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IMPACT OF FLY ASH AND MARBLE DUST ON THE PROPERTIES OF HARDENED CONCRETE

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Abstract
This research study aimed at finding the percentage utilization of fly ash and marble dust by replacing cement and sand respectively, in concrete so that significant results for strength and durability may be achieved. Therefore, fly ash and marble dust were incorporated in cement mortars in different proportions to determine the best performance sample based on the compressive strength tests. As a result, the replaced sample with 30% fly ash and 25% marble dust resulted in the highest compressive strength values. This combination was then selected for preparing concrete samples and thereafter conducting various laboratory tests such as compressive strength, split-tensile strength, and sorption test up to the 90th day. The results showed that the replaced sample gave lower strength results up to the 28th day as compared to the control group. However, an increase in strength values was observed on the 56th and 90th days. This is because after substantial hydration of cement, fly ash starts reactions with calcium hydroxide which is obtained as a byproduct of hydration reaction. The fly ash reactivity with calcium hydroxide gives CSH and CAH gel which results in a dense and strong structure. Moreover, the finer marble dust particles also contribute towards dense particle packing. In addition, the density and compressive strength relationship shows better agreement with the R^2 value of 0.966.

INTRODUCTION

Concrete, as a construction material, has been used extensively to build various structures such as buildings, rigid pavement in roads, bridges and culverts, canal lining and drains, retaining walls and foundations, etc. The ever-increasing demand for concrete in the construction industry is due to its various properties such as workability, strength, and moldability. Moreover, the primary ingredients of concrete such as cement, fine aggregate, coarse aggregate and water are readily and easily available almost everywhere [1] [2].

Due to the huge consumption of concrete, it has been affecting the environment badly. Cement, utilized as binding material, has been a significant constituent of concrete and plays a vital role in concrete's behavior. However, its huge consumption has been contributing to the increased carbon emissions and overall global warming. Several studies have been conducted to minimize cement consumption by incorporating supplementary cementitious materials and industrial byproducts [3], [4], [5], [6].

It has been practiced replacing cement by using pozzolanic materials such as fly ash, silica fume, furnace slag etc. [7], [8]. Among these pozzolanic materials, fly ash is the residue obtained after burning coat in thermal power plants and it is dumped in open agricultural fields or into the natural streams thus causing environmental degradation [9], [10]. However, fly ash can be incorporated in concrete, to enhance its properties and reduce cement consumption, by replacing cement [11]. For example, Singhal et al. [12] conducted a research study involving 30% cement replacement by fly ash where it was observed that lower compressive strength values were obtained on the 7th and 28th days as compared to the control group. However, the resistance to water penetration was improved by utilizing 30% fly ash in place of cement as compared to the control group sample. Similar results have been observed by Dhawan et al. [13]. Likewise, Bendapudi et al. [14] have been concluded that only 15% to 20% cement replaced by fly ash gives significant results and higher replacements compromise the early strength properties of concrete. However, other studies have shown that fly ash reactivity accelerates in the presence of finer amorphous particles and so results in early strength gain [15], [16], [17].

Sand, commonly used as fine aggregate in concrete, is easily available and contributes to various properties of concrete. However, its extensive mining has been causing degradation of the natural environment. It has been predicted that, if this demand for sand persists, the world would run out of it by 2050 [18]. Moreover, it has been studied that extensive mining of sand results in the deterioration of the physical and the biological environment [19], [20]. Moreover, during a case study, it has been found that the clean drinking water of natural stream at Toustang Locality has been polluted due to sand mining [21]. Similarly, another study has revealed that the water intake structure at Manimala, India, was exposed due to lowering of riverbed. It has also been caused by sand mining in large quantities [22].

In addition, industrial byproducts, dumped into natural streams or in the open agricultural fields, have been affecting the environment adversely. These industrial byproducts have been generated in humongous quantities and are being dumped with little or no reuse and recycling [23].

Marble Dust is one of the industrial wastes generated because of the cutting and finishing of marble stones in marble processing factories [24]. Marble is a metamorphic rock obtained from the transformation of limestone, a sedimentary rock, after a long time and it is chemically calcite and dolomite minerals [25], [26], [27]. It has been found beneficial as finishing and decorative material, particularly in sophisticated buildings, however, causes environmental degradation because of the formation of marble dust and waste slurry in the marble processing factories [28]. It has been found that about 25% of the total mass results in the generation of waste marble slurry after cutting and finishing marble blocks [26]. However, the reuse of marble dust in concrete has been studied to improve the properties of concrete. For example, Aliabdo et al. [4] studied the effect of marble dust utilized as partial replacement of cement, in various proportions up to 15%, on the strength properties of concrete and mortar. It was found that no significant effect was observed up to 10% replacement, however, at 15% replacement strength was compromised. Similarly, Vardhan et al. [25] found that the use of marble dust as partial replacement of cement may be limited to 10% because beyond this proportion the strength properties of mortar are being compromised. It has been understood through various studies that marble dust does not contribute significantly when used as a partial replacement of cement because of having no cementitious properties [29], [30].

