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Properties of concrete paving blocks made with waste marble

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ABSTRACT

Marble industry produces large amounts of waste marble – what causes environmental problems. In paving blocks based on two cement types we have partly replaced aggregate with waste marble. Physical and mechanical tests were performed on blocks so produced. The cement type turns out to be an important factor. Mechanical strength decreases with increasing marble content while freeze-thaw durability and abrasive wear resistance increase. Waste marble is well usable instead of the usual aggregate in the concrete paving block production.

1. Introduction

USA, Belgium, France, Spain, Sweden, Italy, Egypt, Portugal, Brazil and Greece are among the countries with considerable marble reserves. Turkey has even more, 40% of total marble reserves in the world. Seven million tons of marble are produced in Turkey annually. In processing marble such as cutting to size and polishing etc. for decorative purposes, marble dust and aggregate are created as byproducts. More specifically, during the cutting process 20–30% of the marble block turns into dust. Thus, waste materials from marble processing plants represent millions of tons. Such waste is often disposed near residential areas. Stocking of these wastes is impossible, hence marble wastes constitute an environmental pollutant (Alyamac and Ince, 2009). 1400 tons of waste marble per day are left and stored in depot areas as wastes in Turkey (Topcu et al., 2009). Saboya and coworkers (2007) report that the amount of waste from cutting and sawing processes in Brazilian decorative stone industries easily reaches 20–25% of the total volume of the stone material. Hebhoub and coworkers (2011) reported that a high volume of marble production generates a considerable amount of waste materials; almost 70% of this mineral gets wasted in the mining, processing and polishing stages – with obvious impact on the environment.

In this situation, marble waste has been used as aggregate in *asphalt* pavements. However, little is known on the influence of marble wastes as aggregate in concrete paving blocks on the properties of those blocks. This while recently concrete block pavements have become an attractive engineering and economical alternative to both flexible and rigid pavements. The strength, durability and aesthetically pleasing surfaces have made paving blocks attractive for many commercial, municipal and industrial applications such as parking areas, pedestrian walks, traffic intersections, container yards and roads. Making concretes has been well described in the literature (Mindess, 1982; Regoud, 1986; Roy et al., 1993, Mcphee and Glasser, 1993; Davidovits, 1994; Martinez-

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Barrera et al., 2011; Habert et al., 2011). Concrete paving blocks are produced based on a mixture of Portland cement, natural fine and coarse aggregate.

There has been before us some work on applying marble waste. Thus, Alyamac and Ince (2009) as well as Topcu and coworkers (Topcu et al., 2009) studied the feasibility of using waste marble dust as a filler in self-compacting concrete (SCC). They reported that in general, marble dust had no effect on the workability of fresh SCC. Mechanical properties of hardened SCC have become somewhat worse using marble dust. Terzi and Karasahin (2003) investigated the use of marble dust in asphalt mixtures as a filler material for optimum filler/bitumen and filler ratio. They have concluded that marble wastes in the dust form could be used in such cases. Abkulut and Cahit (2007) studied the use of marble quarry waste in asphalt pavements with bitumen. They reported that waste materials can potentially be used as aggregates in light to medium trafficked asphalt pavement binder layers. Binici and coworkers (Binici et al., 2008) studied durability of concrete containing granite and marble as coarse aggregates. The result indicated that marble, granite and ground blast furnace slag replacement provide a good durable concrete. Some of us (Martínez-Barrera and Brostow, 2010) studied effects of gamma irradiation and the marble particle size on compressive properties and the dynamic elastic modulus of polymer concretes. One of the conclusions was that both compressive properties and the dynamic elastic modulus values depend on the combination of the marble-particle sizes and the applied radiation dose. Higher numbers of dispersed particles per unit volume provide more resistance to crack propagation. Medium size marble particles provide better compression modulus.

Wattanasiriwech et al. (2009) investigated the use of waste mud from ceramic tile production in paving blocks and determined compressive strengths of these blocks. They observed that the blocks containing cement ≥20 wt.% gave satisfactory strength values. As expected, several processing parameters affecting development of strength in the blocks.

Richardson et al. (2011) investigated the effects of recycled aggregate on durability of concrete. They reported that recycled aggregate concrete is at least of equal durability as concrete manufactured with virgin aggregates.

In recent years, irrespective of political, economic or ecological reasons, recycling has been encouraged throughout the world. It is undoubtedly the best alternative to reduce the impact that the environment can suffer from the consumption of raw materials and the almost random generation of waste (Correia et al., 2011; Pelisser et al., 2011).

Our above literature survey shows there was no study on utilization of marble waste in fabrication of concrete paving blocks. Therefore, the purpose of our work was determination of feasibility of using waste marble in fabrication of concrete paving blocks and the effects of waste marble on physical and mechanical properties of concrete paving blocks so produced.

Table 1
Physical and mechanical properties of the cements.

