Properties of Fine Aggregate-Replaced High Volume Class F Fly Ash Concrete

Rafat SIDDIQUE

Department of Civil Engineering, Thapar University, Patiala (Punjab) - 147004, India.
E-mail(s): siddique_66@yahoo.com

[*] Corresponding author: Phone: (91) 9876078644; Fax: (91) 2393005

Abstract

This study focused on evaluating the effects of replacement of fine aggregate (sand) with high percentages of Class F fly ash on the properties of concrete. A Control mixture was designed to have 28 days cube compressive strength of 30 MPa, and then fine aggregate was replaced with three percentages (35, 45, and 55%) of Class F fly ash by mass. Tests were performed for compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, and abrasion resistance. Test results indicated that replacement of fine aggregate with high volumes of Class F fly ash increased 28 days compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, and abrasion resistance depending upon the fly ash content, and showed continuous improvement at later ages (91 and 365 days).

Keywords

Abrasion resistance; Compressive strength; Concrete; Fine aggregate; Flexural strength; Fly ash; Modulus of elasticity; Splitting tensile strength.

Introduction

The use of fly ash in concrete is very common as partial replacement for cement, and both Class C and Class F fly ash have been successfully used in high-volumes in structural and other applications. However, the percentage utilization of fly ash in many countries is between 15 to 30 percent. Disposal of unutilized fly ash causes severe ecological problems and is quite expensive. This study was undertaken to utilize large quantities of Class F fly ash produced in India, where percentage utilization is between 10 to 15 percent. So, this investigation explored the possibility of replacing part of fine aggregate with Class F fly ash in concrete.

Significant work has been reported on the use of Class F fly ash in concrete. Authors [1-5] reported that concrete containing high volumes of Class F fly ash exhibited excellent mechanical properties and durability characteristics. Influence of Class F fly ash on the abrasion resistance of concrete has been reported by many authors [4-9]. Ghafoori and Diawara [10] reported that resistance to wear of concrete containing silica fume, as a fine aggregate replacement was consistently better with increasing amounts of silica fume up to 10 percent. Poon [11] reported that concrete with a 28 days compressive strength of 80 MPa could be obtained with a low-calcium fly ash content of 45%.

Ravina [12] reported the effects of high volume of fly ash (two Class F and two Class C fly ashes) as partial fine sand replacement on the fresh concrete properties. Ghafoori et al. [13] concluded that good strength, stiffness, drying shrinkage and resistance to wear and repeated freezing and thawing cycles could be obtained with concretes containing bottom ash. Hwang et al. [14] concluded that rheological constants (yield and plastic viscosity) increased with higher replacement level of fine aggregate with fly ash and that, when water to portland cement ratio was maintained, the strength development and carbonation properties were improved. Bakoshi et al. [15] reported that use of bottom ash as replacement for fine aggregate increased the compressive and tensile strength of concrete. Siddique and Kadri [16] reported reinforcement of high-volume fly ash concrete with natural fibres.

This research was carried out to evaluate the performance of Class F fly ash in concrete with respect to compressive strength, splitting tensile strength, flexural strength, modulus of elasticity and abrasion resistance. Results of this investigation could be very useful in the use of high volume of class F fly ash in concrete construction.

Material and Method

Materials

Ordinary Portland (43 grade) cement was used. It met all the requirements of Indian Standard Specifications IS: 8112 [17]. Class F fly ash was used, and it met all the requirement of ASTM C 311. It had SiO_2 (53.3%), Al_2O_3 (25.4%), Fe_2O_3 (5.6%), (SiO_2 + Al_2O_3 + Fe_2O_3) (84.3%), CaO (4.2), MgO (2.1%), TiO_2 (1.3%), K_2O (0.6%), Na_2O (0.4%), SO_3 (1.4%), LOI (1.9%), and moisture (0.3%). Fine aggregate was natural sand having a 4.75 mm nominal size. The coarse aggregate was 12.5 mm nominal size gravel. Both aggregates met the requirements of Indian Standard Specifications IS: 383 [18]. The specific gravity of fine and coarse aggregate was 2.64 and 2.62, respectively whereas their fineness modulus was 2.32 and 6.65, respectively.

