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Case study

Impact of marble waste as coarse aggregate on properties of lean cement concrete

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ABSTRACT

Marble industry produces large amount of waste during mining and processing stages. This waste is dumped on to open land which creates a lot of environmental problems. The main objective of this study was utilization of marble waste as a replacement for conventional natural coarse aggregate in concrete. Experimental investigations were carried out to examine the feasibility of use of marble waste as a coarse aggregate in concrete. Conventional natural coarse aggregate was replaced by marble aggregate in different percentages 0–100% by weight. The concrete formulations were prepared with a constant water–cement ratio 0.60. It was observed that workability of concrete mixes containing marble aggregate was 14% more than that of control concrete. The average compressive strength of all the concrete mixes containing marble aggregate increased by 40% and 18% at 7 and 28 days, respectively.
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1. Introduction

The stone has played significant role in human endeavors since earliest recorded history. Marble ranks the largest produced natural stone in the world and it accounts for 50% of the world's natural stone production. Approx 85% of production of marble in India is from Rajasthan state [11]. The marble mining industry has come up significantly in recent past. Rajasthan has around 4000 marble mines and about 1100 marble gang saws (processing plants).

The industry involves mines, processing plants, cutters for the production of tiles for walls and floors, household articles. The industries produce a lot of waste of marble in the form of powder/slurry and pieces of irregular size of stones. The waste generated during the quarrying operations is mainly in the form of rock fragments (called "Stones" in the common parlance). The stones obtained from the quarries are usually dumped in empty pits in the forest area; thereby creating huge amounts of waste. There is absolutely no method of systematic disposal of waste in the quarrying areas. The waste & overburden is dumped on forestland, Roads, riverbeds, pasture lands & agricultural fields leading to widespread environmental degradation. There is no segregation of the overburden from the stones thereby causing a loss of fertile top soil. The quarry operations express their inability in proper segregation and disposal of waste.

In a study by Binici et al. [3]. the marble waste was used as 100% replacement for natural coarse aggregates by weight in concrete with constant water–cement ratio 0.4. 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 3–6%, respectively higher than that

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of concrete with river sand as fine aggregate and marble waste as coarse aggregate. In a study by Hebhoub et al. [10] natural coarse aggregate was replaced by marble waste aggregate with constant water–cement ratio 0.5. The results showed that, workability decreased with increase in replacement level. Compressive and tensile strength of all concrete mixes containing marble aggregate was increased up to 75% replacement of conventional coarse aggregate. In a study by Andre et al. [1], it was reported that, workability of concrete mix decreased as the replacement level increased, the same trend was reported by Hebhoub et al. [10]. Compressive strength of all concrete mixes shows downward trend with increasing incorporation ratio but this decrease may be considered almost insignificant with variations up to 10.3%. In case of water absorption by immersion and depth of carbonation, the behavior of concrete containing marble aggregate shows similar results to that of control concrete. Part of this generated waste was used in preliminary studies by several researchers in medium strength concrete mixes in the past.

In the present study, the generated waste was used in lean cement concrete as a replacement of conventional coarse aggregate in different percentages 20–100% by weight. The idea of working on lean concrete mixes was maximum utilization of marble waste which saves the natural resources.

2. Experimental study

2.1. Characterization of materials

2.1.1. Cement

Portland Pozzolane cement used in this study fulfills the requirement of Bureau of Indian standards BIS: 8112-1989 [7]. The initial and final setting time, consistency and compressive strength of cement are shown in Table 1.

2.1.2. Fine aggregate

Sand was collected from Banas River, Rajasthan. The sand used in this study was conforming to grading zone II of BIS: 383-1960 [6]. The results of specific gravity and water absorption of sand are presented in Table 2.

2.1.3. Coarse aggregate

Crushed stone aggregate used in this study was used from a nearby quarry. Specific gravity and water absorption of coarse aggregate are presented in Table 2.The nominal maximum size of coarse aggregate used was 20 mm. The chemical compositions of natural aggregate are presented in Table 4.

2.1.4. Marble aggregate

Marble waste used in this study was nearby Rajnagar area and crushed in to crusher. Specific gravity and water absorption of marble aggregate are presented in Table 2. The chemical composition of marble waste are presented in Table 4.The nominal maximum size of marble aggregate used was 20 mm. The particle size distribution of marble aggregate and conventional coarse aggregate is given in Table 3.

