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A COMPARISON OF KHORASAN MORTARS PRODUCED USING BLAST-FURNACE SLAG

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ABSTRACT

In the study, blast-furnace slag was used instead of crushed tile and tile powder as aggregate at various proportions. Slaked lime was used as a binder in the mortars. The physical and mechanical tests were conducted on Khorasan mortars to investigate pozzolanic activity. Based on the results, the mortars were non-hydraulic owing to the low pozzolanic activity of crushed tile and tile powder. However, notable improvements were observed on physical and mechanical properties of specimens containing blast-furnace slag compared to the control specimens.

Keywords: Strength, Khorasan mortar, blast-furnace slag, crushed tile

1. INTRODUCTION

Mortars containing lime have been used widely since the ancient Greeks, Romans and Ottoman until the invention of hydraulic cement [1-3]. Khorasan mortar has been used in Ottoman buildings especially in 15th and the following centuries [4-6]. In general, such mortars were used in construction of wells, cisterns and baths in Roman, Byzantine, Seljuk and Ottoman which survive up to date [7-9]. Mixing of brick or tile dust, and similar materials with mortars containing lime was used in many historical constructions [10-12]. Therefore, Turkish, Roman, Byzantine and Medieval mortars and plasters have been studied by several authors [13-15].

In Ottoman, the lime was mixed with water to form slaked lime then heated and sifted to use in mortars [16-17]. Furthermore, egg whites were added and mixture was rest in wells, additionally hydraulic brick pieces or powder and straw particles were added in the mixture. The lime reacts

with brick or tile dust to produce calcium silicate hydrates. The water absorption capability of porous brick of dust allows mortars to gain adhesion and strength in moisture and addition of straw gives ductility and flexibility while drying and settling process.

2. MATERIALS AND METHODS

2.1. Materials

2.1.1. Lime

The chemical and physical properties of the lime were suitable in respect of TS EN 459-1, as given in Table 1 [18]. The unit weight of lime used in experiments was determined as 0.53 kg/dm^3. Calcium hydroxide, traditionally called slaked lime, is an inorganic compound. It is a colorless crystal or white powder and is obtained by mixing calcium oxide with water.

Table 1. Chemical and physical properties of slaked lime

Chemical composition	Value (%)
CaO + MgO	92
MgO	1.5
SO_3	0.8
CO_2	4
Insoluble substance + SiO_2	1
R_2O_3	0.5
LoI	0.2
Physical properties	
630μ (over sieve)	0.5
90μ (over sieve)	4
Unit weight (kg/dm^3)	0.46

2.1.2 Crushed tile and tile powder

The contents of tiles were evaluated by chemical analysis in the study. The tiles were crushed and ground into sizes of 0-1 mm and 0-4 mm. The crushed tiles were sifted and grouped due to the sizes and labeled as crushed tile (CT) and tile powder (TP). The unit weight and specific weight of crushed tiles were 1.21 kg/dm^3 and 2.63, respectively.

2.1.3 Blast-furnace slag

The chemical and physical properties of the blast-furnace slag were given in Table 2.

Table 2. Chemical and physical properties of BS

Chemical composition (%)	BS
SiO_2	39.41
Al_2O_3	11.63
Fe_2O_3	3.35
CaO	36.56
MgO	5.52
Na_2O	0.32
K_2O	1.21
Cl	0.014
LoI	0.71
Physical properties	
Specific gravity	2.88
Specific surface (cm^2/g)	4320

2.1.4 Water

The tap water of Eskisehir city was used in production of specimens. The water was found suitable to use as mixture water due to chemical analysis in respect of TS 1247 [19].

2.2 Mixture preparation and proportions

In the study, Khorasan mortars were prepared by using mortar mixture due to dry weight ratios. The specimens were produced by replacing 0-10-20-30-40% ratios of BS instead of CT and TP, individually, and 15% lime was added as a binder while mixing. Lime-water ratio was determined as 1:2 respectively and standard molds at the sizes of 4x4x16 cm were used in the mixture production. The proportion of slaked lime was determined due to recent studies to obtain optimum water/mixture ratios owing to various CT and BS contents [1-7]. The water was mixed with three equal periods and quantity for each mixture to ensure homogeneity. Subsequently, mixtures were mixed at a low speed then molded and subjected to vibration for only 1-2 seconds. The specimens were kept 72 hours in molds then demolded and subjected to curing for 7

and 28 days at 20±3 ºC and 50±3% humidity. The curing conditions were same for both ages (7 and 28 days) of specimens. Tests were conducted on specimens after curing for 7 and 28 days individually.

