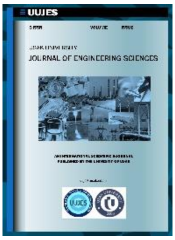

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*Research article*

# MECHANICAL PROPERTIES EVALUATION OF CONCRETE WITH CRUMB RUBBER PARTICLES USED AS FINE AGGREGATE

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## Abstract

Crumb rubber is basically tiny rubber particles produced from scrap vehicle tires. This rubber is crumbled into uniform tiny particles with the help of shredders. In the present work, an attempt has been made to utilize rubber particles as a partial substitute of fine aggregates in fabricating cement concretes. Concrete is a mixture of cement, coarse aggregates, fine aggregates and water. Rubber particles of size ranging between 0.297 and 0.250 mm are used as a substitute in the proportion of 5, 10 and 15% by weight to partially replace fine aggregates. Grade 43 Portland cement has been used. Mechanical properties such as compressive, flexural and impact strength are experimentally investigated. Further, dynamic characteristics such as damping ratio and natural frequencies of test samples with different amounts of crumb rubber particles are compared with neat cement concrete samples. Experimental data for different mechanical and dynamic properties are obtained by curing test samples in water for a period of 7, 14, 21 and 28 days respectively. Substitution of crumb rubber particles to partially replace fine aggregates results in reasonable improvement in impact resistance. A decrease in compressive and flexural strength is observed. Further, addition of rubber particles improves the damping property of the samples along with a decrease in natural frequencies.

***Keywords:*** crumb rubber; flexural strength; compression strength; impact resistance; damping ratio; natural frequency.

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## 1. Introduction

India is one of the leading producers of waste automobile tires. Millions of waste tires are dumped every year without any plan of effective disposal. The most common practice of waste tire disposal is by land filling. Rubber tires are durable and highly non-biodegradable. Using a large chunk of land as a dump yard for a longer period is not advisable due to high cost of land. Further, it is a breeding ground for insects, pests and mosquitoes causing diseases such as dengue, chikangunia and malaria during the rainy season [1]. Pyrolysis is another method to decompose waste tires into carbon and oil by heating in the absence of oxygen. It is a good method to manage the problem of waste tires but with a major drawback of environmental pollution [2]. Efforts have been made to utilize waste tires by making composites using materials like concrete, waste plastic and wood, among others, for construction purposes, furniture and other uses. Waste tire bales are used for walls in residential areas and commercial structures in non-seismic areas [3].

A number of researchers have studied the strength and dynamic properties of cement concretes introducing rubber of different shapes and sizes in them. Raghavan et al., 1998 [4], investigated the workability, mechanical properties and chemical stability of a recycled tire rubber-filled cementitious composite using two different shapes of rubber particles. A decrease in the flexural strength and plastic shrinkage was reported. Smaller rubber particles resulted in a lower density and apparent porosity giving increased compressive strength. Skripkiūnas et al., 2009 [5], investigated the strength and damping behavior of concrete with rubber waste additives. A decrease in compressive and flexural strength of concrete was reported with increased waste tire rubber additives. Addition of rubber to concrete results in a decrease in the dynamic modulus of elasticity and increase in the damping decrement of the concrete. Torgal et al., 2012 [6], recommended tire waste concrete for concrete structures located in areas prone to severe earthquake and also for applications involving severe dynamic actions like railway sleepers. It can also be used for non-load bearing purposes such as noise reduction barriers. Bala, 2014 [7], studied the effect of fly ash and waste rubber on concrete composites. The rubber content was taken in the range of 0 to 40% as a replacement of fine and coarse aggregates, while the fly ash was varied from 0 to 30% for cement. Experimental results showed a decrease in density, compressive and bond strength, while an increase in the workability with increasing rubber content. Gupta et al., 2014 [8], assessed the mechanical and durability properties of concrete containing waste rubber tire as a partial replacement of fine aggregates in the form of rubber ash and rubber ash with rubber fibers (combined form). A reduction in the flexural strength of rubber ash concrete was reported with the increase in rubber ash content, while an increase in flexural strength was reported with the increase in rubber fibers content. Gupta et al., 2015 [9], investigated the impact resistance of concrete containing waste rubber fiber and silica fume using three different techniques: drop weight test, flexural loading test and rebound test. The study demonstrated that waste rubber fibers and silica fume may be used as sustainable materials to improve the impact resistance and the ductility of concrete. Karakurt, 2015 [10], examined the microstructure properties of rubberized asphalt and cement-based composites. Adhesion between the rubber particles and cement matrix was found to be a very significant factor in improving the properties of the final product. Addition of waste rubber improved the physical and mechanical properties of the asphalt and cement-based composite.