It can be seen that water absorption of marble aggregate is about 10% of that of natural conventional aggregate. The particle size distribution shows that marble aggregate lacks finer fractions as compared to natural aggregate (Fig. 1).

2.2. Concrete mix proportion

The concrete mix M 10 was designed as per the procedure prescribed by BIS: 10262-2009 [8]. The natural coarse aggregate was replaced by marble aggregate by weight in concrete. The mixture proportions of control concrete and concrete containing marble aggregate are given in Table 5.The concrete was prepared by replacing the natural coarse aggregate by marble aggregate in different percentages 20%, 40%, 60%, 80% and 100% by weight. For all concrete mixes cement content of 310 kg/m^3 and water–cement ratio of 0.60 were kept constant. Before addition of water all the concrete mixes were blended for 5 min to achieve thorough mix in a 160 l capacity mixer.

Table 1
Physical properties of cement.

Initial setting time	47 min
Final setting time	120 min
Compressive strength	
3 days	20 MPa
7 days	24 MPa
28 days	39 MPa
Consistency	27%
Specific gravity	3.11

Table 2
Physical properties of aggregates.

Aggregate type	Specific gravity	Water absorption (%) by weight	Grading zone	Los Angeles Abrassion value (%)
Natural coarse aggregate	2.61	0.54	As per table 2 of IS 383	25.88
Natural fine aggregate	2.66	2.0	Zone II as per table 4 of IS 383	–
Marble coarse aggregate	2.70	0.05	As per table 2 of IS 383	34.87

Mix designated by C0 shows control mix and C1,C2,C3,C4,C5 represent concrete mixes with marble waste percentage increasing from 20% to 100% of coarse aggregate.

Table 3
Particle size distribution of coarse aggregate.

Sieve size	Percentage passing of marble aggregate	Percentage passing of natural aggregate
40	100	100
20	95.28	95
10	37.28	54.88
4.75	0.14	6.8

Table 4
Chemical compositions of marble waste and natural aggregate.

Component	Marble waste (%)	Natural aggregate (%)
LOI	45.07	5.08
SiO_2	3.75	53.70
CaO	33.12	4.83
MgO	17.91	2.01
Fe_2O_3	0.13	10.66
Al_2O_3	Traces	Nil
Sulphate content	Nil	Nil

2.3. Casting and curing of specimens

Concrete cubes of size 150 mm were cast to determine the compressive strength and water permeability test. For determining the resistance against aggressive environment, 100 mm size cube specimens were cast. The moulds were filled with concrete in three layers and each layer was compacted with the help of vibrating Table as per procedure defined in Indian standard BIS: 516–1959. After casting all specimens were de-moulded after 24 ± 1 h and cured in water at room temperature until their testing dates.

Fig. 1. (a) Marble waste dumped on site (b) Coarse aggregates from marble waste.

Table 5
Mix proportion.

Quantity per cubic meter of concrete						
Mix	Water (l)	Cement (kg)	Sand (kg)	Natural coarse aggregate (Kg)	Marble coarse aggregate (Kg)	Marble aggregate as percent of total coarse aggregate
C0	191.91	310.00	646.87	1170.85	0.00	0
C1	191.91	310.00	646.87	963.68	234.17	20
C2	191.91	310.00	646.87	702.51	468.34	40
C3	191.91	310.00	646.87	468.34	702.51	60
C4	191.91	310.00	646.87	234.17	936.68	80
C5	191.91	310.00	646.87	0.00	1170.85	100

2.4. Test Procedures

2.4.1. Workability

The compaction factor test as per BIS 1199 (1999) [4]. was carried out for measuring workability of concrete.

2.4.2. Compressive strength

Compressive strength of concrete specimens was determined at 7 days, 28 days, 90 days and 180 days curing age as per BIS: 516–59 [5]. Digital compression testing machine of 1000 KN capacity was used.

