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Ready mixed concrete behavior of granulated blast furnace slag contained cement

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Abstract. Due to enhanced construction requirement, ready mixed concrete are being popular day by day. The current study aimed to develop ready mixed concrete using GBFS contained cement and determine its properties of fresh and hardened states. A real scale experiment was set up in a ready mixed plant for measuring workability and compressive strength. The workability was tested after mixing (within 5 minutes), 30, 60, 90, 120 and 150 minutes of the running of bulk carrier. The ready mixed carrier employed spinning motion i.e., rotating around its axis with 20 RPM and running on road with 1km/h speed. The mixing ratio of cement: sand:gravel, water to cement ratio, super plasticizer were, 1:1.73:2.47, 0.40 and 6% of cement, respectively. The chemical composition of raw material was determined using XRF and the properties of cements were measured according to ASTM standards. The experimental results confirm that the cement with composition of 6.89% of GBFS, 4% of Gypsum and 89.11% of clinker showed the good compressive strength and workability of concrete after 150 minutes of the spinning motion in bulk carrier.

Keywords: granulated blast furnace slag; ready mixed concrete; workability; compressive strength

1. Introduction

The construction industry is recognized as an environment unfriendly sector due to the emission of CO_2 for cement production, and thus, it is necessary to make efforts to turn it to an environment affable industry (Kim *et al*. 2013). The incorporation of granulated blast furnace slag (GBFS) as a supplementary cementitious in cement-based applications will reduce the green house gas emission as well as increase the workability of ready mixed concrete. Several attempts have been made for low carbon footprint concrete production through incorporating GBFS in composite cement which ultimately save the natural resources i.e., limestone, clay and iron pyrite (Shu and Kuo 2015, Yang *et al*. 2015, Shiha *et al*. 2016). However, the workability is an important consideration of ready mixed concrete when waste materials or by-product of an industry can be used as supplementary materials or as raw ingredient of inter grinding cement (Karim *et al*. 2016, Karim *et al*. 2016, Karim *et al*. 2017). The motivation of this study is to increase the workability with good compressive strength of ready concrete using GBFS contained cement.

The durability and workability of the alkali activated concrete has been increased using GGFS based composite cement (Collins and Sanjayan 1999, Wang and Lee 2014, Ozcan *et al*. 2017) and improved the fresh and hardening properties of self-compacting concrete (Boukendakdji *et al*. 2012, Wang and Lin 2013, Kuo and Shu 2015, Patra and Mukharjee 2016). Moreover, it was shown the excellent ability to retard the setting time and heat of hydration, and for improving the fluidity of concrete (Wang *et al*. 2012). Besides that, it was used as fine aggregate (Saikia *et al*. 2012) for developed the mechanical properties (Qasrawi 2014, Rahman *et al*. 2017). The pozzolanic activity of fly ash was increased using GBFS (Lin *et al*. 2014, Huda *et al*. 2017) which also reduced the heat of hydration in blended cement (Kourounis *et al*. 2007, Kocaba *et al*. 2012). The fine particle of GBFS was act as good pozzolanic materials for compressive strength development of mortar (Burciaga-Díaz *et al*. 2010, Wang *et al*. 2012, Gulbandilar and Kocak 2016). Although, several studies have been conducted in the GBFS contained cement or concrete but the workability with good compressive strength of ready mixed concrete which was spinning in bulk carrier for 150 minutes was rarely determined.

The research on ready mixed concrete is going on frequently due to high demand that makes this industry as profitable business area in recent years. The facts i.e. unavailability of free space beside construction site, strict by laws for dumping and using construction materials, and eliminating the human attitudes to the quality of concrete (Howard *et al*. 2015) influence the public to use the ready mixed concrete. To achieve the good workability and compressive strength of ready mixed concrete are challenge to the ready mixed plant (Azambuja and Chen 2014, Huang *et al*. 2016). Several admixtures and additives like

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plasticizers/super plasticizers and retarders are commonly used to increase the workability (Lei and Plank 2012). A number of limitations are associated with the utilization of super plasticizers in concrete including the reduction of the compressive strength which are mandatory for heavy construction work and the pozzolanic activity of wastes was also decreased, costly and matching of the appropriate superplasticizer (SP) with concrete composition (Lei and Plank 2012). The advance SP can only provide a high strength concrete with high fluidity (Lei and Plank 2012). Furthermore, the effect of water consumption, the flow ability of high-performance concrete is also affected by the SP and pozzolanic additives. The mixing volume of bulk carrier and transition time i.e., required for running from ready mixed plant to the construction site are important factors to be considered (Shi *et al*. 2011). The work ability of the concrete is largely reduced in the transition due to the hydration reaction, which is accelerated with the spinning motion in the ready mixed carrier. The water evaporation or absorption by aggregate, mixed design, constituent material, temperature, humidity and method of transport also affect on the workability. The difficulty is raised due to the reduction of workability for the placement of concrete in construction site. The loss of workability in transition time is important deliberation for ready mixed concrete (Chou 2009). A real scale experiment of GBFS containing composite cement for the workability of ready mixed concrete will provide the better solution.

