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Marble Powder's Effect on Permeability and Mechanical Properties of Concrete

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Abstract**—**Marble industry contributes its fair share in environmental deterioration, producing voluminous amounts of mud and other excess residues obtained from marble and granite processing, polluting soil, water and air. Reusing these products in other products will not just prevent our environment from polluting but also help with economy. In this research, an attempt has been made to study the expediency of waste Marble Powder (MP) in concrete production. Various laboratory tests were performed to investigate permeability, physical and mechanical properties, such as slump, compressive strength, split tensile test, etc. Concrete test samples were fabricated with varying MP content (replacing 5-30% cement), furnished from two different sources. 5% replacement of marble dust caused 6% and 12% decrease in compressive and tensile strength respectively. These parameters gradually decreased with increasing MP content up to 30%. Most optimum results were obtained with 10% replacement. Improvement in consistency and permeability were noticed. The permeability was improved with increasing MP proportion up to 10% without substantial decrease in compressive strength. Obtained results revealed that MP as an alternative to cement in concrete production is a viable option considering its economic and environment friendly implications.

Keywords**—**Waste marble dust, concrete strength, environment, concrete, permeability.

I. Introduction

MARBLE stone is extensively used for construction purposes to provide a pleasing aesthetic look, but with the production of marble stones, huge amounts of waste which is usually referred to as waste marble dust (WMD) is produced. Marble dust is a product of the marble processing and is produced as a result of marble sawing and shaping. It has been estimated that from the mining process of marble to the finished product, about 50% of the mineral is turned to waste; 90% of whose particles are below 200µm [1]. The proper management and disposal of this waste is a worldwide concern to environmental safety [2]. This waste if dumped, will in addition to loss, raising the following environmental concerns [3]:

a) Disposal of marble dust on ground causes loss of water permeability at dumpsites.
b) MP slush leaves a surface residue upon drying which is main reason for enormous air contaminations nearby processing units.
c) Rain water often take these waste deposits to close rivers, streams and reservoirs and results a great deal of water pollution.

On the other hand, if WMD is reused, it will lead to less usage of natural resources and less waste will be dumped in landfills. Plus, it will result in economic benefits by the replacement of expensive and scarce materials with cheap materials [4].

With advancements in concrete technology, efforts have been made to reduce our reliance on natural materials and energy sources and increasing efficiency in reducing the pollutants. By-product or mostly called waste materials left during generation of any particular chemical entity can cause environmental problems. Hence, the reuse of those by-products such as stone slurry and solid waste being produced in marble stone industry is considered essential and vital. Marble industry springs wastes in two forms. Firstly, the under sized chunks of quarried stocks go straight to rejected silos. Secondly, the water containing MP is obtained from sawing and polishing marble products. Currently both of these wastes are augmenting at a staggering rate as more and more companies have joined the industry than before.

Reference [5] discusses the use of WMP (waste MP) and diatomite (pozzolanic material) as a partial replacement to cement in concrete; different tests were conducted to see the enhancement in the respective compressive and flexural strength. The relative compressive strength of the concretes containing diatomite ranged from 1.10 to 1.28 at the age of 7 days, 1.02 to 1.20 at the age of 28 days, and 1.03 to 1.26 at the age of 90 days. However, the relative flexural strength of the concrete specimens with diatomite did not change considerably. The concrete containing Diatomite to 5% showed only 3% increase in strength compared with the controlled sample while for the same % the compressive strength was increased up to 26% after 28 days. Similarly, it has been noticed that additions of marble do not affect the final setting time of fresh concrete. A significant amount of increase in tensile and compressive strength can be observed with partial replacement of cement or sand with marble dust which also affects the steel bond strength [6].