Mixture Proportions

Control mixture (M-1) was proportioned to have 28 days cube compressive strength of 30 MPa. Three additional concrete mixtures (M-2, M-3 and M-4) were proportioned where fine aggregate (sand) was replaced with Class F fly ash. The replacement levels of fine aggregate were 35, 45 and 55% by weight. Mixture proportions are given in Table 1.

Table 1. Concrete mixture proportions

Mixture No.	M-1	M-2	M-3	M-4
Cement (kg/m^3)	400	400	400	400
Fly ash (percent)	0	35	45	55
Fly Ash (kg/m^3)	0	200	257	314
Water (kg/m^3)	185	196	208	224
W/Cm	0.46	0.33	0.32	0.31
Sand SSD (kg/m^3)	570	370	313	256
Coarse Aggregate (kg/m^3)	1190	1190	1190	1190
Superplasticizer (l/m^3)	2.2	4.1	4.4	4.9
Slump (mm)	90	50	30	25
Air content (percent)	3.1	2.5	2.6	2.3
Air Temperature (^{o}C)	26	27	26	27
Concrete Temperature (^{o}C)	27	28	28	29
Density (kg/m^3)	2347	2360	2372	2389

Preparation and Casting of Specimens

150 mm cubes were cast for compressive strength, 150×300 mm cylinders for splitting tensile strength, 100×100×500 mm beams for flexural strength, 150×300 mm cylinders for modulus of elasticity, and specimens of size 65×65×60 mm for abrasion resistance. All the specimens were prepared in accordance with IS: 1199 [19]. After casting, specimens were covered with plastic sheets, and left in the casting room for 24 hours at a temperature of about 23^{o}C. They were demolded after 24 hours, and were put into a water-curing room until the time of the test. Three specimens were cast for each of the properties for all test ages.

Testing of Specimens

Tests for compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity were conducted at the ages 7, 28, 91, and 365 days per Indian Standard Specifications IS: 516 [20]. Abrasion test was performed at the ages of 28, 91 and 365 days in accordance with Indian Standard Specifications IS: 1237 [21].

For abrasion testing, specimens were weighed accurately on a digital balance. After initial drying and weighing, thickness of the specimens was measured at five points (i.e. one at the center and four corners with micrometer). The grinding path of the disc of the abrasion-testing machine was evenly distributed with 20-gram abrasive powder (aluminum powder). The specimens were fixed in the holding device of the abrasion machine, and a load of 300 N was applied. The grinding machine was then put on motion at a speed of 30 revolutions per minute, and the abrasive powder was continuously fed back in to the grinding path so that it remained uniformly distributed in the track corresponding to the width of the test specimen. Each specimen was abraded for 60 minutes. The tests were performed for the specified time periods, and the readings were taken at every 5 minutes interval. When the abrasion test was over, specimens were weighed again to calculate the loss of weight. The thicknesses of the specimens were again measured at five points. The extent of abrasion was determined from the difference in values of thickness measured before and after the abrasion test. The results were also confirmed with the calculated average loss in thickness of the specimens using the following formula:

$$T = \{(W_1-W_2) \cdot V_1\}/(W_1 \cdot A)$$

where: T is average loss in thickness in mm; W_1 is the initial weight of the specimen in gram; W_2 is the mass of the specimen after abrasion in gram; V_1 is the initial volume of the specimens in mm^3; A is the surface area of the specimens in mm^2

Results and Discussions

Compressive Strength

Compressive strength results are shown in Fig. 1.

