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Research Paper

Cost Effective Design of Sustainable Concrete Using Marble Waste as Coarse Aggregate

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ABSTRACT

In the present study attempts have been made to obtain sustainable and cost effective concrete product by use of marble waste. Aggregate obtained from marble quarry waste was *used* as 75% part of coarse aggregate and rest was conventional coarse aggregate. It was observed that, compressive strength was almost same as that of the control concrete. Durability properties like permeability and chloride ion penetration improved by approximately 30% and 15%, respectively. Resistance to acids and carbonation were least affected. Cost comparison showed with 20% less cement requirement, 14% reduction in cost of concrete was achieved when marble waste was used with packing density approach for design of concrete mixes. By minimizing the cement content without losing mechanical and durability properties of concrete resulting in reduction of global cement production from 4.2 billion tons to 3.36 billion tons and correspondingly it reduces CO_2 emission from 3.95 billion tons by 0.79 billion tons.

1 Introduction

Infrastructure development is increasing day by day specially in developing countries. All these activities involve use of natural resources in huge amount. Depletion of natural resources is a big challenge to mankind. On the other hand industrialization is also increasing in developing countries. Disposal of waste generated in industries is another challenge. The best option to overcome both the problems is to utilize the industrial waste in infrastructure development works. Industrial wastes like Fly ash, GGBS are frequently used in concrete replacing cement. The products thus obtained have also been compared with usual products and found to be durable and cost effective. Scarcity of natural resources like fine and coarse aggregate for concrete production is also a big challenge in India. Many times legal complications like ban on quarrying due to environmental hazards have forced the construction sector to seek suitable alternatives. One of the possible alternatives found by some of researchers was to use marble waste obtained from quarry in concrete production.

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State of art

There are around 4000 marble mines and 1100 processing units operating in the state of Rajasthan, India [1]. Mining industries produce a lot of waste in the form of pieces of irregular size of stones during operation. It has been observed that, about 80% of marble production goes in to waste in the form of random size of pieces. Disposal of this waste is another challenge. Fine powder in the form of slurry is also being produced in marble processing industries. There is no proper way for disposal of this waste in the mining and processing areas. In most of the areas, it is thrown randomly on the roadsides or fields resulting in fruitless occupation of land and environmental pollution. A few researchers have studied use of marble aggregate in concrete mixes

In a study by Ceylan et al.[2] reported that, concrete produced using marble aggregate as complete replacement for conventional aggregate achieved target mean strength at all curing ages as per Turkish standards. It was also reported that, higher values of ultrasonic pulse velocity were obtained and Schmidt surface hardness of waste marble aggregate was more than that of conventional aggregate. Hebhoub et al.[3] conducted studies on use of marble waste in the form of fine and coarse aggregate in concrete with water-cement ratio of 0.5. He reported that, workability decreased with increase in replacement level in the range of 0% to 100% for all the formulations. Compressive strength of concrete mix increased by 16% to 25% at 75% replacement of conventional aggregate by marble aggregate. In a study conducted by Andre et al.[4], marble waste was used in different percentages (20% to 100%) as replacement for conventional aggregates. It was reported that, workability and compressive strength of concrete mix marginally decreased as the replacement level increased. They also reported that, water absorption and depth of carbonation of concrete containing marble aggregate showed similar results to that of control concrete. Binici et al. [5] in another study reported, compressive strength of concrete mix containing marble dust and control concrete after immersion in 10% sodium sulphate solution was reduced by 15% and 58%, respectively. In a study by Binci et al.[6] , the marble waste was used as a 100 % replacement for natural coarse aggregates in concrete with a constant water-cement ratio 0.4. In this study, river sand and ground blast furnace slag (GBFS) were used as fine aggregate. It was reported that, compressive strength, Flexural strength, Splitting tensile strength and young's modulus of elasticity of concrete, prepared with GBFS as fine aggregate and marble waste as coarse aggregate was 3% and 6%, respectively, higher than that of concrete with river sand as fine aggregate and marble waste as coarse aggregate. Martin et al.[7]reported, coarse aggregate from marble waste can be used as a partial replacement for conventional coarse aggregate to improve the mechanical properties of concrete. They also reported that, the workability of all concrete mixes increased by 4.16% to 9.34% and density marginally decreased by 0.28% to 4.21% at 20% to 100% replacement level. With regard to compressive and tensile strength, marginal reduction by 5.2% to 6.2% and 1% to 10.4%, at replacement of 20% to 100%, respectively was reported. This decrease was approximately10% and found to be insignificant. It was also reported that, concrete mixes prepared using marble waste as coarse aggregate showed reduction in abrasion resistance by 26.8% as compared to that of control concrete mixes. In a study by Abdul et al. [8] marble waste was used as a complete replacement for conventional coarse aggregate. They reported that, the physical and mechanical properties of concrete improved. The workability of concrete mixes increased by 50% due to smooth flat surface and low water absorption of marble aggregate. It was also reported that, the compressive and flexural strength of concrete containing marble aggregate increased by 29.62% and 11.44% as compared to that of control mix. Kore et al [9] conducted studies on use of marble waste as a partial replacement for conventional coarse aggregates in different percentages (0% to 100%) in low strength concrete mixes designed as per Bureau of Indian Standards (BIS) guidelines. From this study it was observed that, the workability of all the concrete mixes increased with increase in replacement level. The compressive strength of the concrete mixes increased by 35% and 26%, respectively at 80% and 100% replacement level of conventional coarse aggregate.

In the present study, the concrete mixes have been designed by two different methods with partial and complete replacement of conventional coarse aggregate by crushed marble waste. The mechanical and durability performance of concrete mixes such as compressive strength, permeability, resistance to abrasion, carbonation, resistance to acid and chloride ion penetration, etc. have been evaluated. The impact of saving in cement has been computed in terms of CO_2 emission. Cost reduction of concrete product has also been computed.