Reference [7] studied the effect of using marble dust as a partial replacement in cement production. The conclusions were made accordingly with the results from the different

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tests. WMD increased slightly the soundness values of cements and economy was reduced to about 10% compared with the ordinary Portland cement production. Reference [8] studied the usage of waste MP in brick industry. The main objective of this study was to recycle the waste MP produced in brick industry thus making the environment free from pollution. By using the marble dust in concrete, cement and in brick production, the mechanical properties of the respective materials were increased. It was concluded that 10% by weight of the MP can be added to an industrial brick mortar with no sacrifice on the technical properties of the resulting product. Hardness of the brick goes parallel with the addition of the marble dust. In a way, the marble dust recycling is playing a great contribution in terms of ecology and economy. In [9], the applicability of MGR (Marble Granite Residues) as a sustainable alternative for cement replacement has been studied. The main concern was to recycle the MGR (Marble Granite Residues) in order to achieve the benefits in terms of economy and ecology. The X-ray analysis showed a crystalline nature and non-pozzolonic reactivity for the MGR. It also showed the MGR as non-reactive showed relative low compressive strength in cement production or as a partial replacement. 5% Replacement of MGR showed only minor influence upon important mechanical characteristics which can provide footing for the assumption of marble as potential cement replacement. Such promising results of usage of marble slurry in concrete have also been proved by [10] and [11]. Its use as a filler material in self-compacting concrete has also been shown to be beneficial [12]. Among others, its use in the production of asphalt pavements [13], clay ceramics [14], and building materials [1] has already shown to be beneficial. Although extensive research has been conducted on this topic, the permeability properties of concrete produced with WMD as partial cement replacement has rarely been studied before.

This research aims to study the impact of WMD use in concrete, not only as cement replacement but also as an additive in concrete to investigate its usefulness at an extended range of replacements by volume. The novelty of this research lies in assessing the permeability property. Concrete samples were casted using a mix design of 1:2:4 having water to binder material ratio of 0.47. Amount of marble dust was introduced by replacing 5-30% cement keeping the incremental increase in marble dust constant at 5%. Effect of these replacements were assessed using water permeability test by Blain's apparatus, split tensile strength test, compressive strength test, and consistency test.

II. Materials

In this section, the materials used for the investigation purposes are described. Different tests were chosen to quantify the influence of WMD on behavior of concrete viz. Water Permeability Test, Splitting Tensile Strength, Compressive Strength and slump test of which the details are given below.

A. Marble Dust Slurry

Two different sources of Marble dust were used in this research. Source No.1 was collected from Warsak Area in the state of Khyber Pakhtunkhwa (KPK), and Source No.2 Super white marble was collected from Karachi, Sindh Province, Pakistan. WMDs were collected directly from the field in gunny bags and were stored for later use. The possible use of WMD in concrete in lieu of cement from 0 to 30% by weight of cement was later evaluated by carrying out different laboratory tests.

Prior to carrying SEM tests, WMD was examined for its fineness and chemical properties. X-ray fluorescence (XRF) analysis was carried out at Central Research Lab at Physics Department of University of Peshawar for determining the composition of elements present in WMD slurry. The results are shown in Tables I and II. The source No.1 WMD used basically consists of Ca with major traces of Si, Fe and Mg while K, Na, Fe and Al were present in minor contents. This also verifies the fact that WMD consists largely of pozzolanic chemical compounds including calcium oxide, silica and alumina which tend to have the ability to form a bonding action between the particles. While in Source No.2 the major components were Calcium Carbonate, silica, Magnesium oxide and Ca (wallastonte). Soirce No.2 chemical analysis was done on SEM apparatus.

TABLE I
CHEMICAL COMPOSITION OF ELEMENTS IN WMD OF SOURCE NO.1

Elements	Weight (%)
CaO	51
SiO_2	0.5
MgO	2.1
Loss on ignition	43.5
K_2O, Na_2O, Fe_2O_3, Al_2O_3	Are generally less than 1% Each

TABLE II
CHEMICAL COMPOSITION OF ELEMENTS IN WMD OF SOURCE NO.2

Elements	Weight (%)
$CaCo_3$	9.54
SiO_2	51.54
MgO_2	0.29
Ca (wollastonite)	38.34

WMD was further analyzed for physicochemical characteristics which are mentioned in Table III. The specific gravity varied from 2.83 to 2.87 and density was found to be 1.96g/cc.