Granulated blast furnace slag is obtained as a by-product at the time of iron production in the blast furnace at high temperature which is fine, granule in shape, and silicates and alumino-silicate of calcium with noncrystalline in form. These characteristic properties make it appropriate to be used as partial replacement/additive of cementitious materials in cement-based applications (Pal *et al*. 2003). The hydraulic activity of GBFS increases with increasing the content of CaO, Al_2O_3 and MgO, but decrease with increasing of SiO_2 (Özbay *et al*. 2016). The hydration mechanism of GBFS blended cement confirms that the initial hydration rate becomes slow compared to the ingredient of the OPC. The reactivity of GBFS depends on the breakdown and dissolution of its structure in presence of the OH^{-1} ions which are produced as a result of the hydration of OPC. The GBFS react with the oxides of Na, K or Ca metals and formed the C-S-H (Regourd 1980). Previous study found that the workability of the concrete is increased with increasing the replacement level up to 60% which is mainly due to the better cement particle dispersion causes by smooth and dense particle of GBFS, and thus less water absorbing capacity of GBFS (Johari *et al*. 2011, Raghavendra and Udayashankar 2013, Özbay *et al*. 2016). The experimental investigation of the $Ca(OH)_2$ based GBFS concrete showed that workability is enhanced, delay slump loses and also increase compressive strength to that of OPC concrete (Yang *et al*. 2012). The fly ash and GBFS based alkali activated non cement binder enhance strength but lose the workability quickly (Yang and Song 2009). The better workability was obtained at 15% replacement level of OPC by slag up to 90 minutes. However, the disadvantage for using slag to increase the work ability of concrete is the reduction of compressive strength (Raghavendra and Udayashankar 2013). This phenomena was also observed in ordinary concrete (Wang and Lin 2013). Past research found that the fluidity of the cement paste significantly influenced the workability of the concrete which was due to the long needle like ettringite at initial time of setting. The variation of cement has a greater effect on the workability and on the early reactions of concrete. GBFS has been used successfully to improve concrete properties (Wang 2008). Metha *et al*. also suggested that the furnace slag increased the workability because the specific gravity of furnace slag was slightly lower than that of cement (Mehta 1983).

The effect of GBFS on the compressive strength, setting times, chemical composition, IR, LOI and also costing of cement, and the influence of the composite cement in workability and compressive strength of the ready mixed concrete explore through a real scale experiment in this study.

2. Research methodology

2.1 Materials

The Portland cement clinker, GBFS and gypsum were collected from local cement factory of Bangladesh. Gypsum ($CaSO_4$. $2H_2O$) is a raw material which is used mainly to control the rate of hydration of cement. The photographs of clinker, GBFS and gypsum are given in the Fig. 1.

2.2 Cement preparation

The OPC clinker becomes in to smaller pieces through a jaw crusher. A mini ball bill was used for grinding. A hollow cylindrical shell with single compartment rotates about its axis. The axis of the shell was horizontal and it is

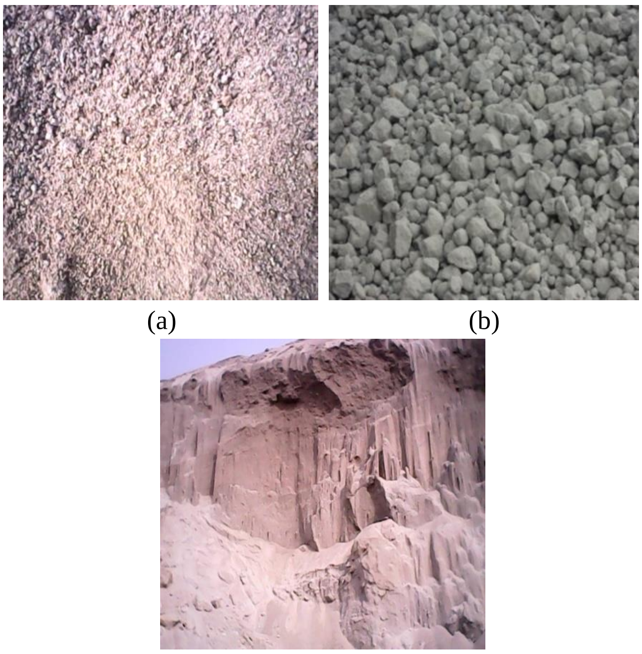

Fig. 1 Photograph of GBFS (a), Clinker (b) and Gypsum (c)

