MECHANICAL PROPERTIES OF BINARY BLENDED CONCRETE MIXES FOR RIGID PAVEMENT

Nikunj Sureja and Dipak Rathva
The Maharaja Sayajirao University of Baroda, Vadodara
nikunj10sureja@gmail.com & dipak_rathva@yahoo.co.in

Dinesh Ganvir and Binod Kumar
CSIR-Central Road Research Institute, New Delhi
dineshvganvir@gmail.com & binod.crri@nic.in

ABSTRACT

With the current demand for rigid pavement sustainability, supplementary cementitious materials (SCMs) are frequently used in concrete mixtures to improve the properties of mixture. The sustainable pavement should minimize the use of natural resources, reduce energy consumption and limit pollution. To construct sustainable rigid pavement, byproduct waste fly ash (FA) and ground granulated blast furnace slag (GGBFS) can be used as partial replacement of cement which can lead to eco-friendly construction of rigid pavement. It also reduces carbon footprint and other greenhouse gases which are emitted into air during manufacturing process of cement.
In this study effort have been made to study the influence of fly ash (FA) and Ground Granulated Blast Furnace Slag (GGBFS) on binary blended concrete mixes. In this experiment both fresh and harden properties of concrete mixes were studied. In this research, thirteen concrete mixtures (one control mixture, twelve binary mixtures) with various combinations of fly ash, GGBFS and portland cement were prepared. Two series of concrete mixes prepared i.e. (1) Binary blended concrete with FA (2) Binary blended concrete with GGBFS. All series of concrete mixes were prepared with same water-binder ratio of 0.38. Total cementitious material was kept constant which replacing cement with fly ash and GGBFS. The blending was done at 20%, 30%, 40%, 50%, 60% and 70% replacement of cement. Fresh properties of concrete were tested in term of compaction factor and harden properties of concrete were tested for compressive strength and flexural strength at 7, 28, and 90 days. Drying shrinkage of concrete was also tested after 28 days for all concrete mixes.

It was concluded that use of FA and GGBFS improve the properties of concrete. The results showed that concrete blended with GGBFS exhibit higher strength than concrete blended with fly ash. Fly ash blended concrete gained strength slowly compare to GGBFS blended concrete. The study indicates that binary blended concrete mixes are better than conventional concrete mixes.

KEY WORD

Fly Ash, GGBFS, Binary, Compressive Strength, Flexural Strength, Drying Shrinkage

INTRODUCTION

Utilization of mineral admixtures like FA and GGBFS in binary blended concrete with cement enhances mechanical and durable properties of concrete. It makes concrete more eco-friendly and economical. Traditionally, ash (Fly ash and bottom ash) generated at coal based thermal power stations has been disposed off in ash ponds as waste material. Ash has now being utilized in most of the civil construction activities in an eco-friendly manner. Fly ash has pozzolanic properties and has a large number of applications in various construction activities.

There are two classes of FA defined by ASTM C618: Class F fly ash and Class C fly ash. Class F fly ash contains less than 7% lime (CaO). Possessing pozzolanic properties and the glassy silica. Class F fly ash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime mixed with water to react and produce the cementitious compound. In addition to having pozzolanic properties, class C fly ash also has some self-cementing properties. In the presence of water, Class C fly ash hardens and gets stronger over time. Class C fly ash generally contains more than 20% lime (CaO) (Pailyn Thongsanitgarn et al 2016).

GGBFS is byproduct acquired in the production of pig iron in the blast furnace. When the molten slag in pig iron blast furnace is rapidly cooled with water in a pond or cooled with water jets, it turns into a fine, granular, almost fully noncrystalline, glassy form known as granulated slag, having latent hydraulic properties (S.C. Pal et al 2003). Such granulated slag has been found excellent cementitious properties so it's used as cementitious material in the concrete mix.