2.4.3. Permeability

In order to assess the porosity in concrete, water permeability test was conducted as per German standard DIN −1048 part 5 (1991) [9]. The specimens were exposed to a constant water pressure of 0.5 N/mm^2 acting normal to the mould-filling direction, for a period of 3 days. The specimens were removed from the apparatus after 3 days and split in to two pieces. After 5–10 min drying, the maximum depth of penetration was measured from the 3 specimens and mean was reported as the depth of penetration.

2.4.4. Acid resistance

Resistance of concrete specimens to acid attack were evaluated as per ASTM C 267-01 [2]. The concrete specimens were immersed in 5% dilute Sulfuric acid solution to determine the resistance against adverse environment. The compressive strengths of concrete specimens were determined after 28, 60 and 90 days.

Reduction in compressive strength after immersion in acid solution,

$$\text{Reduction in compressive strength}(\%) = \frac{fc(28\text{ days}) - fc(t\text{ days})}{fc(28\text{ days})}$$

where, $fc_{(28\text{days})}$ = 28 days compressive strength of the concrete mixture, $fc_{(t\text{ days})}$ = compressive strength at (t) days after immersion in acid solution.

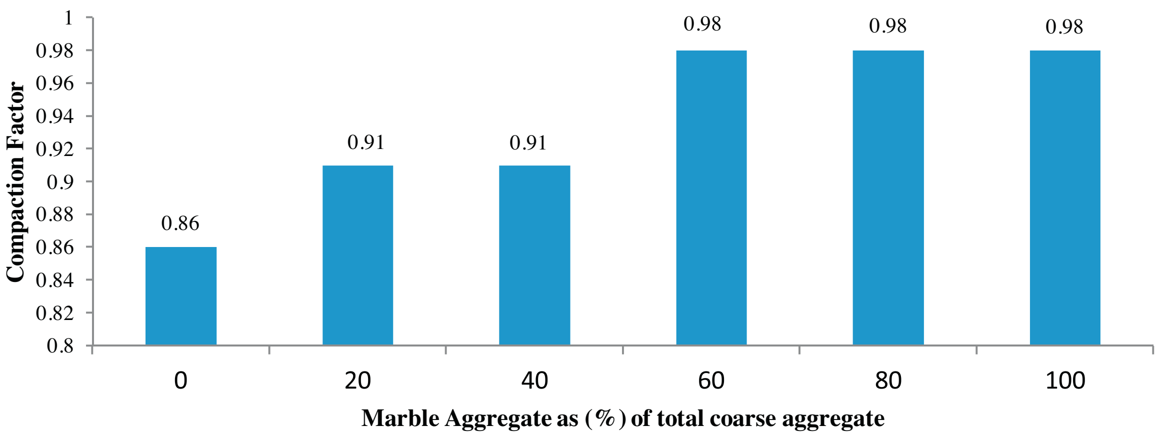

Fig. 2. Workability of concrete containing marble aggregate.

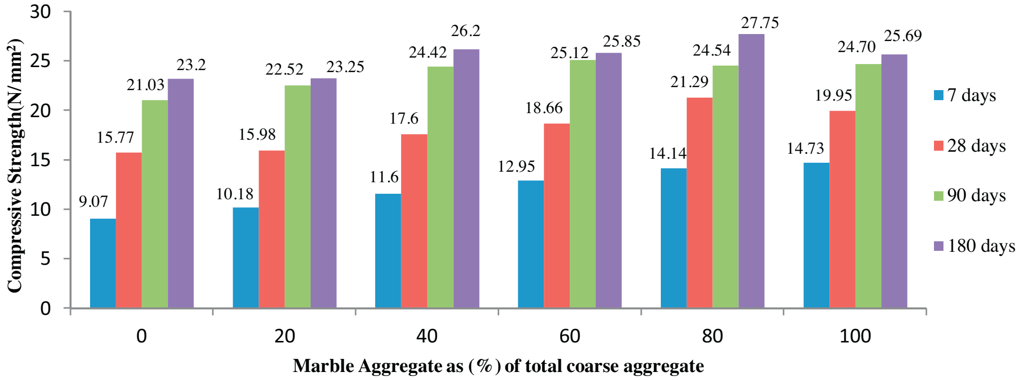

Fig. 3. Variation in compressive strength of concrete.