TABLE III
PHYSICOCHEMICAL PROPERTIES OF WMD OD SOURCE NO.1

Property	Results
Density	1.98g/cc
Moisture Content	0.21-0.41%
Tensile Strength	23.2-25.1MPa
Compressive strength	77-96MPa
Bulk Density	1.31-1.52g/cc
Water absorption rate	0.16-0.41%
Fire retarding tendency	Self-Extinguishing
Exposure to boiling water	No change in dimensions
Chemical action	Appears chemically inactive

1. Particle Size Gradation Analysis

In order to define the particle size of WMD, gradation analysis was carried out as per [15] on material obtained directly from marble factory in Bara Band Area in the state of KPK. Percent finer is shown in Table III. It was evident that WMD consisted largely of big lumps of size greater than 80 mm while the waste powder ranged in size from 0.321 mm to 15.2 mm.

TABLE IV
PARTICLE SIZE DISTRIBUTION OF WMD

Particle Size (µm)	Percent Finer (%)
362.1	100
192-205.7	90
129-140.1	80
81.1-94.3	70
54.15-62.1	60
37.51-43.2	50
23.8-28.3	40
14.14-15.1	30
5.81-7.11	20
1.21-1.70	10
0.322	0

B. Portland Cement

Likewise, ordinary Portland cement of grade 53 conforming to ASTM C-150 Type 1 with 28days strength up to 10,000 psi (70MPa) was procured by Concrete Laboratory of University of Engineering & Technology Peshawar, KPK.

C. Specimen Specifications

The specimens were poured in 150mm x 300mm cylindrical molds. After 24 hours, all specimens were demolded and water cured at room temperature (12^o C +/- 2) for 28 days [16]. After curing period was over, the specimens were tested for properties under investigation. The samples were prepared in order of increasing WMD replacement content as 0%, 5%, 10%, 15%, 20%, 25% and 30%. The concrete mix of 1:2:4 was kept constant throughout the research. Ratio between water and binder material (cement and marble) was maintained at 0.47.

D. Concrete Mixing

Mixing was done in a standard drum-type mixer. Course and Fine aggregates were first dry-mixed until the mixture becomes homogeneous. Binder materials i.e. cement and marble were afterwards added to the mixed and further dry-mixed to obtain the intended homogeneity. Absolute volume method was used unvaried through the course of lab experimentation. The slurry was collected from nearest site of Warsak area and from Karachi Pakistan. WMD were post treated by first drying in open air and later oven drying to remove the water content. It was then crushed to attain a uniform texture free from lumps to allow it blend with the concrete constituents to form a homogeneous mix.

III. EXPERIMENTAL METHODS AND PROCEDURES

A. Splitting Tensile Strength Test

Splitting Tensile Strength Test of the specimens were performed as per [17]. Load was applied gradually in a compression machine proficient of applying the load at a particular rate.

B. Compressive Strength Test

Compressive Strength of the samples was determined as per the requirements of [18]. The load was monotonously applied with incremental increase until the specimen failed withstand further loading. Maximum compressive strength is accordingly worked out considering the cross sectional areas of the test specimens.

C. Slump Test

This test (ASTM C 143) determines the consistency of concrete provided that aggregate size limits remains 38mm. Another utility of the experiment is determining whether the sample is proportioned correctly. Once the slump has been measured, gently touching the heave with rod should result in further slump without collapse. A complete collapse would imply the sample is poorly proportioned.

D. Water Permeability Test

Permeability test was conducted in University of Engineering & Technology Taxila, Civil Engineering Department where the specimens were tested in '*Automatic Concrete Water Permeability Apparatus'*. Concrete cylinders are fabricated with varying proportions of cement and MP and after soaking them to achieve full saturation, the same is tested in Blaine apparatus for finding the water permeability under pressurized conditions. Blaine apparatus is fully automatic apparatus capable for permeability tests on concrete cylinder samples. It is later, possible to conclude the permeability coefficient (Darcy coefficient).

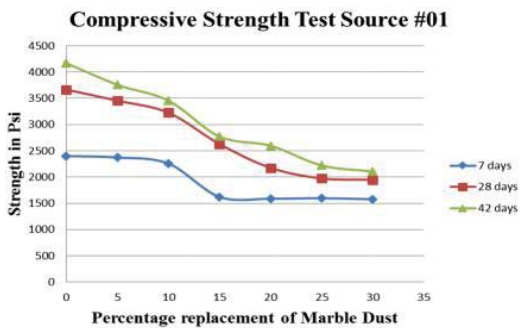

Fig. 1 Source No.1 Compressive Strength Test graphs of 7, 28 and 42 Days

IV. TEST RESULTS AND DISCUSSION

A. Compressive Strength

The compressive strength results are presented in Figs. 1 and 2. It was observed that as the percent replacement of cement by WMD was increased, the compressive strength kept decreasing. With increasing percentage of WMD in concrete, the strengths were documented lower than the strength of control sample with no WMD additive. The strength decreased gradually from 3276 psi (22.6 MPa) of control sample to 1862 psi (12.8 MPa) at 25% replacement of cement by WMD. These decreases in strength mainly occur owing to addition of Portland cement with MP.