Compressive strength, flexural strength and drying shrinkage are important properties for the designing and performance of the concrete pavements. Many researchers have studied the properties of binary blended concrete with FA and binary blended concrete with GGBFS. HVFA concrete attained satisfactory or higher compressive and tensile strengths compared to control mix concrete (Atis 2003). All the FA blended concrete mixes showed higher rates of strength gain as compared to control mix (Naik et al. 2002). Binod et al. 2007 studied the HVFA concrete mixes content with different w/c ratio of 0.3,0.34 and 0.4. The compressive strength and flexural strength with 0.4 w-cm ratio decreased at 7 and 28 days and increased with 0.3 and 0.34w-cm ratio. Drying shrinkage of concrete decreased with decreasing w/b ratio and increasing FA content. The mixture with w-cm ratio of 0.30 and containing 60% FA showed the least shrinkage.

GGBFS is a green construction material used to produce durable concrete. The secondary pozzolanic reactions can result in reduced pore connectivity; therefore, replacing the partial amount of portland cement with GGBFS can significantly reduce the risk of sulfate attack, alkali–silica reactions and chloride penetration.

GGBFS improves the workability and rheological properties. It modifies the segregation resistance and slump loss positively (Erdogan Ozbay et al. 2016). The compressive strength of concrete mixtures containing GGBFS increases as the amount of GGBFS increase. After an optimum point, at around 55% of the total binder content, the addition of GGBFS does not improve the compressive strength. This can be explained by the presence of unreacted GGBFS, acting as a filler material in the paste (A. Oner et al. 2007). It was confirmed by many research that binary blended concretes with GGBFS have the same or relatively higher flexural strength when compare with the Plain concrete at ages of later than 7 days. Malhotra et al. (1992) studied the flexural strength variation of concretes with high volumes of GGBFS. Three series of concrete mixtures were produced with cement dosages of 100, 125, and 150 kg/m^3 and GGBFS replacement rate of from 50% to 75% of the total cementitious materials. It was concluded that 14-day flexural strengths of most of the GGBFS concretes, were relatively higher than the control concretes. Darquennes et al. (2012) investigated the free shrinkage of concretes including up to 75% GGBFS and concluded that less than or equal to 50% of GGBFS, the total shrinkage are lower than that of a PC concrete.

This investigation is aimed at developing binary blended concrete suited to concrete pavement construction and evaluating its short-term and long-term strength and drying shrinkage. Various concrete mixtures with same water-binder (w/b) ratios were prepared with different content of FA and GGBFS as partial replacement of cement and a superplasticizer was used to achieve desired workability.

MATERIALS

Cement

UltraTech Ordinary Portland Cement (OPC) of 43 grade is used in this study. All cement bags belonged to the same batch so that there would be no variation in their composition. The physical properties of OPC are presented in Table 1. Testing of cement is done as per IS 4031 and found to have following properties:

TABLE 1 Physical Properties of OPC

Sr. No	Physical Properties	Results	As per IS 8112-2013
1	Specific Gravity	3.18	-
2	Standard Consistency	27%	-
3	Initial Setting Time	165 min	≥30 min
4	Final Setting Time	240 min	≤600 min
5	Compressive Strength 3 Days 7 Days 28 Days	 23 MPa 34 MPa 44 MPa	 ≥23 MPa ≥33 MPa ≥43 MPa

Fly Ash (FA)

In this study, low calcium FA collected from NTPC Dadri thermal plant (Uttar Pradesh, India) was used as partial replacement of cement in concrete. The tests were conducted to identify the important physical properties of FA. The results are given in Table 2 and satisfied the requirements as per IS: 3812-2013.

TABLE 2 Physical Properties of Fly Ash

Sr. No	Physical Properties	Results	As per IS 3812-2013
1	Lime Reactivity	5.5 MPa	≥4.5 MPa
2	Specific Gravity	2.14	-
3	Residue retain on 45μ (Wet Sieving)	25%	≤34%

Ground Granulated Blast Furnace Slag (GGBFS)

Tests on GGBFS or simply says slag is being performed to check whether this can be used as a pozzolana or not. Then these results can be compared with IS-3812 part1 which specifies guidelines for a material to be used as a pozzolana. Physical properties of GGBFS are given in Table 3.

