A study on use of marble waste as fine aggregate in mortar

By

Rajendra Kumar Khyaliya
(2014PCW5414)

Water Resource Engineering

Supervisor
Prof. A. K. Vyas
Department of Civil Engineering

Submitted for the partial fulfillment of degree of

MASTER OF TECHNOLOGY
In
WATER RESOURCE ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY, JAIPUR

JUNE 2016

A

DISSERTATION REPORT

On

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(**Rajendra Kumar Khyaliya)**

DEPARTMENT OF CIVIL ENGINEERING

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY

JAIPUR, RAJASTHAN-302017

CERTIFICATE

This is to certify that the dissertation report on "**A study on use of marble waste as fine aggregate in mortar** " which is submitted by **Rajendra Kumar Khyaliya** (2014PCW5414), in partial fulfillment for the Master of Technology in **Water Resource Engineering** to the Malaviya National Institute of Technology, Jaipur. It is a recorded of a student's own work carried out by him under my supervision and guidance during academic session (2014-2016).This work is approved for submission.

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Prof. A. K. Vyas

Department of Civil Engineering

MNIT Jaipur

Dedication…..

I WOULD LIKE TO DEDICATE MY THESIS TO

MY BELOVED PARENTS

ABSTRACT

Stone industries of Rajasthan are spread across all its districts, form the backbone of its economy. Rajasthan is known as the mineral majestic state as it produces more than 50 types of rocks and minerals. Rajasthan produces about 90% of total national production of marble. With increasing popularity of marble of Rajasthan, growing demand for finished and unfinished products, discovery of new marble deposits have led to a significant growth in marble industry of Rajasthan. This lead to simultaneous rise in waste generation as well, thereby causing concern towards the deteriorating environmental quality. Marble wastes are just dumped in the open creating health hazards. The powder in particular effects the productivity of the soil. It reduces permeability which prevents from ground water recharge.

The aim of this research is to find an economical and sustainable way to get rid of the marble powder. The use of waste marble powder in place of (0%, 25%, 50%, 75% and 100%) fine aggregate (sand) in mortar mix has been evaluated. In this report, investigation will be carried out to check the suitability of this waste in mortar, hence tests to evaluate compressive strength, workability – flow table test, capillarity test, evaluation of durability properties, water absorption and drying shrinkage on mortar mixes were carried. Results are compared to control mix and experimental mixes (using waste marble powder in different replacement ratios).

This study indicates that the issue of indiscriminate disposal of marble waste was can be solved drastically by use marble powder in mortar since mortar is the most widely used in construction material at present.

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INTRODUCTION

1.1 General

All natural resources though abundant, are non – renewable and finite. Several naturally occurring minerals in their various forms are the raw materials for many products. Their extraction has led to the unprecedented growth of metallic, non – metallic and the building materials industry in India. Their availability has led to the growth of our economy. In India, about 87 minerals and stones are mined. The state of Rajasthan comes third in terms of mineral resource generation among others. Fig1. Shows percentage break up of state wise generation of all minerals in India.

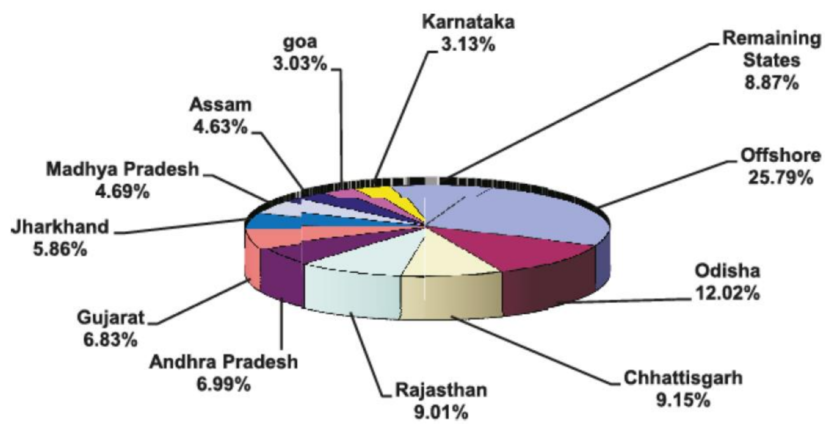


Figure 1.1 Production of minerals, state-wise contribution

The mining industry was valued to be about 2 lakh crore during the year 2011 – 12. Marble being one important stone which is quarried in India, is classified as a ‘minor mineral’ in the Section 3 of Mines and Minerals (Development & Regulation) Act, 1957. Rajasthan contributes about 95% of marble by value in India (1601 corer) (during) and generated 20% of the revenue for mining industry among all other minor minerals in Rajasthan. About 132 lakh tones of marble was produced during the FY 2013 – 14 by Rajasthan alone. Fig 2.Shows the geological distribution of marble resources in Rajasthan.

Apart from mineral resources, the other catalysts to economic development are stable and adequate infrastructure which forms the support system for the developing India. Most of these systems are built around concrete as the main structural material. India produces about 400 Mt of concrete every year. Cement and aggregates go into forming this unique composite material. The worldwide cement production stands as 2850 Mt of which India produces 10%. On the other hand, as stated by 'Sustainalytics', which formulates investment strategies for its customers, due to variability in the mining industry, there are no definitive estimates for about how much of aggregates are actually produced.

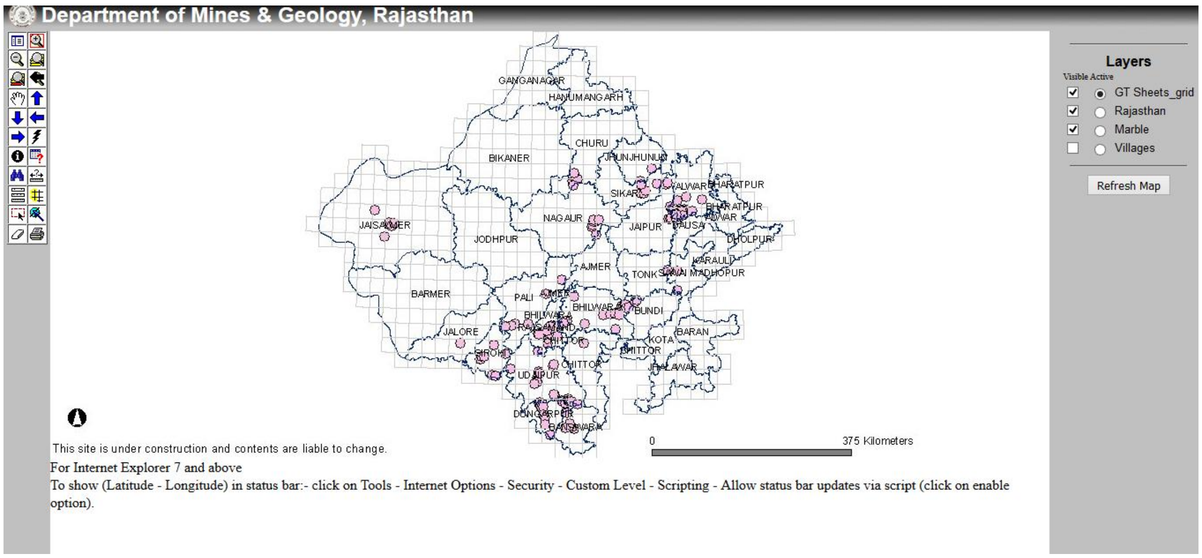


Figure 1.2 GIS map of marble resources in the state of Rajasthan, India [6]

1.2 Environmental concerns

In opencast mining activities, environmental problems are prone to occur. Natural rock is disturbed, soil, flora and fauna, water table are all affected. For one tonne of marble production about 58 MWh embodied energy is associated. Waste is generated as sludge 20 to 25 % of will processing and 60% of waste is generated during the mining operations. Marble processing and mining operations during respectively 153 x 10^6MWh and 459 x 10^6MWh of energy is wasted. These blocks and sludge are just dumped in the open, creating health hazards. The slurry in particular effects the productivity of the soil.

It reduces permeability which prevents from ground water recharge. If these particles become airborne, can cause air pollution causing unfavorable surroundings for humans, animals, vegetation and machinery.

On the other hand 1t of cement requires 1.5t of limestone and releases 1t of CO_2 in the atmosphere. Aggregate quarrying lately have come under the scanner of environmentalist for the associated ecological problems. Changing environmental patterns, depleting natural resources, imbalance in ecosystem have all called for an optimum utilization of the resources without hampering the quality of life of the future generation, i.e. to be sustainable. Therefore it is more than appropriate to utilize a waste product from one mega industry in another one. Hence in this study a review of possible utilization of marble in the construction industry as a building material has been presented. Here marble is being assessed as a possible substitute to fine aggregates in mortar production.

1.3 Objective of study

The objective of this study is to find suitable utilization percentage of marble powder which is produced from the quarrying process of the marble industry. Conventional fine aggregate is proposed to be partly replaced in mortar. The impact of research shall be reduction in environmental pollution, saving of fertile land undergoing barren process and saving of natural aggregate. The main focus of this study is to observe and analyze the strength, water absorption, voids ratio, capillarity and durability properties of mortar incorporated with marble powder.

CHAPTER – 2

LITERATURE REVIEW

The form in which marble waste is generated varies between blocks to slurry particles with fineness equivalent to cement. Following is a review of research works carried out till date where marble has been utilized as fine aggregate in manufacture of concrete, mortar and bricks.

The most recent published literature available is of Romania's **Molnar and Mania (2015).**They explained the suitability of calcite based marble slime in plaster (1:5) as a replacement for fine aggregate. The slime occurs from marble cutting and shaping process. This slime dried at 105 °C until constant weight attained for sand in such a way fit the grading curve as per specifications set for fine aggregates to be used for plasters. Each size fraction was substituted in proportions of 25, 50, 75 and 100% after find out properties (consistency, tensile, compressive strength and adhesion) of mortar.

The authors say that apparent density at fresh and hardened state decreased with increase in substitution of marble sludge and reduces workability which reason due to binding nature of marble powder. Tensile strength (at 25% and 100% marble content) too decrease with increase in marble content compare to control mix. But compressive strength more than control mix at 7 days (at 25% substitution of marble) but compressive strength decrease at 28 and 60 days strength.

Alyamac and Aydin (2015) reported that the marble sludge can be utilized in place of river sand for up to 40% in concrete with aw/c of 0.6. Their study evaluated workability, compressive strength, split tensile strength, abrasion and sorptivity characteristics of concrete mixes having marble powder in the range 0 to 90%. On discussion of these characteristics, they pointed out that workability reduced with increase in marble incorporation which was because of the fineness of marble slurry (<0.125 mm) when compared to the sand it was replacing. For substitution of 50% and above, admixtures had to be added to obtain the required slump. The mechanical characteristics, compressive and split tensile strengths had peaks at 20% substitution (5 and 23% more than control respectively). The authors reasoned out that particle size and rough texture of the marble slurry induced a filler effect and improved the bond strength which resulted in enhanced compressive and tensile strengths respectively. All mixes upto 40% substitution and control concrete performed alike with regard to sorptivity. Only the 90% substitution showed drastic reduction sorptivity coefficients. Mix with 20% marble had the greatest resistance to abrasion (10% more than control), and mixes with 50% or more marble showed a decline in resistance.