Table 1 Composition of the composite cements

Name of cement	Composition of raw materials		
	Clinker (%)	Slag (%)	Gypsum (%)
OPC	96	-	4
SG 1	90	6	4
SG 2	85	11	4
SG 3	80	16	4

Table 2 Mixed design of ready mixed concrete

Ingredient	Quantity
Cement (kg/m^3)	430
Coarse aggregate10-20 mm (kg/m^3)	742
Coarse aggregate3-10 mm (kg/m^3)	421
Fine aggregate (kg/m^3)	640
Water (kg/m^3)	172
Superplasticizer (kg)	2.4

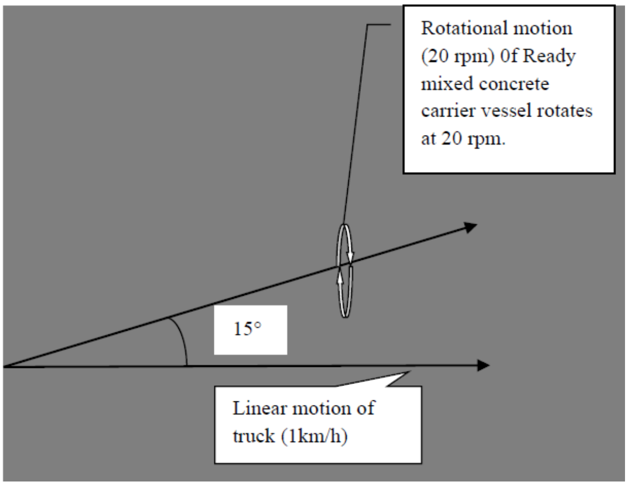

Fig. 2 Spinning motion of bulk carrier

partially filled with balls. The grinding media were used the chrome steel ball. The inner surface of the cylindrical shell is usually lined with an abrasion-resistant material such as manganese steel. The length of the mill is approximately equal to its diameter. The 27% of the mill was filling up the ball. The filling of the mill by ball with diameter of 40 mm, 30 mm, 25 mm, 18 mm were 26%, 33% and 23% and 18%, respectively. The capacity of the ball mill was 5 kg per batch. This specified mini ball mill were used for preparing cements according to the compositions in Table 1.

The specific surface area was maintained within the range of 300 m^2/kg to 320 m^2/kg. The grounded cement was sieved with 120 μ sieve and the reside were 500 gm, 610 gm, 660 gm, and 720 gm for OPC, SG1, SG2 and SG3 samples, respectively. The residue increases with increasing the GBFS which is due to the high hardness of GBFS. The chemical composition was determined using XRF (Penalytical-5). The compressive strength, water for normal consistency, setting time, loss of ignition (LOI) and insoluble residue (IR) (Standard 2013) was tested according to the ASTM standards.

2.3 Ready mixed concrete preparation and test

The Table 2 depicts the mixed design of ready mixed concrete. The local coarse and fine aggregate was used in the experiment. Rheobuild- 6 is a high range water-reducing admixture which was used for increasing the workability. It is a chloride free liquid admixture and meets ASTM C494 requirements. The natural fine aggregates were from the river sand. The gravity of the natural aggregates was 2.66, and the gravity of the natural fine aggregates was 2.64. Fineness Modulus (F.M.) was 2.73. Regular tap water was used as mixing water. Continuously graded crushed coarse aggregates (3/10 and 10/20 mm) and a river sand (0/1 mm) were used in this study. The bulk density of the coarse aggregates i.e., 3/10 mm and 10/20 mm and sand was 2.6, 2.1 and 1.87, respectively and their absorptions were 1%, 1% and 1.2%, respectively. The Rheobuilt-6 supperplasticizer was diluted with 3 liter water before added to the concrete as this permits a better distribution of relatively small quantity of admixtures within the mass of concrete. The OPC, SG1, SG2 and SG3 cement containing concrete designated as SGC-o, SGC1, SGC2 and SGC3, respectively. Four set of samples of ready mixed concrete have been carried out for a constant water/cement (W/C) ratio of 0.4 by weight. Superplasticizer dosage was 0.6% of cement. Concrete normally requires a more efficient mixing, longer mixing time, to make sure that all constituents have been mixed thoroughly. The mixing procedure consisted in mixing the aggregates with intergrinding cement for one a minute before adding water during 1.5 minutes, then the supperplasticizer with water was added another 1 min. The mixing procedure continues for another 3 minutes, then the ready mixed truck moving according to Fig. 2. The spinning motion of carrier as 20 RPM along its axis and running speed was 1 km/h in a road near ready mixed plant which is located in the vicinity of Dhaka, Bangladesh. The total concrete was 3.5 m^3 in carrier which was 2/3 of the volume of the vessel. The 100X100X100 mm mold was used for compressive strength determination. These concrete specimens were tested after 3, 7, 14, 28 and 90 days of water curing to evaluate the strength development. The temperature and humidity of the curing room were 24-28℃ and 65-78%, respectively. Three specimens were tested at each age and the average values were reported. The parameters of workability i.e., slump cone test, flow area and flow time was measured up to 150 minutes in 30 minutes interval. The fresh ready mixed concrete density was measured according to the ASTM standard.

