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Full Length Research Paper

The effect of the using waste marble dust as fine sand on the mechanical properties of the concrete

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In this experimental study, the effects of using waste marble dust (WMD) as a fine material on the mechanical properties of the concrete have been investigated. For this purpose four different series of concrete-mixtures were prepared by replacing the fine sand (passing 0.25 mm sieve) with WMD at proportions of 0, 25, 50 and 100% by weight. In order to determine the effect of the WMD on the compressive strength with respect to the curing age, compressive strengths of the samples were recorded at the curing ages of 3, 7, 28 and 90 days. In addition, the porosity values, ultrasonic pulse velocity (UPV), dynamic modulus of elasticity (E_{din}) and the unit weights of the series were determined and all data were compared with each other. Finally, all of the data were compared with each other. It was observed that the addition of WMD such that would replace the fine material passing through a 0.25 mm sieve at particular proportions has displayed an enhancing effect on compressive strength. Marble dust is a by-product of marble production facilities and also creates large scale environmental pollution. Therefore, it could be possible to prevent the environmental pollution especially in the regions with excessive marble production and to consume fewer natural resources as well through its utilization in normal strength concretes as a substitute for the very fine aggregate.

Key words: Waste marble dust, very fine sand, concrete, dynamic modulus of elasticity, compressive strength, sorptivity.

INTRODUCTION

Marble has been commonly used as a building material since the ancient times. The industry's disposal of the marble powder material, consisting of very fine powder, today constitutes one of the environmental problems around the world (Corinaldesi et al., 2010). Marble blocks are cut into smaller blocks in order to give them the desired smooth shape. During the cutting process about 25% the original marble mass is lost in the form of dust. In Turkey marble dust is settled by sedimentation and then dumped away which results in environmental pollution, in addition to forming dust in summer and threatening both agriculture and public health. Therefore, utilization of the marble dust in various industrial sectors especially the construction, agriculture, glass and paper industries would help to protect the environment (Karasahin and Terzi, 2007).

In addition to marble powder, silica fume, fly ash, pumice powder and ground granulated blast furnace slag are widely used in the construction sector as a mineral admixtures instead of cement (Demirel and Yazicioglu, 2008, 2006, 2007).

Marble dust can be used either to produce new products or as an admixture so that the natural sources are used more efficiently and the environment is saved from dumpsites of marble waste (Hameed and Sekar, 2009).

Many studies have been conducted in literature on the performance of the concrete containing waste marble dust or waste marble aggregate, such as its addition into self compacting concrete as an admixture or sand (Corinaldesi et al., 2010; Alyamac and Ince, 2009; Guneyisi et al., 2009; Unal and Uygunoglu, 2003), as well as its utilization in the mixture of asphaltic concrete (Karasahin and Terzi, 2007; Akbulut and Gurer, 2007; Binici et al., 2008) and its utilization as an additive in cement production (Aruntas et al., 2010), the usage of

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Abbreviation: WMD, Waste marble dust; **UPV,** ultrasonic pulse velocity.

Table 1. Chemical properties of used marble dust and cement.

Oxide compounds (mass %)	CEM I 42.5	Marble Dust (Cherry)
SiO_2	21.12	28.35
Al_2O_3	5.62	0.42
Fe_2O_3	3.24	9.70
CaO	62.94	40.45
MgO	2.73	16.25
Density, (gr/cm^3)	3.10	2.80

Table 2. Grain size distribution of the aggregate.

Sieve size (mm)	Passing (%)
16	100
8	67
4	53
2	44
1	32
0.50	19
0.25	10

marble as a coarse aggregate (Wu et al., 2001) and as a fine aggregate passing through 1 mm sieve (Binici et al., 2007).

Generally, in literature waste marble dust has been replaced with either all of the fine aggregate (0 - 4 mm) or passing 1 mm sieve. However, not a single study on the performance of the concrete prepared by replacing very fine sand (passing 0.25 mm sieve) with WMD.

The studies concerning the utilization of marble dust, which is obtained as a by-product of marble sawing and shaping processes in the factories those operating in our region as a fine sand aggregate into the normal strength concrete have not reached a convincing conclusion; in other words, additional studies and investigations are necessary to fully evaluate the potential usages of this waste material.

