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Full Length Research Paper

Influence of marble and limestone dusts as additives on some mechanical properties of concrete

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In this study, some mechanical properties of concrete containing marble dusts (MD) and limestone dusts (LD) were investigated. Seven concrete mixtures were produced in three series with control mixes having 400 kg cement content. These control mixes were modified to 5, 10 and 15 % MD and LD in place of fine sand aggregate. The compressive strengths of concrete were measured for 7, 28, 90 and 360 days and sodium sulphate resistance were for 12 months. Also, abrasion resistance and water penetration of concretes were investigated. Results indicate that MD and LD fine aggregate concrete has good workability and abrasion resistance is comparable to that of conventional concrete. They also showed that maximum abrasion rate is obtained from control specimen, while minimum abrasion rate is obtained from MD3 specimens. Abrasion resistance is increased as the rate of fine MD and LD is increased. Furthermore, the results indicated that the increase in the dust content caused a significant increase in the sodium sulphate resistance of the concretes. Therefore, the studied MD and LD can be used for more durable concrete production.

Key words: Concrete, mechanical properties, marble, limestone, dust.

INTRODUCTION

Leaving the waste materias to the environment directly can cause environmental problem. Hence, many countries have been working on how to reuse the waste material so that they reduced hazards to the environment (Karasahin and Terzi, 2007).

The author reported that developed countries have strict rules to protect the environment whereas many developing countries have almost no rules to protect the environment against wastes. However, wastes can be used to produce new products or can be used as admix-tures so that natural sources are used more efficiently and the environment is protected from waste deposits. During the cutting process about 25% marble is resulted in dust. In Turkey marble dust is settled by sedimentation and leaved directly *in situ* which result in ugly appearance of environment and also causes dust in the summer and threat both to agriculture and health. Marble and lime stone dust have been used in many study. For instance they have been used in asphalt mixtures as filler material.

The author reported that finer and better-graded limestone dust significantly increases the deformability of the paste (Bokan, 2003). Limestone and dolomite fines are the most frequently used to increase the content of fine particles in self compacting concretes among nonpozzolanic fillers (Billberg, 1999). Compared to plain concrete with the same W/C ratio and cement type, concrete with high limestone filler content with suitable particle size distribution possesses generally improved strength characteristics (Sonerbi et al., 2000; Petersson, 2001). However, the modulus of elasticity as well as the creep and shrinkage strains of concretes with limestone filler admixtures can be higher, the same or lower [Gram and Piiparinen, 1999; Bui and Montgomery, 1999; Persson, 2001), because these characteristics both depend on limestone filler effects and on the volume fraction of the paste matrix.

Durability is a major concern for concrete structures exposed to aggressive environments. Many environmenttal phenomena are known to significantly influence the durability of reinforced concrete structures (Ihekwaba et al., 1996; Castro et al., 2000; Roper and Baweja, 1991;

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Table 1. The chemical and physical characteristics of materials used.

<table>
<tr><th>Samples</th><th colspan="11">Oxides (%)</th></tr>
<tr><th></th><th>SiO_2</th><th>Al_2O_3</th><th>Fe_2O_3</th><th>CaO</th><th>MgO</th><th>SO_3</th><th>Na_2O</th><th>K_2O</th><th colspan="2">Ca SO_3</th><th>LI</th></tr>
<tr><td>PPC</td><td>20.8</td><td>5.3</td><td>3.5</td><td>64.7</td><td>1.6</td><td>0.9</td><td>0.13</td><td>0.27</td><td colspan="2">-</td><td>-</td></tr>
<tr><td>*MD*</td><td>5.1</td><td>0.4</td><td>1.98</td><td>50.13</td><td>2.72</td><td>-</td><td>0.04</td><td>0.09</td><td colspan="2">6.32</td><td>35.5</td></tr>
<tr><td>*LD*</td><td>4.7</td><td>0.3</td><td>1.84</td><td>49.71</td><td>2.58</td><td>-</td><td>0.03</td><td>0.1</td><td colspan="2">6.25</td><td>33.1</td></tr>
<tr><th>Materials</th><th colspan="11">Physical properties of materials</th></tr>
<tr><td></td><td colspan="3">Specific gravity (kg/m^3)</td><td colspan="2">Blaine (m^2/kg)</td><td colspan="3">Vicat time of setting (min)</td><td colspan="3">Compressive strength (MPa)</td></tr>
<tr><td>*PPC*</td><td colspan="3">3155</td><td colspan="2">300</td><td>Initial</td><td colspan="2">Final</td><td>3 day</td><td>7day</td><td>28 day</td></tr>
<tr><td>*MD*</td><td colspan="3">3185</td><td colspan="2">-</td><td>110</td><td colspan="2">210</td><td>24.3</td><td>37.6</td><td>47.1</td></tr>
<tr><td>*LD*</td><td colspan="3">2780</td><td colspan="2">-</td><td></td><td colspan="2"></td><td></td><td></td><td></td></tr>
</table>

