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Utilization of Colemanite waste in Concrete Design

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Abstract*— *Waste material is formed in enormous quantities during the beneficiation of raw ore. These wastes can cause both economic loss and environmental pollution. Thus, in this study, the effect of CW obtained from Eti Mine Establishments Kütahya-Emet Boron Plants on the compressive strength and cylinder splitting tensile strength of concrete and its usability as a concrete admixture is investigated. The results found show that utilization of Colemanite Waste is possible when it is used as additive in concrete.

Keywords*—Boron, Colemanite, Concrete, Utilization, *Waste.

I. INTRODUCTION

Turkey has 72% of the world's total boron reserves and produces 1.72 million tons per annum [1]. There are three important boron mineral in Turkey which are ulexite, tinkle and colemanite. Waste material is formed in enormous quantities during the beneficiation of raw ore. These wastes can cause both economic loss and environmental pollution. The use of these wastes as additives in the production of concrete will contribute to both economic and environmental protection.

Some waste materials, which are very similar to Portland cement and have pozzolanic properties in terms of their basic composition, can be used as building materials. Although the mineral additives used in concrete have similar physical properties and mineralogical and chemical compositions to Portland cement. Due to pozzolanic activity of these substances they have a role in formation of hydration products due to pozzolanic activities. Thus, while the various properties of the concrete are improved, mineral additives with high pozzolanic activity can improve the void structure, resulting in a denser structure, increasing the adherence between the aggregate and matrix interface, and achieve high strengths [2].

Colemanite and Tinkal Concentrator consist of eight oxides (Al_2O_3, SiO_2, MgO, Fe_2O_3, CaO, SO_3, Na_2O, K_2O) forms cement's chemical composition of the wastes and other additives used in cement production [3].These materials has been the subject of many researchers to develop new materials[4-9]. In another study, mechanical properties of colemanite-added concretes were investigated. Colemanite was added at different ratios as cement admixture and it has been reported that the colemanite admixture has no significant effect on workability and the strength values do not show any significant change compared to the control concrete when the amount of added colemanite does not exceed 10% by weight [10]. CW is used as an aggregate, the physical and mechanical properties of the concrete produced were investigated. Properties such as air content, compressive and tensile strength, Schmidt test, modulus of elasticity, freeze-thaw resistance, unit weight were investigated. As the colemanite ratio increases, the engineering properties of concrete are improved [11]. To determine the effect of Kütahya-Emet colemanite on the splitting tensile strength and shrinkage properties of mortar, samples were tested at 7, 28, 56 and 90 days. It has been stated that concrete mixtures containing 3% and 5% CW have higher strength compared to the control concrete and that the shrinkage of the mortar compared to the control sample is reduced by 37%. Based on these results, it was CW could be used as an effective anti-shrink agent in terms of cost [12]. Studies on the use of colemanite waste (CW) as a mineral additive in concrete and mortars instead of a part of cement are limited in the literature.

In this study, the effect of CW obtained from Eti Mine Establishments Kütahya-Emet Boron Plants on the compressive strength and cylinder splitting tensile strength of concrete and its usability as a concrete admixture is investigated.

II. MATERIAL AND METHOD

2.1. Materials

The cement used in this study is normal (CEM I 42.5 R) Portland cement in accordance with TS EN 197-1: 2002, manufactured by Adana Cement Industry. The cement has a specific gravity 3.15 g/cm^3 and 3230 cm^2/g Blaine fineness. Chemical properties of cement (CEM I 42,5 R) Table 1. CW was taken from Kütahya-Emet Eti Boron Plants dried and milled. The grinding process was carried out at Adana Cement Nardüzü Ready-Mixed Concrete Plants. Blaine fineness value is 4140 cm^2/gr and specific gravity is 2.43 gr / cm^3. Natural sand as fine aggregate, crushed stone having maximum aggregate diameter of 22 mm as coarse aggregate was used. The dry surface

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saturated specific gravity of the fine and coarse aggregate were 2.60 and 2.75 gr / cm^3, respectively. Iskenderun city water was used as a mixture water.

