# Experimental Investigation on Damping Property of Coarse Aggregate Replaced Rubber Concrete

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**Abstract.** Rubber has good damping and vibrational characteristics and can reduce cracking significantly due to its elastic nature. This property of rubber can be incorporated in concrete to control vibrations and create better pavements. Crumb Rubber on being dumped in landfills has serious repercussions and causes soil and land pollution. An innovative use of waste tires is shredding them into small pieces and using them as a replacement for coarse aggregate. Crumb rubber is obtained by chopping scrap tires, and in this study it was added in two different sets named SET 1 - Treated Crumb Rubber and concrete, and SET 2 - Treated Crumb rubber with Ultra Fine GGBS as admixture in concrete. Coarse aggregate replaces Rubber in each of the 2 SET's in proportions of 5, 10, 15 and 20%. Properties like Compressive Strength, Young's Modulus, Direct and Semi direct Ultrasonic Pulse Velocity, Sorptivity, Damping ratio and Frequency were found out. Deformation and mode shape were studied with modal analysis and static analysis by applying a uniform pressure corresponding to the highest compressive strength of the slab, using ANSYS.

*Keywords:* Crumb Rubber, treated rubber, UFGGBS, Damping Property, Mode Shape, ANSYS

## 1. Introduction

Crumb Rubber can absorb sudden impact by controlling the movement of waves transmitted by moving loads. Rubber compresses and deforms easily but the rate of deformation decreases with increasing load, which makes it a good shock absorber. Rubber has very little hysteresis and controls energy dissipation in a system subjected to vibration related forces. Structures present close to the roads are affected by vibrations induced by moving vehicles. These vibrations are detrimental to the pavement and to the structures beside the pavement. Usage of rubber in pavements as a replacement for natural aggregate can reduce this effect (L. Zheng et al., 2008). Rubber has an inherent damping ability and this property can be exploited to improve damping and vibrational characteristics of concrete. Moreover, rubber being light-weight and non-corrosive is easy to use and apply. It is relatively inexpensive when compared to other conventional dampeners like steel springs and tuned mass dampers (GintautasSkripkiunas et al., 2009; Imran Ahemad Khan et al., 2014; Khalid B. Najim., 2012). Aggregates account for 60 to 75 percent of the total volume of concrete and are divided into distinct categories like coarse and fine. Aggregates are the least expensive ingredient in concrete and their usage is directly linked to economy. According to the United States Geological Survey, Sand and gravel production is close to 1.32 billion tons of which 264 million tons is used in concrete alone as aggregates. The problem lies in the fact that natural aggregates formed by geological processes are finite in nature and will take thousands of years to be formed again(U. Tomas., 2014).

Many research activities are underway for replacement of fine aggregates, but coarse aggregates need more attention and concern. Another pressing issue is disposal of waste rubber. Rubber tires wear out after usage and are dumped into landfills without proper treatment, which lead to serious environmental problems like soil and land pollution. Tires are incinerated and used for fuel generation too. But it occurs at higher temperature and burning tires is hardly eco-friendly. It leads to increased air pollution and is not an efficient method of using scrap tires. Tires have a tendency to migrate to the top of the landfills and they damage the protective layers at the top and increase instability of the sites leading to reduction in landfill lifecycle drastically. An innovative method of solving these issues is to chop these tires and mix it in concrete. Weak bonding exists between rubber and cement interface due to the zinc stearate added during manufacturing process. Treating rubber with Sodium Hydroxide is an effective solution to this problem (Liang He et al., 2016). Ultra Fine Ground Granulated Blast furnace Slag (UFGGBS) is widely used in the production of Portland Blast furnace Cement and High Slag Blast furnace Cement, which makes concrete durable and sustainable in nature. It is a supplementary cementitious material and improves strength considerably. The only disadvantage of using shredded rubber in concrete is its considerable reduction in compressive strength, when replacement of shredded rubber goes beyond 20% (Mansour Fakhri et al., 2016).