Therefore, the aim of this current study is both to avoid the environmental pollution and to investigate the usability of the marble dust instead of very fine sand passing through a 0.25 mm sieve at proportions of 0, 25, 50 and 100% by weight on the concrete. In this way, we will help to protect the environment by consuming the waste marble dust obtained as a by- product of marble sawing and shaping processes in the factories those operating in our region.

MATERIALS AND METHODS

A total of four series of concrete specimens including the control specimen were prepared in order to examine the effect of substituting marble dust (0, 25, 50 and 100% by weight) for the fine material (passing through 0.25 mm sieve) on the mechanical properties of the series.

Cement

Commercial grades ASTM Type I Portland cement, which is produced as CEM I Portland cement (CEM I 42.5) in Turkey was used in order to prepare all concrete specimens.

Waste marble dust

The marble sludge was obtained in wet form as an industrial by-product directly from the deposits of marble factories, which forms during the sawing, shaping and polishing processes of marble in Elazig region. The wet marble sludge was dried up prior to the preparation of the samples. The dried material was sieved through a 0.25 mm sieve and finally the marble dust was obtained to be used in the experiments as fine sand aggregate. The chemical properties of the marble dust and cement are given in Table1.

Aggregate

All concrete specimens were produced with coarse and fine aggregates from the province of Elazig (Turkey). Maximum aggregate size was 16 mm. The density of the 0 – 4 mm (river sand) and 4 – 16 mm river aggregates group were 2780 and 2730 kg/m^3, respectively. In concrete mix proportioning, aggregates were composed of 53% sand (0 – 4 mm) and 47% gravel (4 – 16 mm). Tap water was used as the mixing water during the preparation of the concrete specimens. Table 2 presents the grain size and properties of aggregate used in this study.

As a result of the conducted sieve analysis, the passing percentage of the aggregate passing through 0.25 mm sieve was determined to be 10% (Table 2; last column). Various proportions (0, 25, 50 and 100% by weight) of this sieved material have been substituted with waste marble dust. The grain size distribution of fine sand aggregate and WMD are given in Figure 1. Four different series presented on Table 3 was prepared according to ACI 211.1 (1993).

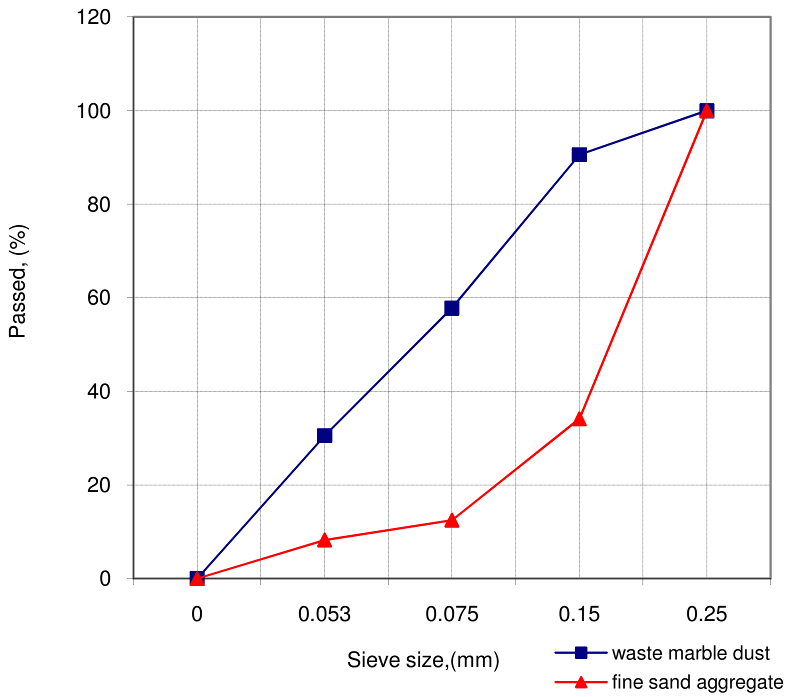

Figure 1. Grain size distribution of fine sand aggregate and waste marble dust.