2.2. Experimental Method

In this research, two sets of experiments with two different water-binding ratios (0.50 and 0.60) and a 350 kg/m^3 binder were designed. Totally 10 different concrete mix design were studied with CW replacement with CEM I 42.5 R by weight of 0%, 3%, 5%, 10% and 15%. The properties of the mixtures are given in Table 2.

Table.1: Chemical compositon of cement and colemanite waste

Chemical Compound	CEM I 42.5R Content (%)	CW Content (%)
SiO_2	19.55	18.25
Al_2O_3	5.31	5.10
Fe_2O_3	4.15	2.70
Mn_2O_3	0.06	0.06
CaO	62.30	21.60
MgO	3.14	3.10
SO_3	2.55	0.0
Na_2O	0.36	0.02
K_2O	0.88	1.85
Insoluble Residue	0.42	-
Free CaO	0.31	-
Loss of ignition	1.73	22.76

Table.2: Mix design of concrete

Mix No	CW (%)	Cement (kg)	CW (kg)	Water (kg)	Aggregate (kg)	w/b
B1	0	350	0	210	1800	0.60
B2	3	388	12	200	1800	0.60
B3	5	380	20	200	1800	0.60
B4	10	360	40	200	1800	0.60
B5	15	340	60	200	1800	0.60
D1	0	400	0	200	1890	0.50
D2	3	388	12	200	1890	0.50
D3	5	380	20	200	1890	0.50
D4	10	360	40	200	1890	0.50
D5	15	340	60	200	1890	0.50

2.2.1. Slump Test

The slump test was carried out to determine the collapse class from the fresh concrete properties. The bottom diameter of cone is 200 mm in diameter and 100 mm in the upper diameter and 300 mm in height. The concrete mixture prepared in accordance with the principles stated in the design was filled in three stages on a flat ground. The slump is raised slowly upwards and fresh concrete will weigh with its own weight. The distance from the top of the concrete to the bottom of the bar is measured and this length is called slump value of fresh concrete.

2.2.2. Compressive Strength

Maximum stress in the concrete under impact of axial pressure loading in this study were determined according to ASTM C 39 [13] standard. In the experimental design, the compressive strengths of concrete specimens were determined with cube samples of dimensions 150x150x150 mm at the ages of 7, 28, 90 and 180 days.

2.2.3. Splitting Tensile Strength

The splitting tensile strength test was executed accordance with the principles specified in the ASTM C 496 [14] standard on 28 and 180 days with 150 x 150 x 150 mm cube samples. The partition jointa are placed on the bottom and top surfaces of the cube samples and the axial load applied by pressing is transformed into linear. Tensile stresses resulting from tensile forces in the perpendicular direction to the loading direction cause fracture of the specimen. The splitting tensile strength of the sample was calculated with the equation (1).

$$\sigma_e = \frac{2P}{\Pi a^2} \qquad (1)$$

"σ_e" , "P" and "a" refer splitting tensile strength, failure load and length of cube specimen, respectively.

2.2.4. Ultrasonic Pulse Velocity Test (UPV)

Ultrasonic pulse velocity test was carried out according to ASTM C 597-02 [15] for 28 and 180 days of concrete samples. The passing time of the ultrasonic pulse from one surface to other of concrete sample was measured.

2.2.5. Schmidt Test

Mix No	7 Day (kgf/cm^2)	28 Day (kgf/cm^2)	90 Day (kgf/cm^2)	180 Day (kgf/cm^2)
B1	285.70	354.53	407.18	441.21
B2	267.33	366.63	421.07	456.80
B3	206.17	306.20	341.50	422.24
B4	223.67	325.60	427.69	430.37
B5	187.87	266.30	308.41	312.17
D1	462.33	548.49	572.20	584.68
D2	468.67	537.53	562.43	588.48
D3	413.80	490.13	518.07	547.60
D4	449.67	531.17	587.82	624.36
D5	421.03	496.40	508.26	528.32

The test specimens were tested on the concrete samples at 7, 28, 90 and 180 days. The restitution coefficient of Schmidt test hammer was recorded.