LI = Loss on Ignition

Table 2. The terminology for all samples.

Samples	System of replacements
C(Control mixture)	Aksu river natural aggregates
MD1	5 % Marble dust by weight of fine sand aggregates
MD2	10 % Marble dust by weight of fine sand aggregates
MD3	15 % Marble dust by weight of fine sand aggregates
LD1	5 % Limestone dust by weight of fine sand aggregates
LD2	10 % Limestone dust by weight of fine sand aggregates
LD3	15 % Limestone dust by weight of fine sand aggregates

Table 3. Cumulative passing for the Aksu river aggregate grades for EN TS 706.

Sieve size	Cumulative passing (%)		
mm	A16	Aksu river aggregate	C16
16	100	100	100
8	60	75	88
4	36	41	74
2	21	30	62
1	12	22	49
0.5	8	13	33
0.25	3	9	18

Haque and Kawamura, 1992; Tahir and Salih, 2007).

In Turkey, a huge quantity of limestone dust and mar-ble dust is produced. This is often a cause of major envi-ronmental problems. However, in recent years many qua-rries were closed off because of the environmental pro-tection rules put into practice (Karasahin and Terzi, 2007). Hence, these waste material as filler material ne-eds to be investigated for construction material. In the paper, use of marble and limestone dust is investigated in concrete mixtures as filler material. For this purpose, marble and limestone dust were added to replace a por-tion of the fine aggregates used in the control concrete mixture; then the concrete durability (subjected to 7% sodium sulfate solution, abrasion resistance and wa-ter penetration), were inspected. According to the results ob-tained from the experiments, the reliability of the mention-ed organic originated materials as additives was evalua-ted.

MATERIALS USED

Aggregate and cement

A pure Portland cement (PPC) was used for all concrete mixtures. Local Aksu river natural aggregate was used for making concretes. The mentioned materials were first taken to the Kahramanmaras Sutcu Imam University, Civil Engineering Department, structure ma-terial laboratory where after the grading process it was brought to a size of 1 mm. The chemical and physical characteristics of mate-rials used are given in Table 1 and the terminology for all samples is given in Table 2. Maximum aggregate size 16 mm was used and grading analyses performed according to EN TS 706. Cumulative passing for the Aksu river aggregate grades for EN TS 706 and the grading dates for aggregate and grain size distribution of fine sand aggregates used in test specimens (as defined by sieving) are given in Table 3 and Figure 1, respectively.

Dusts

Limestone dust (LD) and marble dust (MD) were used. Limestone dusts were obtained through sieving test of the aggregate from 1 mm sieve and marble dust was obtained in wet form directly taken from deposits of marble factories. Wet marble dust must be dried

Table 4. Concrete mixture proportions.

