Int. J. Pure Appl. Sci. 2(1): 13-21 (2016)

IJPAS
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ISSN: 2149-0910

Research article/Araştırma makalesi

Compressive Strength and Abrasion Resistance of Concrete with Waste Marble and Demolition Aggregate

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Abstract

The main goal of this paper is to disseminate strength and engineering properties of concrete produced with waste marble aggregate and waste demolition materials. For this purpose, Tunceli province was selected as a case study. The purpose of selection Tunceli is this province is small and still remains natural due to un-existing industrial facilities. Two different materials were evaluated. These are marble waste and demolition waste. Four type of mix design were used. These are control concrete, concrete produced with demolition waste, concrete with waste marble aggregate and concrete with waste marble dust. Replacement of demolition waste by aggregate was 55 % by mass. In addition to demolition waste, marble aggregate was replaced with natural aggregate 67.5 % by mass for third mix and last mix design was prepared with marble aggregate and dust 37.5 % and 7.5 % by total mass respectively. Compressive strength tests were performed on the base of current Turkish regulation, TS EN 12390-3 and abrasion resistance tests were performed according to ASTM-C 944. Results were compared and disseminated.

Keywords: Concrete, demolition, engineering properties, marble waste, waste material

Atık Mermer ve Atık Moloz ile Üretilmiş Betonun Basınç Dayanımı ve Aşınma Direnci

Özet

Bu çalışmanın temel amacı atık mermer ve atık moloz malzemelerden üretilmiş betonların mukavemet ve mühendislik parametrelerini neşretmek. Bu amaçla durum çalışması için Tunceli ili seçilmiştir. Tunceli ilinin seçilmesindeki temel amaç bu şehrin halen küçük olması ve endüstriyel aktivitelerin var olmaması. İki çeşit malzeme seçilmiştir. Bu malzemeler atık mermer ve moloz. Dört çeşit karışım hesabı kullanılmıştır. Bunlar; kontrol betonu, moloz ile üretilmiş beton, atık mermer agregası ile üretilmiş beton ve son olarak hem atık mermer agregası hem de atık mermer tozu ile üretilmiş beton. Moloz ile üretilmiş betonda ağırlıkça % 55 agrega ikame edilmiştir. Mermer agregası ile üretilmiş betonda doğal agrega ağırlıkça % 67.5 oranında ikame edilmiştir. Hem mermer agregası hem de mermer tozu ile üretilmiş betonda ise mermer agregası % 37.5 oranında doğal agrega ile mermer tozu ise % 7.5 oranında çimento ile ikame edilmiştir. Basınç testi ve aşınma testleri numunelere uygulanmıştır. Basınç testi TS EN 12390-3 standardına göre yapılmıştır. Aşınma testi ise ASTM-C 944 standardına göre yapılmıştır. Sonuçlar karşılaştırılmış ve neşredilmiştir.

Anahtar kelimeler: Beton, atık molozu, mühendislik parametreleri, atık mermer, atık malzeme

INTRODUCTION

Developed countries look for reusing methods of residue elements of mine quarry industry. Because, these residue elements are huge amount of cumulative environmental waste. These residue materials marble dust and marble particles. Quarry industry is developed in Turkey.

Marble is more abundant and taken out many part of Turkey like Elazig (Cherry), Aksehir (Black), Manyas (White), Bilecik (Beige), Ege (Claret Red), Milas (Lilac), Afyon (Sugar), Kutahya (Chocolate) (URL-1, 2014) Distribution of this materials can be seen in Figure 1 (MTA, 2011).