The present work is an attempt to utilize crumb rubber particles as a partial replacement of fine aggregates in cement concrete to investigate its mechanical and dynamic characteristics. Experimental data for different mechanical and dynamic properties are obtained by curing test samples in water for a period of 7, 14, 21 and 28 days, respectively. Rubber has a good shock absorbing capacity which can be useful in improving the damping capacity and impact resistance of concrete structures.

## 2. Materials and Method

### 2.1 Ingredients of Rubber Cement Concrete

Crumb rubber has been produced using ambient mechanical grinding which involves the passing of rubber tires through the shredder which breaks the tires into small chips. Granulators and high-speed rotary mills were used to further reduce the size of rubber particles. Crumb rubber particles of mesh size 0.297 to 0.250 mm were used as shown in Fig. 1. Ordinary Portland cement of Grade 43 has been used. Two sizes of coarse aggregate particles—10 to 20 mm aggregates and 4.75 to 10 mm aggregates in the ratio of 1:1 were used. Fine aggregates with a size of around 4.75 mm were used. Fresh water was used for the curing of the rubber cement concrete composite samples. The concrete mix achieves approximately 98% of the strength after curing for 28 days [11].

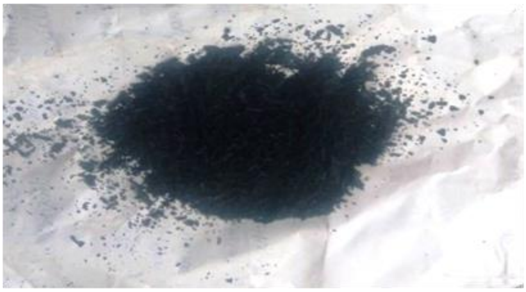

**Fig. 1** Crumb rubber particles

### 2.2 Sample Preparation

The concrete mix design used for the fabrication of the cement concrete control samples was as per the M50 standards with ingredients in the ratio of:

Cement/Fine Aggregate/Coarse Aggregate/Water: 0.20:0.28:0.50:0.15.

Rubber concrete samples were fabricated by partially replacing fine aggregates with waste crumb rubber particles to the extent of 5, 10 and 15% by weight. Crumb rubber concrete samples and their composition as per standard IS 456-2000 for M50 [12] are listed in Table 1. Samples prepared for different tests are shown in Fig. 2a–d.

**Table 1.** Rubber concrete samples used in the experimental investigation

| Sample Nomenclature | Sample Type | Sample Composition |
|---|---|---|
| R0 | control sample | cement concrete with no rubber |
| R5 | rubber cement concrete | cement concrete with 5% rubber |
| R10 | rubber cement concrete | cement concrete with 10% rubber |
| R15 | rubber cement concrete | cement concrete with 15% rubber |