	CEM II 32.5N	CEM II 42.5N
Initial setting time (min)	223	200
Final setting time (min)	300	280
Volume expansion (mm)	1	1
Specific gravity (g/cm^3)	2.91	3.15
Blaine fineness (cm^2/g)	4.55×10^3	3.54×10^3
Compressive strength (MPa)		
2 days	15.5	25.3
7 days	27.4	40.5
28 days	38.5	51.7

Table 2
Chemical analysis of the cements (Weight %).

	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	LOI[a]
CEM II 32.5N	51.44	21.52	6.10	2.54	2.01	2.71	11.15
CEM II 42.5N	55.25	23.45	6.30	2.76	1.76	2.71	4.40

[a] Loss of ignition.

2. Experimental program

2.1. Materials

2.1.1. Cement

The cement used in all the concrete mixtures was Portland cement CEM II 32.5N and CEM II 42.5N. Physical and mechanical properties and chemical analysis of cement are presented in Tables 1 and 2, respectively.

2.1.2. Aggregates

Dry and clean natural river sand (NRS), crushed sand (CS) and crushed stone (Cst) were used in concrete mixture. The Cst was 12.5 mm maximum nominal size with 0.93% water absorption value and its density at saturated surface dry (SSD) condition was 2.70 g cm^{-3}. The water absorption values of the NRS and CS sands used were 3.02% and 2.91%; their densities at SDD condition were 2.67 and 2.69 g cm^{-3}, respectively.

Crushed waste marble and dust used were obtained from marble processing plants in Afyon territory located in the Aegean region of Turkey. Coarse waste marble aggregates had 0.1% absorption value and its density at saturated surface dry (SSD) condition was 2.7 g cm^{-3} and 0.12% and 2.68 g cm^{-3} for fine waste marble aggregates, respectively. Both coarse and fine aggregates were separated into different size fractions and recombined to a specific grading. The gradations of aggregates and the grading of the mixed aggregate are presented in Fig. 1. The size of aggregate and grading of the mixture play an important role to pack paving blocks tightly.

2.2. Methods

2.2.1. Mixture compositions and fabrication of paving blocks

A total two series of mixtures was initially prepared. Each series included five mixtures. The first series called A was prepared using CEM II 32.5N. The second series called B was prepared using CEM II 42.5N. Control mixtures called A0 and B0, for each cement type were prepared with only NRS, CS and Cst. These aggregates were blended in the ratio of 25% NRS, 25% CS and 50% Cst. In each series, an aggregate-to-cement (A/C) ratio = 4.5 was used. In each series, marble waste was added by replacing 10%, 20%, 30% and 40% ratios.

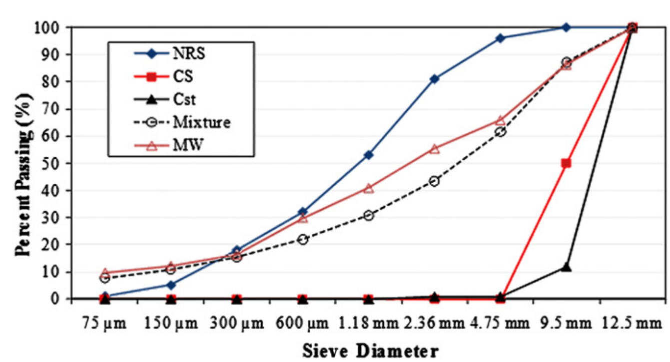

Fig. 1. The gradations of aggregates and the grading of the mixed aggregate.

Table 3
Mix proportions.

Codes	Cement type	w/c	Cement (kg/m^3)	Water (kg/m^3)	Marble waste (%)	Marble waste (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)
A0	32.5	0.48	400	192	0	0	907	913
A1	32.5	0.50	400	200	10	177	806	812
A2	32.5	0.52	400	208	20	349	708	713
A3	32.5	0.55	400	220	30	514	608	612
A4	32.5	0.60	400	240	40	663	505	509
B0	42.5	0.40	400	160	0	0	954	961
B1	42.5	0.46	400	184	10	182	830	835
B2	42.5	0.49	400	196	20	357	724	729
B3	42.5	0.52	400	208	30	526	622	627
B4	42.5	0.55	400	220	40	688	524	527

The mix proportions of the blocks in series A and B are presented in Table 3.

In laboratory, extensive trial mixes were done. Initially, coarse and fine aggregates and cement were mixed in a 5 l Hobart mixer for approximately 3 min. Afterwards water was added to the materials. The procedure of mixing and adding water was repeated until the desired moisture content was obtained. A few early trials were performed in a factory with the paving block machine to ensure proper material proportions and water amounts. The main sets of tests were performed in the factory mixer with 200 l of concrete; the materials were added directly to the mixer with the other dry ingredients. The concrete was automatically placed by conveyors and mechanically compacted on the paving block machine. All concrete paving blocks were prepared using pressure and vibration until complete compaction was obtained from the compaction machine shown in Fig. 2. All the test specimens were cured under constant temperature of 20 °C and relatively humidity of 65%. The specimens were subjected to the local environmental conditions and were tested under 3, 7 and 28 days curing conditions. The weight of a paving block specimen ranged between 3.0 and 3.3 kg.

