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Assessment of Potential of Marble Slurry as a Mineral Admixture in Concrete: A Review

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ABSTRACT

Marble is a metamorphic rock composed of recrystallized carbonate minerals, most commonly calcite or dolomite. Marble is typically not foliated, although there are exceptions. In geology, the term marble refers to metamorphosed limestone, but its use in stonemasonry more broadly encompasses unmetamorphosed limestone. Marble is commonly used for sculpture and as a building material.

Quite a few industrial by-products have found their use as a partial replacement of cement. Also, they have been found to positively influence the properties of concrete. Fly ash (FA), silica fume (SF) and blast furnace slag (BFS) are the by-products of a coal-based thermal power plant, Ferro-silicone industry, and steel industry, respectively.

Cement industry all around the world is facing the pressure of continuously rising demand as there is a need to develop an enormous amount of infrastructure, such as power plants, roads, and ports, finding an alternative material, which can partially replace the cement clinker, are one of the best ways to meet this challenge. The experimental program, design compositions of the experimental samples and the methodology adopted to conduct the experimental trials. In first section material used in making of the cement mortar and the concrete mixes, and then their physical & chemical composition are determined. Concrete mix proportions, their design compositions and mixing procedures are mentioned in the second section. In the third section the experimental setup, tests adopted, reference codes used for testing have been discussed in detail.

KEYWORDS: *Marble Slurry, Compressive Strength, Tensile Strength, Concrete Mix, Physical & Chemical Composition, Partial Replacement*

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1. INTRODUCTION

This chapter gives an overview of the research work presented in the thesis. It begins with a description of research background which provides an outline of waste marble dust production in India and needs for it to be used in the construction sector, especially in cement industry. In addition, motivation to pursue this work, research aims and objectives are provided in this chapter. Finally, it discusses the organization of thesis.

Marble processing

Marble is a metamorphic rock composed of recrystallized carbonate minerals, most commonly calcite or dolomite. Marble is typically not foliated, although there are exceptions. In geology, the term marble refers to metamorphosed limestone, but its use in stonemasonry more broadly encompasses unmetamorphosed limestone. Marble is commonly used for sculpture and as a building material.

The size of solid particles may vary from 1 micron up to hundreds of millimeters Marble Slurry is a suspension of marble fines in water, generated during processing and polishing, etc. It comes inform of cake after drying and in powder form after grinding. Making different kind of environmental hazards.

It is shaping to major threat of the Environment in the state by mining and processing activities. According to references given below marble slurry can be utilized in preparing cement mortar up to some extent.

Marble is a common construction building materials used since ancient times. It is a condensed variety of restructured limestone and has a crystalline structure. The main constituents of marble are dolomite and calcite. These large amounts of wastes produced by marble processing industry are dumped as unused wastes. The dust causes environmental degradation and escalates health problems in the surrounding areas. Also, the waste dust clogs agricultural lands causing long- term damage to the soil and crops. Figure 1-1 shows the percentage waste produced in the marble industry mostly dumped as unused materials. Figure 1-2 shows the dry dumped marble slurry and being crushed and sieved before using.

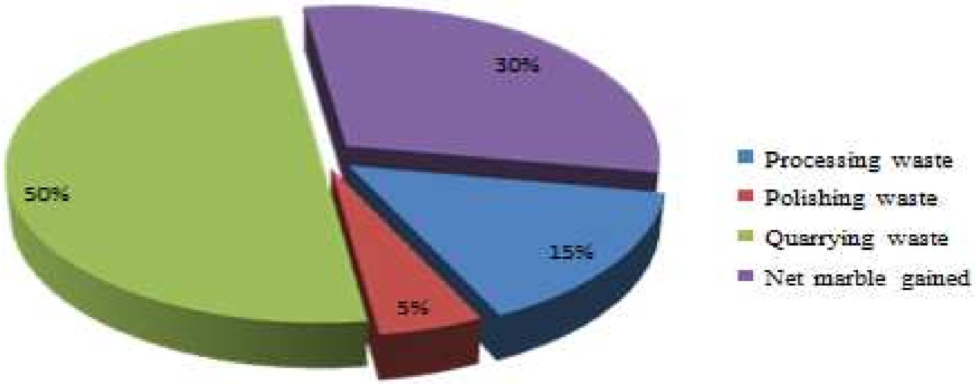

Figure 1-1: Percentage waste produced in marble industry (MSME 2008)

Figure 1-2: Dumped and dried marble slurry crushed and sieved before using

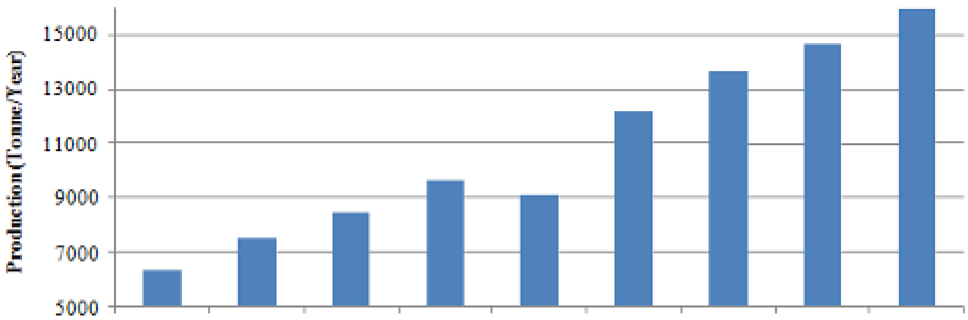

Figure 1-3: Year wise production of marble (MSME 2008)

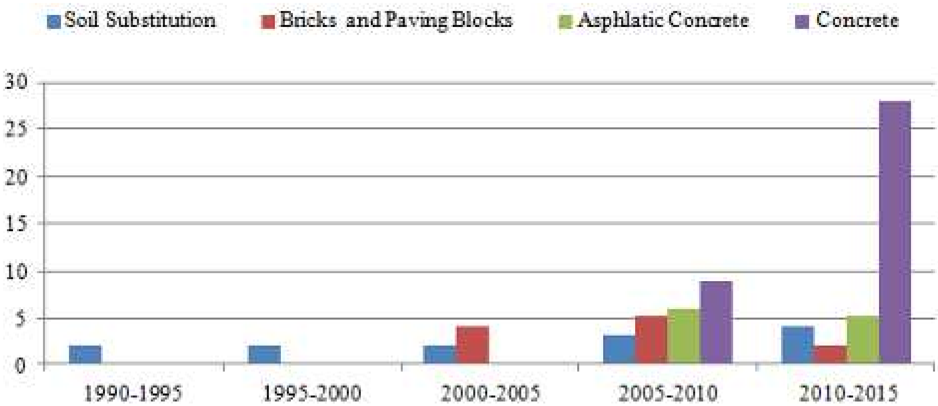

Figure 1.4: Trend in studies conducted in various usage areas of marble dust

CONCRETE AND CEMENT PRODUCTION

Figure 1-5 shows percentage consumption of cement in the construction industry.