2 Experimental Study

2.1 Characterization of Materials

Portland Pozzolana cement used in this study fulfills the requirement of BIS: 1489-part 1:1991[10]. The sand used in this study conforms to grading zone II as per BIS: 383-1997 [11]. The conventional coarse aggregate quartzite used in this study conforms to BIS: 383-1997 [11]. Marble waste used in this study was crushed in to crusher to obtain desired gradation of coarse aggregate. The nominal maximum size of conventional aggregate and marble waste used was 20 mm. The physical and chemical properties of coarse aggregate, marble aggregate and fine aggregate are presented in Table 1 and Table 2, respectively. The particle size distribution of conventional coarse aggregate, marble aggregate and fine aggregate is given in Figure 1. To achieve the desired slump of 75 mm to 100 mm, a third generation poly-carboxylate based super-plasticizer Rheobuild 522 ND conforming to BIS: 9103-1999 [12] was used.

Table1 Physical and Mechanical Properties of Aggregates

Aggregate Type	Specific gravity	Water Absorption (%) by weight	Grading Zone
Conventional Coarse aggregate	2.78	0.54	As per Table 2 of BIS 383
Fine Aggregate	2.66	2.0	Zone II As per Table 4 of BIS 383
Marble coarse Aggregate	2.88	0.05	As per Table 2 of IS 383

Table 2 Chemical compositions of Marble Waste and Natural Aggregate

Component	Marble Waste Aggregate (%)	Natural Aggregate (%)
LOI	45.02	5.08
SiO_2	3.75	53.70
CaO	33.12	4.83
MgO	17.9	2.01
Fe_2O_3	0.11	10.66
Al_2O_3	0.09	-
Sulphate content	-	-

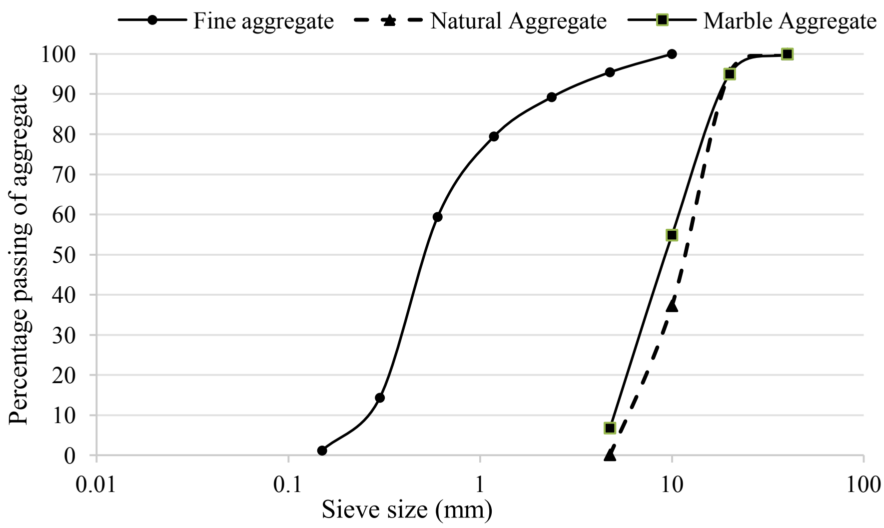


Figure 1 Particle size distribution of aggregates

2.2 Concrete Mix Proportioning

Coarse aggregate was taken as mix of 75% marble aggregate and 25% conventional aggregate as per best results obtained by the authors in trial mixes. All the concrete mixes were prepared with a constant water-cement ratio of 0.45. Mix proportion of concrete was based on achieving maximum packing density of all in aggregate by trials conducted in the laboratory. It was found that, mixing of 60% coarse aggregate and 40% of fine aggregate resulted in maximum packing density of aggregate. The voids were estimated to be 23% in the dry aggregate mixture. Then cement paste 10% in excess of voids was mixed to the aggregate in concrete mixer in order to get desired workability in the range of 75 mm to 100 mm. The mixture proportions of concrete designed by BIS code method and packing density approach are given in Table 3.

Table 3 Mix Proportion of concrete (Quantity for 1 m^3)

Mix	Paste content in excess of voids (%)	Water (L)	Cement (kg)	sand (kg)	Coarse Aggregate (kg)			
					Natural Aggregate		Marble Aggregate	
					20 mm	10 mm	20 mm	10 mm
C1	-	191.58	425.73	663.35	531.2	649.24	-	-
C2	-	191.58	425.73	663.35	132.80	162.31	239.04	646.29
C3	10	154.34	342.98	805.35	181.20	120.80	543.62	362.41

Note: Mix designated by C1 shows control mix and mix designated by C2 shows concrete mix containing 75% marble aggregate and 25% conventional aggregate designed as per BIS 10262-2009.

Mix designated by C3 shows concrete mix containing 75% marble aggregate and 25% conventional aggregate designed by Packing Density approach.

2.3 Sample preparation and test methods

Cubes of size 150 mm × 150 mm ×150 mm were cast to determine the compressive strength and permeability of test specimens. All the specimens were de-molded at the age of 24 ± 1 h and were cured in the water tank at room temperature up to the specified age of the test. The slump cone test for freshly prepared concrete mix was carried out as per BIS-1199:1959 [13] in order to determine workability of concrete. Compressive strength of concrete specimens was determined at 7 days, 28 days, 90 days and 180 days as per BIS: 516-1959 [14]. To assess the porosity in concrete, water permeability test was conducted as per German standard DIN -1048 part 5-1991[15]. Test specimens100 mm × 100 mm ×100 mm cubes were cast for determination of water absorption test. This test was conducted according to BIS 15658:2006 [16]. Resistance to abrasion was measured in terms of depth of wear of concrete under standard testing conditions. It was performed according to BIS 1237: 1980 [17] , on test specimens of 100 mm concrete cubes. The carbonation test was conducted on 28 days cured concrete prisms (50 × 50 ×100 mm) as per CPC:18- RILEM guidelines [18]. The chloride penetration test was conducted on 28 days cured (100×100×100 mm) concrete specimens. The silver nitrate spraying method was used to study the depth of penetration as per Reference [19]. Resistance of concrete specimens to acid attack was evaluated as per ASTM C 267-01[20].

2.4 Microstructural study

The X-ray diffraction method was adopted for the identification of most probable phases of control concrete and concrete with marble waste. The powder sample of concrete after crushing was taken and sieved from 90 micron. The micro-structural analysis of the specimen was analyzed using Scanning Electron Microscope (SEM) micrographs that illustrate the microstructure characteristics of concrete. The prism of size 10 ×10 ×20 mm was cut from the concrete specimens at a depth of 50 mm. Then these specimens were soaked in acetone to stop further reaction.

