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An Experimental Study on Strength Development of Concrete with Optimum Blending of Fly Ash and Granulated Blast Furnace Slag

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Abstract:

Utilization of industrial wastes and by-products has emerged as new scope for sustainable development of concrete along with combating the major issues as depletion of the natural resources, disposal issue of solid wastes and demand of fast growing population in the world. The present work experimentally investigated the influence of partially replacing fly ash (FA) as binder and granular blast furnace slag (GBFS) as fine aggregate separately and in combined form on the fresh and hardened properties of concrete. Eight series of concrete mixes were prepared as control mix, single blended mixes and combined blended mixes by weight batching. Single blended concrete mixes were prepared by different percentages of FA (20%, 30% and 40%) and 50% GBFS while combined blended concrete mixes by 50% GBFS with 20, 30 and 40% of FA respectively. Concrete mixes were evaluated for workability and compressive strength, split tensile strength and flexure strength after 7, 28 , 60 and 90 days, respectively. The test results indicated that strength of single blended mixes shows degradation in strength as compared to control mix while combined blending of fly ashes more than 20% with 50% GBFS improves the strength with respect to single blended mix at all ages. It is therefore suggested that concrete mix made with combined blending can be effectively practiced in concrete with acceptance of marginal loss in strength as utilization must be considered as first criteria than strength for sustainability perspective. Moreover, validation of test data with various codes and formulation indicates that the relationship between compressive strength with split tensile strength and flexure strength for concrete mixes containing GBFS and fly ash is similar to the conventional concrete. Such concrete mixes not only will enhance the volume of waste utilization but also reflect the interactive effect of wastes on the strength development, thrusting sustainable development of concrete.

Keywords: Granular blast furnace slag, Fly Ash, Sustainability, Compressive strength, Split tensile strength, Flexure strength, blending

INTRODUCTION

Sustainable development of concrete, conservation of natural resources and current demand of cement or construction industry are the major driving forces which encourages to utilize the industrial solid wastes and by-products in concrete not only for ecological and economic benefit but also to avoid day to day changing environmental regulations [1-4]. Researchers across the globe attempted to utilize alternative cementitious and aggregate materials such as blast furnace slag, fly ash, coal bottom ash, silica fume, rice husk ash, rubber tyre, recycled aggregate, granite waste, waste foundry sand etc. in concrete as binary or ternary constituents to enhance the properties of concrete and paved a path for sustainable development of concrete[5-10].

Blast furnace slag and fly ash are the major by-products of steel industry and thermal power plants. Normally these by-products are utilized by cement industry in manufacturing Portland slag cement (PSC) and Portland pozzolanic cement (PPC) to improve several performance characteristics of concrete [11]. In India, utilization of fly ash has increased from 85.05MT in 2011-12 to a level of 107.77MT in 2015-16 with 60.97% utilization of 176.74 million ton per annum (MT) of fly ash generation with a target of 100% fly ash utilization at the end of 2017 [12]. Majority of fly ash produced are of Class F type used as replacement of cement in the manufacturing of cement. Even though, fly ash is used in manufacturing pozzolanic cement, the overall percentage utilization remains very low [13]. India's slag production capacity is close to 10 MT from its existing steel plants and can consume up to 70% of the blast furnace slag generated. There is still scope for further utilization of all forms of blast furnace slag in all forms in order to enhance the total production of cement [14]. Furthermore, scarcity of river bed fine aggregate, illegal sand exploration, protection of natural resources, high volume generation of solid waste from industries are the major factors which created a scope to effectively utilize the granular blast furnace slag as fine aggregate in concrete.

Blast furnace produces hot metal slag at a temperature of 1500-1600°C during iron making process. Rapid quenching minimizes crystallization and converts the molten slag into glassy fine-aggregate-sized particles generally smaller than a 4.75 mm sieve, which when dried and ground is latently hydraulic. Granulated blast furnace slag (GBFS) particles are angular in shape and having very rough surface the surface of slag is rough [15, 16]. X-ray diffraction showed that slag was generally a glassy material comprising of dominantly rankinite ($Ca_3Si_2O_7$) and di-calcium silicate (Ca_2SiO_4) as primary content [17]. Fine aggregate is a major component of the concrete having significant impact on the workability, durability, strength, weight, voids and shrinkage of concrete. It is usually a larger component of the mix than cement responsible for void filling [18, 19]. The workability performance of the concrete mixes having alternative sand such as GBFS, granite waste, zink slag or lead slag etc. was observed poor due to their angular shape, roughness, high percentage of power size particles and high water absorption capacity [20-22]. A certain dose of super plasticizer is required to enhance the workability of concrete having industrial slag more than optimum content.

