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OBTAINING LIGHTWEIGHT CONCRETE USING COLEMANITE WASTE AND ACIDIC PUMICE

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Abstract: This paper presents some results of ongoing laboratory work to design a lightweight concrete using colemanite waste and pumice. Hisarcik and Espey colemanite wastes, acidic pumice aggregate as well as normal Portland cement were used to produce lightweight concrete with economic and environmental advantages. Two different groups and twenty different prescriptions were tried to produce lightweight concrete. The effect of colemanite waste on workability and strength of lightweight concrete were analysed by fresh and hardened concrete tests. The properties of materials examined include slump, air content, density and uniaxial compressive strength of the mortar. The results obtained were compared with control concrete properties and Turkish standard values. The examined tests results showed that lightweight concrete can be produced by the use of acidic pumice aggregate and colemanite waste. Furthermore, the colemanite waste can be used as cement additives and can reduce the cost and environmental pollution with using natural stone aggregate.

Keywords: *lightweight concrete, colemanite waste, acidic pumice, density, uniaxial compressive strength*

Introduction

In recent years boron waste materials have been used in a number of construction materials as a partial cement replacement and as an aggregate in concrete. The presence of boron oxide (B_2O_3) in colemanite ore waste has remarkable effects on the mechanical properties of cement (Kula et al., 2001) and the increased replacement of colemanite waste with Portland cement results in higher setting time and specific surface (Olgun et al., 2007). Waste containing boron improves concrete properties, lowers the costs of cement production, and is ecologically beneficial. Furthermore, as colemanite waste and pumice have low density, they can be used to reduce dead load to minimise earthquake risk. For these reasons, colemanite waste and pumice materials can be used to produce lightweight concrete.

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Turkey has 851 teragrams (Tg) of boron reserves which comprise 73% of the total world reserves. The most important boron ores in Turkey are tincal, colemanite and ulexite. These minerals contain different amounts of B_2O_3. The average boron ore production of Turkey is about 1.3 Tg per year (Tbar, 2008; Tspo, 1996; Figen et al., 2010; Bocukoglu et al., 2002).

Turkey's boron operations are under the control of Eti Holding A.S, formerly Etibank, through its subsidiary Eti Boron Inc. Boron production is managed by five operations, four of which are integrated mine and plant facilities and one is a plant facility. The Eti Holding Emet Boron Plant has been operational since 1958 in Emet county, Kutahya. In the facilities, open pit mines of Hisarcık and Espey colemanite produce 28-30% B_2O_3 and boric acid (H_3BO_3) grade to a total of 1 Tg/year (Tbar, 2008). Annually, 0.08 Tg of clay and colemanite waste (CW), known as Hisarcik colemanite waste (HCW) and Espey colemanite waste (ECW) are produced in the concentrated colemanite and boric acid units during production. These wastes are stored in tailing dams. Colemanite wastes of the Hisarcik and Espey areas containing about 8-28% B_2O_3 are discharged to the plant area. As the wastes contain boron oxide in quite high concentrations, this represents an environmental pollution problem as well as an economic loss (Kavas, 2006; Ozdemir and Ozturk, 2003).

Pumice is a natural rock of volcanic origin produced by the release of gases during the solidification of lava. Acidic pumice aggregate (APA) obtained from the Nevsehir area and has been used as aggregate with colemanite waste in the production of lightweight colemanite waste. Satisfactory concrete which has approximately three times lighter than normal concrete and good insulating characteristics with high absorption and shrinkage can be manufactured using acidic pumice (Nevile, 1995; Hossain, 2004).

The use of lightweight aggregate (LWA) in concrete has a number of advantages (Mays and Barnes, 1991; Fragoulis et al., 2004; Yasar et al., 2003; Erdogan, 2007). These advantages include the reduction of dead load that may result in reduced footing sizes and lighter and smaller upper structures, reductions in the sizes of columns and slab and beam dimensions that result in larger space availability, lighter and smaller pre-cast elements needing smaller and less expensive handling and transportation equipment, high insulation rating and enhanced fire resistance (Kayali, 2008).

The aim of this study is to investigate the use of colemanite waste containing boron and pumice for the production of lightweight concrete, to find the best combination of these mixtures and evaluate acidic pumice aggregate, colemanite waste and Portland cement. Therefore, various combinations of concrete containing acidic pumice aggregate, Hisarcik colemanite waste, Espey colemanite waste and Portland cement were prepared. The properties of the prepared concrete and materials examined include slump, air content, density and uniaxial compressive strength (UCS) of the mortar.