Properties	Mixture						
	C	MD1	MD2	MD3	LD1	LD2	LD3
Cement, PPC (kg/m^3)	400	400	400	400	400	400	400
MD (%)	0	5	10	15	5	10	15
MD (kg/m^3)	0	30	60	90	30	60	90
LD (%)	0	5	10	15	5	10	15
LD (kg/m^3)	0	30	60	90	30	60	90
Water, W (kg/m^3)	200	190	190	190	190	190	190
W/C	0.50	0.48	0.48	0.48	0.48	0.48	0.48
Sand SSD (kg/m^3)	600	570	540	510	570	540	510
Coarse aggregate (kg/m^3)	1200	1200	1200	1200	1200	1200	1200
Superplasticizer (l/m^3)	3	3.5	3.6	3.7	3.5	3.6	3.7
Slump (mm)	120	90	85	80	90	85	80
Air content (%)	2.4	2.2	2.1	2	2.3	2.2	2.1
Air temperature (^{0}C)	27	26	26	26	27	27	27
Concrete temperature (^{0}C)	27	28	28	29	27	28	29
Unit weight (kg/m^3)	2340	2329	2320	2318	2322	23118	2311

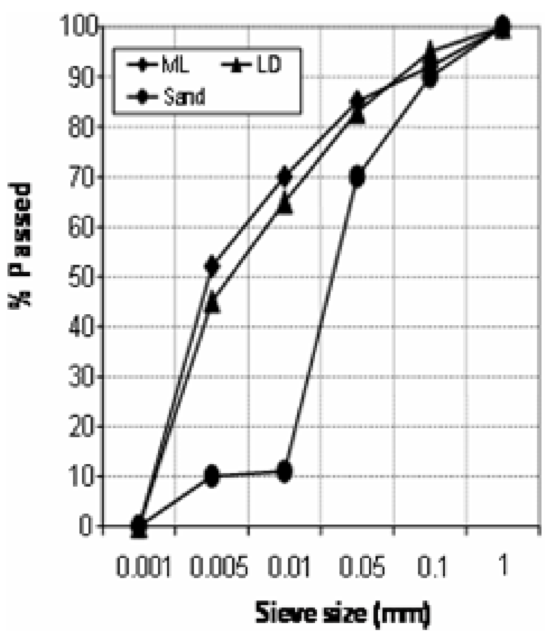

Figure 1. Grain size distribution of fine sand aggregates used in test specimens (as defined by sieving).

before the sample preparation. Waste marble dust contains several marble types, saw parts and marble particles. Hence, waste marbledust was washed at first and sieved from 1 mm sieve.

Experimental study

Water used in the production of the concrete samples was drinking water from Kahramanmaras Sutcu Imam University, Kahramanmaras and the cement used to complete the experiments was pure Portland cement (PPC) with addition, produced by Adana Cement factory, Adana. For sampling TS 3068 ISO 2736-2, for grading EN TS 706 were used. The mixture is designed according to the absolute volume method given by Turkish Standard EN TS 802. Concrete composition is given in Table 4. The concrete specimens were prepared with the same average slump of 8.5 - 12 cm, dosage of 400 kg/m^3. The temperature of the mixing water kept constant at 18^{o}C before mixing and of the mixing room at 22^{o}C along the mixing process. Marble and limestone dusts, which were used as additives in this study, were added into the concrete mixtures instead of fine sands in separate amount ratios, which were 5, 10 and 15%. The water penetration test was performed according to EN TS 10967.

Concretes specimens were prepared to investigate the effect of sulphate attack on the compressive strengths. Also, concretes were prepared and their compressive strengths were determined. Standard cubic specimens of 150 mm size were cast; the compressive strengths of concretes were measured by immersing in 7% sodium sulphate solution for 12 months. The behaviour in sodium sulfate solution was determined according to ASTM 1012.

Abrasion resistance was performed to establish the effects of the dust type and amount of dust on abrasion resistance of concrete. Abrasion testing was performed in according to DIN 52108 / 2002. In this standard, abrasion testing is applied on specimens of size 75 x 75 x 55 mm at the ages of 28, 90 and 360 days. First, the concrete specimens were cleaned using a wire brush and kept 24 h in a water tank at 20^{o}C temperature. At the end of this period the specimens were taken out and wiped with a wet cloth. The specimens were surface dry saturated (SDS). Sand blasting pressure is 40 N/mm^2. The rate of flow of abrasive sand was 500 g per minute. In the present study, the test was carried out at 20^{o}C temperature and 60% relative humidity. SDS specimens were measured and the length was denoted as I_0. Sand blasting was performed for 60 s, applied to at least eight different points. At the process the specimens were kept in 20^{o}C water for two hours. Then, they are wiped with a wet cloth. Finally, samples were measured and the result was denoted I_1. Hence, $I = I_1 - I_0$ was found as the loss of mass.