3. Results and discussions

3.1 Characteristics of raw materials

The chemical composition of the clinker, granulated blast furnace slag and gypsumare obtained from XRF and is presented in the Table 3. The main oxides of GBFS fraction used are CaO, Fe_2O_3, SiO_2, MgO and Al_2O_3. The 66.81% and 38.75% of CaO are present in clinker and slag, respectively. The SiO_2 and MgO are comparatively higher

Table 3 Chemical composition of raw materials

Name of ingredients	Clinker	GBFS	Gypsum
CaO (%)	66.81	38.75	31.75
SiO_2 (%)	22. 10	34.51	2.51
MgO (%)	3.26	8.23	0.39
Fe_2O_3 (%)	1.11	1.10	0.19
Al_2O_3 (%)	5.52	11.52	0.45
SO_3 (%)	0.40	3.10	44.35
Na_2O (%)	0.20	0.30	-
K_2O (%)	1.14	0.47	-
Cl_2 (%)	0.001	-	-
LOI (%)	0.30	0.19	-
IR (%)	0.71	0.70	0.32
Moisture (%)	0.21	0.31	1.21
Bulk density (g/m^3)	1400	1632	1200
0-1 mm particles (%)	10.28	2.13	5.34
1-5mm particles (%)	22.50	**97.87**	**91.45**
5-25 mm particles (%)	61.89	-	3.21
>25mm particle (%)	5.31	-	-

Table 4 Properties of composite cements

Name	OPC	SG-1	SG-2	SG-3
CaO (%)	64.10	62.15	60.25	57.85
SiO_2 (%)	20.15	20.96	21.58	22.63
MgO (%)	0.96	1.15	2.20	2.85
Fe_2O_3 (%)	2.96	3.15	3.65	3.89
Al_2O_3 (%)	3.85	4.40	4.98	5.15
SO_3 (%)	2.21	2.58	2.67	2.96
IR (%)	1.15	1.56	2.10	2.21
Cl (%)	0.025	0.019	0.016	0.013
LOI (%)	1.04	0.96	0.89	0.76
Residue (75 μ)(%)	3.10	3.20	3.34	3.39
W/C (%)	24.5	25.9	27.5	29.5
IST (minutes)	124	137	142	150
FST (minutes)	234	245	253	260
3 days (MPa)	17.6	16.15	14.92	13.21
7 days (MPa)	27.6	26.12	25.62	23.98
28 days (MPa)	44.1	45.8	44.5	42.4
56 days (MPa)	45.98	46.12	45.21	43.15
90 days (MPa)	46.32	49.12	47.10	45.56

in composition in GBFS compare to the clinker.