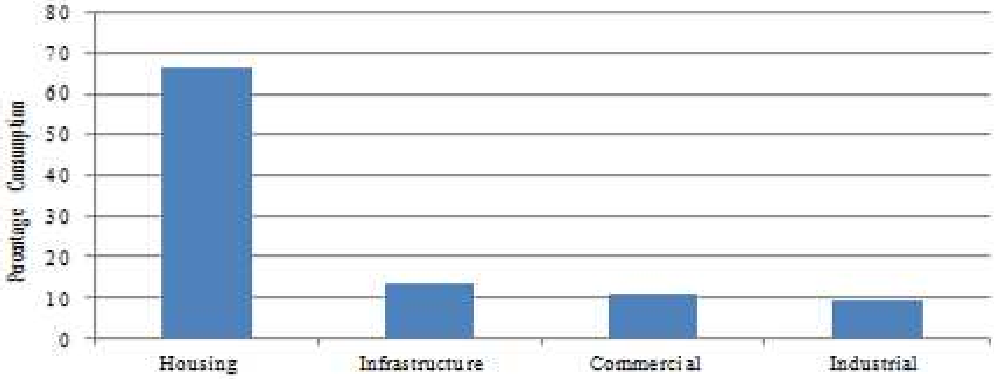

Figure 1.5: Percentage consumption of cement in construction industry

Quite a few industrial by-products have found their use as a partial replacement of cement. Also, they have been found to positively influence the properties of concrete. Fly ash (FA), silica fume (SF) and blast furnace slag (BFS) are the by-products of a coal-based thermal power plant, Ferro-silicone industry, and steel industry, respectively. On the other hand, rice husk ash (RHA) is agro-waste product ash. Metakaolin (MK) is not an industrial waste, but it is produced by the calcinations of Kaoline (China clay), naturally occurring clay. They have been further classified as three general types of mineral admixtures: filler materials, pozzolans, and latent hydraulic materials. Filler materials are non-hydraulic materials, such as finely ground limestone or quartz. Finely-ground filler materials added to concrete can accelerate hydration reactions by providing nucleation sites for the early-age hydration products even before the commencement of pozzolanic reaction and also their particles fill the intergranular voids between cement particles, thus improving the compactness of concrete (Lothenbach et al. 2011; Moosberg- Bustnes et al. 2004; Rahhal and Talero 2005). A hydraulic material is one that can directly react with water to directly form hydration products that have cementitious properties. Even though such materials do not need the presence of Portland cement for hardening and strength gain, these reactions get accelerated in the presence of cement. Ground granulated blast furnace slag falls under thiscategory.

All these waste materials have gained a lot of attention in the recent past and have found uses as supplementary cementitious materials in the concrete industry. However, marble powder has not gained much attention which gives the authors the motivation to study this material in detail as a part of their research.

Need of the research

The motivation of this study is the gainful utilization of waste marble slurry produced during quarrying and processing of marble. A few reasons why this material is chosen are discussed below;

- Cement industry all around the world is facing the pressure of continuously rising demand as there is a need to develop an enormous amount of infrastructure, such as power plants, roads, and ports, finding an alternative material, which can partially replace the cement clinker, are one of the best ways to meet this challenge. Because theusage of mineral admixtures mentioned in Table 1-1 has been well established, there is a growing need to introduce new supplementary materials that have a potential to replacecement.
- The state of Rajasthan which accounts to 85% to total country's production of marble dust is facing a serious problem with the disposal of waste marble powder without any use. This has proved a malady to the society bringing about potential risk to human, plant and animal growth. Research shows that the inhalation of marble dust provokes pathological changes in lungs and there is a positive relation between respiratorylesions and marbledust.
- The marble slurry incorporated concrete can prove to one of the very effective materials for the continued growth of the infrastructural needs of any country. Apart from reducing the consumption of cement by a significant amount, it is eco-friendly as it uses the industrial waste, which is the primary motivation for this research.

Table 1.1Properties and uses of mineral admixtures

Type of MA	Production	Optimum replacement	Nature	Uses
FA	FA is produced when coal is burnt during power generation at about 1600ºC (2912ºF) (ACI 2006)	The IS Specification for PPC (Atiş 2003) allows the addition of **15 to 35%** PFA to cement as a replacement.	Very fine- Filler Otherwise- Pozzolanic	Use as a pozzolan for part replacement of cement
GGBS	GGBS is a by-product of iron manufactured in a blast furnace. (Newman 2003)	Generally, **25 to 70%** of cement is replaced with GGBS in the concrete (Higgins 2010).	Latent Hydraulic Binder.	GGBS is used as a direct replacement for Portland cement, on a one-to-one basis by weight. Also, it is used in in-situ soil stabilization. (Suresh and Nagaraju 2015)
SF	*SF* is a by-product obtained after reducing high-purity quartz with coal in electric arc furnace by heating upto 2000ºC (3632ºF) during the production of silicon.	Found to improved concrete properties for **upto 15%** replacement of cement. (Thomas et al. 2012)	A highly reactive pozzolan	Use as a pozzolan for part replacement of cement
RHA	*RHA* is produced by slow burning of rice husk at a temperature between 500 and 700ºC (932 to 1292ºF) (Neville and Brooks 2010)	Improved durability when replaced cement upto **30%** by mass.	RHA has high pozzolanic activity due to non-crystalline silica and high specific surface area	RHA has been used in lime pozzolan mixes for partly replacement of Portland cement (Zhang et al. 1996)
Metakaolin	Metakaolin (MK) is obtained by subjecting kaolin clay to heat treatment (calcination) at 500-800°C. (Shvarzman et al. 2003).	**15% cement replacement** by Metakaolin is superior to all other mixes (Narmatha and T.Felixkala 2016)	Pozzolanic material	Use as a pozzolan for part replacement of cement
Limestone	Naturally occurring mineral in form of Dolomite and calcite.	Limestone is found to be optimally suitable upto **10%** replacement levels. (Bentz et al. 2015)	Filler material	Used as partial replacement of cement.

ORGANIZATION OF THESIS

This thesis consists of seven chapters and is organized in the following manner.

Chapter 1 is the Introduction, which highlights the need of use of marble slurry in the construction industry, especially as a partial replacement of cement in concrete. It also presents the motivation of this study, followed by the objectives of the thesis work. The remainder of the thesis is as follows.