2.3 Test method

The consistency of mortar mixtures was measured by mortar flow table in respect of TS EN 1015-3 [20]. The funnel was filled with mixture to obtain slump flow of each mixture. The flow value was found by measuring the mean diameter of a sample. The mold was placed in the center of the flow table and filled in two layers by ten times tampering. The table was jolted 15 times for 15 second. The diameter of the spread mortar was measured in two directions at right angles to obtain mean diameter.

The unit weights of hardened specimens were measured by sensitive balances; ultrasonic pulse velocities of specimens were calculated by ultrasonic test equipment in respect of ASTM C 597-97 [21]; flexural strengths were calculated by Michaelis cement testing equipment owing to lower strength values and uniaxial compressive strengths of specimens were measured by point load test machine in respect of TS EN 196-1 [22]. Tests were repeated for specimens at the age of 7 and 28 days, individually.

3. RESULTS AND DISCUSSION

3.1. Consistency of fresh mixtures

The flow diameters of mixtures containing BS were lower compared to control specimens. It can be explained by the lower water absorption capacity of CT and TP compared to BS. The flow diameters decreased with increasing replacement ratios of BS as given in Fig.1. The minimum value was approximately 13.5 cm in TPBS40 mixture and nearly 15% decrement was calculated compared to control specimen at the same type.

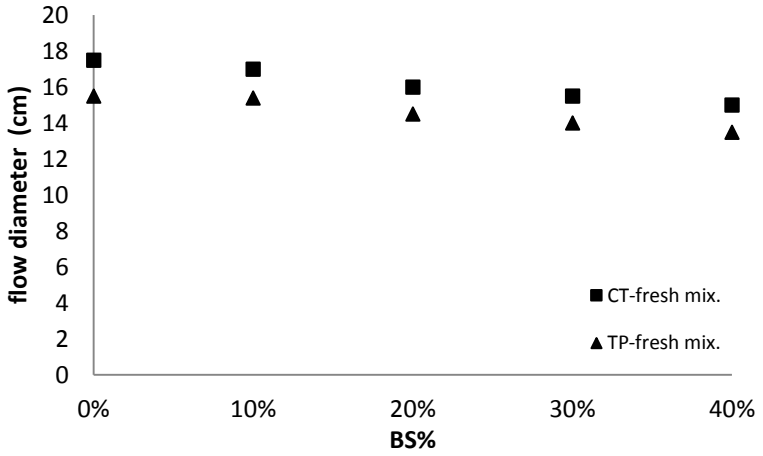


Fig. 1. Flow values of fresh mixtures

3.2. Hardened unit weight

The change of hardened unit weights according to BS ratios was given in Fig.2. In general, all series showed similar behavior, however the hardened unit weights of specimens cured for 7 days were slightly higher than that of 28 days. This is explained by the higher water content of specimens at the early ages. The increments in hardened unit weights can be explained by the higher water absorption capacity of CT and TP compared to BS. In general, the hardened unit weights of CTBS and TPBS specimens were higher than that of control specimens. In general CTBS series had higher hardened unit weights compared to TPBS series. The maximum value was approximately 1.75 g/cm^3 in TPBS40 specimen at the age of 7 days and nearly 20% increment was calculated compared to control specimen at the same type.

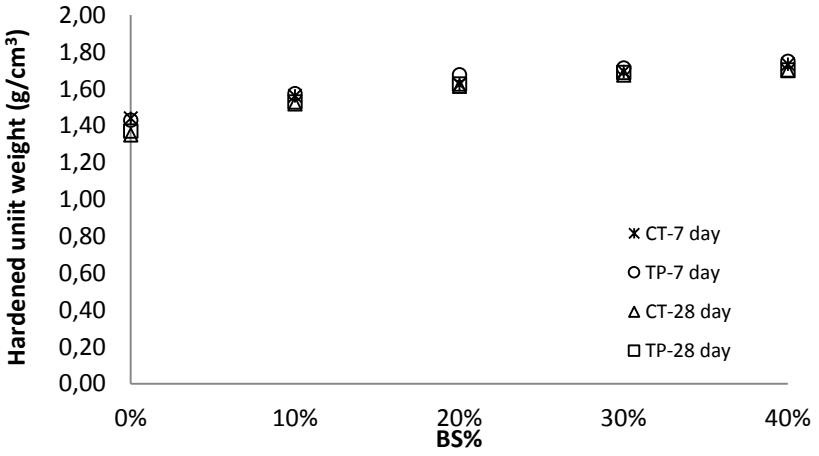


Fig. 2. Hardened unit weight of specimens

3.3. Ultrasonic pulse velocity

The change of ultrasonic pulse velocity according to BS ratios was given in Fig.3. According to Fig.3, the ultrasonic pulse velocity values of all series increased with the increasing replacement ratios of BS. In general, the values were higher in CTBS and TPBS specimens compared to control series. However, the values irregularly increased with increasing replacement ratios of BS. The maximum value was approximately 2.2 km/s in TPBS40 specimen at the age of 7 days and nearly 60% increment was calculated compared to control specimen at the same type.