## 2. Literature Review

Many research activities have been done on rubberized concrete and its properties ranging from its shape and size to varying proportions of crumb rubber. Research on dynamic properties of rubbberized concrete by L. Zheng et al (2008) showed that, as percentage of rubber content in concrete increased, damping ratio increased significantly. The improvement in properties of concrete was dependent on the size of the crumb rubber used. Crumb rubber of size 40mm fared better than granulated rubber in terms of performance of concrete. N. I. Fattuhi and L. A. Clark (1996), showed from their analysis that there was a reduction in density and compressive strength by 20% and 70% respectively for concrete made from OPC and containing rubber when compared to ordinary concrete. Wider cracks were seen in reinforced rubberized concrete slab when compared to ordinary concrete slab. Gintautus Skripkiunas et al (2009) concluded from his research findings that the dynamic modulus of elasticity was dependent on internal damping and energy dissipation in materials. Rubberized concrete is more elastic than ordinary concrete and internal damping is better for a lower quality factor. Mechanical and Durability tests conducted by Trilok Gupta et al (2014) indicated that crumb rubber made concrete more flexible, but reduced its static and dynamic modulus of elasticity. Micro structural analysis showed that reduction in elasticity values were due to weak interfacial bonding existing between crumb rubber and cement. Xiaoyu Wu et al (2016) showed that lightly pyrolyzed trye rubber can be used as an alternative for asphalt and can replace asphalt by upto

50%. Crumb rubber also improved rhoelogical properties of asphalt pavement.Study by Osama Youssf (2015) reflected that hysteretic damping ratio increased with increasing rubber content and energy dissipation in columns increased by 13% and 150% respectively. Viscous damping ratio reduced with crumb rubber content. Studies by Liang He et al (2016) indicated that oxidation and sulphonation can bring strong polarity groups to crumb rubber surface and generate a strong chemical bond between rubber and cement in concrete. Mansour Fakhri et al (2016) showed that rubber particles in combination with silica fumes improved the compressive and flexural strength and reduced water absorption and unit weight considerably.

## 3. Experimental Analysis

### *3.1 Materials*

#### *3.1.1. Cement*
Pozzolana Portland cement (ACC brand) was used. The specific gravity of PPC according to IS 1727: 1967 was found to be 2.85.

#### *3.1.2. Crumb Rubber.*
Crumb rubber is recycled rubber made from automotive and truck scrap tires. Steel and reinforcement materials were removed during recycling process and the rubber alone was taken for this research. Crumb rubber passing through 20 mm and retained on 12.75 mm IS sieve was used. Crumb rubber was collected from VB rubbers, Coimbatore, Tamil Nadu.

#### *3.1.3. Aggregate.*
Specific gravity of fine aggregates was found according to IS-2386-3:1963. Aggregate passing through 2.36mm IS sieve was found to have a specific gravity of 2.8. Coarse aggregate particles passing through 20mm and retained on 12.36mm sieves were used. The specific gravity, according to IS 383:1970, was found to be 2.75.

#### *3.1.4. UFGGBS.*
*It* is a supplementary cementitious material which was collected from Ambuja Cements, Mumbai. The chemical composition of UFGGBS is shown in table 1. It is as per manufacturer's booklet.

**Table 1.** Chemical composition of UFGGBS.

| Contents | Percentage (%) |
|---|---|
| $SiO_2$ | 21-23 |
| $Al_2O_3$ | 5-5.6 |
| $Fe_2O_3$ | 3.8-4.4 |
| CaO | 61-64 |
| $SO_3$ | 2-2.4 |
| MgO | 0.8-1.4 |

**Table 2.** Size of specimen.

| Sl No. | Specimen | Size (in mm) |
|---|---|---|
| 1 | Cube | 100 x 100 x 100 |
| 2 | Cylinder | 200 x 100 |

### *3.2 Treated Rubber*
Raw crumb rubber was added to concrete in the proportion of 5%, 10%, 15% and 20% respectively. Zinc Stearate is added during the rubber manufacturing process for obtaining a smooth finish on rubber but this will weaken the bond existing between rubber and concrete and will reduce the strength of concrete considerably. As the proportion of rubber in concrete mix increased, strength decreased significantly. To

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reduce the loss of strength and increase the bonding between crumb rubber and concrete, sodium hydroxide (NaOH) solution was used. Sodium hydroxide removes the zinc stearate layer and provides a rougher surface to the rubber. This will provide good bonding between the concrete and the crumb rubber, which will reduce the loss of strength. Crumb Rubber was washed 2-3 times with water to remove dust. It was then immersed in sodium hydroxide solution for 24 hours, when its pH gradually increased to 13. It was washed further to neutralize the pH and was dried.

