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Physical and Mechanical investigation of concrete having marble dust and partial replacement of fine aggregate

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Abstract

Marble dust is intended to increase mechanical properties like compressive, tensile and flexural strength of concrete as well as to reduce the cost of fine aggregate. The concrete mix consists of cement, fine aggregate, coarse aggregate and marble dust as fine aggregate replacer. Fine aggregate is replaced by marble dust by 10, 20, 30,40,50,75 and 100 percent by weight. Primarily, the concrete specimens with and without marble dust will be casted to determine the improvement of certain mechanical properties. The water to cement ratio was kept constant i-e 0.55. The compressive strength, tensile strength and flexural strength of cylinders and beams was measured for 28 days. All the materials used in the project are acquired from the local resources. The compressive strength increase with the addition of marble. Sand is 100% replaceable by marble, but the ultimate strength is gained with the addition of 50% of marble dust. Split tensile strength of marble concrete has also increased by the addition of marble dust up to 50%. While flexural strength was increased with the addition of marble dust up to 30%. Further addition reduces the strength. The water demand of the marble concrete increases with increase in marble dust. Hence it can be concluded that marble dust is completely compatable with locally manufactured concrete materials.

1. Introduction

Today we are faced with an important consumption and a growing need for aggregates because of the growth in industrial production, this situation has led to a fast decrease of available resources. On the other hand, a high volume of marble production has generated a considerable amount of waste materials. Marble powder can be obtained as by-product of marble sawing and shaping as well as by crushing the marble. Almost 70% of this mineral gets wasted in the mining, processing and polishing stages which have a serious impact on the environment. The processing waste is dumped and threatening the aquifer. . According to the United States Geological Survey, U.S. domestic marble production in 2006 was 46,400 tons valued at $18.1 million, compared to 72,300 tons valued at $18.9 million in 2005 [1]. India is among the top world exporters of marble stone. The Indian marble industry has been growing steadily at an annual rate of around 10% per year. Cutting of stones produces heat, slurry, rock fragments and dust. 20 to 30% of marble blocks are converted in to powder. 3,172 thousand tons of marble dust was produced in year 2009-10 [2]. Pakistan has enormous wealth of marble, re-crystallized lime stone, dolomite and granite. More than 300 billion tons of marble has been estimated. Turkey has 40% of the total marble reserves in the world. About seven million tons of marble is produced in Turkey annually.

As we know that the advancement of concrete technology can reduce the consumption of natural resources and energy sources and lessen the burden of pollutants on environment greatly. Therefore, it has become necessary to reuse these wastes particularly in the manufacture of concrete products for construction purposes. The main goal of this study is to demonstrate the possibility of using marble wastes as a fine aggregate replacer in concrete production. The report presents the study methodology, the characterization of waste marble aggregates and various practical formulations of concrete [3].

2. Literature Review

Marble is a non-foliated metamorphic rock composed of recrystallized carbonate minerals, most commonly calcite or dolomite. Geologists use the term “marble” to refer to metamorphosed limestone; however, stonemasons use the term more broadly to encompass metamorphosed limestone. Marble is commonly used for sculpture and as a building material.

Marble is a naturally occurring stone used in construction industry. In powder paste and tile form it is used for both the interior and exterior decoration and protection of buildings. Marble blocks can be crushed into very tiny pieces called chips which are used in flooring and facing of the buildings. These are processed on completely different machines that include stone crushers of various grades and size cutting chips with size ranging from 0.5 to2.54cm, depending on the requirement and choice of the consumer [4]. Marble is a rock resulting from metamorphism of sedimentary carbonate rocks, most commonly limestone or dolomite rock. Metamorphism causes variable recrystallization of the original carbonate mineral grains. The resulting marble rock is typically composed of an interlocking mosaic of carbonate crystals. Primary sedimentary textures and structures of the original carbonate rock (protolith) have typically been modified or destroyed [5].