Materials and methods

Cement

The cement used was ASTM Type I normal Portland cement (NPC) with a 28-day compressive strength of 42.5 N/mm^2. The specific gravity of the cement was 3.15 g/cm^3, and the initial and final setting times of the cement were 4 and 5 h, respectively. Its Blaine specific surface area was 3140 cm^2/g and its chemical and physical compositions are given in Table 1.

Table 1. Chemical and physical characteristics of used materials

Component	Clinker	HCW	ECW	APA
Boron oxide (B_2O_3)	-	27.20	25.77	-
Calcium oxide (CaO)	61.87	17.42	15.90	0.75
Silica (SiO_2)	20.65	20.59	22.46	71.10
Iron oxide (Fe_2O_3)	4.13	0.95	1.51	1.74
Alumina (Al_2O_3)	5.60	2.40	5.83	16.3
Magnesia (MgO)	2.60	5.76	5.02	0.14
Sodium oxide (Na_2O)	0.14	-	-	0.52
Potassium oxide (K_2O)	0.83	-	-	0.60
Titanium oxide (TiO_2)	-	5.25	4.84	-
Loss on ignition	1.39			
Physical Properties				
Fineness, (wt.%)				
+32 µm sieve	26.4	26.9	26.7	-
+90 µm sieve	3.05	10.6	10.4	-
+200 µm sieve	0.3	0.2	0.2	-
Specific surface (cm^2/g)	2390	3594	3542	
Specific gravity (g/cm^3)	3.21	2.42	2.48	0.85

Aggregate and its grading

The chemical and physical compositions of the colemanite waste and pumice which were used as an aggregate in the production of the LWC were determined. Acidic pumice aggregates were obtained from Nevsehir and the ARBIMS Brick Factory in Osmaniye, Turkey. Colemanite waste was provided from Eti Holding, Emet Boron in Kutahya, Turkey. The chemical and physical properties of the Portland cement, the Hisarcık colemanite waste, the Espey colemanite waste and the acidic pumice aggregate are given in Table 1.

The dry density and compressive strength of pumice were 850 kg/m^3, and 8.7 MPa, respectively. Colemanite waste and pumice were separated according to their size. They were sieved using standard sieves and separated into seven groups (0/0.15, 0.15/0.3, 0.3/0.6, 0.6/1.18, 1.18/2.36, 2.36/4.75, 4.75/9.5) as shown in Table 2. A combination of separated aggregates was obtained with a grading that complied with the requirements of ASTM C136-01.

Table 2. Grain size distribution of aggregates

Sieve size, mm	% Passing		
	APA	HCW	ECW
9.5	100.0	100.0	100.0
4.75	87.5	100.0	100.0
2.36	69.0	90.5	91.0
1.18	54.0	68.0	69.5
0.6	37.5	43.0	44.0
0.3	21.5	24.0	24.5
0.15	9.0	10.5	11.0

Concrete mixture composition and sample preparation for tests

Three series of mixtures noted as Hisarcik (H: APA + PC + HCW), Espey (E: APA + PC + ECW) and the reference mix (R), were prepared according to ASTM C330-00 and TS 699. The grading of Acidic Pumice Aggregate (APA) met the requirement of lightweight aggregate for concrete as per ASTM C330-00. A laboratory ball-mill was used for the grading process, and particle size analysis was carried out according to ASTMC136-01. Specimen preparation for the tests was performed at room temperature. The mix proportion of the reference mix specimens corresponded to 400 g of cement content, 1600 g of APA and 0.55 water-to-binder (W/B) ratio. LWC mixtures were made using 2, 4, 6, 8, 10 % CW as NPC replacement. The W/B ratio of the LWC was kept constant at 0.55.

The slump values of fresh LWC were determined as per ASTM C143-00 while the air contents were determined by pressure meter as per ASTM C231-97. Super-plasticizer (SP) content was adjusted in order to achieve a slump ranging between 65 and 80 mm SP content (based on solid mass) in percentage by weight of binder. No air entraining admixtures were used. The details of the mixtures are given Table 3.

The cement-water mixture were stirred at low speed for 30 s, and following the addition of CW and APA, the mixtures were stirred for 5 min. Twenty-one batches were prepared and cast into 100 x 100 x 200 mm moulds for density and compressive strength tests. After 24 h of curing at 20^0C with 95 % humidity, the samples were demolded and immersed in tap water and cured for up to 7, 14, 28 and 90 days. All the specimens were compacted by external vibration using a table vibrator.

The density and strength values were the average of six specimens. Some of the prismatic specimens were not perfectly regular due to difficulties encountered in demolding (H10, E10), hence the compressive strength values of these samples were tested on two or three samples.