*3.3 Preparation of Test Specimen*

This research aims to investigate and study in detail the effective use of crumb rubber when used as a replacement for coarse aggregate in concrete. The Compressive strength, Sorptivity, Young's modulus, damping ratio and Frequency and Ultrasonic Pulse Velocity were analyzed and studied using specific size cylinders and cubes as shown in Table 2. The entire mix was hand-made and was compacted using a vibrator. The standard moulds were filled, and demoulded after 24 hours, and the samples were allowed to cure for 28 days. As per IS 10262, the mix design for concrete was maintained as 1:1.37:2.42:0.48 between cement, fine aggregate, coarse aggregate and water content respectively. The ratio maintained for concrete was same for SET 1 and SET 2, except that SET 2 had 10% UFGGBS added as a replacement for cement.

## 4. Methodology

*4.1 Compressive Strength*

Compressive strength is one of the basic strength tests for any material and is given by the ratio between load and area of the specimen. Compressive strength is the maximum compressive stress which a material can sustain before failure. The tests were conducted on cube specimens after 28 days as per IS 516:1959. Compressive strength test cube specimens of size 100 x 100 x 100 mm were tested using compressive strength testing machine having a maximum capacity of 2000kN. The concrete mix was prepared by hand mixing. Each mould was filled with concrete in three layers and each layer was compacted with 25 strokes using a tamping rod. The specimen was demoulded after 24 hours and allowed to cure.

*4.2 Ultrasonic Pulse Velocity (UPV)*

UPV is a non-destructive testing method to determine the passage of velocity through the concrete cubes within a particular time interval. This test measures travel time, T of an ultrasonic pulse that is produced by an electro-acoustical transducer. The UPV is given by the ratio between length of the specimen and travel time of the specimen. The UPV assesses the quality of concrete in terms of density, homogeneity and continuity in concrete without cracks. Higher velocity indicates good quality and continuity in cross-section whereas lower quality indicates flaws like cracks and voids. The UPV is dependent on density and elastic properties of the material and is measured in terms of direct and semi-direct UPV values. Semi-direct UPV is used when accessibility of specimen is limited. The direct UPV was measured by placing the transmitting and receiving transducers on opposite faces of the concrete slab whereas for semi-direct UPV test, the transducers were placed on adjacent faces. The test was conducted on a cube specimen of size 100 x 100 x 100 mm according to IS13311 (Part 1)-1992. Concrete with varying proportions of crumb rubber was tested for its direct and semi-direct UPV values and the data obtained was studied.

*4.3 Damping ratio and Natural Frequency Analysis*

Crumb rubber is good in damping and this property can be exploited for improving vibration characteristics of concrete. Accidental loading, wind, earthquake or vehicle passage will cause vibration in concrete structures, leading to crack formation. Damping and frequency analysis will help in analysis and early mitigation of these hazards. The damping ratio and natural frequency tests were conducted on cube specimens of size 100 x 100 mm. Initially the surface of the cube specimen was cleaned. By using a Fast Fourier transform (FFT) device, damping property was quantified. A transducer was fixed on the surface of specimen and an impact load was given. The stress waves are sensed by the transducer which was mounted on the surface of the specimen. Natural Frequency and damping ratio were found out using the FFT device. The highest peak value of amplitude from various wave cycles was taken and the frequency value was plotted between acceleration and amplitude.

*4.4 Sorptivity*
Sorptivity test is used to indicate the porosity in concrete and is a measure of the uni-directional capillarity in concrete cubes. The specimens of size 100 x 100 x 100 mm were cast and allowed to cure for a period of 28 days. They were later dried in an oven at 110°C for 24 hours. After being air cooled, these cubes were coated with a non-absorbent material on the bottom side and the specimens were weighed. Water was filled in a pan and the cubes were immersed to a depth of 3mm, in water. They were placed in such a way that only one face was in contact with water. The start time of the test was recorded once the cubes were immersed in water. The weights of the cubes were noted at time intervals of 5, 10, 15, 30, 60 and 120 minutes. The cube specimen gained weight after each time interval due to water absorption. Equation 1 shows the expression to calculate the sorptivity coefficient;

$$I = S \text{ x } \sqrt{t} \quad (1)$$

Where, I is the Absorption of water, S is the Sorptivity coefficient, t is the time period.

*4.5 Young's Modulus (E)*
Young's Modulus is an important property that analyses concrete's elastic properties and deformation patterns and measures the stiffness of a material. Young's Modulus is the proportionality constant in Hooke's Law and is given by the ratio of normal stress to normal strain. The test was conducted on a cylindrical specimen of size 100 x 200 mm, of which the deflection was found by fixing a dial gauge parallel to the side of the specimen. The change in stiffness value with varying proportion of rubber was studied. The effect of addition of UFGGBS was also analyzed.