Pure white marble is the result of metamorphism of a very pure (silicate-poor) limestone or dolomite protolith. The characteristic swirls and veins of many colored marble varieties are usually due to various mineral impurities such as clay, silt, sand, iron oxides, or chert which were originally present as grains or layers in the limestone. Green coloration is often due to serpentine resulting from originally high magnesium limestone or dolostone with silica impurities. These various impurities have been mobilized and recrystallized by the intense pressure and heat of the metamorphism. Leaving the waste materials to the environment directly can cause environmental problem. Hence the reuse of waste material has been emphasized. Waste can be used to produce new products or can be used as admixtures so that natural resources are used more efficiently and the environment is protected from waste deposits. Marble stone industry generates both solid waste and stone slurry. Whereas solid waste results from the rejects at the mine sites or at the processing units, stone slurry is a semi liquid substance consisting of particles originating from the sawing and the polishing processes and water used to cool and lubricate the sawing and polishing machines. Stone slurry generated during processing corresponds to around 40% of the final product from stone industry. These industrial wastes are dumped in the near by land and the natural fertility of the soil is spoiled [6].

The process in which change in the apperance, shape or character of land occurs is called topographic alteration”. Presence of marble wastes in abundance causes topographic alteration. The topographic alteration can be analyzed using Scanning Electron Microscope (SEM) [7]. Stocking of marble wastes also occupy land. In majority cases the land occupied is a valuable land [8]. Marble wastes reacts with water making it contaminated water. The water may be surface or ground water.

Slurry is produced at almost every operation and its dumping is a great problem. When it gets dried and airborne, it causes air pollution and related problems [9]. Due to open cast nature of the mining, vegetation in the area occurs. Also dried slurry deposited over plants and vegetation stops their growth [10].

Running mines, abandoned mines, dumping sites, slurry waste sites, deposition of dried slurry over almost every structure in surrounding areas are a very bad sight. Hills having been excavated and dumps over them are very unaesthetic. Marble dust causes chronic obstructive pulmonary disease (Silicosis: lung disease caused by the inhalation of dust contaning silica) to the surrounding community [11].

White marble has been prized for its use in sculptures since classical times. This preference has to do with its softness, which made it easier to carve, relative isotropy and homogeneity, and a relative resistance to shattering. Also, the low index of refraction of calcite allows light to penetrate several millimeters into the stone before being scattered out, resulting in the characteristic waxy look which gives "life" to marble sculptures of any kind, which is why many sculptors preferred and still prefer marble for sculpting. Construction marble is a stone which is composed of calcite, dolomite or serpentine which is capable of taking a polish [12]. More generally in construction, specifically the dimension stone trade, the term "marble" is used for any crystalline calcitic rock (and some non-calcitic rocks) useful as building stone. For example, Tennessee marble is really a dense granular fossili ferous gray to pink to maroon Ordovician limestone that geologists call the Holston Formation. Marble can also be used as fine or coarse aggregate in concrete mix as replacer depending upon the available conditions, the purpose of construction and the performance of marble. Although little concentration has been given to such topic. Yet there is a lot of work to do and to achieve the required goals. Marble production is dominated by 4 countries that account for almost half of world production of marble and decorative stone. Italy is the world leader in marble production, with 20% share in global marble production followed by China with 16% of world production. India is third ranking with 10% of world production, followed by Spain in fourth ranking position with 6% of world production. The other marble producing countries of the world represent the remaining other half of world marble production. According to the United States Geological Survey, U.S. domestic marble production in 2006 was 46,400 tons valued at $18.1 million, compared to 72,300 tons valued at $18.9 million in 2005. Crushed marble production (for aggregate and industrial uses) in 2006 was 11.8 million tons valued at $116 million, of which 6.5 million tons was finely ground calcium carbonate and the rest was construction aggregate. For comparison, 2005 crushed marble production was 7.76 million tons valued at $58.7 million, of which 4.8 million tons was finely ground calcium carbonate and the rest was construction aggregate. U.S. dimension marble demand is about 1.3 million tons. The DSAN World Demand for (finished) Marble Index has shown a growth of 12% annually for the 2000–2006 period, compared to 10.5% annually for the 2000–2005 period. The largest dimension marble application is tile. India is among the top world exporters of marble stone. The Indian marble industry has been growing steadily at an annual rate of around 10% per year. Cutting of stones produces heat, slurry, rock fragments and dust. 20 to 30% of marble blocks are converted in to powder. 3,172 thousand tons of marble dust was produced in year 2009-10 Pakistan, especially KPK, possesses huge marble reservoirs. According to an official of Pakistan Stone Development Company (Pasdec), that oversees the marble sector, Pakistan has approximately 300 billion tons of marble reserves scattered mainly in KPK, the tribal belt and Balochistan. About 30 kinds of marble were found in the province and the adjoining tribal belt. "The most famous of these are Ziarat marble, super-white, off-white, Badal, Zebra, pink, Nowshera, Jet-black, Bampokha and golden marble [13].