Water penetration test was performed in accordance with EN TS 3455. The tests were performed after 28 and 56 days. Concrete cylinders were demoulded after a day and a series of specimens was kept under water for 28 days after demoulding and tested.

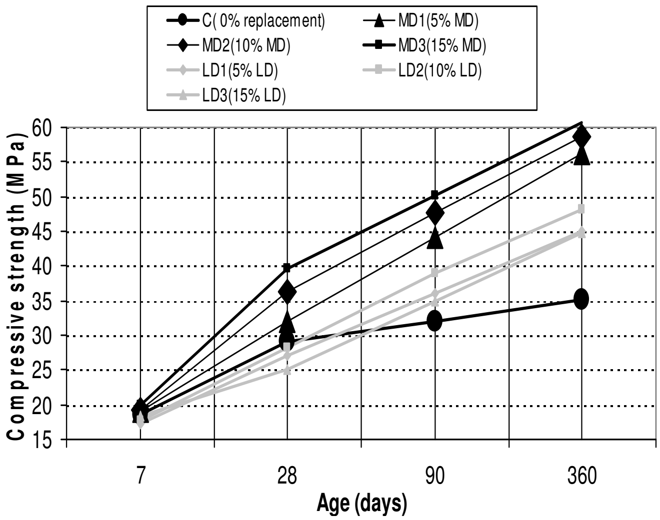

Figure 2. Compressive strength of concrete mixtures versus age.

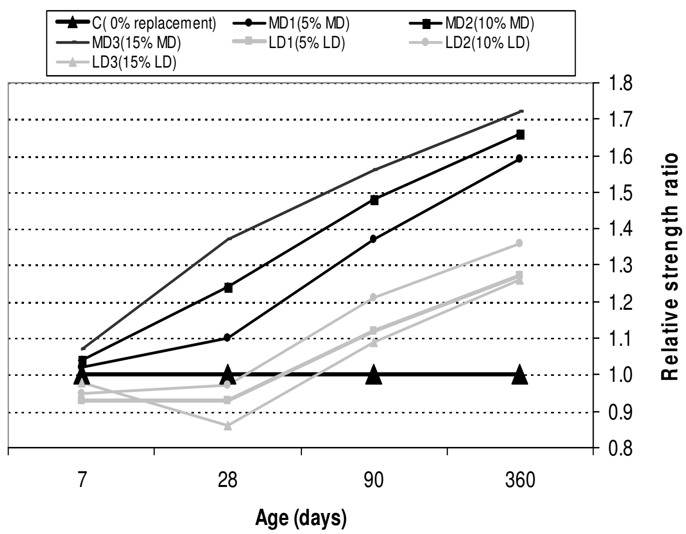

Figure 3. Relative strength of tested concrete specimens

After that they were sliced 50 mm thickness with the 50 mm ends discarded. The sliced cylinders were left to dry in laboratory condition for 24 h before application of epoxy coatings. All specimens were epoxy coated around the cylindrical surface and after finishing the process then they were left in the laboratory for testing. Water permeability of concrete was determined from the water penetration depth in concrete exposed to water with a pressure of 4 MPa for a given period of time.

RESULTS AND DISCUSSION

Compressive strengths

Over 200 standard cubic specimens 150 mm size were cast. Based on ASTM and TS standards, all results are acceptable. The mechanical strengths upon compression are the main features that allow qualitative assessments of concrete durability. Compressive strength of concrete mixtures versus age relative strength of tested concrete specimens is given in Figures 2 and 3, respectively. It can be seen from these Figures that there are clear increases of compressive strength, with increasing percentage marble dusts additions. However this is not true for limestone dusts, especially 15% additions.