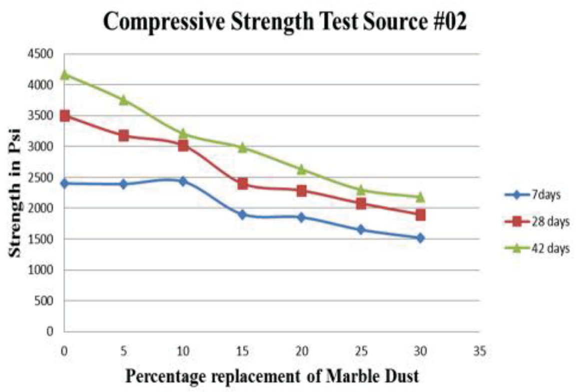

Fig. 2 Source No.2 Compressive Strength Test graphs of 7, 28 and 42 Days

1. Effect of WMD as Additive on Compressive Strength of Concrete

In order to investigate the effect of WMD as an additive on compressive strength, two sources of MWD were selected. 13 concrete mixes of 0%, 5%, 10%, 15%, 20%, 25% and 30% for each source were prepared in 1:2:4 ratio and water to cement and marble dust ratio was 0.47. it was observed that compressive strengths were decreased with increase in the proportion of WMD in concrete, but the decreases are compromise-able, because at 28 days in sources No.1 at 5% and 10 % replacement the strength is reduced by 5.7% and 9.89%. While in source No.2 the decrease at 5% and 10% replacement were 1.6% and 10% at 28 Days respectively.

Scientifically, micro fines have higher surface area that results in higher water demand which results in lower strength. Use of well graded aggregates results in more compact mass, the gaps between the larger particles are filled by the smaller ones and less paste is needed to fill in the further smaller gaps. Moreover, all the surface area of the aggregates gets coated with mortar substrate which helps with the workability of the concrete.

In our case as the strength of specimens was gradually reduced by addition of MP than the corresponding control specimen. Concrete density reflects the density of its components and their packing. With addition of WMD as admixture, the particle packing density of the concrete mass is significantly improved thereby increasing the chance of excess coating on each aggregate.

B. Splitting Tensile Strength

The results of splitting tensile strength of concrete samples are shown in Figs. 3 and 4.

TABLE V
SOURCE NO.1 COMPRESSIVE STRENGTH TEST RESULT OF 7, 28 AND 42 DAYS

WMD % Replacement	7 Days	28 Days	42 Days
0	2400.4	3231.7	4169.5
5	2373.36	3456.07	3757.2
10	2357.52	3226.13	3355.7
15	1621.05	2628.69	2771.9
20	1589.75	2176.98	2595.2
25	1597.67	1974.35	2221.1
30	1478.58	1948.8	2106.8

TABLE VI
SOURCE NO.2 COMPRESSIVE STRENGTH TEST RESULT OF &, 28 AND 42 DAYS

WMD % Replacement	7 Days	28 Days	42 Days
0	2400.4	3501.27	4169.5
5	2392.6	3179.75	3752.98
10	2431.57	3018.68	3210.8
15	1901.61	2400.4	2981.3
20	1852.25	2286.09	2629
25	1649.62	2078.27	2299.1
30	1519.72	1899.02	2179.6