3. Methodology

All the procedures and methods adopted in this project are according to specific standards. The concrete mix was designed using ACI method. The concrete mix design ratio makes the proportion of cement, sand or marble and coarse aggregate as 1:2:4 by mass. This ratio was chosen keeping in view the ratio of concrete for local ordinary works in Pakistan. The water to cement ratio of the designed concrete comes out to be 0.55. The compressive, flexural and split tensile strength of concrete with and without the addition of marble dust was kept at 28 days of age. 28 days is a reasonable compromise to distinguish good concrete (that will continue to strengthen a bit more with a longer wait) from poor concrete (which may strengthen a little more, but in way weaker than the good stuff). It is about the earliest time that allows a prediction of the ultimate strength attained both by the original composition and also the cure process. The other main reason of selecting the 28 days age is that concrete gains its ultimate strength at 28 days i-e 95%. All the materials used in this project acquired locally. The cement used is Askari Cement and was purchased from taxila, the sand was acquired from Lawrencepur, marble dust (Super White) was acquired from local dealer in taxila and coarse aggregates were acquired from Margalla hills near Pakistani Capital Islamabad.

The research work is composed of experimental work to investigate mechanical properties (compressive and modulus of elasticity) of concrete having natural

Concrete specimen

For this work first of all cylindrical and beams specimens were prepared. A mix proportion of 1:2:4 with 0.55 water cement ratio to differentiate the mechanical properties after adding marble dust was considered for this study. The exact quantity of materials for each mix was calculated. The constituent of materials used for making the concrete were tested before casting concrete. The cement, fine aggregate, coarse aggregate were tested prior to the experiments and checked for conformity with relevant ASTM standards. Concrete was mixed using a tilting type mixer and specimens were cast using steel moulds, compacted with tamper rod.

Curing

Curing is the process during which hydration takes place, resulting in a harder, tougher, or more stable concrete. The samples were removed from moulds after 24 hours and kept in curing tank for 28 days for curing. All the test specimens were cured under room temperature of 20-25 ^{0}C. The specimens were subjected to local environmental conditions. The drinking water was used for curing.

Table 1: Number of Specimens

Marble Dust (% by mass)	***Compression Test (cylinders)***	***Split Tensile Test (cylinders)***	***Flexural Test (beams)***
0	*3*	*3*	*3*
10	*3*	*3*	*3*
20	*3*	*3*	*3*
30	*3*	*3*	*3*
40	*3*	*3*	*3*
50	*3*	*3*	*3*
75	*3*	*3*	*3*
100	*3*	*3*	*3*
Total	*24*	*24*	*24*

Fresh State

Slump

To determine and keep the workability of concrete constant, slump tests were performed on each batch of concrete according to ASTM C143 M03.

Figure 1: Slump Test

Compression test

The compressive strength is the capacity of a material or structure to withstand loads tending to reduce size. This test covers the determination of the compressive strength of cylindrical concrete specimens. The test method consists of applying a compressive axial load to molded cylinders at a rate which is within a prescribed range until failure occurs. The compressive strength of the specimen is calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimen. Procedure of test can be performed according to ASTM C-39.

Figure 2: Schematic diagram of compression test

Split Tensile Test

This test method covers the determination of splitting tensile strength of cylindrical specimens. This is the maximum stress that a material can withstand while being stretched or pulled before failing or breaking. Tensile strength is not the same as compressive strength and the values can be quite different. Such test is performed according to ASTM C496-06.

Figure 3: Split tensile test (after splitting)

Flexural test

This test method covers the determination of flexural strength of concrete specimens by using standard beams with center point loading. Such test is also called Three Point Loading or Center Loading Test. t is performed according to ASTM C293-10.

Figure 4: Flexural test (thre point loading test)

Schmidt Hammer

A Schmidt hammer, also known as a Swiss hammer or a rebound hammer, is a device to measure the elastic properties or strength of concrete or rock, mainly surface hardness and penetration resistance. It is one of the oldest non-destructive test still widely used. The hardness measured by rebound hammer is quite different from the hardness determined in test on concrete by destructive test. The difference between the compressive strength of concrete by UTM to the rebound hammer values typically for a change in strength of a approximately 5 MPa (700 psi).