2.2.2. *Testing methods*

The density of paving blocks was determined using a water displacement method as per BS 1881 Part 114 for hardened concrete (BS, 1881-114, 1983).

We have determined uniaxial compressive strength, splitting tensile and flexural tensile strength according to ASTM standards (ASTM C-39, 2001), TSE (TS EN 12390-5, 2002) and BS (BS EN 1338, 2003). At least five core samples (with a length to diameter ratio of 2:1) from each mixture of concrete paving block were subjected to the strength tests which were carried out in an instrumented and computer controlled press machine with a maximum capacity of 3000 kN. The load was applied to the nominal area of paving blocks. The compression load was applied at a rate of 3 kN s^{-1}. Prior to the loading test, the paving blocks were soft capped with two pieces of plywood. The compressive strength was calculated by dividing the failure load by the loading area of the paving blocks.

The tensile splitting strength was determined in accordance with BS 6717 (2001). The tests were carried out along the longest splitting section of the block specimen. Prior to testing, each block specimen was concentrically packed with two steel packing pieces on the top and bottom faces in contact with the platens of the loading machine. A load was then gradually applied and the test was terminated when the specimen split into halves. The failure load was recorded and the tensile splitting strength was calculated based on the failure load.

Rebound hardness tests on the paving block specimens were performed using a Digi-schmidt 2000 machine according to the procedures described in ASTM C 805 (1997). At least 20 measurements in different points of each mixture samples were taken for the rebound hardness of the concrete paving blocks.

Ultrasonic pulse velocity was determined according to ASTM C597 (1997), each time for three identical specimens, using a device that measures the amount of time it took for ultrasonic waves to pass between clean specimen surfaces from the wave transmitter to the receiver nozzle. The wave speed was calculated as.

$$V = (d/t) \times 10^3 \quad (1)$$

where V is the supersonic wave speed (km/s), d is distance in m from the surface of the concrete specimen at which the ultrasonic wave is transmitted to the surface at which the wave is received, t is time from transmitting to receiving the wave in μs.

Fig. 2. Paving block production.

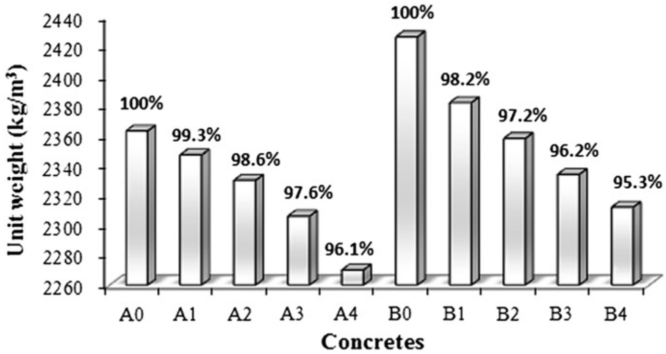

Fig. 3. Unit weights of concretes.

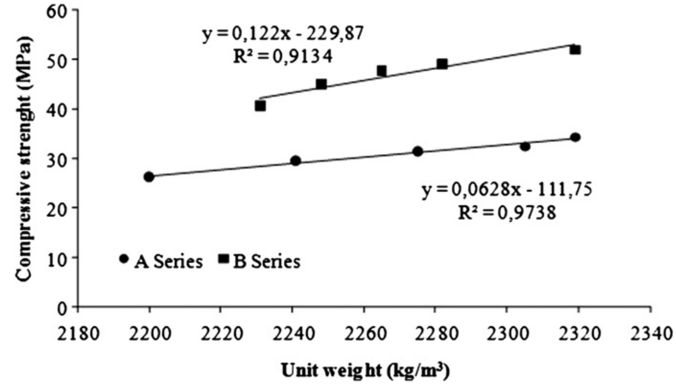

Fig. 5. Relation between compressive strength and unit weight of the concrete paving blocks at 28 days.

Water absorption was determined according to TS 2824 EN 1338 (2005).

Freeze-thaw durability was determined according to ASTM C 666 (ASTM C 666/C 666 M, 2003). All specimens were subjected to 30 Freeze-thaw cycles, 2 h freezing at -20 ± 2 °C and 1 h thawing at 4 ± 1 °C.

The Blaine fineness determination method follows the ASTM C-204-07 standard. The Blaine air permeability apparatus allows drawing a definite quantity of air through a prepared bed of cement of definite porosity. The permeability cell is a rigid cylinder made of stainless steel.

Abrasion resistance tests were performed using Bohme method which is based on TSE (TS 2824 EN 1338, 2005). We recall that there is a variety of methods of determination of abrasion (Brostow et al., 2003; ASTM C779/C779 M, 2010; Brostow et al., 2010). In our case, the abrasion system had a steel disc with a diameter of 750 mm and rotating speed of 30 ± 1 cycles/min, a counter and a lever. 20 ± 0.5 g of abrasion dust was spread on the disc, the specimens were then placed, the load of 5.0, 10.0 and 15.0 kg was applied to the specimen and the disc was rotated for four periods, while a period was equal to 22 cycles. After that, the surfaces of the disc and the sample were cleaned. The above-mentioned procedure was repeated for each edge of concrete samples (total 88 cycles) by rotating the sample 90° in each period. The volume decrease was measured in cm^3/50 cm^2 due to wear. Abrasive dust used in this test was corundum (crystalline Al_2O_3).