Table 3. Details of concrete mixes (kg/m^3).

Specimen	Water	Fine aggregate (0 - 0.25 mm)	Fine aggregate (0.25 – 4 mm)	Coarse aggregate (4 - 16 mm)	Cement	Marble dust
MD0	255	156	680	725	500	-
MD25	255	117	680	725	500	39
MD50	255	78	680	725	500	78
MD100	255	-	680	725	500	156

Mix proportions

For each series, total of twenty pieces of concrete specimens were prepared, with five specimens being taken from each curing age (3, 7, 28 and 90 days). Because four different series are used in the experiments, a total of 80 cubic specimens (100 × 100 × 100 mm) were prepared in order to determine the properties of the concretes such as compressive strength, apparent porosity, sorptivity and UPV.

Mixtures prepared according to Table 3 were cast in cubic mould. After casting, these specimens were kept in the molds for 24 h at room temperature of 20°C. After demolding, these specimens were cured in lime saturated water at 23 ± 1°C for 3, 7, 28 and 90 days.

Ultrasonic pulse velocity

The ultrasonic pulse velocity value was automatically determined with a device in what duration ultrasonic waves passed from specimens surfaces of which are clean and remained between wave transmitter and receiver transducer heads nozzles and wave speed was calculated by using Equation (1) (Erdogan, 2003).

$$V = (h / t)*10^6 \qquad (1)$$

Where V = ultrasonic wave speed (m/sec), h = distance between the surface of concrete specimen from which the ultrasonic wave is sent and the surface the wave is received (m), t = time passed from concrete surface from which the ultrasonic wave is sent and the surface the wave is received (μs).

Sorptivity

After measurement of the UPV values, these three specimens were also used for sorptivity measurement. Measurements of capillary sorption were carried out using specimens pre-conditioned in the oven at about 50°C until constant mass was achieved. Then, the concrete specimens were cooled down to room temperature. As shown in Figure 2, test specimens were exposed to the water on one face by placing them on a pan. The water level in the pan was maintained at about 5 mm above the base of the specimens during the experiment. The lower areas on the sides of the specimens were coated with paraffin to achieve unidirectional flow. At certain

Table 4. Results of mechanical and physical tests of the specimens.

Code	f_c (MPa)				Unit weight (kg/m^3)	Porosity (%)	Sorptivity (cm/s$^{1/2}$)	E_{din} (GPa)	UPV (Km/s)
	3d	7d	28d	90d					
MD0	14.32(1.67)*	35.5(1.95)	48.68(1.96)	60.51(1.48)	2235	7.125	1.256	36.03	4,233
MD25	15.8(1.88)	35.54(2.24)	50.25(2.64)	61.44(2.29)	2252	7.085	1.189	41.45	4,521
MD50	17.66(2.03)	36.43(3.75)	50.69(3.12)	61.50(3.35)	2284	6.729	1.162	43.35	4,592
MD100	21.46(1.58)	38.97(2.23)	53.39(2.11)	63.30(2.21)	2305	6.596	1.124	45.01	4,658

* The value in the parentheses is standard deviations.

times, the mass of the specimens was measured using a balance, then the amount of water absorbed was calculated and normalized with respect to the cross-section area of the specimens exposed to the water at various times such as 0, 5, 10, 20, 30, 60, 180, 360 and 1440 min. A test was also carried out to determine the sorptivity coefficient of specimens at the 28th day. For each mixture three cubic specimens were prepared. The sorptivity coefficient (k) was obtained by using the following equation:

$$\frac{Q}{A} = k\sqrt{t} \qquad (2)$$

Where Q = the amount of water absorbed in (cm^3); A = the cross-section of specimen that was in contact with water (cm^2); t = time (s) and k = the sorptivity coefficient of the specimen (cm/s$^{1/2}$).

To determine the sorptivity coefficient, Q/A was plotted against the square root of time ($\sqrt{t}$), and then, k was calculated from the slope of the linear relation between Q/A and $\sqrt{t}$. This method for measuring the capillary absorption of the concrete specimens were also used by Tasdemir (2003) and Turkmen (2003) was also used by (Tasdemir, 2003; Turkmen, 2003).