The previous literature shows that fly ash as partial replacement of cement contributes to the properties of concrete, but results in lower early strength gain. However, early strength may be gained in the presence of finer materials. Moreover, marble dust has been generated in huge quantities, and it has not been reused for beneficial purposes. In addition, it cannot be used in concrete by substituting cement while achieving significant results. Lastly, sand mining has been increased which also threatens the natural environment and ecosystems. Therefore, it is direly needed to utilize fly ash and marble dust as partial replacement of cement and sand respectively, to achieve early strength, to reduce cement consumption, to reduce extensive sand mining, and avoid huge amounts of disposal of industrial waste. This study aims at finding the percentages of fly ash and marble dust which could be used in concrete to replace cement and sand respectively, to achieve desired strength and durability properties. To do this, mortar and concrete specimens were prepared for control group and several replaced samples. Moreover, to compare the performance of fly ash and marble dust, various laboratory tests were conducted including standard compressive strength test of mortar cubes, compressive strength test of concrete cylinders, split-tensile strength test of concrete cylinders, and sorption test of concrete.

2 Properties of Raw Materials

2.1 Cement

Ordinary Portland Cement, manufactured by Cherat Cement Company Limited, has been utilized as a binding material in concrete. The fineness of cement test was performed by following the ASTM C184 [31] and it was found 91%.

2.2 Fine Aggregate and Coarse Aggregate

The properties of fine aggregates and coarse aggregates such as specific gravity [32], [33], moisture content, water absorption capacity, particle size distribution curve and fineness modulus [34] must be determined before conducting the mix design of concrete following the ACI Mix Design method [35]. The specific gravity and water absorption of fine aggregate and coarse aggregate have been demonstrated in Table 1. The gradation curves for both fine aggregate and coarse aggregate have been exhibited in Figure 1.

Table 1: Specific Gravity and Water Absorption of Fine and Coarse Aggregates

Material	Property	Test Results
Coarse Aggregate	Apparent Specific Gravity	2.49
	Bulk Specific Gravity (OD)	2.46
	Bulk Specific Gravity (SSD)	2.47
	Water Absorption, %	0.6
Fine Aggregate	Specific Gravity	2.76
	Water Absorption, %	1.9