Samanta et al, in 2014 [20] investigated the influence of GBFS on mechanical strength of GBFS concrete mixes incorporating granular slag as fine aggregate. They observed that marginally improved or partially degraded with respect to control mixes for 50-70% replacement, whereas Patra and Mukherjee, in 2017 [17] reported optimum replacement percentage of GBFS of 60% , further increment deteriorates the strength. The pozzolanic activity of GBFS was found to help in improving the strength of concrete as it reduces the voids and improves the interface characteristics of concrete [23]. Similarly, significant improvement in the strength properties of plain concrete was observed by the inclusion of class F fly ash as partial replacement of fine aggregate up to 50%. This increase in strength due to the replacement of fine aggregate with fly ash was reported due to the pozzolanic action of fly ash [13]. The ratio of GBFS and sand is the governing criteria for the effects on the strength and durability characteristics. If the GBFS/ sand ratio is high in concrete mix, the concrete will be porous and exhibit relatively low compressive strength [24]. Rao and Bhandari, in 2014 [25] reported that the substitution of natural aggregate with stone sand and granulated slag sand in equal proportion of total fine aggregate in concrete has positive impact on workability, compressive strength and durability. In case of mortar containing granulated ferronickel slag (FNS) up to 50% and granulated blast furnace slag (GBFS) up to 75% improved the strength significantly and beyond that degradation in strength along with poor flow ability of mortar was observed [26, 27].

Class F fly ash is well known supplementary powered form inorganic material contains small quantity of lime. It reduces the strength as its percentage increases due to late pozzolanic reaction and improves the strength at later stage of curing. The incorporation of fly ash also reduces the need of chemical admixture to achieve required workability or flow ability [28-30]. But, it is not necessary that fly ash from all sources will improve the properties of concrete at high replacement levels [31]. It was reported that fly ash/cement ratio is an important factor determining the efficiency of fly ash. Strength increased with increase in amount of fly ash up to an optimum value, beyond which strength started to decrease with further addition of fly ash. The optimum value of fly ash for the four test groups was about 40% of cement [32]. Blending of industrial slag as fine aggregate and supplementary cementitious material is an innovative way to counteract the negative effect of one constituent with another to improve the properties of fresh and hardened concrete thereby, increasing the percentage utilization of alternative material for sustainable development of concrete. Concrete mixes incorporating coal bottom ash (0,20,50,75 and 100%) as fine aggregate have not positive impact on fresh and hardened properties of concrete up to 91 days of curing while mix containing 75% bottom ash and 20% fly ash exceeded much more than the control sample [9]. Partial replacement of cement with fly ash by 30% along with 50% ferronickel slag (FNS) as replacement of sand increased the flow of fresh mortar and decreased the strength of hardened concrete [26]. Mustafa et al, in 2017 [33] developed concrete made with 100% spent foundry sand (SFS) as fine aggregate and 70% FA as Portland cement which enabled the manufacturing of green, lower cost self-compacting concrete (SCC) with proper fresh, mechanical and durability properties.

Although alternative materials have developed a scope for sustainable concrete, the test results need to be validate with national [34], international codes [35-40] and empirical relationship propped by various researchers [39-45,21]. Furthermore, even though analysis and design of concrete structure is based on strength parameter as compressive, split tensile, flexure strength, young modulus of elasticity of concrete etc., compressive strength is adopted as the basic property of concrete and expressed as independent variable for derived parameters. Table 1 shows the non-dimensional co-efficient of various formulation proposed by various design codes and investigators. Some studies suggest that ACI 318 [7] coefficients underestimate the splitting tensile strength for high strength concrete and overestimate it for low strength concrete [5]. Ros and Shima [5] indicated that JCI 2008 [8] coefficients are consistent with their experimental data.

From the past research, it was observed that there was boundless investigations have been carried out taking fly ash and ground granulated blast furnace salt as cement replacement. However, the investigation dealing the concrete made by effect of combined blending of slag as fine aggregate and fly ash mineral admixture is not wide spread in existing literature. Therefore, the present study is focused on systematic investigation of fresh and hardened properties of eight types of concrete mixes containing various percentages of FA (0, 20, 30 and 40%) as part replacement of cement and the GBFS as 50% of natural sand. The main objectives of this investigation have been set as follows;

- To compare the properties of natural fine aggregate and GBFS collected from Durgapur steel plant.
- To evaluate the fresh concrete properties by slump cone test to study the effect of fly ash and granulated blast furnace slag on the flow ability of concrete as these materials may affect the plasticity of concrete.
- To examine the blending effect on hardened concrete of concrete after 7, 28, 60 & 90 days of curing.
- To perform statistical analysis to validate the proposed blending concept with various proposed models
- Selection of the optimal mix in all concrete mixes with respect to strength of concrete.