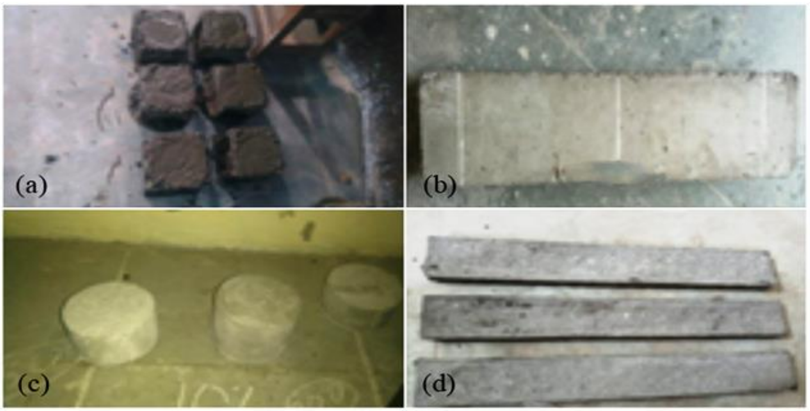

**Fig. 2** (a) Sample for compressive test, (b) flexural test, (c) impact test and (d) natural frequency and damping test

## 2.3. Testing Procedure

### 2.3.1. Compression Test

The compression test was performed as per the standard ASTM C39/C39M (Fig. 3a). Samples of size 15 × 15 × 15 cm were prepared (Fig. 2a).

### 2.3.2. Flexure Test

A flexural test was performed as per the standard ASTMC78/C78M-1 on a 3-point flexural strength testing machine having a ram diameter of 62 mm and a maximum load of 100 KN (Fig. 3b). Samples of size 50 × 15 × 15cm were prepared (Fig. 2b). Flexure strength was calculated using Eq. 1:

$$\sigma = \frac{3FL}{2bd^2} \tag{1}$$

*Where,* $\sigma$ is the flexural strength, $F$ is the load applied, $L$ is the length of the beam, $b$ is the width and d is the depth of the beam.

### 2.3.3. Impact Strength

Impact resistance has been evaluated using the classical pendulum impact testing machine as per the IS: 2386 standard (Fig. 3c). Cylindrical samples have been prepared along with the control samples (Fig. 2c). The height of the mold is 4.4 cm and the diameter of the mold is 8.4 cm.

### 2.3.4. Damping Characteristics

Samples were used in the form of a cantilever beam as per the ISO 18324:2016 standards. The sample size for the damping test is 40 × 6 × 2 cm (refer Figs. 2c and 3d). The logarithmic decrement is determined using Eq. 2:

$$\delta = \frac{1}{N}\ln\left(\frac{x_i}{x_{i+2}}\right) \tag{2}$$

where $\delta$ is the logarithmic decrement, $N$ represents the number of cycles, $x_i$ represents the maximum amplitude in a cycle and $x_{i+2}$ represents the minimum amplitude in a cycle. The damping ratio can be expressed as [13].

$$\zeta = \frac{\delta}{2\pi} \tag{3}$$

Natural frequency is the frequency at which a structure tends to vibrate in the absence of any driving force. It is a dynamic property of the system. Dynamic property evaluation becomes very important in the case of railway sleepers, dams, bridges and earthquake-resistant buildings, etc. Natural frequency depends on mass and stiffness. Change in stiffness and mass of the structure leads to changes in the natural frequency.

**Fig. 3** (a) Compression testing machine (b) Flexural testing machine. (c) Impact testing of samples. (d) Setup for determining the damping ratio and natural frequency