*4.6 Modal Analysis using ANSYS*

In this study a concrete slab of 3500 x 4500 x 250 mm was modeled for SET 2, with optimum percentage rubber and UFGGBS inclusion. Young's modulus - 29891 N/mm$^2$, Poisson Ratio - 0.2 and Density - 2.372kg/m$^3$ were used as the basic inputs and were incorporated in the analysis of mode shape using FEM software, ANSYS. A concrete slab resting on a Winkler foundation with the stiffness coefficient of 10,000 kg/m$^3$ was modeled as an 8 node brick element (SOLID 185). A spring element (COMBIN14) with fixed support was designed for the Winkler foundation. The stress contour, deformations and behavior of rubberized concrete on application of a uniform static pressure of 0.016N/mm$^2$ throughout the slab was analyzed using model analysis.

## 5. Results and Discussion

*5.1 Compressive Strength*
Compressive Strength test was conducted on the cube specimens on the 28$^{th}$ day. From the Figure 1, it is clear that SET 1 had lower strength when compared to SET 2. The usage of crumb rubber as a partial replacement for coarse aggregate reduced the compressive strength of both SETs of cubes, as proportion of rubber content increased from 5 to 20%. This can be attributed to the presence of UFGGBS in concrete,

which filled the voids and increased the density of the SET 2 specimens when compared to that of SET 1. Overall, the cubes with 5% replacement of coarse aggregates with crumb rubber in SET 2 had the highest strength.

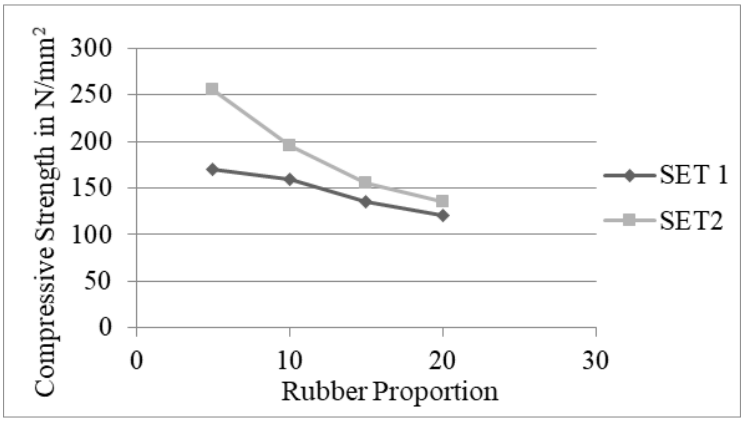



**Figure 1.** Compressive Strength of SET 1 and SET 2.

*5.2 Ultrasonic Pulse Velocity (UPV)*

*5.2.1. Direct Ultrasonic Pulse Velocity (Direct UPV).*
Direct UPV transmission through the concrete slab was measured using an electro-acoustical transducer. Figure 2, shows the variation of Direct Ultrasonic Pulse Velocity in SET 1 and SET 2 samples. The velocity of SET 2 increased drastically when compared to SET 1, as the percentage of rubber increased from 5%, 10%, 15% and 20%. It was found that, as the rubber content increased, the stress waves reduced significantly. SET 2 contained UFGGBS, which filled the voids, increased the density and allowed easier flow of stress waves, whereas, SET 1 had more voids thus reducing flow of stress waves. The reduced velocity can be related to the higher porosity and lesser density of the concrete.

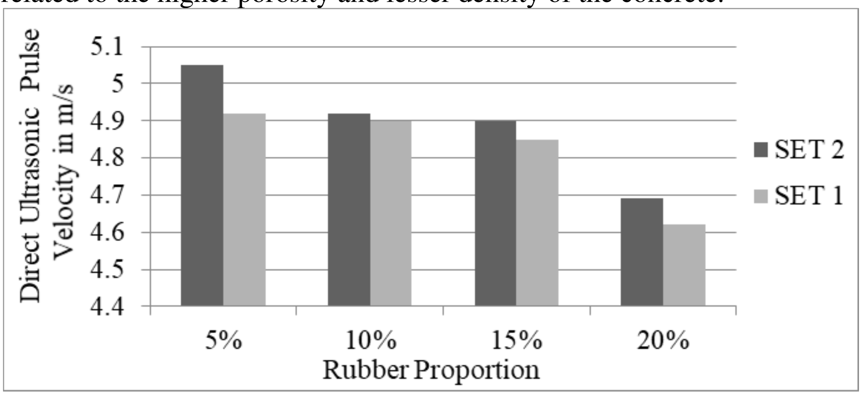



**Figure 2.** Direct Ultrasonic Pulse Velocity of SET 1 & SET 2.

*5.2.2 Semi Direct Ultrasonic Pulse Velocity (Semi Direct UPV).*
The semi direct UPV method is used in situations where the complex geometry of a structure makes direct testing impossible. Semi-direct UPV transmission through the concrete slab was also measured using an electro-acoustical transducer. The transmitter was placed on one face of the specimen and the receiver was placed on the adjacent face of the specimen. Figure 3 shows the variation of Semi Direct Ultrasonic Pulse

