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Effects of fly ash fineness on the mechanical properties of concrete

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Abstract. The present study reviews the effects of fly ash fineness on the compressive and splitting tensile strength of the concretes. A fly ash of lignite origin with Blaine fineness of 2351 cm^2/g was ground in a ball mill. As a consequence of the grinding process, fly ashes with fineness of 3849 cm^2/g and 5239 cm^2/g were obtained. Fly ashes with three different fineness were used instead of cement of 0%, 5%, 10%, and 15% and ten different types of concrete mixture were produced. In the concrete mixtures, the dosage of binder and water/cement ratio were fixed at 350 kg/m^3 and 0.50, respectively. Slump values for the concretes were adjusted to be 100 ± 20 mm. Cubic samples were cast with edges of 100 mm. The specimens were cured in water at 20°C. At the end of curing process, compressive and splitting tensile strengths of the concrete samples were determined at 7, 28, 56, 90, 120 and 180 days.

It was observed that compressive and splitting tensile strength of the concretes was affected by fineness of fly ash in short-and long-terms. It was found that compressive and tensile strength of the concretes increased as fly ash fineness increased. It was concluded that Blaine fineness value should be above 3849 cm^2/g fineness of fly ash to have positive impact on mechanical properties of concrete. The effects of fly ash fineness on the compressive and splitting tensile strength of the concretes were remarkably seen in the fly ash with FAC code with fineness of 5235 cm^2/g.

Keywords. Fly ash; fineness; concrete; compressive strength; splitting tensile strength.

1. Introduction

Fly ash is an industrial waste and a material of puzzolanic characteristic occurring due to burning the pulverized coal in the thermal power plants. In the construction sector, the fly ash is used in the production of cement as an additive-material, in production of concrete instead of some of the cement or instead of some of the fine aggregate, as a base and sub-base material in highway construction, as a filling material in dams, in retaining walls, and for production of light construction materials (ACI Committee 1987; Erdoğan 1997).

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The fly ash, similar to other pozzolans, affects the technical properties of the concretes and mortars by its pozzolanic characteristics and filler effect. It is known that the filler effect of the fly ash is more effective than the pozzolanic characteristics when affecting the properties of concrete (Goldman & Bentur 1993; Aiqin *et al* 2003). The fly ashes have pozzolanic activity because they contain surplus amount of silica, alumina and iron oxide; they have a structure with very fine particles and amorphous. Materials with silica and alumina in the structure of fly ashes make additional calcium silicate hydrate (C-S-H) by reacting with calcium hydroxide occurring as a consequence of hydration of the cement. The resultant C-S-H gels cause increase in strength of the concrete. Furthermore, the fact that fly ash contains very fine particle increases compactness in the concretes or mortar and causes filling of the spaces. Using the fly ash in the concrete generally increases the workability of the fresh concrete, decreases the bleeding, decreases the hydration temperature, decreases the permeability of the hardened concrete, increases resistance of the concrete to the chemical effects, and decreases the costs (ACI Committee 1987; Erdoğan 1997; Chindaprasirt *et al* 2005; Toutanji *et al* 2004).

Strength of the concretes in which fly ash is used instead of up to 30% of the cement is lower than Portland cement concretes at the early stages but the ultimate strength in the later years is higher. The increase in the strength of the concrete with fly ash changes depending on the fineness, type and usage ratio of the fly ash and the cement type. The contribution of the type C ashes to the strength in the earlier times is higher than the type F ashes (Erdoğan 1997; Malhotra 1995; Toutanji *et al* 2004). Increasing fineness of the fly ash also increases its puzzolanic activity and density. As a result of this, strength and durability of the concretes containing fly ash are affected positively (Erdoğan 1997; Jaturapitakkul *et al* 1999; Kiattikomol *et al* 2001).

The coarse fly ash was ground and obtained fly ashes which had particles between 1.9 and 17.2 micron (Kiattikomol *et al* 2001). The ground fly ashes were classified as fine, medium and coarse ashes and their physical–chemical properties were evaluated. Additionally, they produced mortar by using fly ashes of different fineness instead of 20% of the cement. They compared compressive strength of the produced mortar with each other and controls. As a result of their study, it was observed that compressive strength of mortars and puzzolanic activity index of fly ash increased as fineness of the fly ash increased. Furthermore, they reported that the most important factor affecting index of puzzolanic activity was fineness of the fly ash, not its chemical composition.