# 3. Results and discussion

## 3.1. Compressive Strength

A compression test is performed on different test samples after curing in water for a period of 7, 14, 21 and 28 days. The cement concrete sample with no rubber has an appreciable increase in its compressive strength till 28 days of water curing, beyond which a little decrease is observed. It is a proven fact reported by a number of researchers that the best compressive strength is obtained after a curing of 28 days. The compressive strength of R5 samples is almost equal to the R0 sample after a curing of 7 days. However, any curing beyond 7 days hardly improves the compressive strength of R5 samples. The compressive strength of R10 and R15 is fairly low in comparison to R0 and R5 after 7 days of curing. It hardly improves with increased curing time. This is mainly due to the poor bonding of crumb rubber particles with the other ingredients of the cement concrete causing an uneven distribution of stresses. A greater addition of rubber particles results in further loss in bonding leading to reduced compressive strength (refer to Table 2 and Fig. 5). Similar observations have been reported by others. Control sample R0 shows a brittle fracture under compressive stresses, while mix rubber concrete samples absorb some energy before they fracture. The fracturing of R0 and R5 samples is shown in Fig. 4 a, b. Further, rubber particles have very poor adhesion with other ingredients and on application of stress, where they deform suitably causing voids and points of stress concentration. These voids and points of stress concentration are the starting points of fracturing [14–17]**.** The mode of failure for rubberized concretes under compression is the same as in the case of plain concrete. This may be due to the small content of rubber particles of fairly small size in the concrete mix. Fractured samples from the compressive test show a transition in failure from a conical-shear failure mode to a tensile failure cracking mode with the introduction of rubber. Rubber particles act as compressible porous inclusions in the cement matrix. Large numbers of visible tensile cracks appear on the surface of the fractured samples as reported earlier [18].

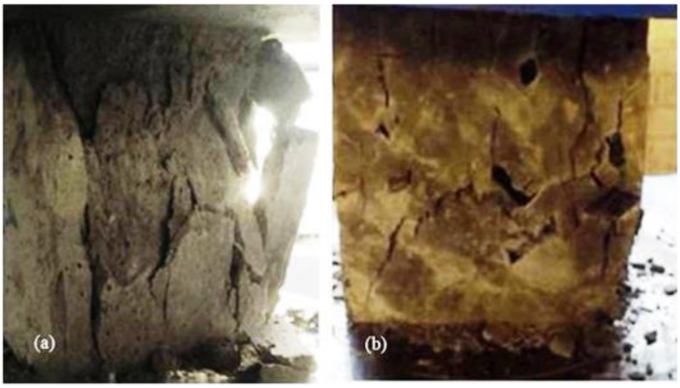

**Fig. 4** Fracture under compression for (**a**) control sample, R0. (**b**) Rubber concrete sample, R5

**Table 2.** Effect of curing period on the compressive strength of test samples.(ACS:Average Compressive Strength and SD: Standard deviation)

| **Sample Nomenclature** | **Day 7** | | **Day 14** | | **Day 21** | | **Day 28** | |
|---|---|---|---|---|---|---|---|---|
| | **ACS** | **SD** | **ACS** | **SD** | **ACS** | **SD** | **ACS** | **SD** |
| R0 | 28.3 | 2.6457 | 34.8 | 2.3065 | 41.4 | 1.9078 | 46.2 | 2.0518 |
| R5 | 29.6 | 1.1269 | 29.6 | 2.2546 | 29.6 | 2.2007 | 30.4 | 3.12249 |
| R10 | 18.3 | 4.5825 | 19.6 | 4.1218 | 17.4 | 5.37028 | 20.5 | 5.0269 |
| R15 | 15.4 | 3.4281 | 15.2 | 1.6822 | 14.3 | 1.3203 | 17.4 | 2.4576 |

