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Partial replacement of fine aggregates with laterite in GGBS-blended-concrete

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Abstract. This paper presents a preliminary study on the influence of laterite soil replacing conventional fine aggregates on the strength properties of GGBS-blended-concrete. For this purpose, GGBS-blended-concrete samples with 40% GGBS, 60% Portland cement (PC), and locally available laterite soil was used. Laterite soils at 0, 25, 50 and 75% by weight were used in trails to replace the conventional fine aggregates. A control mix using only PC, river sand, course aggregates and water served as bench mark in comparing the performance of the composite concrete mix. Test blocks including 60 cubes for compression test; 20 cylinders for split tensile test; and 20 beams for flexural strength test were prepared in the laboratory. Results showed decreasing trends in strength parameters with increasing laterite content in GGBS-blended-concrete. 25% and 50% laterite replacement showed convincing strength (with small decrease) after 28 day curing, which is about 87-90% and 72-85% respectively in comparison to that achieved by the control mix.

Keywords: admixtures; concrete; construction materials; environmental effect; fly ash/slags; strengthening

1. Introduction

Ground granulated blast furnace slag (GGBS) is one of the commonly used mineral admixtures in concrete to improve the performance and quality of the concrete. Moreover GGBS used as replacement to the ordinary Portland cement (PC) has been one of the environmental friendly and cost effective approach of producing concrete which is durable, efficient and perhaps resistant to the corrosion of reinforcement steel (Babu and Kumar 2000, Cheng *et al.* 2005, Chore and Joshi 2015). Environmental friendly because GGBS is a by-product from the blast furnace used for manufacturing iron (Khan *et al.* 2014) is replacing the inorganic cement-production of which utilizes energy, natural resources and produces greenhouse gases (Van Oss and Padovani 2003). Hogan and Meusel (1981) reported a significant improvement in the strength when 40-65% of PC replaced with GGBS in the concrete. Similar figures were presented by Oner and Akyuz (2007) showing maximum compressive strength of concrete when prepared by replacing 55-59% of PC

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with GGBS. Both the literature however stressed on one point, that the GGBS-concrete to have lower strength than the ordinary concrete at early ages - three days of hydration, and the strength to develop with curing period depending upon the chemical composition and fineness of GGBS.

On the other hand, fine aggregates used in concrete generally relates to sand extracted from rivers, sea, and/or land (Sakai 2005, Sunil *et al.* 2015). Owing to the constant demand in construction industry and concrete production, continued extraction and consumption of these resources (fine aggregates) significantly influences the environment and the process (Marinković *et al.* 2010). The depleting natural resources have motivated numerous research in search of an alternative aggregate, mostly recycled, to replace fine aggregates. Some of the commonly used alternative aggregate include crushed concrete and bricks, crushed stone, ceramic wastes, powdered glass etc. However utilizing recycled aggregates pose several drawbacks; the recycling process at first place may demand more energy when compared to the extraction of natural aggregates (Marinković *et al.* 2010). Secondly, the chemical compatibility of the alternative aggregate with cement is crucial in dictating the efficiency of the concrete; the alkali-silica reactivity – reaction between cement and the alternative aggregate (Terro 2006, Shaikh 2014) is one such example. Hence utilizing naturally available material, preferably with abundance of local availability, and resembling natural sand is an ideal option. Laterites are one such natural materials traditionally used for complete or partial replacement of sand in concrete (Adepegba 1975, Balogun and Adepegba 1982). Lasisi *et al.* (1984) emphasized on the suitability of laterite-cement mortars, while cautioned that the clay content in the laterite to adversely influence the strength of the mortar. Similar outcomes presented by Balogun and Adepegba (1982) stated the suitability of laterite soil up to 50% of the total fine contents with only slight variation in the mechanical properties of laterized concrete; however smaller clay content advices for a better concrete.

Summarizing the literatures, GGBS replacing cement and laterite replacing fine aggregates have been shown to have a positive direction, especially considering the environmental foot print involved in producing or procuring cement and aggregates. In fact, usage of GGBS-a by-product, and laterite-locally available soil, is rather environmental friendly and economical. However, limited literature demonstrate the influence of blending GGBS and laterite to produce concrete. The current paper therefore presents a preliminary experimental investigation on the possible replacement of fine aggregates with locally available laterite soil in the GGBS blended concrete. For this purpose a GGBS blended cement with 40%-60% of GGBS-cement ratio by volume respectively was used in all the trials excluding the control mix. The concrete samples were then prepared in the laboratory using the GGBS-blended-cement and fine aggregates replaced with laterite soil at 0, 25, 50 and 75% by weight. The analysis in this paper specifically focus on evaluating the influence of varying per cent of laterite on the strength parameters of the concrete including compressive strength (f_c), flexural strength (f_b) and split tensile strength (f_s), with curing period.