Chapter 2 reviews the prior research conducted on the use of waste marble slurry in the construction industry and in detail concrete industry as a partial replacement of cement and sand, in the current scenario. On the basis of the technical review, research gaps are specified and accordingly the objectives of the thesis are defined.

Chapter 3 shows some preliminary investigation conducted on environmental impact analysis of using marble dust in concrete and also an overview of how particle packing of concrete is affected on partial replacement of sand and cement by marble dust.

Chapter 4 discusses the materials, design compositions of the experimental samples and the methodology adopted to conduct the experiments.

Chapter 5discusses the results obtained from the characterization of materials and experimental investigations on tests conducted on cement, mortar, and concrete.

Chapter 6 discusses the methods and data arrangement for analytical modeling of data to develop empirical relations, strength prediction models using regression analysis and Artificial Neural Networks (ANN).

Chapter 7 concludes the thesis work with the contributions, practical implications, limitations and proposes the future work. Guidelines for the use of waste marble slurry in concrete as a partial replacement of cement are proposed in the thesis based on the literature review, experimental and analytical investigations.

2. LITERATURE REVIEW

This chapter describes a state of art literature review on the use of waste marble dust in construction industry. Initially, studies related to life cycle assessment of concrete have been discussed. The literature was reviewed for both partial replacements of cement and sand to compare the effects. However, the main focus of study is partial replacement of cement by marble dust. The latter part of this chapter involves discussion of literature on the use of regression analysis and ANN in developing prediction models for concrete. Finally, gaps in the present research and scope of the work have been discussed.

Braga et.al. 2017- Nowadays LCA used widely in environment product such as TV and monitor and is observe. And even LCA of the concrete and the raw materials is carried out for the study of the impact on enviro. Some of the studies are environmental with economical comparison between natural. the various results can be noticed that which are recycled from concrete can reduce environmental impact and cost.

Munir et al. 2017- A 10 to 20% decrease in compressive strength at the late age has reported 10% replacement of the cement by the marble dust. It has observed with increase of marble dust strength falls up to 10 N/mm^2 for replacement ratio of 15% to 20%, and the falls was uniform after 15% replacement. Decrease could be the reason for the fall in strength.

Aliabdo et al (2014) reported 1, 10 and 12% increases 5% and 10 % cubes, while 5% lower. They also done 10% as a suitable % of addition of the marble in the cement production found that the strength of specimens with WMP as replacement of cement increased with the time, could be attributed to hydration process. It has been observed that the strength after replacing 10% cement with wmp. Wmp can also helpful to increase binding property of concrete matrix through reaction of calcite with c3a. It has been also stated that it is neither a pozzolanic material nor a fully inert material and it can react with C3A.As a result of this reaction, binding of concrete matrix improves leading to increase in the strength.

reported better results For the sand the sand replacement a 10% of decrease in has observed and for cement replacement 20% decrease has observed this shows that the without changing workability, in almost all identical results are reported for the 10% replacement of the sand with the marble dust. marble dust exhibits filler effect and does not takes part actively in hydration process. Further studies hydration process. scanning electron microscope, X-ray diffraction, and thermo gravimetric analysis of the dried samples were performed. these results reported by the author were almost similar, according to his study SEM images of the hydrated mortar with the marble dust shows an increase in the porous area thus making the structure less homogenous comparing with control paste. CHS gel and the needles of the ettringite has seen are also complied with results as strength has found to decrease with incorporation of the marble dust. lesser dense indistinct calciaum silicate hydrate gel was reason stated for negative effect on the compressive strength. TGA profits of the cement paste samples shows that no change in the chemistry phase. XRD also shows no significant qualitive change in phase composition on using marble dust as partial replacement of cement in the mortar. results indicates that marble dust does not cause any change in phase compositions of concrete mix and behaves as an inert material which is similar to findings from TGA.

Knoeri et al.-2013 – analysed six stages of life cycle of the concrete, use, and the demolition. and concrtete aggregates, found out that material is in natural aggregates. according to study life cycle stage of concrete C & DW reuse and natural aggregates with higher EI are- extraction, transportation and material operation. the production.

Rana et al. -2015- found a reduction in the capillary pores when comparing control concrete with mix 10% marble slurry as the partial replacement of the cement in SEM images. the dense microstructure of the concrete contain upto 10% marble dust has stated as reason of enhanced durability of the concrete. for the TGA analysys observed that mix control. they reported also that as replacement % increased, the weight lost by samples due to the decomposition of the carbonates also increased. marble that the in TGA analysis the 700^{0}C. reason states has similar compressive strength. there is ambiguity in the results reported by different author. it is requires to perform a detail micro structural analysis to confirm the actual effect marble dust has on hydration process of the cement.

Tikkanen et al. 2014- rock residues of the calcium carbonate. origin and physical, even though they have almost similar chemical nature. In general, these are used as construction material and as raw material for various other industries. Limestone. There are 2 dissolve. marble is formed when the carbonate material in limestone gets recrystallized. The internal carbonate crystal of the lime stone and the marble are different fron each. according to the literature, calcite and the dolomite has been found to be the constituents of marble dust. However, calcite is the main constituent. They would differ in the result depanding upon and its polymorphs present in both the marble dust and lime stones are available as fine powders to be used in concrete. Fine powders may have been found to have 3 types on effects.

Matshei et al. (2007) whichever properties of concrete are affected on addition of the filler depands mainly on amount of the material and wheter its is used as replacement or as an addition. After a certain percentage, the fillers start acting as diluents and thus reducing the compressive strengths compared to control concretes.

Factors as particle size distribution and density of the mix, the type of cement and usage of plasticizer also are significant for the properties of frwesh and the hardened concrete. Research explain the=at cement samples with the lime stone has the largest strength as compared to some pozzolonic fillers. In the early age samples, a maximum increase of about 10 % in strength on cement by the lime stone were noted. It has been conludeded that the reason of increase in strength could be accelerated cement hydration due to availability of crystaliation nuclei provided by that filler. Thus calcite is for 2 function one is to participate in hydration and other is as an inetr filer. In most studies, high levels of calcite have been used, such that most of them acts as fillers.

Bentz et al (2015) research investigation on aggregates on the concrete performace. They found fine limestone powders as clcite provides a favorable surface for the nucleatin and growth of calcium silicate hydrate get at early age, accelerating and amplifying silicate hydration, and act source of carbonate ions that participate in reaction with aluminate phases present in the cement. conversely the different crystal (andsurface) structure hence the surface area. These 2 formof caco3 have same solubility in water, aragonite contribute to an enhacement in the reactity of the aluminate in the investigate sytems, Specifically, carboaluminate formation. concretes, 10% of the OPC by volume can be substituted with an equal volume of the output will be appropriate.

