Mechanical Behavior of White Concrete

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Abstract – **In this study, possibility of the use of WPC 42.5 containing pyrophyllite in the production of white concrete was investigated. Normal and light-weight concrete samples were produced with WPC. In normal-weight concrete mixture, WPC and white aggregate were used. In light-weight concrete mixtures, WPC, FA, SF and SP were used. Setting time and soundness of cement paste specimens and compressive strength of light and normal weight white concrete specimens were determined. According to the test results, normal weight white concrete can be used in the construction of frames and light-weight white concrete can be used in the production of concrete/reinforce concrete panels.**

Keywords – **White Cement, Pumice, Fly Ash, Silica Fume, White Concrete, Compressive Strength.**

1. Introduction

White Portland cement (WPC) has similar bonding characteristics as gray Portland cement. WPC has also higher performance due to use of high quality materials and control process in its production [1]. In Turkey, WPC is generally used in the production of non-structural members, which are built for decorative and aesthetical purposes. 202.589 tons of WPC were used in domestic and 739.072 tons of WPC were exported in 2011 [2]. White concrete produced with WPC has higher compressive strength and reaches its ultimate compressive strength faster than normal gray Portland cement. The compressive strength of the low dosage white concrete increased when maximum aggregate size was increased. However, the compressive strength of high dosage white concrete was not affected when maximum aggregate size was increased. This occurs due to fact that in low dosage concrete, the compressive strength of the concrete mainly depends on the strength of the aggregates but in high dosage concrete, the compressive strength of the concrete mainly depends on the strength of cement paste. Moreover, in low dosage concrete, when the maximum aggregate size was reduced, cement paste does not cover the all surfaces of the aggregates and consequently strength of matrix reduced. Production of white concrete with a compressive strength between 25 and 50 MPa is possible by using white cement [3]. It was also found out in a study that white concrete had higher compressive strength than normal gray concrete [4, 5].

Moreover, general view of the cities would be better if the buildings were built with the white concrete without plaster. Also, barriers made with the white concrete would be much safer due to better reflection of the light by the white color [6, 7]. It was also found out that the strength and density of the lightweight concrete is suitable to be used in the production of the light building members when lightweight concrete is produced with volcanic pumice [8]. In this study, the compressive strength of the white normal and lightweight concrete produced with various dosages and aggregate sizes was investigated.

2. Materials

White Portland cement is a white colored hydraulic bonding material produced by grinding of white clinker, obtained by white clay and limestone and calcium sulfate ($CASO_4.2H_20$). In this study, WPC 42.5 was produced with pyrophyllite which was substituted in place of kaolin. White cement produced in Turkey was classified according to level of whiteness as WPC 70 and WPC 80 [9]. Chemical characteristics of the pyrophyllite, which were obtained in Pötürge province of Malatya, SiO_2 and Al_2O_3 high percentage (59.5%, 37.9%) were determined [10]. Chemical and physical characteristics of WPC 42.5 were given in Table 1. Several equations between the oxide ratios were used to verify the composition of the cement.

Oxides and other requirements	(%)	TS 21	
		Min.(%)	Max. (%)
L.I.	2.58	-	5
U.R.	0.12	-	5
MgO	1.12	-	5
SO_3	3.19	-	4
Cl	0.005	-	0.1
CaO	66.0	-	-
SiO_2	22.2	-	-
Al_2O_3	4.3	-	-
Fe_2O_3	0.2	-	-
K_2O	0.5	-	-
Na_2O	0.2	-	-
Specific Gravity	3.03	-	-
Whitenesses	-	85	85.6

Table 1. Chemical and physical properties white Portland cement

Aggregate was obtained by crushing white marble stone in rock crusher. Crushed materials were collected in four groups according to the size of crushed pieces. These groups were marble powder and crushed pieces with size not larger than 5 mm (fine), 7–15 mm (medium) and 15–25 mm (large). Abrasion ratio in Los Angeles test after 500 revolutions was determined as 44%. This ratio was close to limit value of 50%. The main reason for high abrasion ratio is that crushed stone has rough surface. In this study, two mixtures were prepared for normal weight concrete. In the first mixture, marble powder and fine, medium and large were used. In the second mixture, marble powder and marble pieces fine and medium.