Velocity in SET 1 and SET 2 samples. The velocity in SET 2 cubes increased drastically when compared to those of SET 1 as the percentage of rubber content increased from 5 to 20%. Similar to observations made in the Direct UPV test, increased rubber content resulted in reduced stress waves. Presence of UFGGBS in SET 2 resulted in closer packing, lesser voids, increased density and easier flow of stress waves.

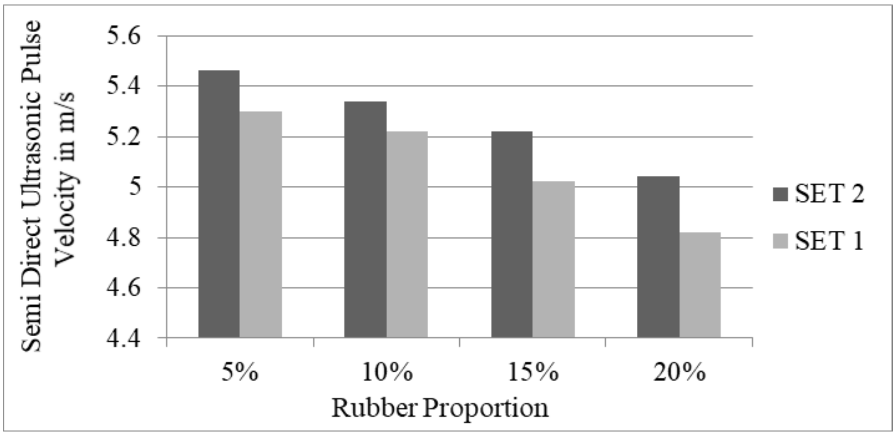



**Figure 3.** Semi Direct Ultrasonic Pulse Velocity of SET 1 and SET 2.

*5.3 Damping Ratio*

Damping Ratio is a dimensionless parameter which describes the decaying oscillations of a vibration caused by a disturbance in the system. Figure 4 shows Variation of damping ratio and rubber proportion. Increasing damping ratio is an indication of higher tolerance to vibration. Increased rubber proportion results in higher damping and loss of vibration energy. The damping ratio of the specimens showed that the peak amplitude of the response may have occurred in the second or third cycle and not necessarily in the first cycle. Friction was generated at the voids and between the rubber particles during wave propagation, which resulted in partial loss of energy. Damping ratio increased with increasing rubber content within a particular set and the highest damping ratio was attained at 20% replacement. It is clearly observed that damping ratio is higher for SET 1 samples when compared to SET 2.