Table 1 : Various formulation for prediction of split tensile strength and flexure strength

Split Tensile strength (f_{spt})		Flexure Strength (f_f)	
ACI:318 (2011) [35]	$0.56\sqrt{fc'}$	IS:456-2000 [34]	$0.7\sqrt{f_c}$
CEB(1993) [36]	$1.56\,((f_c'-8)/10)^{2/3}$	ACI:318 (2011) [35]	$0.62\sqrt{f_c'}$
GB 10010(2002) [40]	$0.19f_c'^{0.75}$	CEB (1993) [36]	$0.81\sqrt{f_c}$
NBR 6118(2003) [39]	$0.3\,f_c'^{0.667}$	DG/TJ-008 (2008) [37]	$0.75\sqrt{f_c}$
Carino and Lew (1982) [41]	$0.272\,f_c'^{0.71}$	NZS-3101 [38]	$0.60\sqrt{f_c'}$
Gardner (1990) [42]	$0.33\,f_c'^{0.667}$		
Oluokun et al.(1991) [43]	$0.294\,f_c'^{0.69}$		
Hueste et al. (2004) [44]	$0.55\sqrt{fc'}$		
Xiao et al. (2005) [45]	$0.55\,f_c'^{0.65}$		
Arioglu et al.(2006) [46]	$0.38\,f_c'^{0.63}$		
Kou and Poon (2008) [47]	$0.093\,f_c'^{0.8842}$		
Lavanya and Jegan (2015) [48]	$0.249\,f_c'^{0.772}$		
Vijaylakshmi et al. 2013 [21]	$0.241\,f_c^{0.712}$		

Where f_{spt} = Splitting tensile strength at 28 days; f_f = flexure tensile strength at 28 days; f_c = cube compressive strength at 28days in MPa; f_c' = cylinder compressive strength at 28days in MPa

MATERIALS AND METHODOLOGY

Materials

Natural sand of Ajoy river and GBFS procured from Durgapur steel Plant were used as fine aggregate which conforms to Zone II of Indian standard code naming IS 383:1970 [49] as shown in Fig.1. Crushed granite stone with maximum size of 20mm and 12.5mm well graded aggregate blended in the ratio of 60:40 were used as coarse aggregate as presented in Fig. 2. The physical test results of fine and coarse aggregates used in mixes is presented in Table 2. Ordinary Portland cement (OPC) of 53 Grade conforming to the requirement of IS12269:1987 [50] was used for concrete mix. The test results for physical properties and chemical requirements of cement are given in Table 3 and Table 4. Class F fly ash collected from NSPCL thermal power plant, Durgapur conforming to IS3812 (Part 1) 2013 [51] was used. The physical property of fly ash is presented in Table 5. Chemical composition of GBFS and fly ash is shown in Table 6. X-ray florescence analysis of GBFS and Fly ash has been conducted to determine the chemical composition of main oxides. Furthermore, chemical admixture Sika Plastiment-100 complies with IS9103:1999 [52] was used in concrete mix to achieve designed workability. It is based on Modified Lignosulfonate polymers and is supplied as a brown liquid, instantly dispersible in water. Its specific gravity is 1.16kg/ltr (at 25 °C) and chloride content is Nil.

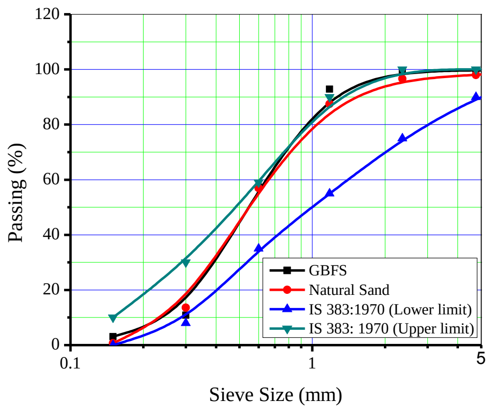

Figure 1 : Sieve analysis of fine aggregates (NS and GBFS)

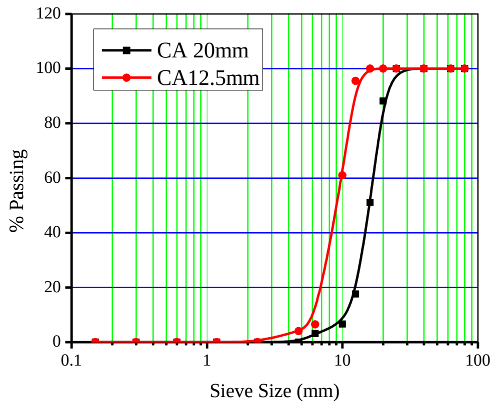

Figure 2 : Sieve analysis of coarse aggregates

Table 2: Properties of Aggregate

Property	Fine Aggregate		Coarse aggregate (CA)	
	NS	GBFS		
Maximum Size (mm)	4.75	4.75	20	12.5
Specific gravity	2.62	2.32	2.87	2.84
Water absorption (%)	0.28	4.06	0.2	2.38
Loose unit wt.(Kg/m3)	1.69	1.95	-	-
Dense unit wt.(Kg/m3)	1.56	1.78	-	-
Fineness Modulus	3.46	3.37	9.33	7.33
Zone (IS:383-1970)	II	II		
Fines through 75µ, %	0.7	6.24	-	-

Table 2: Properties of Cement (IS12269:1987)

Fineness (m^2/kg)	Consistency (%)	Specific gravity	Initial setting time (min)	Final setting time (min)	Soundness (mm)	Compressive strength (MPa)		
						3 days	7days	28days
317.2	32	3.15	38	212	3.5	24.6	42.3	54
(max. 225)			(≥30)	(≤600)	(≤10)	min.27	min.37	min. 53

