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EFFECTS OF CRUSHED STONE DUST ON SOME PROPERTIES OF CONCRETE

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ABSTRACT

Crusher dust is a fine material formed during the process of comminution of rock into crushed stone or crushed sand. This dust is composed by particles which pass 75 μm BS sieve. Effects of dust content in aggregate on properties of fresh and hardened concrete are not known very well. An experimental study was undertaken to find out the effects of various proportions of dust content on properties of fresh concrete, and hardened concrete.

Introduction

There has been a long-term growing demand for aggregates to produce concrete and this has presented increased problems of supplying of sand and gravel (1). Besides this, environmental rules and regulations and scarcity of natural aggregates result in a continuously increasing trend towards the use of crushed rock aggregates in concrete.

Crushed rock aggregates are more suitable for production of high strength concrete compared to natural gravel and sand (2). Crushed rock aggregates differ from sand and gravel in particle shape and surface texture and in the grading of fines. British Standard, BS 882: Part 2: 1983 (3) specifies the grading requirements of crushed rock fine aggregate which is slightly different than that of the natural sand. The difference is related to the very fine particles, often referred to as "crushed rock dust" or simply "dust", i.e. particles passing 75 μm BS test sieve. BS 882: Part 2: 1983 allows a dust content of up to 15 percent by mass for crushed rock fine aggregates and 10 percent by mass for crushed rock all-in aggregates. If there is a reluctance to use crushed rock aggregates in concrete manufacturing, it is primarily based on this allowance of a higher dust content in crushed rock fines than that in the natural sand. Most of the crushed rock fine aggregate produced in N. Cyprus contains approximately 17 - 25% of dust. So, an upper limit of 30% dust content was chosen in this investigation to find out the optimum percentage of dust content as a partial replacement of fine aggregate that is positively improve the properties of fresh and hardened concretes.

ENV 197 defines a Portland - filler cement (Type II F) which may include up to 20% limestone filler of a certain level of purity (4), and all types of concreting works can be done with filler cements (5). A research program by Matthews J. D. (6), was carried out to examine the effect of the addition of calcareous fillers to ordinary portland cements at addition levels of

0, 5, and 25% on the chemical and physical properties of cements and fillers, properties of fresh concrete and properties of hardened concrete. Target strengths were 43-45 MPa for 0 and 5% addition levels and 36-38 MPa for 25% addition levels.

Higher content of dust in the aggregate increases the fineness and the total surface area of aggregate particles, where surface area is measured in terms of specific surface, i.e. the ratio of the total surface area of all the particles to their volume (7). Aggregates with higher specific surface area require more water in the mixture to wet the particles surfaces adequately and to maintain a specific workability (8). Obviously, increasing water content in the mixture will adversely affect the quality of concrete.

Crushed rock dust acts as a filler and helps to reduce the total voids content in concrete. Consequently, this contributes to improve the quality of concrete. In this research, some part of the sand replaced by crushed rock dust at amounts of up to 30 percent keeping all the other ingredients and proportions constant. The effects of varying dust contents on the physical and mechanical properties of fresh and hardened concrete were investigated. Slump and air content of fresh concrete and absorption, compressive strength, flexural strength, impact resistance, water permeability and drying shrinkage of hardened concrete were also investigated.

Objectives of the Research

The main objective of this research is to provide more information about the effects of various proportions of dust content as a partial replacement of crushed stone fine aggregate on workability, air content, compressive strength, flexural strength, impact resistance, absorption percentage, water permeability, and drying shrinkage of concrete. Once the effects of crushed stone dust on concrete properties are obtained, it will be possible to take necessary measures to alleviate its adverse effects on concrete.

Experimental Program

Materials. In all mixes limestone crushed rock coarse and fine aggregates were used. Dust passing 75 μm BS sieve was produced in a laboratory crusher. The maximum size of coarse aggregate was 28 mm. The specific gravity of aggregate was 2.65. The fineness modulus of fine aggregate was 3.39. The grading of fine aggregate is shown in Table 1.

The cement used was Blast Furnace Slag cement complying with TS 20 DPÇ 325 (9).

Mix Proportions. Mix proportioning was performed by using weight batching method. The concrete mix proportion was designed accordance with Reference 10, and it was as follows:

Cement	: 420	Kg/m^3
Fine aggregate	: 210	Kg/m^3
Coarse	: 965	Kg/m^3
Water	: 210	Kg/m^3

Seven different mixes were prepared using, fine aggregate partially replaced by dust at varying percentages of 0, 5, 10, 15, 20, 25, and 30.