TABLE 3 Physical Properties of GGBFS

Sr. No	Physical Properties	Results	As per IS 3812-2013
1	Lime Reactivity	14.86 MPa	≥4.5 MPa
2	Specific Gravity	2.96	-

Fine Aggregate

In this present investigation, locally available river sand was used as fine aggregate. Sand used in the study was tested according to the guidelines of Indian standard IS: 2386-1963. The physical properties of fine aggregate is given in Table 4

TABLE 4 Physical Properties of Fine Aggregate

Sr. No	Physical Properties	Results
1	Specific Gravity	2.62
2	Apparent Specific Gravity	2.64
3	Water Absorption	0.303
4	Fineness Modulus	1.94

Coarse Aggregate

In this study crushed quartzite coarse aggregates of nominal m.s.a. (mean size aggregate) of 10mm and 20 mm were used. The aggregate was tested as per the procedure given in IS: 2386-1963 and verify by IS: 383-1970. Mix proportion of coarse aggregate 10mm and 20mm are given in Table 5 and the results of physical properties of coarse aggregate are given in Table 6.

TABLE 5 Mix Proportion of CA

Sieve size (mm)	Analysis of CA Fraction, % Passing		Percentage passing of different Fraction			% passing for graded Agg. (IS 383-1970)
	20mm	10mm	55%(20mm)	45%(10mm)	100	
20	91.83	100.00	50.50	45.00	95.50	95-100
10	8.53	84.52	4.69	38.03	42.72	25-55
4.75	0.58	14.50	0.32	6.52	6.84	0-10

TABLE 6 Physical Properties of Coarse Aggregate

Sr. No	Physical Properties	10mm Aggregate	20mm Aggregate	Standards
1	Water Absorption	0.46	0.46	<2% (MORTH 2013)
2	Specific Gravity	2.74	2.74	-
3	Apparent Specific Gravity	0.77	0.78	-
4	Flakiness Index	31.11		<35% (IS:383-1970)
5	Elongation Index	16.93		
6	L.A. Abrasion Value	22.20		<30% (IS: 383-1970)
7	Impact Value	15.57		<30% (IS:383-1970)
8	Crushing Value	24.11		<30% (IS:383-1970)

Chemical Admixture

Chemical admixtures are used to help reach desired concrete mixture properties. The superplasticizer used is Master Glenium Sky 8777 which is a superplasticizer based on the second generation polycarboxylic ether polymers, developed using Nano-technology.

Water

Potable tap water was used to cast all mortar and concrete mixes as well as being used for curing the specimens.

MIX PROPORTION

Mix design for PQC M-40 grade concrete is done as per IRC: 44-2008 with the available materials viz. cement, sand and aggregates in the laboratory. Concrete mixtures with w/c ratio of 0.38 was prepared with 0.4% of PC based superplasticizer for getting proper workability. The cement content of the control mix was fixed as 400 kg/m^3, which is more than 350 kg/m^3 (min limit specified in IRC 44-2008) and less than 425 kg/m^3 (max limit specified by IRC 44-2008). For preparing binary blended concrete, the replacement of cement by FA or GGBFS was considered as 20%, 30%, 40%, 50%, 60% and 70% by mass of cement. The various mix combinations of binary blended concrete and control mix are shown in the Table 7. In binary blended FA concrete, the increase in volume of equal mass of FA, due to lesser specific gravity of them as compared to that of cement, was adjusted by decreasing the content of fine aggregate.

EXPERIMENTAL PROGRAM

Green Properties of Concrete:

Green properties or fresh properties of concrete like workability of concrete was measured in terms of compacting factor. The compacting factor of the concrete is determined as per IS: 1199-1959.Workability of concrete is a composite property which includes mobility, stability, compatibility and finish ability of fresh concrete. This test is performed to get the compatibility aspect as a workability of fresh concrete.