Table 3: Physical Properties of Cement (IS12269:1987)

Fineness (m^2/kg)	Consistency (%)	Specific gravity	Initial setting time (min)	Final setting time (min)	Soundness (mm)	Compressive strength (MPa)		
						3 days	7days	28days
317.2	32	3.15	38	212	3.5	24.6	42.3	54
(max. 225)			(≥30)	(≤600)	(≤10)	min.27	min.37	min. 53

Table 4: Chemical Properties of Portland Cement

Ingredients	Test Results	Requirement as per (IS 12269, 1987)
Lime (CaO)	62.93	
Silica (SiO2)	19.58	
Alumia (Al2O3)	6.85	
Iron oxide (Fe2O3)	3.58	
Magnesia (MgO)	0.81	≤ 6
Sulphuric anhydride (SO3)	2.44	Max. 3% (C_3A > 5) Max. 2.5% (C_3A < 5)
Chemical requirements		
Lime Saturation Factor (LSF) (CaO- 0.7SO3) /($2.8SiO_2+1.2Al_2O_3+0.65Fe_2O_3$)	0.936	0.08≤ LSF ≤ 1.02
Ratio of alumina to iron oxide (Al2O3)/ (Fe2O3)	1.84	≥ 0.66

Table 5: Physical properties of Fly ash (FA)

Physical property	Test observation
Colour	Blackish grey
Fineness (45 µ)	4.0%
Specific gravity	2.10
Lime reactivity	4.7MPa

Table 6: Chemical properties of GBFS, Fly ash

Component Type	Cao	SiO_2	Al_2O_3	MgO	S	Fe_2O_3	Total Sulpher (SO_3)	Insoluble residue (MnO)	Alkali (Na_2O)	K_20
GBFS	31.6	30.8	22.4	11.6		0.44	-	0.25	-	0.73
FA	0.95	57.75	36.67	-		6.93	0.19	0.08	-	0.68

Field emission scanning electron microscope (FESEM) analysis of GBFS and fly ash was conducted at NIT Durgapur, Centre of excellence in Advance Materials. Images are obtained in the different bright field mode to understand their surface morphology and presented in Fig.3. A FESEM is used to visualize very small topographic details on the surface or entire or fractioned objects. Surface morphology of GBFS indicated that particles are angular in shape and having rough surface. Also, the morphology of the fly ash shows that the fly ash particles are a spherical shape with a wide size distribution of particles and smooth surfaces. It was also observed that handling of this material through uncovered hand could be unsafe as glassy particles can penetrate the skin. In addition to the above, the main chemical oxide compounds present in cement, GBFS and fly ash were investigated by using X-ray fluorescence (XRF) method at SAIL-Durgapur steel plant. GBFS contains high percentage of calcium oxide (CaO), silicon oxide (SiO_2) and aluminium oxide (Al_2O_3) as main constituents similar to cement.

Methodology

M30 grade of control mix (M-0) was designed as per IS 10262:2009 [53] and IS456:2000 [34] with aim to achieve the target mean strength of 38.25 MPa by adopting design mix proportion of 0.41: 1: 1.36: 2.67 by weight for 25-50mm of slump. Table 7 shows the details of concrete mixes, proportion of various ingredients by weight, properties of fresh concrete as slump etc. The mixes are coded in such a way that the percentages of GBFS and fly ash can easily be identifiable from their identifications (ID). In the single blended mixes, four types of mixes were prepared by replacing fine aggregate with GBFS by 50% and the cement with fly ash by 20%, 30%, and 40%. Furthermore, three combined blended mixes by replacing cement and natural sand with fly ash (20%, 30%, 40%) and GBFS by 50%, respectively. For casting purpose, normal drinking water was used for all the series of concrete mixes. Furthermore, 0.5 to 1% of super plasticizer has been finalized after making trials to get the slump in the range of designed slump.