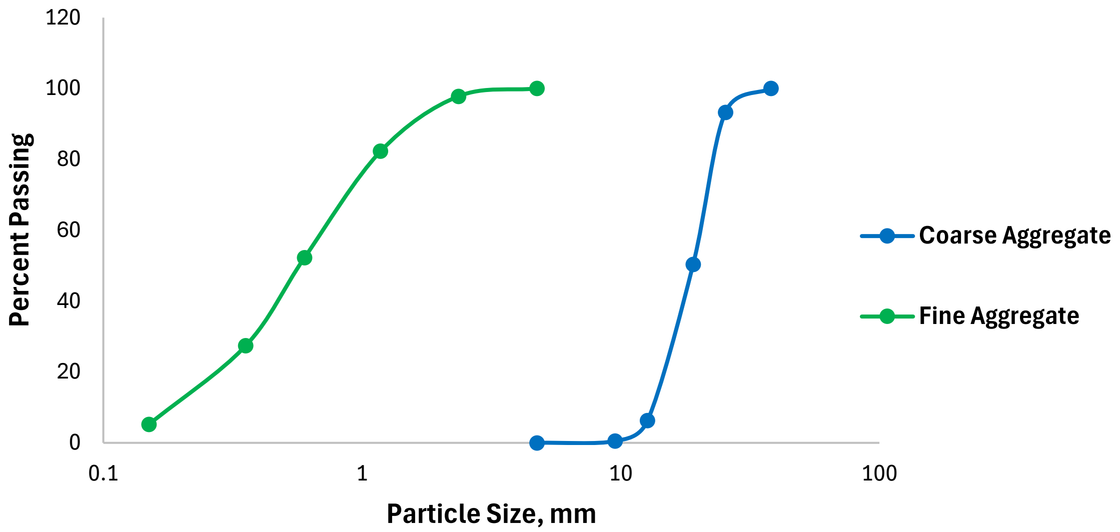

Figure 1: Gradation Curves for Fine and Coarse Aggregates

2.3 X-Ray Fluorescence Analysis of Fly Ash and Marble Dust

Fly ash has been classified into various classes such as Class F, C and N by ASTM C618 [36]. This classification is based on the chemical ingredients present in fly ash and its physical properties. To study its chemical composition, both X-ray fluorescence (XRF) and X-ray diffraction analysis are conducted. XRF analysis exhibits the proportions of various oxides present in fly ash whereas, XRD analysis presents the percentage contributions of both the crystalline phase and the amorphous phase in a fly ash sample. The test results for XRF analysis on fly ash samples have been exhibited on Table 2. It can be observed that the fly ash sample is classified as Class F. It is because the percentage of CaO is less than 18% and the total sum of the percentage of SiO_2 and Fe_2O_3 is greater than 50%. Moreover, the XRD results shown in Figure 2 demonstrate that the fly ash sample is amorphous in nature, as depicted by the broader and shallow peaks.

Table 2: XRF Results for Fly Ash

Chemical Compound	Proportion (%)
SiO_2	63.751
Fe_2O_3	15.767
K_2O	12.867
CaO	5.352
SO_3	0.912
MnO	0.495
TiO_2	0.440
Rb_2O	0.141
CuO	0.103
SrO	0.072
ZnO	0.055
Y_2O_3	0.029
NbO	0.017

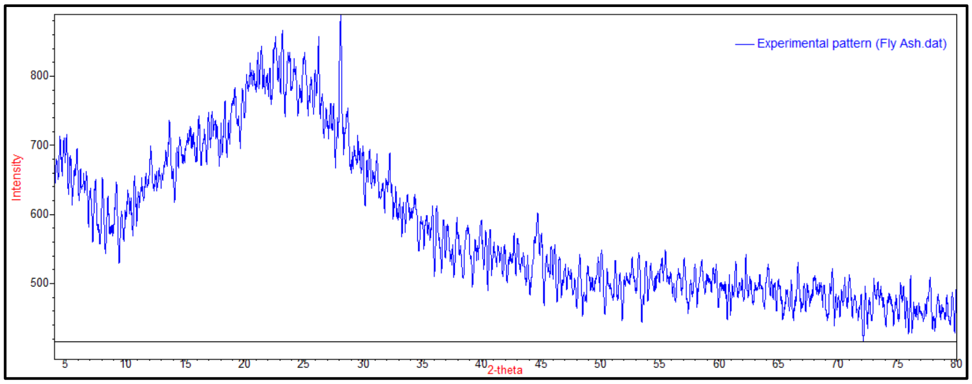

Figure 2: XRD Results for Fly Ash

Similarly, XRF and XRD analysis, exhibited in

Table *3* and Figure 3 respectively, have been performed on marble dust samples to determine its chemical composition and crystalline and amorphous phases. It can be observed that the sample is composed mostly of CaO. Moreover, the XRD analysis shows that there is a narrow and steep peak which demonstrates that the sample is composed of crystalline substance.

Table 3: XRF Results for Marble Dust

Chemical Compound	Proportion (%)
CaO	99.677
Fe_2O_3	0.160
SrO	0.074
CuO	0.059
NiO	0.030