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Figure 1. Available mine reserve of Turkey (MTA, 2011)

There are many studies to evaluate reusable of marble residue as cement and aggregate like Binici et al. (2008). They studied marble and granite particles as coarse aggregate in concrete. They investigated air content, slump, setting time of fresh concrete and then flexural strength, split tensile strength and compressive strength of concrete produced by granite and marble. It was reported that air content and slump were decreased. However, abrasion resistance and compressive strength were considerably increased by replacement of marble and granite. Topçu et al. (2009) investigated effect of reusing Marble Dust (MD) in Self Compacting Concrete as filler material. Topçu and his colleagues (2009) implemented Slump-flow, V-funnel and L-box tests on fresh concrete and flexural strength, ultrasonic pulse velocity, and compressive strength tests on hardened concrete. It was emphasized that optimum amount for MD is 200 kg m^{-3} for many properties of concrete. This amount let the mentioned engineering properties of concrete to increase for benefit of Self Compacting Concrete (Topçu et al., 2009). Aruntaş et al. (2010), studied Blended Marble Dust (BMD) in concrete as cement. They added BMD in concrete 2.5 %, 5.0 %, 7.5 % and 10 % by weight. According to their test results, 10 % of replacement amount developed many properties of concrete. An experimental study was implemented by Hebhoub et al. (2011) to research engineering properties of concrete produced by coarse marble aggregate replaced by coarse aggregate. It was reported that 75 % replacement level is beneficial for all investigated properties of concrete. A laboratory work was carried out to investigate the effect of diatomite and Waste Marble Powder as cement in concrete by Ergün (2011). In this paper different amount of waste material replaced. It was emphasized that optimum mix design composed of 5 % replacement of Waste Marble Powder with cement. According to the same paper this optimum amount substitution developed compressive strength and water demand of concrete (Ergün, 2011). Marble Dust is also investigated as filler materials in Self Compacting Concrete by Gesoğlu et al. (2012). This study proved that increasing amount of substitution has no great effect on fresh phase properties of concrete. Furthermore, compressive strength, split tensile strength, chloride penetration, sorptivity coefficient and electrical resistance targets were achieved while compared

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control specimens according to this study. The same manner with previous paper, Marble and Granite Waste were studied in concrete by Bacarji et al. (2013) to open a new aspect by protecting environment from waste Marble residue. Bacarji et al., (2013) studied MGR in concrete on behalf of mechanical performance of concrete in Brazil. MGR replacement in concrete as binder results a slight strength decrease in concrete in their study, whereas there is an increase in other parameters. Coarse Marble Aggregates (CMA) was studied also in another unique study. CMA was replaced with Natural Aggregate 20 %, 50 %, and 100 % by weight of total volume. André et al. (2014) were reported that many properties of concrete produced by CMA showed approximately the same properties with reference concrete in terms of carbonation, chloride penetration, workability, capillary action. However, there is a slight loss of compressive strength. Durability performance of concrete produced with Fine Waste Marble Aggregate (FWMA) was studied by Gameiro et al. (2014). FWMA replaced with Natural Fine Aggregate. In their study FWMA was replaced with Fine Aggregate by weight at amounts 0 %, 20 %, 50 % and 100 %. It was reported that 20 % is the optimum amount to obtain beneficial effect for concrete in terms of carbonation, shrinkage, compressive strength, water absorption and permeability. Aliabdo et al. (2014), implemented a series of tests to see the effect of Waste Marble Sand in concrete replaced by Natural Sand at constant w/b ratio. Physical, chemical and mechanical properties were studied in their paper. It was reported that 15 % replacement ratio by fine sand showed a contribution to concrete in terms of compressive strength, tensile strength and ultrasonic pulse velocity. It was also emphasized that this concrete has less porous structure (Aliabdo et al., 2014).

