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Effect of Fly Ash and Ground Granulated Blast Furnace Slag on The Strength of Concrete Pavement

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Abstract

In this study, the effects of Fly Ash (FA) and Ground Granulated Furnace Slag (GGBFS) on design of concrete pavement are investigated. It has been observed how these mineral additives change the 7 days compressive strength and splitting tensile strength of the concrete pavement, the 28 days compressive strength, splitting tensile strength and bending strength of concrete pavement. The cement dosage is 350 kg/m^3 and water/cement ratio is 0.42. Three concrete mixture are produced. The first concrete mixture does not contain FA and GGBFS (reference concrete). The second concrete mixture contains 20 percent of the Portland cement is replaced with fly ash. Finally, the third concrete contains GGBFS displaced at the rate of 20% with cement. Three different molds are used in experiments. The first is cubic mold whose dimensions are 150 mm. The second is cylinder mold whose diameter and length are 150 mm and 300 mm, respectively. Finally, the third is beam mold whose dimension of cross-section and length are 150 mm x150 mm, and 550 mm, respectively. The study was carried out according to the Specifications of General Directorate of Turkish Highways (GDTH) (2016).

Keywords: Concrete, Concrete Pavement, Fly Ash, Slag, Compressive Strength, Splitting Tensile Strength, Bending Strength

1. Introduction

Concrete pavement (rigid superstructure) is a road superstructure made with concrete material. Also, they distribute the wheel and axle loads to the base [1]. Concrete pavement (rigid superstructure) and asphalt pavement (flexible superstructure) are used alternatives to each other in a lot of countries in the world. Also, the right choice of the road type to be built depends on many factors as the resources and budget of the country, the traffic load thought to pass the road, ground properties etc.

Concrete pavements according to asphalt pavements are relatively insufficient in number and length in Turkey. There are a few concrete roads built by the General Directorate of Turkish Highways (GDTH) for testing. “Technical Specifications of Concrete Pavement” which contains construction techniques and applications of concrete roads was published by the General Directorate of Turkish Highways in 2016.

Micron-sized ash particles are formed a result of the combustion of the powdered coal during the production of

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electricity in thermal power plants. Ash particles which are carried by the flue gasses are prevented from getting out of the atmosphere by the help of electron filters. Those ashes are an industrial waste called fly ash (FA) [2, 3]. Fly ashes occur as a by-product in ground granulated coal power plants. They are also stored as waste away from power plants. Specific gravity is between 1.90 and 2.8 g/cm3. Its color is gray or light brown. Size of grain is under 35 µ. Surface area is between 300 and 500 m^2/kg.

Fly ash effects a lot of properties of fresh and hardened concrete and it effects durability of hardened concrete. Unlike other pozzolans, fly ash reduces the water requirement of the mixture and makes it easier to workability. However, the amount, fineness and carbon content of ash are an impressive factor [4].

Fly ash reduces early strength and hydration heat but increases ultimate strength and extends initial setting time. It also increases the resistance of concrete to alkali silica and sulfate attack reactions. Fly ash reduces the cost of concrete when substituted with cement.

The ground granulated blast furnace slag (GGBFS), which is produced as a by-product in iron and steel plants, has a great influence on the fresh and hardened concrete such as fly ash. It reduces the water requirement and makes easier workability of fresh concrete. It reduces hydration heat and extends initial setting time. It improves durability properties of hardened concrete and reduces permeability of hardened concrete. It reduces early strength of concrete but increases ultimate strength of concrete.

Blaine fineness of GGBFS is between 400 and 700 kg/m^2. Specific gravity is between 2.85 and 2.95 g/cm^3.

Strength is the ability of concrete of a certain age to resist stresses or forces [5]. Tensile strength of concrete is approximately 10% of compressive strength. Bending strength is about 15-20% of the compressive strength.

Positive and negative factors affect compressive strength of concrete. Those factors are aggregate type and its gradation, amount of cement and its type, rate of water/cement, curing, usage of chemical and mineral additive, production method of fresh concrete, mixing time, mixing stages, and placement methods of concrete.