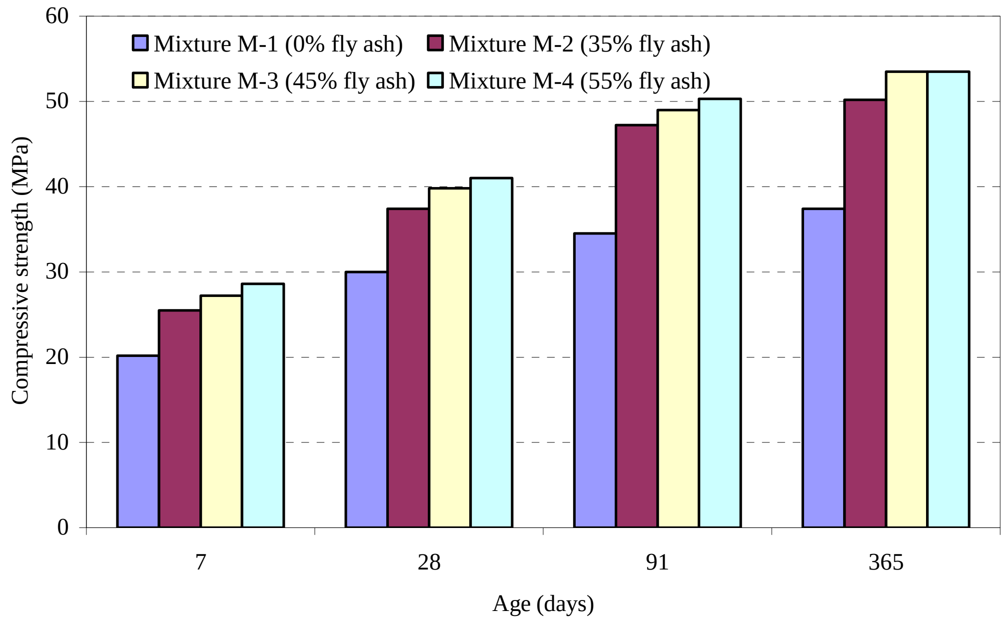

Figure 1. *Compressive strength vs age*

Compressive strength of concrete mixtures with 35, 45, and 55% fine aggregate replacement with fly ash was higher than the Control mix (M-1) at all ages. It is also evident that the strength increased with increase in fly ash percentages for all ages. At 7 days, the percentage increase in compressive strength with respect to the Control mixture was 26, 35, and 41% for Mixtures M-2 (35% fly ash), M-3 (45% fly ash), and M-4 (55% fly ash), respectively, whereas the increase in strength was 25, 33 and 41% at 28 days, 37, 42, and 46% at 91 days, and 34, 43, and 43% at 365 days. However, beyond, 45% fly ash content, the rate of increase in strength decreased with the increase in fly ash content. Beyond 45% fly ash content, the lack of significant increase in strength of the concrete mixtures is probably due to the non-availability of calcium hydroxide from hydration reaction. The increase in strength due to the replacement of fine aggregate with fly ash is attributed to the densification of the paste structure due to the pozzolanic action between fly ash and calcium hydroxide liberated as a result of hydration of cement, and also due to the increase in cementitious materials in the mixtures and subsequently reduced water to cementitious materials ratio (w/cm).

Splitting Tensile Strength

Splitting tensile strength results are shown in Fig. 2. Splitting tensile strength of concrete mixtures increased with increase in fly ash content at all ages. At 7 days, the percentage increase in strength was 7, 10 and 7% respectively for Mixtures M-2 (35% fly ash), M-3 (45% fly ash), and M-4 (55% fly ash), whereas increase in strength was 12, 18, and 21% at 28 days, 19, 24, and 22% at 91 days, and 18, 21, 21% at 365 days.