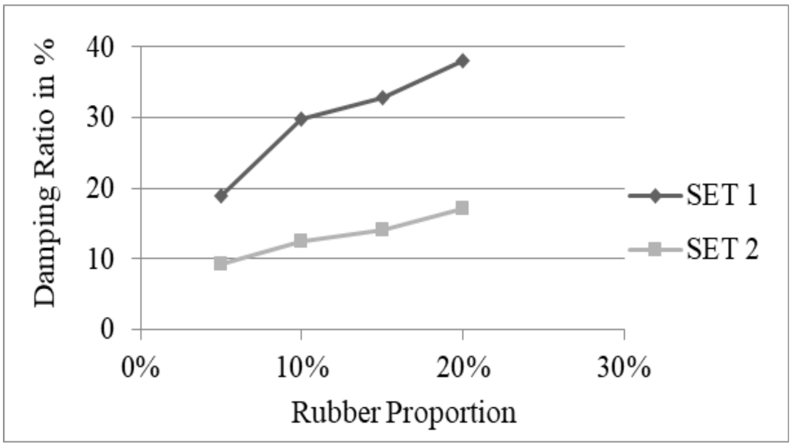



**Figure 4.** Damping Ratio of SET 1 and SET 2.

*5.4 Frequency Response Function (FRF)*

The Frequency Response Function was obtained from the Fast Fourier Transform (FFT) device and was plotted between acceleration and amplitude. The test was repeated for different proportions of crumb rubber in both the sets. Figure 5 shows that with increasing rubber content, SET 1 showed better damping properties than SET 2. Increasing percentage of rubber content reduced the frequency of the specimens, owing to higher energy dissipation within the specimens. With an increase in porosity of specimens, the density decreased and damping characteristics improved, and vice versa. Vibration was effectively controlled when the percentage of rubber content increased from 5 to 20%. With increasing rubber content, damping ratio increased and a highest damping ratio was attained at 20% replacement, whereas frequency followed a decreasing trend. Damping ratio and frequency are inversely proportional for specimens within a particular SET.

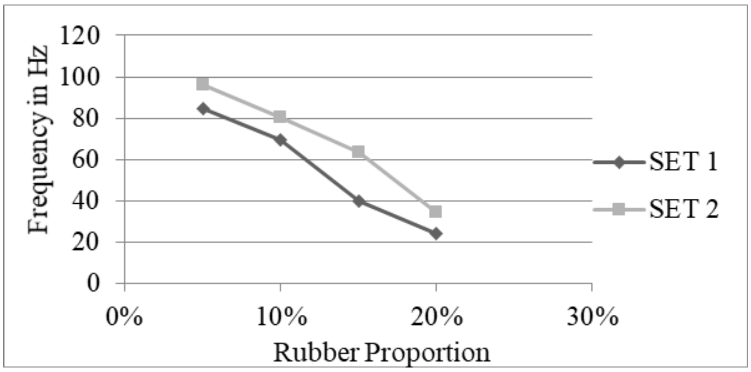



**Figure 5.** Variation of natural frequency with rubber.

*5.5 Sorptivity*

Absorption due to capillary rise controls the rate of ingress of water or other liquids in unsaturated concrete, and this parameter is quantified by the Sorptivity test. The sorptivity coefficient for SET 1 and SET 2 concrete samples are shown in Figure 6. The sorptivity coefficient for SET 1 and SET 2 samples gradually increased with an increasing proportion of rubber, which can be directly linked to the increase in porosity and hence higher absorpsion of water by the specimens. The results showed that SET 2 concrete had the lower rate of absorption when compared to that of SET 1. SET 1 had more voids and thus the specimens absorbed more water, whereas SET 2 had UFGGBS which filled the voids and thus reduced the water absorption significantly.

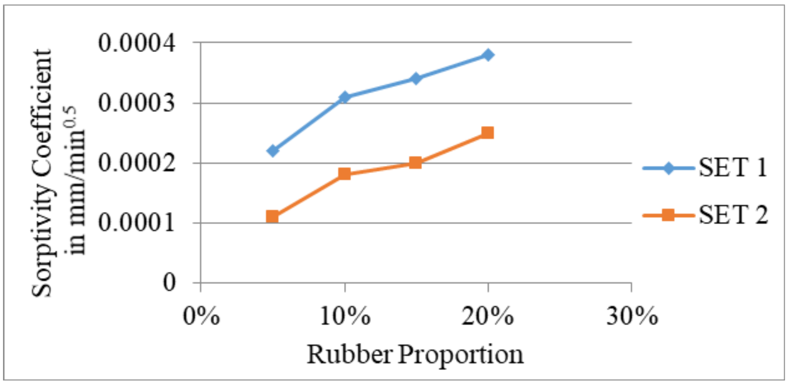



**Figure 6.** Sorptivity Coefficient of SET 1 and SET 2.

*5.6 Young's Modulus*

Young's Modulus represents the stiffness of a material and Figure 7 shows that SET 2 samples attained higher young's modulus values than those in SET 1. This indicates that SET 2 concrete was more resistant to elastic deformation and achieved higher strength than SET 1 samples. The UFGGBS added concrete in SET 2 performed better than SET 1, because of reduced deformation patterns, closer packing and hence lesser porosity. The SET 2 specimens lowered the young's modulus of concrete by 8.68%, 10.88%, 9.2% and 12.34% at 5%, 10%, 15% and 20% replacement of crumb rubber respectively

