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Particle Packing Density Approach for Design of Concrete Mixes Using Marble Waste

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ABSTRACT: The particle packing density approach was followed to design the concrete mix. In this study, 75% conventional coarse aggregate was replaced by aggregate produced from marble waste and fine aggregate were replaced by up to 25% at a 5% increment by fine aggregate produced from marble waste. The water-cement ratio was kept 0.45 for all the mixes. The test results revealed that, workability of concrete mix increases as the percentage of marble waste as fine aggregate increased. The compressive strength of concrete mix containing 20% replacement of fine aggregate by marble powder shows maximum strength than that of control concrete, which is 9% more as compared to that of control concrete. The optimum percentage of replacement of marble waste by fine aggregate was 20%. From the experimental investigation it was observed that, conventional coarse aggregate can be replaced by 75% and fine aggregate can be replaced by 20% aggregate produced from marble waste. The concrete mixes, prepared by using aggregates produced from marble waste showed the economy in concrete production with 11% savings in overall production cost of concrete. The utilization of marble waste as replacement for aggregate in concrete mixes resulted in conservation of natural resources.

Key words: Packing density, Marble Waste, Cement-Concrete, Economy

INTRODUCTION

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 India's production is received from Rajasthan (MSME Developement Institute Govt. of Indian 2009). The marble mining industry has come up significantly in the 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 industry produces a lot of waste of marble in the form of powder / slurry and pieces of irregular size called as Khandas. The Khandas generated by 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. This generated waste can be used in concrete as a partial replacement for natural coarse aggregate in concrete. These industries produces lot of waste in the form of pieces of irregular size of stones and powder/slurry as shown in Figure 1.

(a) (b)

Figure 1. Marble waste dumped in open lands (a, b)

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State of Art

In a study by Binici et al. (2008), the marble waste was used as 100% replacement for coarse aggregates by weight in concrete. River sand and ground blast furnace slag (GBFS) was 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 6.14%, 7.25%, 5.72% and 3.04%, respectively higher than that of concrete with river sand as fine aggregate and marble waste as coarse aggregate. In a study by Sadek et al. (2002), the waste generated from the marble processing units was used as a partial replacement of conventional coarse aggregate and fine aggregate in different percentages (0%- 100%) by weight in solid concrete bricks. It was reported that, compressive strength of concrete bricks increased when marble as 75% of coarse aggregate fine marble powder as fine aggregate to a limit of 50% by weight was used in concrete mixes. In a study by Hebhoub et al. (2011) conventional coarse aggregate was replaced by marble waste aggregate with constant water-cement ratio 0.5. The results showed that, workability decreased as replacement level increased. Compressive and tensile strength of all concrete mixes containing marble aggregate increased up to 75% by weight. In a study by André et al. (2014), Marble waste was used as a replacement for natural coarse aggregate. It was reported that, workability of concrete mix decreased as the replacement level increased, the same trend was reported by Hebhoub et al. 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 concretes. Kore and Vyas (2016) reported that, replacement of conventional coarse aggregate by marble aggregate increases the workability of concrete mixes. The compressive strength of the concrete mixes increased by 35% and 26%, respectively at 80% and 100% replacement level of conventional coarse aggregate. They suggested that, the optimum replacement level of conventional coarse aggregate by marble waste was 75%.

In a study by Bhattacharjee et al. (2014), the compressive strength obtained by packing density approach are comparable to that of BIS code method for a given water-cement ratio. They had developed co-relation curves between compressive strength and waster-cement ratio and compressive strength vs. cement paste content. Theses curves were used to decide the water-cement ratio and paste content for specified grade of concrete in packing density method. Walraven and Fennis (2011), in their study reported that concrete mixes can be designed by using particle packing method and it is possible to reduce the cement content up to 50% and the CO_2 emission can be reduced by 25%. Another study carried out by Jeenu et al. (2012), the packing density was measured by using seven types of fractions of aggregate with four different series of mixes. A generalized empirical equation for obtaining an effective particle size distribution of aggregates for optimal performance of concrete was proposed. By using this equation the gradation curve was plotted, the packing density and compressive strength was found to be maximum as compared to the standard gradation curves. Wong and Kwan (2008) reported that, the packing density of concrete mix with pulverized fuel ash, and condensed silica fume increases with use of third generation poly-carboxylate based super plasticizers. He also reported that, the use of cement in the range of 15% to 20% by volume in concrete mixes gives minimum void content.

In the present study attempt has been made to study workability and strength properties of the concrete designed by packing density approach. The aggregate produced from marble waste was used as a partial replacement for conventional fine and coarse aggregate.