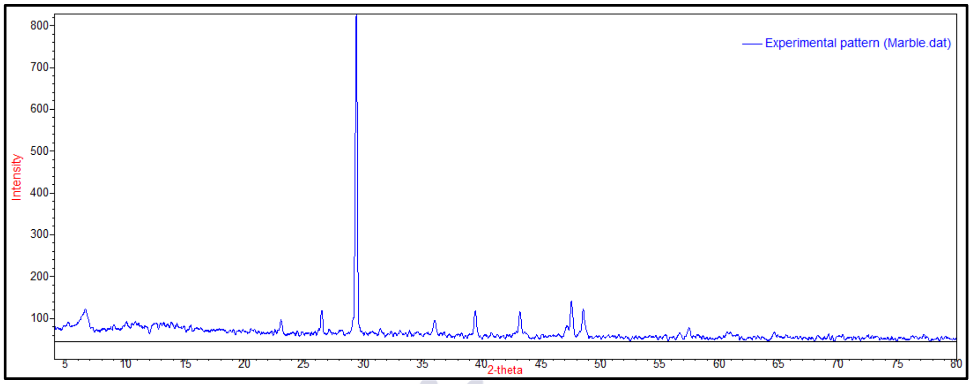

Figure 3: XRD Results for Marble Dust

3 Methodology

To determine the effect of fly ash and marble dust, incorporated as partial replacement of cement and sand respectively, on the strength and durability of concrete, two separate testing programs were adopted. Firstly, mortar cube specimens were prepared both for control group samples and partially replaced samples. Fly ash has been utilized as partial replacement of cement in the proportions of 20%, 30%, 40%, 50% and 60%. Similarly, sand was replaced partially with marble dust in proportions of 10%, 15%, 20% and 25%. There were thirty samples prepared in total with designations showing the percentage composition of fly ash and marble dust. For instance, FA0MD0 shows the control group sample and FA20MD10 shows a partially replaced sample containing 20% fly ash by replacing cement and 10% marble dust by replacing sand. After obtaining the results for compressive strength of mortar cubes, the best performed combination of fly ash and marble dust was selected and detailed concrete tests were performed up to the curing age of 90 days. Those tests included compressive strength tests on standard concrete cylinder, split-tensile strength tests and sorption tests. In addition, three different water to cement ratios were utilized while preparing the concrete samples. Those water to cement ratios were 0.45, 0.40 and 0.35 represented by A, B and C respectively.

Mix Design

Control group concrete's mix design was performed using the ACI mix design procedure [35]. Moreover, three different water to cement ratios were adopted to determine the proportions of various ingredients such as cement, fine aggregate, coarse aggregate and water, as exhibited in Table 4. The purpose of using three different water to cement ratios was to study the effect of lower water to cement ratios on the early strength gain of concrete when cement is partially replaced with fly ash.

Table 4: Mix Design Proportions for Control Group Concrete

Concrete Ingredient	Proportion (kg/m^3)		
	w/c = 0.45	w/c = 0.40	w/c = 0.35
Cement	415	467	534
Fine Aggregate	788	794	801
Coarse Aggregate	1037	1027	1068
Water	187	187	187

4 Results and Discussions

Laboratory tests such as standard compressive strength test on cement mortar [37], compressive strength test on standard concrete cylinders [38], split-tensile strength test [39] and sorption test [40] were conducted to study the behavior of mortar and concrete by comparing the control group samples and replaced samples.

4.1 Compressive Strength of Mortar Cubes

In the first laboratory experimental program, a total of thirty samples of mortar cubes were prepared including the control group samples and partially replaced samples. There were six specimens prepared for each sample to be tested at the ages of 7th day and 28th day of casting (three specimens being tested on each day for each sample). The tests results, as exhibited in Figure 4, show that the control group samples achieved average compressive strengths of 8.64 MPa and 21.48 MPa on the 7th day and 28th day respectively. Furthermore, there is a consistent increase in compressive strength as the percentage of marble dust replacement as sand increases, achieving the highest strength at 25% replacement having a compressive strength of 25.95 MPa on 28th day (approximately 21% more than control sample).

Moreover, the results for both fly ash and marble dust replacements indicate that there is gradual increase in compressive strength up to FA30MD25 and then it declines. This is because higher amounts of calcium hydroxide are required to activate the fly ash reactivity [41]. The highest compressive strength achieved by FA30MD25 is due to the presence of marble dust as partial replacement of sand, thus achieving a compact granular structure. Moreover, calcium hydroxide produced as a byproduct of cement hydration results in a higher pH environment and activates the fly ash reactivity and produces secondary CSH gel [42].

Based on the results for compressive strength tests on mortar cubes, the best proportion were 30% fly ash, and 25% marble dust incorporated as partial replacement of cement and sand respectively. Based on these proportions, concrete specimens were prepared and tested in the laboratory.