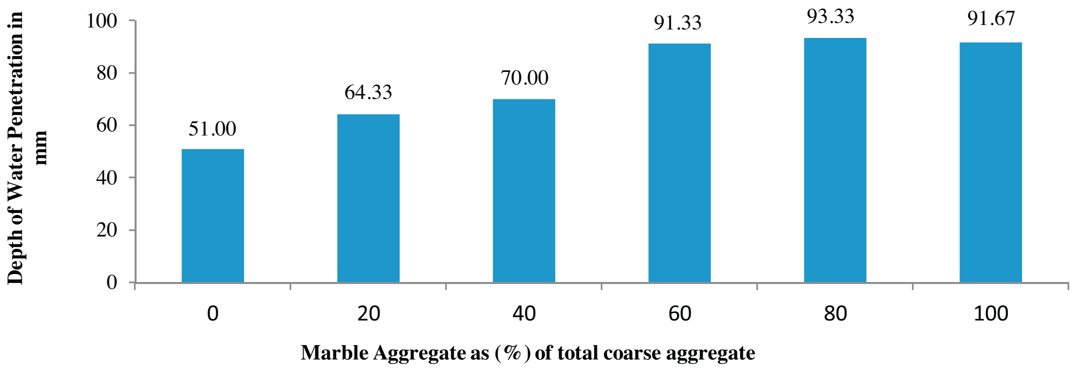

Fig. 4. Variation in water permeability of concrete.

2.4.5. Micro structural analysis

The powder method of X-ray diffraction was adopted for the identification of most probable phases of control concrete and concrete containing 80% marble waste.

The micro-structural study on concrete was done by SEM analysis (Scanning Electron Microscope).

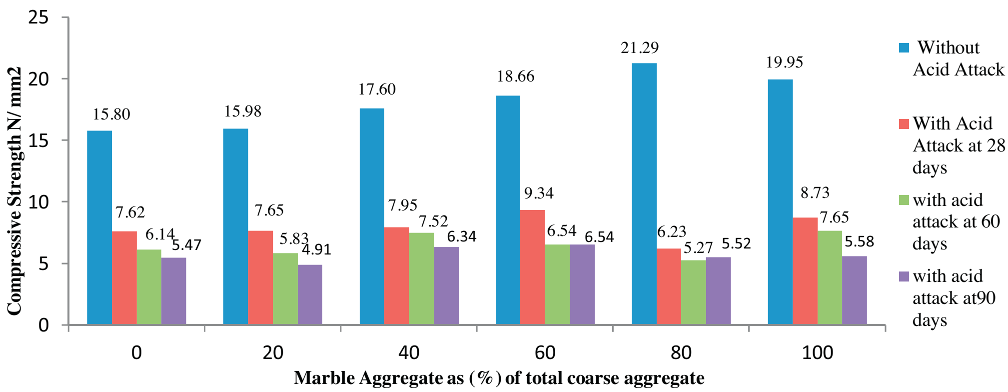

Fig. 5. Variation in compressive strength of concrete due to acid attack.