A similar work was carried out by **Kushwah et al. (2015)** where only compressive strength was evaluated for M20 grade of concrete. Mix with 30% substitution was regarded to be comparable with the control mix.

Earlier in 2014, **Kelestemur et al.'**Study directed to at utilization of marble sludge occurs by the Turkey's marble cutting and sawing industry, as a replacement of fine sand (<0.25 mm). Marble sludge dried before use mortar to replace fine sand in content of 20%, 40% and 50% by volume. Mix ratio1:3 by volume at a take constant w/c ratio 0.5. The compression and flexure strengths were evaluated after 30 cycles of freeze and thaw.

Authors conclusion that marble was finer than fine sand, marble powder used as a filler resulting in better compressive and flexural strength. But same filler effect reduced the mortars resistance to freeze and thaw cycles.

In a preceding study conducted by the same research group **(Kelestemur et al. (2014)),** followed the same methodology as mentioned earlier. Here, instead of studying the effect of freeze thaw cycles, effect of elevated temperature on compressive strength and porosity values were evaluated. Specimens were treated to a temperature of 400, 600 and 800˚C and held at the same for an hour, so that steady state could be achieved. Taguchi method of design of experiments was used reduce the number of experiments from 64 to 16. On testing, it was found that, the filler effect of marble helped reduce porosity, thereby achieving higher compressive strength. Alteration of aggregate cement paste was also linked to lesser reduction of porosity and compressive strength at elevated temperature.

Studies of inclusion of marble powder as fine aggregate in medium strength concrete has also been carried out, **Aliabdo et al. (2014),** being latest to report. They investigated the use of oven dried marble slurry from the marble cutting and shaping industry in Egypt as a partial replacement of cement in blended cements and concrete at substitution of 5, 7.5 10 and 15% by weight. Fine aggregate was also replaced in concrete in the same proportions. Marble slurry particles finer than 0.075 mm were used for the replacement. Limestone was used as coarse aggregate, siliceous sand as fine aggregate. Concrete mixes of two w/c ratios 0.4 and 0.5 with a slump range of 100±20 were tested for compressive, splitting tensile and steel concrete bond strengths along with evaluation of pulse velocity and porosity.

From their work it was understood that compressive strength was more than control for the maximum substitution of 15% for sand replacement. Peak was obtained at 10% substitution, though. The trends were same for both w/c ratios and significant change was obtained at the lower w/c ratio of 0.4 (15% increase at 28 days). Similar trends were also obtained for splitting tensile strength with a 15% increase for 0.4 w/c ratio at 10% substitution at 28 days. Steel concrete bond strength evaluated at 56 days showed maximum strength at 7.5 and 10% substitutions for w/c of 0.5 and 0.4 respectively. UPV results showed no appreciable changes in results. The gains attained in the mechanical properties were reflected in the porosity values, with 10% substitution having the least pores. Hence it was concluded that marble slurry acted as filler in enhancing these mechanical properties.

In India, the effect of marble slurry on low strength concrete was studied by **Hashim and Agarwal (2014).** Concrete with two w/c ratios were studied, 0.5 and 0.61. Marble replaced 50% of sand in the mixes which resulted in negligible fall in compressive and flexural strengths. The pattern was similar for tensile strength for mixes of w/c ratio of 0.5. But for mixes of w/c ratio of 0.61, tensile strength increased by 38% on marble incorporation. Finally with regard to permeability there was no significant change on inclusion of marble into concrete.

With the aim to completely replace or reduce the maximum possible extent of dependency on river sand.

Malpani et al. (2014) tried to arrive at a possible combination of river sand, quarry sand and marble powder (1:0:0, 0.5:0:0.5, 0.5:0.5:0, 0:0.5:0.5, 0.33:0.33:0.33, 0.4:0.2:0.4, 0.2:0.4:0.4, 0.4:0.4:0.2) which would result in a concrete mix performing better or equivalent to the conventional mix. Slump, compressive and split tensile strengths were their evaluating criteria. On analyzing the results, it was pointed out that with increase in incorporation of marble powder and quarry sand, slump decreased drastically, but still the proportion 0.4:0.4:0.2 was deemed acceptable. Compressive strength results were very encouraging with all mixes showing better strength in comparison with the control mix. But the authors stressed on the mix 0.4:0.2:0.4 to be the better one amongst others. On the flip side the split tensile strength did not show positive trends of the compressive strength results. Only three mixes (0:0.5:0.5, 0.4:0.2:0.4 and 0.4:0.4:0.2) had more strength than the control mix with 0:0.5:0.5 being the recommended one.

Portugal's problem associated with waste generated from the industry is no different than Romania, Egypt, India and Turkey as pointed out by the above researchers in their work. 80% of the marble rocks quarried in Portugal end as waste products. Hence the research carried out by **Gameiro et al. (2014)** aimed at evaluating the potential of utilization of these waste in concrete mixes in order to make the extraction of marble more sustainable. This is in continuation of the work reported by Silva et al. (2014), where mechanical properties have been listed. In this research work, the authors have reported the durability characteristics of concrete mixes when marble waste is used as fine aggregates (4.75 to 0.63 mm). The effect of using marble was evaluated on comparison with river sand, granite sand and basalt sand. Replacement was done by volume, keeping size grading constant. The replacement ratios were 0, 20, 50 and 100%. Limestone gravel was used as coarse aggregate. Mixes were designed to achieve 28^{th} day mean compressive strength of 44 MPa having a slump of 125±15 mm. Apart from slump, bulk density of fresh concrete, water absorption by immersion and capillary action, carbonation, chloride penetration and drying shrinkage of the hardened concrete specimens were evaluated at prescribed ages of exposure. All these tests were carried out according to the specifications of Portuguese standards.

The authors stated that to keep the workability class constant, w/c ratio had to be increased slightly to negate the effect caused by the incorporation of elongated and flaky aggregates of marble. Bulk density also reduced by 1.3% with marble inclusion. It is believed that the bulk density of concrete mixes depend on the compactness of the mix and bulk density of the aggregates. Marble having a lesser bulk density than primary aggregates reinforced the same ideology, and hence the fall. With regard to water absorption by capillary action, 20% substitution of marble showed the least absorption of water. Further addition of marble resulted in negative effect. Same trend was observed for water absorption by immersion. But only for 100% substitution, water absorption increased by 11.2% when compared to river sand specimens, but when compared to basalt sand and granite sand, specimens with marble performed better for complete substitution also.

The results of carbonation followed a similar trend of water absorption results. When compared to granite, marble performed better, but marble increased the depth of carbonation when compared to river sand and basalt sand aggregates mixes. Similar trend was obtained for chloride migration into concrete. But the variation was considered insignificant. Shrinkage also reduced greatly for all mixes with marble and these changes were more pronounced within the first 20 days of testing.

All the positive benefits were attributed to the rough texture of marble aggregates. This enhanced the bonding between the cement pastes with the aggregate. But with increasing incorporation generally more than 20%, required more water to make the mixes workable which led to the increase in porosity, hence reduction in resistance to water, carbon-di-oxide and chloride ions penetration. The same nature of marble helped reduce shrinkage though. The rough texture of marble aggregates reduced the tendency for water to evaporate, in turn reducing the development of stress and hence less shrinkage.

Silva et al. (2013) reported the mechanical properties of the mixes of which **Gameiro et al. (2014)** had reported the durability characteristics. Compressive strength for all substitutions decreased, with the sand family showing the most reduction. w/c ratio had to be adjusted to main the required slump values to negate the effect of size and shape of marble aggregates. Adding to this the texture of marble particles was smooth, meaning weaker bond between cement paste and aggregate and hence lesser strength. The maximum reduction was for 100% substitution with a difference of 20% when compared to river sand. Baring basalt family, all other mixes showed reduction splitting tensile strength. Basalt aggregates are made of fledspars, which on contact with cement paste breakdown chemically leading to the formation of clay minerals which lead to reduced aggregate cement bond strength. Tensile strength is dependent on this bond strength only. On the other hand marble aggregates are carbonate based, which have better bond strength than siliceous aggregate. Hence on incorporation of marble in basalt mixes lead to the improvement of tensile strength. With regard to Modulus of Elasticity, sand family mixes showed greatest reduction (14.6% for 100% substitution), and this was linked to the change in compressive strength while the other two families showed negligible change. Abrasion resistance too showed negative trend (47.8% for 100% substitution when compared to 100% sand mix). This was reasoned to be because of higher water cement ratio and lesser abrasion resistance of marble stone.

Ural et al. (2013) studied the effect of marble dust in concrete by replacing sand in proportions 5, 10, 15%. Particles finer than 1mm were used for replacement of sand. Water – cement ratio was adjusted such that a slump of 100 mm was obtained in all four mixes. Hence to obtain this target slump, water had to be increased, which resulted in 12% more water content for the 15% substituted mix. Peak values of unit weight, ultrasound pulse velocity and compressive strength (17% more than control) were obtained at 5% substitution. The authors reported that this increase in performance was due to the filler effect of marble dust. However, further increase in marble dust showed negligible increase in UPV and unit weight and decline of compressive strength by 6%.

Sadek et al. (2013) studied the effect of using marble as fine aggregate in the manufacture of bricks. Fine aggregate was replaced in proportions of 25, 50, 75 and 100 in concrete mixes of zero slump. Compressive and flexural strengths and water absorption were evaluated. It was reported that, 25% substitution led to an increase in compressive strength of 5%, but 50% substitution upwards showed a decline in strength. Flexural strength too showed the same trend with 25% substitution of sand by marble fine aggregate enhanced the strength by 9%. Again the same 25% substitution mix showed the least water absorption values.

Patel et al. (2013) conducted a brief study on utilization of marble slurry in concrete of grade M30 by replacing fine aggregate in the proportions 5, 10, 15 and 20%. 28 day compressive strength of all mixes was greater than control while 15% substitution resulted in a peak strength which was 6% more than control concrete.

Singh et al. (2013) evaluated SCC's UPV, rebound hammer and correlated these with compressive strength and reported that 25% replacement of sand with marble powder gave better results than control concrete (21% more than control). 50% substitution showed a reduction of 16% in compressive strength.

The use of marble waste as coarse and fine aggregate in the manufacture of paving blocks was evaluated by **Gencel et al. (2012).** Coarse and fine aggregate were replaced by marble in equal proportions of 10, 20, 30 and 40%. Two grades of cement were used, and hence two control mixes were the basis of comparison. Workability was kept constant. Density, compression, flexure and splitting tensile strengths, rebound hardness, UPV, modulus of elasticity, water absorption and resistance to freeze – thaw and abrasion were determined.