In the production of lightweight white concrete, fine pumice was used due to its light weight and insulation characteristics. Pumice has sound and heat insulation characteristics due to its porous structure. Hardness of fine pumice is between 5 and 6 according to Mohs scale. Fine pumice does not contain any crystal water and has silica up to 75% in its composition [11].

Silica fume (SF) is a byproduct which is obtained from the reduction of pure quartz with coal in electric arc furnace in the production of ferrosilicon alloy and silicone metals and has at least 89% SiO_2 [12]. In this study, SF obtained from Antalya Electrometallurgy Plant was used and its physical and chemical characteristics were shown in Table 2.

Oxide name	FA (%)	SF (%)	TS EN 197-1 FA (%) Siliceous	Calcareous
SiO_2	47.64	93.57	≥25	≥25
Al_2O3	9.35	0.96		
F_2O_3	9.00	0.68		
Total	65.99	95.21		
CaO	19.09	0.54	<10	≥10
MgO	-	0.90		
SO_3	1.52	-		
Alkali	-	-		
L.I.	1.83	2.32	≤5	≤5
I.R.	1.57	1.03		
Specific gravity (gr/cm^3)	2.32	2.04		
Specific area (cm^2/g)	5625	-		

Table 2. Chemical and pysical properties of SF and FA

According to ASTM C 618, FA is defined as high calcareous fly ash when the ratio of CaO is more than 10% [13]. In this study, calcareous FA (Cao =19.09%) obtained from Soma-B Thermal Power Plant was used and its physical and chemical characteristics were shown in Table 2. City drinking water was used in mixtures. FM 14 super plasticizer (SP) was used to reduce water requirement of light-weight concrete.

3. Method

Setting time and volume expansion of cement paste were determined according to TS EN 196-3 [14]. Compressive strength of cement mortar was determined according to TS EN 196-1 [15]. Sieve analysis was performed to have homogenous distribution of aggregates and standard grading curve TS EN 933-10 [16]. Saturated surface dry ratio and specific gravity of aggregates were determined according to ASTM C 127, 128 [17, 18] and abrasion ratio of aggregates were determined according to ASTM C 131 [19].

Mix design of the concrete mixtures with the maximum aggregate size of 16 and 32 mm were determined according TS 802 and given in Table 3 and 4 [20].

Mix No	Materials content (kg/m^3)					Slump (cm)
	Aggregate size (mm)			Cement	Water	
	0-5	5-15	15-25			
1 (C 20)	1050	455	275	312	171	9
2 (C 30)	1050	455	275	351	185	8
3 (C 40)	1050	455	275	383	196	7

Table 3. Mix design and slump values (max. aggregate size 32mm)

Mix No	Materials content (kg/m^3)					Slump (cm)
	Aggregate size			Cement	Water	
	0-5	5-15	15-25			
4 (C 20)	1050	725	0	312	180	8
5 (C 30)	1050	725	0	351	194	8
6 (C 40)	1050	725	0	383	210	9

Table 4. Mix design and slump values (max. aggregate size 16mm)

In concrete mixtures, water/cement ratio for the same workability was determined according to slump value. The compressive strength of concrete samples was determined according to TS EN 12390-3 [21]. One sample was shown in Fig.1.

Figure 1. White concrete sample

Four different mixtures (A, B, C, D) were prepared for light-weight concrete and their mix designs were given in Table 5. Three samples were prepared for each age group in the size of 10cm x 10cm x 10 cm.