WMP can also improve concrete matrix binding properties by reacting calcite with C3A. WMP is neither a pozzolanic nor a truly inert substance. It has the ability to react with C3A in cement. When WMP's CaCO3 (calcite) reacts with C3A, calcium carboaluminate is formed. However, no specific research has been done on this impact. As a consequence, research into the function whether calcite in marble slurry participates in the reaction with C3A in cement.

Tait and Cheung (2016) performed a comprising various cementitious blends from cradle to grave. The greatly enhances sustainability, but the addition of GGBS increases the mix design's environmental efficiency even further. Environmental a portion achieved in the 'no-allocation' and 'economic allocation' cases over the 'mass allocation' scenario assessment.

As can be seen from the studies above, there is no impact evaluation study of concrete with marble dust in the literature. As a consequence, it must be investigated before being used in concrete.

Rai et al (2011) For the same water cement ratio, it was discovered that replacing cement with marble dust had no major impact on slump values. The slump value decreases as the percentage of marble dust rises, according to Aliabdo et al. (2014), Arshad et al. (2014), Hebhoub et al. (2011), and Ergün (2011). The explanation given is that marble dust contains a high percentage of fines, which raises the demand for water in concrete. Gupta et al. (2008), on the other hand, found that as the percentage of cement substituted with marbledust increased, the slump values increased.

Gameiro et al. (2014) 0 percent, 20%, 50%, and 100% of fine aggregates were replaced with waste marble dust produced from quarries. Slightly altering the w/c ratio was found to be a successful way of achieving the desired workability. The use of marble dust as a partial substitute for sand resulted in a lack of workability, according to. Marble powder was used in place of sand, and since marble powder retains the least amount of water compared to basalt and silica sand, workability should have increased. Workability, on the other hand, decreased, which was consistent with the findings. The grading and shape of fine aggregates, the proportion of fine to coarse aggregates, and the characteristics of the materials, they concluded, are some of the factors that which affect the workability of concrete.

Rodrigues et al. (2015) The addition of marble dust to concrete did not result in a major improvement in bulk density. A maximum density increase of 2.3 percent was achieved. The use of superplasticizers, on the other hand, resulted in an increase in bulk density, which was more apparent as the reductive capacity of the superplasticizer increased. The compactness of concrete improves as a result of this reductive force. Similar outcomes have been published.

Silva et al (2014) Incorporating fine aggregates from marble quarrying waste into concrete, he says, had only a slight effect on bulk density in the fresh state. This was due to the fine, primary, and secondary aggregate bulk density values being identical. According to, using marble instead of sand decreases the bulk density of concrete. Jorge and Pedro (2012) discovered that the bulk density is determined by the aggregate bulk density as well as the mix compactness.

Vaidevi and Deshmukh et al. (2015) One of the most significant properties of concrete is its compressive power. It gives an understanding of concrete's long-term toughness. It is important to investigate the compressive strength of nominal concrete and concrete with mineral admixtures. Several studies performed by researchers to better understand the impact of marble dust addition on concrete compressive strength are discussed below. Reported 15% increase in the compressive strength by 15% replacement of cement.. A similar pattern was observed when an additional 20% marble dust by weight of cement was applied without replacing cement, resulting in a decrease in compressive strength of 7%, 4%, 5%, and 14% at the end of 28 days curing for specimens with 5%, 7.5 percent, 10%, and 15% marble dust when used as a partial replacement of cement. For a w/b ratio of 0.5, compare to the control combination. For a 0.5 w/b ratio, marble replacement of 5% and 7.5 percent increased strength, while 15 percent replacement resulted in a decrease in compressive strength. In concrete with a 0.40 w/b ratio, a 10% substitution of cement by marble dust resulted in a small improvement in compressive strength as compared to the control mix. Different conclusions have been drawn. The high compactness in concrete due to the void filling effect of marble dust is the reason given. The compressive strength of concrete cubes was tested for different percent replacements of cement and sand with marble dust (MD) and stone dust (SD) (SD). For 7 days, there is a 16.47 percent increase in initial compressive strength at 10% MP and 20% SD, and for 28 days, there is a 15.23 percent increase in compressive strength. For M20 grade concrete, the optimum percentage of cement replacement with marble dust powder is about 10% for both Ordinary Portland cement (OPC) and Portland pozzolona cement (PPC). The compressive strength of concrete was examined at various percentages of Metakaolin (MK) and Marbledust (MD). MKreplacement ranged from 0% to 13%, while MD remained steady at 0% and 10%. The ideal dosage for replacement was discovered to be 9% MK and 10% MD. According to Rodrigues et al. (2015), the use of superplasticizer resulted in higher compressive strength values as compared to the control combination. Reduction in water cement ratio was the reason stated for this effect.

Sakalkale et al.(2014) According to the report, as the amount of marble dust used to replace sand in concrete increases, the compressive strength of the concrete increases. In contrast to control mix specimens, there was also an improvement in compressive strength. There is a 10.72 percent improvement in compressive strength when sand is replaced with marble dust up to 50 percent. Up to 75 percent replacement resulted in an increase in compressive strength, while 100 percent replacement resulted in a decrease. The 25 percent replacement level was found to be the most effective, resulting in an increase in compressive strength, while the 30 percent replacement level resulted in a decrease in compressive strength. The properties of concrete containing marble dust (MD) and limestone dust (LD) were investigated (LD). When marble dust was used to replace 50% of the sand, the compressive strength was found to be higher than when limestone dust was used. Compressive strength improved for replacement ratios up to 15%, which could be due to the micro fine filler effect of marble dust.

The properties of the cement matrix and transition zone are improved as a result of this effect. The 0.50 and 0.40 w/b ratios followed a similar pattern. In addition, marble dust is more efficient for sand replacement when used with a lower water cement ratio. At 7 and 28 days, compressive intensity decreased in line with the addition of secondary marble fine aggregates.

Sahan Arel (2016) For marble powder incorporated concrete as a partial replacement for cement and sand, a simplified relationship of mechanical and toughness properties of concrete with compressive strength has been given. various experiments using marble dust as a cement and sand substitute, as well as statistical calculations quantifying the replacement of cement with marble dust and the use of dust aggregate.

Safiuddin et (2016) In the same way that the human brain processes information, neural networks, also known as artificial neural networks or parallel processing systems, are used to create models. When it comes to solving problems involving vast quantities of unpredictable and noisy data, the human brain excels. In order to produce intelligent decisions, neural networks seek to replicate the functioning of biological neurons. A neural network's fundamental structure is made up of artificial neurons. The neurons are also known as processing elements (PEs), nodes, neurodes, units, and other words, and are similar to biological neurons in the human brain that are grouped into layers. An input layer, one or more hidden layers, and an output layer make up the most common neural network structure. The basic technique for designing a neural network model for studying material behaviour is to train it using the results of a series of experiments with that material. If the experimental results contain appropriate material behaviour information, the trained neural network may contain enough material behaviour information to qualify as a material model. Early convergence is normal when a network is trained with only a few data tuples. To get more, you can increase the number of training data tuples, decrease the error, and increase the number of epochs.