Chindaprasirt *et al* (2005) studied the effects of the fineness of fly ash on compressive strength and porosity of the mortar, and size of spaces in hardened cement paste. In that study, fly ashes of type F were ground and classified into 2 fineness types. In preparation of mortar mixtures, cement was replaced with two types of fly ashes having different fineness, at replacement levels of 20% and 40%. As a result of the tests performed, it was seen that the compressive strength of the mortar made by using classified fly ash was higher than those made by using unclassified fly ash. However, it was noted that the compressive strength of the mortar with fly ashes was lower than control mortar made with Portland cement in all time periods. It was seen that the grinded ash with high fineness provided higher early strength than the mortars produced with coarse ashes used without grinding. The authors concluded that finer fly ash made the hardened cement paste more compact and denser, and thus its contribution to the strength was higher compared to the original fly ash.

Chindaprasirt *et al* (2003) examined the effects of fineness of the fly ash on compressive strength, shrinkage and resistance to sulphate of the mortar. In the mortar produced, fly ashes with Blaine fineness of 1800 cm^2/g, 3000 cm^2/g, 3900 cm^2/g, 4800 cm^2/g, 4900 cm^2/g, and 9300 cm^2/g were used instead of 40% of the cement. In their study, the highest pozzolanic activity and compressive strength were obtained with the finest fly ash. It was found that increase in the compressive strength was remarkable with increasing fineness. At the end of 90 days period, it was found that, except for the mortars which were prepared with coarse and original fly ashes, the compressive strength of the mortars which included the other ashes with high fineness was more than the compressive strength of the control mortar.

Erdoğdu & Türker (1998) have produced mortars using Portland cement and fly ashes with different degrees of fineness and with high and low calcium content. In this study, the fly ashes with high and low calcium contents were passed through sieves of 125, 90, 63, and 45 μm. These sieved ashes were divided into 6 different grain size groups. Fly ashes were used instead of cement by 25% ratio in the mortar mixtures. From the study, it was observed that the fly ash with high calcium, the fineness of which was less than 45 μm reached the highest compressive strength, but not higher than the strength values of the control mortar.

In this study, the effects of the fineness of the fly ashes on the compressive and splitting tensile strengths of concrete were evaluated at early and late ages. For this purpose, a fly ash has the same origin were obtained by grinding the ash of different fineness. Fly ashes with 3 different fineness, the Blaine fineness of which were 2351 cm^2/g, 3849 cm^2/g, and 5339 cm^2/g were obtained. Ten different types of concrete mixtures were produced using fly ashes with different degrees of fineness instead of the cement at a rate of 0%, 5%, 10%, and 15%. The produced concrete samples were cured in water. These samples subjected to compressive and splitting tensile tests at different ages.

2. Experimental

2.1 *Materials*

In the present study, CEM I 42.5 R type cement and a fly ash of type C obtained from Soma thermal power plant were used as binders in concrete mixtures. Properties of the used cement were given in table 1.

Properties of the fly ash were given in table 2. Blaine fineness of the obtained fly ash was 2351 cm^2/g. This fly ash was grinded in a ball mill at 7200 and 14400 rpm and fly ashes were obtained with Blaine fineness of 3849 cm^2/g and 5239 cm^2/g, respectively. Therefore, the ashes with the same origin but which have 3 different Blaine fineness values [2351 cm^2/g (FAA), 3849 cm^2/g (FAB) and 5231 cm^2/g (FAC)] were obtained.

Aggregates of limestone origin, with 0–5 mm and 5–15 mm particle size were used for concrete production. The mixture of the aggregates used was prepared to have 45% fine aggregate and 55% coarse aggregate by weight. The sieve analysis results and some physical properties of the aggregates used in the concrete mixtures are given in table 3.

Superplasticizer (SP) was used in the concrete mixtures in order to provide desired workability. Water used in the concrete mixture was drinkable water.

2.2 *Preparing the concrete mixtures*

Concretes with 10 different contents, with w/c ratio 0.50, binder dose 350 kg/m^3 and slump value 80–120 mm were produced in the study. The mixture ratios of the concretes produced are given in table 4. The mixture ratios given in the table are corrected values.

A laboratory type concrete mixer of 65 liters capacity with vertical axis was used for concrete production. Concrete production was made according to the procedure below: (i) The fine and coarse aggregates were put into the mixer as dry and mixed for about 2 minutes. (ii) Half of

Table 1. Properties of the cement.

Chemical properties		Physical properties	
Compounds	(%)	Specific gravity	3.13
SiO_2	19.13	Specific surface area, (cm^2/g)	3670
Al_2O_3	5.1	Retained on 0.09 mm sieve (%)	0.70
Fe_2O_3	3.51	Retained on 0.032 mm sieve (%)	18.20
CaO	63.29	Setting time (minute)	
MgO	1.06	Initial setting time	170
Na_2O	0.34	Final setting time	260
K_2O	0.77	Mechanical properties	
SO_3	2.83	Compressive strength, (MPa)	
Loss on ignition	3.51	2 days	27.6
Cl	0.014	7 days	42.7
Unmeasurable	0.79	28 days	58.0
Insoluble residue	0.45		
Free lime	0.96		
Bogue compositions (%)			
C_3S		61	
C_2S		8.82	
C_3A		7.57	
C_4AF		10.68	

Table 2. Properties of fly ash.