Porosity

Porosity value was determined on 100 × 100 × 100 mm cubic specimens according to Archimedes principle related to the weights of saturated specimens in air and in water and the dry weight (oven drying at 105°C to constant weight). The porosity was calculated through Equation (3).

$$P = \frac{(W_{sat} - W_{dry})}{(W_{sat} - W_{wat})}100 \qquad (3)$$

This method for measuring the porosity has previously been reported by Gonen and Yazıcıoglu (2007), Papadikis et al. (1992), Rossignolo and Agnesini (2004) and Topcu et al. (2009) (Gonen and Yazicioglu, 2007; Papadikis et al., 1992; Rossignolo and Agnesini, 2004; Topcu et al., 2009).

Dynamic modulus of elasticity

The dynamic modulus of elasticity of the specimens was calculated with the following formula (Erdogan, 2003; Topcu and Isıkdag, 2008):

$$E_d = \frac{V^2 n(1+\mu)(1-2\mu)}{1 \quad \mu}(10^{-6}) \qquad (4)$$

Where μ = poisson, n = unit weight (kg/m^3) and V = ultrasonic pulse velocity (m/s).

According to the Erdogan (2003), the value of the poisson is considered 0.3 at the low quality concrete and 0.15 at the high quality concrete. A value of 0.2 is generally used for poisson. In this study μ is 0.2.

Compressive strength

The values of unit weight, porosity, sorptivity, UPV and dynamic modulus of elasticity of the specimens were determined before the compressive strength test at the 28th day. Five specimens for each series were used for the determination of the compressive strength according to ASTM C39 (1994). The compression load was applied at a rate of 3 kN/s by using a compression machine with a capacity of 3000 kN. All of the results have been discussed below.

RESULTS AND DISCUSSION

Physical and mechanical properties of concrete

The results given in Table 4 indicate that as the amount of the WMD in the concretes increase, the unit weights of the specimens increase. This is an expected outcome since both specific gravity of WMD is higher than fine aggregate and filler effect of marble dust because of it has finer particles than fine sand aggregate. Therefore the unit weight of concretes WMD increases as the percentage of WMD content increases.

It is seen that from Table 4 that compressive strength have increased with the increase WMD content. These increases for MD100 were approximately 10 and 5% at 28 and 90 days, respectively, compared to the MD0 (without WMD). It is explained that as the curing age increased, its contribution to the compressive strength of the WMD is reduced. As curing time