Scope of the present study

Initially, an environmental impact comparison of normal concrete with the use of marble dust as a partial replacement of cement, as opposed to partial replacement of sand, is carried out in this report. On the basis of the properties of cement, mortar, and concrete, the scope of this study is limited to determining the effect of partial replacement of cement with waste marble dust. The effects of marble dust on the hydration phase of cement and concrete were examined in this research. Experiments on the impact of partial cement replacement on the mechanical and durability properties of hardened concrete were also carried out for various water binder ratios and curing ages. With predictive variables such as water cement ratio, cement content, percentage marble dust, coarse aggregate and fine aggregate content, admixture content, and slump, concrete compressive strength prediction models using Artificial Neural Networks (ANN) and regression analysis have been created. Finally, guidelines have been issued for the use of waste marble dust as a partial substitute for cement in concrete.

3. PROBLEM IDENTIFICATION AND OBJECTIVES

RESEARCH AIMS AND OBJECTIVES

- To characterize marble slurry using Thermo gravimetric Analysis (TGA), X-Ray Diffraction Analysis (XRD), Scanning Electron Microscope (SEM) and X-Ray Fluorescence (XRF)analysis.
- To study the effect of marble slurry addition in concrete and its implications on partial cement replacement in terms of Mechanical properties - compressive strength, elastic modulus, flexural strength & Poisson's ratio; Durability – permeability test, carbonation, abrasion resistance and sorptivity.
- To develop a correlation between the results of destructive compressive strength and nondestructive tests of concrete using the value of rebound hammer and ultrasonic pulse velocities with the help of multiple linear regression.
- Prediction of compressive strength of marble slurry incorporated concrete using Artificial Neural networks.
- To develop guidelines for partially replaced cement with marble slurry in concrete.

4. METHODOLOGY

In this chapter the material used and experiments performed on them are described. The experimental program, design compositions of the experimental samples and the methodology adopted to conduct the experimental trials. In first section material used in making of the cement mortar and the concrete mixes, and then their physical & chemical composition are determined. Concrete mix proportions, their design compositions and mixing procedures are mentioned in the second section. In the third section the experimental setup, tests adopted, reference codes used for testing have been discussed in detail. They have been further classified into mechanical strength tests, durability and microscopic tests.

MATERIALS

The binder material used was OPC (Grade 43) and marble dust. stone chips was used as a coarse aggregate. River sand is used in preparation of mortar and concrete according to IS 650-1996.

RAW MATERIALS

Raw materials used in this study and their properties are discussed in this section

Cement

OPC 43 Grade cement according to IS 8112-2013 & ASTM C150-2016 used as binding material for the preparation of cement mortar and concrete

for high and medium strength. Table 4.1 shows the physical properties of the cement and chemical composition in Table4-2.

Water

for the preparation of concrete and mortar and for curing normal tap water is used in the study.

Table 4.1 Physical properties of OPC 43 Grade cement.

Physical Characteristics	Values
Density (kg/m^3)	3090
Specific gravity	3.15
Fineness (%)	8
Normal Consistency	33

Table 4.2 Chemical properties of OPC 43 Grade cement.

Chemical composition	Values (%)
SiO2	20.27
Al2O3	5.32
Fe2O3	3.56
CaO	60.41
MgO	2.46
SO3	3.17
Loss on ignition	3.55

Aggregate

Crushed stone of maximum size 20mm is used as coarse aggregate. Table 4.3 shows size range of aggregate and physical properties of aggregates.

Table 4.3: Aggregates size & specific gravity

Physical Property	Fine Aggregate	Coarse aggregate
Size range (mm)	0.075 - 4.75	10.5 - 20
Specific gravity	2.45	2.72

Super-plasticizer

For the good workability, a water-reducing super plasticizer is required to be used. They are water-soluble polymers that dissolve in water to form long molecules that carry high negative charges. As the cement particles are dispersed by electrical repulsion between these negative charges, the combined water between the cement agglomerations gets freed and improves the workability of concrete significantly. Glenium B233 conforming to IS 9103 (2004) and ASTM C 494 (2016) was used an admixture for the present study. The properties are listed below in Table 4-4.

Table 4.4: Properties of super plasticizer

Parameter	Glenium B233
Structure of material	Modified Polycarboxylic ether
Color	Light Brown
Relative Density (kg/lt)	1.09 ± 0.01 at 25ºC
Chloride content (%)	< 0.2 %

Marble slurry

Marble slurry in waste form was collected from makrana Rajasthan, India. It was then characterized for physical, chemical and mineralogical properties, results of which are discussed in the next chapter.

Cement mortar

For cement mortar mixes, cement content was taken as 200 gms and standard IS sand as 600gms

i.e. a ratio of 1:3 for cement and sand according to IS 4031 Part 6 (1988). Standard IS sand according to IS 650 (1991) was used. Water content is calculated according to Equation (4.1)

W = (P/4 + 3) % of total weight off sand & cement mixed (4.1)

P- Normal consistency of cement.

The quantities mentioned here are for one specimen only. water cement ratio of 0.44 is adopted for preparation of the Mortar samples. in the study cement is replaced with marble dust in different percentages i.e. 0%, 10%, 15%, 20% & 25%. cubes of mortar were prepared in mortar cube moulds of dimensions

70.6 × 70.6 × 70.6 mm. The same proportion of mix is used for micro structural analysis and compressive strength properties.

Concrete mix proportions

All mix proportions are according to IS 10262 (2009) using the 10-20mm coarse aggregate is taken.3 water cement ratio 0.35, 0.40 & 0.45 are taken in the study.

Mixing procedures and curing methodology

The remaining samples to be tested for long term effects on the mechanical & durability properties were removed from curing tank after 28 days and kept under adverse environmental conditions in open atmosphere with temperatures ranging from 0ºC in winters to 47ºC in summers for 90, 180 and 360 days depending on their age of testing. Figure 4-3 shows the curing tank and samples kept in open atmosphere after water curing of 28 days.