The authors testified that, bulk density of concrete reduced with increase in marble incorporation. It was a consequence of marble having low density and the excess water that was added to make the mix workable. Higher specific area of marble waste was the reason for the extra water requirement when compared to the control mix. Compressive strength reduced with increase in substitution, with 40% substitution registering only 76 to 78% of strength attained by the two control mixes. Splitting tensile strength reduced but only marginally. Since splitting tensile strength is dependent more on the mortar matrix than cement, it was regarded independent of the type of aggregate used. Rebound hammer and UPV results also showed small and negligible decline in values with increase in marble substitution. However, elastic modulus showed a sharp fall. Reduction in water absorption and resistance to freeze thaw were two interconnected positive traits of paving blocks with marble aggregates when compared with control specimens. With the reduction of water absorption capacity, there is lesser water that freezes in the pores which exerted lesser pressure to the concrete hence lesser fall in compressive strength. Incorporation of marble improved the resistance to abrasion, because marble had higher hardness value on the Mohr's scale than the aggregate it replaced.

The authors, **Bilgin et al. (2012)** quote, 25% of the waste generated in processing a marble block consists of particles finer than 2mm. This has led to accumulation of such wastes. Hence the authors targeted to assess the prospective use of such fine waste in the manufacturing of bricks. Wastes from three quarrying sites predominantly of calcite origin were studied. These fines had an average particle size ranging from 2.7 to 3.48 µm. Bricks were prepared by adding the fines in steps of 10 from 20 to 100% to the commercially available dry brick mortars and were sintered at three different temperatures. Shrinkage, bloating, weight changes, water absorption, porosity and bulk density and flexural strength of the samples were studied.

On sintering, calcinations of calcium carbonate takes place. This leads to increase in size and decrease in weight. The increase in size is due to the formation of calcium oxide which is an expandable material and evolution formation of pores due entrapped carbon di oxide gases. Decrease in weight makes the bricks light weight which is a positive aspect. Size change can be controlled if the sintering temperature is kept at 900˚C. But at this temperature the calcination process is not complete which was considered to be disadvantageous. Weight and size change increased with increase in marble content. Water absorption too followed the same pattern. This tests couldn't be conducted for specimens with more than 60% marble content, because CaO reacted and formed $Ca(OH)_2$ when dropped in water, releasing heat and causing disintegration of samples. Finally, Flexural strength dropped with increase in sintering temperature and marble incorporation.

Uygunoglu et al. (2012) evaluated the use of marble waste in the production of pre-fabricated inter locking blocks. Marble waste was used as fine aggregate and compared to crushed sand stone. Mixes were designed with a w/c ratio of 0.45 with zero slump. Splitting tensile and compressive strength along with resistance to abrasion and freeze – thaw, density, water absorption and porosity were evaluated. On comparison with crushed sand stone, marble waste incorporated performed poorly. Compressive strength fell from 32.1 Mpa to 27.8 Mpa (13% reduction). This reduction was attributed to the weakness and surface texture of marble aggregates. Tensile strength also showed decline in value when marble was used. However the initial strength gain of marble incorporated marble blocks was more than crushed sand stone. There was no change in density though. Porosity reduced by 20% and so was water absorption. Concrete made with marble waste showed greatest resistance to alkali silica reaction because the alkali silicate gel generated with marble waste was less. Abrasion resistance on the other hand decreased dramatically. Reduction in freeze thaw resistance quantified in terms of splitting tensile strength after 60 cycles was negligible.

Hameed et al.'s (2012) too aimed at fully replacing river sand by quarry rock dust and marble sludge powder as intended by **Malpani et al. (2014).** Here the authors conducted an extensive study to fix the proportion of marble slurry that can be used in concrete which ranged between 0 to 20%. After conducting several trial mixes, mix proportions for three series of M20, M30 and M40 were fixed and initial mechanical strength properties were conducted on the same. Each series had four mixes namely, PCC with river sand only (NCRS), PCC with crushed rock dust (NCCRD), SCC with crushed rock dust (SCC1) and SCC with crushed rock dust and marble powder (SCC2). On 12ubstitut the results it was pointed out that NCCRD had higher initial strength, but at later ages SCC2 attained the highest strength (10% more than NCRS for M30 at 90 days). In terms of splitting tensile strength, very little changes were observed. With regard to durability, only M30 was evaluated for water absorption, permeability, RCPT, Electrical resistivity and half-cell potential. From the results, the authors pointed out that though the water absorption of SCC2 was more than control, permeability was reduced by 10%. Increase in water absorption was attributed to increase in fines content which increased the surface area of particles and hence the result. The same fines on the other hand were credited to be taking part in the pore filling act and hence led to the fall of permeability. The water permeability results were in line with RCPT values, which too showed reduction in chloride ion penetration. Half-cell potential and electrical resistivity tests showed that NCCRD had greater resistance to corrosion and SCC2 performed better than control mix.

To tackle the problem associated with the waste generation of marble quarrying in Algeria, **Hebhoub et al. (2011)** replaced coarse and fine aggregate of concrete with marble waste. The fine marble powder used was coarser than fine sand it replaced. Replacement ratios were 25, 50, 75 and 100%. Coarse aggregate used was of limestone origin and a constant w/c ratio of 0.5 was used. For fresh mixes, bulk density showed no significant change. Air content reduced with increase in substitution but for 100% substitution the air content was the maximum. Slump values decreased, which was a consequence of increased coarser portion of marble as fine aggregate. Compressive strength (23.65% more than control) and tensile strength were maximum at 50% after 28 days of curing. Completely substituted mix had lesser compressive and tensile strength than the control mix.

Rai et al. (2011) find out the marble granules effect when used as a replacement of fine aggregate in mortar and concrete .this replacement was done by 5, 10, 15, and 20% in mix ratio 1:3 and concrete mix was as M30. A constant w/c of 0.44 was maintained for both mortar and concrete. When evaluated the compressive strength attained at a 10%subtitution after which resistance to compression dropped. The increase in compression strength was attributed to cementing property of the marble waste. Compressive strength and tensile strength increased with increase in substitution which peaked out at 15%.

Hamza et al. (2011) determined the suitability of using marble slurry from cutting and sawing industry in the production of concrete bricks. Slurry was substituted in place of both coarse and fine aggregate in percentages of 10, 20, 30 and 40. Compressive strength, density, resistance to abrasion, change in compressive strength after exposure to heating and cooling cycles, NaCl and immersion cycles followed by heating were reported. Only the 40% substituted concrete mix did not fulfill the criteria of minimum compressive strength at 28 days. 10% substituted bricks samples were able to produce identical compressive strength to that of control samples after 28 days of curing. With regard to density, addition of marble slurry led to the reduction in weight. On the durability front all substitutions performed on par with the control specimens.

Palestine's **Al Joulani (2011)** conducted a preliminary investigation on incorporation of marble sludge in the production of cement, concrete bricks, floor tiles, PVC pipes, texture paints, pottery, ceramic, decorative and ornamental products. Tiles made with 20% marble slurry performed as good as tiles made with 100% fine aggregates. Concrete bricks too proved to be economical and robust.

Demirel in 2011 used marble waste finer than 0.025 mm to replace sand of same size in concrete with w/c of 0.51.The waste used here was the same used by Kelestemur et al. in the same size grading in both of their studies. Though Kelestemur et al didn't mention the proportion of this fine sand (<0.025 mm) in the entire sand grading, Demirel pointed out that it was 10% in the river sand he was using.

In this current research the author evaluated properties like UPV, sorptivity, dynamic Young's modulus, porosity and compressive strength of mixes with marble substitution of 25, 50 and 100%. All these parameters showed a positive trend with 100% substitution showing the best performance. This enhancement was due to decrease in porosity with SEM images showing the same.

Corinaldesi et al. (2010) Investigate that marble powder produced from sawing and cutting industry which use in mortar and concrete.90% of the marble particles had a diameter lesser than 50 µm. Rheological parameters were determined where cement was replaced by 10 and 20% levels with and without super plasticizing admixture and two w/c ratios of 0.4 and 0.5. That presence of marble powder increase yield stress of the cement pastes and improving cohesiveness necessary for self-compacting concrete. Marble powder also improved segregation resistance. High thixotrophy means lesser pressure exerted on the formwork also. The enhanced rheological attributes were indicative of the marble powders' fineness and grading.

Evaluate compressive strength on mortars of ratio 1:3 (cement: sand). Marble slurry was used in place of cement and sand (10% substitution separately) and flow value was kept constant for all mixes. Marble slurry was used in wet state and subsequent corrections were made to the required w/c ratio based on the moisture content of the marble slurry. Compressive strength decrease by 20% when cement was replaced and 10% sand replaced. That marble slurry played the role of filler in mortar and in concrete.

Hameed and Sekar (2009) were the pioneer in evaluating the use of marble as fine aggregate in concrete. In their work, they completely substituted river sand by marble sludge and quarry dust in equal proportions in concrete of a constant w/c ratio of 0.55. Marble slurry was obtained from processing units and was limestone based. Silica based quarry sand had similar properties of the river sand it was replacing. Fresh concrete properties like slump, slump flow and V-funnel time were evaluated. Specimens were also tested for compressive and split tensile strength along with water absorption, permeability and resistance to sulphate attack.

They presented that concrete with marble sludge and quarry sand had better workability in all three aspects. Slump and slump flow increased by 21% and 56% respectively while V-funnel flow time reduced from 23 s to 14 s. Compressive and split tensile strength increased by 9 and 8% respectively at 28 days of testing. Resistance of marble and quarry incorporated mix against sodium sulphate, magnesium sulphate and sulphuric acid improved which was quantified in terms of weight change. Mortar bars were also prepared to study the change in compressive strength with increasing exposure age to sulphates. The attack was prominent when magnesium sulphate was used. Mixes having marble and quarry dust performed better. Mix containing equal proportions of quarry dust and marble showed the least change in weight (increase in compressive strength by 8% over a 90 day exposure to magnesium sulphate). Lastly permeability to water penetration reduced by 19%.

The forerunner of incorporating marble waste in concrete products, Hanifi Binici in his work **Binici et al. (2007)** investigated the effect of using marble particles finer than 1 mm as suitable fine sand replacement. They authors chose the replacement ratios of 5, 10, 15% for a concrete of mix ratio 1:1.5:2 and study the changes in compressive strength, permeability, resistance to sulphate attack and performance under abrasion. On testing, it was seen that compressive strength increased with increase in substitution, with 15% substitution recording the highest value. The same mix also had the highest resistance to sulphate environment showing a fall of only 15% of compressive strength when compared to control concretes' 58%. The results of abrasion too were inclined towards the use of 15% marble powder in place of fine sand in concrete. Lastly, water penetration decreased with increase in marble content

CHAPTER - 3

METHODOLOGY

3.1 Material used and testing of raw materials

Following raw materials are used:

1. **Cement**: Portland Pozzolana Cement (PPC) procured locally, conforming to IS 1489 (Part 1) was used.
2. **Fine aggregate/sand**: River sand was obtained locally. Sieve analysis, bulk density and specific gravity tests were carried on the material.
3. **Fine aggregate/Marble**: Marble waste was obtained from Kishangarh and was crushed by a local dealer. Material passing through 4.75 mm was acquired and sieve analysis, bulk density and specific gravity tests were carried out.