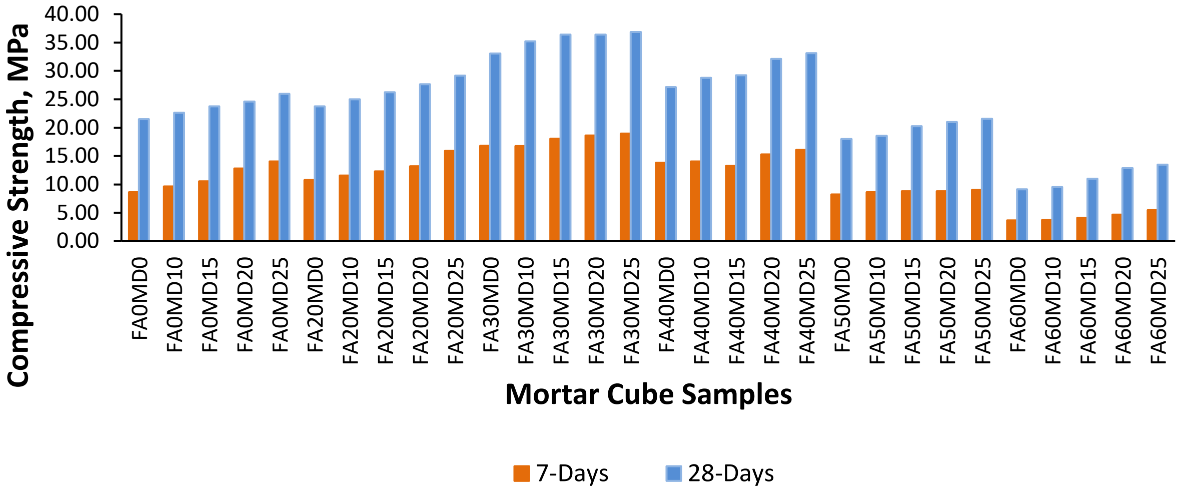

Figure 4: Compressive Strength Test Results for Mortar Cubes

4.2 Compressive Strength and Split-Tensile Strength of Concrete

To investigate the behavior of control and replaced samples of concrete, at the ages of 3, 7, 14, 28, 56, and 90 days and upon utilization of three different water to cement ratios, compressive strength tests on standard concrete cylinders were performed at the corresponding age. The test results for the compressive strength of concrete cylinders have been presented in Figure 5. It can be observed that the control group sample (A) achieved the target strength at 28 days and the other two control group samples have exceeded the target strength. This is because of the lower water to cement ratios and thus resulted in a dense structure. Similar behavior can be observed for the replaced samples at all ages also.

Furthermore, comparing the results for replaced samples with those for control groups, lower compressive strength values have been obtained for the replaced samples up to 28 days. This is because enough calcium hydroxide is not available for activating fly ash reactivity. Comparing the results of control group (A) and FA30MD25 (A) at the age of 28 days, it can be observed that there is almost 40% lower compressive strength achieved by FA30MD25 (A) as compared to control group (A) sample.

On the other hand, comparing compressive strength test results with the same samples on the 56th day and 90th day, higher values have been achieved by FA30MD25 samples as compared to the control group. There is approximately 8% and 12% increase in compressive strength for FA30MD25 on the 56th day and 90th day as compared to control group samples at the same ages.

The test results for split-tensile strength on both the control group and replaced samples have been shown in Figure 6. It can be viewed that almost similar trends have been obtained. The 28th day split-tensile strength for control group (A) was 3.16 MPa. Moreover, lower values were obtained for the replaced samples on 3rd, 7th, 14th and 28th days as compared to the control group. However, the split-tensile strength values for FA30MD25 (A) sample on the 56th and 90th days increased by 8% and 12% respectively, as compared to the control group (A).

The laboratory test results of compressive strength and split-tensile strength exhibited that the partially replaced samples achieved strength slowly as compared to the control group samples up to the 28th day. After that, there was a rapid increase in the strength of concrete as illustrated by the results on the 56th day and 90th day. This increase is because of the higher amounts of calcium hydroxide produced as a byproduct of hydration reactions of cement. The hydration reactions substantially complete till the 28th day and after that there is enough calcium hydroxide available to activate fly ash reactivity [41], [42].