MATERIAL AND METHODS

Characterization of Materials

Cement: Portland Pozzolana cement used in this study fulfils the requirement of BIS: 1489-part 1 1991 (Bureau of Indian Standards 1991). The initial and final setting time, consistency and compressive strength of cement are shown in Table 1.

Fine Aggregate: Sand was collected from Banas River, Rajasthan. The sand used in this study conforms to grading zone II of BIS: 383-1960 (Kisan et al. 1999). The physical properties are shown in Table 2.

Coarse Aggregate: The coarse aggregate used in this study confirms to BIS: 383-1960 (Kisan et al. 1999). The Specific gravity and water absorption of coarse aggregate are presented in Table 2. The nominal maximum size of coarse aggregate used was 20 mm.

Aggregate from Marble waste: The marble waste was brought from Rajnagar area Rajasthan and fed into the crusher to obtain the desired gradation of fine and coarse aggregate as per BIS: 383-1960 (Kisan et al. 1999).. The particle size distribution of coarse and fine aggregate are shown in Table 3 and Table 4. The chemical composition of marble and conventional aggregate are shown in Table 5.

Table 1. Physical properties of cement

Initial Setting Time	**47 minute**
Final setting time	483 minute
Compressive strength	
3 days	20MPa
7 days	24MPa
28 days	39MPa
consistency	27%
Specific gravity	3.11

Table 2. Physical Properties of Aggregates

Aggregate Type	Specific gravity	Water Absorption (%) by weight	Grading Zone
Coarse aggregate	2.61	0.54	As per Table 2 of BIS 383
Fine Aggregate	2.66	2.0	Zone II As per Table 4 of BIS 383
Aggregate from Marble waste	2.70	0.05	As per Table 2 of IS 383

Table 3 Particle size distribution of coarse aggregate

Sieve size (mm)	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. Particle size distribution of Fine aggregate and marble powder

Sieve size	Percentage passing of Marble powder	Percentage passing of Sand
10 mm	100	100
4.75 mm	100	95.45
2.36 mm	96.3	89.25
1.18 mm	80.8	79.45
600 μ	59	59.4
300 μ	19.9	14.35
150 μ	5.4	1.2
Grading Zone	Zone II	Zone II
Fineness Modulus	3.77	2.62

Table 5. Chemical compositions of Marble Waste and Natural Aggregate

Component	Marble Waste Aggregate (%)	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

Admixture: To achieve the desired slump of 75 mm, a third generation poly-carboxylate based super-plasticizer Rheobuild 522 ND conforming to BIS: 9103-1999 (Bureau of Indian Standards 1999 a) was used.

Concrete Mix Proportioning

The mixture proportion of concrete designed by packing density approach are given in Table 6. . For the design of concrete mix by packing density approach various formulations of aggregate fractions were prepared. Firstly two size fractions of coarse aggregate 20 mm and 10 mm were mixed in a definite proportion by weight, such as 90:10, 80:20, 70:30 and 60:40, etc., and the bulk density of each mixture was determined. However, a stage was reached when the bulk density of the coarse aggregate mixture, instead of increasing, decreases again. The mixture giving highest bulk density was mixed with fine aggregate in the ratio of 90: 10, 80: 20, 70: 30, 60: 40, 50: 50, etc. By increasing the finer content, the bulk density increases up to a peak value after which it again reduces. Thus, the proportion obtained for maximum bulk density was fixed for total aggregates, i.e., coarse aggregates 20 mm: coarse aggregates 10 mm: fine aggregates was 36: 24: 40 by weight. The bulk density, packing density and voids contents are plotted against the weight fraction of all in aggregate are presented in the Figure 2 and Figure 3, respectively.

After getting all the values of bulk density, packing density and void contents the mix proportion of concrete were calculated. The concrete mix was prepared by taking cement paste content 10% in excess of void content in the aggregate mix. The mix proportions are given in Table 6. All the concrete mixes were prepared by using a constant water-cement ratio of 0.45. Before the addition of water, the dry concrete mixes were blended for 5 minutes to achieve a thorough mix in a 160 lit capacity mixer.