The various tests run on the materials and code they conform to, are given in the following table:

Table 1.1 Test conducted on the raw material

S.No	Test	IS code Specification
1	Specific gravity of fine Aggregate	IS 2386 (Part III): 1963
2	Bulk density of fine Aggregate	IS 2386(Part III): 1963
3	Sieve Analysis	IS 2386 (Part I): 1963
4	Compressive strength	IS 2250: 1981
5	Capillarity Test	ASTM C 1403-00
6	Workability – Flow table test	IS 2250: 1981
7	Evaluation of durability properties	ASTM C 267-01
8	Water absorption	ASTM C 642-06
9	Drying shrinkage	ASTM C 1148-92

3.2 Mix Proportioning

A mortar mix of proportion 1:6 (cement: sand) was chosen with a 28 day target strength of 3 to 5 MPa as per BIS 2250-1981. River sand was replaced by volume in steps of 25% from 0 to 100%.

3.3 Preparation of specimens

The dry raw material were weighed as per mix proportions and mixed manually for about 5 a minute after which tap water was added as per the required water cement ratio to obtain the specified flow value. For evaluating mechanical and durability properties, the moulds were oiled to prevent adhesion of mortar on mould walls. Cubes of size 50mm for evaluation of compressive strength, resistance to sulphate and acid attack and water absorption for capillarity were cast. 70mm cubic specimens were used for measuring extent of chloride penetration and water absorption by immersion. The mould were filled in three layers with each layer fully compacted using a vibrator and finally top surface was leveled using trowel.

3.4 Curing of Specimens

After 24 hours, the cubes are de-moulded and were fully immersed in a curing tank with their top surface under water for the required duration till the required conditioning period.

3.5 Testing on Specimens

3.5.1 Workability

Workability of mortar is its ease of use which is measured by the flow table test of the mortar. The standard flow tests uses a standard conical frustum shape of mortar with a diameter of 100mm (4inches). This mortar sample is placed on a flow table and dropped 25 times within the 15 second. As the mortar is dropped, it spreads out on the flow table and its diameter changes. The initial and final diameters of the mortar sample are used to calculate flow. Flow is defined as the change in diameter divided by the initial diameter multiplied by 100.

$$\text{Flow} = [(D_f - D_i)/ D_i] \times 100$$

Where, D_f = diameter after flow.

D_i = initial diameter of mortar sample.

3.5.2 Density, absorption and voids

This test has been performed according to the code ASTM C 642 – 06. Oven dry mass, saturated mass and apparent mass were calculated as per steps outlined below.

Oven Dry Mass—Take the mass of the portions, and place it in an oven at a temperature of 100 to 110 °C for not less than 24 h. After removing the specimen from the oven, allow it to cool in air to at temperature of 20 to 25 °C and determine the mass. If the specimen was comparatively dry when its mass was first determined, and the second mass closely agrees with the first, consider it dry. If the specimen was wet when it's mass was first determined, repeat the procedure till then two consecutive reading comes close to each other (difference between two consecutive values should be within 0.5%). Designate this last value A.

Saturated Mass after Immersion— Immerse the specimen in water, after final drying, cooling, and determination of mass, at room temperature for not less than 48 h and first reading is determined after 48h then take the further reading at an interval of 24h. When two consecutive reading comes within the difference of 0.5% of the larger value, stop this and designate the final reading as B.

Immersed Apparent Mass— Suspend the specimen, after immersion and boiling with the help of wire-mesh and determine the apparent mass in water. Designate this apparent mass D.

By using the following formula determine the result

Absorption after immersion, % = $[(B – A)/A] \times 100$

Bulk density, dry = $[A/(B – D)]\rho = g_1$

Apparent density = $[A/ (A – D)] \rho = g_2$

Volume of permeable pore space (voids), % = $(g_2 – g_1)/g_2 \times 100$

Where:

A = mass of oven-dried sample in air, g

B = mass of surface-dry sample in air after immersion, g

D = apparent mass of sample in water after immersion and boiling, g

g_1 = bulk density, dry, Mg/m^3 and

g_2 = apparent density, Mg/m^3

ρ = density of water

3.5.3 Compressive Strength Test

The compressive strength test are perform on mortar after 7 days and 28 days curing of mortar cubes as per BIS. Four specimens of 50mm x 50mm x 50mm were tested .The standard loading rate on cube was 1.7 kN/s. Compressive strength (MPa) was calculated by dividing the load at failure by the cross sectional area of specimens.

$$F=P/A$$

Where, F=compressive strength of mortar cube

P=load applied on mortar cube

A=cross sectional area of mortar cube

3.5.4 Ultrasonic pulse Velocity Test

This test was performed as per methodology adopted by Pozonio – Antonio. Test was conducted to find out the homogeneity as well as voids, cracks and other characteristics. Test carried out on 70mm cubes. Mortar cubes was completely dryed after curing.

Figure 1.3 UPV Test

3.5.5 Capillary test

This test has been performed according to the code ASTM C 1403 – 00. Cube size of 50 mm kept in the immersion tank on the mesh. Before putting into the tank take weight of the cube specimen also. Take minimum of three specimens from each mortar batch. Place the immersion tank on a flat surface. Pour water to the immersion tank so that the specimens are partially immersed in 3.0 ± 0.5 mm. At 15 min, 1 h, 4 h, and 24h, measure the weight in grams to the nearest 0.1 g of each specimen. Wipe off surface water from each specimen with a moist cloth prior to each weighing. Calculate and note the result as the water absorption (A_T) in grams/100 cm^2, at each time period, T, for each specimen

$$A_T = (W_T - W_O) \times 10000 / (L_1 \times L_2)$$

Where:

W_T = the weight of the specimen at time T in grams.

W_O= the initial weight of the specimen in grams.

L_1= the average length of the test surface of the mortar specimen cube in mm and

L_2= the average width of the test surface of the mortar specimen cube in mm.

3.5.6 Shrinkage Test

This test was performed as per ASTM C 1148-92 a; test conducted on 25 x 25 x 285mm prisms. These moulds are kept moist for 48h and after which these specimens are removed from the mould and moist curing is continued up to 72h from the time of molding. After 72h the specimens are kept in room atmospheric conditions, taking an initial reading in the length comparator. Measure the length of the specimen 4, 11, 18 and 25 days from when the specimens were exposed to the room conditions.

Calculate the % shrinkage, S, of the five specimens

$$S = [(L_1 - L)/L_o] \text{ X100}$$

L_o= effective gage length, cm

L_1= initial measurement after removal from moist cure, cm

L= measurement during or after drying, cm

Figure 1.4 Shrinkage test

3.5.7 Chemical Resistance on Mortar

These tests were performed according to C 267-01 on cube size 50 mm after curing of 28 days.

Na_2SO_4 Attack: Specimens were exposed to 5% Na_2SO_4solution prepared using distilled water. Cube should be completely immersed in Na_2SO_4 solution. At 7 days and 28 days, a minimum number of 3 cubes of each specimen were tested for change in weight and compressive strength of the cubes specimen.

H_2SO_4 Attack: This test is similar to the Na_2SO_4 attack. Prepare a solution of normal water and H_2SO_4, and proportion of H_2SO_4 is 5% of total solution and rest of the procedure of the tests follow as Na_2SO_4 methodology.

Figure 1.5 Cube in H_2SO_4 solution

NaCl Attack: -This test is carried out on the cube of size 70mm. Prepare a solution of NaCl and normal water and proportion of NaCl is 10% of total solution. After exposure to the salt solution, the cubes were split in to two. 0.1N $AgNO_3$ solution was sprayed. Change in color was noted. The portions were mortar remained colorless indicated the penetration of salt solution.

CHAPTER – 4

RESULTS AND DISCUSSION

4.1 Material Tests

In materials testing was performed**:**

- Sieve analysis for gradation of sand and marble slurry as per IS
- Specific gravity test for sand and marble slurry and cement

4.2 Sand gradation

Locally available river sand has been use as fine aggregate for the test perform on 200gram sand

Table 1-1 Sieve Analysis of sand

Sieve sizes	**Weight retained**	**Cumulative weight retained**	**Percentage weight retained**	**Percentage passing**
4.75 mm	0	0	0.00	100.00
2.36 mm	4	4	2.05	97.95
1.18 mm	16	20	10.23	89.77
600 µm	38.5	58.5	29.92	70.08
300 µm	88	146.5	74.94	25.06
150 µm	41	187.5	95.91	4.09
75 µm	3.5	191	97.70	2.30
Pan	4.5	195.5	100.00	0.00
Total	195.5			

Fineness modulus=2.13

4.3 Marble slurry gradation

As the marble slurry were to fine aggregate perform sieve analysis done 200 gram

Table 1-2 Sieve Analysis of Marble

Sieve sizes	Weight retained	Cumulative weight retained	Percentage weight retained	Percentage passing
4.75	0	0	0	100
2.36	0.5	0.5	0.25	99.75
1.18	15	15.5	7.75	92.25
0.6	27	42.5	21.25	78.75
0.3	52	94.5	47.25	52.75
0.15	43	137.5	68.75	31.25
0.075	27.5	165	82.5	17.5
Pan	35	200	100	0
Total	200			