III. RESULTS AND DISCUSSION

3.1. Fresh Concrete Properties

3.1.1. Slump Test

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Slump test is the most common form of experimentation used to determine workability. Literature on this experiment is presented in previous sections. The slump test results are shown in Table 3. When the results of the test are examined, it is seen that in all the mixture groups, KW generally decreases the workability. The reason for this is thought to be the high ignition loss (22.76) that KW has.

Table.3: Slump test results

Mix Number	Slump (cm)
B1	22.00
B2	18.50
B3	20.00
B4	15.50
B5	20.00
D1	4.00
D2	3.00
D3	4.50
D4	2.00
D5	0.80

3.2. Hardened Concrete Properties

3.2.1. Compressive Strength Test

The compressive strengths obtained from concrete samples containing colemanite are presented in Table 4. The tests were formed by compressing concrete having 15x15x15 cm^3 dimensions. Figures 1 and 2 show the compressive strength results of each mixture graphically.

Table.4: Compressive strength test results

Mix No	28 Day (kgf/cm^2)	180Day(kgf/cm^2)
B1	36.25	42.63
B2	38.57	43.26
B3	36.41	44.58
B4	30.37	40.29
B5	30.37	34.03
D1	49.76	52.34
D2	50.04	52.51
D3	49.79	54.22
D4	44.80	51.66

When the compressive strength results of samples with 350 doses and 0.60 W/B ratios were examined, the samples (B2) with 3% CW improved compressive strength which is nearly the same with control sample (B1) on the 7th day and reached higher compressive strengths than the control sample on 28, 90 and 180 days. The samples (B3) containing 5% CW additive has a strength resistance value very close to the control sample at 180 days, showing lower compressive strengths than the control sample at all ages. Samples containing 10% CW additive (B4) developed lower compressive strength than the control sample on days 7 and 28. However, the samples of the same confluence reached the value of the strength resistance quite close to the control sample at 180 days higher than the control sample at 90 days. Samples with 15% CW (B5) developed lower compressive strengths than control samples at all ages.

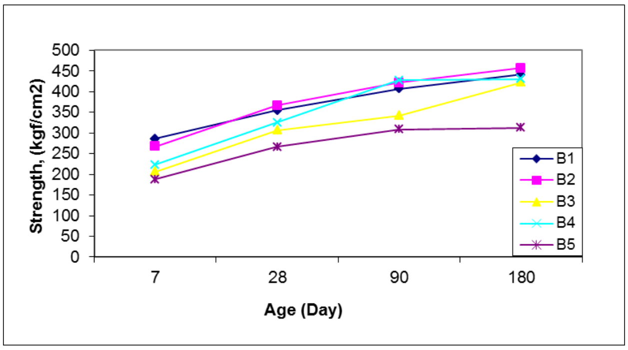

Fig.1: Compressive Strength test results (W/B=0,60 and 350 dose)

When the compressive strength results of samples with 350 doses and 0.50 W/B ratios were examined, samples with 3% CW (D2) improved compressive strength comparable to high values from control samples of all ages. The compressive strength values of the samples containing 5% CW (D3) are less than the control sample of each age. On the other hand, samples with 10% CW were very close to the control sample on days 7 and 28, and developed higher compressive strengths from the control sample on days 90 and 180. The compressive strength values of samples containing 15% CW (D5) were less than the control samples of each age.

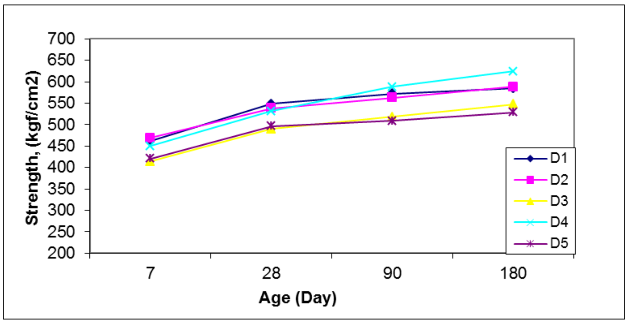

Fig.2: Compressive Strength test results (W/B=0,50 and 350 dose)

3.2.2. Splitting Tensile Strength Test

Splitting tensile strength resistance is determined by cylinder splitting test. Tests were carried out on the specimens kept in the curing pool for 28 and 180 days. Table 5 presents the results of cylinder splitting tensile strength resistance of the test samples. Figures 3 and 4 show graphical representation of the strength results for each mixture.

