Aggregate Replacement and Its Usefulness in Cement Concrete for Sustainable Development—A Study on Rubber, Jarosite and Sandstone Aggregates

Sanjeev Kumar, Ramesh Chandra Gupta, Blessen Skariah Thomas and Priyansha Mehra

Abstract Disposal of wastes such as tire rubber, jarosite and sandstones have become a major environmental issue in all parts of the world especially in India. Every year millions of tires are discarded representing a serious threat to ecology. It was estimated that almost 1000 million tires end their service life every year and out of that, more than 50 % are discarded to landfills or garbage without any treatment. By the year 2030, there would be 5000 million tires to be discarded on a regular basis. Similarly, huge quantity of jarosite is being released as solid residues during the process of metallic zinc extraction from sulphide ore or zinc sulphide. Rajasthan in India alone produces 900 million tons of sandstone waste thus leading to a large dumping of these materials without any essential utilisation. The increasing annual production and those already accumulated is one of the major sources of environmental pollution. This study focusses on the effective utilisation of these wastes as aggregate in cement concrete which leads to an overall sustainable development in the field of concrete research.

Keyword Tire rubber · Jarosite · Quartz sandstone · Compression · Flexure

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1 Introduction

Concrete is a mixture of cement, aggregates and water. Aggregates constitute about 70 % by weight of the concrete. There is a great demand for natural aggregates as the construction activities are increasing every day. As the natural resources are decreasing every day, some alternative materials that will serve the purpose of the natural aggregates should be introduced [1]. Solid waste disposal is a worldwide problem. If not properly disposed, these materials become sources of environmental pollution and the problems related to it. Various studies are done worldwide to dispose these solid waste materials by using them for partial or complete replacement of aggregates in cement concrete. Discarded tyre rubber is an important solid waste material that destroys the ecological environment. Environmental and Ecological disturbances have been caused due to huge accumulation of waste/by-products generated during the different manufacturing and production processes. Extraction of metal from its ore is one such process, generating non-hazardous as well as hazardous by products. Sandstones are sedimentary type of rock which are composed of rock grains and silt sized particles. They are of different types based on the geological property, elemental framework and most of the sandstones has quartz and feldspar due to abundance of them in earth's crust. Being a widespread aggregate resource, sandstones are widely used in concrete construction around the world [2]. The geological properties of sedimentary rocks are fairly diverse such as quartzite, arkose, subarkose and greywacke aggregate that may produce a range of hardened concrete properties. This paper discusses compression and flexural strength results in utilising tire rubber, jarosite and quartz sandstones in concrete as a partial replacement for aggregates.

2 Materials and Methods

2.1 Rubber Tire

Ordinary Portland cement of grade 43, conforming to IS 8112: 1989 [3] was used (specific gravity 3.15, normal consistency 34 %, initial setting time 99 min, final setting time 176 min). Natural river sand confirming to zone II as per IS 383: 1970 [4] (void content 34 % as per ASTM C 29/C 29M: 2009 [5], specific gravity 2.63, free surface moisture 1 %, fineness modulus 2.83). Coarse aggregates, 10 mm size was used 40 % (fineness modulus 5.573) and 20 mm size was used 60 % (fineness modulus 7.312) crushed stone were used as coarse aggregates with an average specific gravity 2.63. Discarded tyre rubber was grinded into three sizes (powder form of 30 mesh, 0.8–2, 2–4 mm). The specific gravity of rubber powder was 1.05 and that of the other two sizes were 1.13. The three sizes of crumb rubber were mixed in definite percentages (2–4 mm size in 25 %, 0.8–2 mm size in 35 % and rubber powder in 40 %) to bring it to zone II as per IS 383: 1970.

2.2 Jarosite

Jarosite and fly ash have been procured from Hindustan Zinc Limited, Debari, Udaipur, Rajasthan and Kota Super Thermal Power Station, Kota, Rajasthan respectively. Other raw materials for concrete such as aggregates, water, cement and chemical admixtures have been used as per the requirement for concrete mix design. The compressive and flexural strength of concrete was tested as per procedure laid in IS: 516 (BIS 1959) [6]. Concrete cube specimens of size 100 mm were used for compression test at 3, 7, 28 and 90 days and concrete beams of size 100 × 100 × 500 mm were used for flexural test at 7 and 28 days [7, 8].