Other of the most important waste material is demolition or waste concrete blocks. It is predicted that generation of Construction and Demolition Waste in EU per year around 450 million tons. This is the largest waste generation except for farm waste after harvesting (Rao et al., 2007). Topçu and Şengel (2004) studied mechanical and physical properties of concrete casted with Waste Concrete Aggregate (WCA). It was reported that while replacing 30, 50, 70 and 100 % of WCA with Natural Aggregate (NA). Quality class of WCA was C16 that was used in concrete production as it was reported by authors. These amounts were mixed and then related benefits were reported like; specific gravity of WCA was lower than NA, water absorption of WCA was higher than NA, compressive strength of WCA depended on mostly w/c ratio. Workability performance of WCA concrete was depended on the amount of replacement ratio of WCA and it was observed that workability decreased with increasing proportion of WCA. Furthermore it was reported that specific gravity of WCA concrete was lower than NA concrete. Water absorption ratio of WCA concrete was much higher than water absorption of NA Concrete. This study was concluded that under this condition, concrete with WCA production is vital for environmental safety than using in concrete as inadequate aggregate for concrete (Topçu and Şengel, 2004). According to review paper of Evangelista and Brito (2014), compressive strength of fine recycled aggregate concrete decreases from 42 MPa to 32 MPa with increasing replacement ratio while compared with concrete produced by fine natural aggregate. Maximum loss for study is 6.5 % in terms of compressive strength. On the base of the same paper, general perspective of compressive strength of concrete produced by Fine Recycled Aggregate (FRA) and Coarse Recycled Aggregate (CRA) was compared to prove contradiction with replacement ratio. While increasing the FRA ratio, compressive strength starts to decrease from 23 MPa to 22 MPa. There is a reverse relationship between substitution ratio of CRA and compressive strength. The demolished CRA were substituted in 0 %, 50 % and 100 % by weight volume and then strength of concretes obtained 21.5 MPa, 22.5 MPa and 24 MPa respectively. However, increase in CRA is about 4 % and on the contrary decrease in FRA is about 12 %. This differential amount is profitable for this type of production. Other important mechanical property of concrete is tensile strength; there is not a certain increase or decrease in tensile strength with arising replacement ratio. This increase and decrease depends completely on w/b ratio. For instance, if replacement ratios are considered 10 %, 50 %, 90 % and 100 %, it was reported that tensile strength values are 3.0 MPa, 3.1 MPa, 3.3 MPa and 3.4 MPa at 0.6 w/b ratio. Other example pertinent to

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0.4 w/b ratio, If replacement ratio considered 10 %, 50 %, 90 % and 100 %, it was emphasized that tensile strength values are 4.9 MPa, 4.7 MPa, 4.5 MPa and 4.4 MPa (Evangelista and Brito, 2014). Chan and Sun (2006) reported that fresh concrete that was prepared with Recycled Aggregate (RA) with replacement ratio 50 % had relatively high initial slump for workability. Use of Fine RA as sand reduced the compressive strength and elastic modulus but not considerable amount. Other impressive result for this study is related to shrinkage. It was reported that shrinkage of this type of concrete has not a remarkable increase on concrete with arising RA content. Wagih et al. (2013) used Recycled Concrete Aggregate in their studies at 25 %, 50 %, 75 % and 100 % amount and then reported corresponding results. 100 % replacement ratio resulted in only 10 % decrease. In their studies replacement ratio of RA results 6-13 % reduction at compressive strength and arising replacement ratio, more than 50 %, results a decrease between 15-23 %. 100 % replacement ratio of RA causes a decrease at Elasticity Modulus around 8 %.

In this study, demolition waste, marble dust and marble aggregate were used as aggregate and sand for concrete production. Only compressive strength and abrasion resistance were evaluated and results were demonstrated. Waste marble aggregates and waste marble dust were studied by Cemalgil and Onat (2015) on marble to search usability of these waste materials in construction industry. Engineering properties of these materials like water absorption and specific gravity of these waste materials are suitable for using in concrete (Cemalgil and Onat, 2015).

MATERIAL AND METHOD

Material

Marble

In this study Elazig Cherry Marble Waste is used in concrete as cement and aggregate. In addition, crushed stone and CEM II 42.5 R type cement was used for control group of specimens comply with TS EN 197-1 (2012). Cement was obtained by Elazig Cement Production Plant. Maximum diameter of aggregate is determined 16 mm due to crushed marble particles. Natural sand was used 0 and 4 mm, Elazig Cherry Marble was used two sizes. One of them 4 and 8 mm other of them is 8 and 16 mm size. Water absorption and specific gravity values of marble dust and marble aggregate can be seen in Table 1. Water absorption and specific gravity tests were performed according to TS EN 3526 (TS EN, 1980).