The paving block machine was also used to compact a small concrete specimen from each concrete mixture made in the factory for determination of elasticity modulae of the cylindrical concrete specimens with 150 mm diameter and 300 mm height while all other tests were performed on concrete paving blocks. Secant modulus was used to determine elasticity modulus of the concretes so produced. The modulus of elasticity was taken as the slope of the chord from the origin to a point on the linear part of the stress-strain curve. The secant modulae calculated this way correspond to 40% of the maximum stress.

3. Results and discussion

3.1. Dry unit weight

The density of values of the produced block specimens are presented in Fig. 3, each value is an average of three measurements. As seen from Fig. 3, the density of paving blocks decreases with an increase in the waste marble content in the mixture for series A and B. This is due to the fact that marble waste has lower density when compared to the other aggregates used in the mixture. When we look at the mixture proportions, water demand increases with an increase of marble aggregate content. Consequently, the water-to-cement ratio had to be increased – as seen in Table 3. The increased water demand comes from large surface areas of the small marble dust particles. Series B using CEM II 42.5N is denser than series A using CEM II 32.5N. This is attributed to higher specific gravity of CEM II 42.5N than that of CEM II 32.5N. Mixtures with CEM II 42.5N demand less water, the result is higher density.

3.2. Compressive strength

Compressive strength is an important parameter in evaluation of paving block quality. Compressive strength values of the blocks in series A and B are presented in Fig. 4. As seen clearly from Fig. 4, compressive properties of paving blocks were affected by both

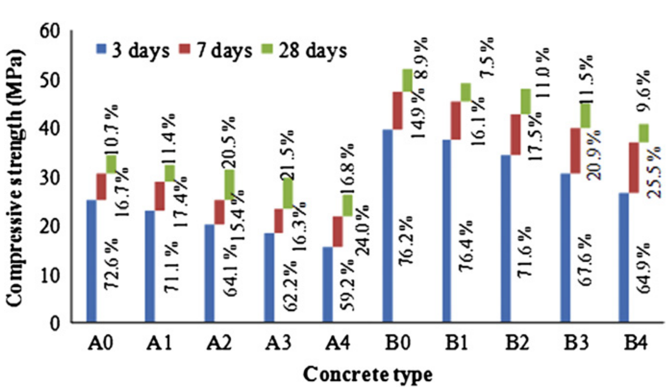

Fig. 4. Compressive strength values for the blocks.

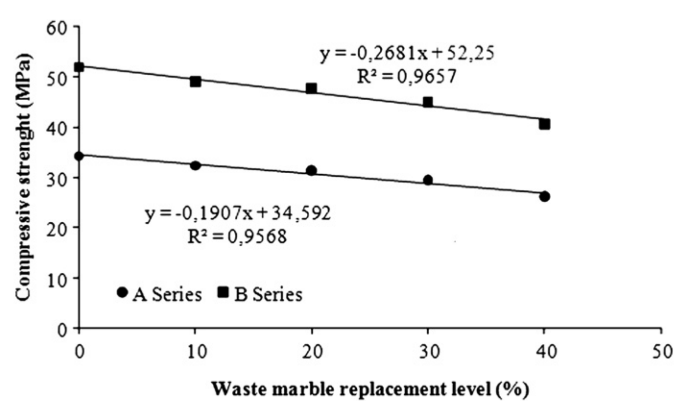

Fig. 6. Relationship between 28-day compressive strength and waste marble content.

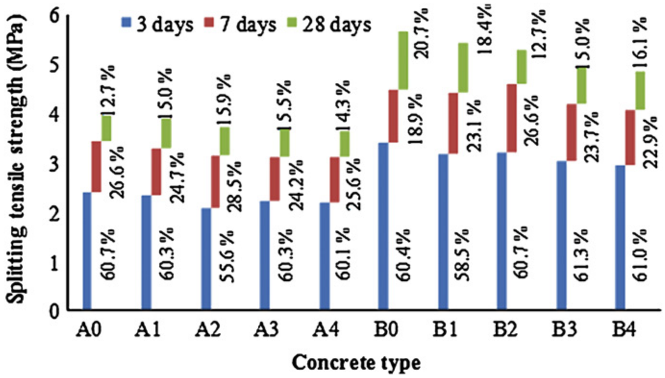

Fig. 7. Splitting tensile strengths of the blocks.