2.3 Quartz Sandstone

Ordinary Portland cement of grade 43, conforming to IS 8112: 1989 was used (specific gravity 3.15, normal consistency 32 %, initial setting time 66 min and final setting time 164 min). Natural river sand confirming to zone II as per IS 383: 1970 (void content 34 % as per ASTM C 29/C 29 M: 2009, specific gravity 2.63, free surface moisture 1 % and fineness modulus 2.83). Coarse aggregates, 10 mm size (fineness modulus 6.08) and 20 mm size (fineness modulus 7.22) crushed stone were used as coarse aggregates with an average specific gravity 2.64. Quartz sandstone coarse aggregate, 10 mm size (fineness modulus 6.04) and 25 mm size (fineness modulus 7.24) were used as partial replacement for coarse aggregates with an average specific gravity of 2.45. The particle size distribution, composition of aggregates, cement properties and gradation details given are same as in Kumar et al. [9].

3 Results and Discussions

3.1 Rubber Tire

Compressive Strength. Concrete cubes of size 100 mm × 100 mm × 100 mm size were cast with varying percentages of crumb rubber and varying water-cement ratios. The specimens were de-moulded after 24 h and tested for compressive strength after 7 and 28 days of curing as per IS 516: 1959. Specimens stored in water were tested immediately on removal from the water, while they are still in the wet condition. Surface water and grit were wiped off the specimens and the projecting fins were removed. The results showing the variation in compressive strength (average of three test values) are given in Figs. 1, 2 and 3.

From the results of the compressive strength test, for water-cement ratios of 0.4, 0.45 and 0.5, the compressive strength showed a decreasing trend when the

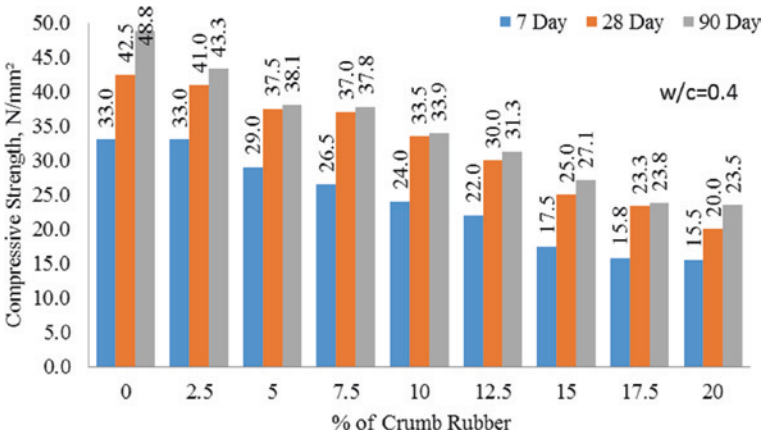


Fig. 1 Compressive strength of *cubes* for water-cement ratio 0.4

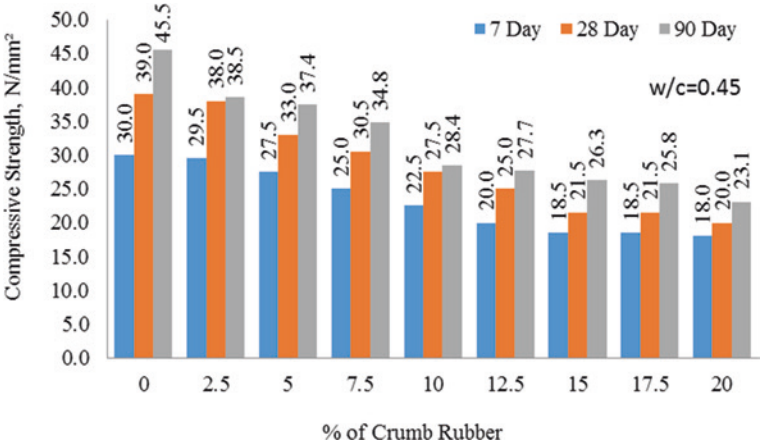


Fig. 2 Compressive strength of *cubes* for water-cement ratio 0.45

percentage of crumb rubber is increased. This loss in strength is mainly due to the lack of adhesion between the rubber particles and the cement paste. When the water–cement ratio is 0.4, the strength above 30 N/mm^2 has been obtained up to 12.5 % of crumb rubber replacement and up to 7.5 % replacement when the water–cement ratio was 0.45 and 5 % replacement when the water-cement ratio is 0.5. The compressive strength showed a decrease up to 50 % in all the three water–cement ratios when the percentage of tyre rubber reached 20 % of fine aggregates.