TABLE 7 Mix proportions for various mixes per m^3 of concrete

Mixes	Cement (kg)	FA (kg)	GGBFS (kg)	CA 20mm (kg)	CA 10mm (kg)	Sand (kg)	Water (kg)
*CM	400	0	0	715	584	641	160
$^+$BF-20	320	80	0	715	584	609	160
BF-30	280	120	0	715	584	593	160
BF-40	240	160	0	715	584	577	160
BF-50	200	200	0	715	584	561	160
BF-60	160	240	0	715	584	545	160
BF-70	120	280	0	715	584	529	160
$^{++}$BS-20	320	0	80	715	584	636	160
BS-30	280	0	120	715	584	634	160
BS-40	240	0	160	715	584	631	160
BS-50	200	0	200	715	584	629	160
BS-60	160	0	240	715	584	626	160
BS-70	120	0	280	715	584	624	160

**CM – Control Mix, $^+$BF20 – Binary blended concrete with 20% FA, $^{++}$BS20 – Binary blended concrete with 20% GGBFS*

Compressive Strength

Concrete cubes of size 100×100×100 mm were casted for compressive strength test. Nine concrete cube specimens were casted for each mix. All the cube specimens were casted at average temperature of 27^{0}C and demoulded after 24 hours. They were tested at a period of 7, 28 and 90 days for compressive strength. The tests were carried out on a compression testing machine at constant loading rate as per IS 516:1959.

Flexural strength

The flexural strength is determined using flexural strength test. This test was conducted on beams of standard size of 500mm × 100 mm × 100 mm by three point loading system. Nine beam were casted for each mix. The constant load rate was applied till the failure of beam specimen. They were tested at a period of 7, 28 and 90 days for flexural strength.

Drying Shrinkage of Concrete

The drying shrinkage of the concrete was found as per the procedure of Indian Standard IS1199 (BIS 1959). The shrinkage of concrete takes place beyond 28 days is mainly because of drying shrinkage. This shrinkage of concrete takes place when the moisture from the pores of concrete evaporates or removed due to high temperature and then after concrete comes to normal temperature, a change in length have been recorded. For this concrete prism of 75*75*285 mm has been casted with gauge studs on both sides and tested at beyond 28 days.

RESULTS AND DISCUSSION

Green Concrete Properties

As per IS 1199-1959 workability is the property of concrete which determines the amount of useful internal work necessary to produce complete compaction. Here, workability of concrete was tested by conducting compaction factor test. The result of compaction value tests is given in Table 8. The compaction factor value for control mix concrete is 0.92. For a given w/b, increasing the dosage of FA increased the workability of binary blended concrete. For GGBFS, it increased up to 0.93 at 40% replacement after that it started decreasing.

TABLE 8 Compaction Factor Value

Cement Replacement by SCMs (%)	Binary Blended Concrete with FA	Binary Blended Concrete with GGBFS
20	0.91	0.91
30	0.92	0.92
40	0.92	0.93
50	0.93	0.92
60	0.94	0.92
70	0.94	0.92

Compressive Strength

The compressive strength of binary blended concrete with FA and GGBFS up to 70% was studied. Development of strength with age for different FA content is shown in Figure 1. In FA blended concrete, strength up to 28 days is mainly due to hydration of cement. The pozzolanic reaction of FA in concrete depends on the breakdown and dissolution of the glass phase. The pozzolanic reaction takes place between the FA and the $Ca(OH)_2$ produced from the hydration of portland cement. This pozzolanic reaction is a slow process and is responsible for the low early strength of the high volume FA concrete. After 28 days it started to gain the strength due to pozzolanic reaction produces some more C-S-H gel.

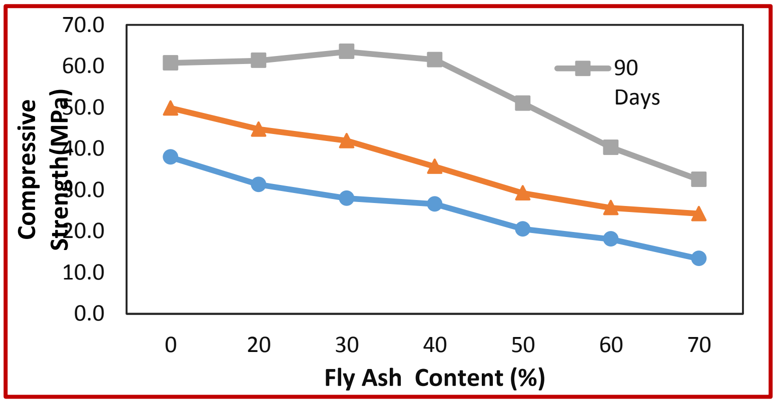

FIGURE 1 Development of compressive strength of concrete (FA)