3 Results and Discussion

3.1 Workability

The results of slump test of concrete mixes are shown in Table 4. It was observed that, the desired workability of concrete mixes 75 mm to 100 mm was achieved but the required quantity of super-plasticizer increased. A third generation poly-carboxylate based Rheobuild522 ND super-plasticizer was used. This increase in quantity of super-plasticizer in mix C3 was more as compared to that of control mix due to increased amount of sand content. This is because increased sand content in mix C3 absorbs more water resulted in stiff mix. On the other hand the incorporation of marble increases the slump. This increase in the value of slump in mix C2 and C3 was due to presence of round shaped marble aggregates. The water absorption of marble aggregate was also less than that of conventional coarse aggregate resulting in availability of adequate water for lubrication.

Table 4 workability of concrete mix

Mix	Excess Cement Paste	slump (mm)	Dose of super-plasticizer (%)by weight of cement
C1		78	0.25
C2	-	90	0.25
C3	10	95	1.3

3.2 Water Permeability

The test results of the water permeability of concrete mix are shown in Figure 2. The results show that, the depth of water penetration decreases significantly from 101 mm to 86 mm. The incorporation of marble aggregate in mix C2 reduces the water penetration by 8.22%. On the other hand the depth of water penetration in C3 mixes was decreased by 15.12% as compared to that of control mix C1. This reduction in water permeability was due to improved packing of fine and coarse aggregates particles which reduced the porosity in concrete mixes.

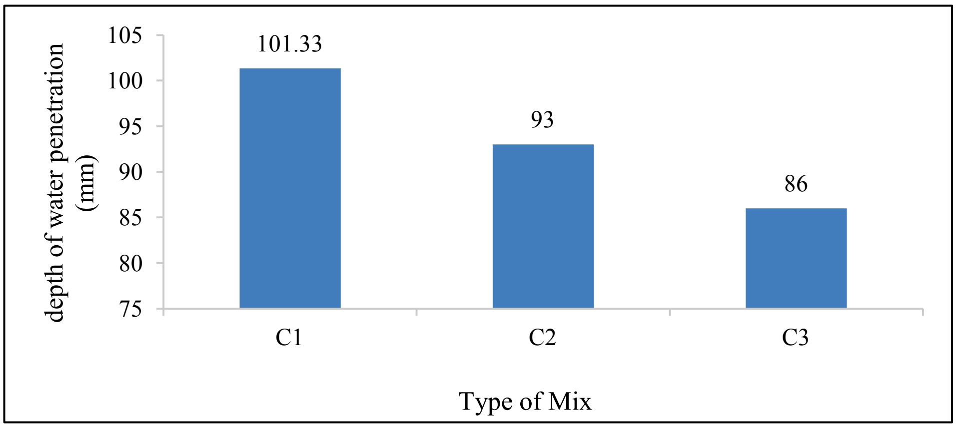


Figure 2 Variation in depth of penetration of concrete

According to de Larrard [21] and Quiroga et al [22] flaky, elongated, angular, and unfavorably graded particles lead to higher voids content than, cubical, rounded, and, well graded particles. Therefore the possible reason for reduction in permeability of concrete mix C2 and C3 was, better packing of marble aggregate due to round shape of marble aggregate. Reduced permeability indicates increased durability of concrete and increased sustainability of material.

3.3 Compressive strength

The variation in the compressive strength of concrete mixes at different curing ages is shown in Figure 3. It can be seen that, the concrete mixes C2 and C3 showed marginal reduction in compressive strength. The decrease in compressive strength of concrete mix C2 and C3 was within 10% at 28, 90 and 180 days curing age. That is insignificant in view of saving of 19% cement and 75% natural coarse aggregate in C3 mixes. In the past studies on use of coarse aggregate produced from marble waste as replacement for conventional coarse aggregate does not show any clear trend regarding its physical and mechanical behavior of concrete. The results obtained in the compression test of this study with partial replacement of conventional coarse aggregate by marble aggregate are in accordance with the Hebhoub et al [3] and Andre et al.[23].

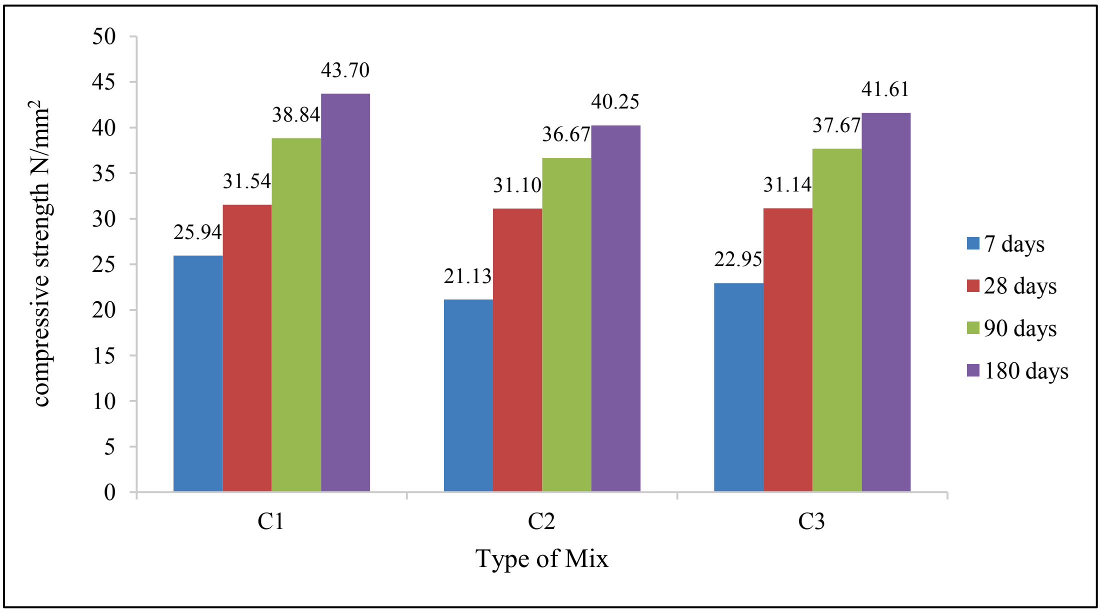


Figure 3 Variation in compressive strength of concrete

3.4 Flexural Strength

The effect of partial replacement of conventional coarse aggregate by marble aggregate on flexural strength of concrete mixes are shown in Figure 4.The test was conducted on beam specimens of size 500×100×100 mm. The flexural strength of control mix is more than that of concrete mix containing marble aggregates. The marginal reduction in flexural strength of mix C2 and C3 was observed. This decrease is almost insignificant up to 10% variations except for C3 the decrease of flexural strength at 28 days is 17% and this fact was also reported by Binici et al.[6] in their study.