Fineness modulus= 1.45

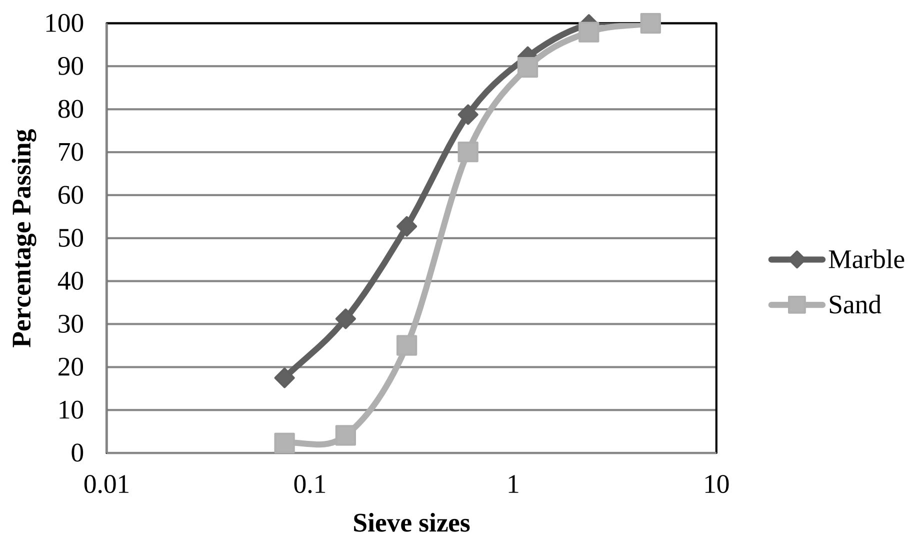


Figure 1.1 Gradation curve

4.4 Specific gravity test for cement, sand and marble powder

Find out Specific gravity test by pycnometer test

Table 1-3 Specific Gravity of various Materials

Materials	Specific gravity
Sand	2.72
Marble powder	2.9
Cement	2.9

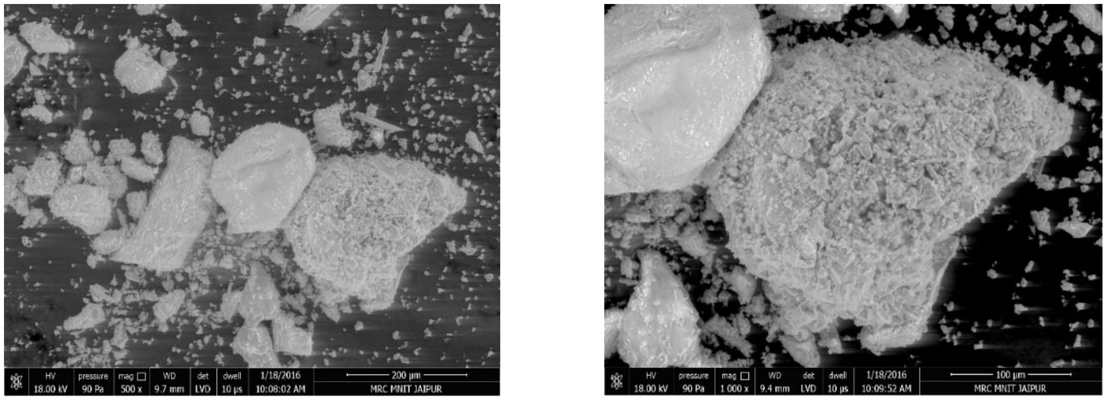


Figure 1.2 SEM of marble powder

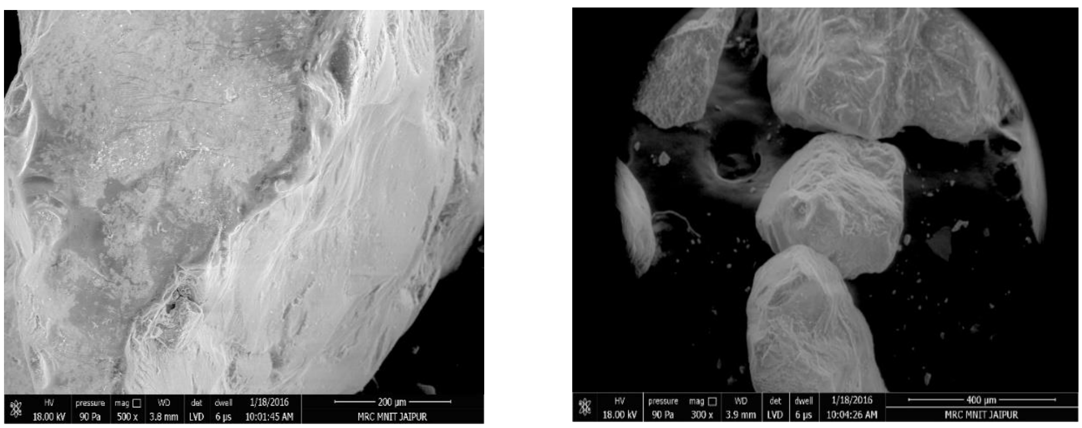


Figure 1.3 SEM of sand

4.5 Chemical Proportions

This test performed at XRD –diffraction on marble powder

Table 1-4 Chemical Analysis

Element	Proportion in Marble Powder	Proportion in Sand
O	49.62	54.07
Ca	22.76	-
C	22.74	8.57
Si	1.81	19.09
Mg	1.48	-
AL	0.84	7.20
Fe	0.74	0.67
Na	-	0.31
K	-	10.09

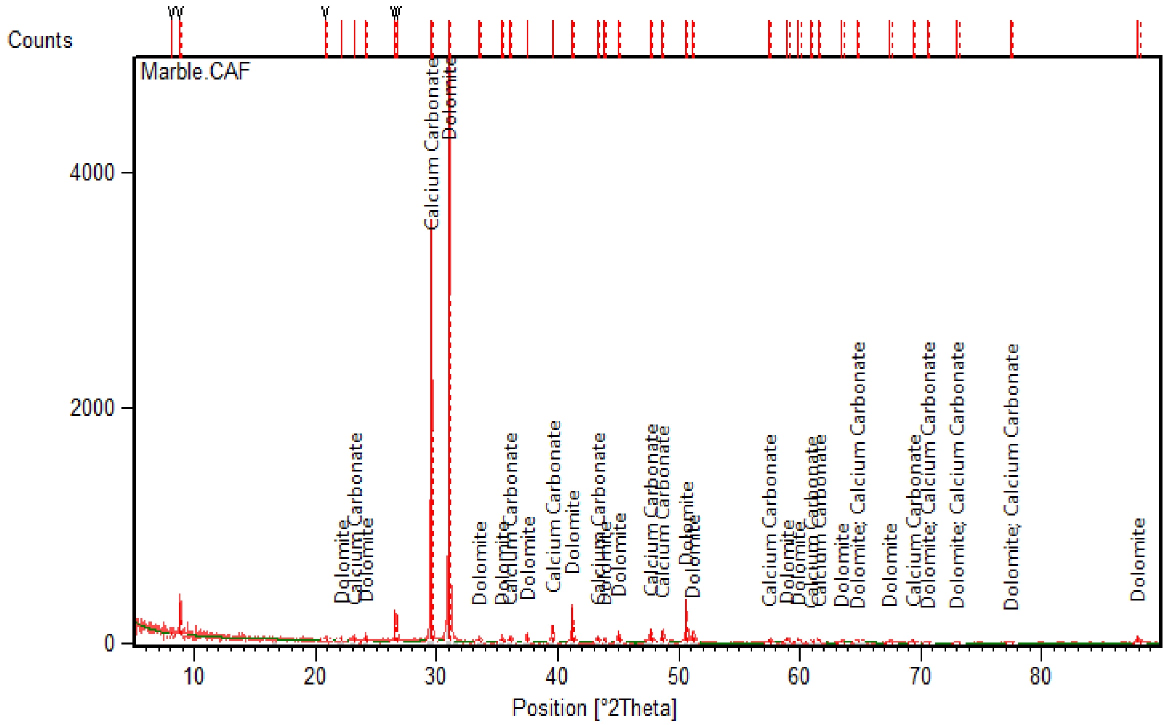


Figure 1.4 XRD pattern for Marble powder

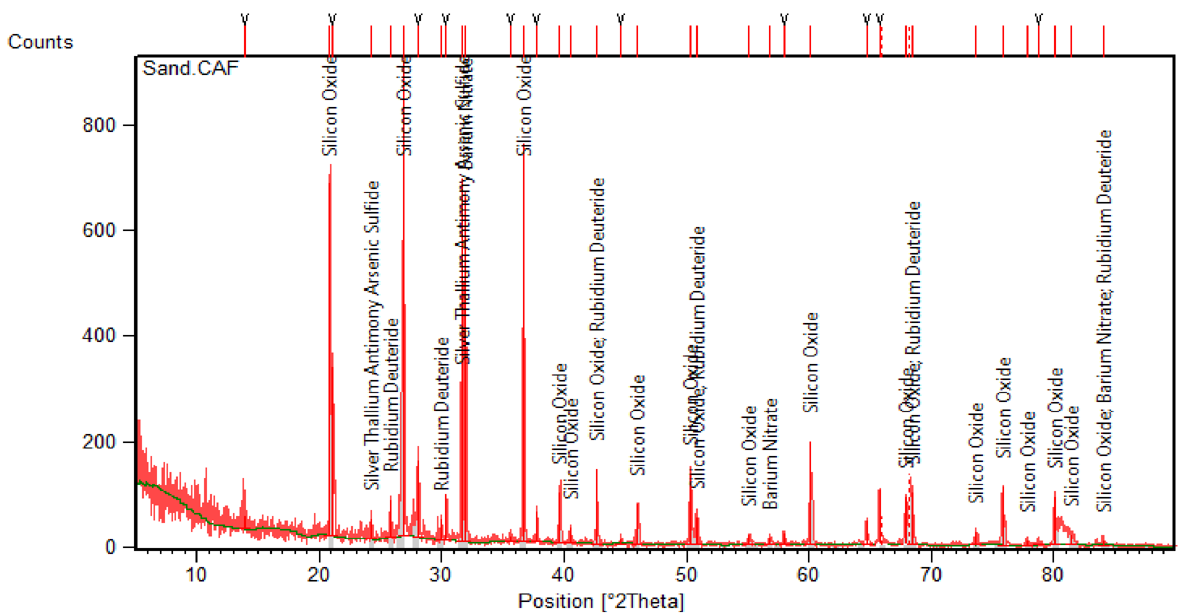


Figure 1.5 XRD pattern for sand

4.6 Flow test

Table 1-5 W/C Ratio as per Substitution

Marble powder as % of total fine aggregate	W/C ratio
0	1.30
25	1.24
50	1.22
75	1.27
100	1.33

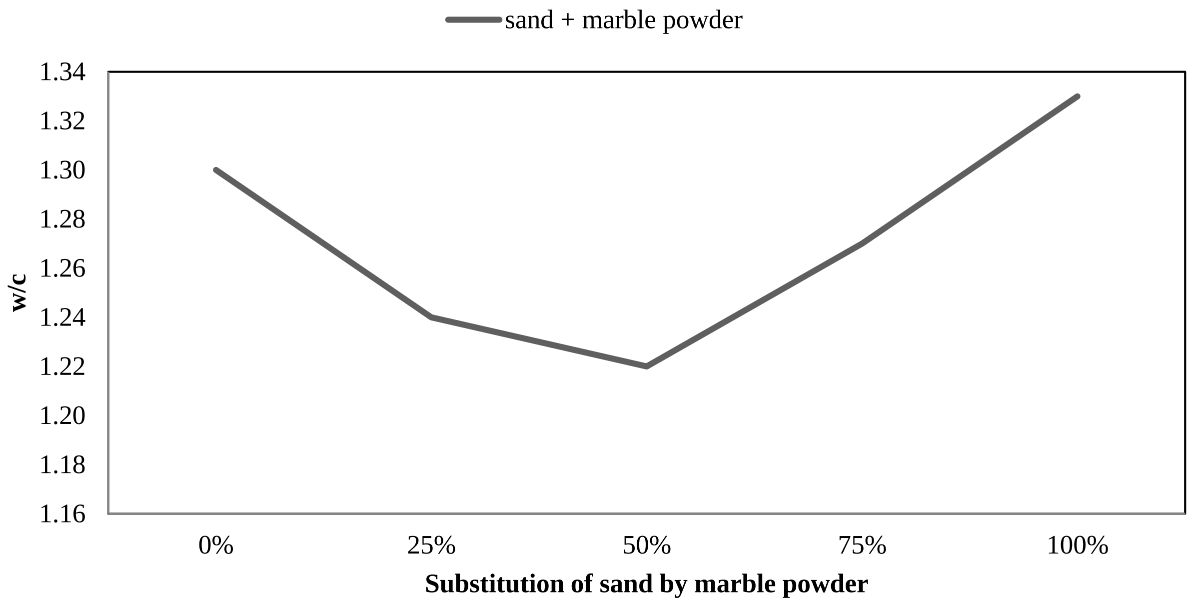


Figure 1.6 Marble powder replacement workability

Fig 4.6 show that For the replacement up to 50% of marble powder, W/C ratio decrease and then after W/C ratio increase up to 100% replacement. In this minimum W/C ratio occurs at 50% substitution of sand by marble powder.