Chemical properties			
Compounds	(%)		
SiO_2	45.98		
Al_2O_3	23.55		
Fe_2O_3	4.91		
CaO	18.67		
MgO	1.54		
Na_2O	0.24		
K_2O	1.80		
SO_3	1.47		
Loss of ignition	2.31		
Cl^-	0.0053		
Free lime	0.64		
Physical properties			
Property	FAA	FAB	FAC
Specific gravity	2.21	2.45	2.52
Blaine fineness (cm^2/g)	2351	3849	5239
Percent retained on 45 μm sieve	33	18.8	12.2
Percent retained on 90 μm sieve	14.3	2.3	1.6

Table 3. Particle distribution and some physical properties of aggregates.

Sieve size (mm)	Passing (%)		
	5–15 mm	0–5 mm	Mixture
32	100	100	100
8	57	100	81
4	8	90	53
2	2	56	32
1	2	42	23
0.5	2	28	15
0.25	2	17	9
Pan	0	0	0
Physical properties			
		5–15 mm	0–5 mm
Specific gravity (*SSD)		2.67	2.6
Water absorption (%)		0.61	1.64

*SSD: saturated-surface dry

the binder material, water, and plasticizer were poured into the dry aggregate mixture and the mixer was operated for 2 minutes. (iii) The remaining binder material, water, and plasticizer were added to the mixture in the mixer and the mixer was operated again for 2 minutes. The total mixing time was 6 minutes.

2.3 *Preparing and curing the samples*

Samples of cubic form with edges of 100 mm were cast from the concretes produced. Fresh concrete placed in the cubic molds was compacted in two layers by rod. The samples cast were

Table 4. Mix proportions of concrete mixtures.

Concrete code	Fly ash (%)	Fly ash Blaine value (cm^2/g)	Cement (kg)	Fly ash (kg)	Water (l)	*Aggregate (kg)		**SP (kg)	Unit weight kg/m^3
						0–5 mm	5–15 mm		
KB	0	0	354	0	177	986	822	1.75	2341
UKB1	5	2351	339	18	179	990	825	1.70	2353
UKB2	10	2351	320	36	178	983	819	1.68	2338
UKB3	15	2351	302	53	178	978	816	1.58	2329
UKB4	5	3849	335	18	176	980	817	1.70	2328
UKB5	10	3849	317	35	176	976	813	1.77	2319
UKB6	15	3849	301	53	177	978	815	1.93	2326
UKB7	5	5239	337	18	178	987	823	1.81	2345
UKB8	10	5239	319	35	177	983	819	1.95	2335
UKB9	15	5239	300	53	176	976	813	2.07	2320

*The amount of aggregate is based on saturated-surface dry. **SP: Superplasticizer removed from their molds 1 day after they were cast, and they were cured in water at 20 ± 2°C until the test dates.

2.4 *The tests*

The concrete samples were subjected to unit weight and slump test in fresh concretes and compressive and splitting tension tests in hardened concrete. A total of 240 cubic samples were tested for compressive and tension tests in this study.

3. Results and discussions

3.1 *Results of compressive strength*

The results of compressive strength of the concretes are shown in table 5. Compressive strength in the produced concretes ranged between 29.3 and 38.2 MPa on day 7, between 36.8 and 49.7 MPa on day 28, between 39.1 and 52.1 MPa on day 56, between 40.5 and 52.6 MPa on day 90, between 41.3 and 52.8 MPa on day 120, and between 42.5 and 53.4 MPa on day 180. Based on these results, at all times, the highest compressive strength was obtained in the concretes in which the fly ash with highest degree of fineness was used at rates of 5%, 10% and 15% (UKB7, UKB8, and UKB9). Compressive strength obtained with these concretes for all ages were 3% to 16% higher than those of control concretes. The worst performances in terms of compressive strength were observed in the concretes produced with fly ashes with fineness of 3849 and 2351 cm^2/g.

As it can be seen in the table 5, the highest compressive strength at early ages (at the end of cure period of 7 days) was obtained in the concretes produced with the highest degree of fineness (the concretes with UKB7, UKB8 and UKB9 codes). The compressive strengths in day 7, obtained in these concretes were even 2 and 4 MPa (between 5% and 12%) higher than the compressive strength of the control concrete and the strengths decreased about 1 MPa as the usage ratio increased. The compressive strengths of the concretes produced with UKA and UKB ashes, the fineness of which was coarser when compared to the UKC ash in day 7 was below the strength of the control concrete.