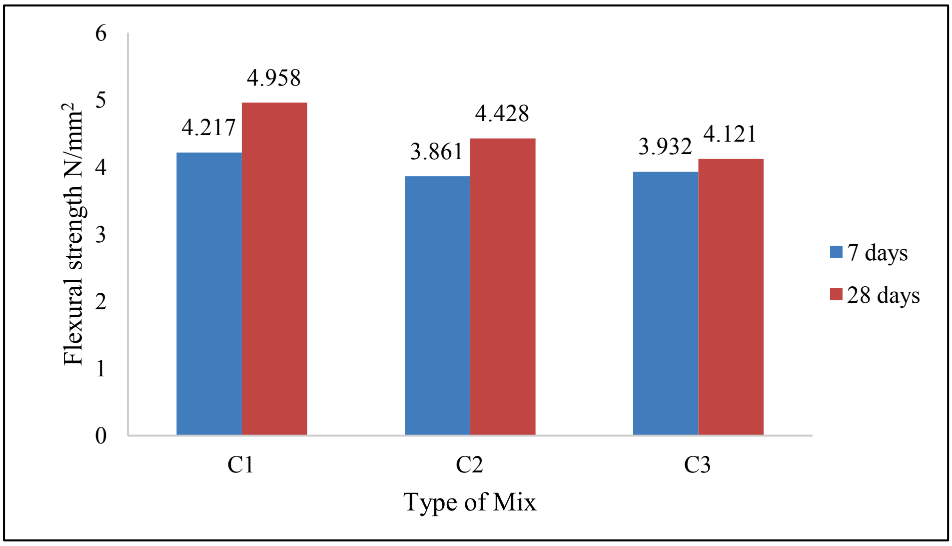


Figure 4 Variation in Flexural strength of concrete

3.5 Abrasion Resistance

Figure 5 shows the results obtained for abrasion test carried out on the 28 days cured concrete specimens measured in terms of depth of wear. The values of depth of wear range between 1.53 mm to 1.93 mm. The highest value of abrasion was for control concrete and lowest value for concrete containing marble aggregate. The lowest abrasion value was obtained in mix C3 due to denser structure of particles within the concrete. Due to dense packing of particles the resistance against wear increases. As per the BIS 1237: 1980[17], in general purpose tiles the average maximum wear shall not exceed 3.5 mm and wear on any individual specimen shall not exceed 4 mm and for heavy-duty floors, it is 2 mm and 2.5 mm, respectively. However the results obtained in this test depict that, depth of wear in all the concrete mixes are within the permissible limits specified by the code and can be used for heavy duty flooring tiles.

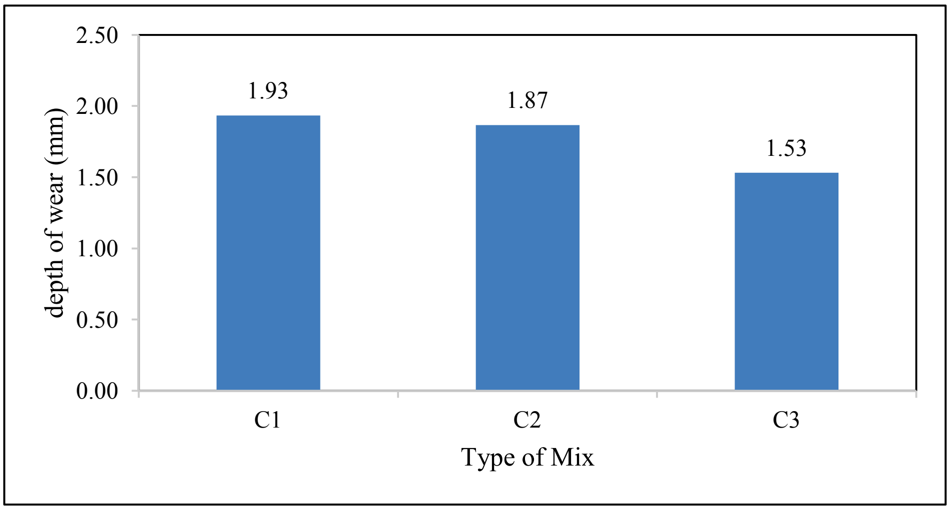


Figure 5 Variation in Abrasion resistance of concrete

3.6 Carbonation

The results of the carbonation test for all the concrete mixes at different exposure durations are presented in Figure 6. The resistance to carbonation in all concrete mixes increases with increase in exposure duration. The results obtained for mix C2 and C3 are closer and slightly lower than that of control mix. Also the incorporation of marble aggregate as replacement for conventional coarse aggregate does not affect the carbonation resistance. The concrete mix C3 shows lowest values of carbonation. The carbonation resistance of concrete mainly depends on its porosity. The porosity in the concrete mix C3 was reduced due to dense microstructure resulting in favorable results.

