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Strength and shrinkage properties of mortar containing a nonstandard high-calcium fly ash

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Abstract

A laboratory study was undertaken to assess the compressive and flexural tensile strength and drying shrinkage properties of mortar mixtures containing high-calcium nonstandard Afsin-Elbistan fly ash (FA). Possibility of using Afsin-Elbistan FA in cement-based materials as shrinkage-reducing or compensation agent was also discussed. Five mortar mixtures including control Portland cement (PC) and FA mortar mixtures were prepared. FA replaced the cement on mass basis at the replacement ratios of 10%, 20%, 30% and 40%. Water–cementitious materials ratio was 0.4 for all mixtures. The mixtures were cured at 65% relative humidity and 20 ± 2 °C. The compressive and flexural tensile strength and drying shrinkage values of the mortar mixtures were measured. The results show that Afsin-Elbistan FA reduced drying shrinkage of the mortar by 40%. Therefore, it was concluded that Afsin-Elbistan FA can be used as a shrinkage-reducing agent. The mortar containing 40% FA expanded. This indicates that Afsin-Elbistan FA may be utilized to compensate drying shrinkage of cement-based materials.

Keywords: Fly ash; Drying shrinkage; Compensation agent; High calcium; Mortar

1. Introduction

Currently, blending cement with fly ash (FA), silica fume, slag or a natural pozzolan using FA in concrete is widespread in practice. The use of FA in concrete modifies the properties of concrete in both fresh and hardened states, with improvements to workability, strength, drying shrinkage, temperature rise and abrasion resistance [1–8]. It solves the storage and disposal problems of FA [9–11].

The volume changes due to shrinkage are of considerable importance. In practice, this movement is partly or wholly restrained in concrete slabs laid on granular subbases, which provide high friction and may cause high tensile stresses. Differential shrinkage, which can occur in a concrete slab used for road construction, can also cause warping or curling and tensile stresses [12]. Thus, if there are no joints between slabs or no reinforcement in concrete, the concrete will crack. Furthermore, in rock engineering, cement grouted rock bolt has been widely used in tunneling and foundation applications as reinforcement member. In this area, shrinkage of grouting materials is of utmost significance. Shrinkage reduces the pullout capacity of rock bolt by reducing the adherence between grouting material and the rock.

Ghosh and Timusk [13] studied the influence of using FA in concrete on creep and shrinkage properties and reported that FA results in a reduction in shrinkage of concrete. The findings of Cripwell et al. [14] and Nelson et al. [15] supported the results of Ghosh and Timusk [13]. In addition, Teorenau and Nicolescu [16] concluded that the shrinkage of FA concrete is reduced as the FA replacement ratio increased.

The primary objective of this study is to investigate the usability of nonstandard Afsin-Elbistan FA in cement-based materials as a mineral additive in terms of strength and particularly drying shrinkage properties. Another objective is to demonstrate if the present FA has a shrinkage-reducing or compensating property.

2. Materials used in the investigation

2.1. Cement

The cement used was ASTM Type I normal Portland cement (PC, 42.5 N/mm^2), which conformed to the current

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Table 1
Oxide composition of cement and FA (%)

Oxide	PC	FA
SiO_2	20.65	18.95
Al_2O_3	5.60	7.53
Fe_2O_3	4.13	3.82
CaO	61.87	51.29
MgO	2.60	1.58
SO_3	2.79	12.06
K_2O	0.83	0.32
Na_2O	0.14	1.51
LOI	0.50	2.94

specifications as described in TSI [17] and BSI [18]. Specific gravity of the cement used was 3.16. Initial and final setting times of the cement were 3.5 and 4.5 h, respectively. The Blaine specific surface area was 3100 cm^2/g. The remaining cement on 200- and 90-μm sieve were 0% and 0.4%, respectively. The chemical composition is given in Table 1.

2.2. Fly ash

The FA used was obtained from a power plant, Afsin-Elbistan Thermal Power Station, in Turkey. It contains high amount of calcium and sulfate [11,19]. It is classified as Class C FA, because it is obtained from lignite coal [20]. The chemical composition is given in Table 1. The specific gravity was 2.70 and Blaine specific surface area was 2900 cm^2/g. Remaining FA on the 45-μm sieve was 14%.

Some standard specifications ASTM [20], BSI [21], TSI [22] and EN [23] and properties of the FA are given in Table 2. Table 2 shows that the FA used in this investigation does not fully meet these standards requirements.