TABLE 1
Sieve Analysis Results for Limestone Based Crused Rock Fine Aggregate Used

Sieve Size	Cumulative Percentage Retained	Cumulative Percentage Passing
6.30 mm	0	100
5.00 mm	2	98
2.36 mm	32	68
2.00 mm	39	61
1.70 mm	46	54
1.18 mm	54	46
850 mm	60	40
600 mm	65	35
425 mm	71	29
300 mm	73	27
212 mm	75	25
150 mm	78	22
75 mm	82	18
pan	100	0

Curing Procedure. Specimens were cured in accordance with BS 1881: Part 3: 1970 (11).

Mixing and Testing. For mixing a laboratory pan mixer was used. The slump and air content of freshly mixed concrete accomplished with BS 1881: Part 2 :1970 (12) were tested. Having completed the slump and air content tests the following specimens were cast for each mix:

1. Three 150x150x150 mm cubes for compressive strength test according to BS 1881: Part: 1970 (13).
2. Three 150x150x750 mm beams for flexural strength test according to BS 1881: Part 4: 1970 (13).
3. Three 150 mm diameter by 60 mm height cylindrical specimens for impact resistance test (14).
4. Four 75x75x150 mm prisms for absorption test (15).
5. Three 127 mm diameter by 95 mm height cylindrical specimens for water permeability test.
6. Two 75x75x300 mm beams for drying shrinkage test according to BS 1881: Part 5: 1970 (16).

In flexural strength test, third point loading was used, and the flexural strength was computed by using the following expression (13):

$$f_b = \frac{p\ l}{b\ d^2} \qquad (1)$$

where f_b is the flexural strength (MPa), p is the maximum applied load (N), l is the span length (mm), b is the width of specimen (mm), and d is the depth of specimen (mm).

In order to measure the impact resistance of concrete, a standard manually operated 10-lb (4.54 kg) compaction hammer was used and experiment was performed according to ACI Concrete Manual (14).

To find out the absorption of concrete, specimens were dried at a temperature of approximately 105°C for 72 hr, and this dry weight was designated as A. After final drying, cooling and weighing, the specimens were immersed in water at approximately 21°C for 72 hrs. Then the specimens were taken out and their surfaces were dried by removing surface moisture with a towel, and weighed. This final saturated-surface dry weight was designated as weight *B*. The absorption of concrete was calculated as following (15):

$$Absorption\ ,\ \% = \frac{B - A}{A} \times 100 \tag{2}$$

In water permeability test the specimens were covered by silicon and kept under water pressure of 0.1 MPa for 48 hr, then 0.3 MPa for 24 hr, and finally 0.7 MPa for 48 hr. In the calculation of coefficient of permeability, the time and pressure considered were 48 hr and 0.7 MPa, respectively. The following expression according to Darcy's law was used in the calculations of the coefficient of permeability:

$$K = \frac{Q\ L}{H\ A\ T} \tag{3}$$

where K = Coefficient of permeability (cm/sec)
Q = Quantity of water that flows through the sample (cm^3)
L = Height of concrete specimen (cm)
H = Hydraulic head loss for height L (cm)
A = Cross-sectional area of the specimen (cm^2)
T = Time required for Q to occur (sec)

Experimental Results

Fresh Mix Test Results. Results of slump test (average of five tests) are given in Table 2. From Table 2 it can be concluded that, as the percentage of dust in the concrete increases, the slump of concrete decreases. As the percentage of dust increases, the fineness of aggregate increases and in turn, the specific surface of aggregate particles increases. So, more water was required to wet the increased amount surfaces of particles and consequently, workability decreases (17).

Air content of fresh concrete test results (average of two tests) are also given in Table 2. As it can be seen from Table 2, while the dust content of fresh concrete increases, the average air content of the fresh concrete decreases. In this investigation, the W/C ratio, the aggregate type, the cement content were kept constant for all mixes of different dust content replacement, and the only variable here was the percentage of dust content. Therefore, the total air content is affected by the dust percentage replacement where dust acts as a filler material, in which the

TABLE 2
Slump and Air Content Test Results of Fresh Concretes

Dust Content (%)	Slump (mm)	Air Content (%)
0	92	2.77
5	87	2.40
10	80	2.15
15	76	1.90
20	72	1.73
25	65	1.48
30	60	1.28

voids in fresh concrete are filled with dust, hence the total air content decreased as the percentage of dust content replacement increased.

Absorption. The results of absorption of concrete are shown in Fig. 1. The curve shown in Fig. 1 represents the average of four tests. According to Fig. 1, the absorption percentage of concrete decreased for dust contents from 0 to 15%, and then it started to increase for 20, 25, and 30% of dust contents. Crushed stone dust acts as a filler in the concrete and contributes to reduce the absorption of concrete. However, increasing the dust content more than 15% causes an increase in absorption which is a parallel leading with compressive strength.