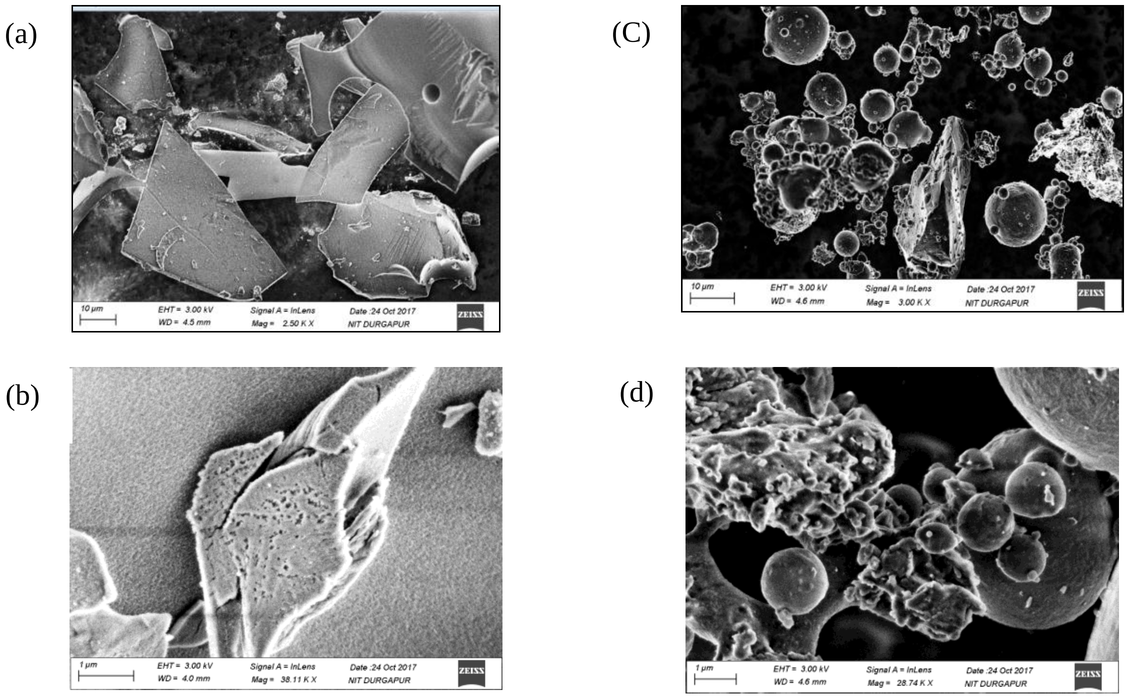

Figure 3: FESEM images of GBFS (a) & (b) and fly ash (c) & (d)

Table 7: Mix Proportion for 1 Cubic Meter of Concrete of Grade M30 (0.41:1:1.36:2.67)

Concrete Mixes ID	Replacement (%)		Water	Cement	Class F Fly ash	Sand	GBFS	Coarse agg.		Ch. Admixture	Slump
	GBFS	FA	(Ltr.)	(Kg)	(Kg)	(Kg)	(Kg)	Max. 20mm	Max. 12.5mm	(%)	(mm)
M-0	0	0	184.5	450	0	612	0	720.9	480.6	0	43
M-1	50	0	184.5	450	0	306	306	720.9	480.6	0.5	35
M-2	0	20	184.5	360	90	612	0	720.9	480.6	0.5	47
M-3	0	30	184.5	315	135	612	0	720.9	480.6	0.5	38
M-4	0	40	184.5	270	180	612	0	720.9	480.6	0.5	35
M-5	50	20	184.5	360	90	306	306	720.9	480.6	1	37
M-6	50	30	184.5	315	135	306	306	720.9	480.6	1	34
M-7	50	40	184.5	270	180	306	306	720.9	480.6	1	32

Moulds and number of specimen were used for compression, split tensile and flexure strength tests as per IS 516:1959 [54] Concrete specimens such as 150 mm cubes, 150 mm Φ x 300 mm size cylinders and 100 x 100 x 500 mm size prisms were prepared. De-moulding was done after 24 h and the specimens were cured under water at 27° C ± 2°C and 90% ± 1% relative humidity for specified period of curing. All specimens were tested in fully digitalized universal testing machine of maximum compression capacity of 300T. The test for compressive strength was carried out after 7, 28, 60 and 90 days of wet curing. The splitting tensile strength and flexure strength tests concrete specimens were determined after 28, 60, 90 days of curing. Observation is based on test results of three specimens for each strength parameter of hardened concrete.

RESULTS AND DISSCUSSION

Properties of Fresh Concrete

From Table 3 and Table 4, it is clear that specific gravity of GBFS and FA is lower than corresponding natural fine aggregate and cement which increases the overall volume of dry concrete mix. Also, the measured water absorption for GBFS is 4.06% compared with 0.28 % for natural sand. Also, FESEM micrograph of GBFS in Fig.3 shows its angular shape and rough texture. These factors had significantly affected the need of chemical admixture to get desired workability. Concrete mixes were prepared with aim to achieve the slump value ranging from 25-50mm. The influence of blending GBFS and fly ash on the workability of fresh properties of concrete mixes is presented in Fig. 4. Concrete mix (M-0) made without any additives exhibited a slump of 43 mm which reduced to 35mm with incorporation of 50% GBFS. In single blended concrete mixes (M-1 to M-4) having 50% GBFS, 20%FA, 30%FA and 40%FA, 0.5% of super plasticiser by weight of cement were added which helped to get the slump of 35, 47, 38 and 35mm, respectively while the slump test for combined blended concrete mixes (M-5, M-6 and M-7) having 20,30,40% FA and 50% GBFS are 37 mm, 34mm and 32 mm respectively. The negative effect of replacing GBFS and FA on workability of concrete mixes could be attributed to high volume of fine power, shape and surface characteristics of GBFS and high water absorption capacity of GBFS which cause hindrance against mobility of fresh concrete.