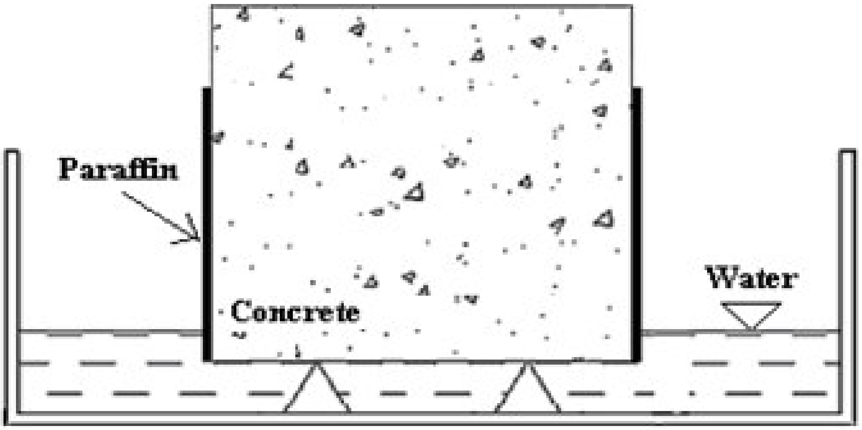

Figure 2 The measurement of water capillary sorption

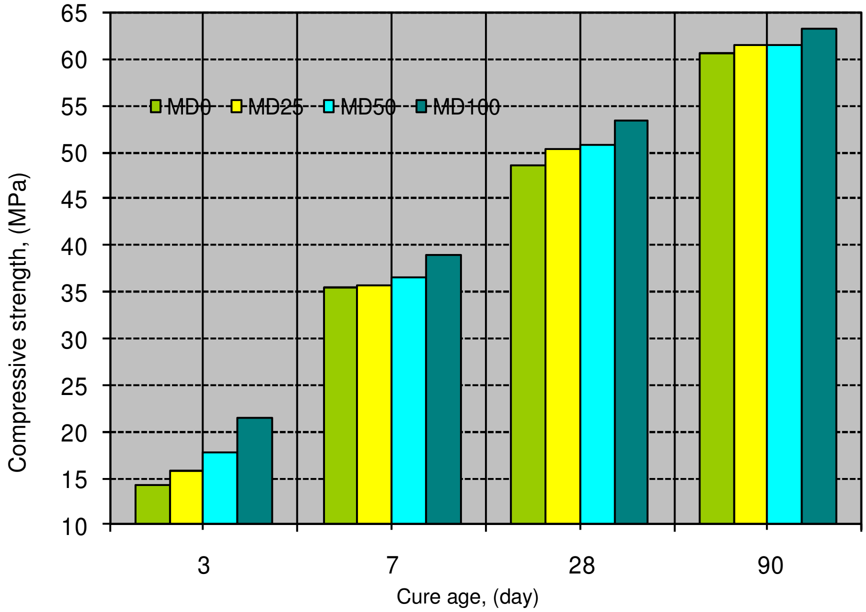

Figure 3 Change of the compressive strength related to the curing age

increases, the WMD's contribution to the compressive strength decreases. Despite the increase in compressive strength at lower level, the standard deviation values that they are given in Table 4 support the accuracy of the experimental data.

The change on the compressive strength with increasing cure age can be better seen in Figure 3, for all series. The highest compressive strength at curing ages of 3, 7 28 and 90 days has been exhibited by MD100. Similar results have been reported earlier by Binici et al. (2007).

In cases where the marble dust has been used as a substitute for cement at equal weights, an increase in amount of added marble dust decreases the compressive strength (Valls et al., 2004). Türker et al. (2002), have stated that this decrease arises from the dilution of C_2S and C_3S, which are the main constituents and strength providers of cement, by the marble dust additive. But in this current work, since the marble dust has replaced the fine sand aggregate (passing through a 0.25 mm sieve) instead of the cement, as also seen in Table 4, increases in the compressive strength have been recorded, rising with higher percentage marble dust additions at all curing ages.

Figures 4 and 5 shows the changes of the porosity and UPV with the usage of marble dust, respectively. In Figures 4 and 5, the porosity of the concrete decreased and its UPV increased with increasing percentages of marble dust additions. As mentioned in the literature, the filler effect of marble dust on cement hydration is

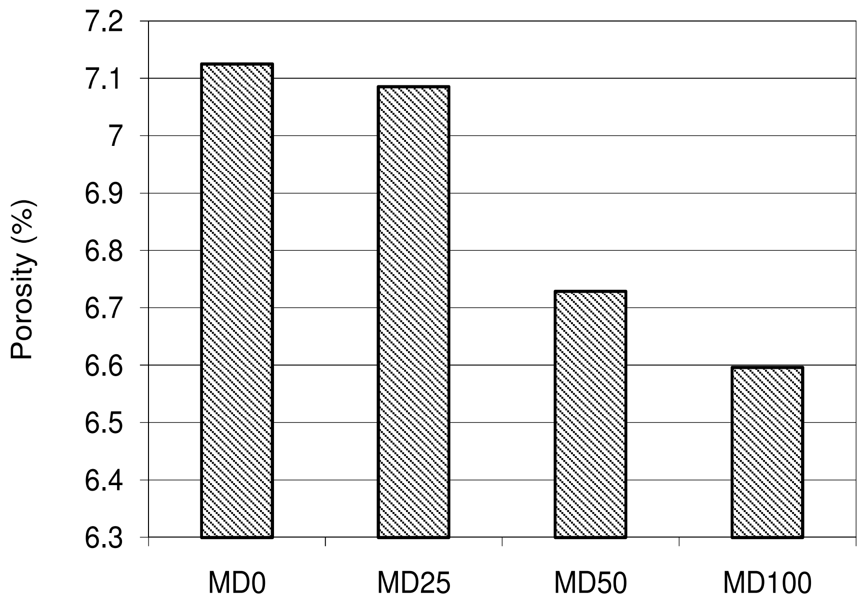

Figure 4. Porosity values of series.