Used waste marble dust and waste marble aggregates can be seen in Figure 2 below.

Table 1. Water absorption and specific gravity of marble aggregates (Cemalgil and Onat, 2015)

	Size (mm)	Water absorption (%)	Specific gravity (g m^{-3})
Sand	0-4	2.14	2.65
Crushed aggregate	4-8	0.31	2.70
Crushed aggregate	8-16	0.31	2.70
Marble aggregate	4-8	0.20	2.69
Marble aggregate	8-16	0.20	2.69
Marble dust	0-4	2.35	2.75

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(a)

(b)

Figure 2. Waste marble dust and waste marble aggregate (a) Waste marble dust used as cement (b) Waste marble particles as aggregate (Cemalgil and Onat, 2015)

Demolition waste

Demolished concrete waste obtained by structural material laboratory of Tunceli University after compressive strength of tests. These materials were crushed and transported from production industry to laboratory to produce concrete. After production of sand and aggregate from demolition waste, this material seen as in Figure 3.

Specific gravity and water absorption values can be seen in Table 2 below.

Method

After determination of water absorption and specific gravity, concrete mixtures were prepared four sets. One set was called as M0, this was control concrete. This set was prepared conventional type and materials. Second set was called as M1. This set of concrete was prepared by marble aggregate. Replacement ratio is 67.5 % by weight at second set. Then, third set was prepared and called M2. This set was composed of both marble aggregate waste and marble dust waste. Composition of third set, called as M2 was contains 37.5 % waste marble aggregate and 7.5 % marble dust by weight. M3, which is last the set of the experiment, composed only of demolition waste. Replacement ratio of this set by aggregate is 55 % by weight. Mix design of all sets was tabulated in Table 3.

Figure 3. Sand and aggregate produced with demolished waste concrete

Table 2. Water absorption and specific gravity of demolition waste aggregates (Cemalgil and Onat, 2015)

	Size (mm)	Water absorption (%)	Specific gravity (g cm^{-3})
Demolished sand	0-4	1.03	2.46
Demolished aggregate	4-8	0.69	2.70

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Table 3. Mix design of all sets

Material name	M0	M1	M2	M3
Cement (kg m^{-3})	273.77	273.77	253.24	250.00
Water / Binder	0.61	0.61	0.61	0.61
Marble dust (kg m^{-3})	--	--	20.53	--
Crushed aggregate (kg m^{-3})	724.54	235.52	235.52	363.93
Waste marble aggregate (kg m^{-3})	--	489.15	489.15	--
Demolition aggregate (kg m^{-3})	--	--	--	451.28

Moreover before casting specimens into the mold whom dimensions are 100x100x100 mm, workability of the fresh concretes was checked by slump test. Average slumps were measured 11 cm, 9 cm, 7 cm and 13 cm for M0, M1, M2 and M3 sets respectively. After casting into the molds, specimens were exposed to water cure in the cure tank at 22°C. Compressive strength tests of 7 and 28 days were implemented on the specimens on the base of TS EN 12390-3 regulation (TS EN, 2010).

After compression test, tested specimens were wasted and then abrasion test was carried out on different samples. Abrasion test was implemented on the samples that dimensions 100x100x100 mm. This test was carried out according to ASTM C 944 regulation (ASTM, 2012). According to this standard, three surface of the specimens are exposed to abrasion test. Each surface is exposed to abrasion along 120 second. Totally, one specimen is exposed to abrasion along 6 minutes. After 6 minutes, loss of mass is weighted and then reported. This test was implemented on 28 days' age specimens. During this period of time abrasion module of machine revolved 60 rev/min. Abrasion resistance test machine can be seen in Figure 4 below.