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Table.5: Splitting tensile strength results

Mix No	7Day (kgf/cm²)	28Day (kgf/cm²)	90 Day (kgf/cm²)	180 Day (kgf/cm²)
B1	119.80	142.00	193.50	212.00
B2	115.90	144.00	189.00	210.00
B3	106.80	132.50	140.00	198.00
B4	104.70	140.00	194.40	211.00
B5	113.80	133.00	145.00	190.80
D1	189.00	223.60	271.80	304.00
D2	201.00	204.00	285.00	318.70
D3	172.00	255.00	300.00	335.50
D4	170.00	295.00	310.00	347.20
D5	135.00	250.00	275.00	313.00

When the results of the splitting tensile strength are examined, it is seen that the samples containing 3% and 5% CW in all mixture groups (B and D) have higher strength than the control sample at both ages. It is seen that these results are compatible with the results of 28 days of tensile strength determined by [16]. The samples with 10% CW reached almost the same splitting tensile strength with the control sample at the end of 180 days in all groups. On the other hand, the samples with 15% CW also give a value of splitting tensile strength slightly lower than the control sample at all ages in all mixture groups.

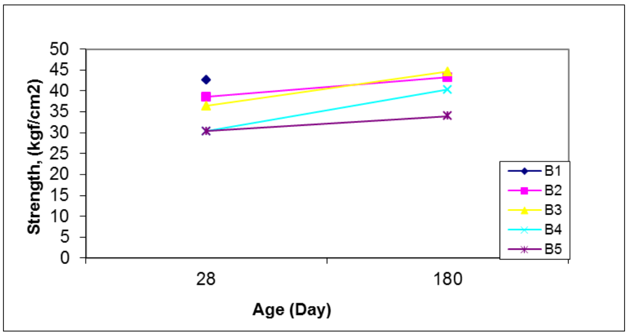

Fig.3: Splitting tensile strength test results (S/B=0,60 and 350 dose)

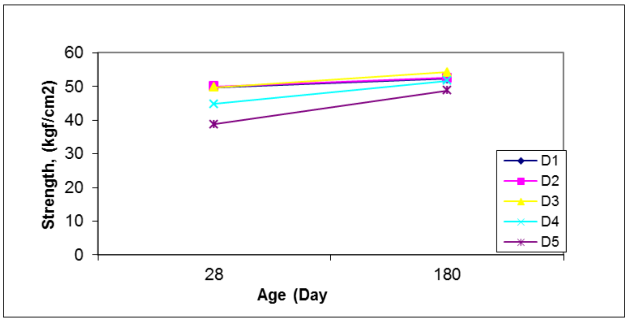

Fig.4: Splitting tensile strength test results (S/B=0,50 and 350 dose)

3.2.3. Approximate Compressive Strength with Concrete Surface Hardness (Non- Destructive Test with Schmidt Hammer)

Schmidt hammer tests were carried out on cube specimens of 15X15X15 cm in size to determine the compressive strength in the test press. The Schmidt hammer test results are given in table 6.

When Schmidt hamer test results of mixtures (group B) are examined, it is seen that all CW -added mixtures have developed compressive strengths close to the control sample at almost all ages.

When Schmidt hamer test results of mixtures (group D) are examined, all of the KW-added mixtures which developed higher compressive strength close to the witness sample on the 7th and 28th days showed a behavior exceeding the control sample compressive strength on days 90 and 180.

Table.6: The Schmidt hammer test results

3.2.4. Ultrasonic Pulse Velocity Test

Ultrasonic pulse velocity tests were carried out on cube specimens of 15X15X15 cm in size.