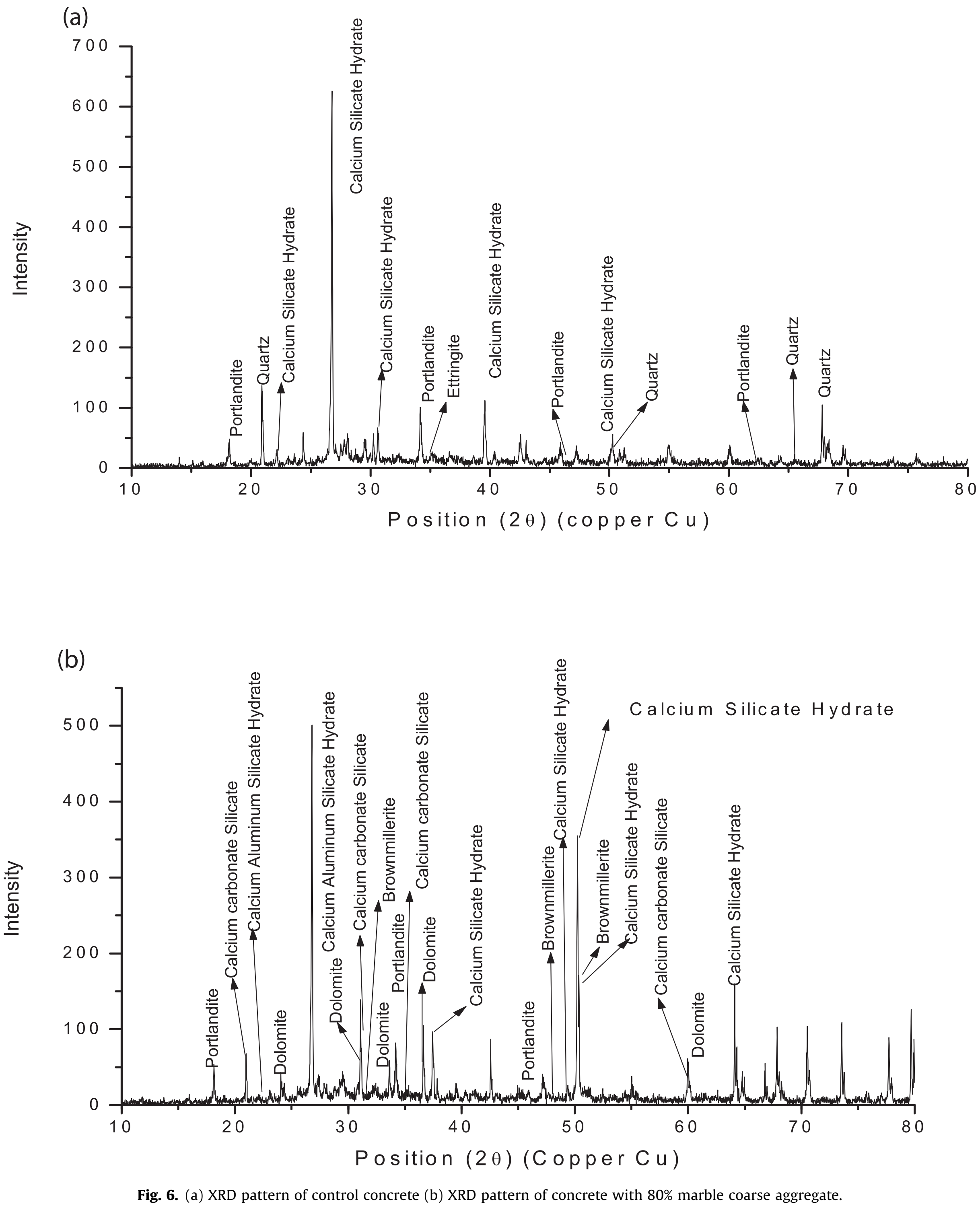

Fig. 6. (a) XRD pattern of control concrete (b) XRD pattern of concrete with 80% marble coarse aggregate.

3. Result and discussion

3.1. Workability

It can be seen from Fig. 2, that workability was minimum for control concrete and increase in marble aggregate resulted in increase in workability. An increase of 11% in compaction factor was observed when natural aggregate was completely replaced by marble aggregate. This fact is attributed to low water absorption and flat smooth surface of marble aggregate.

3.2. Compressive strength

These specimens were tested at 7, 28, 90 and 180 days of curing and the results are given in Fig. 3. From the test results it was observed that, compressive strength increased with increase in marble content. The increase was prominent in 7 days strength and 28 days strength. It depicts that compressive strength of C4 specimens containing 80% marble aggregate was 35% higher than that of control concrete at 28 days and 60% higher at 7days. A marginal dip in compressive strength at 100% marble aggregate was probably due to lack of fine fraction in marble aggregate. The marble aggregate have higher carbonate content than the natural aggregate, which improves the aggregate – cement paste bond [10] that is the reason for the increase in compressive strength of concrete at different curing ages.

3.3. Permeability

The variation in the depth of water penetration in concrete specimens is shown in Fig. 4. From the figure it can be seen that, the depth of penetration of water was increased by 26–83% with increase in percentage of replacement of natural coarse aggregate by marble aggregate as compared to that of control concrete. The permeability of concrete depends on various factors, one of the major factor is the inter connectivity of pores in to the concrete. These results show that the inter connectivity of pores in concrete containing marble aggregate is more as compared to that of control concrete. This increase in permeability is due to deficiency of particle below 10 mm size in marble aggregate as seen in Table 1 particle size distribution of marble aggregate.