Flexural Strength. Concrete beams of size 100 mm × 100 mm × 500 mm size were casted with varying percentages of crumb rubber and varying water-cement ratios. The specimens are cured and tested on a flexural testing apparatus for 7 and 28 days as per IS 516: 1959. The results showing the variations in flexural

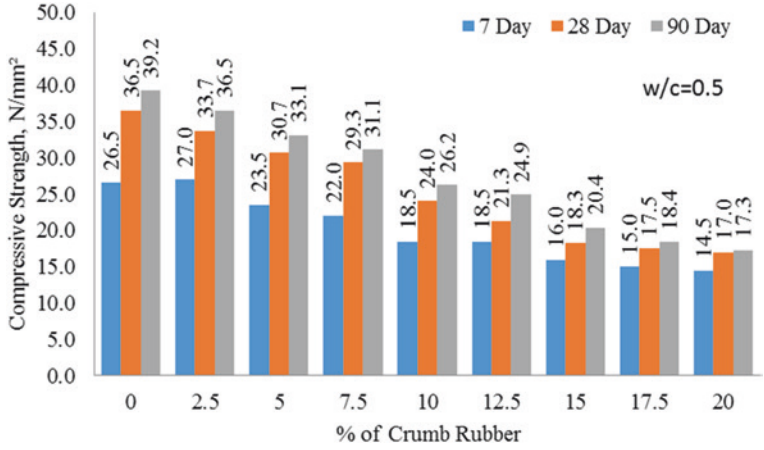


Fig. 3 Compressive strength of *cubes* for water-cement ratio 0.50

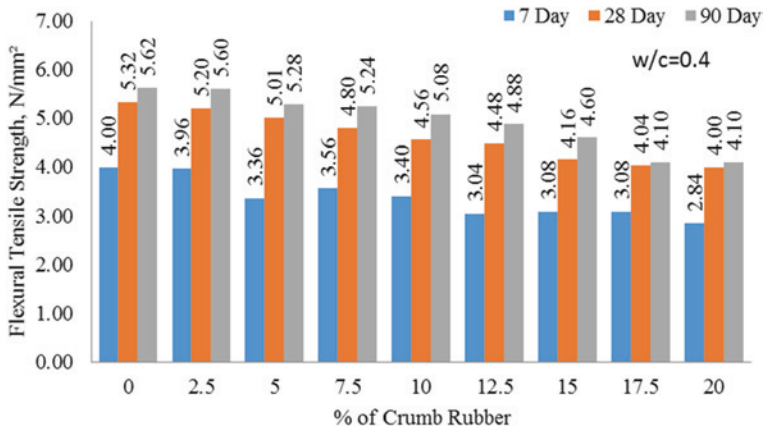


Fig. 4 Flexural strength of *cubes* for water-cement ratio 0.4

strength (average of three test values) of beams are given in Figs. 4, 5 and 6. From the results of the flexural strength test, there was decrease in the strength upon increasing percentage of crumb rubber. But the reduction in flexural strength was approximately half of that of compressive strength. When the water–cement ratio was 0.4, the flexural strength at 28 days was 5.28 N/mm^2 for the control mix and 4 N/mm^2 for the concrete with 20 % tyre rubber. When the water–cement ratio was 0.45, the flexural strength at 28 days was 5.28 N/mm^2 for the control mix and 4 N/mm^2 for the concrete with 20 % crumb rubber.