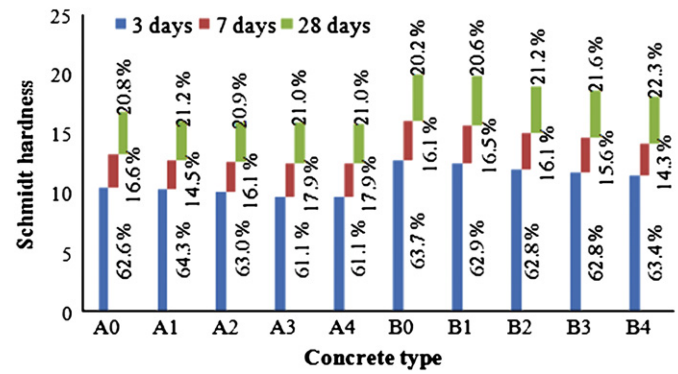

Fig. 9. Schmidt hardness values of the blocks.

cement type and marble waste content. The strengths decreased to different extents in response to the marble content at ages of 3, 7 and 28 days. Comparing with the control concrete A0, replacing marble aggregate at 10%, 20%, 30% and 40% affects relative strength between 92.5%, 81%, 73.7%, 62.3 at 3 days, 93.6%, 81.7%, 75.6%, 71.2% at 14 days and 94.3%, 91.7%, 86% and 76.4% at 28 days, respectively. When compared with the control concrete B0, replacing marble aggregate at 10%, 20%, 30% and 40% affects the strength by 94.6%, 86.4%, 76.7%, 66.6% at 3 days, 95.9%, 90%, 84%, 77.6% at 14 days and 94.4%, 92%, 86.5% and 78.2% at 28 days, respectively. A higher percentage of replacement resulted in lower compressive strength. Compressive strength increases with increment in density of blocks – as presented in Fig. 5. As seen from Fig. 6, at the same replacement level in series B the strength is higher than in series A. This is attributed to the cement type used.

3.3. Splitting tensile strength

Fig. 7 shows the splitting tensile strength of our paving blocks. The values for series A are approximately 3.7 MPa while for series B we have 5.2 MPa. We also note that the values decrease with an increasing level of waste marble aggregates in the mixture. However, effects of waste marble addition are not large. Mortar matrix rather than aggregate quality is important for the splitting tensile strength of paving blocks.

Compressive strength and splitting tensile strength are known as two important indices used for characterizing mechanical properties of concrete. It has been reported that splitting tensile strength can be estimated from compressive strength of concrete (Xu and Shi, 2009), namely

$$f_{spt} = A(f_{cs})^B \qquad (2)$$

where f_{spt} is the splitting tensile strength and f_{cs} is the compressive strength, both typically in MPa; A and B are adjustable parameters. For our materials we find

$$f_{spt} = 0.5(f_{cs})^{0.6} \qquad (2a)$$

Coefficient of determination (R^2) of this proposed relation is 0.831 for series A and 0.938 for series B – highly satisfactory; see Fig. 8.

3.4. Schmidt hardness

The Schmidt hardness test is one of the oldest non-destructive methods and it is widely used (Gencel et al., 2010). Non-destructive tests provide high safety and allow improved scheduling of construction. The rebound number is an arbitrary measure since it depends on the energy stored in the given spring and on the size of the mass. The rebound hammer test is largely comparative in nature and useful in the assessment of uniformity of concrete paving block within a structure or in the manufacture of a number of similar products such as precast elements (Atici and Ersoy, 2008).

A uniform compressive stress of 2.5 MPa is applied to the test specimen along the vertical direction (the same as the casting direction) before striking it with a hammer; this prevents dissipation of the hammer striking energy due to lateral movement of the specimen.

Striking points were uniformly distributed to reduce the influence of local aggregates distribution and averages of the rebound energy calculated. The results are presented in Fig. 9.

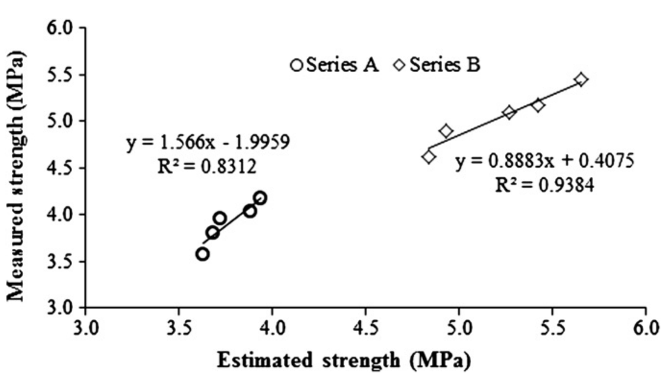

Fig. 8. Relationship between compressive strength and splitting tensile strength of blocks.

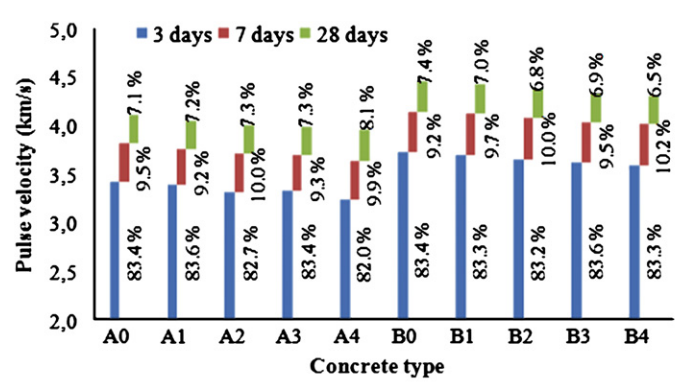

Fig. 10. Comparison of pulse velocity results for paving blocks.