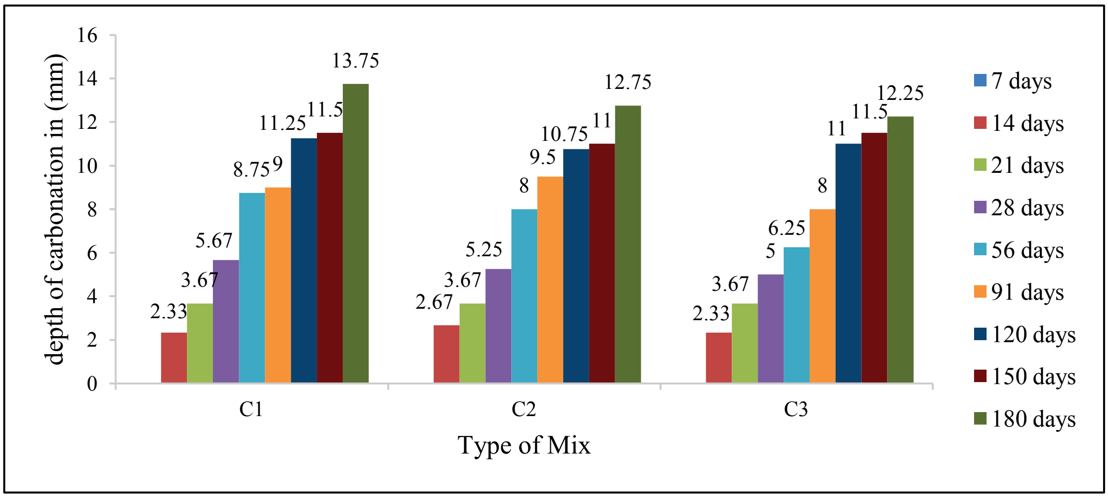


Figure 6 Variation in depth of carbonation

3.7 Chloride Penetration

Resistance to chloride penetration by test specimens at different exposure durations are presented in Figure 7. Form the results it was observed that, the depth of chloride penetration of concrete containing marble aggregates exhibited superior trend than that of control concrete. The mix C3 shows lowest values of depth of penetration as compared to that of control mix. The possible reason for decrease in penetration depth is the reduced porosity in concrete mix due to better packing of particles within the concrete mix. Another reason for this reduction is due to presence of Al_2O_3 in the marble aggregates as shown in Table 2. The presence of alumina favors the formation of tricalcium aluminate (C_3A), which fixes the chloride ions and forms insoluble compounds. Binci et al. [5] also reported, concrete prepared by replacing primary aggregates by marble aggregates enhances the resistance against chloride penetration.

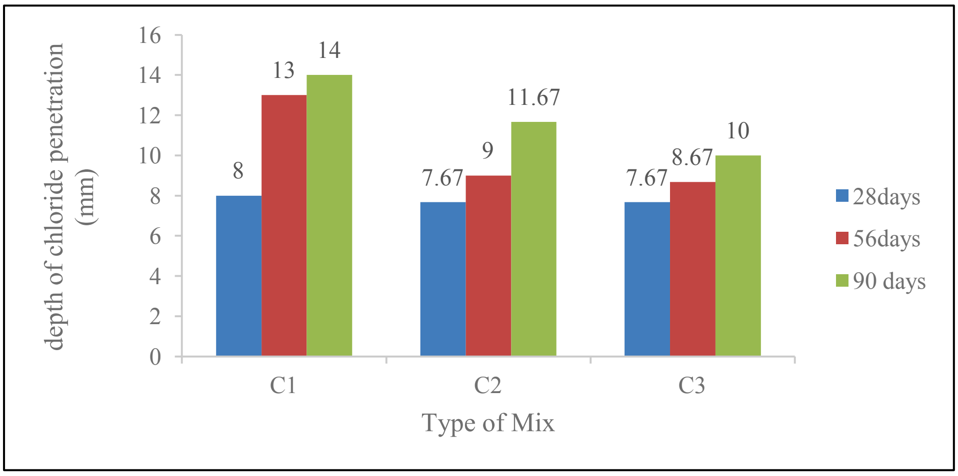
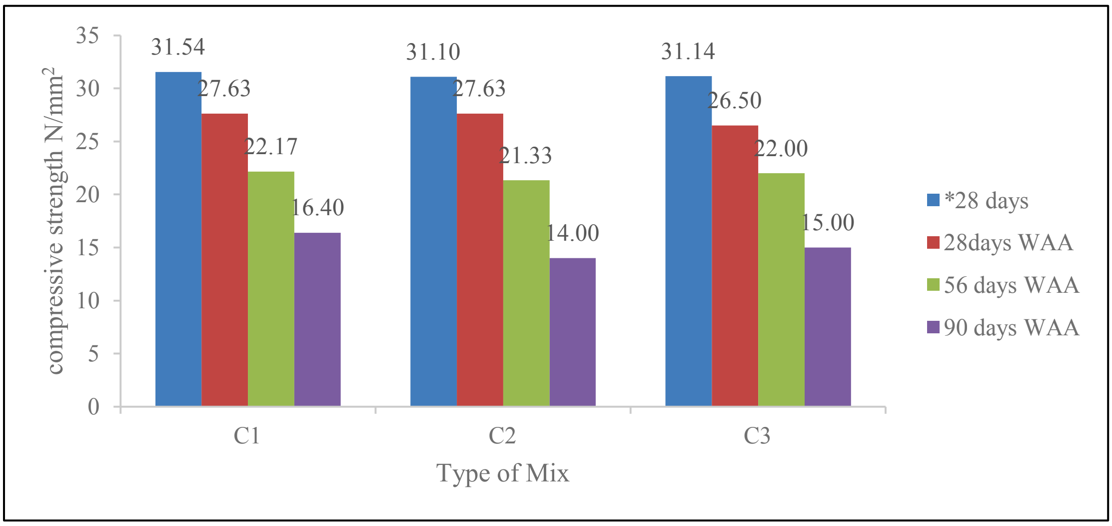


Figure 7 Variation in depth of chloride penetration

3.8 Acid Resistance

One of the key durability issues which affect the performance of concrete structure under acidic environments is degradation of concrete. The durability of concrete structures which are situated in the industrial areas are likely to be affected by acids present in the environment. The effect of sulfuric acid on the properties of concrete was investigated. The loss in compressive strength and weight of concrete specimens after immersion in 5% dilute sulfuric acid at different curing ages is illustrated in Figure 8 and Figure 9, respectively.