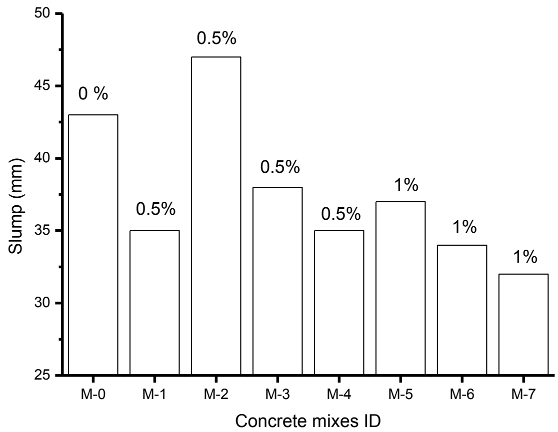

Figure 4: Slump and doses of super plasticizer versus concrete mixes

Compressive Strength

Test results of all concrete mixes (M-0 to M-7) are shown in Fig.5 for various ages. Control mix concrete (M-0) achieves the strengths of 35.28, 41.59, 48.36 and 50.04 MPa at 7, 28, 60 and 90days. A marginal loss of 4.4%, 2.84% and 3.3% in strength was observed for (M-1) containing 50% GBFS at 28, 60 and 90days. Concrete or Mortar containing GBFS exhibited a lower compressive strength for more than 50% of replacement percentage which may attribute to weak bond developed in mortar because of high content of glassy and rough textured GBFS particles. Also, high absorption of water in concrete due to increase in replacement percentage of GBFS played a major role making concrete harsh. Furthermore, as the percentages of fly ash in concrete mix increases from 20 to 40%, mixes (M-2 toM-4) exhibited lower compressive strengths ranges between 32.09 to 22.49 MPa at 7 day; 38.07 to 26.93MPa at 28 day; 40.45 to 31.57MPa 60day; and 43.85 to 33.74 MPa at 90 day. This is well known finding about fly ash is that compressive strength decreases with the increase in the percentage of the fly ash and at the same water-to-cement ratio. But, this development in strength of concrete containing FA is slower at initial stage, but it continues to gain strength in the long time. However, compressive strength of all the mixes of single blended type increased with the age of concrete. After combined blending of 50% GBFS with 20, 30 and 40% fly ash mix, strength of concrete mixes (M-5 to M-7) changes by -18.01% to 18.93% at 7days, -18 to 25.93% at 28days, -13.68% to 17.55% at 60days and -17.65% to 13.93% at 90days, respectively over single blended mixes (M-2,M-3 & M-4) containing fly ashes. At 20% FA and 50% GBFS does not improves the strength with respect to 20% fly ash concrete mix. This may be attributed to the higher percentage of GBFS may need high volume of binding power to make mortar of higher strength. It was observed that GBFS addition didn't deteriorate the further strength with the increase of fly ash content. The reason may be attributed to the fact that higher volume of angular, rough texture particles of GBFS needs more volume of fly ash to strengthen the bond in concrete or mortar. Also, the various oxide compounds present in GBFS and FA might have contributed for the improvement of strength of concrete by pozzolanic or hydraulic activity [13, 23]. Although combined blending of 50% GBFS and 40% FA were found to reduce strengths as compared to strength of control mix, producing sustainable concrete with compressive strengths around 36.36 MPa at 28 days, 38.29MPa at 60days and 39.2MPa at 90days.