The compressive strength of all concrete mixtures with w/b of 0.38 at 7 and 28 days decreases with increases in FA content. The compressive strength at 7 days decreases from 31.3 to 13.3 MPa and at 28 days it decreases from 44.7 to 24.2 MPa with increase in FA content from 20 to 70%. This is due to more percentage of cement is replaced by FA and FA is not taking part in achievement of compressive strength during initial period of setting. At 90 days the maximum compressive strength was observed as 63.5 MPa for BF-30 mix. With replacement of cement by FA more than 30%, same decreasing trend has been observed similar to 7 and 28 days.

Development of strength of binary blended concrete with different GGBFS content is shown in Figure 2. Unlike FA blended concrete, GGBFS blended concrete shows high strength at the early age of concrete due its high pozzolanic reactivity. The pozzolanic reaction of the GGBFS is more rapid when compared to that of the FA. For the dissolution of the glass phase of GGBFS , and this alkalinity level occurs in a short period after mixing the slag portland cement blend with water. This more rapid reaction is one of the factors causing a higher early strength of slag concretes.

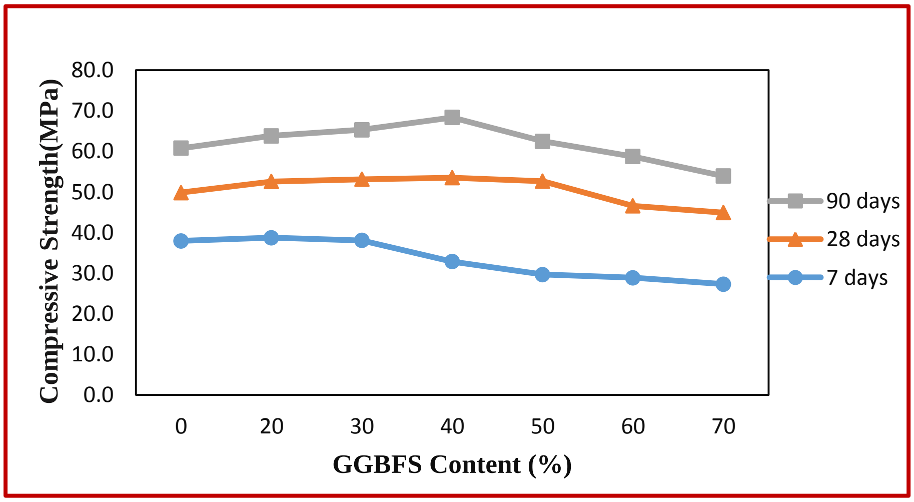

FIGURE 2 Development of compressive strength of concrete (GGBFS)

The compressive strength of GGBFS blended concrete started gaining the strength from 7 days. There is a reduction in compressive strength from 38.7 to 27.3 MPa with increasing GGBFS content at 7 days. In case of compressive strength at 28 and 90 days increasing trend has been observed for GGBFS content up to 40% and then there is a reduction in compressive strength with increase in GGBFS content beyond 40% at 28 and 90 days.

Flexural Strength of Concrete

The concrete prisms were tested under a third-point loading system to obtain the flexural strength at different ages. Development of flexural strength of GGBFS blended concrete is given in Figure 3. Flexural strength of binary blended concrete with FA decreases in 7 days with increased FA content. Maximum flexural strength at 7 days was observed 4.1 MPa for BF-20. Similar trend was observed for 28 days. Maximum flexural strength obtained was 4.7 MPa for BF-20 mix at 28 days and 6.5 MPa for BF-30 mix at 90 days. The flexural strength of control mix at 7 (4.6 MPa) and 28 (5.5 MPa) days comes higher compare to all blended concrete with FA while at90 days up to 30% FA having high flexural strength than control mix (6.2 MPa).