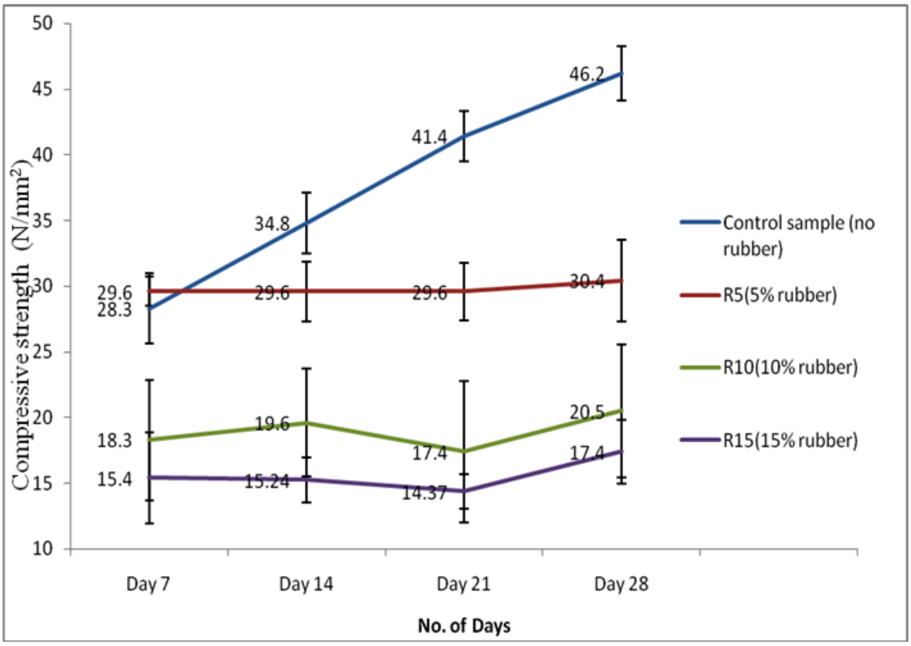

**Fig. 5** Variation in compressive strength with curing time for different test samples

### 3.2. Flexural Strength

The results of the flexural test are presented in Table 3 and Fig. 6. It is clear that the best flexure properties are shown by the control sample, R0. It is important to note that there is a sharp rise in flexure strength of all test samples including the neat cement concrete sample for a curing period of 14 days. Beyond this period, all the test samples have only a nominal increase in the flexure strength pattern. Similar results have been reported by others. Rubber particles are elastomers and act as micro-elastic bodies in cement mortar. They absorb strain energy and improve the deformability and toughness of a cement mix. Considering the fact that rubber particles introduce microstructural defects in the mix, they do not adversely affect the flexural strength of rubberized concrete due to the lower absolute density of rubber particles in the concrete mix [17,19].

**Table 3.** Effect of curing period on the flexure strength of test samples (AFS: Average Flexural Strength and SD: Standard Deviation )

| **Sample Nomenclature** | **Day 7** | | **Day 14** | | **Day 21** | | **Day 28** | |
|---|---|---|---|---|---|---|---|---|
| | **AFS** | **SD** | **AFS** | **SD** | **AFS** | **SD** | **AFS** | **SD** |
| R0 | 1.20 | 0.1732 | 4.80 | 0.9643 | 4.92 | 0.5196 | 5.16 | 0.32186 |
| R5 | 0.90 | 0.1000 | 4.50 | 0.2645 | 4.53 | 0.2523 | 4.80 | 0.1000 |
| R10 | 0.60 | 0.2992 | 3.60 | 1.5219 | 4.20 | 1.5836 | 4.62 | 1.7384 |
| R15 | 0.60 | 0.2587 | 3.48 | 1.3268 | 3.96 | 1.4292 | 4.20 | 1.5253 |