Figure 4.1 Curing tank and samples kept after water curing

Table 4.5: Proportions of concrete mixtures

Water Binder Ratio	Cement (kg/m^3)	Marble dust (%)	Marble dust (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)	Admixture (L/m^3)	Water (kg/m^3)
0.35	422	0	0	1278	689	0.90	148
0.35	400.9	5	21.1	1278	689	1.00	148
0.35	379.8	10	42.2	1278	689	1.10	148
0.35	358.7	15	63.3	1278	689	1.20	148
0.35	337.6	20	84.4	1278	689	1.30	148
0.35	316.5	25	105.5	1278	689	1.40	148
0.4	394	0	0	1257.2	707.2	0.63	158
0.4	374.3	5	19.7	1257.2	707.2	0.67	158
0.4	354.6	10	39.4	1257.2	707.2	0.74	158
0.4	334.9	15	59.1	1257.2	707.2	0.84	158
0.4	315.2	20	78.8	1257.2	707.2	0.95	158
0.4	295.5	25	98.5	1257.2	707.2	1.00	158
0.45	351	0	0	1183	858	0.35	158
0.45	333.45	5	17.5	1183	858	0.39	158
0.45	315.9	10	35.1	1183	858	0.45	158
0.45	298.35	15	52.6	1183	858	0.52	158
0.45	280.8	20	70.2	1183	858	0.61	158
0.45	263.25	25	87.7	1183	858	0.70	158

TESTS ON COARSE AGGREGATES

The following tests are performed on coarse aggregate of maximum size 10mm, resticted as per IS Code 15658:2006.

Impact value test

Table 4.6: Recommended classification of aggregates using aggregates impact value

SI. No.	Aggregate impact value	Classification
1.	< 10%	Exceptionally strong
2.	10 – 20 %	Strong
3.	20 – 30%	Satisfactory for road surfacing
4.	> 35%	Weak for road surfacing

Crushing Value Test

All the crushing values of coarse aggregates are considered according to IS: 2386 (PART IV)–1963.Test samples are in range of 10-12.5mm size. The aggregate which has to be tested, should be oven dried for minimum 4 hours duration. The steel cup cylindrical in shape is filled in three layers of approximately equal thickness by CA & tamped with 25 strokes by the tamping rod with rounded end and the extra aggregate struck off from the top surface, using the straight edge of temping rod. After temping with rod net weight of the aggregates is determined (WA).

Then the whole assembly is placed in between the plates of testing machine and loaded at a uniform rate so as to reach a load of forty tons in ten minutes. Then the load is released and aggregate is removed from the cylindrical cup. The aggregates are then sieved on 2.36 mm and the fraction passing the sieve was weighed to an accuracy of 0.1 g (WB).

Aggregate crushing Value = (WB/WA) × 100

Figure 4.2: Crushing value apparatus

Abrasion Resistance test

Abrasion Value = ((W1 – W2)/W1)X 100

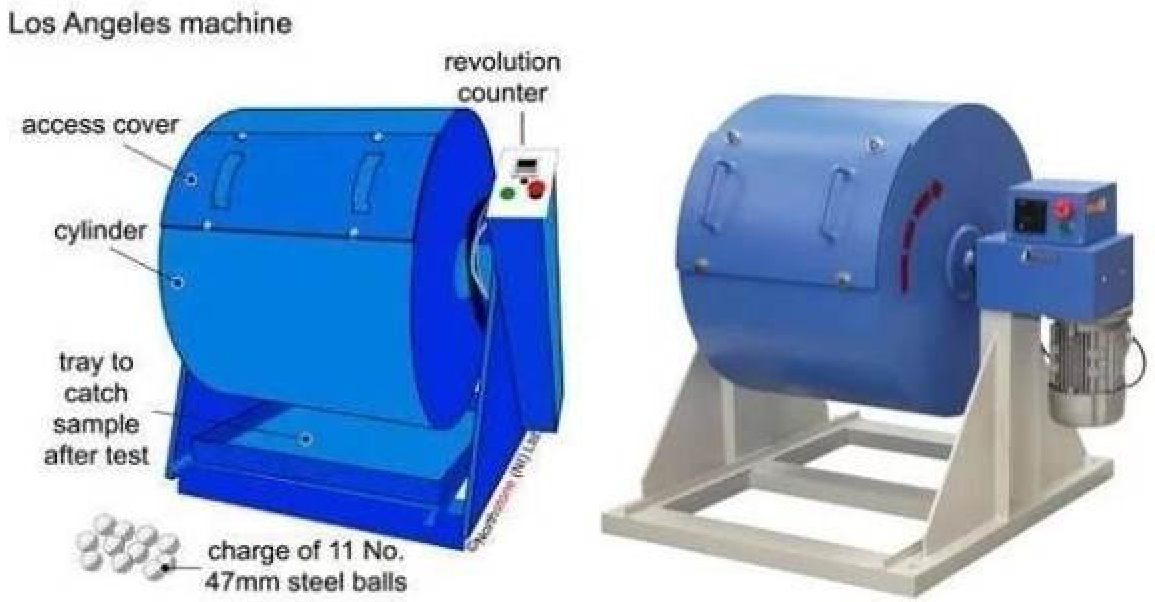

Figure 4.2: Los Angeles Abrasion resistance apparatus

Table 4.7: Grading of Test Samples (Source: IS:2386 (PART IV)–1963)

Designated sieve size	Weight of test sample	Grading of the coarse aggregate						
Passing (mm)	Retained (mm)	A	B	C	D	E	F	G
80	63					2500		
63	50					2500		
50	40					5000	5000	5000
40	25	1250					5000	5000
25	20	1250						
20	12.5	1250	2500					
12.5	10	1250	2500					
10	6.3			2500				
6.3	4.75			2500				
4.75	2.36				5000			

Table 4.8: Selection of abrasive charges (Source: IS:2386 (PART IV)–1963)

Grading	No. of steel bars	Weight of charge in gm
A	12	5000 ± 25
B	11	4584 ± 25
C	8	3330 ± 20
D	6	2500 ± 15
E	12	5000 ± 25
F	12	5000 ± 25
G	12	5000 ± 25

Table 4.9 : Pavement type & permissible abrasion value (Source - IS:383 – 1970)

Sr. No.	Type of pavement	Max. permissible abrasion value in %
1	WBM and sub base course	60
2	WBM base course with bituminous surfacing	50
3	Bituminous bound macadam	50
4	WBM surfacing course	40
5	Bituminous penetration macadam	40
6	Bituminous surface dressing, cement concrete surface course	35
7	Bituminous concrete surface course	30

Grading of coarse aggregates

Grading of 10mm nominal size aggregates is done as per IS code 456:2000.

Table – 4.10 : Gradation chart for 10mm size aggregates (Source: IS: 983 – 1970)

Sr. No.	Nominal size of aggregate (mm)	% Passing through designated sieve
1	10	85-100
2	4.75	0-20
3	2.36	0-5

Specific gravity

The specific gravity of coarse aggregates shall conform to IS:2386 (PART III)–1963. The aggregates should be dipped in a basket which should have a weigh balance. Then the weight of aggregates in the water as well as in the air is taken to calculate the specific gravity of coarse aggregates.

