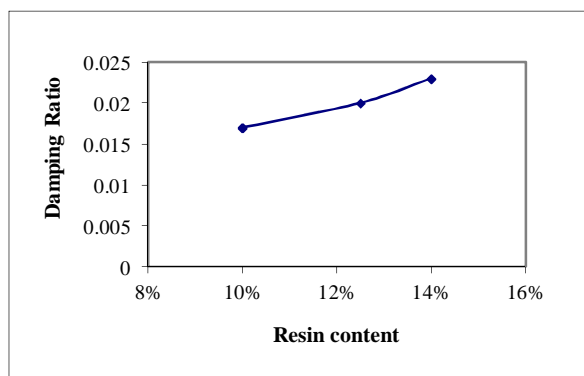


Fig.11. Variation of damping ratio with resin content of granite epoxy

Table I. Surface index for 40%coarse+60%fine aggregate mix

40%coarse +60% fine sample			
Aggregate Size (mm)	Weight retained (%)	Surface Index value on sieve size	Total
10.0- 4.75	40%	1	40
4.75-2.36	20%	4	80
2.36 to 1.18	10%	7	70
1.18 to 0.60	10%	9	90
0.60 to 0.30	06%	9	54
0.30 to 0.15	04%	7	28
0.15to 0.075	10%	2	20
Grand Total			382
Surface index of the mix = $(382 + 330)/1000$			0.712

Table II. Results of analysis of grading of various samples

Sample	C <sub>u</sub>	C <sub>c</sub>	Void ratio	Volume fraction	Total Surface index
A	12.4	1.03	0.36	0.64	0.85
B	30.0	2.02	0.30	0.70	0.78
C	40.0	2.30	0.28	0.72	0.66
D	12.0	5.72	0.40	0.60	0.65
E	2.0	0.88	0.44	0.56	0.50

Table III. Results of compression tests

Sample Specification	Average Density ( $g/cm^3$ )	Average Comp. Strength (MPa)	Average Modulus (GPa)	Comp.
A.25%coarse	2.3	114	25	
B.40%coarse	2.4	120	28	
C.50%coarse	2.5	125	30	
D.70%coarse	2.2	65	20	
E.90%coarse	2.0	55	12	

Table IV. Experimental results of vibration test.

S. No.	Details						
		90% coarse	70% coarse	50% coarse	40% coarse	25% coarse	Cast iron
1	Resonant frequency (Hz)	695	895	900	840	800	830
2	Logarithmic decrement ( $\delta$ )	0.163	0.091	0.1269	0.05947	0.074	0.0147
3	Damping ratio ( $\xi$ )	0.025	0.014	0.020	0.0094	0.011	0.0023
4	Modal damping	0.0255	0.015	0.018	0.011	0.014	0.003
6	Ratio of damping of epoxy granite / cast iron	10.68	5.98	8.69	4.04	4.79	-----
7	Young's Modulus (GPa)	23.2	38	38	34	30.8	107

Table V. Damping ratio for different percentages Epoxy content

S.No.	Percentage of Epoxy content (by weight)	Damping Ratio
1	14%	0.023
2	12%	0.020
3	10%	0.019

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