Figure 4. Abrasion resistance machine

RESULTS AND DISCUSSION

In this paper, waste marble aggregates and waste marble dust were replaced with cement and aggregates to see the effect of waste material on concrete properties for sustainability concrete technology. In this study, it was focused on the compression strength and abrasion resistance of concrete specimens.

Bearing Properties of Concrete

Compressive strength of concrete specimens was measured at 7 days and 28 days age. These average results were tabulated in Figure 5.

M0 set concrete simulates reference concrete. Compressive strength test results of 7 days and 28 days are 24.45 MPa and 32.42 MPa respectively. M1 set concrete composed of Waste Marble Aggregate and compressive strength test results are 24 MPa and 30.7 MPa. Third set is produced with both marble aggregate and marble dust. Test results are 23.75 and 31.58 MPa respectively as seen in Figure 5. Fourth set is produced with waste demolition material and compressive strength is 24.29 MPa and 29.85 MPa for 7 days and 28 days respectively. Results of the all sets were nearly the same. These results show that marble particles and marble dust can be use in the same mix even if water absorption of marble dust is relatively high. Concrete produced with waste marble aggregate has not showed expected low strength due to void. This result is an asset for marble particles.

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Abrasion Resistance of Concrete

Abrasion resistance experiments were made with Rotating Cutter Method according to ASTM C 944. This experiment was implemented on three faces of specimens. Results were plotted in Figure 6.

As seen in Figure 6, after abrasion tests, specimens lost different amount of mass.