Figure 4.4: Specific gravity appartaus; Weighing balance

Tests on fine aggregate

The aggregate passing through 4.75mm are considered as fine aggregates. The tests should conducted according to the clauses given in IS:383-1970.

Grading of fine aggregate

Figure 4.5: Sieve Analysis

Tests on Cement

Tests on cement confirms to IS:4031(PART IV)-1988. The following test results assure the good quality of cement, and its suitability to use in construction of paver blocks as per requirement of IS:15658-2006.

Fineness of cement

Approximately ten grams of cement should be taken and kept the sample on the sieve. By uniform swirling, and linear movements, agitate the sample either manually or mechanically, until.

Figure 4.6: 90μ sieve

Consistency test

The surface of the paste should be smoothened and making it leveled at the top of the mould. Shake the mould slightly for the expulsion of the air. for filling the mould, only the operators hands and the blade of the gauging trowel shall be used.

Figure 4.7 : Vicat Apparatus for consistency of cement

Initial and Final Setting Time

The same experiment should be recurred in by keeping different positions of the mould till the plunger doesn't stop penetrating for 5mm from the bottom of the mould. The time consumed between, the moment water is added to the cement and the needle fails to penetrate in the mould for 5mm, when measured from the bottom of the mould, is known as the initial setting time**.** Then the needle is replaced with the another one which is having an annular attachment at its bottom. The cement is assumed to be completely set if the needle makes an impression there on the cement paste, while the annular attachment fails to do so. Time elapsed between addition of water and the moment at which needle makes an impression on the top surface of the mould, but the attachment cannot, is referred as final setting time of cement.

Figure 4.8: Needle used for initial 4.9: Needle with annular
attachment setting time Figure for Final setting time

Soundness test

Soundness of cement is calculated by Le-Chatelier method which is according to the IS: 4031 (Part III) – 1988. Le-Chatelier apparatus should conform to IS: 5514 – 1969, whose acceptable deviation for a load of 1000g is 1.0g. The mould is placed on a glass sheet and filled with the cement paste prepared cement with 0.78 times of the water required for standard consistency. Mould should be covered with an another sheet of glass then a small weight on this covering is kept after this submerge the whole assembly in water immediately at a temperature of 27 ± 2°C and place it there for one day. Then the distance is measured, keeping the indicator points apart, to the nearest 0.5mm (represented as D1). Submerge the mould again in water at the temperature prescribed above. Boiling point should be 25 to 30 minutes and keep it boiling for 3hrs. After the mould is removed from the water, allowed to cool. The distance between the indicator points is measured (designated as D2). (D 2 – D 1) represents the expansion of cement which represents the soundness of cement.

Figure 4.10: Le Chatelier apparatus

TESTS ON CEMENT MORTAR

Tests on drying shrinkage and compressive strength of mortar were conducted in this section.

Drying shrinkage

Drying shrinkage is associated with the hydration process of the concrete. Hydration of concrete continues for a very long time, so drying shrinkage also keeps taking place for a very long time. It is analogous to the drying mechanism of a wood specimen. No appreciable change in the volume comes due to the loss of free water contained in hardened concrete. But, when the water contained in gel pores is lost (under drying conditions), volume changes. This process continues for a long time.

Theoretically, total change in the linear dimensions of the concrete can be upto 10,000 microns. Practically, shrinkage upto 4,000 microns have been observed. Volume change apparatus were filled with the wet mortar. After 24 hrs, samples were taken out and measured using the length comparator. Then the specimen was put in hot air oven at a temperature of 110° C for 6 hrs. After 6 hrs, the samples were taken out and again measured in the length comparator.

Compressive strength of cement mortar samples
Mortar cubes were prepared in mortar cube moulds of dimensions 70.6 × 70.6 × 70.6 mm from the mixes prepared according to section 4.1.1.6 and were tested for compressive strength by loading the samples with a uniform load applied, starting from zero and gradually increasing at a rate of 35 N/ mm^2/ min. Failure load at the end of 28 days curing was noted for mortar cubes of size 70.6 x 70.6 x 70.6 mm as per IS 4031 (2014) Part 6. The samples were tested at a room temperature 27 ± 2 ºC. They were tested for micro structural analysis using XRD and TGA for change in hydration process.

Strength activity
In order to test whether marble slurry acts only as a filler material or any reaction takes place between calcite in marble and tri-calcium aluminate (C3A) in cement, strength activity test was conducted. Three cases were devised for preparing cement mortar blocks -

1. In the first case, 100 percent cement and standard silica sand were used.
2. In the second case, 90 percent cement and 10 percent silica sand were taken. Gain in strength would be due to 90 percent cement and filler effect of sand.
3. In the third case, 90 percent cement and 10 percent marble dust were taken. Gain in strength would be due to 90 percent of cement and filler effect of marble dust. If any extra additional in strength was observed, it would indicate towards possibility of a chemical reaction taking place.

Case 2 and 3 were planned in such a way that the material replacing cement are of similar particle size distribution. Silica sand (Standard sand) is chemically inert which is already well established. However, the aim of the study was to check whether marble dust reacts in one or the way to compounds present in cement i.e. whether it takes part in the hydration process or not. Both marble dust and silica sand would exhibit some filler effect because of their particle size distribution Therefore, if any extra strength is found in the case with marble dust it would hint towards a chemical reaction taking place.

The procedure for preparing samples used was as follows: Three mortar blocks each for 3 days, 7 days and 28 days curing were casted. Mortar pastes were prepared using 600g sand; 200g Portland cement for each cube and water content was taken according to standard consistency of cement paste, which was 31 percent. Mortar pastes were then mixed and cast in 70.6 x 70.6 x

70.6 mm moulds. All blocks were de-molded after 24 hours and placed in a water bath at 23ºC for curing. After removing them from the bath they were surface dried and finally tested for compressive strength. The strength activity index (SAI) is therefore reported according to Equation(4.7)

SAI = (A/B)* 100 (4.7)

where A is the compressive strength of the mix sample (MPa) and B is the strength of the control mortar (MPa).

Generally, for pozzolanic materials according to BS 3892, SAI results greater than 0.80 after 28 days are indicative of a positive pozzolanic activity for fly ash (FA) for a cement replacement of 30 percent. ASTM C 186 (2015) requires a SAI greater than 0.75 after 7 and 28 days for FA and natural pozzolans at a cement replacement level of 20 %.

TESTS ON HARDENED CONCRETE
MECHANICAL STRENGTH TESTS

Compressive strength
This test was performed in accordance with IS 516 (2004). The cubes are placed in such a way that the application of load is done to the opposite sides of the cubes as cast where the casting face and the testing face are perpendicular to each other. The load is axially applied without any shock and increased continuously at a rate of approximately 140 kg/cm^2/min. The maximum load sustained by the specimen is recorded and divided by cross-sectional area to obtain the compressive strength of the specimen.