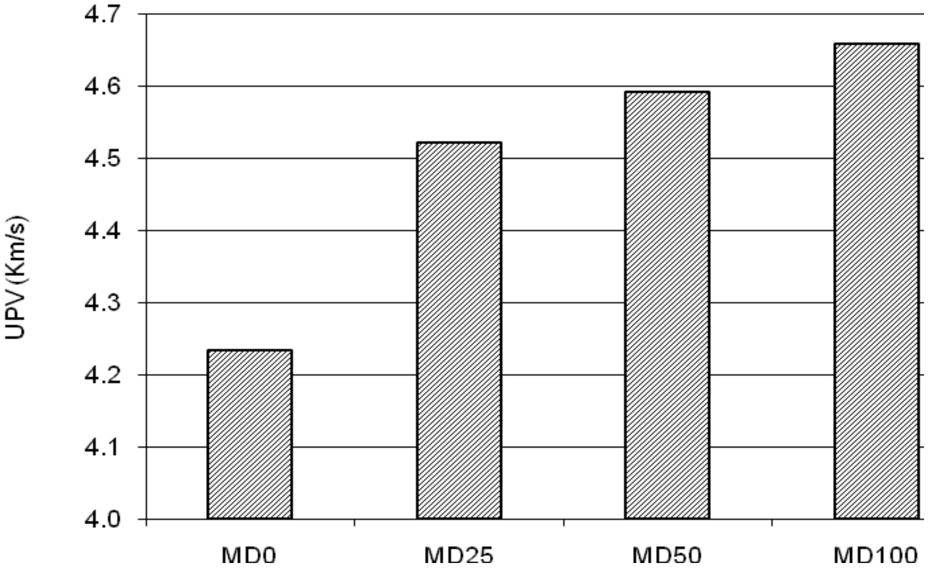

Figure 5. UPV values of series.

associated with the reduction of the porosity (Kristuloviç, 1994). These two graphs provide support for the compressive strength values of the samples.

In addition, as can be seen in Table 4, the sorptivity coefficient of the concrete also has been decreased with the increase in WMD content. Similar findings have been reported earlier by Topcu et al. (2009) and Türkmen and Kantarcı (2007). Again in Table 4, sorptivity coefficient of the concrete has decreased with increasing compressive strength. This finding is in accordance with the literature. Taşdemir (2003), reported that the sorptivity coefficient of concrete decreases slightly with increasing compressive strength. Again, Topcu et al. (2009) reported that concrete has lower compressive strength as a result of the higher capillarity coefficient obtained in self compacting concrete.

UPV values were used for calculating dynamic modulus of elasticity of the specimens. The relationship between compressive strength and dynamic modulus of elasticity of the series at 28 days is shown in Figure 6. Figure 6