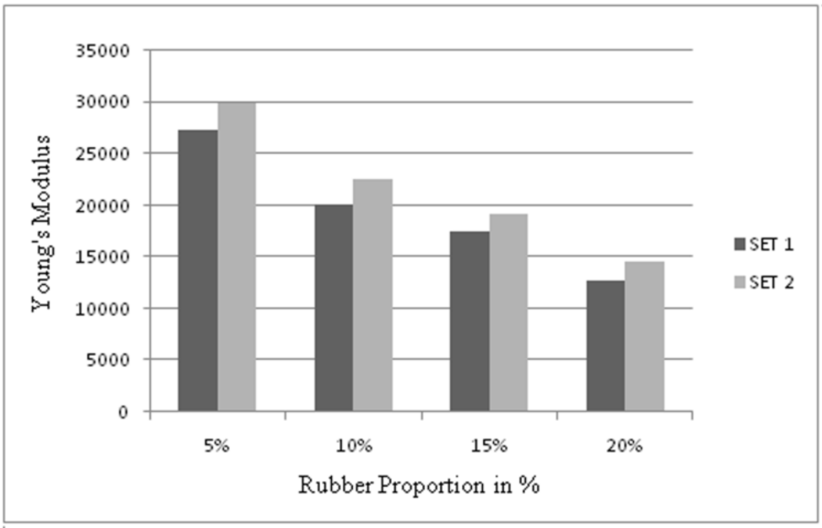



**Figure 7.** Young's Modulus value of SET 1 and SET 2.

*5.7 Analysis of Mode Shape in ANSYS*

*5.7.1. Without Loading Condition .*

The mode shapes were analysed using mechanical ANSYS APDL software for the optimum 10 % of rubber and UFGGBS addition in concrete. The linear response of the structure can be analyzed by Modal analysis. Figure 8 shows the contour plot and the location of maximum and minimum stress values for the concrete slab with a winkler foundation.

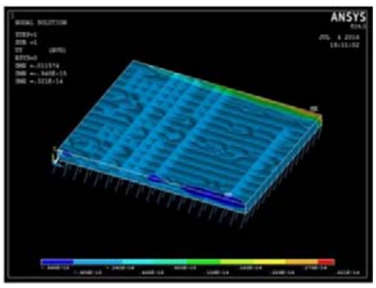
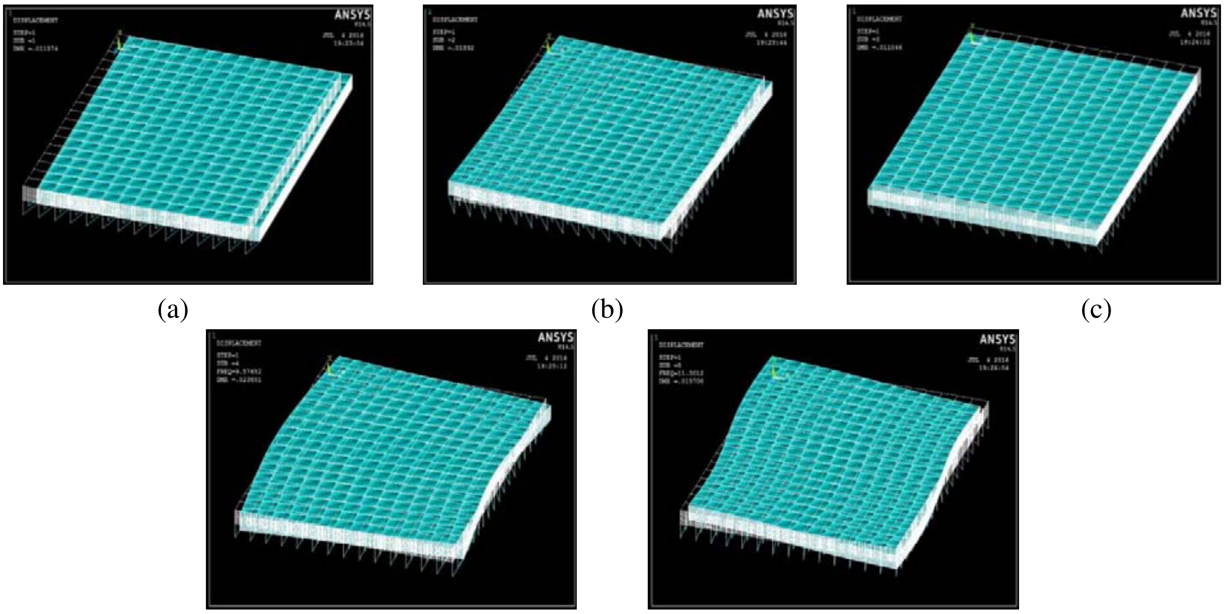



**Figure 8.** Contour Plot of concrete slab with winkler foundation.

In this study, the concrete pavement slab of five mode shapes was considered and analyzed. The mode shapes were drawn for the first five peak frequency values. Each Figure shows the deformation pattern of the concrete with respect to the original shape corresponding to the peak frequency. Figure 9 a to e represent the Mode Shapes for Optimum % of Rubber Concrete.