4.7 Compressive strength

Compressive strength measure by compressive strength testing machine after curing of 7 days and 28 days on 3 cubes (50 x50 x 50 mm) size.

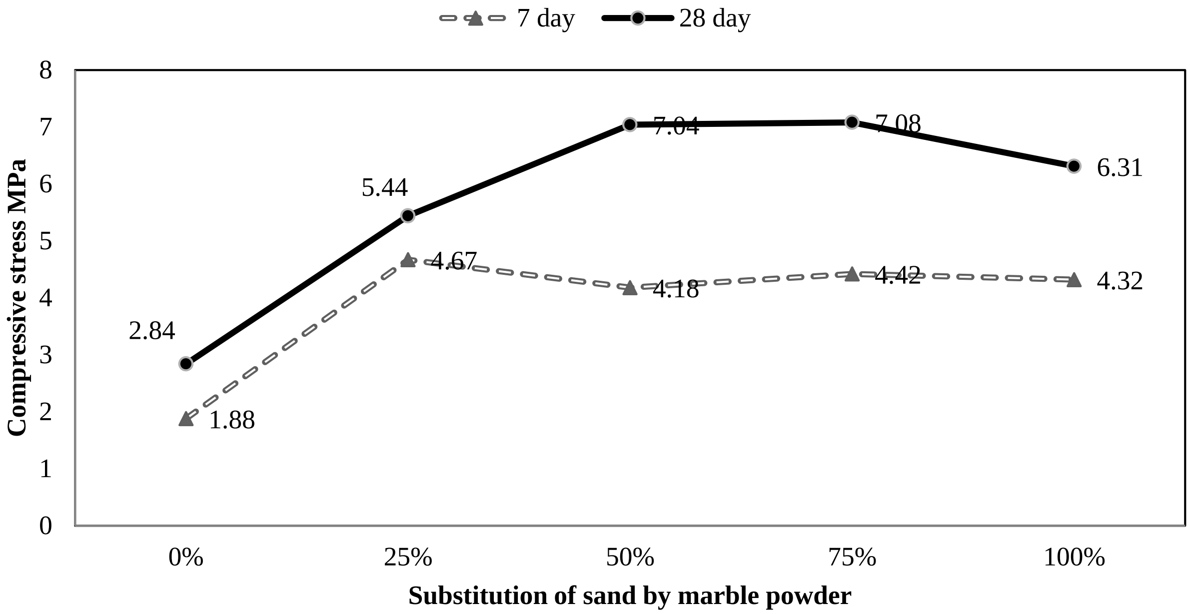


Figure 1.7 Variation in Compressive strength V/S Substitution of marble

Fig 4.7 show that maximum compressive strength occurs at 7 days, 25% replacement of sand by marble slurry and 50% replacement give maximum compressive strength at 28 days.

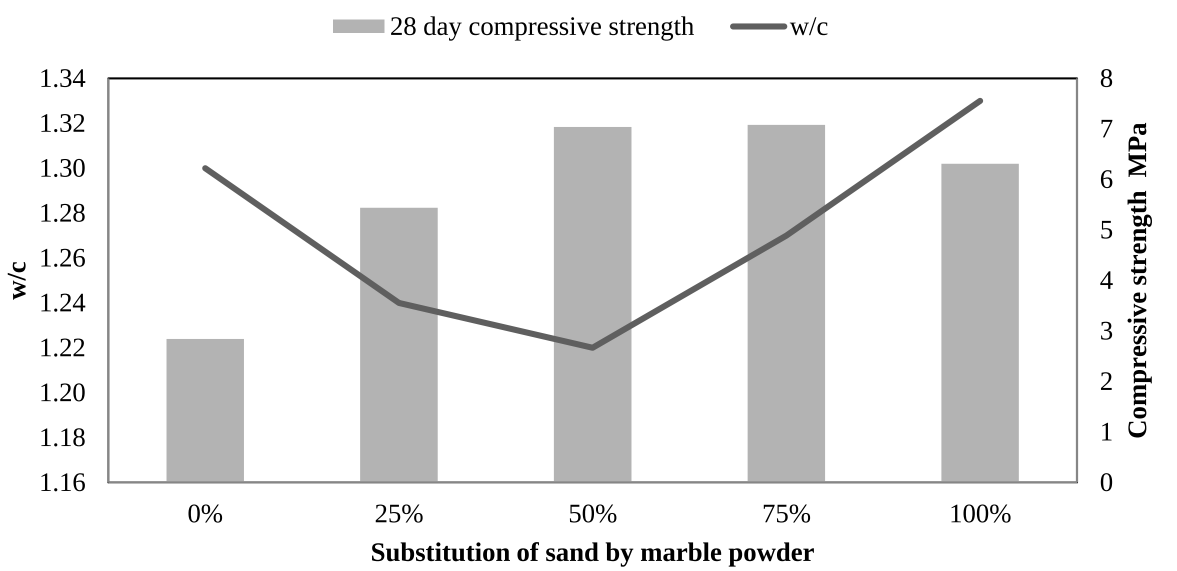
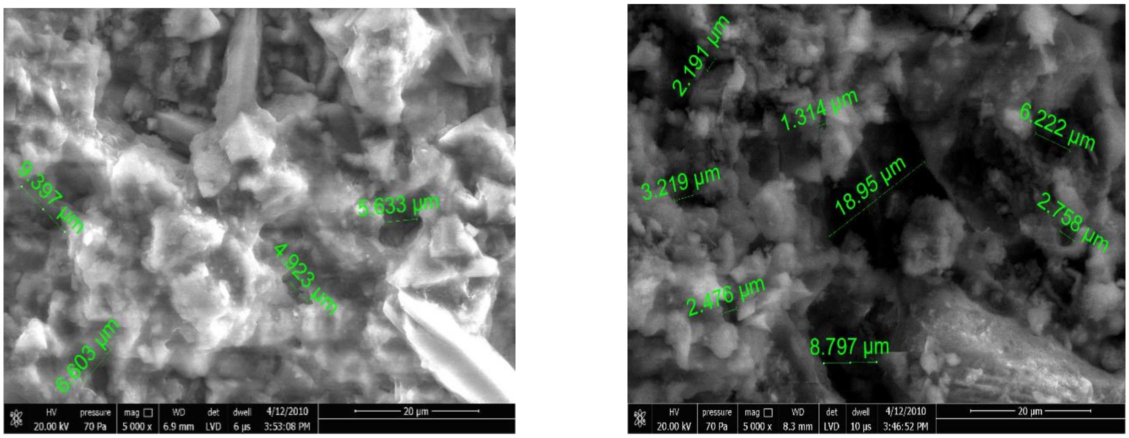


Figure 1.8 Relation b/w compressive strength, w/c ratio and substitution of sand by marble powder

Fig. Show that 50% substitution of sand by marble powder find out minimum w/c ratio (1.22) on give the maximum strength.



Control mix **50% replacement of sand by marble powder**

Figure 1.9

4.8 Water absorption, density and voids

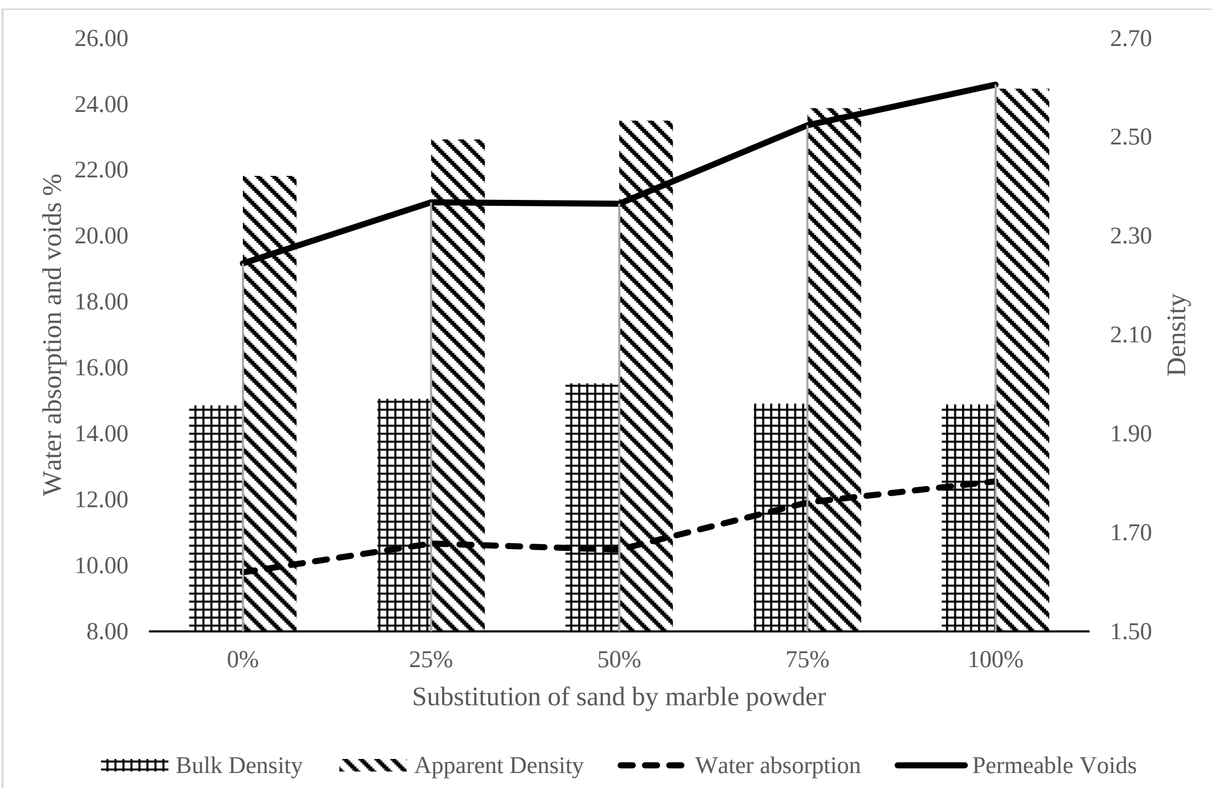


Figure 1.10 Water absorption, density and voids

Fig.show that water absorption of control mix 9.79%, after the replacement of sand by marble powder water absorption increase up to 100% replacement. Then so no proper good result find out by this replacement. But 50% replacement mix (ZN), show water absorption nearly control mix. If permeable voids increase so water absorption property also increases.