In Figure 2, it can be seen that the compressive strengths of concrete samples, treated for 7 days, were of close with that of the control sample. However, the compressive strength of the MD and LD concretes, in particular that treated for 90 days was higher than the control sample.

The highest compressive strength at all ages has been marble dust concretes after 28 days. Considering 28 days average compressive strength, the compressive strength of group MD3 specimens was found to be 38% higher than that of group LD specimens and 24% higher than that of control specimen. Considering 360 days average compressive strength, the compressive strength of group MD specimens were found to be 56% higher than that of group LD specimens and 29% higher than that of control specimen (Figure 2).

The strength development characteristics of the concretes were affected not only by the dust type, but in some cases, also by dust percentages. Specimen MD3 had the highest compressive strength at 28, 90 and 360 days. Furthermore, this value was higher 12% and 20% for the MD1and MD2 specimens at 28 days, respectively. Considering 90 days, the values are 8% and at 360 days 5 and 8% respectively. It can be observed from Figure 3 that relative strength values of the all specimens were almost equal early ages. On the other hand, the relative strengths of the group MD concrete specimens were higher after 28 days. Compared to those for the marble dusts concrete specimens (MD1, MD2 and MD3) this value is higher than those for all others (Figure 3). However, for specimen LD3, this value was lower 8 and 12% for the MD1 and MD2 specimens at 28 days, respectively. Considering 90 days, these values are 3 and 10%, respectively.

Sulphate resistance of concretes

The results of the sulphate resistance test, obtained from the concretes are shown in Table 5. These results show that there is an obvious increase in the sulfate resistance of the concrete with an increase in the percentage of the dusts replacement with fine sand aggregates. Other researchers reported that both natural and artificial pozzolans can contribute to increasing chemical resistance of the concrete (Erdogan and Dogulu, 1997). Table 5 showed that compressive strength at 12 months for three kinds of concretes. Sulfate resistance of MD and LD concretes are greater than those obtained with normal Aksu river aggregate concretes. The positive effects of con-x

Table 5. Compressive strengths of concretes in immersed sodium sulphate solution (MPa).

Samples	Compressive strength after 28 days	Compressive strength after 12 months		
		Tap water	7 % Na_2SO_4	Compressive strength reduction (%)
C	29	35.2	15.1	58
MD1	32	56.3	41	28
MD2	36.2	58.6	48.4	18
MD3	39.7	60.7	52	15
LD1	27.1	45	36.2	20
LD2	28.2	48.1	39.3	19
LD3	25	44.7	35.1	22

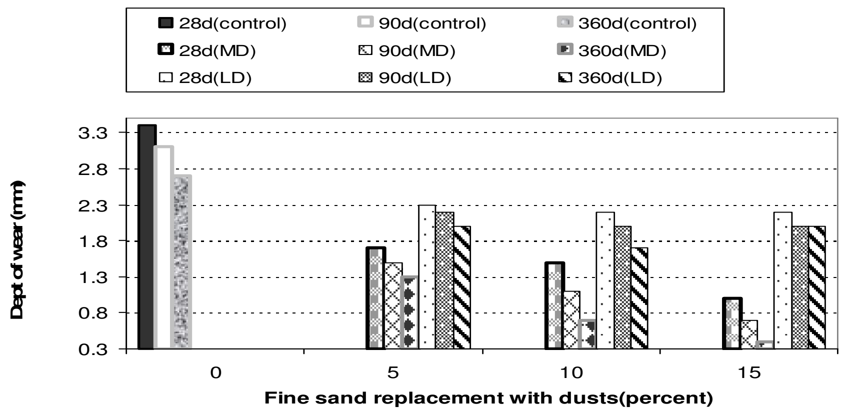

Figure 4. Dept of wear at 60 min of abrasion.

samples, and increased progressively, thereafter, with increasing MD and LD contents. Compressive strengths of all MD and LD concretes in the sodium sulphate solution decreased. Therefore, MD and LD con-cretes had higher potential sulphate resistance, compared to the control specimens (Table 5). Increases in the additive content caused significant increases in sulphate resistance of concrete to a period of up to 12 months of exposure. These results indicated that as the amount of dust in concretes increased, the resistance of the concretes against sulphate attack increased. For instance, the MD3 specimen had the highest sulphate resistance among all the samples.