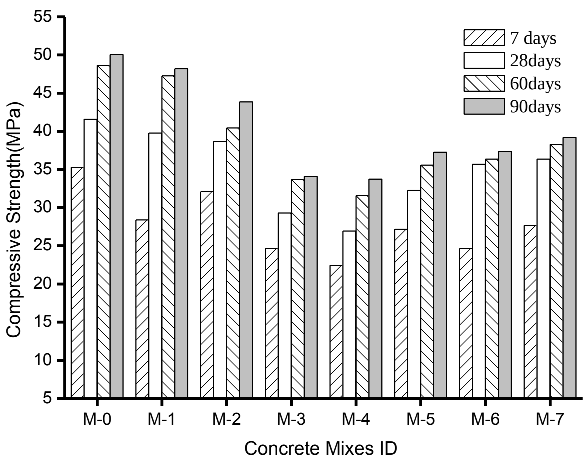

Figure 5: Compressive Strength of concrete mix with various % of FA and GBFS

Split Tensile Strength

Test results of split tensile test for all the concrete mixes (M0-M7) for various ages are shown in Fig. 6. Control mix concrete achieves the strengths of 3.14, 3.78 and 3.91 MPa at 28, 60 and 90days. It is observed that mix (M-1) having 50% GBFS shows a marginal decrease of 3.82 to 4.6% in strength with respect to all ages while concrete mixes (M-2 to M-4) with fly ash 20 to 40% deteriorate the strength by 21.0% to 27.93% at 28days, 27.78 to 33.6% at 60days and 28.39 to 34.27% at 90 days, respectively. As explained for compressive strength case, decreases in strength of GBFS mix (M-1) could be attributed to its physical texture and high water absorption, the demand in cement paste volume for GBFS which is contributed to the weak bond between the aggregate and cement paste. Splitting tensile strength decreases with the increase in the percentage of the fly ash at constant water-cement ratio. After combined blending of 50% GBFS with 20 and 30 % fly ash, concrete mixes (M-5 to M-7) improves the strength by 1.61 to 15.35% at 28days, 8.92 to 28.69% at 60days and 9.57 to 35.02% at 90days with respect to corresponding fly ash concrete mixes (M-2 to M-4). At higher ages, improvement in split tensile strength is not significant at 60and 90days for all of the concrete mixes. Overall, maximum enhancement in strength due to combined blending is observed for concrete mix (M-7) with 50% GBFS with 40% fly ash concrete mix, producing sustainable concrete with compressive strengths around 2.63 MPa at 28 days,3.22MPa at 60days and 3.47MPa at 90days. Even though, combined blended mix (M-7) performs better than single blended fly ash mixes, it needs higher curing age to achieve the strength in the range of control mix. Enhancement in strength after combined blending might be due to improvement in bond strength of mortar due to availability of sufficient amount of angular, rough texture particles for light weight fly ash power. Role of pozzolanic or hydraulic activity of GBS and fly ash in strength development is quoted in compressive strength case.

Fig.7 represents the comparative study between the test value and the values obtained by using formulations given in the Table1. The 28-days cube compressive strength (f_c) is assumed as characteristic compressive strength and a correction factor 0.8 is used for converting the cube compressive strength to cylinder compressive strength (f_c'). It can be observed that the test results is lower than the values given by [21,35,39,42,43,46,48] while higher than the values given by [36,40,45,47] respectively. Moreover, the line plot shows that single blended mix and combined blended mix concrete mixes incorporating GBFS and fly ash performed in the similar way as conventional concrete.

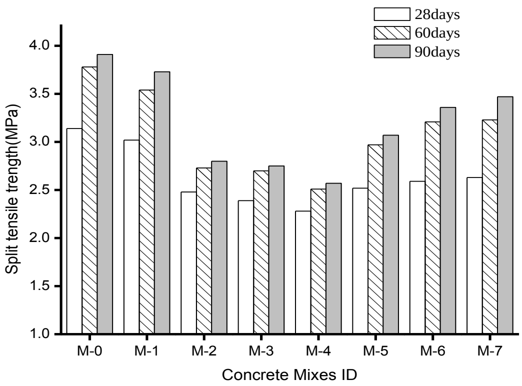

Figure 6: Split tensile Strength of concrete mixes with various % of FA and GBFS

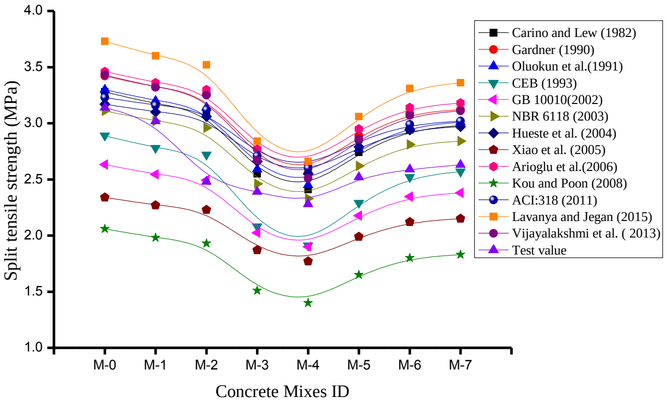

Figure 7: Line plot of split tensile strength obtained by various proposed models

Flexure Strength

Test results of flexure test for all concrete mixes (M0-M7) for various ages are shown in Fig. 8. Flexure strength of control mix at 28, 60and 90 days are 5.11, 6.19 and 6.44 MPa respectively. It is observed that mix (M-1) having 50% GBFS shows a marginal decrease of 4.97 to 5.17 % in strength with respect to all ages while concrete mixes (M-2 to M-4) with fly ash 20 to 40% deteriorate the strength by 17.03 to 23.29% at 28days, 13.25 to 17.93% at 60days and 15.53 to 19.79% , respectively. As mentioned in literature, decreases in strength of GBFS mix (M-1) could be attributed to high water absorption, the demand in cement paste volume for GBFS which is contributed to the weak bond between the aggregate and cement paste. Flexure strength decreases with the increase in the percentage of the fly ash at constant water-cement ratio. Concrete mix having higher percentage of fly ash increases the volume of mix and delays the strengthening of mortar because of late pozzolanic reaction. After combined blending of 50% GBFS with 20 and 30 % fly ash, concrete mixes (M-5 to M-7) improves the strength by 4.01 to 18.37 % at 28days, 2.98 to 15.75% at 60days and 4.96 to 15.06 % at 90days with respect to corresponding fly ash concrete mixes (M-2 to M-4). However a close observation of Fig. 8 shows that there is regular improvement in flexure strength for all cases of combined blending. Furthermore, concrete mix (M6) having 40% fly ash and 50% GBFS exhibits a marginal decrease in strength with respect to control mix, about 9.19%, 5.0% and 7.6 % at 28, 60 and 90days respectively. As observed in previous cases for compressive and split tensile strength case, combined blending improves the strength which may attribute to the fact that higher volume of GBFS blended with fly ash improves the bond strength of mortar which contributes to the strong interlocking between the coarse aggregate and mortar.