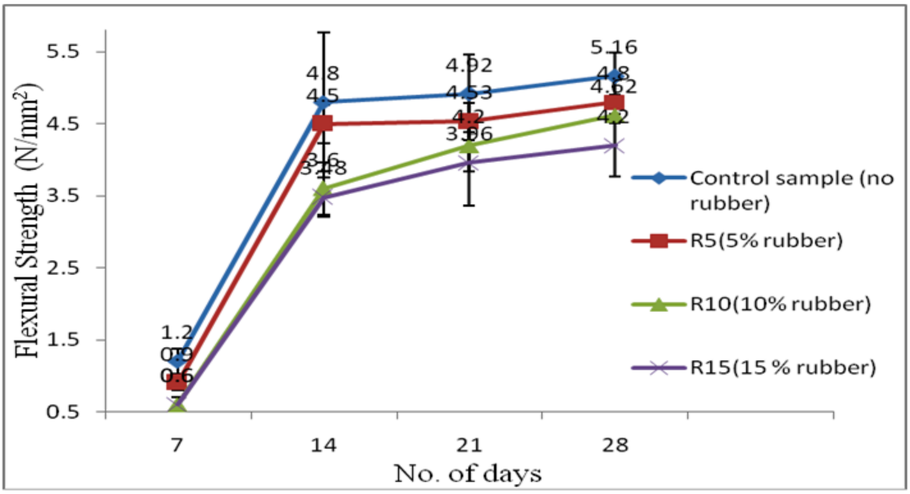

**Fig. 6** Variation in flexure strength with curing time for different test samples

### 3.3. Impact Strength

The effect of curing period on the impact strength of test samples is presented in Table 4. The neat cement concrete sample, R0, goes on to gain strength and hardness with a greater curing time and it requires greater effort to initiate cracking and its failure by a brittle fracture (refer to Fig. 7a, b and c). Rubber concrete samples have greater resistance to impact or shock as rubber particles embedded in concrete act as a cushion and absorb the impact energy, and they are fairly pliable and deform suitably to damp out external stimuli. It is clear from Table 4 that the greater amount of rubber particles in the R10 and R15 mix concrete samples gives them better resistance to impact or shock and they require greater effort in the number of blows to initiate cracking and its eventual failure due to a fracture. Similar results have been reported by others [20].

**Table 4** Effect of curing period on the impact strength of test samples

| Sample Nomenclature | 7 days (blows number) | | 14 days (blows number) | | 21 days (blows number) | | 28 days (blows number) | |
|---|---|---|---|---|---|---|---|---|
| | First Crack | Failure | First Crack | Failure | First Crack | Failure | First Crack | Failure |
| R0 | 4 | 6 | 5 | 7 | 5 | 7 | 6 | 8 |
| R5 | 4 | 6 | 5 | 7 | 6 | 9 | 7 | 9 |
| R10 | 5 | 7 | 6 | 8 | 7 | 9 | 7 | 9 |
| R15 | 6 | 8 | 6 | 9 | 8 | 10 | 8 | 11 |

**Fig. 7** Failure under impact load. (**a**) Crack initiation R0 sample. (**b**) Fracture of R0 sample. (**c**) Fracture of R5 sample.

### 3.4. Damping Characteristics

A cantilever beam setup has been used to investigate the dynamic characteristics of the test samples. The beam is subjected to an impulse shock at the end by striking it with a hammer and the impulse force response is recorded. The test setup and the impulse force recorder are shown in Fig. 8 a, b. The effect of curing period on the damping behavior of the test samples is presented in Table 5. It is clear from the results that all the test samples including the control sample exhibit under damped behavior and the vibratory nature dies down in a finite settling time. The under damped behavior of the R0 and R15 samples is compared in Fig. 9. Rubber particles do not have good bonding with cement and fine aggregates. Further, addition of small-size rubber particles in lower amounts will have little effect in improving the damping performance [21].

**Table 5** Effect of curing period on the damping behavior of test samples

| Sample nomenclature | 7 Days | 14 Days | 21 Days | 28 Days |
|---|---|---|---|---|
| R0 | 0.015 | 0.021 | 0.029 | 0.031 |
| R5 | 0.025 | 0.032 | 0.035 | 0.036 |
| R10 | 0.034 | 0.023 | 0.021 | 0.026 |
| R15 | 0.033 | 0.026 | 0.020 | 0.025 |

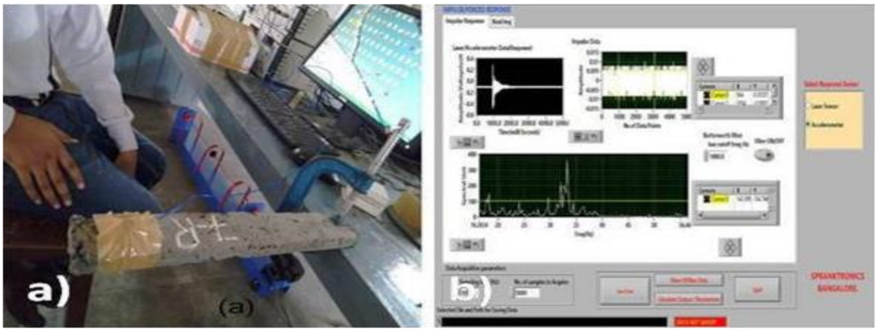

**Fig. 8.** (**a**) Cantilever beam setup for testing dynamic characteristics. (**b**) Impulse force response curve recorder