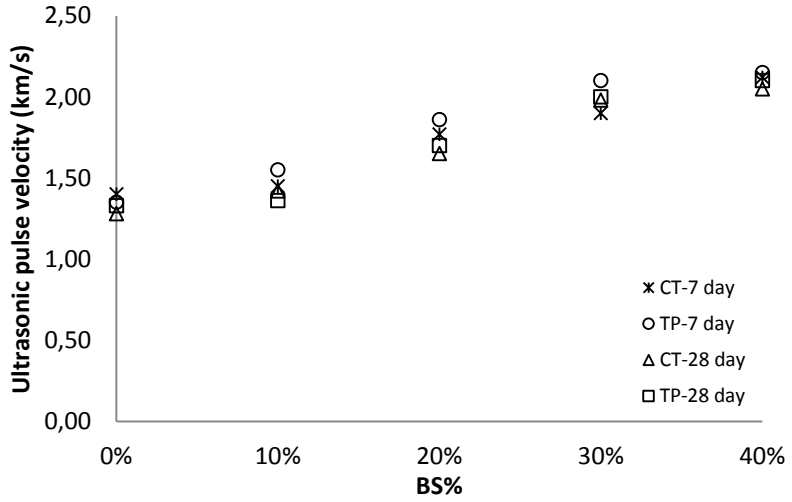


Fig. 3. Ultrosonic pulse velocity of specimens

3.4. Compressive strength

Tests were conducted on specimens after flexural strength tests, thus the half of a specimen was used for testing compressive strengths. Investigating the results, compressive strengths of all specimens improved with increasing replacement ratios of BS as shown in Fig.4. In general, the values of TPBS were higher than the values of CTBS. This can be explained by the lower porous structure of TPBS compared to CTBS. According to Fig.4, the compressive strength values increased irregularly for all series with exceptions. The values were generally higher at the age of 28 days compared to that of 7 days. The maximum value was approximately 9 MPa in TPBS40 specimen at the age of 28 days and nearly 75% increment was calculated compared to control specimen at the same type.

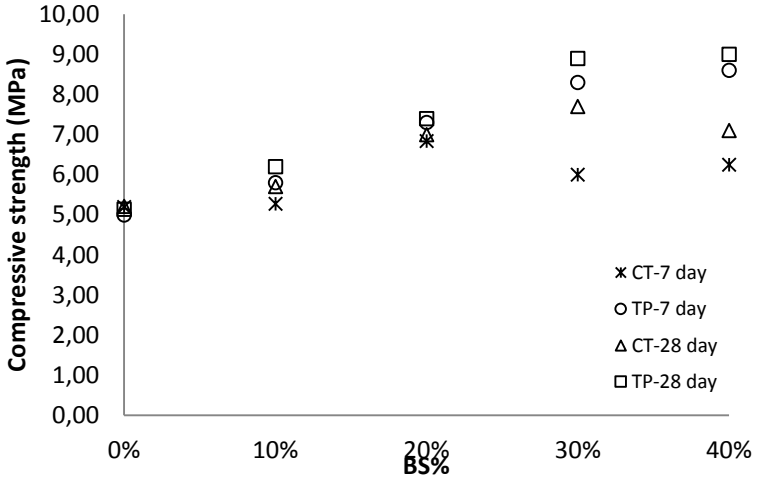


Fig. 4. Compressive strength of specimens

3.5. Flexural strength

According to experimental results, flexural strength values increased irregularly with the increasing replacement ratios of BS as seen in Fig.5. The values of TPBS at the age of 28 days were generally higher compared to CTBS owing to porous structure of CTBS. The values for the specimens at the early ages were certainly lower. The maximum value was approximately 0.5 MPa in TPBS40 specimen at the age of 28 days and nearly 120% increment was calculated compared to control specimen at the same type.



Fig. 5. Flexural strength of specimens

4. CONCLUSION

As a result of the experimental tests, mechanical and physical properties of the Khorasan mortars and freeze and thaw performances within the BS changed in various ways depending on curing periods, replacement ratios of BS and the gradation of crushed tiles. It was concluded that the addition of BS in Khorasan mortars improved the various properties such as compressive strength and binding effect in mortar matrices.