Figure 5: Schmidt hammer test

4. Result Analysis

Physical Properties (Fresh State)

Slump Test

Table 2: Slump Value (mm)

Percentage of Marble Dust Replaced by Sand	Average (mm)
0	17
10	17
20	15
30	14
40	14
50	10
75	08
100	08

Mechanical Properties (Hardened State)

Table 3: Average Compressive strength (psi)

Percentage of Marble Dust Replaced by Sand	Average Strength (Psi)
0	3839.6
10	4184.7
20	4200.6
30	4439.9
40	4525.6
50	4538.5
75	4414.8
100	4263

Table 4: Splitting Tensile Strength (Psi)

Percentage of Marble Dust Replaced by Sand	Average Strength (Psi)
0	340
10	356
20	388
30	391
40	393
50	412
75	342
100	336

Table 5: Modulus of Rupture Strength (Psi)

Percentage of Marble Dust Replaced by Sand	Average Strength (Psi)
0	812
10	899
20	928
30	822
40	765
50	700
75	685
100	674

Table 6: Compressive Strength (Psi) by Schmidt Hammer

Percentage of Marble Dust Replaced by Sand	Average Strength (Psi)
0	3300
10	3340
20	3380
30	3600
40	3700
50	3950
75	3575
100	3400

5. Relations

The governing property of concrete is its compressive strength. Although concrete is weak in tension, yet it must be strong up to some extent in tension region such in beams etc. Greater the tensile strength of concrete, less will be chances of cracking. Therefore, reinforcement will be safe from corrosion. The tensile and flexural behavior of concrete is defined in terms of compressive strength. There are some specific relations between compressive, tensile and flexural strength. Figure 6 shows the different relations.

TENSILE STRENGTH	Normal weight concrete,psi	Light weight concrete,psi
Direct tensile strength, f'_t	3 to 5$\sqrt{f'c}$	2 to 3$\sqrt{f'c}$
Split-cylinder strength, f_{ct}	6 to 8$\sqrt{f'c}$	4 to 6$\sqrt{f'c}$
Modulus of rupture, f_r	8 to 12$\sqrt{f'c}$	6 to 8$\sqrt{f'c}$

Figure 6: Relations between compressive, tensile and flexural strength

Compressive strength relation

Strength at 0% of marble = 3839.6 psi

Strength at 50% replacement of sand by marble = 4538.5 psi

Increase = (4538.5-3839.6/3839.6)*100= 18.2%

Hence increase of strength of 50% replacement of sand by marble=18.2%

Tensile strength relation

Strength at 0% of marble = 483 psi

Strength at 50% replacement of sand by marble = 548.3 psi

Increase = (548.3-483/483)*100= 12%

Hence increase of strength of 50% replacement of sand by marble=12%

Flexural strength relation

Strength at 0% of marble = 812 psi

Strength at 20% replacement of sand by marble = 928 psi

Increase = (928-812/812)*100= 14.3%

Hence increase of strength of 50% replacement of sand by marble=14.3%

6. Conclusion and Future Research

The following conclusions are drawn out from this research study:

1. Marble dust is completely compatible with locally manufactured concrete materials.
2. The recycling of marble dust which is an industrial waste, has a very significant environmental impact
3. The physical properties of marble dust were found suitable for its proposed use.
4. The compressive, tensile and flexural strength of concrete has been increased with the addition of marble dust.
5. The slump obtained with 0.55 water to cement ratio is significantly lower than the prescribed value of 3/4”(75-100 mm) for ordinary concrete.
6. Due to the high fineness of marble dust, it is effective in obtaining good cohesiveness of concrete.
7. The use of marble dust in construction is cost effective in such areas where it is found in abundance because it is available free of cost.

1. Compressive strength decrease on addition of natural Pakistani bentonite clay 28 days of curing period
2. Modulus of elasticity is increased on 10% replacement.

The following suggestions were made from this research study:

1. Study can be carried out with different plasticizers, water reducers.
2. Additives like silica fume, fly ash and ground granulated blast furnace slag can also be used in combination with marble dust to increase the strength furthermore.
3. Similarly fly ash can be separately added to reduce the water demand of marble concrete.
4. The studied concrete can also be steam cured.
5. Some other properties like porosity, permeability can also be analyzed with marble concrete.
6. The micro structure of marble concrete can be studied through Scanning Electron Microscope (SEM).
7. The present study was carried out using mainly one sized aggregate (3/4”). Further study with well graded coarse aggregate is recommended.
8. In addition, fracture energy and impact studies of marble concrete will further improve the knowledge about normal concrete.

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