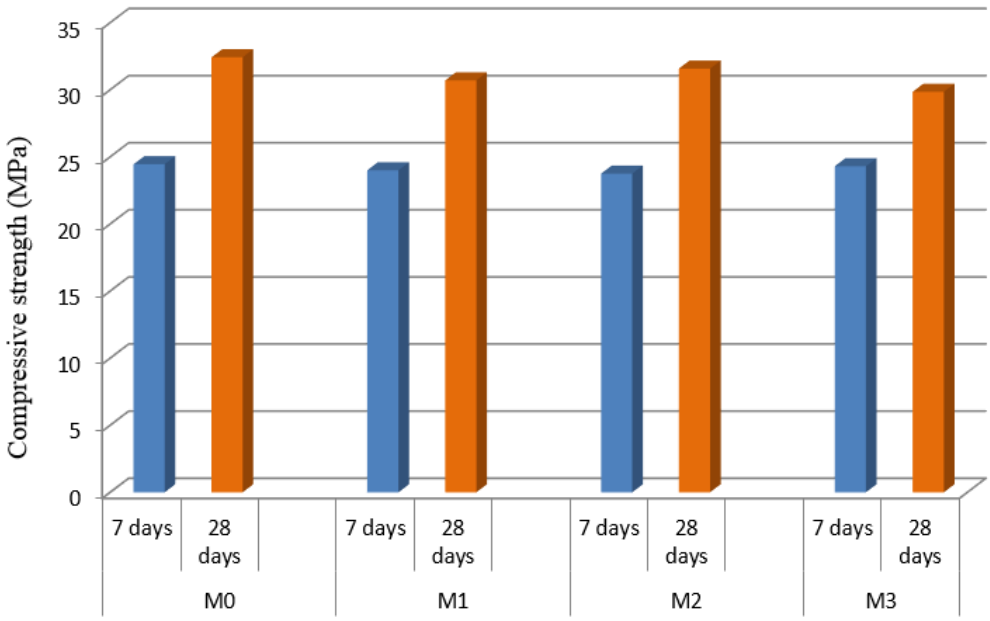

Figure 5. Compressive strength of four sets

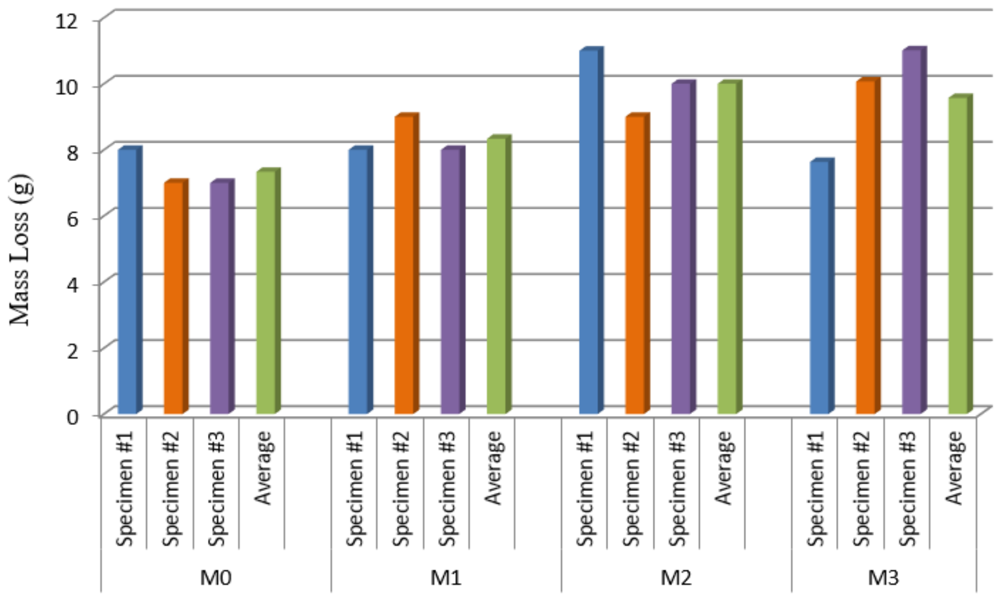

Figure 6. Loss of concrete mass after 6 min abrasion test

These loss amounts were average 7.33 g, 8.33 g, 10.00 g and 9.57 g for M0, M1, M2 and M3 respectively. The highest loss of mass occurred at M2 set of specimens. These specimens are composed of both with waste marble aggregate and waste marble dust. This result is expected due to void. Void prevents perfect connection between the materials. Then

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second highest loss occurred at M3 set of specimens. Loss amount of M1 is 13 % according to M0 control specimen, M2 is 36 % according to M0 control concrete and M3 is 30 % according to M0 control concrete. These concrete specimens were casted with demolition waste. These revealed test results are also showed a good match with literature search by Topçu et al., (2009), Aruntaş et al., (2010), Hebhoub et al. (2011), Ergün (2011), Aliabdo et al. (2014) for waste marble dust and waste marble aggregate. Morever, these results are compatible with the study implemented by Karaşahin and Terzi (2007) and Keleştemur et al., (2014).

CONCLUSION

This paper presents the effect of waste materials on engineering properties of concrete. Used waste materials are marble dust as sand, waste marble aggregates as aggregate and demolition waste as aggregate in concrete. For this purpose, four sets of specimens were produced at constant w/b ratio to implement a series of tests to see the mechanical properties of concrete produced with waste materials at fresh state and hardened state. Firstly, control specimens were produced in a conventional manner called as M0. Secondly set M1 was produced with waste marble aggregate was replaced with crushed stone in this set. Then set M2 was produced with waste marble aggregate and waste marble dust as cement. Last, M3 set was produced with demolition waste in concrete as aggregate. Results of this study listed below;

- Slump values increased while adding waste marble aggregates and waste marble dust. However, the highest slump ratio obtained from fresh concrete produced with demolition waste. This is occurred due to high water absorption of waste marble materials especially dust and demolition waste.
- Compressive strength of specimens is nearly the same, this is a good result to use waste materials in concrete.
- Abrasion resistance of concrete was decreased due to high porosity and low bonding of materials especially demolition waste.
- Mass loss of specimen increased with replacing conventional concrete material with waste material.
- Moreover, low strength of specimen was obtained with increasing waste amount of concrete material.

Results of this paper proved that waste marble residue and demolition waste are the best alternatives for concrete production to eliminate natural hazard of waste materials in environment for sustainability. Because adding this type of materials keep the properties of concrete either constant or develop their properties.

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