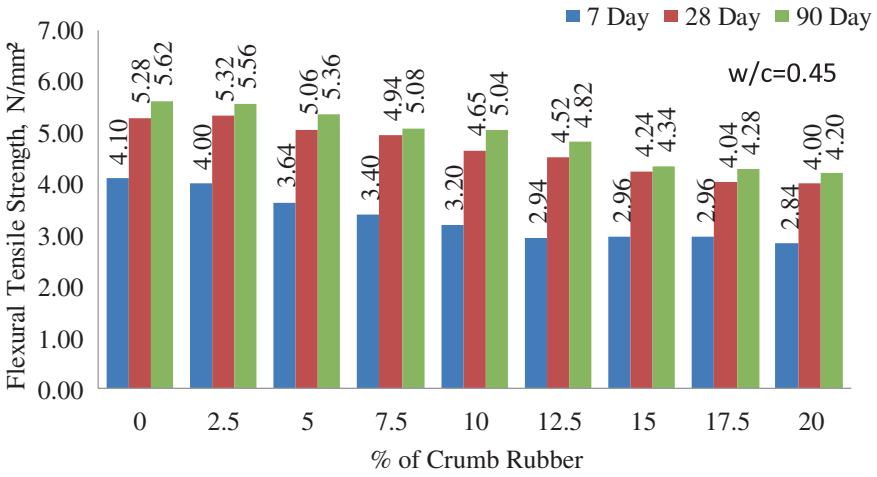


Fig. 5 Flexural strength of *cubes* for water-cement ratio 0.45

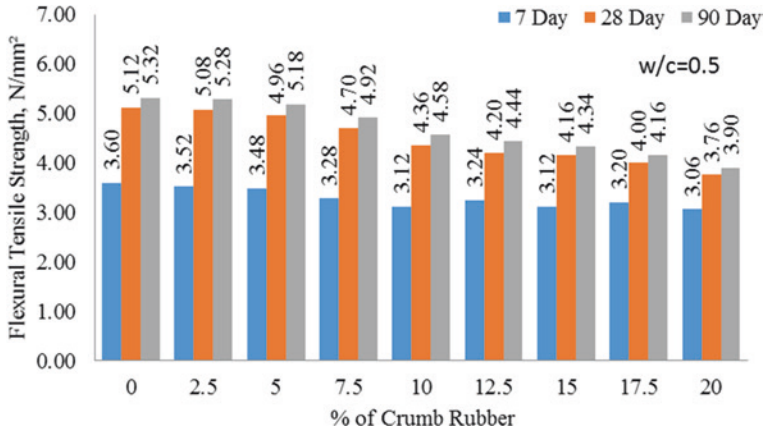


Fig. 6 Flexural strength of *cubes* for water-cement ratio 0.50

3.2 Jarosite

Compressive Strength. At the early age of 3 days, there seems an increasing trend in strength with reference to replacement levels of jarosite in concrete with all water-cement ratios (0.40, 0.45 and 0.50). Moreover, concrete mixtures with w/c ratios 0.40 and 0.45 experienced almost the same strength up to 20 % replacement of fine aggregates. The lower strength of the concrete samples with w/c 0.50 has been observed at all replacement levels in comparison to samples with w/c 0.40 and 0.45. After 7 days curing, the strength following the same trend as that of 3 days strength. However, the concrete mixtures with w/c 0.50 has achieved the strength almost similar to mixtures with w/c 0.45. At later ages of 28 and 90 days, the strength improvement has been clearly visible in concrete mixtures with all w/c ratios (0.40, 0.45 and 0.50). At 28 days, the concrete mixtures with w/c 0.50, strength is almost constant up to 15 % replacement levels and increased further till 25 %. The concrete mixtures with w/c 0.40 have obtained good strength after 28 and 90 days (Fig. 7). Complete hydration of cement and binder (fly ash) has resulted in good mechanical strength (compressive and flexural strength). Also, the increasing percentage of jarosite has properly filled the pores and developed a dense particle packing.

Flexural Strength. Flexural tensile strength of concrete at 7 and 28 days is shown in Fig. 8. Flexural tensile strength seems to be following almost the same trend of compressive strength. However, in 7 days, concrete mixtures with w/c 0.40 and 0.45 achieved almost the same strength at all percent of jarosite while