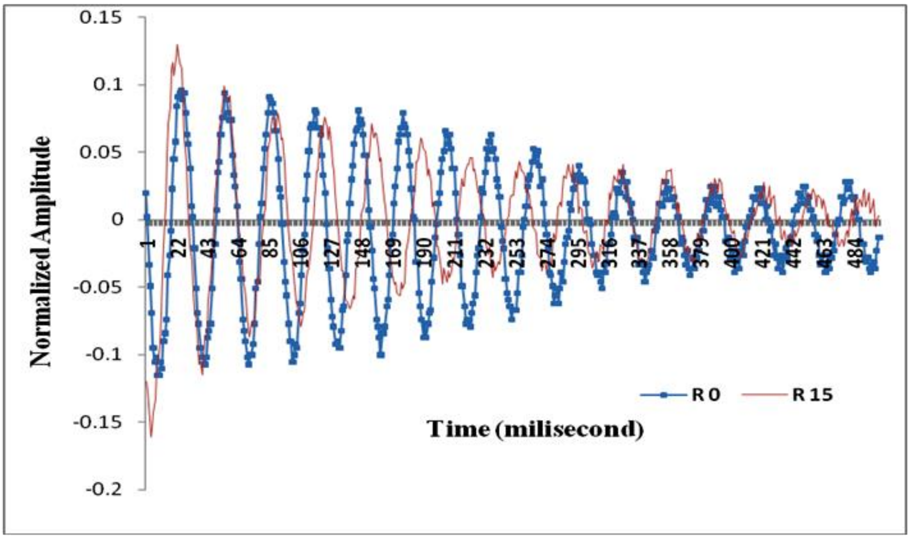

**Fig. 9.** Comparison of damping behavior of R0 and R15 samples

### 3.5. Natural Frequency

The effect of curing period on the natural frequency of the test samples is presented in Table 6. A gradual decrease in the natural frequency of the neat concrete sample, R0, is seen with an increase in curing time. After curing for 28 days when the R0 sample has the most stable structure, its natural frequency is 28.15 Hz. Addition of rubber particles in the concrete sample results in a reduction in the stiffness as rubber particles are fairly pliable and act as a cushion to absorb energy. The greater the content of rubber particles, the greater the loss is in the dynamic modulus of the sample. This is mainly due to the inadequate interaction between the rubber particles with the other ingredients. Further, an increase in rubber content results in a small decrease in the weight of the rubber concrete samples as rubber has a smaller specific density in comparison to other ingredients. Since frequency is dependent on stiffness and mass, a gradual decrease in natural frequencies is seen across the board with an increase in the content of rubber. The natural frequency of the R5, R10 and R15 samples (as reported in Table 6 and Fig. 10) exhibits a decrement of 23.21%, 23.24% and 24.61%, respectively, after 28 days of curing as compared to the control sample, R0. Curing is a process of bond making in the presence of water (hydrogenation). Water in an appropriate amount is required during curing for the best strength. A small amount of water is absorbed by rubber particles to make them swell. After the completion of the curing process, the rubber particles loose water and shrink to original sizes, leading to the generation of voids causing poor interaction of rubber particles with other ingredients. This poor interaction is responsible for the loss in the dynamic modulus of elasticity per unit weight of rubber mix concrete. Loss of the dynamic modulus has a direct bearing on the natural frequency and accordingly, the natural frequency decreases with an increased curing period [22–23].