4.9 Ultrasonic pulse Velocity Test

The method measuring the time of travel of an ultrasonic pulse passing through the mortar being of 70mm side of cube. Higher velocity is obtained then mortar quality is good in terms of density, uniformity, homogeneity etc.

Maximum pulse velocity at 50 % substitution of sand by marble powder =3987.3 m/s

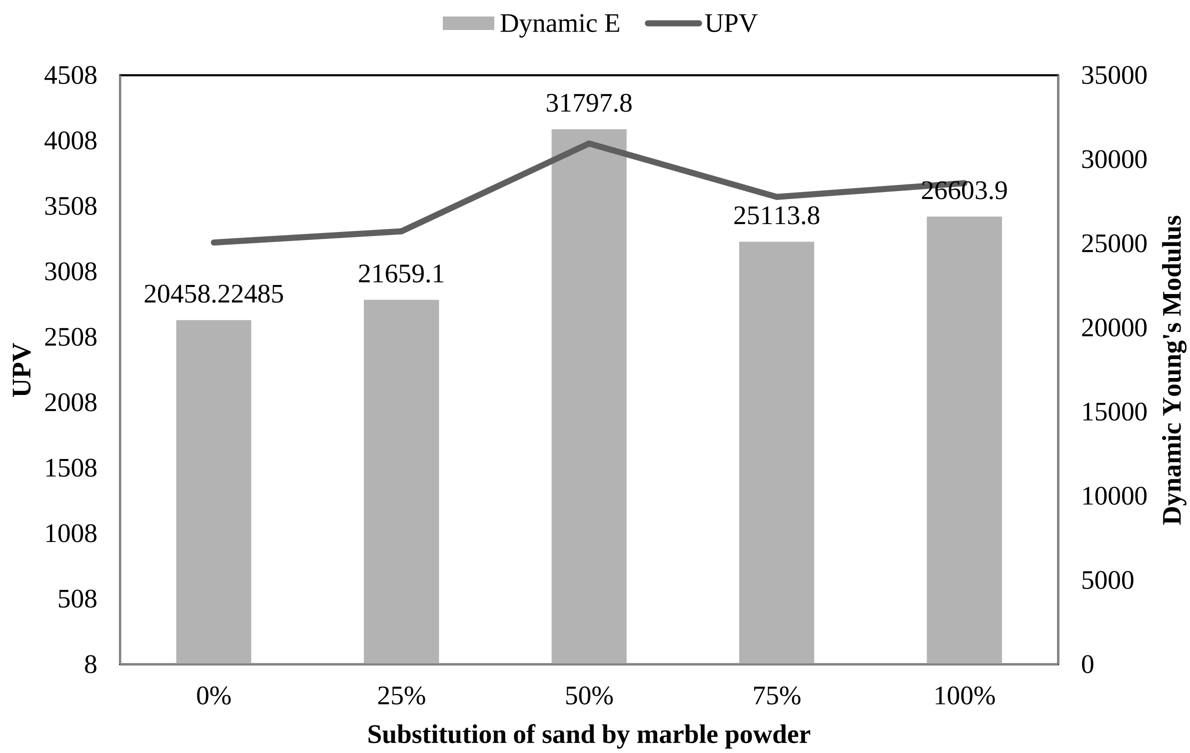


Figure 1.11 Relation b/w UPV, dynamic young modulus and substitution of sand by marble powder

4.10 Rate of water absorption (Capillarity test)

In this graph show that 100 % substitution of sand by marble powder more capillarity compare to control mix. But 25% and 50% substitution less water capillarity to control mix. Here ZN(50%) sample give more compressive strength and less capillarity than control mix.

Table 1-6 Capillarity test

Sample	Water absorption(g)/100cm^2			
	0.25h	**1h**	**4h**	**24h**
Z(0%)	21.3	42.7	77.3	81.3
ZK25%)	13.3	29.3	61.3	86.7
ZN(50%)	6.7	12.0	37.3	80.
ZX (75%)	17.3	37.3	81.3	109.3
ZM (100%)	28.0	57.3	93.3	98.7

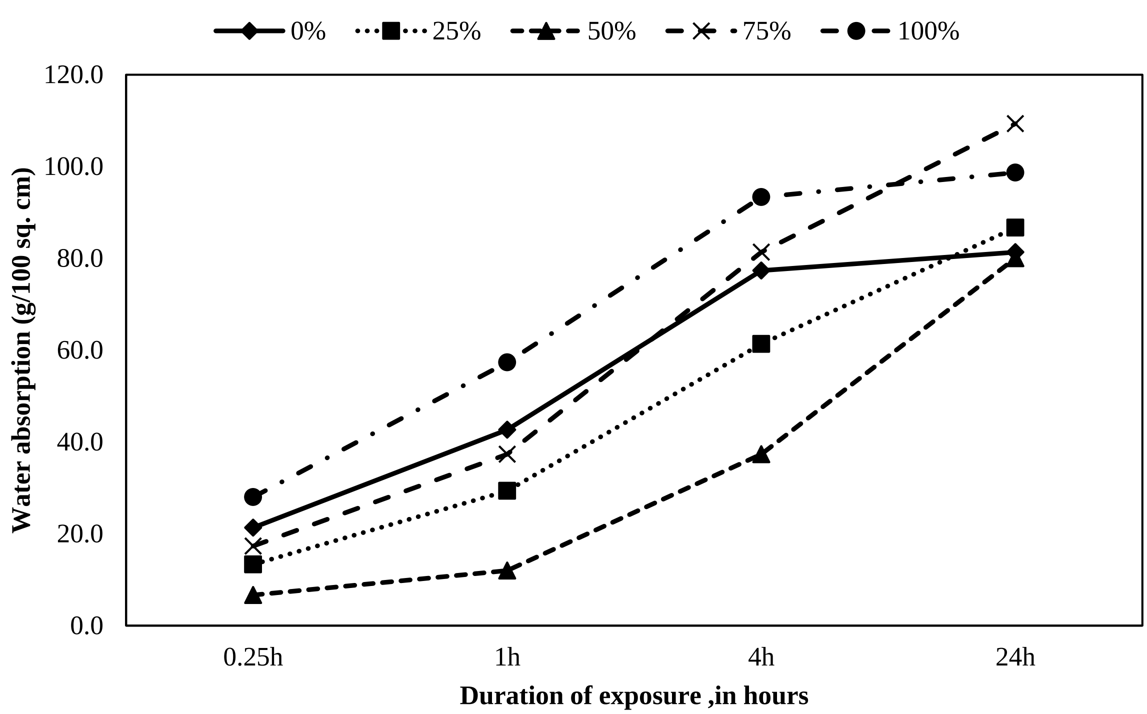


Figure 1.12 Water absorption v/s duration of exposure

4.11 Shrinkage

Drying shrinkage measure by length comparator after 4, 11, 18and 25 days of air storage room. Graph show that initial day shrinkage increase but last days (25 days) shrinkage almost constant. 25% and 50% substitution of sand by marble powder drying shrinkage are less in starting days than control mix.