After the density and compressive strength tests, the results for the LWC were tabulated and are given in Figs. 1-4.

Table 3. Admixture ratios in LWC mixture (%)

Symbol	PC	AP	HCW	ECW	Slump (mm)	Air Content (%)	SP (%)
R_H	20	80	-	-	68	2.3	1.6
H1	10	80	10	-	70	2.6	1.6
H2	10	82	8	-	68	2.8	1.6
H3	10	84	6	-	70	2.8	1.6
H4	10	86	4	-	72	2.9	1.6
H5	10	88	2	-	76	3.0	1.6
H6	5	85	10	-	72	3.1	1.6
H7	5	87	8	-	76	3.1	1.6
H8	5	89	6	-	76	3.3	1.6
H9	5	91	4	-	80	3.4	1.6
H10	5	93	2	-	76	3.4	1.6
E1	10	80	-	10	72	2.7	1.6
E2	10	82	-	8	70	2.8	1.6
E3	10	84	-	6	70	2.9	1.6
E4	10	86	-	4	74	2.9	1.6
E5	0	88	-	2	74	3.1	1.6
E6	5	85	-	10	70	3.1	1.6
E7	5	87	-	8	78	3.2	1.6
E8	5	89	-	6	76	3.2	1.6
E9	5	91	-	4	78	3.3	1.6
E10	5	93	-	2	80	3.3	1.6

Results and Discussion

The air content and slump values of non-air entrained LWCs are presented in Table 3. The air content ranges between 2.3% and 3.4% and generally increases with increased APA content. All the mixtures produced a slump ranging between 65 and 80 mm.