Compressive Strength. The results of compressive strength for 7 and 28-day are shown in Fig. 2. The figure represents the average of two and three tests for 7 and 28-day, respectively. It can be seen from Fig. 2 that the compressive strength in 7 and 28 days increases to a maximum of 22.47 and 32.38 MPa respectively at a dust content of 10%. As the dust content exceeds the value of 10%, the compressive strength decreases.

For specimens of dust content percentages of 0, and 5, the dust particles amount is not enough to fill all voids between cement paste and aggregate particles, hence they have lower compressive strength values than specimens of with 10% dust content. As the dust content exceeds 10%, the amount of fines in the concrete increases, so much that, there is not enough cement paste to coat all the coarse and fine aggregate particles, and this consequently leads to a decrease in compressive strength. In an investigation (18) on the strength development characteristics of a range of cements containing calcareous fillers at addition proportions of 5 and 25%, it was concluded that 5% OPC and 5% RH (Type I cements made by blending 5% filler with RHPC) developed strengths within the same range of values as their counter parts without filler, and also the strength class of Type I cements was not affected by the addition of 5% filler.

Flexural Strength. Fig. 2 shows also the relation of dust content and flexural strength, which represents the average of two and three tests for 7 and 28-day, respectively. It can be seen from Fig. 2 that the flexural strength increases to a maximum of 3.09 and 4.32 MPa respectively for 10% dust content. As the dust content exceeds the value of 10%, the flexural strength decreases. Similar arguments as mentioned above for compressive strength can be applicable also for flexural strength.

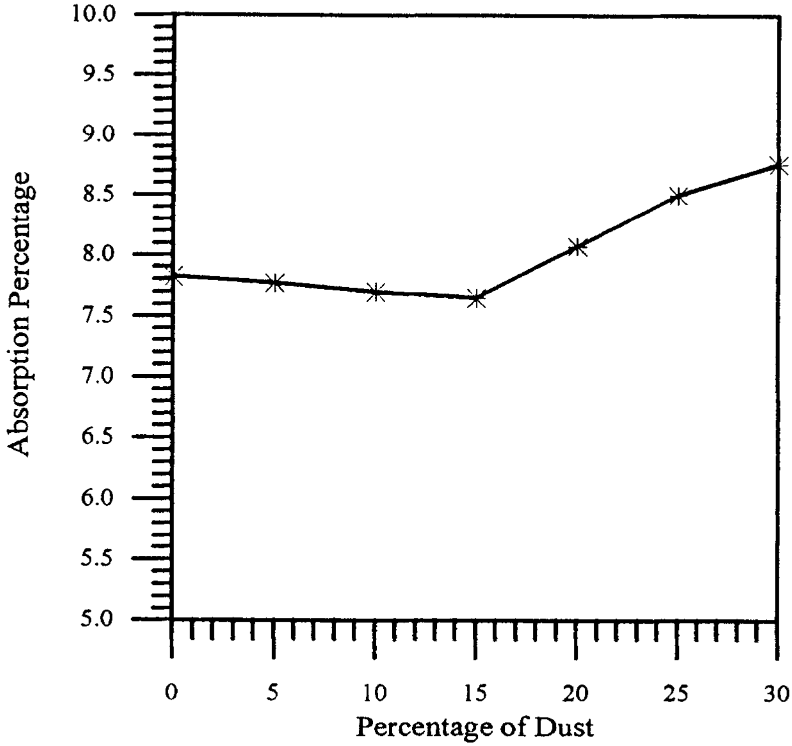

FIG. 1.
Absorption percentages of concretes made of various dust contents at age of 28-day.

Impact Resistance. Fig. 3 shows the relation of dust content and impact resistance of concrete. According to Fig. 3, the maximum number of blows, 81 blows, was reached when the mix included 5% of dust. However, for higher dust contents the impact resistance decreases and reaches to a minimum value of 33 blows for 30% of dust. So, 5% dust content improved the impact resistance of the concrete specimens although the compressive strength is maximum at a 10% dust content, but beyond 5% dust the impact strength decreases may be due to the increase in the amount of fines in concrete.

Water Permeability. The results of water permeability of concrete are shown in Fig. 4. The curve shown in Fig. 4 represents the average coefficient of permeability, K, for the three concrete test cylinders. It can be seen from Fig. 4 that the coefficient of permeability, K, decreases as the dust content increases. The highest coefficient of permeability was 6.59×10^{-10} cm/sec for 0% dust content, and the lowest was 1.93×10^{-10} cm/sec for 30% dust content. The addition of dust to the concrete improves the impermeability of concrete because it blocks the passages connecting capillary pores and the water channels. This blockage is affected by the amount of dust content, and the more water passages were blocked, the more reduction in the permeability of concrete specimens is observed.