Strength of concrete is not characteristic. Results which is obtained a certain concrete mix are linked to the geometry and size of the sample, preparation of concrete, and loading method [6].

In this study, the effects of FA and GGBFS on the compressive, splitting tensile, and bending strength of concrete used in concrete pavement are investigated. It is also intended to provide an archive for future in Turkey for concrete pavements.

2. Experimental Study

2.1. Used Materials

a) Aggregate

Limestone aggregate is used in concrete mixtures. Supplied in 3 groups (0-5 mm, 5-13 mm, 13-25 mm) from Ankara Hisarlıkaya Quarry. The aggregates conform to the standard TS 706 EN 12620 (Concrete Aggregates).

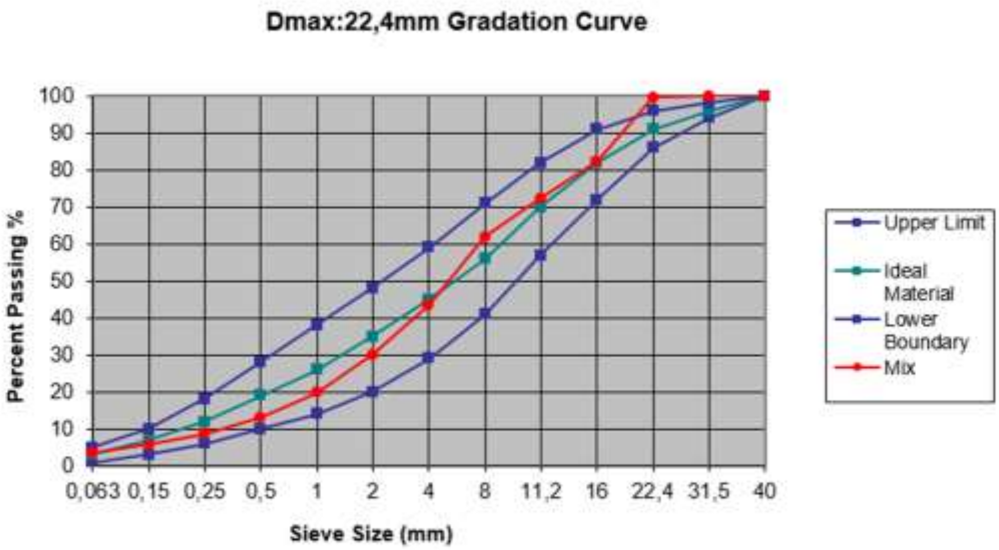

Fig. 1. Aggregate Gradation Curve

Table 1. TS 802 (June 2009) Specification Values

Sieve (mm)	Passing Through From Sieve (%)			Mix (%)
	Min.	Mean	Max.	
0,063	1	3	5	3,4
0,15	3	7	10	6
0,25	6	12	18	9
0,5	10	19	28	13
1	14	26	38	20
2	20	35	48	30
4	29	45	59	43
8	41	56	71	62
11,2	57	70	82	72
16	72	82	91	82
22,4	86	91	96	100
31,5	94	96	98	100
40	100	100	100	100

Table 2. Selected Mixtures Percentages

	% 49	**% 21**	**% 30**	
Sieve (mm)	0-5 mm	5-13mm	13-25 mm	
	% Passing			Mix
40	100,0	100,0	100,0	100
31,5	100,0	100,0	100,0	100
22,4	100,0	100,0	98,4	100
16	100,0	100,0	41,0	82
11,2	100,0	97,6	9,2	72
8	100,0	58,8	1,5	62
4	86,9	2,3	1,3	43
2	59,7	1,3	1,3	30
1	39,1	1,3	1,3	20
0,5	25,5	1,2	1,3	13
0,25	16,2	1,2	1,3	9
0,15	10,3	1,2	1,3	6
0,063	6,0	1,1	0,9	3

b) Cement

Cement (Portland) belongs to Limak Cement Factory. The cement conform to the standard TS 197-1.