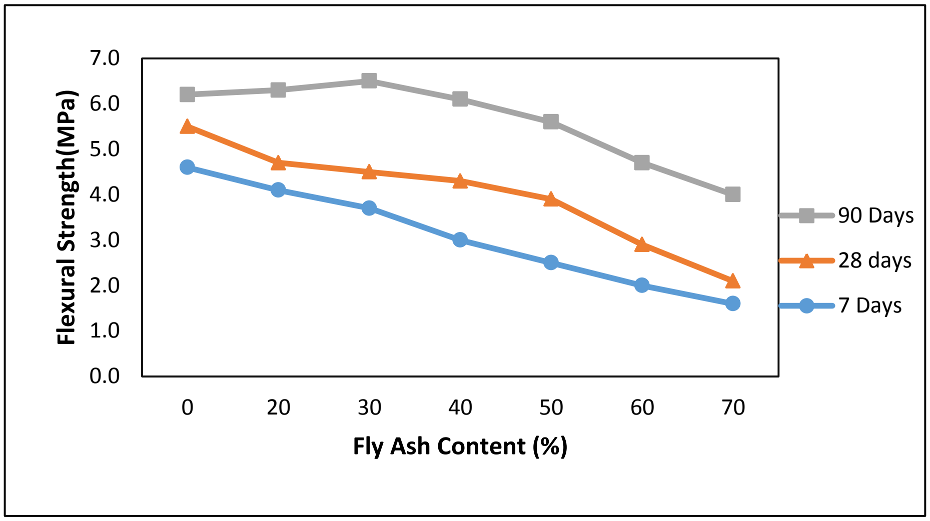

FIGURE 3 Development of flexural strength of concrete (FA)

Flexural strengths of binary blended concrete with GGBFS at different ages are shown in Figure 4. Flexural strength of BS-20 and BS-30 was 4.9 and 5.1 MPa which was more than flexural strength of control mix (4.6 MPa) at 7 days. After that, it decreases with increasing GGBFS content. 28 days flexural strength of all mixtures were greater than design strength (4.5 MPa). Maximum flexural strength was obtained 6.2 and 7.1 MPa of BS-40 mixture at 28 days and 90 days respectively. As shown in Figure 4, development of flexural strength of BS-40 mixture was 57.8% from 7 days to 90 days.

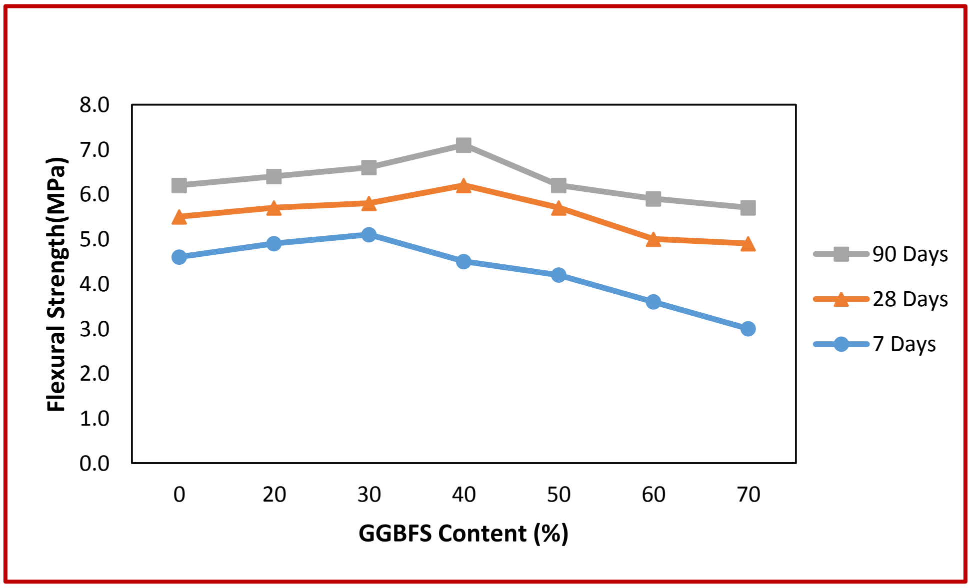

FIGURE 4 Development of flexural strength of concrete (GGBFS)