The mineralogical parameter of clinker was as silica ratio (SR), Alumina to iron ratio (A/F), Tricalcium Silicate (C_3S- $3CaO{\cdot}SiO_2$), Dicalcium Silicate (C_2S- $2CaO{\cdot}SiO_2$), Tetracalcium Aluminoferrite (C_4AF- $4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3$), Tricalcium Aluminate (C_3A- $3CaO{\cdot}Al_2O_3$), lime saturation factor (LSF) and free CaO were 2.52, 1.69, 61.01%, 16.50%, 9.13%, 9.91%, 96, and 0.35%, respectively. Previous study was observed the similar phases presences in clinker (Ludwig and Zhang 2015). The structure of the Tricalcium Silicate (C_3S) is complex polymorphism depend on the forming temperature as well as impurities (Taylor 1997). The crystalline information of the C_3S is not clear because its' complex structures and difficult to prepared single crystal. Studies found that the content of ionic bonded O_2 increase reactivity (Ludwig and Zhang 2015). The crystalline structure of C_2S is also polymorphism but its less reactive than C_3S (Ludwig and Zhang 2015). Belite polymorphs have a low reactivity which depends on crystallographic modification, fineness, foreign ion substitution (Young *et al*. 1996). Previous studies found that GBFS consists with crystalline minerals with glassy phases (Piatak *et al*. 2015). It has hydraulic propertiessimilar to that of clinker. Natural gypsum was used in this study which is also mixtures of inorganic oxides with 97.2% of purity. The unit weight of the 5-10 mm size clinker was 1445 g/liter and gray in color. The unit weight of average sample of GBFS was 1635 g/liter and grainy, metallic substance, and gray in color. The GBFS are heavier than clinker. The particles of the GBFS are smaller than clinker.

3.2 Characteristicsof GBFS containing composite cement

The properties of the GBFS inter grinding composite cement are presented in the Table 4. The content of CaO decreases with the addition of GBFS. The uprising trends of the SiO_2, MgO, Fe_2O_3, Al_2O_3 and SO_3 in inter grinding cement was observed. This is due to chemical composition variation in GBFS and clinker.

The GBFS contained cement was a higher water demand than standard reference OPC cement. The blended cements showed longer settling times than the OPC. This is due to cement dilution effect (Kourounis *et al*. 2007). As a result, the hydration process slows down causing setting time to increase. The longer setting time of slag cements has also been reported by other authors and has been associated with the low Al_2O_3 content and/or high MgO and MnO_2 content in the GBFS. It must be noted that this particular GBFS has lower MgO and MnO_2 content and higher Al_2O_3 content in comparison with others mentioned in the literature and this seems to be the reason for the less pronounced setting delay (Saikia *et al*. 2012). The low hydration rate is an advantage for certain applications, since it means low rate of heat evolution, a fact that is of great importance in mass concrete constructions.

The compressive strength of OPC and GBFS contained cement mortars are shown in Table 4. The 28 days compressive strength of cements i.e., OPC, SG1, SG2 and SG3 were 44.1, 45.8, 44.5 and 42.4 MPa, respectively. The relative compressive strength of SG 1, SG 2 and SG 3 were 91.76%, 84.77% and 17.06% of the OPC cement mortars in curing age of 3 days. The relative compressive strength of SG 2 and SG 3 are 106.04%, 101.68% and 98.36 %, respectively of the OPC cement mortars in curing ages of 90 days. The compressive strength of the GBFS composite mortars increased with curing time but decreased with an increase in the replacement level. Relative compressive strength of GBFS composite cement at early age i.e., 1-7 days is very closed to OPC, whereas after 90 days of curing were relative higher which are due to pozzolanic activity of GBFS (Wang and Lin 2013). These GBFS phases cannot produce calcium silicate hydrate (C-S-H) polymeric layer in the presence of water, which are mainly responsible for strength in Portland cement (Gopalan 1993, Lee *et al*. 2012,

Table 5 Costing in composite cement

Name of Cement	Raw Materials Cost (Tk)	Electricity Cost (Tk)	labour Cost (Tk)	Total Cost (Tk)
OPC	256.54	10.37	8.97	275.88 (3.51 USD)
SG1	250.41	11.88	8.97	271.26 (3.45 USD)
SG2	245.10	13.30	8.97	267.37 (3.40 USD)
SG3	239.80	14.81	8.97	263.58 (3.35 USD)

Lin *et al*. 2014). The packing effect is a physical interaction in which small particle place inside of cement particle and increases overall matrix density that result in increase in compressive strength.

3.3 Cost for production of GBFS contained cement

The cost of the intergrading cement is calculated based on the price of raw materials at local cement factory in Bangladesh. The Table 5 shows the costing of GBFS contained cement. The total price of per tonesof clinker, slag and gypsum are 5200, 3000 and 2200 Tk, respectively. The grinding time were measured using stop watch to attain the specific surface area of 300-320 m^2/kg using a control mini ball mill. The consume electricity was 1.13 kW/h. The electricity consumption of mini ball mill was measure using digital meter. The electricity price to run the mini ball mill was 5.02 Tk /h in Bangladesh. The litre weight of GBFS is higher than clinker. Slag is harder than clinker and is therefore more difficult to grind. GBFS grind ability depends on the bulk characteristics of raw slag, such as fractions of coarse and fine slag, as well as intrinsic characteristics of the coarse slag, such as micro hardness.