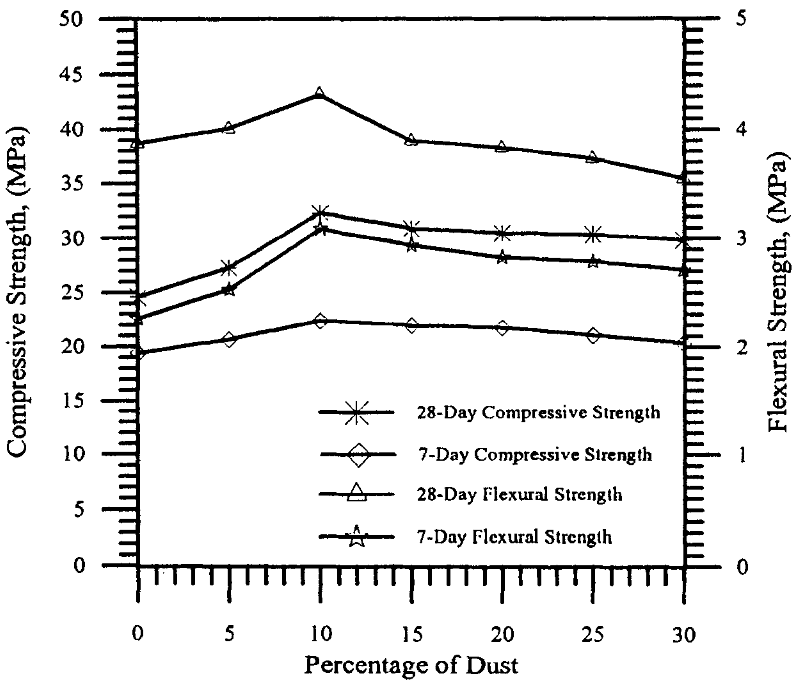

FIG. 2.
Compressive and flexural strength test results of concretes made of various dust contents at ages of 7 and 28-day.

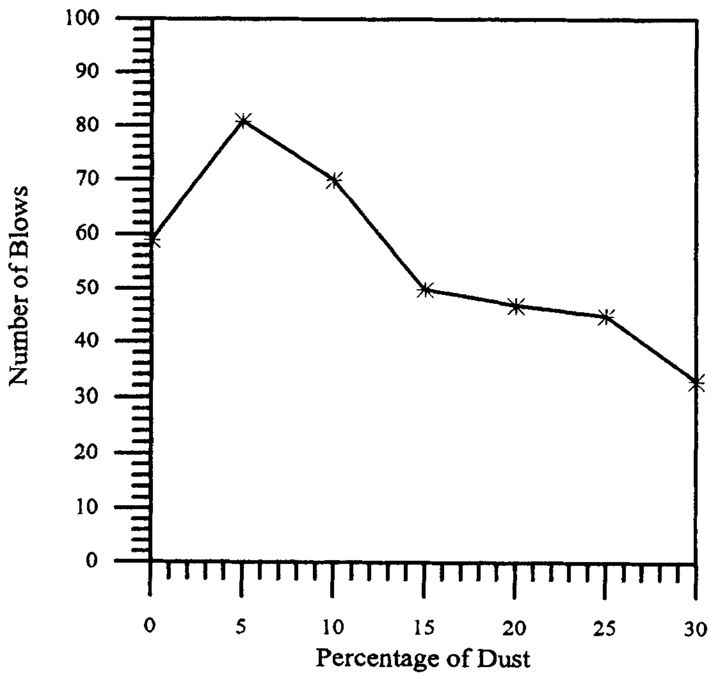

FIG. 3.
Impact resistance in number of blows of concretes made of various dust contents at age of 28-day.