Table 2
Limits of standards for chemical composition and physical properties of FA

	BSI [21]	ASTM [20] Class C	TSI [22], EN [23]	FA
Max moisture	0.5	3	–	–
Max LOI	7.0	6	5.0	2.94
Max SO_3	2.5	5	3.0	12.06
Max MgO	4.0	5	–	1.58
Max alkali	–	1.5	–	1.83
Min SiO_2	–	40	–	18.95
Al_2O_3	–	–	–	–
Fe_2O_3	–	–	–	–
Min SAF	–	50	–	30.3
Max free lime	–	–	1.0–2.5	3
PAI min (%)	–	75	75% at 28 days, 85% at 90 days	84%, 92%
Max fineness (%) (remaining on 45-μm sieve)	12.5	34	40	14
Max expansion	–	–	10 mm	41

Table 3
Mortar mixture proportions for a cubic meter

Mixture name	PC (kg)	FA (kg)	Water (l)	Sand (kg)
M0	700	0	280	1400
M1	630	70	280	1400
M2	560	140	280	1400
M3	490	210	280	1400
M4	420	280	280	1400

2.3. Aggregate

The sand was uncrushed, quartzitic, natural sand with maximum size of 4 mm. The grading of sand complied with the requirements of ASTM C33. The absorption value of the sand was 1.5% and the relative density at saturated surface dry (SSD) condition was 2.67.

3. Mixture proportions and sample preparation

The proportions of control PC mortar mixture were 1:2:0.4 cement, sand and water, respectively. For the purpose of evaluating the influence of the FA on the strength and particularly shrinkage properties, the mortar mixtures containing 10%, 20%, 30% and 40% FA as cement replacement by mass were prepared. Although it was not quantified, a reduction was observed in the workability of mortar by the use of FA. Table 3 presents the compositions of the mortars prepared and tested.

Prismatic specimens with $40 \times 40 \times 160$ mm dimensions were prepared from both fresh PC and FA mortar mixtures for the strength measurements. After 24 h, they were then demoulded and placed in a humidity cabinet at 65% relative humidity and 20 ± 2 °C temperature. For the shrinkage measurement, the prismatic specimens with $25.3 \times 25.3 \times 284.6$ mm dimensions were prepared and demoulded the day after. Initial lengths of shrinkage specimens were measured before placing them into the humidity cabinet.

The flexural tensile strength measurements were performed on the prismatic specimens by four point loading test. The compressive strength measurements were carried out using the broken pieces of the prism specimens. The strength measurements of concrete were made at 1, 3, 7

Table 4
Compressive and flexural strength (MPa) of mortars produced

Mixture	1 day	3 days	7 days	28 days
M0	14.0 (2.40)	36.9 (3.60)	44.9 (5.11)	48.0 (6.12)
M1	16.3 (2.90)	36.1 (3.16)	39.0 (4.58)	47.3 (5.10)
M2	15.2 (2.65)	28.6 (3.25)	32.8 (4.06)	44.0 (5.01)
M3	12.6 (2.20)	25.0 (2.92)	29.1 (3.83)	41.0 (4.48)
M4	11.2 (1.90)	21.4 (2.62)	26.4 (3.85)	37.3 (4.12)

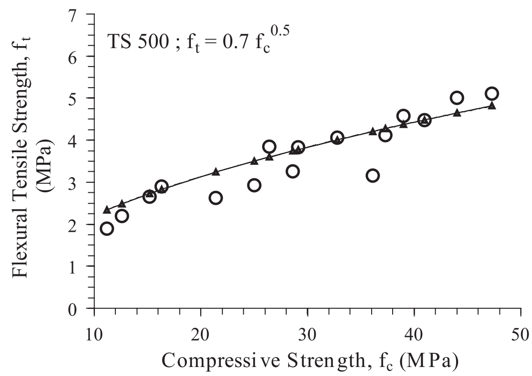

Fig. 1. The relation between flexural tensile strength and compressive strength.

and 28 days. The shrinkage measurements were carried out at the ages of 1, 2, 3, 7, 14 and 28 days, 3 months and 5 months.

4. Results and discussions

4.1. Compressive and flexural tensile strength

The compressive and tensile strength properties of PC and FA mortars measured in the laboratory are presented in Table 4. The values given in parentheses represent the flexural tensile strengths of mortars. Table 4 shows that all the mortar samples developed satisfactory compressive and flexural tensile strength at 1 day regardless of containing FA. Table 4 also shows that the compressive and tensile strengths of mortar containing FA were lower than the strengths of PC mortar in general. However, the strengths of the mortars containing 10% and 20% FA were comparable with the strength of PC mortar at 28 days.