Table 7. Ultrasonic pulse velocity tests results

Mix No	7 Day, (km/s)	28 Day, (km/s)	90 Day, (km/s)	180Day, (km/s)
B1	4.25	4.61	4.66	4.70
B2	4.03	4.59	4.61	4.84
B3	4.21	4.35	4.66	4.73
B4	4.18	4.39	4.60	4.66
B5	4.01	4.18	4.27	4.65
D1	4.26	4.75	4.75	4.87
D2	4.65	4.75	4.79	4.98
D3	4.55	4.76	4.77	4.92
D4	4.36	4.76	4.92	5.01
D5	4.38	4.76	4.81	4.95

Table.8: Ultrasonic Pulse Velocity avaluation Table [17]

Pulse Velocity (V) km Is	Quality of Concrete
>4.5	Very Good
3.5-4.5	Good
3.0-3.5	Avarage
2.0-3.0	Poor
< 2.0	Very Poor

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Table.9: Ultrasonic Pulse Velocity evaluation results

Mix No	7 Day, (km/s)	28 Day, (km/s)	90 Day, (km/s)	180 Day, (km/s)
B1	Good	Very Good	Very Good	Very Good
B2	Good	Very Good	Very Good	Very Good
B3	Good	Good	Very Good	Very Good
B4	Good	Good	Very Good	Very Good
B5	Good	Good	Good	Very Good
D1	Good	Very Good	Very Good	Very Good
D2	Very Good	Very Good	Very Good	Very Good
D3	Very Good	Very Good	Very Good	Very Good
D4	Good	Very Good	Very Good	Very Good
D5	Good	Very Good	Very Good	Very Good

Ultrasonic pulse velocity measurements on concretes are given in table 7. In Table 9, these results are evaluated accord6 given by Whitehurst, 1951. When Table 7 is examined, it can be seen that mixture D can be evaluated very well, except some samples in the 7th day. It can be seen that mixture B can only be evaluated very well on day 180.

When the ultrasonic pulse velocity results of group B mixtures are examined, it is seen that mixtures B2, B3 and B4 with 3%, 5% and 10% CW contribution reach higher pulse velocity close to the control sample at all ages. On the other hand, B5 mixtures with 15% CW contribution reached a value of ultrasonic pulse velocity very close to the control sample in 180 days while giving a lower pulse velocity value than the control sample on days 7,28 and 90.

When the the ultrasonic pulse velocity results of group D mixtures are examined, it is seen that all mixtures containing CW have higher pulse velocity than the control sample at all ages.

IV. CONCLUSION

In the light of the test results the following implications can be concluded;

Slump test results show that the CW contribution reduces the workability of fresh concrete.

The results of compressive strength of specimens with 350 doses and 0.60 W/B ratios show that 3% CW doped samples developed higher compressive strengths close to the control sample at every age. The specimens containing 5% CW reached a compressive strength value very close to the control sample on the 180th day. On the other hand, samples with a 10% CW contribution gave higher compressive strength values comparable to the control samples on days 90 and 180.

When the compressive strength results of samples with 350 doses and 0.50 W/B ratios are examined, the samples containing 3% CW additive show comparable compressive strength with control samples of all ages.

When the results of the cylinder splitting tensile strength are examined, it is seen that the samples containing 3% and 5% CW in all mixture groups improved the cylinder splitting tensile strength higher than the control sample at both ages. The samples with 10% CW reached almost the same cylinder splitting strength with the control sample at the end of 180 days in all groups.

When examining the test results of mixtures with 350 Dose 0.6 W/B ratios, it is seen that all CW -added mixtures have developed compressive strengths close to the control sample at almost all ages.

The ultrasonic pulse velocity results of group B mixtures (350 doses, 0.6 W/B ratio) show that mixtures with 3%, 5% and 10% CW contribution reach higher pulse transmission rates which are close to the control sample at all ages. On the other hand, mixtures with a contribution of 15% CW were found to have a velocity transit speed very close to the control sample on the 180th day.

When the ultrasonic pulse velocity results of the D group mixtures (350 doses, 0.5 W/B ratio) are examined, it appears that all mixtures containing CW have higher pulse transmission rates than the control sample at all ages.

It has been found that there is a strong relationship between the compressive strengths of the test hammer and the concrete test press.

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