**Table 6** Effect of curing period on the natural frequencies of test samples.(ANF: Average Natural Frequency and SD: Standard Deviation)

| **Sample Nomenclature** | **Day 7** | | **Day 14** | | **Day 21** | | **Day 28** | |
|---|---|---|---|---|---|---|---|---|
| | **ANF** | **SD** | **ANF** | **SD** | **ANF** | **SD** | **ANF** | **SD** |
| R0 | 32.99 | 1.7153 | 29.39 | 0.90088 | 28.15 | 1.8529 | 28.15 | 1.27078 |
| R5 | 30.53 | 0.9706 | 23.34 | 1.2572 | 21.62 | 1.81052 | 21.62 | 0.1965 |
| R10 | 27.82 | 1.2139 | 23.28 | 0.9175 | 21.61 | 0.6670 | 21.61 | 2.3500 |
| R15 | 27.33 | 1.0369 | 22.92 | 0.86608 | 21.23 | 1.77837 | 21.23 | 1.149435 |

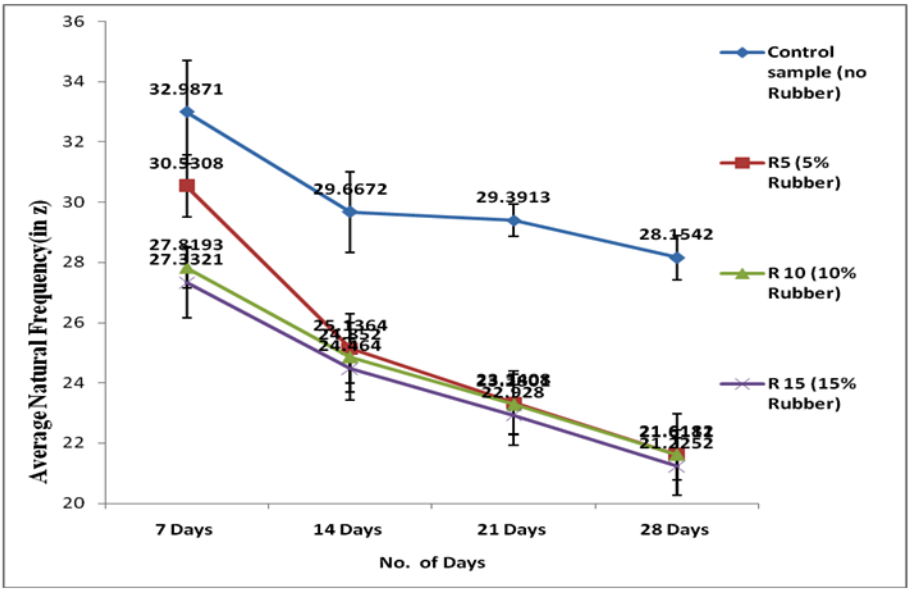

**Fig. 10** Effect of curing period on the natural frequencies of test samples

## 4. Conclusion

The aim of this research work is to gainfully utilize waste rubber tires in cement concrete to improve the damping capacity and impact strength of rubber concrete without compromising the compressive and flexure strengths of standard 43 grade of cement concrete. Rubber concrete samples are fabricated by partially replacing fine aggregates with waste crumb rubber particles to the extent of 5, 10 and 15% by weight. Addition of rubber particles to cement concrete results in reasonable improvement in the damping capacity of the concrete. This has a potential to reduce the vibration of such structures and enhance its resistance to impact and shock and to avoid brittle fractures. Experimental investigations suggest that there is a considerable decrease in compressive strength of rubber concrete; however, addition of 5% rubber particles gives reasonable compressive strength to cement concrete. A small drop in flexure strength in all rubber concrete samples in comparison to the neat concrete sample is observed but they have a reasonable level of flexure strength to be used safely in real-life situations.

### Author Contributions

Conceptualization; methodology; writing—review and editing; supervision; project administration; funding acquisition, visualization and validation etc. was jointly accomplished by Dr. Anand Kumar and Dr. Vinay Pratap Singh. Mr. Arjun Diwakar was involved in experimentation; formal analysis; investigation; data curation and preparation of original draft.

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**Conflicts of Interest**

The authors declare that there is no conflict of interest.

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