Table 5 shows the reduction of the relative compressive strength (the ratio of the compressive strength in sulfate to the compressive strength in tap water). Group MD concretes very stable and achives a minimum of 5 to 10% compressive strength reduction. The relative compressive strengths of all concretes decrease with the relative compressive strength decreases rapidly whereas; all MD and LD concretes preserved their integrity till then. Therefore, MD concrete can be used for increasing exposure to sodium sulphate solutions. However, their amplitudes of decrease are different. For C, sulphate environment.

At the end of this 12 months period, concrete specimens showed non resistance to sodium sulfate effect. They decreased compressive strengths for control specimens 58%. However, the compressive strengths for the MD and LD concrete decreased 15 and 19%, respectively.

Abrasion resistance

Mass loss at 60 min of abrasion versus replacement with MD and LD were given in Figure 4. This figure shows that the abrasion resistance of C specimens, without dust, was insufficient to resist the abrasion of concrete. Specimens with MD as fine sand aggregate were more suitable for abrasion resistance than the C or LD specimens. Use of higher percentages of ash would be superfluous. Concretes where MD was used as fine sand aggregate had enhanced abrasion resistance compared to control specimens. Concrete compressive strength can be enhanced by adding all dusts to the mix. However, the grain size distribution of the aggregate is an important feature in this process. Above all, the mortar specimen MD1, MD2, and MD3 was proposed, with raw materials readily available in Turkey. The better abrasion resistance behavior of the

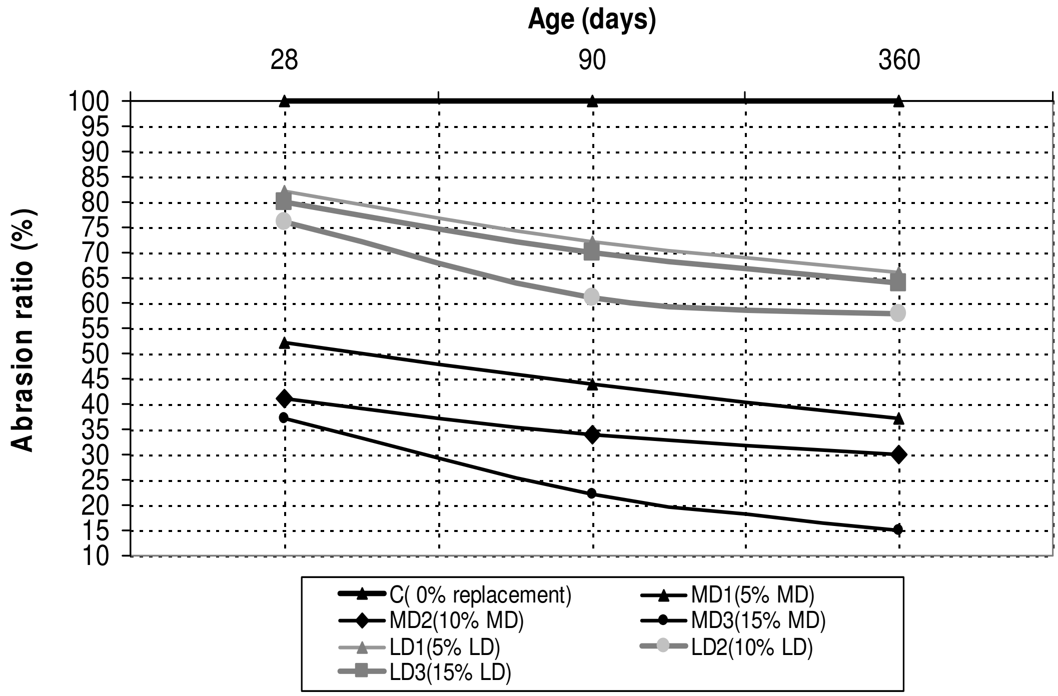

Figure 5. Abrasion ratio of specimens.

concretes with the addition of fine marble and limestone dusts is believed to result from a denser pore structure of the concretes.