Fig. 9 represents the comparative study between the test value at 28days and the values obtained by using formulations given in the literature Table 1. The cube compressive strength (fc) is adopted for computing flexural strength using the formulation given by [34, 35,37] and for other formulations cylinder compressive strength is used. A correction factor 0.8 is used for converting the cube compressive strength to cylinder compressive strength (f_c'). It can be observed that the test results are lower than the values given by CEB (1993) and close to [37] while higher than the values given by [34,35,38] respectively. Moreover, the line plot shows that single blended mix and combined blended mixes performed in the similar way as conventional concrete.

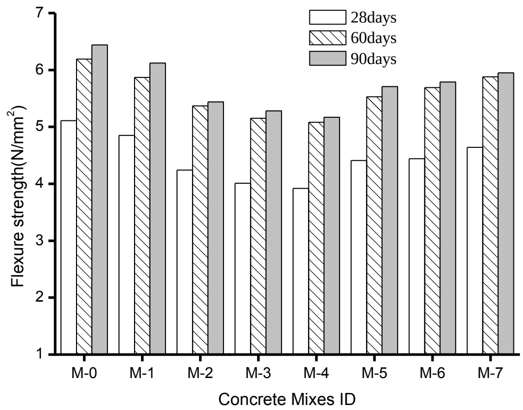

Figure 8: Flexure Strength of concrete mixes with various % of FA and GBFS

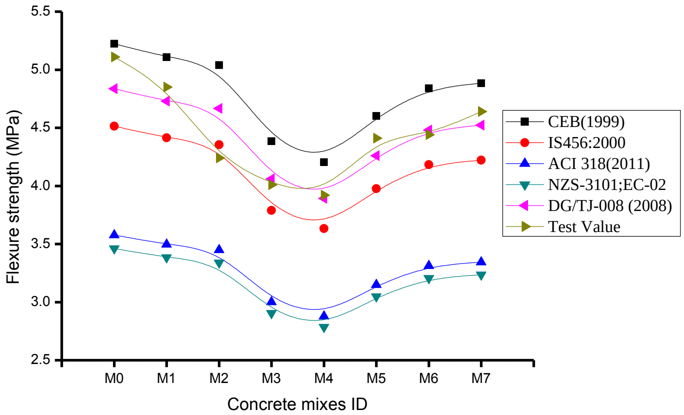

Figure 9: Line plot of flexure strength obtained by various proposed models

CONCLUSION

This paper aims at feasibility of using fly ash and granulated blast furnace slag as constituents of single blended mix and combined blended mix to enhance the scope of utilization in construction. The influence of partial replacement of fly ash (FA) and granulated blast furnace slag (GBFS) on fresh and hardened properties of concrete mixes are experimentally investigated. From the experimental data obtained during this research, the following conclusions and recommendations can be drawn:

- Physical testing and FESEM images reveal that GBFS is a lightweight glassy material having high percentage of rough, angular and flaky particles. As its water absorption is also very high, the slump of the fresh concrete reduces. On the other hand, high replacement level of cement with fly ash enhances the content of power particles, combined blending demand high percentage of super plasticizer to achieve adequate workability.
- GBFS is balancing the strength of concrete, to some extent, the decreases coming from higher percentage of fly ash substitution. Development in strength due to combined blending indicates that concrete mixes should have a suitable proportion of GBFS and fly ash to strengthen the bond between binding paste/mortar and aggregates. Adopting of high percentage of rough slag as fine aggregate demand higher percentage of spherical shaped powder particles to strength the inter-particle bond of mix.
- All series of concrete mixes shows aggradation in strength with age, irrespective of content of slag and fly ash which exhibits the pozzolanic property of materials used in mixes. Furthermore, combined blending exhibited a positive sign of strength development which indicates that interaction of particles play a major role in improving the bond of mortar.
- Even though replacing of natural sand with GBFS by 50% marginally degrade the strength in single blended mix case, blending of 40% fly ash as portland cement and 50% granulated blast furnace slag as natural sand in improves the strength over 40% fly as concrete mix which may provide a solution for maximizing the utilization of alternative material as filler and binder in construction.
- The assessment results show that split tensile strength for all concrete mixes is lower than the values given by NBR 6118(2003); ACI 318 (2011); Oluokun et al., 1991; Gardner,1990; Vijaylakshmi et al., 2013, Lavanya and Jegan, 2015 and Arioglu et al., 2006 while higher than the values given by CEB(1993); Xiao et al., 2005; GB 10010 (2002) and Kou and Poon, 2008, respectively. But, flexure strength of combined blended mixes are very close to DG/TJ-008 (2008) while higher than the values given by IS456 (2000), ACI 318 (2011); NZS-3101 respectively. Moreover, combined blended mix concrete mixes is not significantly different from the proposed models, performed in the similar way as conventional concrete.
- Before implementing in real practices, further investigations are required to suggest right optimum based on durability performance of the concrete.

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