Although the electricity consumption slightly increases, but the total costing decreases with the increase the content of GBFS in composite cement production. The 4.66 % of cost saved in 30% addition of the GBFS with clinker. Previous studies found that the producing of the composite cement with GBFS would significantly improve the benefits of land resource and materials conservation and significantly decrease the comprehensive environmental impact (Piatak *et al*. 2015, Li *et al*. 2016, Karim *et al*. 2017).

3.4 Workability of ready mixed concrete

The relationships among the slump flow, *V*-funnel time and composition of the concrete are presented in Fig. 3. The flow ability is related with shear stress of the mix. The slum flow increases with the increasing patterns of the GBFS content in inter grinding cement as illustrated in Fig. 3. Amongst the other several factors, one is the spherical nature of the GBFS particle size which elevate the shear stress between the paste and aggregate (Khan and Ghani 2004). Furthermore, the less hydraulic phase in GBFS influences to increase the slump diameter. The volume of paste plays a vital role in affecting the viscosity and flowability of ready mixed concrete. Despite having a small

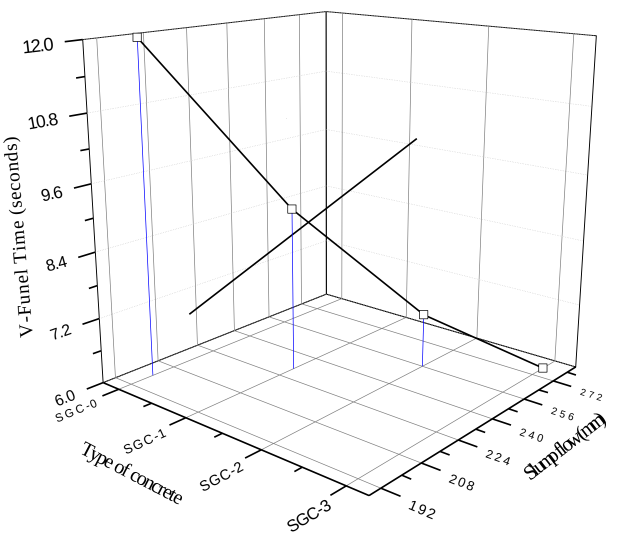

Fig. 3 Relation among slump flow, *V*-funnel time and concrete composition

variation in the *V*-funnel flow time between SGC-0 to SGC-3, the time of flow generally decreases with the escalating GBFS replacement ratio. The coating of paste helps to enhance the rolling capability ofthe GBFS. The lubrication effect between the aggregate; hence, resulting in a highly viscous mix with a longerflow time. This increases the tendency of the fresh concrete to have high friction internally between the aggregate and the paste phase leading to higher viscosity.

Previous studies also found that the slump flow after 30 minutes for the 15% furnace slag sample was within the value of 550-700 mm, whereas, the compressive strength of the 15% furnace slag replacement sample was higher than that of the control samples (Wang and Lin 2013).

The ready mixed concrete should remain in position without loss of workability setting and stiffening. The transition time of ready mixed concrete becomes critical in case of huge traffic jam (average travel time 2-3 hours). It is important to consider the time interval between mixing and placing concrete in a construction site. The loss of the workability of the ready mixed concrete with time is due to the continue hydration of cement reaction phase, evaporation of water and absorption of water by the aggregate. Other factors also consider is the methods of transport and the motion of mixing vessel and truck.

The typical relationship of the workability loses of the concrete by the transit time is shown in the Fig. 4. The figure should be taken as indicative of experimental condition, mix proportion, constituents of materials. Slump test was performed to evaluate the workability of ready mixed concrete up to 150 min or 2 h 30 min. The result shows a general trend that slumps decrease with reaction time of the concrete. The reason behind that actually some part of the binding materials already takes part in hydration reaction. The workability lose of the SGC1, SGC2 and SGC3 concretes mixed were less than that of the SGC0 concrete mixed at employed transition time. The relative workability loses of the SGC1 concrete were 17.85%, 19.2%, 17.85%, 41.96%, 65.38% and 53.65% of SGC0