****Without acid attack, WAA: - With Acid Attack***

Figure 8 variation in compressive strength of acid attacked concrete specimens

The results show that, compressive strength of concrete mix C1, C2 and C3 decreased by 48%, 55% and 52%, respectively after 90 days of exposure. The decrease in compressive strength in mix C3 is slightly 4% more than that of control concrete. The reason behind the more loss in strength of concrete mix C2 and C3 is, the calcium carbonate present in marble waste reacts with sulphuric acid resulting in formation of gypsum. Further reaction of gypsum with the calcium aluminate leads to formation of ettringite resulting in volume expansion which causes decomposition and removal of cement matrix inside the concrete [24], [25]. Due to removal of cement matrix the concrete becomes weak causing loss in compressive strength. Figure 8 shows the concrete specimens after exposure to 5% dilute sulphuric acid solution after 28 days, 56 days and 90 days, respectively.

The loss in weights of concrete specimens after immersion in 5% dilute sulphuric acid solution at different curing ages is shown in Figure 9. From the Figure, it can be seen that, the percentage loss in weight of concrete mix C2 at 28 days was 39% more as compared to that of control mix. At 56 days and 90 days the percentage loss in weight was 33% and 43% more than that of control concrete. The loss in weight of concrete mix C2 was more due to excessive formation of gypsum during reaction with sulphuric acid. The formation of gypsum leads to decrease in density of concrete [24]. As the density decreases the weight of specimens also decreases. On the other hand the mix C3 shows approximately 21% less reduction in weight as compared to that of mix C2 and 28% higher than that of control mix. The lower reduction in weight of mix C3 specimens was due to better packing and dense microstructure of particles which restricts the entry and flow of acid solution within the pores.

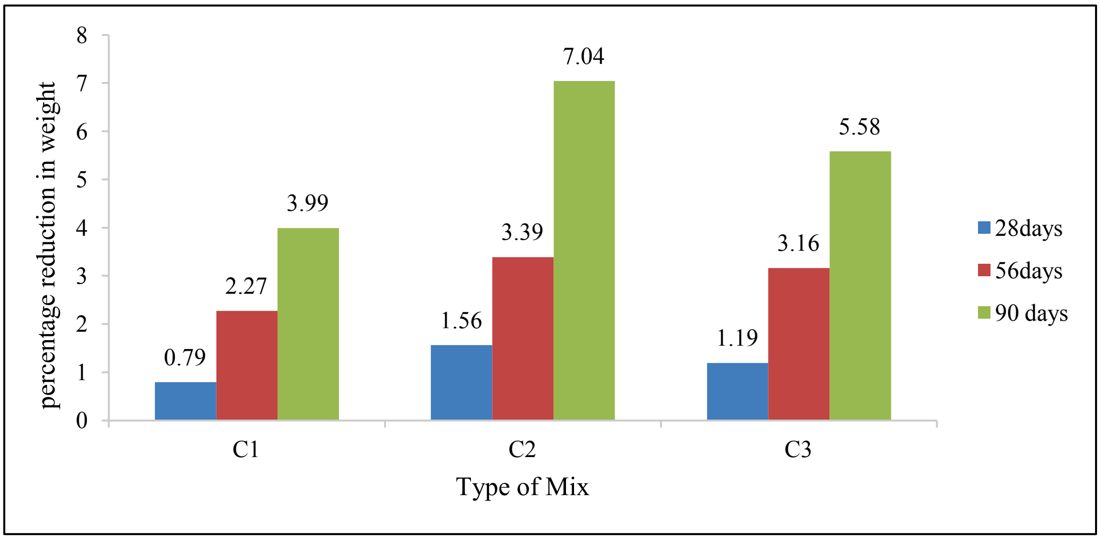


Figure 9 loss in weight of acid attacked concrete specimens

3.9 X-Ray Diffraction Analysis

The X-ray diffraction analysis was carried out on the concrete specimens exposed 5% dilute sulfuric acid solution. The results of the study are shown in Figure 10 (a), Figure 10 (b) and Figure 10 (c), respectively.

From the X-Ray diffraction analysis it was confirmed that, the ettringite and gypsum compounds are formed within the concrete matrix due to reaction of sulfuric acid with marble. The formation of gypsum leads to decrease in density of concrete [24] results in decreasing weight of specimens. The loss in compressive strength and mass of concrete specimens in mix C2 are more due to the excessive formation of ettringite and gypsum minerals. This can be seen in Figure 10 (b) of X-ray diffraction analysis of mix C2. The concrete mix C3 was less affected as compared to mix C2 due to action of sulfuric acid because of presence of excessive sand resulting in dense microstructure formed by the particles. This also depicts that, the packing density approach followed for design of concrete mixes results in better durability aspects.