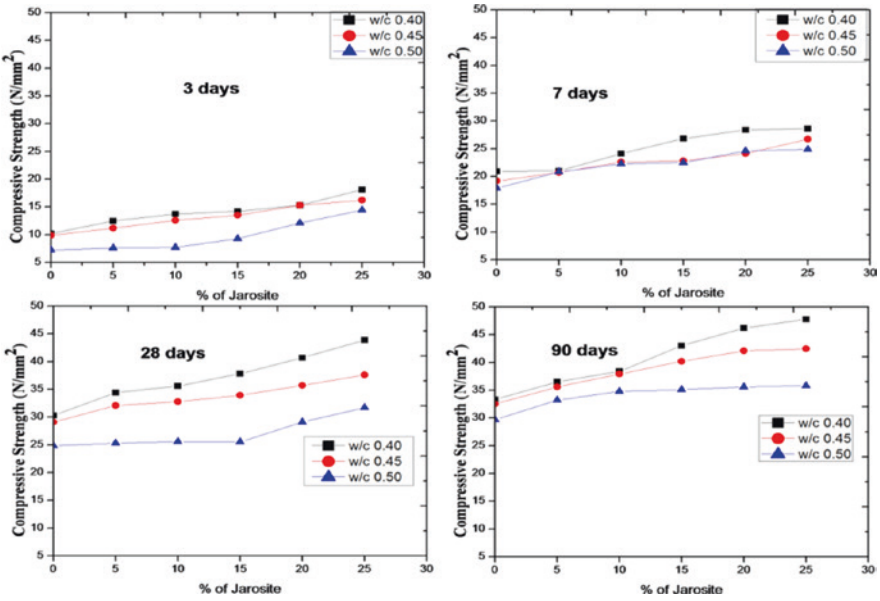


Fig. 7 Compression strength of *cubes* for water-cement ratio 0.4, 0.45 and 0.5

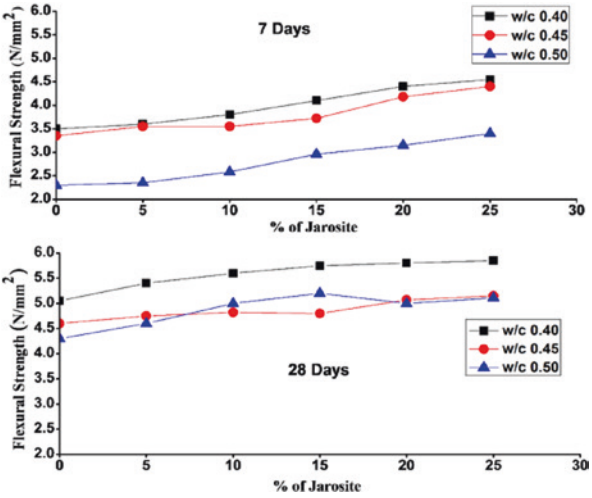


Fig. 8 Flexural strength of *beams* for water-cement ratio 0.4, 0.45 and 0.5

after 28 days curing, concrete mixtures with w/c 0.45 and 0.50 hold the same strength at higher replacement levels.

At higher replacement levels, the flexural strength of coal bottom ash concrete seems to be comparable with control concrete. Concrete with higher ash content (30 % and up to 50 %) possessed increased strength. However, at lower levels (up to 20 %), reduction in strength was observed.

3.3 Quartz Sandstone

Compressive Strength. From the test results of three average values for water-cement ratios of 0.35, 0.4 and 0.45, the compressive strength showed a decreasing trend whilst adding quartz sandstone as coarse aggregate. Upon 100 % replacement, a maximum of 21 % decrease in compressive strength was observed at 0.45 water/cement ratio. However, a maximum decrease of only 8 % in compressive strength was observed up to 40 % substitution when compared with the control concrete (Figs. 9, 10 and 11).

Flexural Strength. Concrete beams of 100 mm × 100 mm × 500 mm size were cast with various percentages of quartz sandstone aggregates and various water/cement ratios. Flexural strength tests were carried out in accordance to IS 516: 1959 after 7 and 28 days. The test samples were stored in water at a temperature of approximately 27–29 °C for 24 h before testing. The samples were tested whilst they were still in wet condition. Loose and foreign materials were wiped off the bearing surfaces and the axis of the specimen was aligned with that of the loading device. Then load was applied at a rate of 400 kg/min until the specimen