Table 3. Chemical Properties of Cement

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	C_3S	C_3A	C_4AF
% 18,16	% 4,62	% 2,95	% 64,15	% 1,98	% 0,11	% 0,61	% 80,30	% 7,25	% 8,98

Table 4. Chemical Properties of Cement

Limestone	Loss on Ignition	Insoluble Residue	Sulfate Content (as SO_3)	Chloride Content	Pozzolanicity
% 4,76	% 3,23	% 0,44	% 2,47	% 0,01	Approprıate

Table 5. Mechanical and Physical Properties of Cement

	Initial Setting Time (minute)			**Expansion (mm)**		
Strength Class	Desired Value	Test Result		Desired Value	Test Result	
42,5 R	≥ 60	180	Approprıate	≤ 10	0,5	Approprıate

c) Fly Ash

F class fly ash used in mixtures produced by AKSA Akrilik Kimya San. A.Ş. The fly ash conform to the standard TS EN 450-1.

Table 6. Properties of FA

Loss on Ignition	SiO_2	Chloride (Cl^-)	Fe_2O_3	Al_2O_3	MgO	SO_3	CaO (free)	CaO (reactive)	Na_2O	K_2O
% 3,41	% 54,03	% 0,0050	% 11,81	% 15,47	% 3,73	% 0,58	% 1,55	% 0,065	%2, 34	% 1,89

d) Ground Granulated Blast Furnace Slag

Ground Granulated Blast Furnace Slag used in mixtures produced by Bolu Cement Factory. The GGBFS conform to the standards TS EN 15167-1 and TS EN 15167-2.

Table 7. Properties of GGBFS

Loss on Ignition	MgO	SO_3	(Na_2O)	(K_2O)	Sulphit ($S^=$)	Chloride (Cl^-)	Moisture	Total Content Of Alkalis (Na_2O Equivalent)
% 0,01	% 6,16	% 0,22	% 0,90	% 0,53	% 0,67	% 0,0177	% 0,05	% 1,24

2.2. Mixing Information and Specimens

Water/cement ratio of mixture 0.42. Cement dosage is 350 kg/m3 and C30/37 strength class determined.
Mold sizes for Reference concrete mix, % 20 FA concrete mix and %20 GBFS concrete mix;

- 3 pieces of 150 × 150 × 150 mm cube mold for 7 and 28 days compressive strength
- 3 pieces of 150 mm diameter – 300 mm length cylinder mold for 7 and 28 days splitting tensile strength
- 3 pieces of 150 × 150 × 550 mm beam mold for 28 days bending strength

Concrete mix made and fresh concrete was placed in the molds in accordance with the standards. Temperature of reference concrete mix measured approximately 23°C. The temperature of % 20 FA concrete and %20 GGBFS concrete mixes measured 21°C. Samples in the mold at a temperature of 20±5 °C, relative humidity of % 95 in the curing room was kept for 24 hours. Then the samples were then removed from the mold sand placed in the curing pool at 20 ± 2 °C.

Table 8. Slump and Air Content Values of Fresh Concrete Mixtures

	Reference Mixture	**Mixture With % 20 FA**	**Mixture With % 20 GBFS**
Slump (mm)	2	3	2
Air Content (%)	5,4	5,7	4,5

For compressive strength test 0,6 MPa/s (N/mm2.s), for splitting tensile strength test and two-point bending test 0,05 MPa/s (N/mm2.s) loading rate applied.

3. Test Results

Table 9. 7-Days Compressive Strength

Reference Mixture (MPa)	**Reference Mixture Average (MPa)**	**Mixture With % 20 FA (MPa)**	**Mixture With % 20 FA Avarage (MPa)**	**Mixture With % 20 GBFS (MPa)**	**Mixture With % 20 GGBFS Avarage (MPa)**
44,34		35,54		38,55	
41,52	**42,10**	36,34	**35,78**	38,41	**38,14**
40,44		35,46		37,47	

Table 10. 7-Days Splitting Tensile Strength Results

Reference Mixture (MPa)	**Reference Mixture Average (MPa)**	**Mixture With % 20 FA (MPa)**	**Mixture With % 20 FA Avarage (MPa)**	**Mixture With % 20 GBFS (MPa)**	**Mixture With % 20 GGBFS Avarage (MPa)**
3,91		3,36		3,61	
4,23	**4,08**	3,72	**3,58**	3,82	**3,81**
4,11		3,66		4,02	