Mix No	Pumice powder (g)	WPC 42.5 (g)	FA (g)	SF (g)	W/CM* (%)	SP (%)
1	1000	250	-	-	50	-
2	1000	150	100	-	50	-
3	1000	150	100	-	43	1
4	1000	150	-	100	50	-

* CM = Cementitious material

Table 5. Mix design of light-weight white concrete

4. Results and Discussion

4.1. Chemical Analysis, Setting Time and Soundness

WPC 42.5 has similar characteristic with CEM I [22] in terms of oxide ratio. Comparison of WPC 42.5 characteristics with TS 21 requirement is in Table 1. WPC 42.5 satisfies requirement of TS 21. Also, level of whitening of WPC 42.5 is %86.5. The main reason of high silica and alumina modulus was that raw material (limestone and pyrophyllite) with low Fe_2O_3, MnO and TiO_2, was used to get whiteness of white Portland cement as shown Table 1. Since A/F=4.3/0.2=21.5 >0.64, main components determined according to Bogue formulation were found as [23];

C_3S= 4.071x CaO+7.600x SiO_2+6.718x Al_2O_3+1.430x Fe_2O_3+2.852x SO_3=61.95%

C_2S= 2.876xSiO_2-0.7544xC_3S=17.11%

C_3A= 2.650x Al_2O_3 + 1.692x Fe_2O_3=11.06%

C_4AF= 3.043x Fe_2O_3=0.61%

Series of complex chemical reactions occur in hydration of cement. In hydration of cement , it was assumed that each main component was involved in a chemical reaction with mater separately. Chemical reaction of calcium silicates (C_3S and C_2S) with water led to calcium-silicate-hydrate gel ($C_3S_2H_3$) (C-S-H), which is the main bonding component of cement. C_3A and C_4AF components affect the bonding characteristics of cement only in the beginning. The bonding characteristics of cement mainly depend on C_3S and C_2S components [9]. WPC 42.5 is similar to ASTM C Type III cement in terms of main components except C_4AF component. Setting time and soundness of WPC 42.5 was shown in Table 6.

Cement Type	Water content (%)	Setting time (min.) Initial	Final	Soundness (mm)
WPC 42.5	30	140	165	4
TS 21 Specifications		≥45	≤600	≤10

Table 6. Water content, setting time and soundness

Initial and final of setting time and soundness were lower than the values given in TS 21 [9].

4.2. Compressive strength

Six samples were prepared for each age group (3, 7, and 28 days) and tested to have average compressive strength of mortar samples. The average compressive strength of mortar samples were shown in Table 7. 3, 7 and 28 days the average compressive strength of mortar samples 37, 51 and 63 MPa were determined respectively. These compressive strength are higher than the values given in TS 21 for WPC 42.5 [9].

Sample age (Day)	Compressive strength (MPa)	TS 21 specifications	% Difference
3	37	20.0	85
7	51	31.5	62
28	63	42.5	48

Table 7. Compressive strength of mortar samples

Before compressive strength tests, the normal and light-weight concrete specimen surfaces were inspected with crack meter and no cracks were observed at 28 days due to chemical reactions in WPC. The average compressive strength of white concrete was determined by testing of three samples. The average compressive strength of white concrete samples with the maximum aggregate size of 32 mm and 16 mm were shown in Fig. 2 and Fig. 3, respectively.

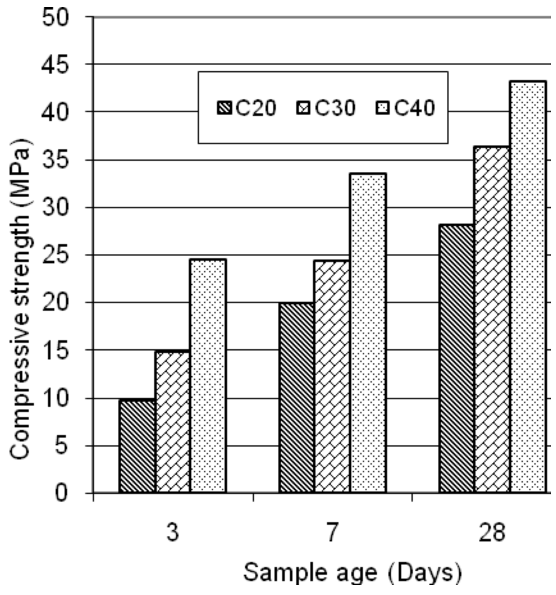
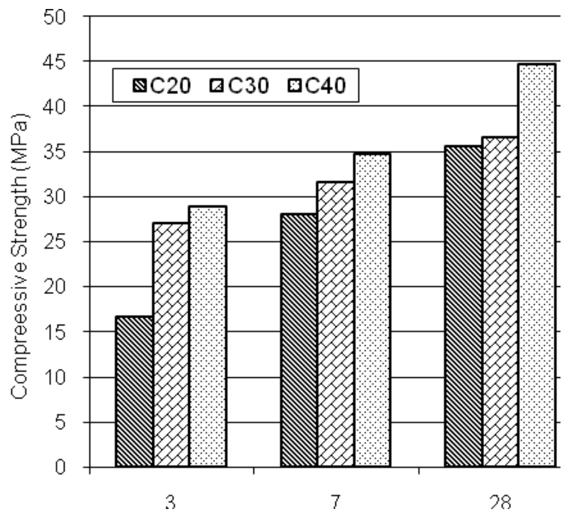