4.2. The relation between compressive and tensile strength of FA mortars

An attempt was made to relate FA mortar compressive strength to its flexural tensile strength. The compressive strength and the corresponding flexural tensile strength data are plotted in Fig. 1. The ratio of flexural tensile strength to compressive strength of FA mortar was between 0.10 and 0.16, which is similar to PC concrete. A comparison was made between the experimental data of FA mortars and a function that was proposed by TS 500 [24] to express the relationship between compressive strength and flexural tensile strength of traditional concrete (Fig. 1). It is clear that there is a correlation between the present data and traditional relationship.

4.3. Drying shrinkage

Results of drying shrinkage or length change of mortar samples are presented in Fig. 2. The figure shows that FA mortar shrank less than PC mortar did at all ages. When the shrinkage value at 5 months was considered, the shrinkage of FA mortar samples showed considerable reduction compared with PC mortar shrinkage. The more the replacement of FA, the more the reduction in shrinkage. For example, compared with PC mortar, the shrinkages of mortar containing 10%, 20% and 30% FA reduced 25%, 37% and 43%, respectively, at the end of 5 months. The mortar containing 40% FA expanded. This may, however, be due to free lime and MgO content of FA. It should be noted that SO_3 content of the FA was very high. This may be another reason for the expansive behavior, which may cause longer-term instability. Therefore, longer-term properties of the mortars should be monitored.

It is known that shrinkage is associated with all PCs. Shrinkage increases as the amount of cement increases for a unit volume of a mixture. The reduction in shrinkage with

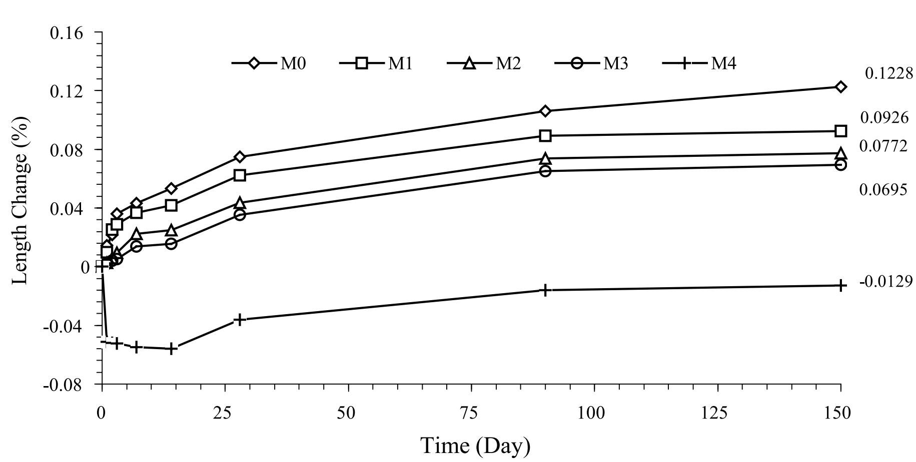

Fig. 2. Length change of mortar produced versus time.

the use of FA in mortar could be explained by the dilution effect of FA. The expansive property of FA most probably contributed to the reduction in drying shrinkage.

Based on the strength and shrinkage measurement results, it can be concluded that the Afsin-Elbistan FA could be utilized in cement-based materials as a mineral additive particularly in concrete pavement, large industrial concrete floors, parking lot applications or rock bolt applications of rock engineering where shrinkage should be avoided.

The expansive property of the FA demonstrates that it may be used as a shrinkage-reducing agent or in production of a shrinkage compensating cement. The right amount of FA for a mixture can be determined through a testing trial for compensating the shrinkage.

5. Summary and conclusions

The laboratory testing results showed that mortar samples containing Afsin-Elbistan FA developed satisfactory compressive and flexural tensile strengths 1 day after casting. In addition, FA mortar samples of 10% and 20% FA as cement replacement developed comparable strength with PC mortar at 28 days. Furthermore, the drying shrinkages of FA mortar samples were reduced about 30–40% when compared with PC mortar. The mortar samples containing 40% FA expanded instead of shrinking. Based on the strength and shrinkage measurement results, it was concluded that the nonstandard Afsin-Elbistan FA could be utilized in cement-based materials as mineral additive, particularly in concrete pavement, large industrial concrete floors, parking lot applications or rock bolt applications of rock engineering where shrinkage should be avoided. Based on expansive property of present FA, it may also be concluded that the FA may be utilized as cement reducing agent or in production of a shrinkage compensating cement. However, further studies are needed to investigate long-term properties of the mortars produced before using the Afsin-Elbistan FA as a mineral additive or in production of a shrinkage compensating cement.