Table 11. 28-Days Compressive Strength Results

Reference Mixture (MPa)	**Reference Mixture Average (MPa)**	**Mixture With % 20 FA (MPa)**	**Mixture With % 20 FA Avarage (MPa)**	**Mixture With % 20 GBFS (MPa)**	**Mixture With % 20 GGBFS Avarage (MPa)**
47,94		44,87		47,95	
51,19	**49,48**	45,83	**44,85**	48,41	**48,84**
49,33		43,85		50,16	

Table 12. 28-Days Splitting Tensile Strength Results

Reference Mixture (MPa)	**Reference Mixture Average (MPa)**	**Mixture With % 20 FA (MPa)**	**Mixture With % 20 FA Avarage (MPa)**	**Mixture With % 20 GBFS (MPa)**	**Mixture With % 20 GGBFS Avarage (MPa)**
4,21		3,92		4,41	
4,31	**4,30**	4,03	**3,87**	4,45	**4,26**
4,38		3,68		3,93	

Table 13. 28-Days Bending Strength Results

Reference Mixture (MPa)	**Reference Mixture Average (MPa)**	**Mixture With % 20 FA (MPa)**	**Mixture With % 20 FA Avarage (MPa)**	**Mixture With % 20 GBFS (MPa)**	**Mixture With % 20 GGBFS Avarage (MPa)**
8,71		6,44		8,28	
7,44	**7,71**	6,05	**6,25**	7,89	**7,98**
7,00		6,26		7,77	