Concrete cubes of 150 x 150 x 150 mm dimension were casted to test for compressive strength and tested as specified in IS 516 (2004). The cubes were tested for optimum dosage at 7, 28 and 56 days of curing age. Then the samples were also tested for 90, 180 and 360 days to study thelong term effect of partially replacing cement by marble slurry on concrete. Optimum dosage and long term effect was tested for all the water binder ratios i.e. 0.35, 0.40 and 0.45 and all percentage replacements i.e. 10%, 15%, 20% and 25%. Figure 4-9 shows the testing of concrete specimen for compression.

Figure 4.11: Compressive strength samples

Effect of dosage of super plasticizer on compressive strength

To study the additional effect of super plasticizer two mix proportions were prepared. One with increasing admixture dosage to maintain slump at 100 ±10 mm as shown in Table 4-5 and other with constant dosage of admixture as for zero replacement for each w/b ratio with decreasing slump were considered for the tests on compressive strength. They were tested after 7 and 28 days of water curing for a water binder ratio of 0.45 for all percentage replacements.

Effect of particle size on compressive strength

Split tensile strength

$$f_{ct} = \frac{2P}{\pi dl}$$

where
'P' is maximum load in kN
'l' is length of the cylinder in mm
'd' is depth of the cylinder in mm

The cylinders were tested for optimum dosage at 7, 28 and 56 days of curing age. Then the samples were also tested for 90, 180 and 360 days to study the long term effect of partially replacing cement by marble slurry on concrete. Optimum dosage and long term effect was tested for all the water binder ratios i.e. 0.35, 0.40 and 0.45 and all percentage replacements i.e. 10%, 15%, 20% and 25%.

Figure 4-10 below shows the testing of concrete cylinders for split tensile strength used in the present study.

Figure 4.12: Testing of concrete cylinders for split tensile strength

Flexural strength

Modulu.s of rupture fb is calculated using the following Equations (4.9) and (4.10)

$$f = \frac{(p \times l)}{b \times d^2} \qquad (4.9)$$

$$fb = \frac{(3p \times a)}{b \times d^2} \qquad (4.10)$$

where 'p' is maximum load in kN
'l' is length of the prism in mm
'b' is width of the prism in mm
'd' is depth of the prism in mm
'a' is distance between line of fracture to the nearest support in mm.

Equation 3.10 is used when 'a' is greater than 200 mm for 150 mm specimen, or greater than 133 mm for a 100 mm specimen and Equation 3.11 is used when 'a' is less than 200 mm but greater than 170 mm for 150 mm specimen or less than 133 mm but greater than 110 mm for a 100 mm specimen, where 'a' equals the distance between the line of fracture and nearest support, measured on the centerline of the tensile side of the specimen in mm as shown in Figure 4-11.

The beams were tested for optimum dosage at 7, 28 and 56 days of curing age. Then the samples were also tested for 90, 180 and 360 days to study the long term effect of partially replacing cement by marble slurry on concrete. Optimum dosage and long term effect was tested for all the water binder ratios i.e. 0.35, 0.40 and 0.45 and all percentage replacements i.e. 10%, 15%, 20% and 25%. Figure 4-12 below shows the testing of concrete beams for flexural strength used in the present study.

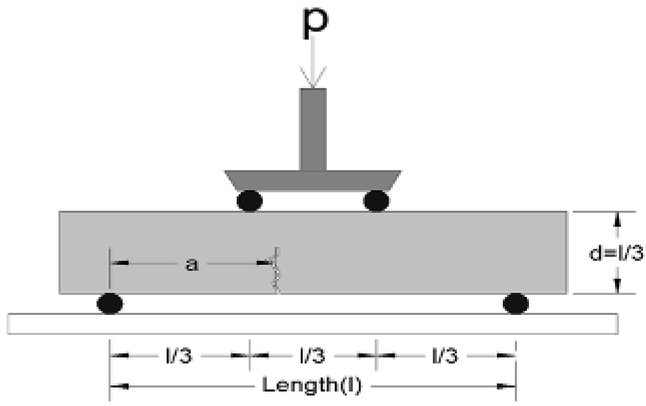

Figure 4.13: Flexural Strength test of concrete specimen

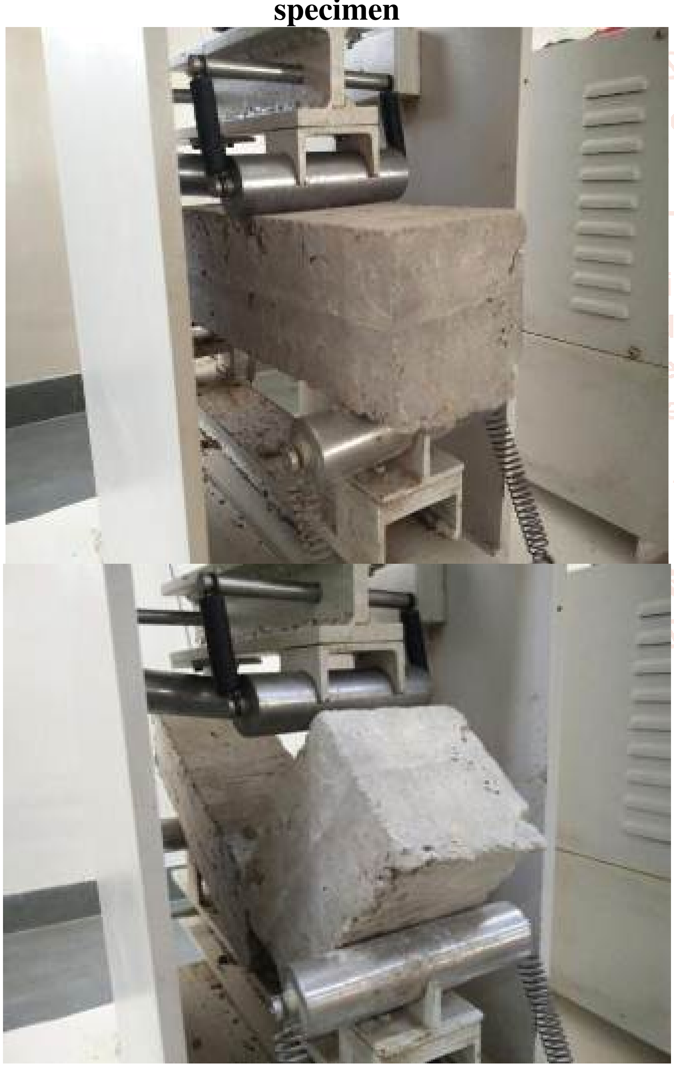

Figure 4.14: Testing of beams for flexural strength

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