Table 5. Compressive strength results.

Concrete code	Fly ash, (%)	Fly ash Blaine value, (cm^2/g)	Compressive strength, (MPa)					
			7 days	28 days	56 days	90 days	120 days	180 days
KB	0	–	34.2	43.1	45.1	46.7	47.6	47.7
UKB1	5	2351	30.8	39.7	41.7	43.1	44	45
UKB2	10	2351	29.6	38.1	40.2	41.4	42.1	43.2
UKB3	15	2351	28.7	36.8	39.1	40.5	41.3	42.5
UKB4	5	3849	32.4	41.3	43	44.3	44.8	46
UKB5	10	3849	30.6	39.4	40.9	42.6	42.7	44.4
UKB6	15	3849	29.3	38.8	40.7	41.7	41.9	43.5
UKB7	5	5239	38.2	49.7	52.1	52.6	52.8	53.4
UKB8	10	5239	37.4	46.9	48	48.8	50.6	51.3
UKB9	15	5239	36	44.3	46.2	46.9	48.8	49.6

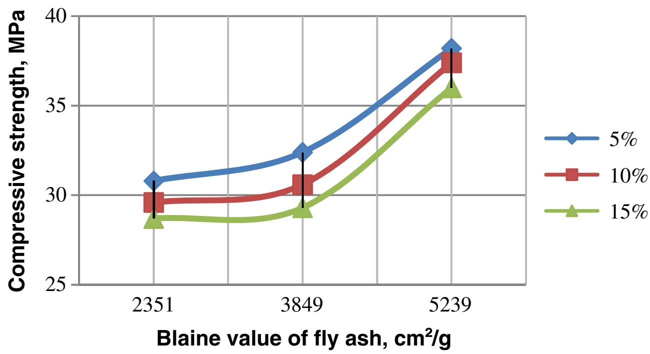

Figure 1. Relationships between fineness of fly ash and 7 days compressive strength on the produced concretes.

It was seen that the strength losses of the concretes produced with UKA and UKB ashes in curing period of 7 days were up to 16% and 14%, respectively compared with the control concrete. In both of these types of ashes, strength losses were understood to reduce as rate of use of fly ash increased.

As it can be seen in table 5, the compressive strengths of the concretes produced with UKA and UKB ashes the fineness of which are coarser than the UKC ash are below the control concrete in the cure periods of 28 days and more.

The highest compressive strength values were obtained from the concretes (coded UKB7, UKB8 and UKB9) produced with the fly ash with highest fineness in the cure periods of 28 days and more. It is seen that the ultimate strengths obtained from these concretes are about 4% and 12% higher than the compressive strength of the control concrete in day 180. It is seen that the compressive strength of the control concrete in day 28 and later is higher than the concretes produced with UKA ash in ratios between 15% and 6%, than the concretes produced with UKB ashes in ratios between 12% and 4%. Also, it is understood that as the fly ash usage ratio increases as the compressive strength decreases for all concretes with fly ash.

As it can be seen in figures 1–6; increasing the fly ash fineness from 2300 cm^2/g to 3200 cm^2/g does not increase the compressive strength significantly in the concretes which include fly ashes

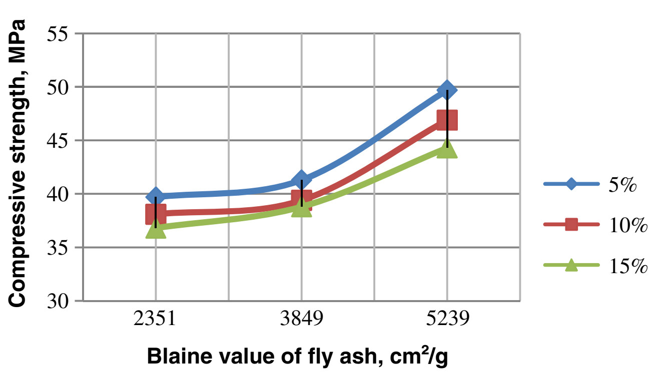

Figure 2. Relationships between fineness of fly ash and 28 days compressive strength on the produced concretes.

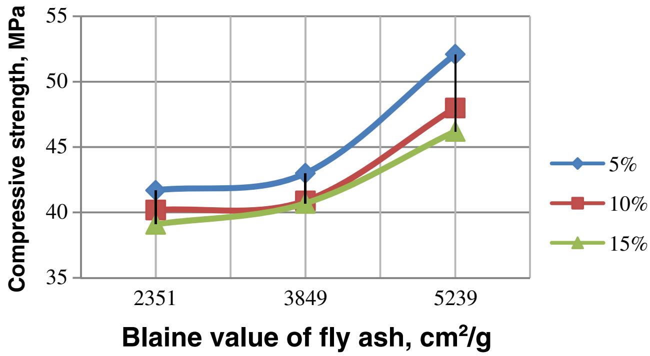

Figure 3. Relationships between fineness of fly ash and 56 days compressive strength on the produced concretes.