Abrasion ratio of specimens was given in Figure 5. It can be said that from this figure, maximum abrasion rate was obtained from control specimens, while minimum abrasion rate was obtained from MD3 specimens. Abrasion resistance is increased as the rate of ashes was increased. However, over 5 and 10% LD replacement levels, abrasion ratio and strength losses concrete were higher than 15% LD specimen. The authors reported that there was no any restriction about concrete abrasion ratio in Turkish standard. However, amount of concrete abrasions was lower 1.2 mm was denoted high resistant abrasive concrete and amount of concrete abrasions higher than 3 mm was indicated as poor resistant abrasive concrete [Postacıoglu, 1987; Binici , 2007).

Generally, the abrasion resistance of concrete can be improved by replacement as fine sand aggregates with marble and limestone dusts (Figure 5). The abrasion resistance improved with increasing dusts. However, this not true for the all limestone percentage of dusts. Therefore, especially marble dusts and definite percentage limestone dusts concrete had higher compressive strength and lower abrasion ratio. This might be express-ed to the fact that all dusts replacement allowed a good interfacial a condensed matrix.

MD series concretes show that while marble dust slightly improve concrete abrasion resistance, 15% re-placement is more significant. LD series concretes, focusing on the effect of replacement on abrasion resis-tance, reveal that as long as replacement percent-tage is maintained at 15%. It is noted, that the LD concretes are of roughly equal abrasion resistance, the MD concretes itself exhibits slightly higher resistance than either of them alone.

The effects of both the dust type and the amount of dust on abrasion resistance of concrete were noticeable. All concrete mixtures with and without dust exhibited high abrasion resistance in accordance with the ASTM requirement. Concrete abrasion resistance was not greatly influenced by inclusion of limestone dust up to 15%. However, a slight decrease in abrasion resistance of marble dust concrete (especially at dust content above 15%) was noted as compared to the control specimens.

Water penetration

Water penetration depths of the mixtures are given in Figure 6. It can be seen from the figure that water penetration depth for MD 15% mixes was considerably less than those of other specimens. An increase in the percenttage of MD additives from 5 to 15% reduced the water penetration depth significantly. Control specimens show considerably greater water penetration depth.

The penetration depth was reduced with an increase in the MD and LD percentage and an increase in the compressive strength of the specimens. The penetrations of the control concretes were higher than that of the MD con