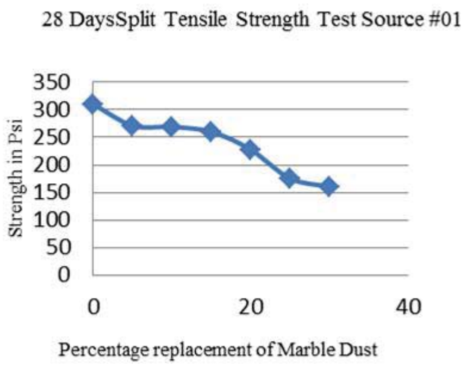

Fig. 3 Tensile strength for replacing of cement with cement with WMD Source No.1

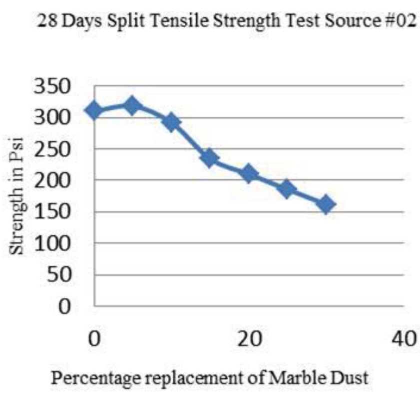

Fig. 4 Tensile strength for replacing of cement with cement with WMD Source No.2

Fig. 3 elaborates the trend of 28 days tensile strength obtained from source 2 results. It is evident from the graph that the strength reduction in the range of 10% replacement does not have very significant effect on the strength reduction. This phenomenon may have occurred owing to establishment of better compact mass of concrete due to finely divided MD that fills the empty spaces between the concrete lattice. And, Fig. 4 elaborates the trend of 28 days tensile strength obtained from source 2 results. It is evident from the graph that the strength reduction in the range of 10% replacement does not have very significant effect the strength reduction. It was a surprising observation to notice even a slight gain in strength at 5% replacement. Moreover, the strength characteristics of source 2 were found better than source 1. This phenomenon may be occurred owing to establishment of better compact mass of concrete due to better compaction achieved during tempering operation.

1. Effect of WMD as an Additive on Splitting Tensile Strength of Concrete

As an additive, WMD presence in concrete affects the results. Table VII summarizes 28 days strength against various replacement conditions. The optimum value is reached at 05% WMD content in concrete sample. Due to the fine filler effect of WMD powder, maximum packing density of the mass is achieved with WMD grains filling up the vacant spaces.

TABLE VII
28 DAYS TENSILE STRENGTH

Source No.1		Source No.2	
WMD Percent Replacement	28 Days	**WMD Percent Replacement**	28 Days
0	310.1	**0**	310.01
5	271.28	**5**	317.92
10	269.07	**10**	291.42
15	260.1	**15**	233.97
20	227.86	**20**	209.66
25	175.48	**25**	185.23
30	160.27	**30**	161.6

C. Concrete Slump Test

The concrete slump test is an extent of workability of the mix which is handy in adjusting the quality of the concrete manufactured. It provides information on the special effects of the characteristics and volumes of mixture aggregates. As is shown in Figs. 5 and 6, the concrete workability remains constant at 2 in for mixes of 0%, 5% and 10% WMD in concrete while beyond 10% WMD, the workability decreases. Some of the factors that may affect the workability of samples are grading and shape of fine aggregates, proportion of fine to coarse aggregates and characteristics of the materials [11].

Workability of concrete is intrinsically determined by the nature and forms of the constituents itself. These characteristics significantly influence the outlook of concrete in terms of its consistency and should be considered vis-à-vis the water contents during mix designing phase.

In regards to the consequence of limestone (calcium carbonate) add-ons on water use and workability literature review reveals contradictory results. These contradictions can be attributed to the particle size distribution of the added materials which would alter the particle packing. Subsequently the remainder of the space will be taken by water and cement. This is due to the reduction of the cement paste quantity as some part of the cement is replaced by the waste powder and as the particle size of the marble waste used was not much finer than the cement to enhance the particle packing density of the cement.