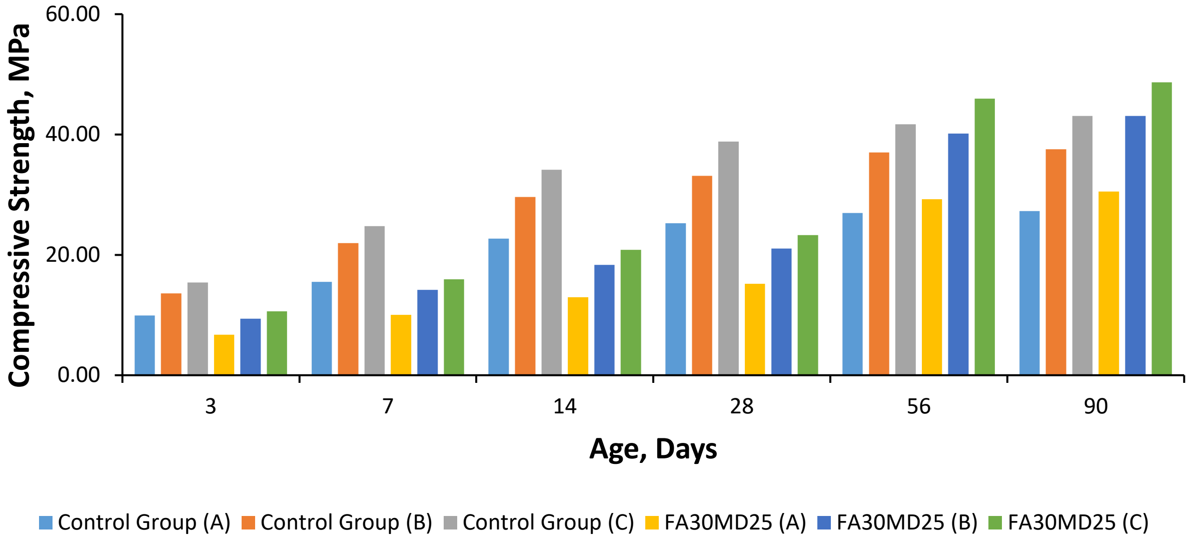

Figure 5: Compressive Strength Test Results for Concrete Samples

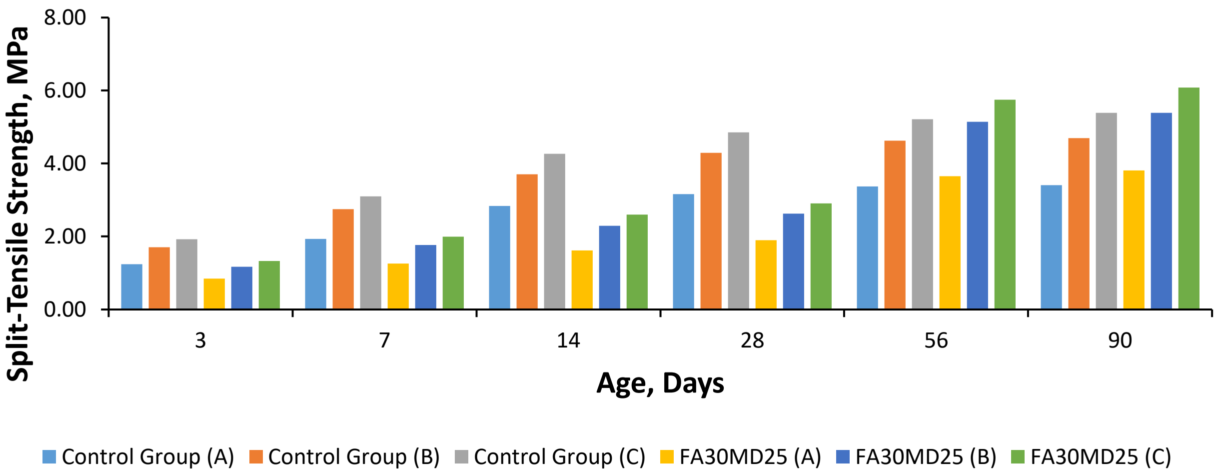

Figure 6: Split-Tensile Strength Test Results for Concrete Samples

4.3 Sorption Test

The sorption test was conducted by following the standard ASTM C1757 procedure to determine the depth (in mm) of water ingress into the concrete, thus determining the durability of concrete sample. After sequence of drying and the sample's exposure to water, the depth of water penetration was calculated by using Eq. (1).

$$Sorption\ (depth\ in\ mm) = \frac{(M_1 - M_2)}{(A \times \rho)} \tag{1}$$

Where, M_1 = weight of concrete sample after submerging in water, M_2 = oven dried weight of concrete sample, A = concrete specimen's area, ρ = density of water.

The test results for sorption have been shown in *Figure* 7. It can be observed that lower values of depth of water ingress have been obtained for FA30MD25 as compared to the control group samples. It is evident that the decrease in water penetration for replaced samples was significant on and after the 14th day of casting the concrete specimens.

The percentage decrease in the depth of water ingress for FA30MD25 (A) sample as compared to control group (A) sample were 2%, 4%, 19%, 24%, 35% and 40% on the 3rd, 7th, 14th, 28th, 56th and 90th day after casting, respectively.