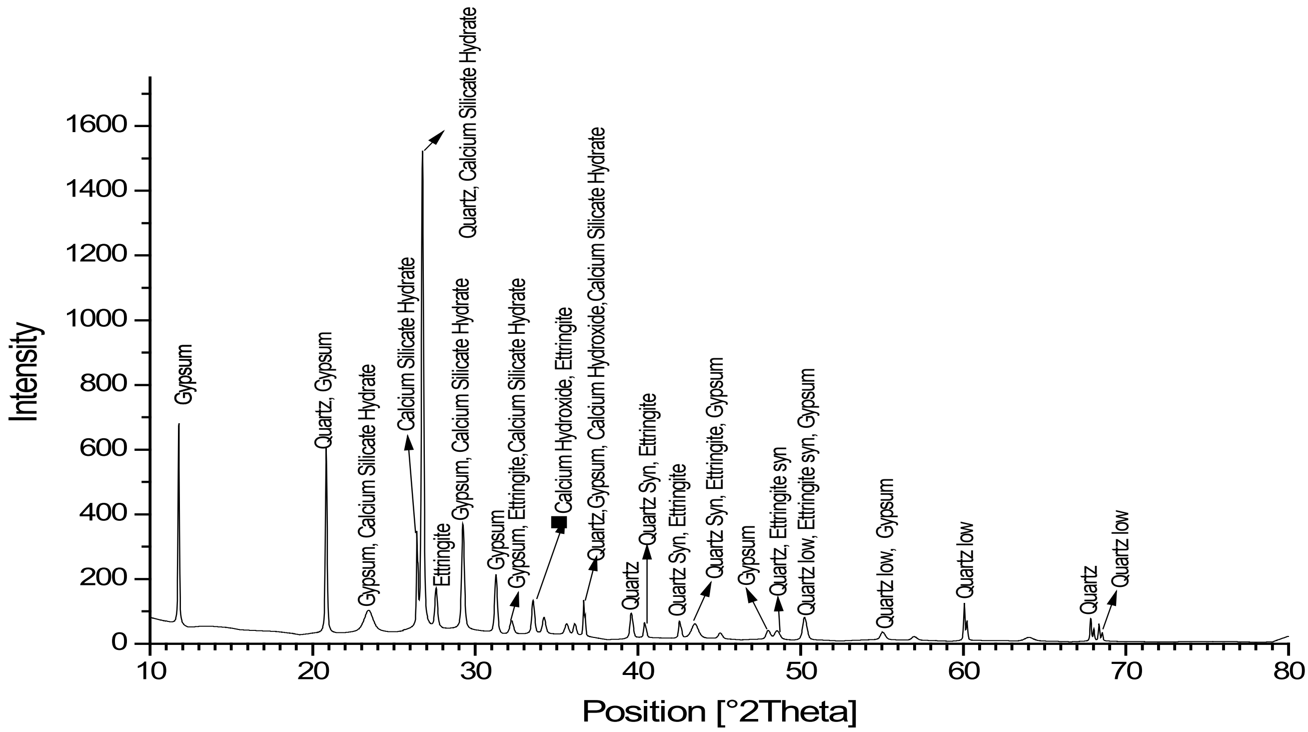


Figure 10 (a) XRD of control concrete exposed to 5% H_2SO_4 solution after 90 days