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References

[1] M.N. Haque, B.W. Langan, M.A. Ward, High fly ash concrete, ACI Mater. J. 81 (1) (1984) 54–60.
[2] K.D. Hansen, W.G. Reinhardt, Roller-Compacted Concrete Dams, McGraw Hill, New York, 1991.
[3] A. Nanni, D. Ludwig, J. Shoenberger, Roller compacted concrete for highway pavements, Concr. Int. 18 (5) (1996) 33–38.
[4] A. Delagrave, J. Marchand, M. Pigeon, J. Boisvert, Deicer salt scaling resistance of roller compacted concrete pavements, ACI Mater. J. 96 (2) (1997) 164–169.
[5] D.W. Pittman, S.A. Ragan, Drying shrinkage of roller-compacted concrete for pavement applications, ACI Mater. J. 95 (1) (1998) 19–25.
[6] C.D. Atis, Heat evolution of high-volume fly ash concrete, Cem. Concr. Res. 32 (5) (2002) 751–756.
[7] C.D. Atis, High volume fly ash abrasion resistant concrete, J. Mater. Civ. Eng. 14 (3) (2002) 274–277.
[8] C.D. Atis, O.N. Celik, Relation between abrasion resistance and flexural strength of high volume fly ash concrete, Mater. Struct. 35 (248) (2002) 257–260.
[9] P.K. Mehta, Pozzolanic and cementitious by-products as mineral admixtures for concrete—a critical review, Proceedings of 1st International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-Products in Concrete, Proceedings of Montebello Conference, ACI SP-79, American Concrete Institute, Detroit, USA, 1983, pp. 1–48.
[10] V.M. Malhotra, Fly ash, silica fume and rice-husk ash in concrete: a review, Concr. Int. 15 (4) (1993) 23–28.
[11] T.Y. Erdogan, Admixtures for Concrete, Middle East Technical University Press, Ankara, Turkey, 1997.
[12] A.M. Neville, Properties of Concrete, 4th ed., Longman Group, UK, 1995.
[13] R.S. Ghosh, J. Timusk, Creep of fly ash concrete, ACI Mater. J. 78 (5) (1981) 351–357.
[14] J.B. Cripwell, J.J. Brooks, P.J. Wainwright, Time dependent properties of concrete containing pulverised fuel ash and a superplasticizer, Proceedings of the 2nd International Conference on Ash Technology and Marketing, Barbican Centre, London, Central Electricity Generating Board, London, UK, 1984, pp. 313–320.
[15] P. Nelson, V. Srivivatnanon, R. Khatri, Development of high volume fly ash concrete for pavements, Proceedings of the 16th ARRB Conference, Perth, Australia, Austroads, Australia, 1992, pp. 37–47.
[16] I. Teorenau, L.D. Nicolescu, The properties of power station fly-ash concrete, Proceedings of the International Symposium on the Use of PFA in Concrete, Leeds, England, Central Electricity Generating Board, London, UK, 1982, pp. 231–241.
[17] TSI, TS19, Portland Cements, Ankara, Turkey, 1992, in Turkish.
[18] BSI, BS 12, Specification for Portland Cement, London, 1996.
[19] M. Tokyay, K. Erdogdu, Characterisation of Fly Ash Obtained from Turkish Thermal Power Station, TÇMB/AR-GE/Y-98.3, Publication of Turkish Cement Manufacturers Association, Turkey, 1998.
[20] ASTM C-618, Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete, Annual Book of ASTM Standards, 1991.
[21] BSI, BS 3892, Part 1, Specification for Pulverized-Fuel Ash for Use with Portland Cement Part 1, London, 1993.
[22] TSI, TS EN450-1, Fly Ash for Concrete—Definitions, Requirement and Quality Control, Ankara, Turkey, 1998, in Turkish.
[23] European Standard, EN 450, Fly Ash for Concrete—Definitions, Requirement and Quality Control, Brussels, 1994.
[24] TSI, TS 500, Requirements for Design and Construction of Reinforced Concrete Structures, Ankara, Turkey, 2000, in Turkish.