Figure 2. Compressive strength of concrete samples (Dmax: 31.5 mm).



Sample age (Days)

Figure 3. Compressive strength of concrete samples (Dmax: 16 mm).

The compressive strength of white concrete samples with the maximum aggregate size of 16 mm was higher than that of the samples with the maximum aggregate size of 32 mm. 28 days compressive strength of mixture #6 was 3.7% higher than that of mixture #3. The compressive strength of all mixtures increased when dosage of cement was increased. For example the dosage of cement in mixture #1 was increased from 312 kg/m^3 to 383 kg/m^3, 28 days compressive strength was also increased from 28.1 MPa to 43.2 MPa.

The increase in the compressive was about 53.7%. Moreover, compressive strength of mixtures was also depended on the age of mixture samples. For example, in mixture #6, there was an increase in 7 and 28 days compressive strength of the samples compared to 3 days compressive strength by 20.4% and 55%, respectively.

The compressive strength of light-weight white concrete determined by taking the average of three samples was shown in Figure 4.

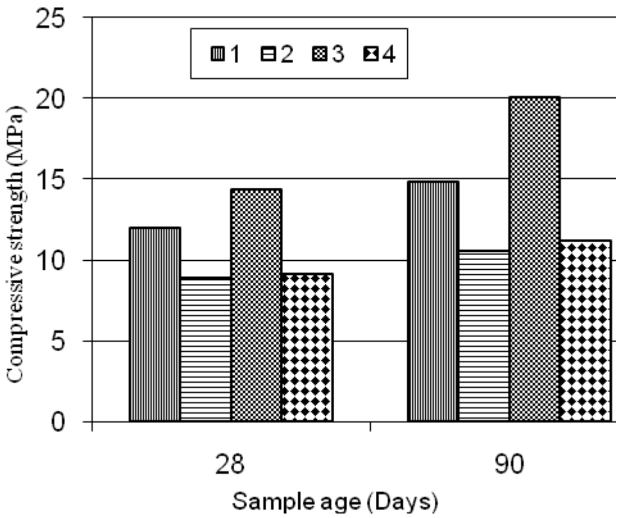


Figure 4. Compressive strength of lightweight white concrete

The compressive strength of light-weight white concrete was less than that of normal weight concrete. The maximum compressive strength was obtained in sample #3. 28 and 90 days compressive strength of sample #3 was determined as 14.4 MPa and 20.1 MPa, respectively.

5. Conclusions

Although the white cement has been used only in aesthetic and decorative purposes, white cement can be used in the production of white concrete because of its high enough compressive strength. The unit weight and compressive strength of white concrete, which was prepared by crushed stone and white cement, increased when the dosage of white cement was increased. The compressive strength of the concrete samples with the maximum aggregate size of 16 mm was higher than that of the concrete samples with the maximum aggregate size of 32 mm. The compressive strength of WPC 42.5 mortar samples was in the range of the values given in the standards.

The light-weight white concrete has strength enough to be used in the construction of wall and slab panel.

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