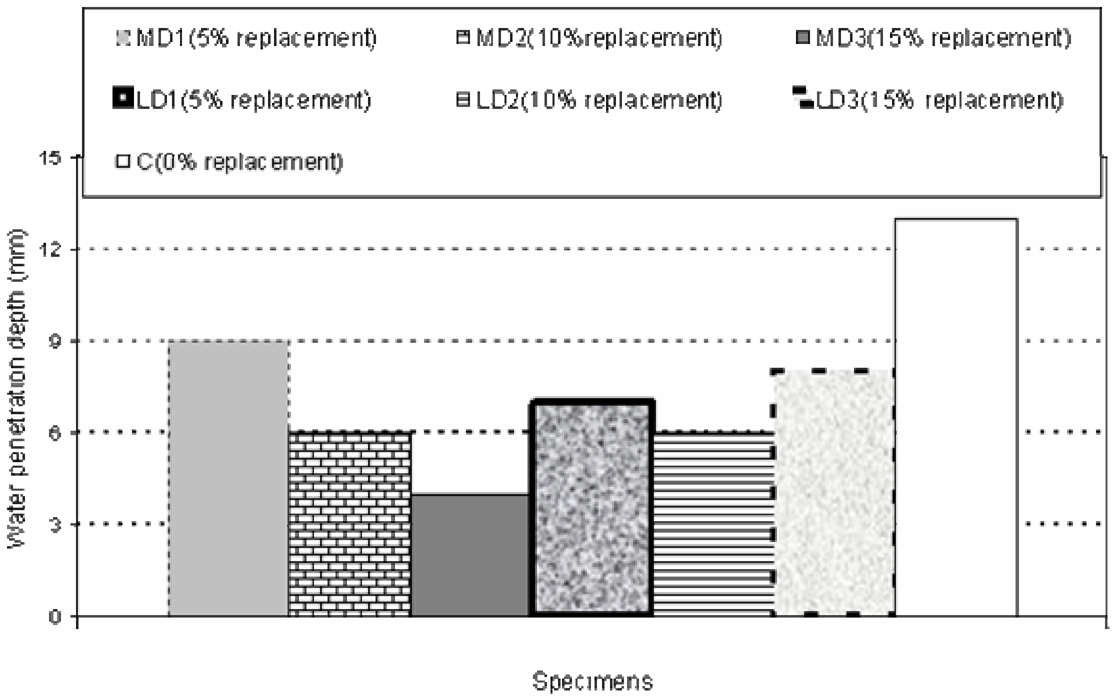

Figure 6. Water penetration depth of specimens.

cretes. This again indicated that the use of fine MD and LD increased the chloride penetration resistance of concrete.

In general all dusts had a profound effect on the water penetration depth. Also, as the marble dust addition percentage decreased, water penetration depth increased (Figure 6). Test of water penetration depths correlated well with the dust type and replacement percentage of the mixtures. MD 15% specimens were significantly more resistant to water penetration than those of other specimens.

Also, these additives and by-products may serve as sticky or adherent chemical reagents that combine with these elements to form more dense and homogeneous forms of concretes. Furthermore, these additives fill the gaps within the concrete products, giving less porous structures. All these may contribute to enhanced mechanical properties of concrete. Also, the uses of these additives result in excellent durability, which in effect have positive effects on concrete formation (Binici and Yucegok, submitted).

The main difference between MD, LD and control concrete is pronounced dust type and fine sand replacement percentage. This means that the porosity and the pore sizes are different for all concretes.

Figure 6 has shown that water penetrates more into concrete which has dried for a certain period of time. The differences between LD concrete are rather small and also the percentage of limestone does not create a significant effect.

Results indicate that at a strength level of 55 - 60 MPa, the water permeability of the MD concretes is lower than that of the LD and control concretes with the same w/cm and mix proportion. The lower permeability of the MD may be attributed to a dense interface zone between the aggregate and the cement paste matrix in the MD due to the water absorption of marble fine sand aggregate. The LD and control concretes probably have a more porous interface zone that may have led to higher water permeability. With a decrease of the incorporation of marble dust in concrete, the interface zone in the MD is improved significantly. At higher strength levels, the water permeability of the MD and LD of equivalent w/cm and mix proportion is significantly different.

Conclusions

Based on the experimental investigation reported in the paper, the following conclusions are drawn: 1- MD concrete group MD3 specimens have higher compressive strength than any of the other specimens. 2- Greater resistances of concrete against sodium sulphate were achieved with greater dusts additive ratios. The resistance of concretes compared to the sodium sulphate of the MD concrete was greater than the LD specimens. It is understood that sulphate performance on the control cement was poor, compared to the MD and LD concretes. 3- Abrasion resistance of concrete was strongly affected by its compressive strength, irrespective of marble dust content. MD and LM concrete up to 15% fine sand replacement exhibited lowest abrasion resistance than those LM and control specimens. Abrasion resistance of MD concrete with 5, 10 and 15 % fine sand replacement was lower than the LD and control concrete. Generally, abrasion resistance is increased as the rate of MD and LD was increased. MD concrete had averagely 71, 38 and 31% lower abrasion than C and LD, respecttively. 4- Measurement of water penetration depths correlated well with the differences between additive type and replacement percentage of the mixtures. MD 15% specimens were considerably more resistant to water ingress than those of other specimens. An increase in the percentage of dust also affected the water penetration depths sharply. Besides water penetration depths, the amount of water penetrated in MD 15% concretes was lower than that of the others.

As the MD concretes had higher compressive strength than that of the corresponding LD and control concrete with equivalent w/c and mix proportion, the results indicate that the MD concrete would probably have lower water permeability than the LD and control concrete.

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