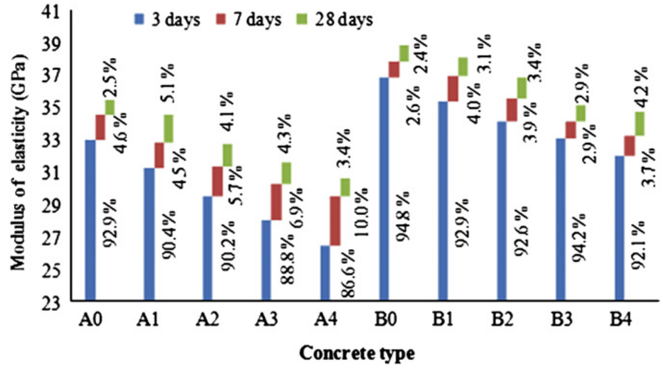

Fig. 11. Elasticity modulae.

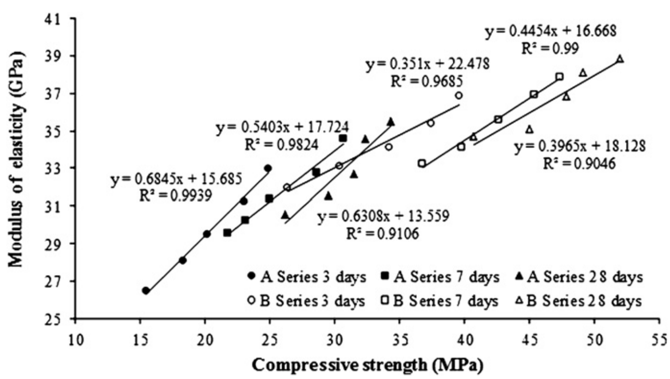

Fig. 12. Relationship between compressive strength and elastic modulus.

Schmidt hardness is a method related to compressive behavior since it is based on the rebound ratio from surfaces of samples. Therefore, similar behavior is expected as in Figs. 4 and 7. The Schmidt hardness values decrease when waste marble is added to the mixture. The effects are small.

3.5. Pulse velocity

Experimental results of pulse velocity for our concrete paving blocks are presented in Fig. 10. The values decrease with increasing concentration of waste marble. This result can be related to decreasing unit weight of the blocks. The density of CEM II 32.5N is lower than that of CEM II 42.5N. As seen in Fig. 10, pulse velocity values range from 3.24 km s^{-1} to 3.72 km s^{-1} at 3 days, from 3.63 km s^{-1} to 4.13 km s^{-1} at 7 days and from 3.95 km s^{-1} to 4.46 km s^{-1} at 28 days. Clearly the effects are not large while sound travels faster in a more compact medium.

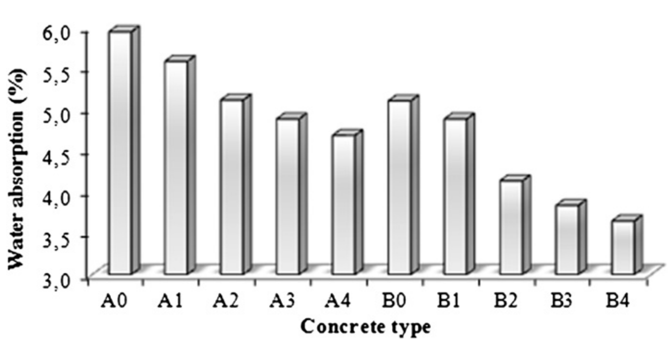

Fig. 13. Water absorption results.

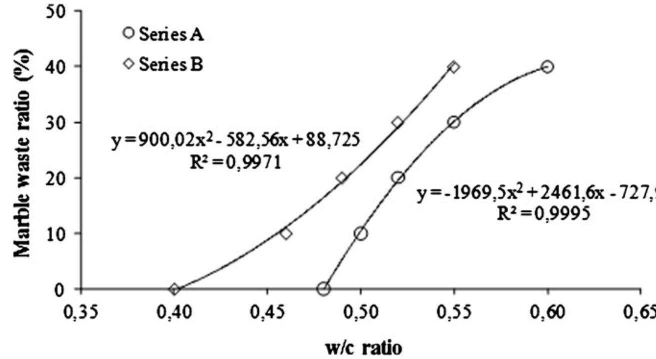

Fig. 14. Water demand dependent on waste marble concentration in the mixture.

3.6. Modulus of elasticity

The modulus of elasticity values, presented as the averages of two measurements, are summarized in Fig. 11. Incorporation of waste marble aggregate decreases the modulus of elasticity of the concrete. As expected, the cement type has a significant effect on the modulus of elasticity of concrete.