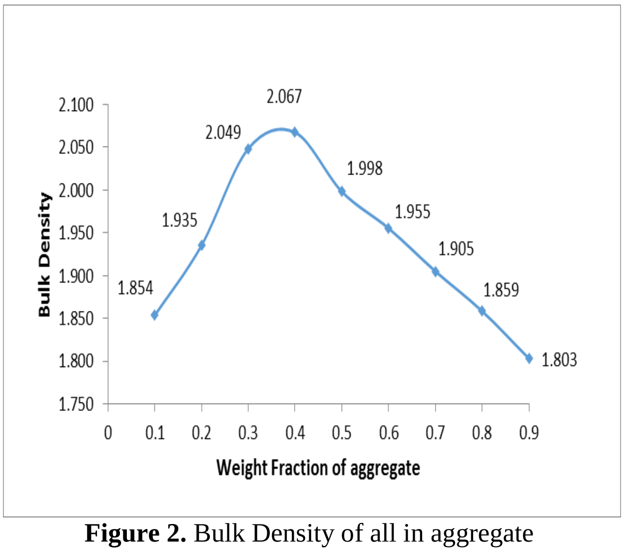

Figure 2. Bulk Density of all in aggregate

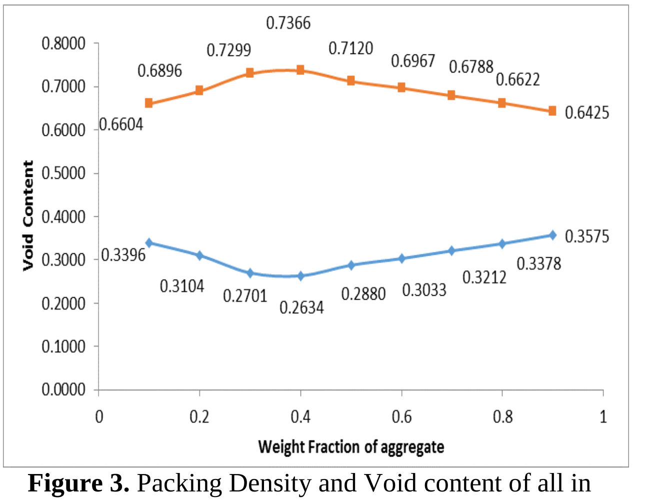

Figure 3. Packing Density and Void content of all in aggregate

Sample preparation and test methods

The ingredients of concrete were mixed in a mixer and cubes of size 150 mm × 150 mm ×150 mm were cast for determining the compressive strength and permeability of test specimens. All the specimens were de-moulded at the age of 24 ± 1 h and thereafter were cured in water tank at room temperature up to the specified age of test.The slump cone test on freshly prepared concrete mix was carried out as per BIS 1199 (Bureau of Indian Standards, 1999b) for measuring workability of concrete. Compressive strength of concrete specimens was determined at 7 days and 28 days curing age as per BIS: 516-1959 (Bureau of Indian Standards 2002).

Table 6. Mix Proportion of concrete containing Marble Waste as coarse aggregate and fine aggregate

Mix	Paste content in excess of voids (%)	Water (kg)	Cement (kg)	Natural coarse aggregate (kg)		Marble coarse aggregate (kg)		Fine Aggregate (kg)	
				20 mm	10 mm	20 mm	10 mm	Sand	Crushed Marble waste
P 0	10	157	348	720	480	-	-	800	-
P5	10	157	348	181	121	542	362	761	40
P10	10	157	348	181	121	542	362	721	80
P15	10	157	348	181	121	542	362	681	120
P20	10	157	348	181	121	542	362	641	160
P25	10	157	348	181	121	542	362	601	200

Note: The mix designated by P0 shows control mix and mix designated by P5, P10, P15, P20, P25 shows conventional fine aggregate were replaced by crushed marble waste with an increment of 5%. In the mixes containing crushed marble waste as fine aggregate the 75% conventional coarse aggregate were also replaced by aggregate produced from marble waste.

RESULTS AND DISCUSSION

Workability

The results of the slump test are presented in Figure 4.

It can be seen from Figure 4 that, replacement of fine and coarse aggregate by crushed marble waste gradually increases the slump of concrete mixes. The maximum slump achieved by mix P25 is 110 mm and approximately 38% more than that of control mix with same water-cement ratio. The workability of concrete mainly depends on various factors such as size, shape, surface and water absorption of aggregates. As reported by Mehta and Monteiro (2001) in their study, the concrete is more workable when smooth and round shaped aggregate are used instead of angular or elongated aggregates. In this study the aggregates obtained from marble waste have very low waster absorption as compared to that of conventional aggregates which gives sufficient amount of water to lubricate the particles and these are round in shape. Because of this reason, concrete mixes produced by using aggregates produced from marble waste showed high values of that that of control mixes.

Compressive strength

The variation in compressive strength of the concrete mixes prepared by replacing fine and coarse aggregate by the aggregate produced form marble waste are shown in Figure 5.

From the Figure 5 it can be seen that, the compressive strength of concrete mix P5, P10 and P15 was decreased by 23%, 19%, and 11%. As compared to that of control concrete. At 20% replacement level the compressive strength of mix P20 was increased by 9%. The increase caused by the filling up pore by the fine fractions of crushed marble waste particles within the concrete. This makes concrete denser and resulted in increased compressive strength. Another reason behind the increase in compressive strength of concrete mix P20 was, the aggregates containing higher content of calcium carbonate exhibits stronger bond as it reported by Hebhoub et al. (2011) in their study. Further increase in replacement of fine aggregate by crushed marble waste beyond 20% decreases the compressive strength of concrete by approximately 19%. This decrease was due to increased content of fine particles in concrete. The increased fine particles consequently increases surface area to coat the particles which resulted in loss in compressive strength.