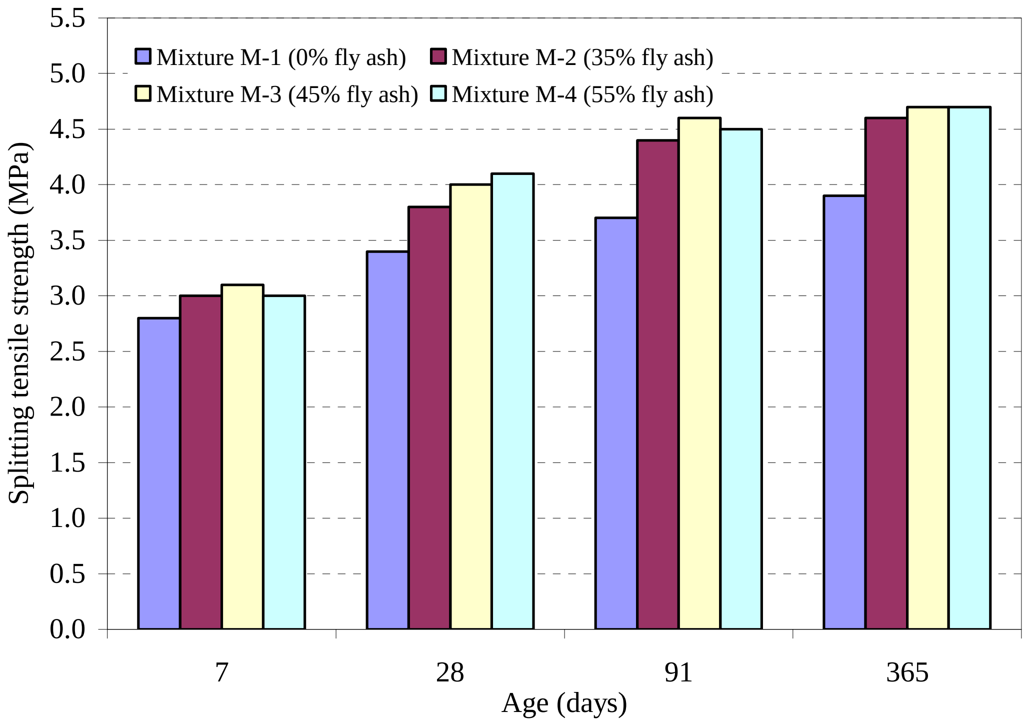

Figure 2. *Splitting tensile strength vs age*

It can also be seen from Fig. 2 that there was increase in strength with the increase in fly ash percentages, however the rate of increase of strength became less with the increase in fly ash content. This trend was more obvious between 45 and 55% replacement level. The rate of increase in strength was more prominent after 28 days. This may be attributed to the late pozzolanic reaction for forming pozzolanic C-S-H gel.

Flexural Strength

The flexural strength results are shown in Fig. 3.