The relationship between the compressive strength and elastic modulus measured at 28 days is shown in Fig. 12. A good correlation existed between these two properties is seen.

3.7. Water absorption

Water absorption of concrete is naturally related to the nature of the pore system within the hardened concrete. Aggregate can also contain pores, but these are usually discontinuous. Moreover, aggregate particles are enveloped by the cement paste, which is the only continuous phase in concrete so that the pores in aggregate do not contribute to the water absorption of concrete. Thus, the influence of aggregate is very small. The hardened cement paste has the greatest effect on the absorption of fully compacted concrete.

Water absorption of concrete is significantly affected by the properties of cement used. For the same w/c ratio, coarse cement tends to a hardened cement paste with higher porosity than finer cement.

Water absorption of the blocks results are presented in Fig. 13. We see that specimens with CEM II 32.5N have higher absorption than those with CEM II 42.5N. This can be attributed to the Blaine fineness of the used cements (see Table 1) as explained above. We note that the influence of marble aggregates is small. Although absorption is not used as a measure of quality of concrete, most good concretes have absorption below 10%. The highest absorption value was observed was 5.95% - namely for A0.

Table 4
Relative strength loss of blocks after freeze-thaw cycles (%).

Code	Strength loss (%)
A0	15.87
A1	13.12
A2	9.22
A3	7.52
A4	7.19
B0	12.85
B1	10.56
B2	7.20
B3	5.62
B4	4.43

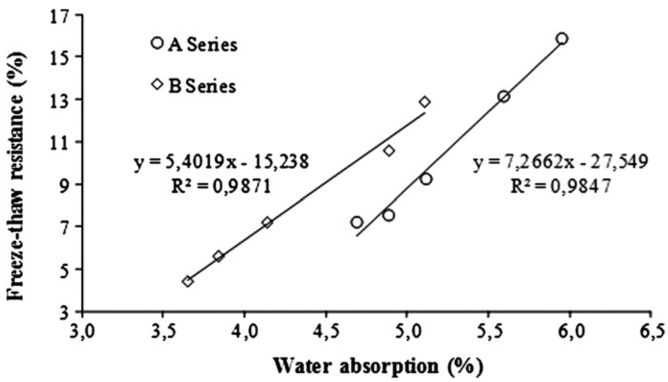

Fig. 15. Relationship between freeze-thaw resistance and water absorption.

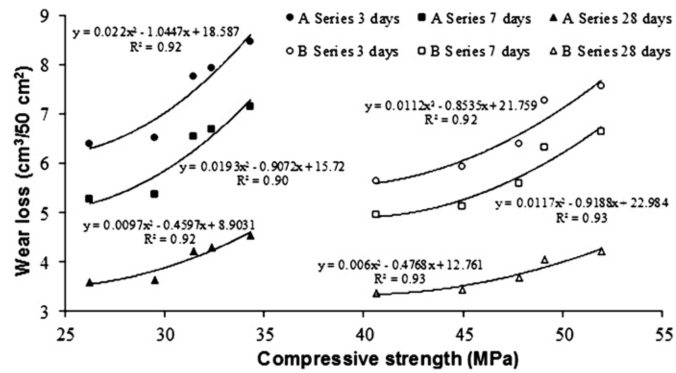

Fig. 16. Relationship between the compressive strength and the wear loss.

Fig. 14 shows a relationship between marble content and the w/c ratio in the mixture. As seen from this figure, w/c ratio increases along with increasing concentration of waste marble aggregate. This effect can be attributed also to the larger surface area of small marble dust particles.

3.8. Freeze-thaw resistance

The results of freeze-thaw cycling (FTC) durability tests are presented in Table 4. As seen in the Table, all concrete types have lost strength in cycling. However, for concrete containing marble the losses are smaller. Concretes using CEM II 42.5N cement resist the cycling better than concretes produced with CEM II 32.5N cement. Apparently, specimens containing marble absorb less water and are thus less affected by FTCs. CEM II 42.5N cement type presents the same behavior. Relationship between freeze-thaw resistance and water absorption of the blocks is shown in Fig. 15.

Micro-cracks mainly exist at cement paste–aggregate interfaces within concrete even prior to any loading and environmental effects. When the number of freeze-thaw cycles (FTCs) increases, the degree of saturation in pore structures increases by sucking in water near the concrete surface during the thawing process at temperatures above 0 °C. Some of the pore structures are filled fully with water. Below the freezing point of those pores, the volume increase of ice causes tension in the surrounding concrete. If the tensile stress exceeds the tensile strength of concrete, micro-cracks occur. By continuing FTCs, more water can penetrate the existing cracks during thawing, causing higher expansion and more cracks during freezing. The load carrying area will decrease with the initiation and growth of every new crack. Necessarily the compressive strength will decrease with FTCs (Gencel et al., 2010; Shang et al., 2008).

Table 5
Abrasive wear values of the paving blocks.