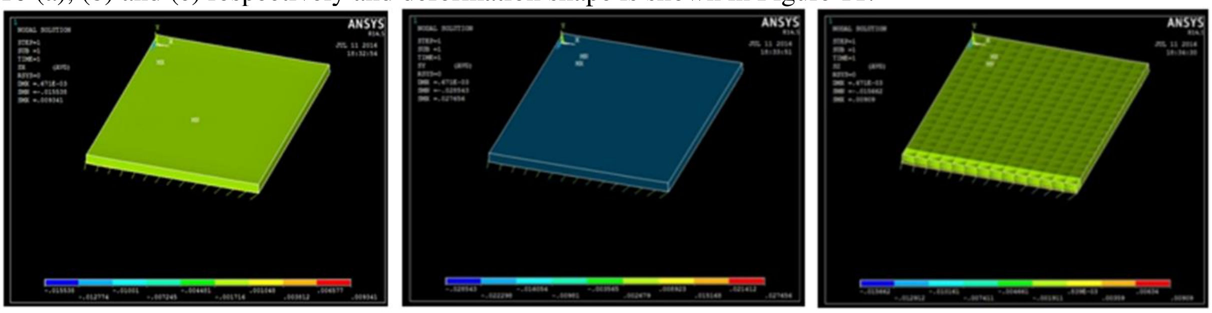

(a) (b) (c)

(d) (e)

**Figure 9.** Mode Shapes (a) First Mode Shape. (b) Second Mode Shape. (c) Third Mode Shape. (d) Fourth Mode Shape. (e) Fifth Mode Shape.

*5.7.2. Static load condition.*

The behavior of rubberized concrete on application of a uniform static pressure of 0.016N/mm$^2$ throughout the slab was analyzed. The stress on x, y and z component under static load is shown in Figure 10 (a), (b) and (c) respectively and deformation shape is shown in Figure 11.




**(a)** (b) (c**)**

**Figure 10.** Stress on static loading

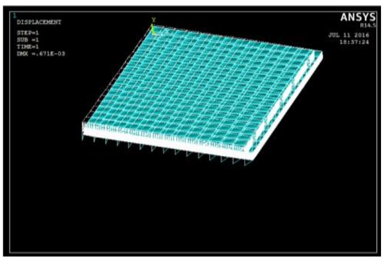



**Figure 11.** Deformed shape of slab on static load.

## 6. Conclusion

SET 2 concrete almost achieved the required target strength of M30 grade concrete with the addition of UFGGBS, whereas the SET 1 concrete experienced a loss in compressive strength due to more voids and lesser density. Percentage increase in 28th day compressive strength of SET 2 compared to SET 1 was found to be 50%, 21.9%, 7.14% and 12.5%, when coarse aggregate was replaced with 5%, 10%, 15% and 20% crumb rubber respectively. In the UPV test, both direct and semi-direct UPV values showed that SET 2 concrete attained higher pulse velocity than SET 1 concrete. This was due to the presence of UFGGBS in concrete which improved its insulating properties and allowed an easier flow of stress waves. Frequency and Damping Ratio follow an inverse proportionality and it was observed that within the specimens of a particular set (5%, 10%, 15% and 20%), reduction in frequency was found to be proportional to an increase in damping ratio. In the Sorptivity test, the ingress of water through the SET 2 UFGGBS added concrete was less when compared to SET 1. This showed that the UFGGBS added concrete had lesser voids, closer packing and reduced porosity. Young's modulus (E) was found out during compression testing and the results showed that strength was greatly affected when rubber was incorporated in concrete. The E value was lesser for SET 1 concrete than SET 2 concrete. In SET 2 samples, higher strength was achieved at 5% replacement of crumb rubber. Mode shape was determined using FEM analysis and the deformation pattern of the concrete corresponding to the peak frequency was analyzed. It was observed that crumb rubber affected the compressive strength but it significantly improved the damping property. The decreased strength characteristics were further improved with the addition of UFGGBS as a cement replacement. From this study, it can be established that an optimum percentage replacement of crumb rubber for coarse aggregate and UFGGBS replacement for cement will promise an economical and environment friendly construction, which can effectively curtail the deteriorating effects of vibratory loads on concrete.

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