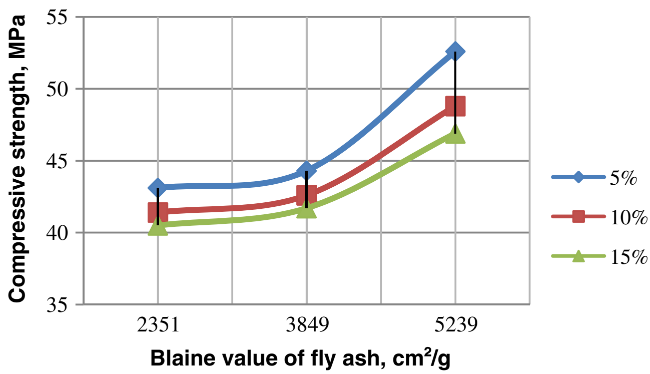

Figure 4. Relationships between fineness of fly ash and 90 days compressive strength on the produced concretes.

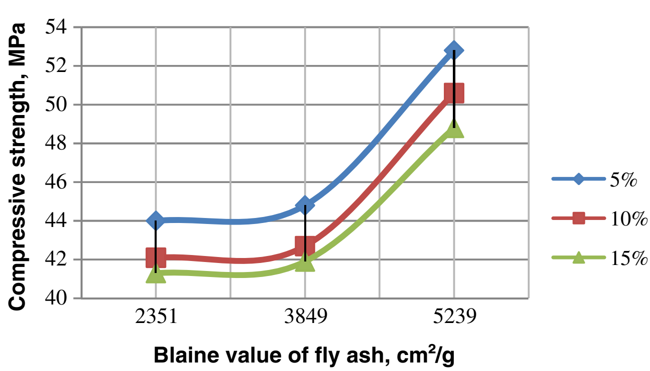

Figure 5. Relationships between fineness of fly ash and 120 days compressive strength on the produced concretes.

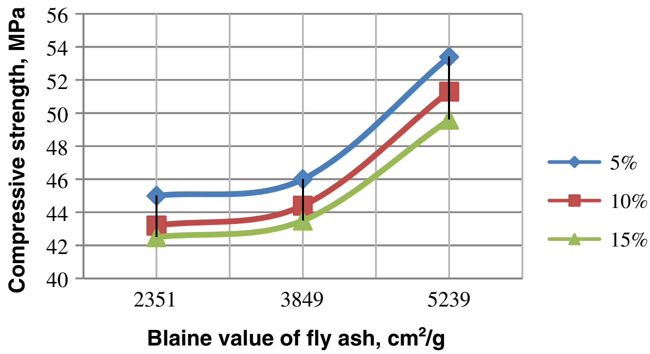

Figure 6. Relationships between fineness of fly ash and 180 days compressive strength on the produced concretes.

by 5%, 10% and 15% in all times. The increases in compressive strength were between 1% and 5%. On the other hand, it is seen that the concrete compressive strengths increased in ratios changing between 16% and 26% as a result of increasing the fly ash fineness from 2300 cm^2/g to 5329 cm^2/g. Also, it is determined that concrete compressive strengths increased in ratios changing between 12% and 23% as a result of increasing the fly ash fineness from 3200 cm^2/g to 5329 cm^2/g. These results shows that when the fly ash fineness is between 2300 cm^2/g and 3200 cm^2/g, similar compressive strengths are obtained in the concretes produced; the fly ash fineness should be higher than 3200 cm^2/g in order to increase the compressive strength.

Additionally, compressive strengths of the concretes produced using fly ashes with different degrees of fineness at different rates were calculated comparatively with the control concretes and the results are given in table 6. As it can be seen in table 6, it is understood that the concretes produced with the finest ash gains strength more quickly than the control concrete at all times, including 7 days. It is seen that 5%, 10% and 15% usages of the ash with the highest fineness have 13%, 7% and 3% higher compressive strength respectively when compared with the control concrete for all curing times.

Table 6. Relative compressive strength.