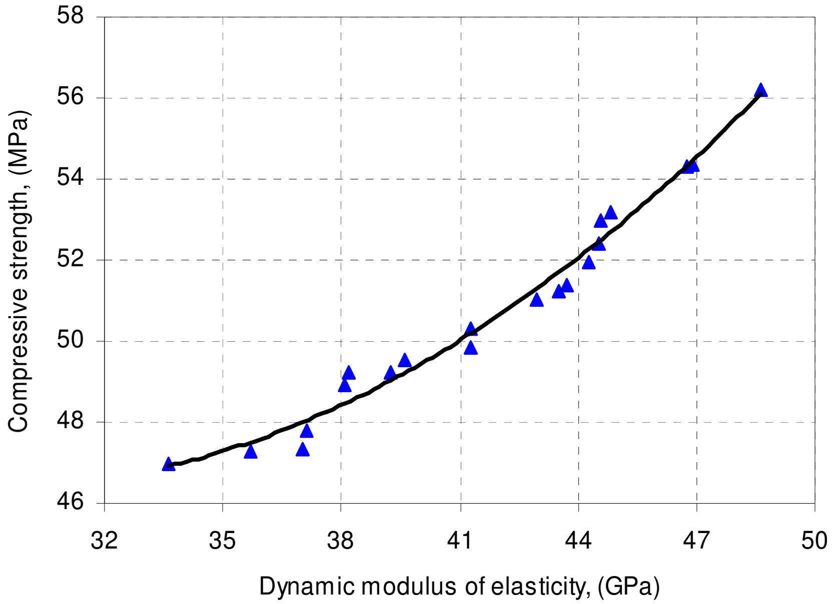

Figure 6. Relationship between compressive strength and dynamic modulus of elasticity.

that is called scattering diagram shows that the positive correlation between modulus of elasticity and compressive strength (Topcu, 2006). At the end of the regression analysis, equation of the curve and regression coefficient (R^2) is determined as $y = 0.0251x^2 – 1.4546x + 67.426$ and 0.9797, respectively.

In this equation, y refers to compressive strength and x refers to dynamic modulus of elasticity. When the value of dynamic modulus of elasticity which calculated by non-destructive testing is known, the compressive strength values can be calculated by using this equation.

In Table 4, it is seen that the highest modulus of elasticity has been obtained from the MD100 sample possessing the highest compressive strength and highest unit weight. This finding is in accordance with the literature. Topcu and Isıkdag (2008), reported that concrete has higher modulus of elasticity as a result of the higher compressive strength.

A number of scanning electron microscope (SEM) micrographs illustrating the microstructure characteristics of some specimens are shown in Figure 7. As observed by the SEM, the CH ($Ca(OH)_2$) morphology in specimens with and without WMD are different from each other. Large and euhedral crystals of CH have accumulated in the fissures and large pores (Figure 7a). This kind of large and euhedral CH crystals were only observed in the specimen produced without any WMD (MD0). On the other hand, the CH crystals with smaller size are well dispersed into the matrix of the WMD added specimen (MD50), (Figure 7b). This situation can be explained by the filler effect of limestone in the concrete (Turker et al., 2002). It can be stated that the usage of marble dust effectively decreases the porosity in hardened concrete. As a result, CH, which is one of the most important compounds in cement paste, cannot find adequate space to grow to larger sizes. Thus in the WMD added specimens, the CH crystals were only observed in the concrete in a scattered and small size (as indicated by the arrow mark in Figure 7b).

Conclusions

On the basis of the experimental study that has been carried out and presented in this paper, the following conclusions can be drawn;

(1) The test results indicated that the unit weight of the concrete increased as a result of the fact that certain proportions of WMD had been added to the concrete as very fine aggregate substitutes. This is an expected outcome due to the high specific gravity of WMD and also filler effect of marble dust because it has finer particles than fine sand aggregate.
(2) Compressive strength of the concrete has increased with increasing percentages of marble dust additions at all curing ages. The highest compressive strength has been demonstrated by MD100 specimen, especially at early curing ages.
(3) The concrete series that employed WMD as the substitute for the very fine aggregate passing through 0.25 mm sieve performed better than the series without any addition of marble dust in terms of compressive strength. As a matter of fact marble dust had a filler effect (particularly important at early ages) and played a noticeable role in the hydration process. Noting that the proportion of