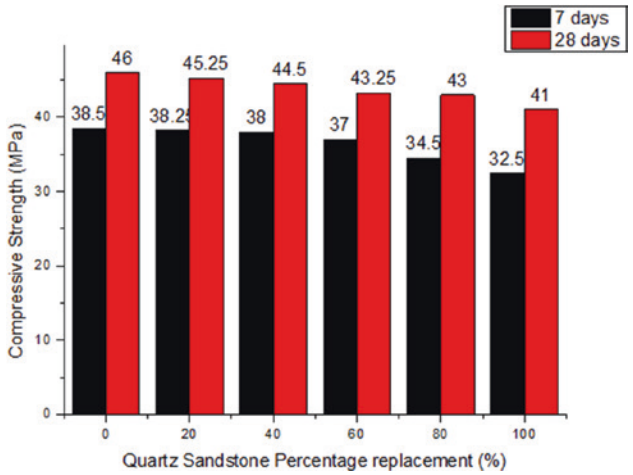


Fig. 9 Compressive Strength of *cubes* for water-cement ratio of 0.35

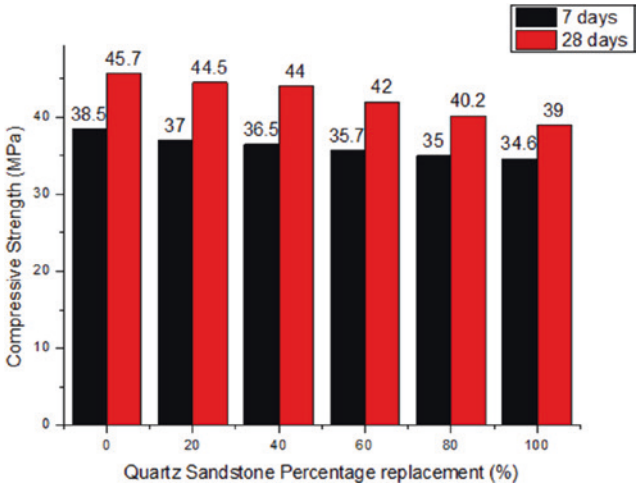


Fig. 10 Compressive Strength of *cubes* for water-cement ratio of 0.40

failed to attain the peak load. The test results showed a decrease in flexural strength as the quartz sandstone was added in concrete. The maximum decrease was found to be 12 % when compared to the control concrete for the water/cement ratio of 0.35 (Figs. 12, 13 and 14).