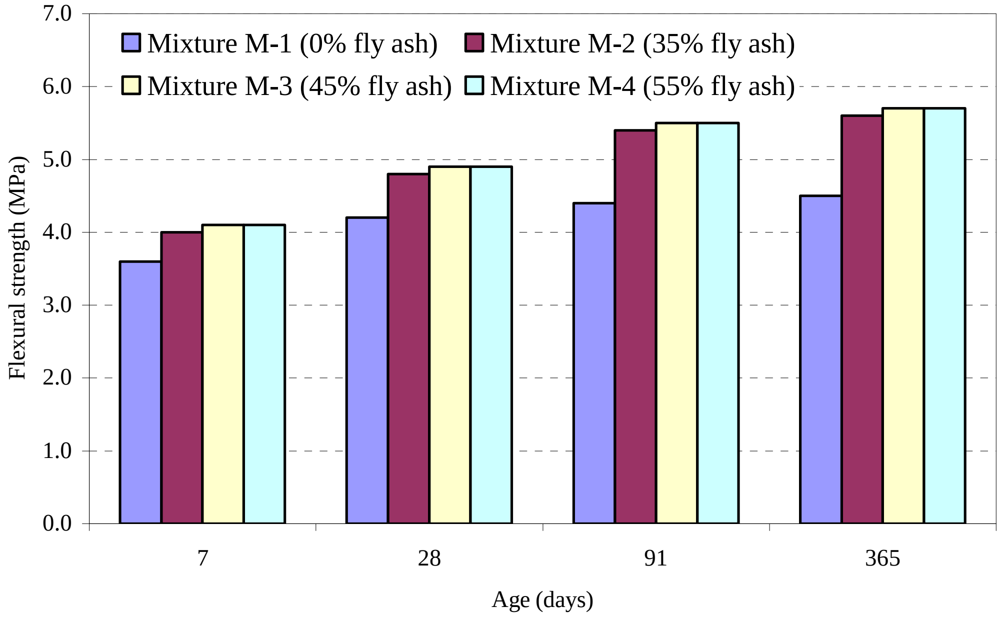

Figure 3. *Flexural strength vs age*

Flexural strength of concrete mixtures continued to increase with the age. At 7 days, fly ash concrete mixtures performed better than the Control Mixture (M-1). At 28 days, all the concrete mixtures containing fly ash produced higher flexural strengths (14 to 17%) more than the Control Mixture (4.4 MPa). Similar trend in strength was also observed at the ages of 91 and 365 days. It can also be seen from the Fig. 3 that flexural strength continued to increase with the increase in fly ash percentages at all ages, and there was significant increase in strength with that of strength of control mixture. This is believed to be due to the large pozzolanic reaction and improved interfacial bond between paste and aggregates.

Modulus of Elasticity

Results of modulus of elasticity are shown in Fig. 4.

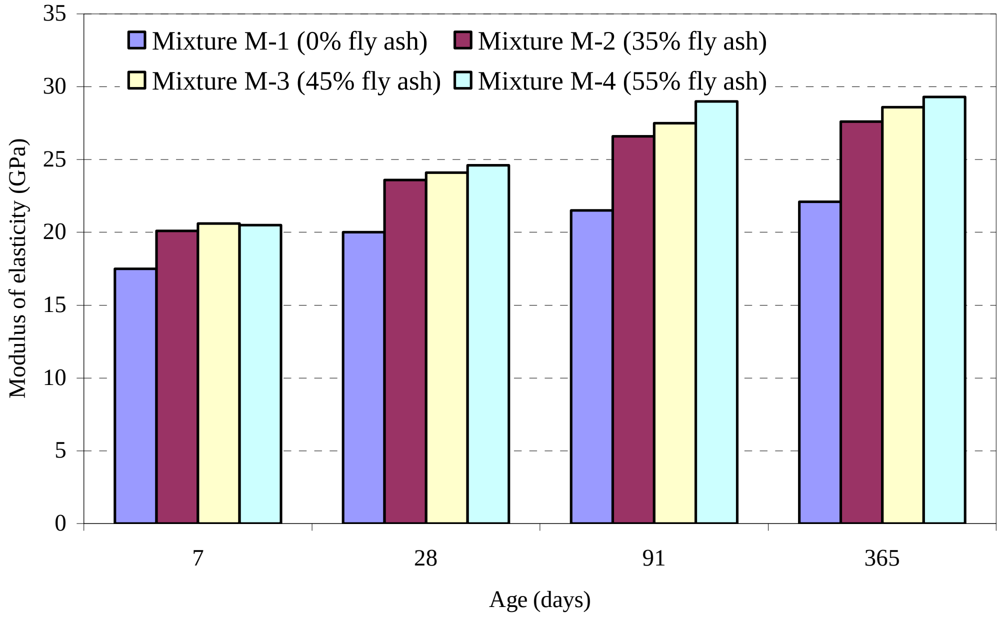

Figure 4. *Modulus of elasticity vs age*

From the test results, it can be seen that the modulus of elasticity of the concrete mixtures with 35, 45, and 55% fine aggregate replacement was higher than the Control mixture (M-1) at all ages. At 28 days, concrete mixtures containing fly ash had higher modulus of elasticity (18 to 23%) than the Control Mixture (20 GPa). From Fig 4, it can be seen that modulus of elasticity of all mixtures continued to increase with age. It is also evident that the modulus of elasticity of concrete mixtures continued to increase with the increase in fly ash content. However the rate of increase is became less with the increase in fly ash content. This trend was more obvious between 45 and 55% replacement level. However, maximum strength at all ages occurs at 55% fine aggregate replacement.

Abrasion Resistance

The abrasion resistance (depth of wear) of concrete mixtures after 60 minutes of abrasion at the ages of 28, 91, and 365 days are shown in Fig. 5. It is evident that with the increase in percentage of fine aggregate replacement with fly ash, depth of wear decreased.