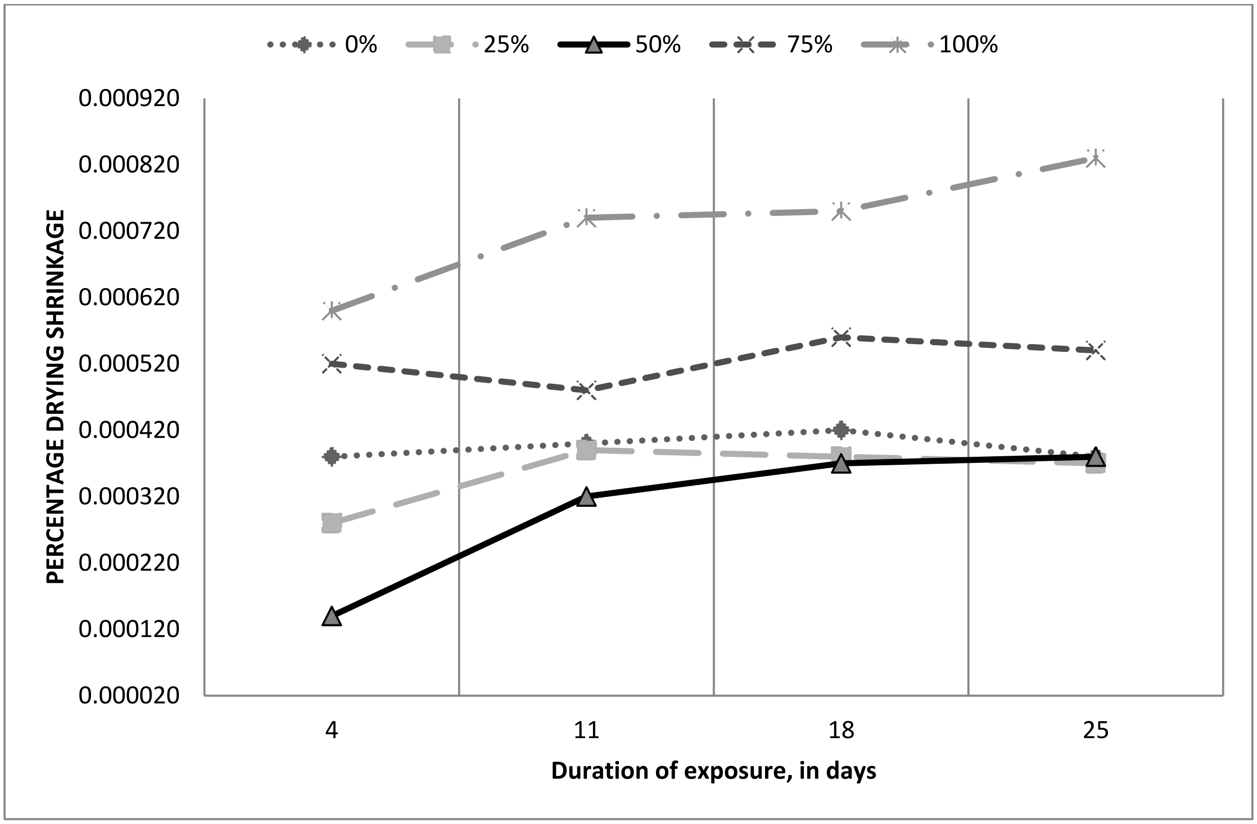


Figure 1.13 Drying shrinkage % and duration of exposure

4.12 Durability

4.12.1 Sulphate Attack

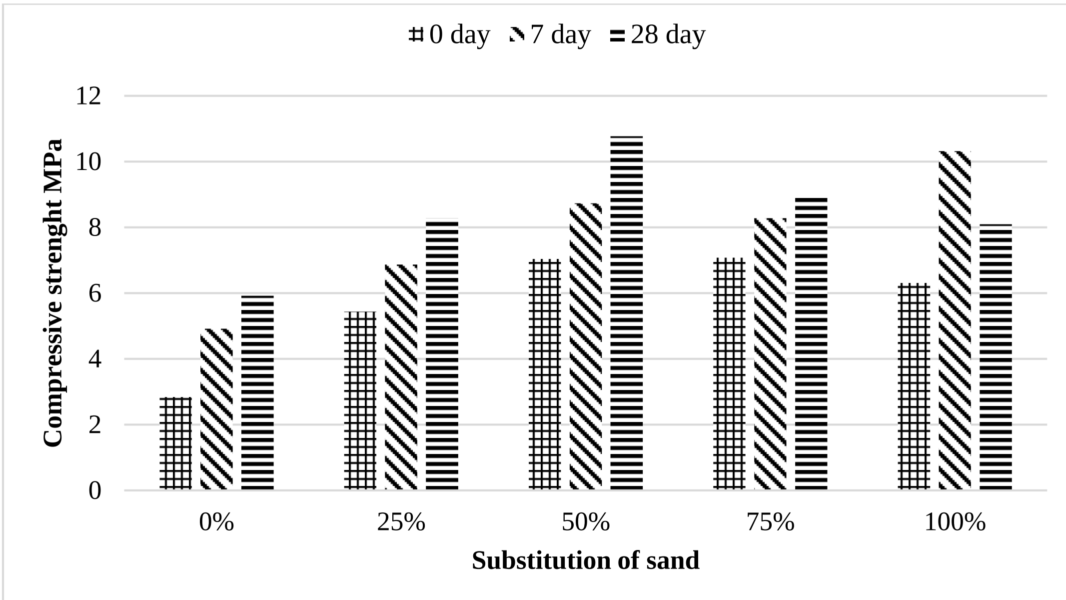


Figure 1.14 Compressive strength in Sodium sulphate solution

Fig.4.14 show that compressive strength continues increase when substitution of sand by marble powder increase and all pass the control mix. Results show that compressive strength of mortar does not effected by sulphate attack. Maximum compressive strength occurs at 50% substitution 10.77 kN/mm^2.

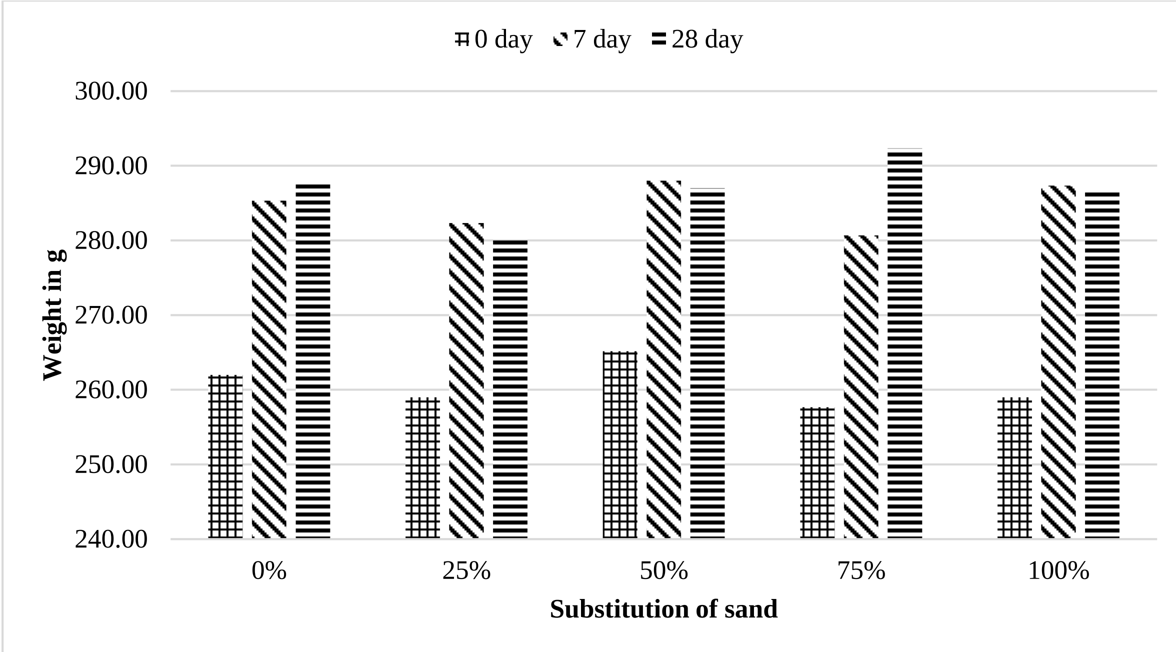


Figure 1.15 Change in mass when exposed in Na_2SO_4 solution

Fig.4.15 show that less weight change is 8.20% in 25% and 50% substitution of sand by marble powder .more change in 75% substitution is 10.68% occurs.

4.12.2 Acid Attack

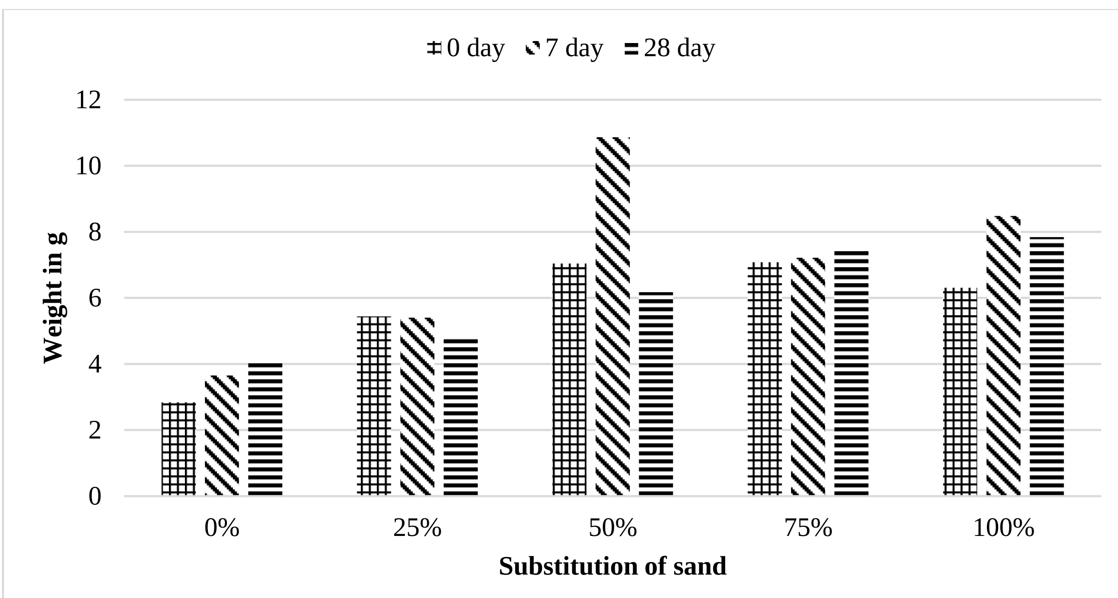


Figure 1.16 Change in compressive strength when exposed to acid solution

Fig. 4.16 show that compressive strength slightly increase at 7days when put in acid solution but 50 % substitution in 7 days compressive strength more increase.

In this graph compressive strength at 28 days more than control mix when exposed in acid solution.

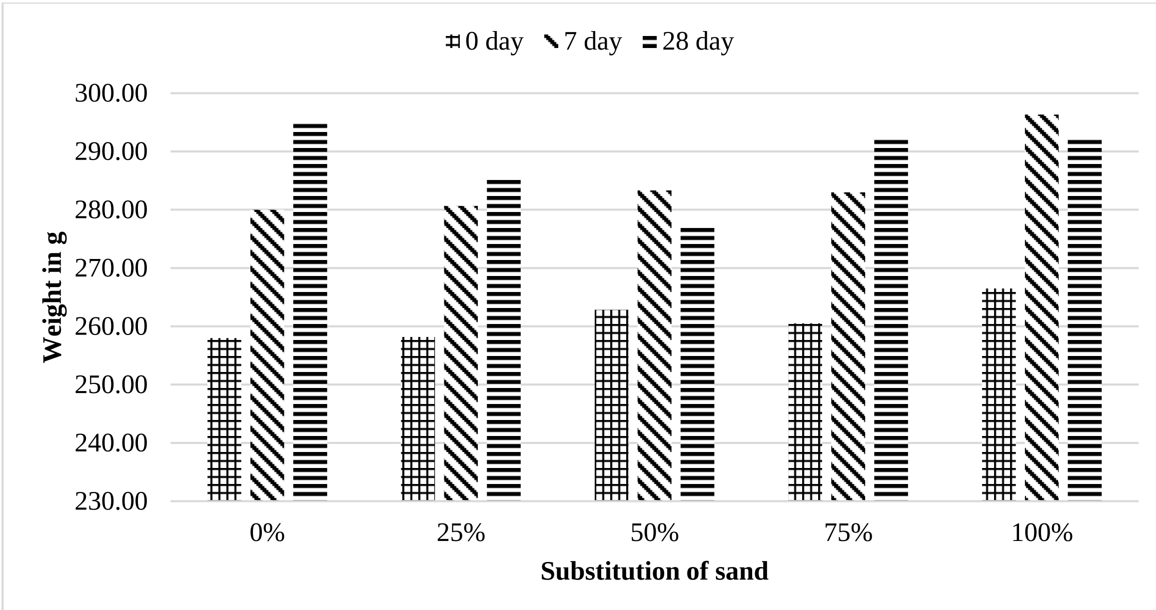


Figure 1.17 Change in mass when exposed in acid solution

4.12.3 NaCl Attack

Table 1-7 NaCl Attack

Marble powder as % of total fine aggregate	Penetration Depth(mm) at 28 days
0(Z)	Full
25(ZK)	Full
50(ZN)	15mm
75(ZX)	25mm
100(ZM)	Full

Figure 1.18 at 7 days ZN (50% Replacement of sand by marble powder), ZX(75% Replacement) Sample

Figure 1.19 ZN (50% Replacement of sand by marble powder) sample at 7 day

Figure 1.20 ZN (50% Replacement of sand by marble powder) at 28 days

CHAPTER -5

CONCLUSION

1. At 50% Replacement of sand by marble powder maximum strength is achieved, but in all other cases (25 to 100%) of substitution compressive strength is always greater than the control mix. It means that replacement of sand by marble powder enhance the compressive strength of the mortar.
2. Rate of water absorption is less than the control mix in case of 25% and 50% substitution but in others cases(75%, 100% substitution) it is more than the control mix.
3. Initial day shrinkage increased with increase in marble content for 75 and 100% substituted mixes. 25% and 50% substitution of sand by marble slurry drying shrinkage are less in early ages of testing is less than control mix.
4. After the replacement of sand by marble powder water absorption is almost same in 0% and 50% substitution. But other cases water absorption is more than the control mix. This increase in water absorption is due to increase in permeable voids.
5. In case of Durability test, 50% replacement shows the good result in case of both sodium sulphate and acid attack. Change in % weight is also less than the control mix in case of 50% substitution.
6. In case of sodium chloride test, sodium chloride partial penetration in 50% and 75% substitution. But in other cases full penetration of sodium chloride was recorded.
7. Based on the result we can recommend that 50% substitution is optimum substitution. It can be used for the hydraulic structures.

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