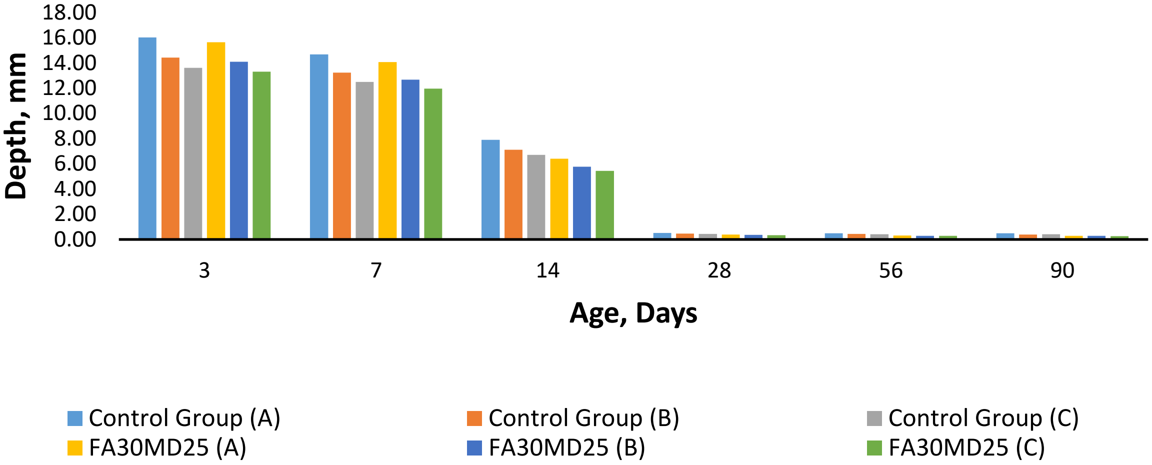

Figure 7: Sorption Test Results for Concrete Samples

Similarly, the results for the density test have been presented in Figure 8. It can be observed that there is a consistent increase in its values with the passage of time for both the control group and the replaced samples. Moreover, the density of control group samples is greater than the replaced samples on the 3rd, 7th, 14th and 28th days. However, the FA30MD25 samples achieve higher values as compared to the control group samples on 56th and 90th days. The increase in the density on the 90th day is almost 2.23%. In addition, the comparison of density and compressive strength of concrete has been exhibited in Figure 9. It can be observed that the relationship between density and compressive strength of concrete has been agreed significantly (R = 0.9662).