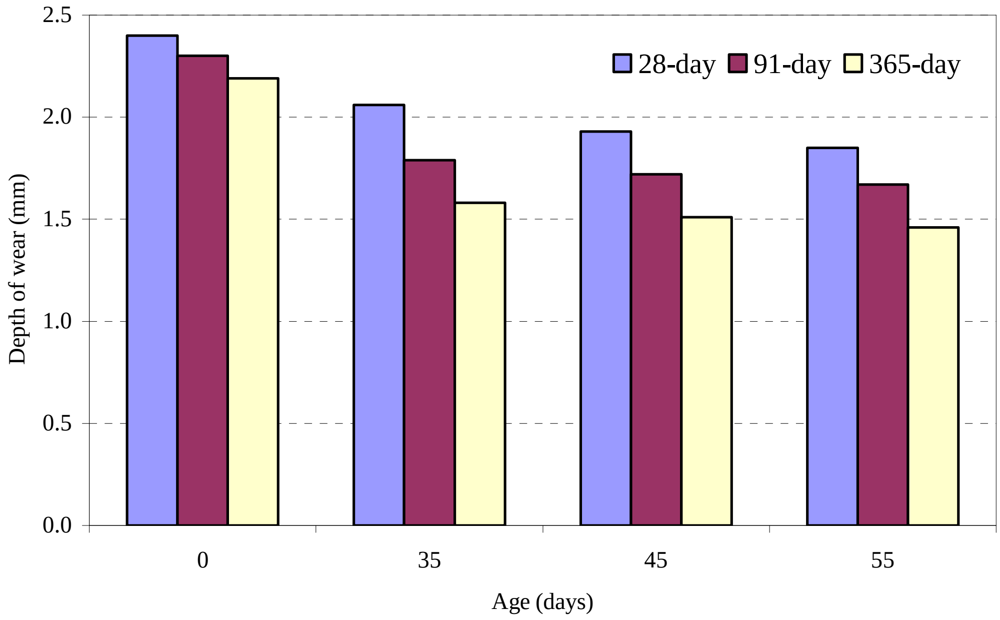

Figure 5. *Depth of wear (abrasion resistance) at 60 minutes of abrasion*

After 60 minutes of abrasion, depth of wear for Control mixture (0% fly ash) was 2.4 mm at 28 days, 2.25 mm at 91 days, and 2.13 mm at 365 days. Whereas depth of wear was 2.06 mm at 28 days, 1.79 mm at 91 days, and 1.58 mm at 365 days for Mixture M-2 (35% fly ash), 1.93 mm at 28 days, 1.72 mm at 91 days, and 1.51 mm at 365 days for Mixture M-3 (45% fly ash), 1.85 mm at 28 days, 1.67 mm at 91 days, and 1.46 mm at 365 days for Mixture M-4 (55% fly ash). This showed that for a particular percentage of fine aggregate replacement with fly ash, depth of wear decreased with increase in age, which means that abrasion resistance of concrete increased with age. This could be attributed to the increase in compressive strength resulting from increased maturity of concrete with age, and densification of the concrete matrix.

Conclusions

Following conclusions can be drawn from this study:

1. Replacement of fine aggregate with high-volumes of Class F fly ash significantly enhanced the compressive strength, splitting tensile strength, flexural strength and

modulus of elasticity and abrasion resistance of concrete with the increase in fly ash content at all ages.

2. At 28 days, compressive strength of concrete increased by 25 to 41%, splitting tensile strength by 12 to 21%, flexural strength 14 to 17%, and modulus of elasticity by 18 to 23%, depending upon the fly ash content, and there was continuous improvement in all these properties at 91 and 365 days.
3. Abrasion resistance was found to increase with the increase in age for all mixtures. Maximum depth of wear is found to be maximum at 60 minutes of abrasion time for all mixtures.