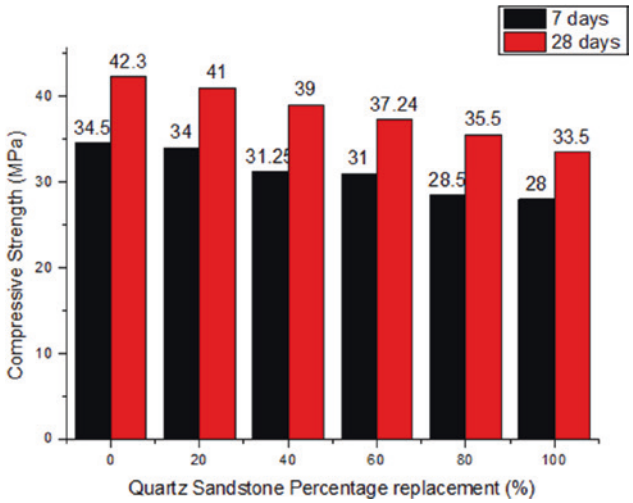


Fig. 11 Compressive Strength of *cubes* for water-cement ratio of 0.45

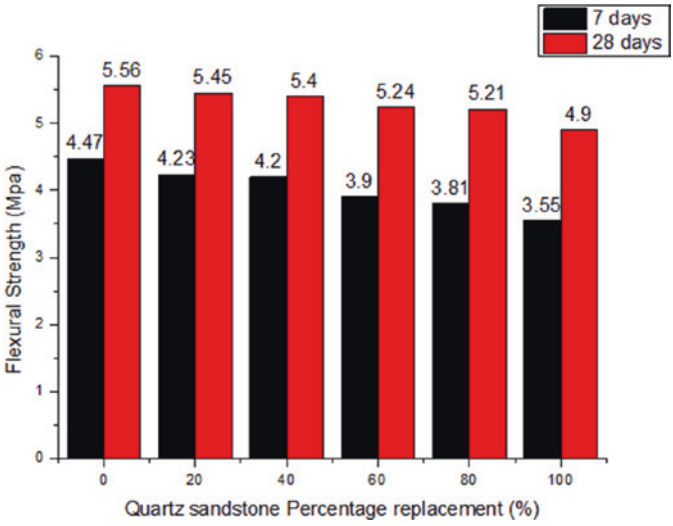


Fig. 12 Flexural Strength of *cubes* for water-cement ratio of 0.35

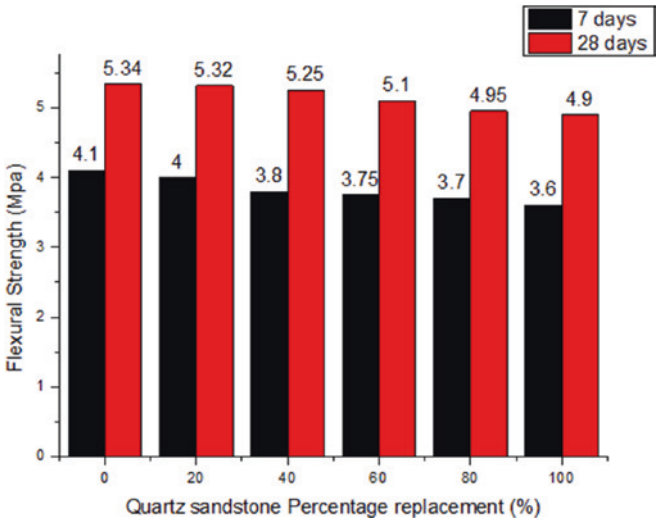


Fig. 13 Flexural Strength of *cubes* for water-cement ratio of 0.40

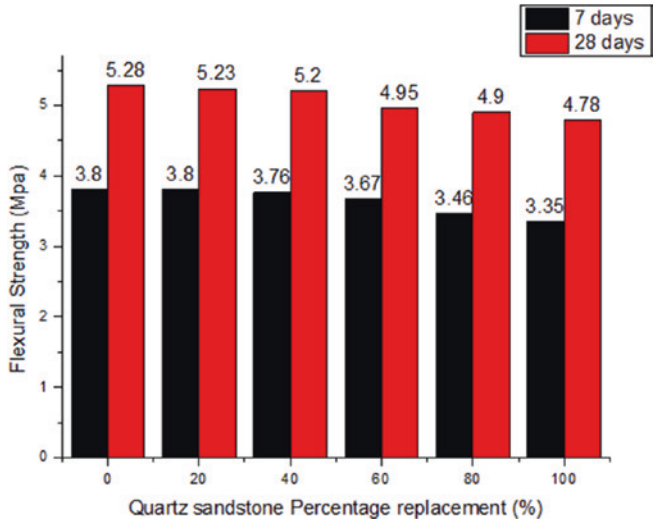


Fig. 14 Flexural Strength of *cubes* for water-cement ratio of 0.45

4 Conclusions

4.1 Rubber Tire

- From the results of the compressive strength test, for water-cement ratios of 0.4, 0.45 and 0.5, the compressive strength showed a decreasing trend when the percentage of crumb rubber is increased. When the water–cement ratio is 0.4, the strength above 30 N/mm2 has been obtained up to 12.5 % of crumb rubber replacement and up to 7.5 % replacement when the water–cement ratio was 0.45 and 5 % replacement when the water–cement ratio is and 5 % replacement when the water-cement ratio is 0.5. The compressive strength showed a decrease up to 50 % in all the three water–cement ratios when the percentage of crumb rubber reached 20 % of fine aggregates.
- From the results of the flexural strength test, there was decrease in the strength upon increasing percentage of crumb rubber. But the reduction in flexural strength was approximately half of that of compressive strength.

4.2 Jarosite

- The compressive and flexural strength of concrete mixtures has been almost higher at higher replacement levels at all w/c ratios.

4.3 Quartz Sandstone

- While utilising quartz sandstone in concrete, proper selection of water/cement ratio becomes mandatory as the strength plots decrease due to increase in water/cement ratio.
- For mix designs having water/cement ratios more than 0.40, quartz sandstone aggregate replacement can be limited to 40 % to attain target strength for M30 grade of concrete.

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