3.4. Acid resistance

Durability of concrete is affected by acids especially in industrial areas. The compressive strength values of various concrete specimens after immersion in dilute sulfuric acid are given in Fig. 5. From the test results it was observed that, the average reduction in compressive strength of all concrete specimens immersed in dilute sulfuric acid is 57% at 28 days, 65% at 60 days and 69% at 90 days. The average reduction in compressive strength of control concrete exposed to acids is 52% at 28 days, 61% at 60 days and 65% at 90 days. From the above results it seen that, the deterioration of the concrete containing marble aggregate is slightly more (5–10%) than the control concrete.

3.5. Microstructure analysis

The X-ray diffractions pattern of concrete mixed with replacement of natural coarse aggregate by marble aggregate are shown in Fig. 6(a) and (b). From the analysis it was concluded that, Dolomite was found in the mix containing 80% marble aggregate as compared to that of control samples. Dolomite is a calcium magnesium carbonate with a chemical composition of $CaMg(CO_3)_2$. Formation of this carbonate compound was well expected because of presence of higher contents of CaO and MgO in marble waste. This mineral is responsible for improved bond between cement pastes and aggregate in concrete

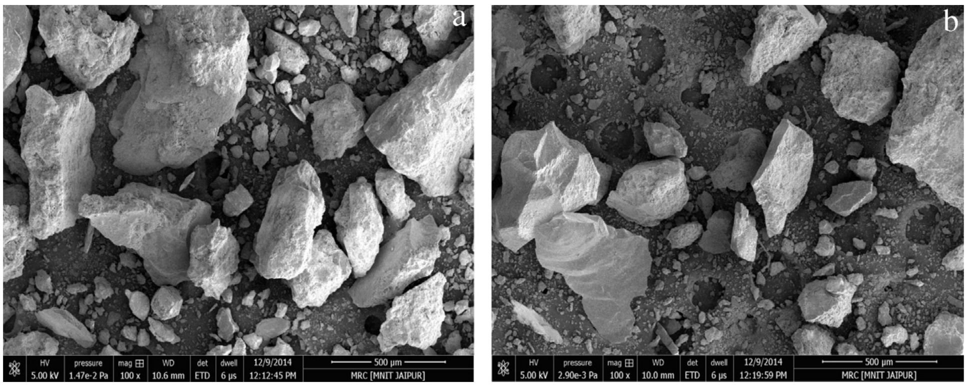

Fig. 7. (a) Control concrete (b) concrete with 80% marble coarse aggregate.

resulting in higher compressive strength of concrete containing marble aggregate. This fact is also supported by Hebhoub et al. [10].

The scanning electron microscope (SEM) micrographs that illustrate the microstructure characteristics of control concrete and concrete containing 80% marble aggregate are shown in Fig. 7(a) and (b). These pictures also show that, the bond between marble aggregates and cement paste was good in concrete containing 80% marble aggregates.

4. Conclusions

In this paper the effect of use of marble aggregate on properties of concrete were studied and it can be concluded that,

i. The workability of all the concrete mix increases with increased percentage of replacement of natural coarse aggregate by marble aggregates.
ii. Compressive strength of the concrete shows upward trend till 80% marble used as coarse aggregate in concrete.
iii. The permeability of the concrete increases with increase in percentage of replacement of natural coarse aggregate by marble aggregate this is mainly due to presence pores in the concrete.
iv. When the concrete is exposed to acids, the average reduction in compressive strength of control concrete is 61% and the concrete containing marble aggregate is 65%. Hence there is not much adverse effect of acids on the concrete containing marble aggregate as compared to that of control concrete.
v. The values obtained in the Los Angeles Abrassion test are within the limits as per BIS: 2386 (part IV)—1963. Hence the marble aggregates can be used in concrete pavement works.

The results of this study show that, marble aggregate can be used to improve the mechanical properties of conventional concrete mixes. The marble waste is available in vast amounts in Rajasthan, India. From the economic and environmental point of view this waste can be used as aggregates in production of concrete mixes. However, from the durability point of view more studies would be required to use this waste as an aggregate in concrete mixes.

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