References

1. Ravina D., Mehta P. K., *Properties of fresh concrete containing large amounts of fly ash,* Cement and Concrete Research, 1986, 16(2), p. 227-238.
2. Bilodeau A., Sivasundaram V., Painter K. E., Malhotra V. M., *Durability of concrete incorporating high volumes of fly ash from sources in the USA*, ACI Materials Journal, 1994, 91(1), p. 3-12.
3. Giaccio G. M., Malhotra V. M., *Concrete incorporating high volumes of ASTM Class F fly ash*, Cement, Concrete and Aggregates, 1988, 10(2), p. 88-95.
4. Langley W. S., Carette G. G., Malhotra V. M., *Structural concrete incorporating high volumes of ASTM Class F fly ash*, ACI Materials Journal, 1989, 86(5), p. 507-514.
5. Malhotra V. M., *Durability of concrete incorporating high-volume of low-calcium (ASTM class F) fly ash*, Cement & Concrete Composites, 1990, 12 (4), p. 271-277.
6. Bilodeau A., Malhotra V. M., *Concrete incorporating high volumes of ASTM class F fly ashes:* mechanical *properties and resistance to deicing salt scaling and to chloride-ion penetration*, Proceedings of the CANMET/ACI Fourth International Conference on the Use of Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete, Istanbul, Turkey, ACI SP-132, Editor V.M. Malhotra, American Concrete Institute, 1992, pp. 319-349.

7. Langan B. W., Joshi R.C., Ward M.A., *Strength and durability of concrete containing 50 percent Portland cement replacement by fly ash and other materials*, Canadian Journal of Civil Engineering, 1990, 17, p. 19-27.

8. Liu T.C., *Abrasion resistance of concrete, ACI Journal Proceedings*, 1981, 78(5), p.341-350.

9. Ghafoori N., Diawara H., *Abrasion resistance of fine aggregate-replaced silica fume concrete*, ACI Materials Journal, 1999, 96(5), p.559-567.

10. Tikalsky P. J., Carrasquillo P. M., Carrasquillo, R. L., *Strength and durability considerations affecting mix proportions of concrete containing fly ash*, ACI Materials Journal, 1988, 85(6), p. 505-511.

11. Poon C. S., *Study on high strength concrete prepared with large volumes of low-calcium fly ash*, Cement and Concrete Research, 2000, 30(3), p.447-455.

12. Ravina D., *Properties of fresh concrete incorporating a high volume of fly ash as partial fine sand replacement*, Materials and Structures, 1997, 30(202), p. 473-479.

13. Ghafoori N., Cai Y., Ahmadi B., *Use of dry bottom ash as a fine aggregate in roller compacted concrete*, ACI Special Publication (SP-171), 1997, p. 487-507.

14. Hwang K. R., Noguchi T., Tomosawa F., *Effects of fine aggregate replacement on the rheology, compressive strength and carbonation properties of fly ash and mortar,* ACI Special Publication (SP-178), 1998, p. 401-410.

15. Bakoshi T., Kohno K., Kawasaki S., Yamaji N., *Strength and durability of concrete using bottom ash as replacement for fine aggregate*, *ACI* Special Publication (SP-179), 1998, p. 159-172.

16. Siddique R., Kadri E.-H., *Properties of High-Volume Fly Ash Concrete Reinforced with Natural Fibres*, Leonardo Journal of Sciences 2012, 21(11), p. 83-98.

17. IS: 8112, *Specifications for 43-Grade portland cement*, Bureau of Indian Standards, New Delhi, India, 1989.

18. IS: 383, *Specifications for coarse and fine aggregates from natural sources for concrete*, Bureau of Indian Standards, New Delhi, India, 1970.

19. IS: 1199, *Indian standard methods of sampling and analysis of concrete*, Bureau of Indian Standards, New Delhi, India, 1959.

20. IS: 516, *Indian standard code of practice- methods of test for strength of concrete,* Bureau of Indian Standards, New Delhi, India, 1959.

21. IS: 1237, *Method for testing abrasion resistance of concrete*, Bureau of Indian Standards, New Delhi, India, 1980.