Drying Shrinkage of Concrete

The fundamental cause of drying shrinkage of concrete is the loss of adsorbed water from the gel particles, which reduces the volume of cement paste (Neville 1995). Thus, any decrease in cement paste due to the replacement of cement by FA or GGBFS is expected to lower the drying shrinkage of concrete.

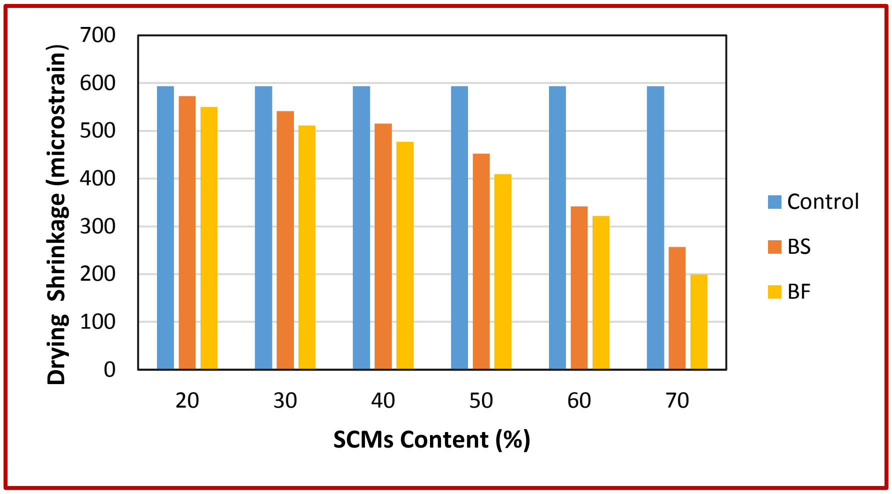

FIGURE 5 Variation of drying shrinkage of concrete with SCMs content

Drying shrinkage of concrete or the change in length due to change in moisture content was determined with an apparatus consisting of a digital dial gauge capable of measuring accurately up to 0.001 mm and mounted on a measuring frame. Figure 5 shows the variation of drying shrinkage of concrete with the increasing amount of SCMs in the mixture at 56 days. It was observed that the drying shrinkage of the concrete decreases with the increase in SCMs content of the mixture at same w/b ratio. The shrinkage value of the control mix was 593.1 microstrain. The shrinkage value of binary blended concrete decreases from 549.8 to 199.1 and 572.6 to 257 microstrain for FA and GGBFS, respectively.

CONCLUSIONS

- The workability of fresh concrete improves with increasing amount of FA and GGBFS. The workability of concrete was increased with increase in FA content. In binary blended concrete with GGBFS, it was comparable with control mix.
- The compressive strength of all the mixes was less than control mix (37.9 MPa) at 7 days except the BS-20 (38.7 MPa) and BS-30 (38.1 MPa) mixes. The compressive strength of BS-20, BS-30, BS-40 and BS-50 were higher than control mix and they achieved design strength at 28 days. All the mixes achieved target compressive strength (48.3 MPa) except BF-60 (40.3 MPa) and BF-70 (32.5MPa) at 90 days.
- Optimum dosage for binary blended concrete with FA and GGBFS were 30% and 40% respectively at 90 days. But it can be replaced up to 50% and 70% with FA and GGBFS respectively to gain the target compressive strength.
- Flexural strength is very important when designing rigid pavement. The minimum flexural strength of beam at 28 days should be equal to or more than 4.5 MPa. In binary blended concrete, 30% and 70% replacement of cement with FA and GGBFS achieves design strength at 28 days. The optimum value of flexural strength for binary blended concrete with FA and binary blended concrete with GGBFS were 4.7MPa (BF-20) and 6.2 MPa (BS-40) respectively.