The hardened unit weights of specimens were generally lower compared among cementitious mortars hence lightweight property of the specimens was notable and consistency of fresh mixtures was adequate due to workability based on the test results.

In general, higher compressive and flexural strengths were observed on specimens for TPBS series in comparison of CTBS series. It can be explained by the lower porosity of TP compared to CT. The highest compressive and flexural strengths were obtained from TPBS40 at the age of 28 days. These specimens also had high resistance under freeze and thaw tests compared to other series of specimens. It was concluded that the mechanical properties of Khorasan mortars improved in the length of time with exceptions.

As a recommendation, the crushed tile or brick used in mixture production needs to be well activated. Therefore, low speed and one step mixing recommended in mixing of fresh mixtures. TP gives better results in mechanical strength owing to slightly higher pozzolanic activity and binder effect compared to CT. The optimum water content used in experiments can be determined as 20-50% of binder weight and the climate of construction is important.

REFERENCES

1. Akkurt S, İpekoğlu B, Böke H. The characteristics of brick powder mortars and plasters used in historic buildings. Yapı Dergisi 2004;269:90-95.
2. Arıoglu N, Acun S. A research about a method for restoration of traditional lime mortars and plasters: A staging system approach. Build Environ 2006;41:1223-1230.

3. Böke H, Akkurt S, İpekoğlu B, Uğurlu E. Characteristics of brick used as aggregate in historic brick-lime mortars and plasters. Cement Concrete Res 2006;36:1115-1122.
4. Akman MS, Güner A, Aksoy IH. The history and properties of khorasan mortar and concrete. The 2nd International Congress of Turkish and Islamic Science and Technology 1986;1:101-112.
5. Spence R. Lime and Surkhi manufacture in India. Appropr Technol 1974;1:6-8.
6. Lea FM. Investigations on pozzolanas. Build Res 1940;27:1-63.
7. Miriello D, Bloise A, Crisci GM, Apollaro C, Marca AL. Characterisation of archaeological mortars and plasters from kyme (Turkey). J Archaeol Sci 2011;38:794-804.
8. Güleç A, Tulun T. Physico-chemical and petrographical studies of old mortars and plasters of Anatolia. Cement Concrete Res 1997;27:227-234.
9. Bakolas A, Biscontin G, Moropoulou A, Zendria E. Characterization of structural byzantine mortars by thermogravimetric analysis. Thermochim Acta 1998;321:151-160.
10. Degryse P, Elsen, J, Waelkens M. Study of ancient mortars from Sagalassos (Turkey) in view of their conservation. Cement Concrete Res 2002;32:1457-1463.
11. Moropoulou A, Cakmak AS, Biscontin G, Bakolas A, Zendri E. Advanced Byzantine cement based composites resisting earthquake stresses: the crushed brickylime mortars of Justinian's Hagia Sophia. Constr Build Mater 2002;16:543-552.
12. Böke H, Akkurt S. Ettringite formation in historic bath brick-lime plasters. Cement Concrete Res 2003;33:1457-1464.
13. İpekoğlu B, Böke H, Çizer Ö. Assessment of material use in relation to climate in historical buildings. Build Environ 2007;42:970-978.
14. Böke H, Çizer Ö, İpekoğlu B, Uğurlu E, Şerifaki K, Toprak G. Characteristics of lime produced from limestone containing diatoms. Constr Build Mater 2008;22:866-874.
15. Uğurlu E, Böke H. The use of brick-lime plasters and their relevance to climatic conditions of historic bath buildings. Constr Build Mater 2009;23:2442-2450.

16. Özkaya ÖA, Böke H. Properties of Roman bricks and mortars used in Serapis temple in the city of Pergamon. Mater Charact 2009;60:995-1000.
17. Binici H, Arocena J, Kapur S, Aksogan O, Kaplan H. Investigation of the physico chemical and microscopic properties of Ottoman mortars from Erzurum (Turkey). Constr Build Mater 2010;24:1995-2002.
18. Turkish Standard, TS EN 459-1. Building lime, definitions, specifications and conformity criteria; 2012.
19. Turkish Standard, TS 1247. Mixing, placing and curing of concrete (Normal Weather Conditions); 1984.
20. Turkish Standard, TS EN 1015-3. Methods of test for mortar for masonry-Part 3: Determination of consistency of fresh mortar (by flow table); 2000.
21. American Standards of Testing Materials, ASTM C 597-97. Standard Test Method for Pulse Velocity through Concrete; 1998.
22. Turkish Standard, TS EN 196-1. Methods of testing cement-Part 1: Determination of strength; 2002.