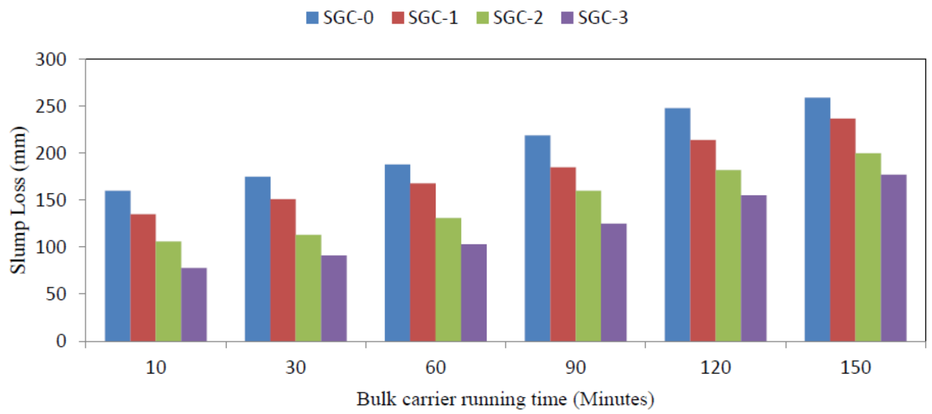

Fig. 4 Slump losses related with bulk carrier running time

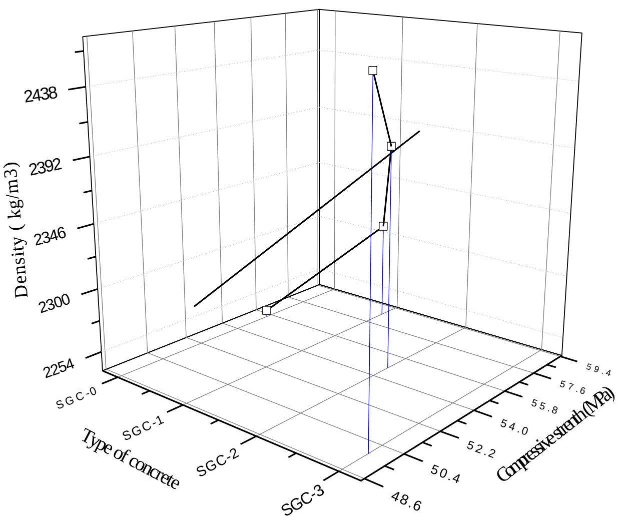

Fig. 5 Compressive strength (28 days) related with fresh density

at 10, 30, 60, 90, 120 and 150 minutes, respectively. The highest workability lose was 63.65% in 120 minutes. It may be due to the combination of the chemical constituent present in the materials. The highest work ability loss of SGC2 and SGC3 concrete mixed was observed at 150 minutes of transition time.

Previous studies found that the addition ratios of furnace slag for the three groups are 0%, 15% and 30%, and the slump losses from 0 min to 90 min are 260-250 mm, 270-260 mm and 260-240 mm, respectively. The maximum slump loss is approximately 20 mm when the amount of furnace slag replacing cement is 30%. Among the three furnace slag addition ratios, the control group and the addition of 15% furnace slag meet the design requirements (Wang and Lin 2013).

3.5 Compressive strength of concrete

The Fig 5 shows that the compressive strength development of concrete in which the OPC and GBFS contained cements used as binder. The compressive strength of the concrete SGC2 and SGC3 were lower that reference concrete SGC-0, whereas SGC-1 have high strength which is due to better chemical composition of GBFS containing cement. The GBFS has a composites mineral phase, which is similar to cement. The slag-mineral phase C_3S and C_2S react with water. The non hydraulic γ of the C_2S reduce activity. As a result GBFS reacts with water to produce calcium silicate hydrate which is responsible for strength development. However, poorly crystalline calcium silicate is the main phase of hydration product which is mainly due to low activity of GBFS and high concentration of iron oxide. On the other hand, clinker contain highly reactive phase C_3A and C_3S to water. The percentage and reactivity of clinker phase is reasonable higher than GBFS. That is why the compressive strength of concrete SGC2 and SGC3 were lower and also the decrease strength concrete with increasing GBFS in cement.

The result also indicates that the compressive strength of later age (28-90 days) of the concrete SGC1, SGC2 and SGC3 go upwards the compressive strength of SGC0 concrete. Actually, strength develops at early age due to part of calcium hydroxide that takes part in reaction. The hydration reaction rate did not accelerate at early age. The only smaller particles of the GBFS accelerate the rate at early age. This effect is not significant in this case because only 3.21% of particle less of GBFS intergrinding cement less than 45 micron. The acceleration of the hydration process of CEM III/A is confirmed by the fact that its slag particles are significantly hydrated. The compressive strength increases in the later age of the concrete for the result of the pozzolonic properties of the GBFS. This fact is responsible for the development of the compressive strength in SG1 containing concrete. The maximum value of the relative compressive strength decrease was observed of SGC3 concrete at 3, 7, 28, 56 and 90 days of the reaction time and corresponding value were 27.21%, 20.87%, 15.88% and 13.74 % respectively.