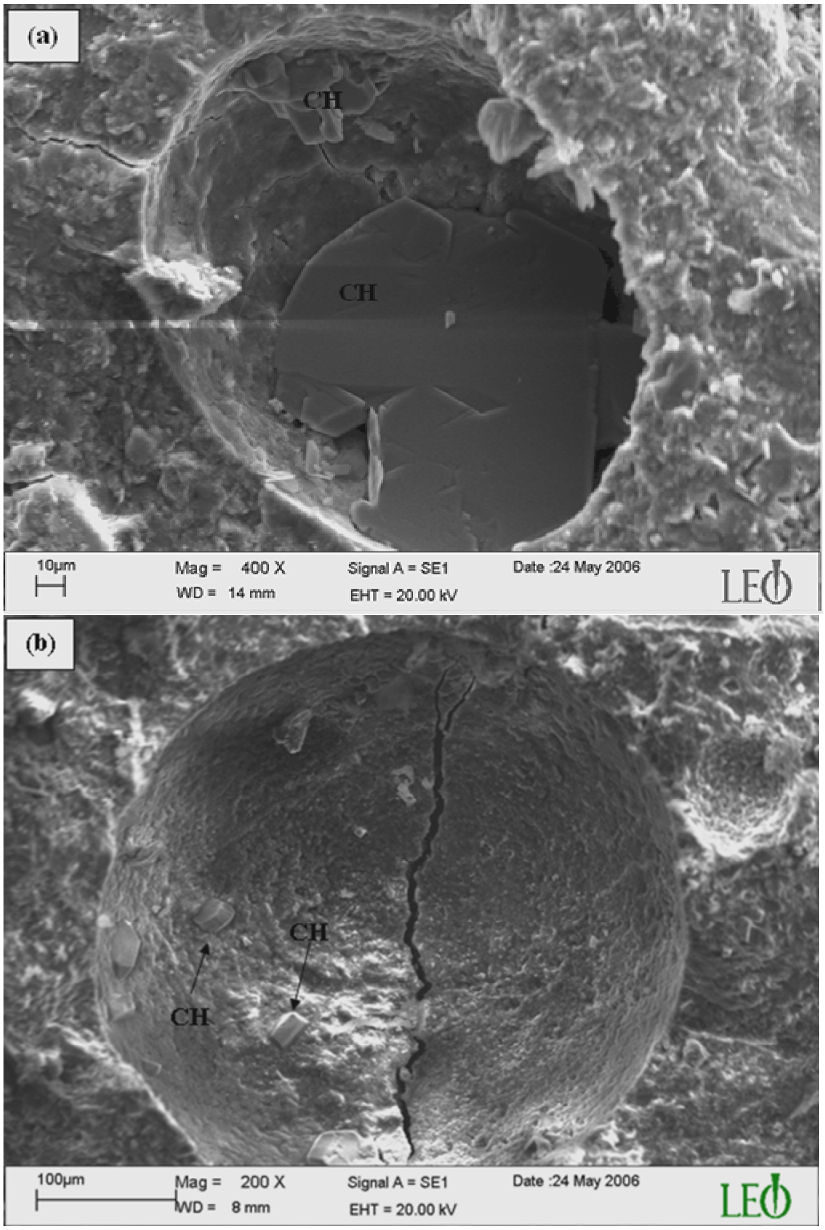

Figure 7. SEM micrographs of MD0 (a) and MD50 (b).

cement is kept constant at each series, it is an expected outcome that an enhancement in the mechanical and physical properties has taken place by virtue of the marble dust's contribution to the hydration process.

(4) The porosity of the concrete decreased and UPV increased with increasing percentage of marble dust additions. As mentioned in the literature, the filler effect of marble dust on cement hydration is associated with the reduction of the porosity. It can be stated that usage of marble dust effectively decreases the porosity of the hardened concrete. Furthermore, the highest dynamic modulus of elasticity has been obtained from the MD100 sample possessing the highest compressive strength.

(5) The SEM investigations indicated that $Ca(OH)_2$ morphology in specimens with and without WMD are different from each other. While the crystals of the series without any replacement of the very fine sand aggregate with WMD have formed in a large and euhedral manner, in the series where a particular weight proportion of fine sand material have been replaced with WMD, the CH crystals are small and have been dispersed through the matrix.

The differences between the appearances of CH crystals verify the fact that the marble dust has also played a noticeable role during the hydration process. The results of this study show that, WMD can be used to improve the mechanical and physical properties of the conventional concrete. The possibility of utilizing WMD as an alternative very fine aggregate in the production of concrete will also induce a relief on waste disposal issues.

In future studies, we think that it would be worthwhile to investigate the effects of elevated temperatures on the mechanical properties of the concretes containing WMD admixtures.

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