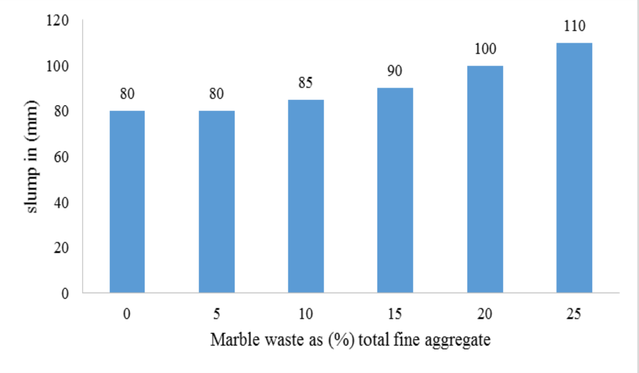

Figure 4. workability of concrete mix

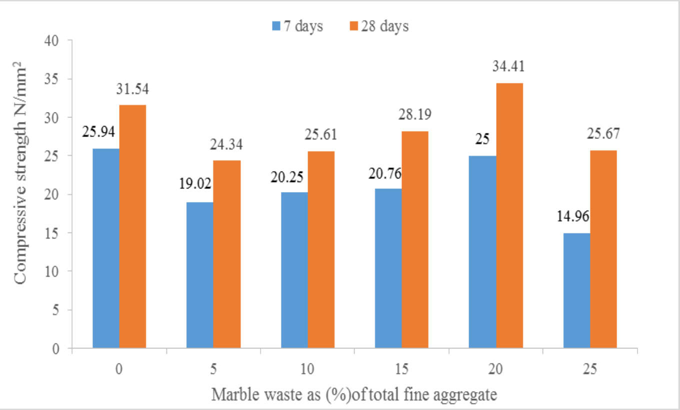

Figure 5. Variation in compressive strength of concrete mix

Cost Analysis and Economic Benefit

The cost analysis of the concrete prepared by using the aggregate produced from marble waste are shown in Table 7.

From the above Table it can be clearly seen that, the cost of material required for concrete production decreases gradually. In this study, the maximum compressive strength was achieved in concrete mix P20. At this replacement level, the cost of material required for concrete production was decreased by 11% as compared to that of control concrete resulted in achieving in economy.

The huge amount of waste is generated during the quarrying and processing operation of marble which occupying vast area due to dumping. The utilization of this waste in concrete mixes as building material will resolve the issues regarding dumping and environmental impacts cued by this. Another most important benefit resulting from the utilization of this waste is conservation of natural resources.

Table 7. Cost for production of materials for 1 m^3 of concrete

Mix	Water	Cement	Sand	Natural Aggregate	Marble Aggregate	Production cost (Rs.)
P 0	-	1949/-	425/-	488/-	-	2862.00/-
P5	-	1920/-	403.75/-	98/-	317/-	2738.75/-
P10	-	1920/-	382.25/-	98/-	317/-	2628.25/-
P15	-	1920/-	361.25/-	98/-	317/-	2607.25/-
P20	-	1920/-	340/-	98/-	317/-	2586.00/-
P25	-	1920/-	318.75/-	98/-	317/-	2564.75/-

CONCLUSION

In this study aggregates produced form the marble waste were used as a partial replacement for conventional fine and coarse aggregate for production of concrete mixes and their impact on the properties of concrete were studied. From the above study the following conclusions are drawn,

- Inclusion of aggregate produced from marble waste improves the workability of concrete mixes.
- The compressive strength of the concrete prepared by using aggregate produced from marble waste showed marginal increase at 20% replacement level.
- The replacement of 75% conventional coarse aggregate by aggregate produced from marble waste does not have any adverse impact on workability and compressive strength of concrete mixes. The optimum replacement level of fine aggregate by aggregate produced from marble waste is 20% and conventional coarse aggregate by marble aggregate is 75%
- The utilization of aggregate produced from marble waste resulted in 11% saving in production cost of concrete which achieves economy in concrete production.

From the above study it can be concluded that, the use of aggregate produced from marble waste can be used as replacement of conventional fine and coarse aggregate in concrete mixes. Thus the product become sustainable with saving in 11% overall cost of concrete due to utilization of this waste with saving in natural resources. But more durability studies will be required to use this waste as a building material in concrete.

Competing interests

The authors declare that they have no competing interests.

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