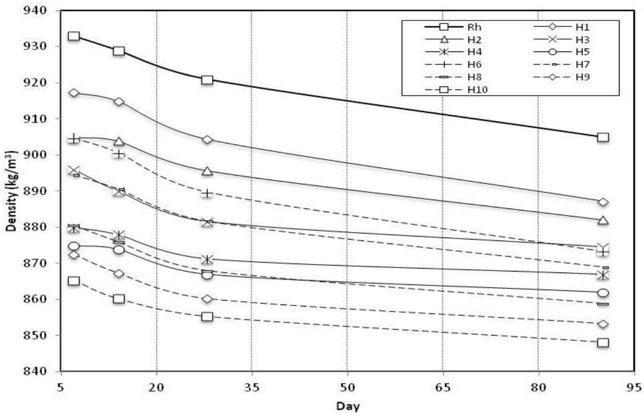

Fig. 1. Changing with time density of LWC containing HCW

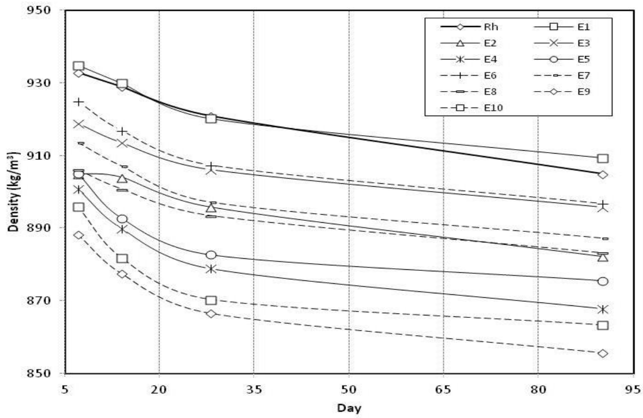

Fig. 2. Changing with time density of LWC containing ECW

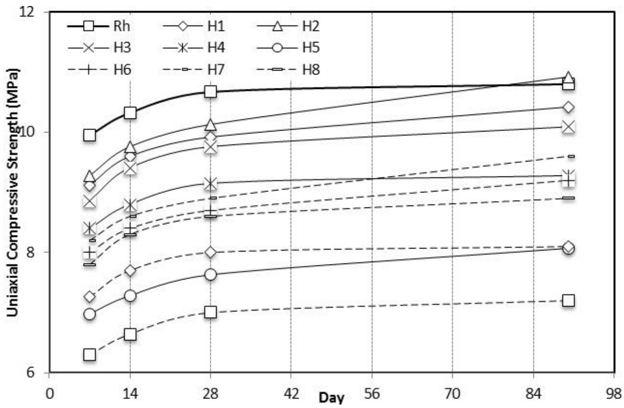

Fig. 3. Changing with time UCS of LWC containing HCW

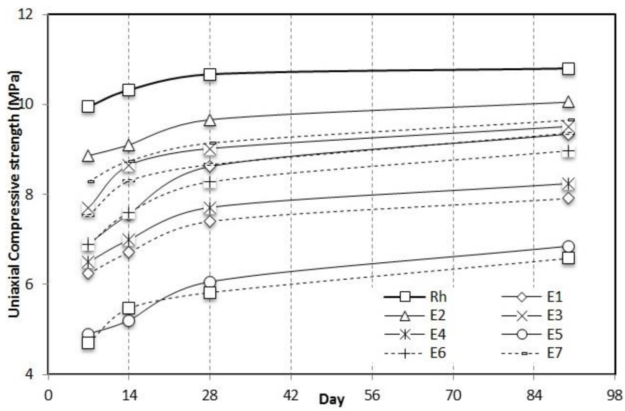

Fig. 4. Changing with time UCS of LWC containing ECW

The chemical and mineralogical composition of HCW were examined. HCW was added in different proportions as cement additive in concrete. The effect of CW on workability and strength of concrete were analysed by fresh and hardened concrete tests. The results obtained were compared with control concrete properties and Turkish standard values. The results showed that the addition of CW had a small effect upon the workability of the concrete but an important effect on the reduction of its strength. As a result of the studies, the ideal lightweight concrete mixture was found to be better by the use of Hisarcik colemanite ores and wastes and also the test results of Espey waste is lower than those of Hisarcik. The good results were found due to both the high percentage of boron and less percentage of the secondary minerals (especially such as Fe_2O_3 and Al_2O_3) in Hisarcik colemanite ores and wastes.

As Figs 1 and 2 show, the density of LWC samples ranged from 850 to 935 kg/m^3. Low density materials are preferred in lightweight construction sector and the earthquake countries. In addition, the density results of concrete with prepared HCW are lower than those for the Espey colemanite concrete.

The mixture of H10 (5 % PC + 93% AP + 2 HCW) has the lowest density value. After 7, 14, 28 and 90 days, the density of the H10 mixture, 865.4, 860.3, 855.4 and 848.3 kg/m^3 were found respectively (Fig. 1).

As seen in Figs 3 and 4, the UCS of LWC samples range from 4.5 to 5.5 MPa. The UCS values of the concrete made with HCW mixtures gave better results than those made with ECW mixtures. As the HCW mixture has been shown to increase the strength, the chemical analysis of HCW in Table 1 was examined due to the high amount of B_2O_3 in the HCW mixture.

The H2 mixture (10 % PC + 82% AP + 8 HCW) has the highest UCS value. After 7, 14, 28 and 90 days, H2 mixture densities of 9.28, 9.76, 10.13 and 10.92 MPa were found, respectively (Fig. 3).

Another purpose of this study was to use colemanite waste instead of cement in concrete. For this purpose, in the mixture with H6, H7, H8, H9, H10 between E6, E7, E8, E9, E10 codes, the amount of cement was reduced by 5%, and the amount of the APA was increased. The results of the CW concrete samples were examined and the test values were not found much difference from the normal concrete samples.

The H7 mixture (5% PC + 87% AP + 8 HCW) is shown to have a much higher strength than the H5 mixture (10% PC + 88% AP + 2 HCW) in Fig. 3.

The E7 mixture (5% PC + 87% AP + 8 ECW) is shown to have a much higher strength than mixture E5 (10% PC + 88% AP + 2 ECW) in Fig. 4.

Although there is a high amount of cement in mixtures H5 and E5, the mixtures H7 and E7 have higher strength. The amounts of CW in mixtures H7 and E7 are shown to increase the UCS.

Conclusions

In this study, the usability of Hisarcik and Espey colemanite wastes as aggregate and a replacement for Portland cement has been determined. Due to their low density and high strength, the Hisarcik and Espey colemanite wastes and acidic pumice are suitable for the production of lightweight concrete and enable the reduction of dead load to lessen earthquake risk. The colemanite waste improves concrete properties, reduces the cost of concrete production and is ecologically beneficial. The density and UCS test results of concrete made with Espey colemanite and pumice aggregate were found to be between 850 and 935 g/cm^3, and 4.5 and 5.5 MPa, respectively. The density test results of concrete made with Hisarcik colemanite and pumice aggregate were found to be between 848.3 and 917.4 g/cm^3, and 6.3 and 10.92 MPa, respectively. According to the test results, the density and UCS of concrete with prepared HCW are preferable to those of Espey colemanite concrete. The difference in the test results depends upon the amount of B_2O_3 in the waste mixture. The examined tests results showed that lightweight concrete can be produced by the use of acidic pumice aggregate and colemanite waste. Furthermore, colemanite waste can be used as cement additives and can reduce the cost and environmental pollution with using natural stone aggregate.

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