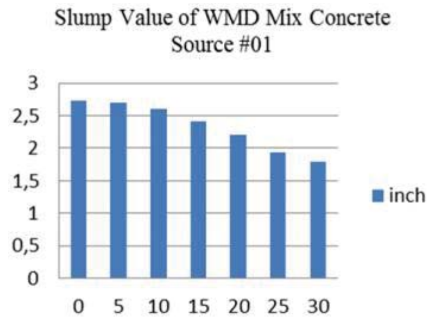

Fig. 5 Slump Test of Source # 01

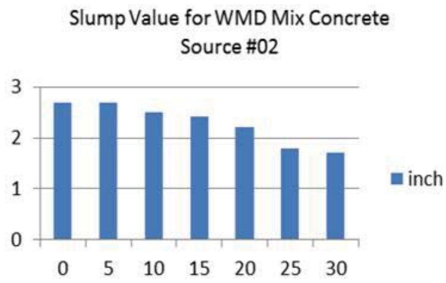

Fig. 6 Slump Test of Source # 02

D. Water Permeability

The results show that as we keep on increasing the proportion of WMD from 0-10% the Permeability of concrete reduces, the reason is that WMD acts as a filler it goes and fill up all the gapes inside the concrete during hardening process. But after the 10% limit all the cavities are get filled with marble dust further marble dust does not act as a filler but it starts acting as an over burdening additive.

When the limit of 10% is crossed and reached 15% there was a drastically increases the water flow through concrete mass as shown in Fig. 7. This is due to the reduction of cement amount that reduces the CHS (calcium hydro silicate) part which was responsible for reducing gel pores. While the reduction in water permeability observed in first three samples is due to the filling effects of certain micro size particles of the MP which makes the paste more compact The presence of multi sized grains make the mass more well-graded and less pore spaces are available which provide the shorter route to water flow. Water intrusion is possible through the present pores and openings left in concrete matrix. Aggregate can also contain pores, but these are usually discontinuous. Amount of water absorption also determines by the type of cement used and other environmental means that determine the rate of hydration. And after crossing the 15% limit was devastated to that limit after that increasing the percentage further would not affect the permeability but effect will be on all the compressive, split tensile and consistency of the concrete.

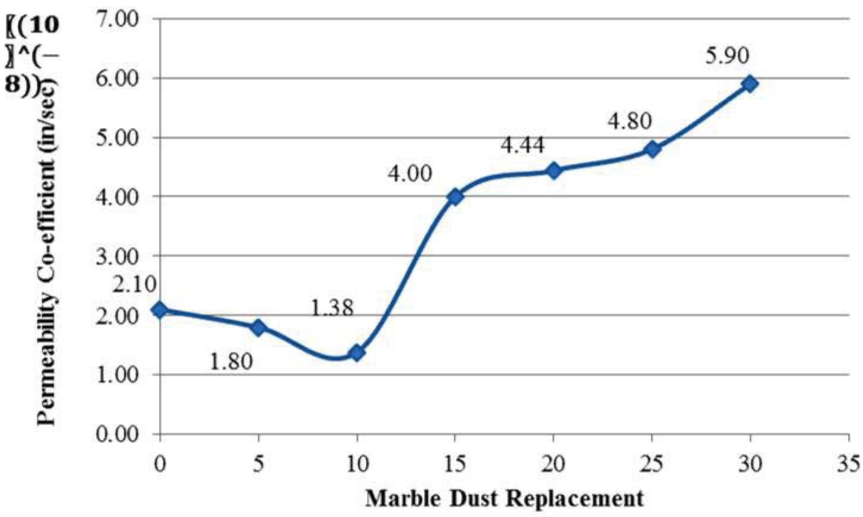

Fig. 7 28 Days cylinders Permeability test result

V. Conclusions

In this research, recycling of marble waste powder for the production of cement and concrete has been studied and the following conclusions are made.

1. The test result shows an improvement in the concrete permeability within the range of 5 to 10 percent. The permeability was improved by 32 percent at 10 percent replacement.
2. At 42 days and 28 days in source No. 01 with 5 percent replacement, the optimum compressive strengths are 90.1 percent and 94.3 percent compared to control mix, while at source No. 02 the optimum compressive strengths are 90 percent and 94.4 percent respectively.
3. For source No. 01 at 28 days with 5 percent replacement, reduction in the split tensile strength was 12.47% while in source No. 02 the split tensile strength is increased by 2.49 percent respectively.
4. Split tensile strength also reduces with increase in marble dust content. From 5 to 15% replacement of cement with marble dust concrete shows good split tensile strength as compared to the other replacements.
5. Consistency of the mix reduces as the percentage of Marble dust increases, because Marble dust entraps water and results in decreasing the workability.
6. 10 percent replacement of MD is recommended for low cast water retaining structures.

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