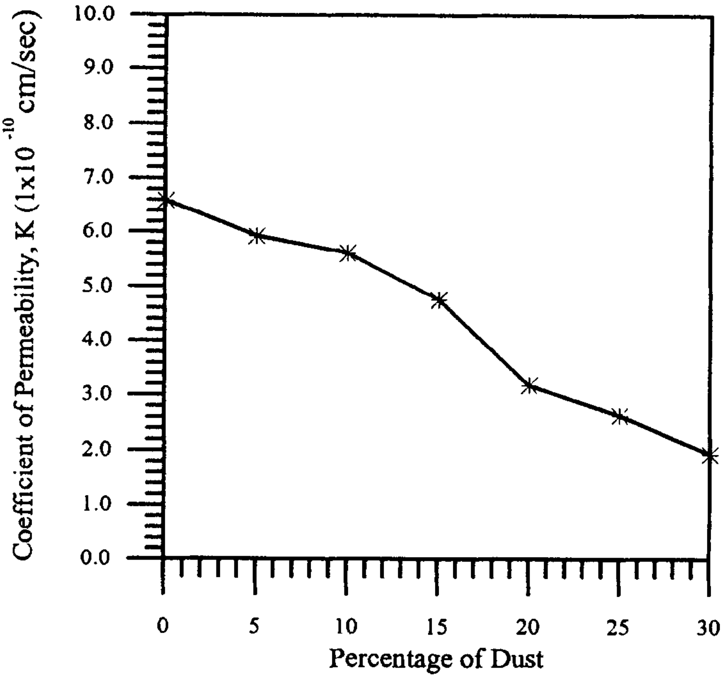

FIG. 4.
Coefficient of permeability of concretes made of various dust contents at age of 28-day.

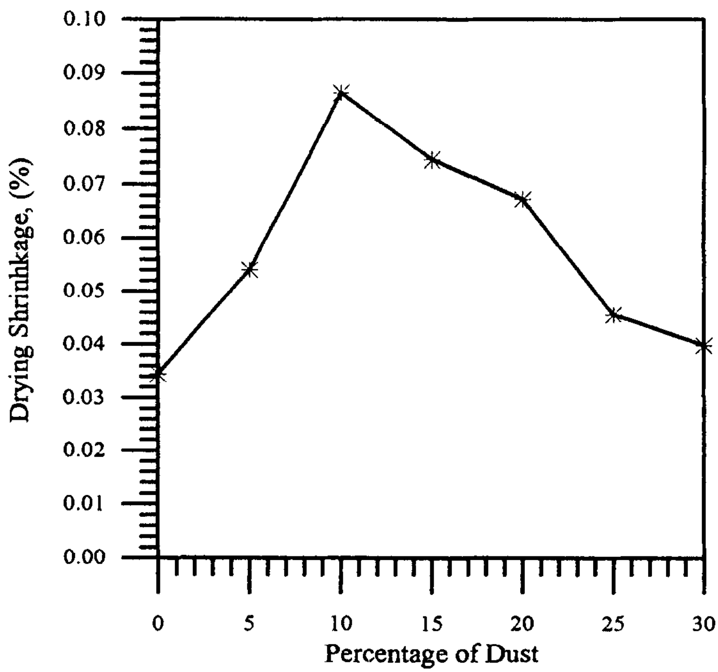

FIG. 5.
Drying shrinkage test results of concretes made of various dust contents at age of drying of 21-day.

Drying Shrinkage. The results of drying shrinkage test are shown in Fig. 5. The curve in Fig. 5 represents the average drying shrinkage of two specimens. As it can be seen from Fig. 5, the drying shrinkage decreases for dust contents of 10% or more. On the other hand, the shrinkage increases while the dust content increases from 0 to 10%. "Stronger concretes are stiffer, more water tight, and highly resistant to weathering, however, they exhibit higher shrinkage" (19). This agrees well with the results of this investigation. The highest value of compressive strength exhibited a higher drying shrinkage value at 10% dust content. Beyond 10% dust content, the compressive strength decreases, while the drying shrinkage increases.

Conclusions

The following conclusions can be derived:

1. Slump decreased as the percentage of dust content increased.
2. Air content of fresh concrete decreased as the percentage of dust content increased.
3. Increasing the dust content up to 10% improved compressive strength of concrete. For higher dust contents than 10%, the compressive strength decreased gradually.
4. Increasing the dust content up to 10% improved the flexural strength of concrete. However, the dust content exceeding 10%, decreased the flexural strength of concrete gradually.
5. Concrete made of up to 5% dust content improved the impact resistance of concrete. However, dust contents more than 5% reduced the impact resistance of concrete significantly.
6. The minimum value for absorption was obtained when the dust content is 15%. Dust contents higher than 15% increased the absorption of concrete.
7. Water permeability of concrete decreased as the dust content percentage increased. The reason for this is that, the more dust content added to the concrete, the more water passages and channels were blocked, hence this leads to a reduction in the permeability of concrete.
8. Increasing the dust content up to 10% increased the drying shrinkage. As the dust content exceeded the value of 10%, the drying shrinkage strain decreased. This has a relationship with compressive strength, the higher the strength of concrete, the higher the drying shrinkage exhibited and maintained.

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