Concrete code	Fly ash (%)	Fly ash Blaine value (cm^2/g)	Relative compressive strength (%)					
			7 days	28 days	56 days	90 days	120 days	180 days
KB	0	–	100	100	100	100	100	100
UKB1	5	2351	90	92	93	92	92	94
UKB2	10	2351	87	88	89	89	88	91
UKB3	15	2351	84	85	87	87	87	89
UKB4	5	3849	95	96	95	95	94	96
UKB5	10	3849	89	91	91	91	90	93
UKB6	15	3849	86	90	90	89	88	91
UKB7	5	5239	112	115	116	113	111	112
UKB8	10	5239	109	109	107	104	106	107
UKB9	15	5239	105	103	103	100	103	104

Table 7. Splitting tensile strength results.

Concrete code	Fly ash (%)	Fly ash Blaine value (cm^2/g)	Splitting tensile strength, (MPa) 7 days	28 days	56 days	90 days	120 days	180 days
KB	0	–	4,5	5,4	5,9	6,1	6,1	6,3
UKB1	5	2351	4	4,9	5,1	5,7	5,8	5,8
UKB2	10	2351	4	4,9	5	5,2	5,4	5,6
UKB3	15	2351	3,5	4,6	5	5	5,4	5,4
UKB4	5	3849	4,3	5,2	5,6	6,3	6,4	6,6
UKB5	10	3849	4	4,9	5,2	5,8	5,8	6,2
UKB6	15	3849	3,7	4,6	5,2	5,7	5,9	6
UKB7	5	5239	4,5	5,9	6,4	6,7	6,9	7,1
UKB8	10	5239	4,1	5,70	6,2	6,5	6,8	7
UKB9	15	5239	4	5,7	6	6,1	6,3	7

For all cure times, it was concluded that the concretes containing fly ash with fineness of 3200 cm^2/g had 14% lower relative compressive strength than the control concretes and the concrete containing fly ash with 2300 cm^2/g had 16% lower relative compressive strength than the control. Also, it is seen that as the ash usage ratio increases as the relative compressive strength ratios decreases for all times.

3.2 *Results of splitting tensile strength*

Results of splitting tensile strength of the cubes with edges of 100 mm prepared from the produced concretes and cured in water at 20°C until the test dates (table 7). The values given in the tables show the average of splitting tensile strength for 3 samples. When the results in table 7 were reviewed, splitting tensile strength in the produced concretes ranged between 3.5 and 4.5 MPa on day 7, between 4.6 and 5.9 MPa on day 28, between 5 and 6.4 MPa on day 56, between 5 and 6.7 MPa on day 90, between 5.4 and 6.9 MPa on day 120, and between 5.4 and 7.1 MPa on day 180.

Table 8. Relative splitting tensile strength.

Concrete code	Fly ash (%)	Fly ash Blaine value, (cm^2/g)	Relative splitting tensile strength, (%) 7 days	28 days	56 days	90 days	120 days	180 days
KB	0	–	100	100	100	100	100	100
UKB1	5	2351	89	91	86	93	95	92
UKB2	10	2351	89	91	85	85	89	89
UKB3	15	2351	78	85	85	82	89	86
UKB4	5	3849	96	96	95	103	105	105
UKB5	10	3849	89	91	88	95	95	98
UKB6	15	3849	82	85	88	93	97	95
UKB7	5	5239	100	109	108	110	113	113
UKB8	10	5239	91	106	105	107	111	111
UKB9	15	5239	89	106	102	100	103	111

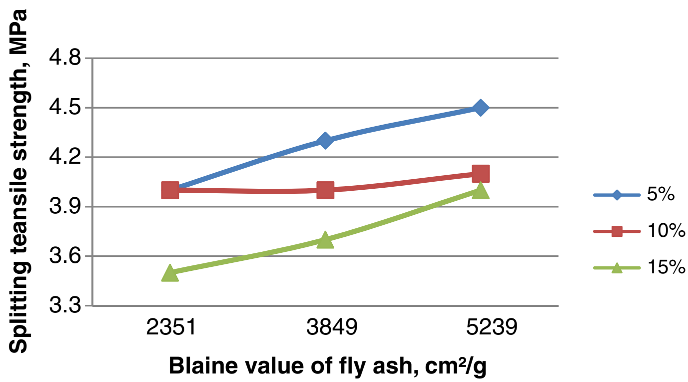

Figure 7. Relationships between fineness of fly ash and splitting tensile strength on the produced concretes for 7 days.

Based on these results, the highest splitting tensile strength at all days was obtained in concretes in which the finest fly ash was used at rates of 5%, 10% and 15% (UKB7, UKB8, and UKB9). The splitting tensile strength values obtained in these concretes were even higher than the control concrete. The worst performances in terms of splitting tensile strength were observed in the concreted produced with fly ash with fineness of 3849 and 2351 cm^2/g.

Also, the relative splitting tensile strengths of the concretes with fly ash additive, produced with different usage ratios by ashes with different fineness compared with the control concrete were calculated and the results are shown in table 8.