- Changing the SCMs type did not significantly affect the shrinkage of binary mixtures but increasing SCMs content reduces drying shrinkage.
- GGBFS blended concrete is more durable and also it gain strength more rapidly than FA blended concrete.

REFERENCES

1. Atis, C. D. High-volume fly ash concrete with high strength and low drying shrinkage. Journal of Material Civil Engineering, 15 (2), 153–156, 2003.
2. Binod Kumar, G. K. Tike, and P. K. Nanda. Evaluation of Properties of High-Volume Fly-Ash Concrete for Pavements. Journal of materials in civil engineering © asce / October 2007
3. Darquennes, E. Roziere, M.I.A. Khokhar, P. Turcry, A. Loukili, F. Grondin. Long-term Deformations and Cracking Risk of Concrete with High Content of Mineral Additions. Material Structures 45, 1705–1716, 2012.
4. Erdoan Ozbay, Mustafa Erdemir, Halil Ibrahim Durmus. A Review on Utilization and Efficiency of Ground Granulated Blast Furnace Slag on Concrete Properties. Construction and Building Materials; 105, 423–434, 2016.
5. IRC: 44-2008 Guidelines For Cement Concrete Mix Design For Pavements
6. IS 1199 (1959): Methods of Sampling and Analysis of Concrete (Reaffirmed 2004)
7. IS 2386-1 (1963): Methods of Test for Aggregates for Concrete, Part I: Particle Size and Shape (Reaffirmed 2002)
8. IS 2386-3 (1963): Methods of Test for Aggregates for Concrete, Part 3: Specific gravity, density, voids, absorption and bulking (Reaffirmed 2002)
9. IS 2386-4 (1963): Methods of Test for Aggregates for Concrete, Part 4: Mechanical properties (Reaffirmed 2002)
10. IS 3812-1 (2013): Specification for Pulverized Fuel Ash, Part 1: For Use as Pozzolana in Cement, Cement Mortar and Concrete
11. IS 383 (1970): Specification for Coarse and Fine Aggregates From Natural Sources For Concrete (Reaffirmed 2002)
12. IS 4031-4 (1988): Methods of Physical Tests for Hydraulic Cement, Part 4: Determination of Consistency of Standard Cement Paste (Reaffirmed 1995)
13. IS 4031-5 (1988): Methods of Physical Tests for Hydraulic Cement, Part 5: Determination of Initial and Final Setting Times (Reaffirmed 2000)
14. IS 4031-6 (1988): Methods of Physical Tests for Hydraulic Cement, Part 6: Determination of Compressive Strength of Hydraulic Cement (Reaffirmed 2005)
15. IS 456-2000: Plain and Reinforced Concrete-Code of Practice
16. IS 516 (1959) Methods of Tests for Strength of Concrete (Reaffirmed 1999)
17. IS 8112 (2013): Specification for 43 grade ordinary Portland cement

18. Naik T. R., Singh S., and Ramme B. Mechanical Properties and Durability of Concrete Made with Blended Fly Ash. ACI Mater. J., 95 (4), 454–462, 1998.

19. Oner, S. Akyuz; An experimental Study on Optimum Usage of GGBS for The Compressive Strength of Concrete. Cement & Concrete Composites 29, 505–514, 2007.

20. Pailyn Thongsanitgarn, Watcharapong Wongkeo and Arnon Chaipanich. Hydration and Compressive Strength of Blended Cement Containing Fly Ash and Limestone as Cement Replacement. Construction and Building Materials 105 (2016) 423–434

21. Pal S C, A. Mukherjee, S.R. Pathak; Investigation of Hydraulic Activity of Ground Granulated Blast Furnace Slag in Concrete; Cem. Concr. Res. 33 (2003) 1481–1486.

22. Sivasundaram V, V.M. Malhotra, Properties of Concrete Incorporating Low Quantity of Cement and High Volumes of Ground Granulated Slag, ACI Mater. J. 1992 (89) (1992) 554–563.