Codes	Wear (cm^3/50 cm^2)		
	3 days	7 days	28 days
A0	8.47	7.15	4.54
A1	7.94	6.68	4.30
A2	7.76	6.55	4.22
A3	6.51	5.36	3.65
A4	6.39	5.27	3.59
B0	7.57	6.64	4.22
B1	7.27	6.32	4.05
B2	6.39	5.59	3.69
B3	5.93	5.13	3.45
B4	5.64	4.96	3.37

3.9. Abrasion resistance

Abrasive wear is known to occur in pavements, floors and concrete highways or other surfaces upon which abrasive forces are applied between the surfaces and moving objects during service. Abrasive resistance of construction materials including mortar and concrete with cement binders is very important for their service life, especially in industrial enterprises. Thus, factors affecting the abrasion resistance and abrasive behavior of concrete were discussed in detail in an earlier paper by some of us (Gencel et al., 2011).

Wear losses of the produced paving blocks are presented in Table 5. As seen in that Table, addition of marble aggregate to the concrete increases wear resistance of the paving blocks. This can be attributed to the higher hardness of marble aggregate (between 3 and 4 on the Mohs scale). We have noted earlier (Gencel et al., 2011) that the hardness is important for protecting the aggregate in concrete from wear. The hard aggregate should protect the softer paste.

Compressive strength of paving blocks is also pertinent for abrasion wear. Fig. 16 shows relationship between the compressive strength and the wear losses of concrete paving blocks tested. As seen in Fig. 16, compressive strength increases with age of paving blocks – as expected. Parallel to increase in the compressive strength, resistance of the blocks to the abrasive wear decreases significantly in each mixture. Apparently an increment in the marble content in the mixture causes decreasing bond strength between paste and marble aggregate, thus lower compressive strength. At the same time and as explained above, marble aggregates are harder than normal aggregates and protect better the softer paste against abrasive forces.

For concrete, its abrasion resistance has been defined in terms of its ability to resist being worn away by rubbing and friction. As abrasive particles achieve relative motion, shear forces are formed on the surface of the abraded material along with a normal load. While normal load helps abrasive particles penetrate into the specimen surface, shear force helps the formation of grooves and scratches on the surface. Thus, material transfer from the specimen surface occurs by a combination of normal load and shear forces.

4. Conclusions

The civil engineering construction industry seems capable of absorbing large amount of waste – incorporating the waste into useful products. This is an example of a more general tenet of industrial ecology for a sustainable future of the world: industry by-product can be used as raw materials in other industries. Usage of waste materials in concrete presents several advantages: conserving mineral resources of a country such as aggregate and sand derived from nature, preventing environmental pollution, also a positive effect on a country's economy because of the high cost of waste storage. No natural resources constitute limitless reserves. For construction industry, maintainability and sustainable improvement aims primarily to protect environment by using alternative materials, new methods, and recycling. The use of our method of incorporation of marble waste is only limited by incidental costs such as transport over large distances.

As for the cost, in Turkey 1 m^3 concrete to produce paving block costs approximately 34 US $. However, when waste marble is used at the ratio of 40%, the cost goes down to approximately 30 US $.

Cements and concretes manufactured in very large quantities for construction and other industries require water (Cazacliu and Ventura, 2010). In some cases *waste* water can be used. We note that waste water can be cleaned by flocculation (Brostow et al., 2007, 2008, 2009; Barrera-Díaz et al., 2011) The result are more environmental friendly buildings and other structures (Chau et al., 2007; Barrera-Díaz et al., 2011).

Shen and co-workers (2010) discussed the principle of sustainable development and the social and environmental performance in the construction industry. In the long term, the concept of sustainability can succeed by providing longer life-cycle materials while staying away from environmentally hazardous materials. In this respect, the civil engineering construction seems to be one of the most important areas to incorporate large amounts of solid waste. When one considers industrial ecology, we have here an example *par excellence*.

The purpose of our work was determination of feasibility of using waste marble – which is an environmental problem – in fabrication of concrete paving blocks and the effects of waste marble on physical and mechanical properties of the blocks so produced. Several conclusions can be drawn from the present work. Water demand of the mixture increases with increment in marble content. In other word, w/c ratio increases due to higher specific surface of fine marble aggregates. Dry density of the blocks is affected differently depending on marble content in the mixture and cement type. If the marble content in the mixture increases, the density decreases due to increase in the water content of mixture. Specimens in series B are denser than those in series A. Although compressive strength decreases with increasing marble content in the concrete, the blocks give satisfactory strength values after 28 days. The cement type is an important factor for strength of the blocks. Abrasive resistance of the blocks is strongly influenced by their marble aggregate content. Highest abrasion rates were obtained for control blocks that do not contain marble (A0 and B0). Freeze-thaw durability of paving blocks containing marble aggregate is higher than those of the control blocks. Also cement type is an important factor for freeze-thaw durability of blocks. Blocks made with CEM II 42.5N have higher resistance to the freeze-thaw cycles than those made with CEM II 32.5N. Cement type has more effect than marble aggregate on elasticity modulus of the concrete. The presence of marble aggregate causes a very small decrease of splitting tensile strength of the blocks. Finally, we conclude that incorporation of marble waste provides concrete paving blocks of sufficient quality.

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