As it can be seen in table 8, the splitting tensile strength of all concretes with fly ash was under the splitting tensile strength of the control concrete in ratios changing between 0% and 22% during the 7 days of curing time. For the curing times after day 7, the splitting tensile strengths of the concrete coded UKB4 and the concretes coded UKB7, UKB8 and UKB9, which were produced with the ash with highest fineness, gave higher results than the splitting tension strength of the control concrete.

Considering the ultimate splitting tensile strength on day 180, splitting tensile strength of the concretes produced using the highest fineness fly ash (UKB7, UKB8 and UKB9) took 11 to 13%

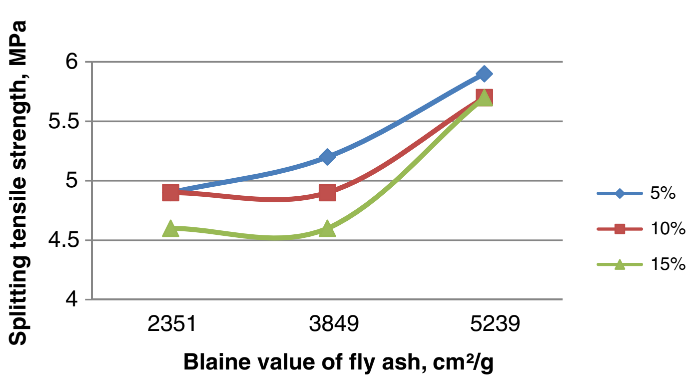

Figure 8. Relationships between fineness of fly ash and splitting tensile strength on the produced concretes for 28 days.

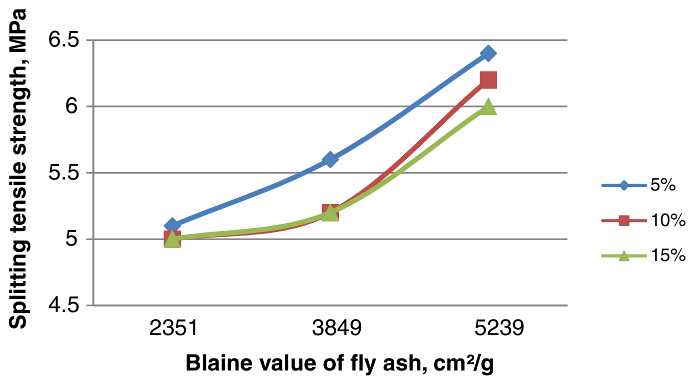

Figure 9. Relationships between fineness of fly ash and splitting tensile strength on the produced concretes for 56 days.

higher than control concrete. On the other hand, for the splitting tensile strengths of the concretes produced with ashes with coarser fineness (except the concrete coded UKB4), values of 14% to 2% less than the splitting tension strength of the control concrete were obtained.

As it can be seen in figures 7–12; as the fly ash fineness increased from 2351 cm^2/g to 3849 cm^2/g in the concretes that included 5%, 10% and 15% fly ash for all days, their splitting tensile strengths increased from 0% to 14%. As a result of increasing the fly ash fineness from 2351 cm^2/g to 5329 cm^2/g, increases varying between 3% and 30% were observed in the splitting tensile strengths of the concretes. Also, as a consequence of increasing fineness of fly ash from 3849 cm^2/g to 5329 cm^2/g, increases were found in splitting tensile strength of the concretes from 3 to 24%. These results indicated that the similar splitting tensile strengths would be obtained with increasing the fineness of fly ash from 2351 cm^2/g to 3849 cm^2/g, and that fineness of fly ash should be above 3849 cm^2/g for it to contribute splitting tensile strength.

In general, the strength gaining speeds of the earlier concretes in which fly ash is used instead of some part of the cement is less than the concretes in which no fly ash is used. In this study, this expected result was observed in the concretes which were produced with coarse ashes (FAA

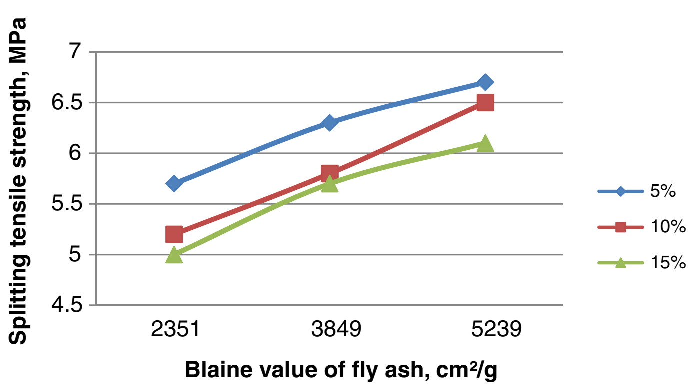

Figure 10. Relationships between fineness of fly ash and splitting tensile strength on the produced concretes for 90 days.