3.6 Optimum cement raw mixed identification

The percentage of the admixture dosage and mixed composition were constant through experiment and also used same graded aggregate and sand. The best composition of the GBFS containing cement composition sorts out from the compressive strength and workability data. The Fig. 6 help to identify optimum point in which composition of the cement shows the better slump at 150 minutes reaction and standard 28 days compressive strength.

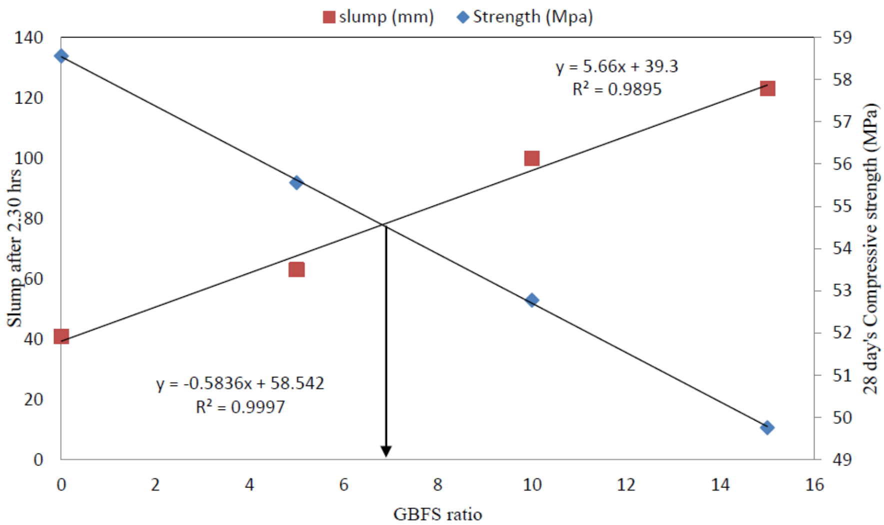

Fig. 6 Optimum composite cement composition identification

The Fig. 6 shown the actually cement composition where the specified concrete getting highest compressive strength at 60 minutes and 150 minutes respectively. The best result of the compressive strength and slump after 150 minutes reaction was identified from the Fig. 6, which is 6.59% GBFS ratio. The composition of the cement contains of 6.89% of GBFS, 4% of Gypsum and 89.11% of clinker. The chemical composition of cement related with slump was given in Fig. 6.

4. Conclusions

The work focused on the analyzing the workability of the concrete up to 2.30 hours transition in bulk carrier which contain different percentage of GBFS grinding composite cement as a binder. A real scale experiment was conducted using bulk carrier. The main conclusions of this research were presented as follows;

1. The chemical ingredients in GBFS and clinker are similar, but composition is difference. The mineralogical parameter of clinker was as MS-2.52, MA-1.69, C_3S-61.01, C_2S-16.50, C_4AF-9.13, C_3A-9.91, LSF- 96, and free CaO-0.35.
2. The unit weight of the 5-10 mm size clinker was 1445 g/liter and gray in color, whereas, the unit weight of average sample was 1635 g/liter and grainy, metallic substance, and gray in color.
3. The GBFS containing cement was a higher water demand and higher of setting time compare to the OPC which is due to mineralogical composition of GBFS and dilution effect.
4. The relative compressive strength of GBFS composite cement 1-7 days are very closed to OPC cement, whereas the relative compressive strength in curing ages of 90 days were relative higher which are due to pozzolanic activity of GBFS.
5. Although the electricity consumption increase is due to higher hardness of GBFS, but the total costing decreases with the increase the content of GBFS in composite cement production. The 4.66% of cost was saved in 30% addition of the GBFS with clinker.
6. The relative workability loses of the SGC1 concrete were 17.85%, 19.2%, 17.85%, 41.96%, 65.38% and 53.65% of SGC0 at 10, 30, 60, 90, 120 and 150 minutes, respectively. The highest workability lose was 63.65% in 120 minutes. It may due to the combination of the chemical constituent present in the materials. The highest work ability loss of SGC-2 and SGC-3 concrete mixed was observed at 150 minutes transition time.
7. The composition of the cement i.e., 6.89% of GBFS, 4% of Gypsum and 89.11% of clinker shows the best result in compressive strength as well as a slump.

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