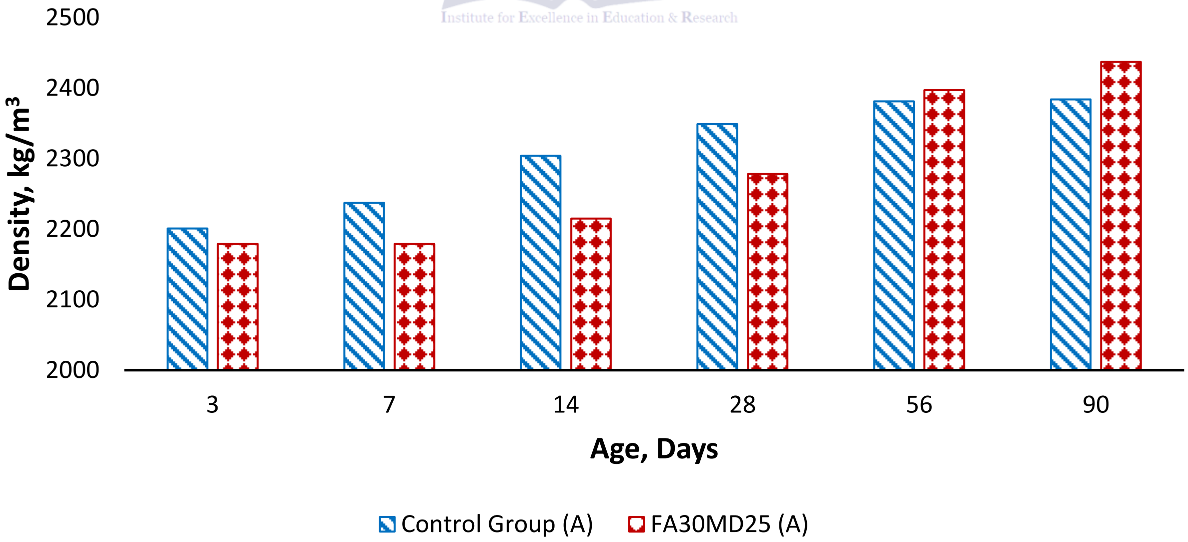

Figure 8: Density of Control Group (A) Samples and FA30MD25 Samples of Concrete

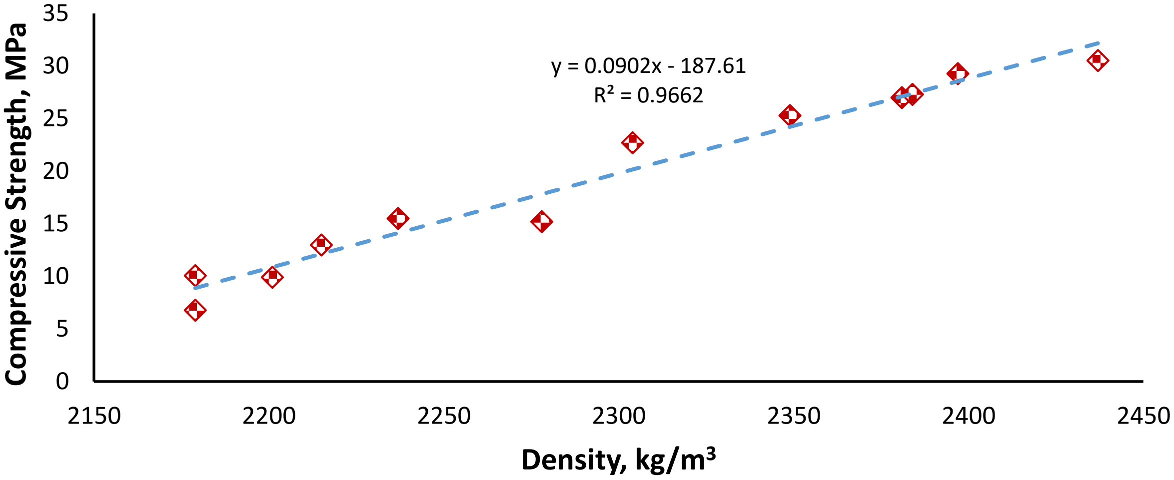

Figure 9: Development of Density Vs Compressive Strength Relationship with Time

The laboratory test results for sorption and density of both the concrete samples exhibited improvement with the passage of time. The results for the FA30MD25 samples were more significant on the 56th and 90th days as compared to that of control group samples. It can be due to the secondary gel formation because of the reactivity of fly ash with calcium hydroxide [43]. Consequently, a denser and less porous molecular structure of the concrete has been achieved. This denser structure is because of the consumption of calcium hydroxide which is less dense compared to C-S-H and C-A-H gels produced as result of the fly ash reactivity with the calcium hydroxide [44].

5 Conclusions

This research study aimed at finding the optimum percentage of fly ash and marble dust incorporated in concrete by replacing cement and sand respectively, so that early strength may be achieved and mitigation of cement and sand consumption. To evaluate the performance of replaced samples as compared to the control group, various laboratory test results were compared such as compressive strength of mortar cubes, compressive strength of concrete, split-tensile strength of concrete, and sorption and density of concrete. Based on the results obtained, the following conclusions were made:

- The chemical composition and molecular structure analyses were performed using XRF and XRD analyses respectively, and it was found that the fly ash is Class F based on the ASTM C618 and composed mostly of amorphous material. Moreover, almost the whole mass of marble dust is composed of CaO and is crystalline in nature.
- Compressive strength tests for standard mortar cubes were aimed at comparing the control group sample and the partially replaced samples so that the best combination of fly ash and marble dust could be determined. These results concluded that the optimum percentage utilizations of fly ash and marble dust are 30% and 25%, by replacing cement and sand respectively.
- The optimum percentages of fly ash and marble dust obtained from the mortar cube tests were then utilized for preparing samples of concrete. Compressive strength tests on standard concrete cylinders show that the replaced samples resulted in lower early strength up to the age of 28 days as compared to the control group. However, the replaced samples showed 8% and 12% higher strengths as compared to the control group on the 56th and 90th days.
- The results for split-tensile strength showed almost similar trends to the compressive strength results. The lower early strength (i.e. up to 28 days) is due to the reduction of cement content due to replacement and smaller amount of calcium hydroxide available for activating fly ash reactivity. Moreover, the marble dust besides resulting in a dense structure has not shown significant impact on the strength properties of concrete.

- The durability results obtained in the form of sorption test have been improved by replacing 30% cement and 25% sand with fly ash at all the testing ages. The largest reduction (i.e. 40%) in depth of water ingress as compared to the control group was observed on the 90th day test. This is due to the dense micro-structure resulting from the finer marble dust particles and fly ash reactivity.
- Lastly, replaced samples resulted in higher densities as compared to the control group on 56th and 90th days. The relationship between density and compressive strength results was also drawn. It was evident that the relationship was significant with the R^2 value of 0.966.

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