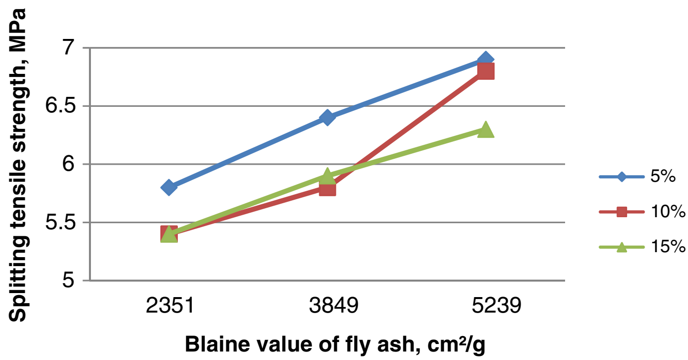

Figure 11. Relationships between fineness of fly ash and splitting tensile strength on the produced concretes for 120 days.

and FAB ashes). However, it was found that speed of gaining strength at early days was higher in the concretes produced using finer FAC fly ash than the control concrete. These results indicate that although the chemical composition of the fly ash is same, activity of the fly ash increased with fineness exceeding a certain limit and thus strength of the concrete at early days was also positively affected. The results obtained in this study support the results obtained by various researchers. Researchers such as Chindaprasirt *et al* (2005), Kiattikomol *et al* (2001) and Chindaprasirt *et al* (2003), reported that as the fineness increases, the compression strengths of the mortars or concretes at earlier ages also increases. Other researchers such as Chindaprasirt *et al* (2005), Erdoğdu *et al* (1998), Kiattikomol *et al* (2001) and Chindaprasirt *et al* (2003) reported that increasing fineness of the fly ash positively affected the compressive strength of the concretes or mortars.

It is known that, as the fineness increases in the fly ash, pozzolanic activity also increases, similar to the other mineral based pozzolanic materials. Besides, depending on the increase in the fineness of the pozzolanic materials, the filling rate of the concretes or mortars increases; a more dense and impermeable structure occurs. As a consequence of these events, increase is seen in strength of concrete with use of fly ash at appropriate rates instead of the cement. The substantial part of the fly ashes, which are obtained from thermal power plants, is generally coarse grained ash. If cost of grinding can be neglected, it will be possible to use the fly ash more

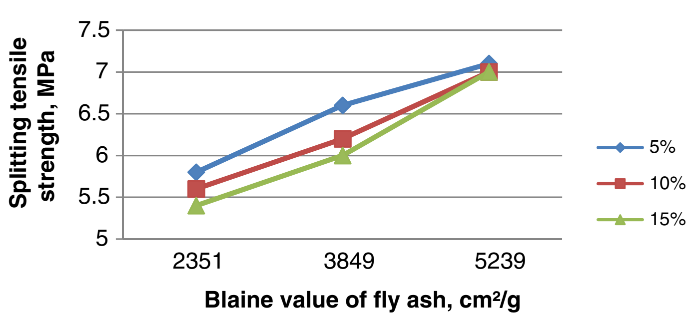

Figure 12. Relationships between fineness of fly ash and splitting tensile strength on the produced concretes for 180 days.

efficiently in the concrete by the means of improving its fineness. This will provide economical interest due to less use of cement and will contribute to less CO_2 emission from production of cement.

4. Conclusions

The conclusions drawn from the present study are as follows.

(i) For the concretes in which fly ash is used at the same rate instead of cement, compressive and splitting tensile strength of the produced concretes increase as fineness of fly ash increases.
(ii) The positive effect of the fly ash fineness on the concrete compression and splitting tensile strengths is seen more clearly in the fly ash coded UKC, the fineness of which is 5235 cm^2/g.
(iii) It was concluded that, among the three fineness levels, the mechanical properties of concrete was positively affected from fineness of fly ash when Blaine fineness value was above 3849 cm^2/g. It should be emphasized that, although it was not investigated in this study, additional factors including the fineness of cement, aggregates gradation, the maximum size of aggregate, cement content and composition of the mixture may also be effective on the mechanical properties of concrete.
(iv) Compressive strength of the concretes produced with FA A and FA B with fineness of 2351 cm^2/g and 3849 cm^2/g were similar. This effect is also true for the splitting tensile strength.
(v) In general, the highest values of the compression and splitting tensile strengths of the concretes produced with fly ash additives are obtained with 5% replacement rates of the fly ashes. It was seen that as the replacement rate increased, compressive and splitting tensile strengths decreased.

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