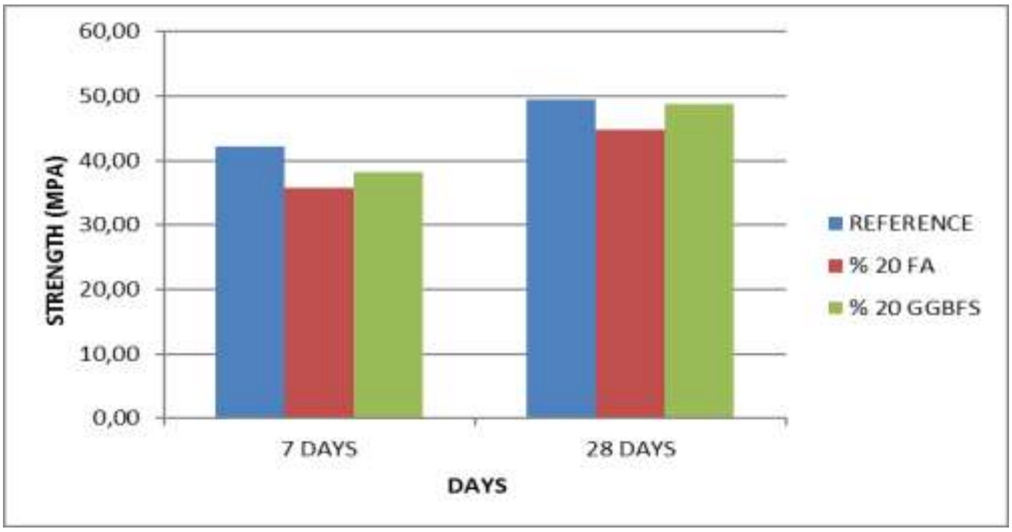

Fig. 2. Compressive Strength

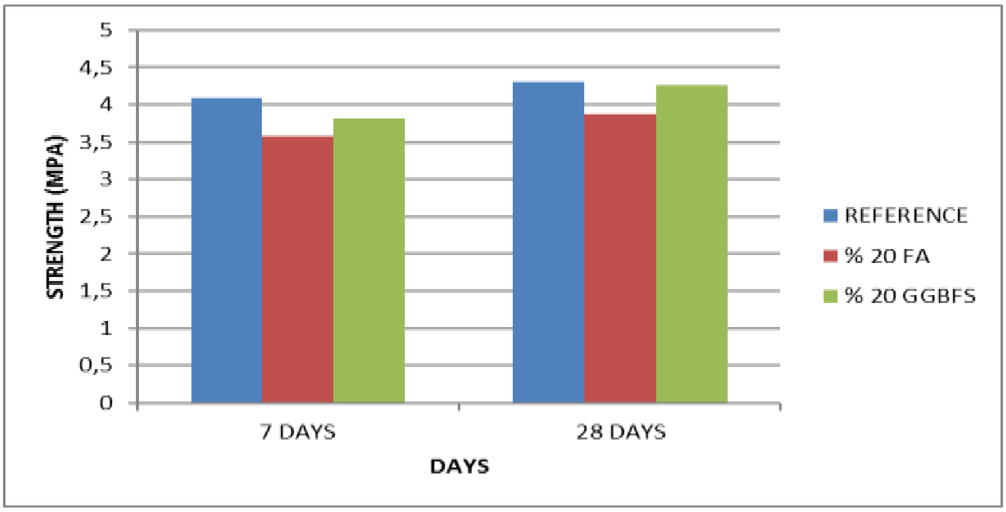

Fig. 3. Splitting Tensile Strength

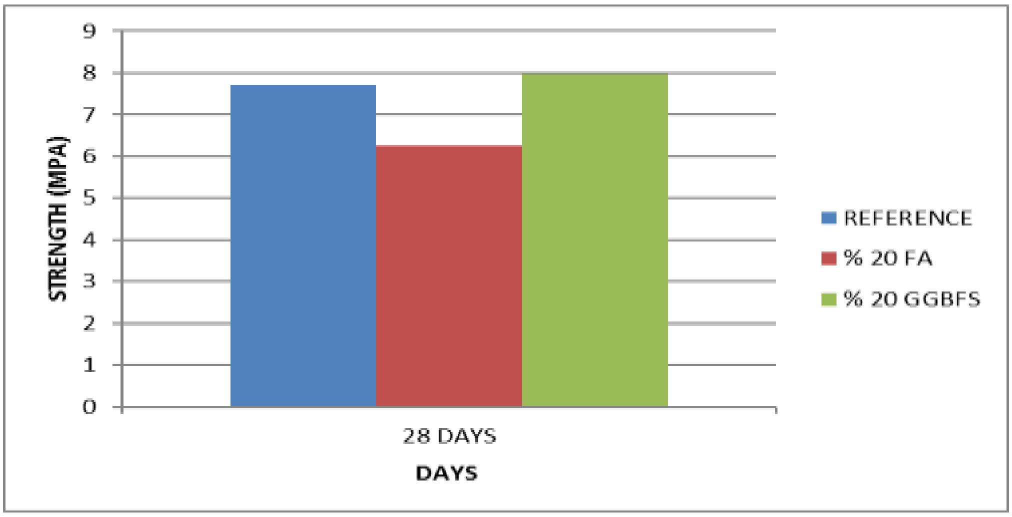

Fig. 4. Bending Strength

4. Results and Discussions

All 28-day strength values of all three mixtures increased according to 7-days strength values. The reference mixture has the highest value for all 7 and 28 days strengths except 28-day bending strength. 28 days compressive and splitting tensile strength of GGBFS mixture almost reached the strength of Reference mixture. 28-days bending strength of the mixture with GGBFS even exceeded the bending strength of Reference mixture.

The 7 and 28 days all strength values of the FA mixture remained below the strength values of the other mixtures. 7-days strength values of GGBFS mixture are greater than 7-days strengths of FA mixtures. In terms of opening concrete pavements to early traffic, ground granulated blast furnace slag can be said to be a small advantage compared to fly ash.

Mineral admixtures such as fly ash and slag can provide great advantages for concrete pavements to different climate zones. Sources in the literature also show that 56 days and 90 days strengths of mixtures with the slag and fly ash reach the values of reference mixtures. In the long term, mixtures containing mineral additives increase the strength to the desired level.

Mineral admixtures provide the economy in concrete provide that they are used in appropriate proportion sand quality. It also reduces the permeability in concrete and positively affects durability.

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