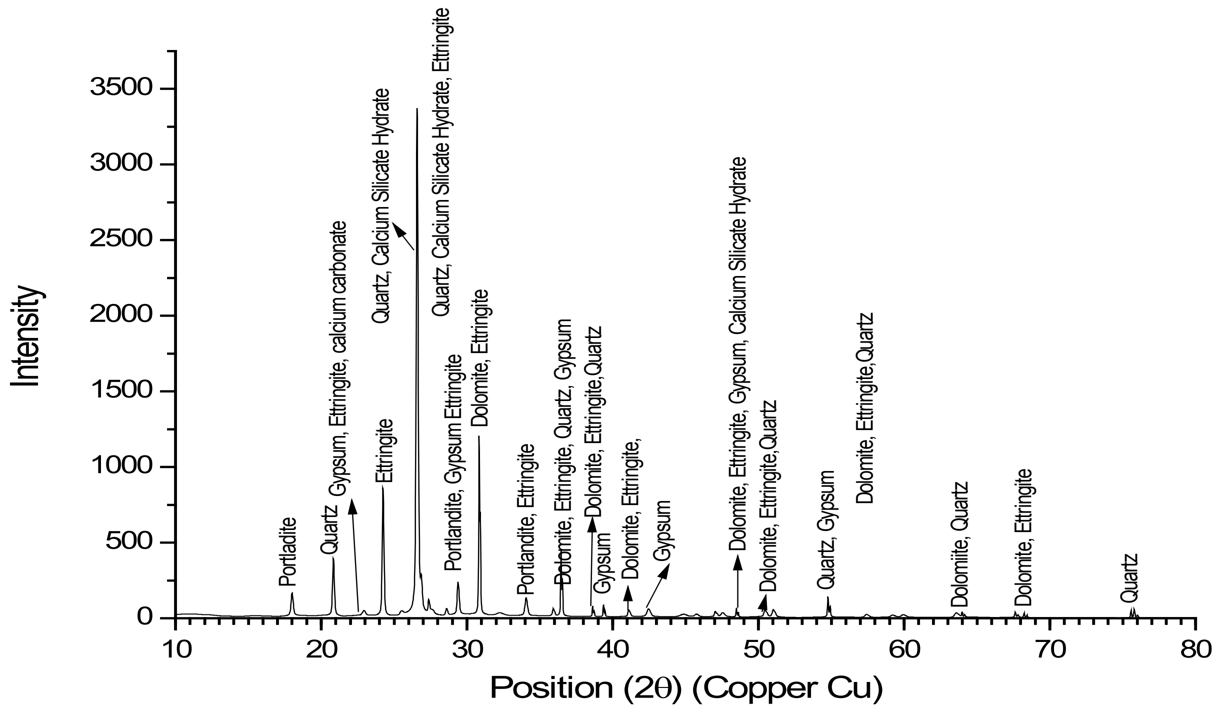


Figure 10 (b)XRD of concrete mix C2 exposed to 5% H_2SO_4 solution after 90 days

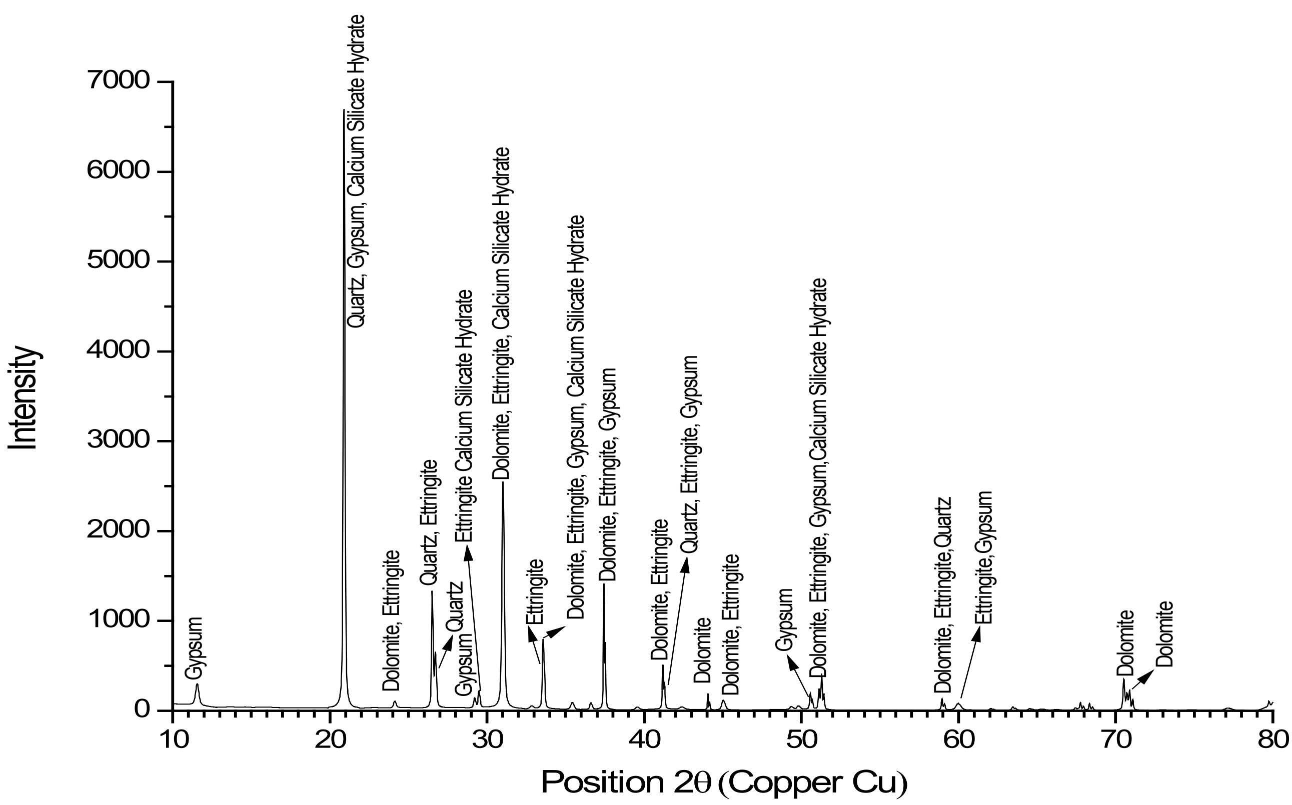


Figure 10 (c) XRD of concrete mix C3 exposed to 5% H_2SO_4 solution after 90days

3.10 Cost Analysis and CO_2 Emission

The cost analysis of the concrete mixes designed by both the methods is given in Table 5.

Table 5. Cost for production of 1 m^3 of concrete

Mix	Water	Cement	Sand	Natural Aggregate	Marble Aggregate	Production cost (Rs.)
C1	-	2386/-	355/-	479/-	-	3220/-
C3	-	1920/-	425/-	98/-	317/-	2760/-

From the Table 5 it is observed that, the change in design mix methodology resulted in approximately 20% reduction in cement consumption of the concrete mix C3 as compared to that of mix C1. Another important benefit resulted from the utilization of the marble waste as a replacement for conventional aggregate saves the natural resources. Overall concrete mix designed by packing density approach and use of marble waste in concrete reduces the overall production cost around 14%. The Carbon dioxide emission from the production of cement and emission generated during the transportation of aggregates is shown in Table 6. The cement manufacturing industry is major contributor for CO_2 emission in the world. The contribution of cement industry in greenhouse gas emission is around 3.95 billion tons annually and that is 7% of the total greenhouse gas emissions on the earth's surface [26]. The global annual production of the concrete in the year 2014 was 4.2 billion tons and it is expected that this figure may increase by 2.9 % by 2018 [27]. In India around 275 MT of cement was produced during the year 2014 which account for generation of equal amount of CO_2 [28][29]. For the production of 1Ton of cement around 0.94 Ton of CO_2 is released [27]. The CO_2 emission factor for road transport, i.e. truck or lorries is considered as 512.2 g/km [30].

Table 6. Reduction in Carbon di Oxide Emission

Mix	Cement (Kg/m^3)	CO_2 emission (Kg/m^3)	CO_2 emission (Kg/m^3)	
			Source of Natural Aggregate	Source of Marble Aggregate Waste
C1	426	401	2.70	-
C3	343	322	0.70	0.26

Form the above table it can be observed that, the cement content required for the design of concrete mix C3 reduced by 20% which resulted in 20% lesser emission of carbon dioxide.

Adopting packing density approach for design of concrete mixes would reduce the annual global cement production from 4.2 billion tons by 0.84 billion tons and CO_2 release from 3.95 billion tons to 3.16 billion tons. The concrete produced using packing density approach is not only cost effective but durable and sustainable product mitigating environmental pollution to a large extent.

4 Conclusions

The influence of coarse aggregate produced from marble waste on the mechanical and durability properties of concrete mixes were studied. Also the effect of packing density approach for design of concrete mixes as well as their response to durability of concrete was studied. From the above study the following conclusions are drawn,

- Incorporation of marble waste as coarse aggregate does not affect the workability of concrete mixes.
- The compressive strength of concrete mixes not affected by use of marble waste as coarse aggregate. The results are nearly close to that of control concrete. But in the concrete mixes designed by packing density approach, the compressive strength is nearly equal to that of control mix with a saving cement content of about 20% at constant water-cement ratio.
- The permeability reduced by 15% as compared to that of control concrete using packing density approach. The reduced permeability is indication for enhanced durability properties of concrete.
- The results of abrasion test shows that, the concrete produced using marble aggregate can be used in pavement works.
- The carbonation depth of concrete containing marble aggregate shows nearly same trend as that of control concrete.
- The significant reduction in the depth of chloride ion penetration was observed in the concrete mix containing marble aggregate.
- Resistance to acid of concrete containing marble waste was observed to be marginally low as compared to that of control concrete. Hence there is not much adverse effect of acids on the performance of concrete containing marble aggregate.
- The use of packing density approach for design of concrete mixes and utilization of marble waste as a coarse aggregate resulted in saving of 20% of cement content and 14% of overall concrete production cost which shows that the packing density approach is cost effective. By minimizing the cement content without losing mechanical properties of concrete results in 20% lesser emission of CO2 in the air.

From the above study it can be concluded that, the use of aggregate produced from marble waste can be used as replacement of conventional coarse aggregate in concrete mixes. The increase in resistance against abrasion and significant reduction in depth of chloride penetration are added benefits ensuring enhanced life of concrete structure without sacrificing strength. Thus the product become sustainable with saving in 14% overall cost of concrete designed by packing density approach.

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