2. Materials

The two cementitious materials used in this study were PC and GGBS. Commercially available Portland cement (PC) of 43 grade was used in the experiments. Initial laboratory tests to determine the specific gravity G_S, and setting times were conducted on the representative PC samples. It should be noted that the experiments were conducted with due care by following the procedures recommended in the respective Indian standards. The detailed procedure and methodology adopted

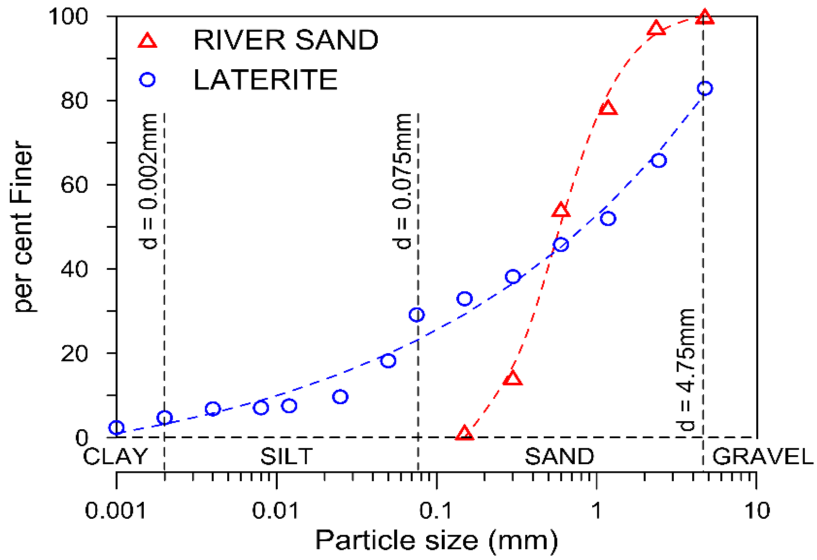

Fig. 1 Grain size distribution curves for river sand and laterite samples

in the study are available in Manjunath (2015). The PC sample had an average G_S value of 3.11. The initial and final setting times was observed to be 70 and 350 minutes respectively. Powdered GGBS was collected from a nearby plant and used in this study to replace the PC samples. The average G_S value of the GGBS was 2.9. It's certain that the mineral admixtures generally have lesser G_S values when compared to PC's (Khan *et al.* 2014); similar observations can be drawn from this study as well. In addition to the cementitious materials, water, course aggregates, fine aggregates and laterite (partially replacing fine aggregates) are among the constituents used in the mix design to prepare concrete in this study. Commercially available gravel with G_S of 2.74 was used as course aggregates in the experiments. Fine aggregates included the locally available river sand (RS) and laterite soil. Fig. 1 shows the gradation curve for RS from the laboratory sieve analysis. The properties and soil classification of RS is tabulated in Table 1. The soil classification was carried out as per the Unified Soil Classification System (USCS). The RS samples with GS equal to 2.64 showed particles well within the sand size (0.0075 mm to 4.75 mm), and with Cu<4 (refer to Table 1), RS can be classified as "SP-poorly graded sand, with little or no fines" as per the USCS.

Laterite soil used in this study was collected from different quarries in Dakshina Kannada district of Karnataka state, south-western part of India. The soil samples were collected via the open pits extending of depths ranging from 1.5 m to 2 m from natural ground level. The visual identification of the field sample showed rusty-red or reddish brown color particles with particles sizes ranging from gravel to clay. Laboratory tests to determine particle gradation and Atterberg's limits were conducted, the data of which was further used to classify the soil as per USCS. Data from the laboratory tests for the laterite are also presented in figure 1 and table 1. The G_S value for the laterite was equal to 2.54. Gradation curve showed the particle sizes including gravel (15 to 20%), sand (approx. 60%), silt (approx. 20%) and clay sizes (less than 5%). The gravel portion in the laterite soil was sieved and excluded prior to replacing the RS; only the remaining portion (sand, silt and clay) was used in this study. Based on the outcomes presented in the literatures

Table 1 Properties of river sand and laterite soil

	River sand	Laterite soil
Specific gravity, G_S	2.64	2.54
Clay size (<0.002 mm)	-	less than 5%
Silt size (0.002–0.075 mm)	-	20% (approx.)
Sand size (0.075–4.75 mm)	100%	60% (approx.)
Gravel size (>4.75 mm)	-	15-20%
D_{10} (mm)	0.21	0.01
D_{30} (mm)	0.4	0.18
D_{50} (mm)	0.6	0.81
D_{60} (mm)	0.7	1.5
Uniformity coefficient, C_u	3.33	150
Coefficient of curvature, C_c	1.09	2.16
USCS Soil classification	SP	SM
Liquid limit, w_L (%)	-	42
Plastic limit, w_p (%)	-	30
Plasticity index, PI (%)	-	12

Note: $C_u = \frac{D_{60}}{D_{10}}$ and $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$

where D_{10}, D_{30}, and D_{60} are the particle sizes (diameter) corresponding to 10%, 30%, and 60% finer respectively

(Balogun and Adepegba 1982, Lasisi *et al.* 1984) - lesser the amount of clay sized particles better is the quality of the laterized concrete. Hence, with less than 5% of clay sized particles, laterite sample used in this study can be assessed as a good replacement for fine aggregates in concrete. The Atterberg's limit for the laterite showed low plasticity index (PI) of 12% corresponding to the liquid (w_L) and plastic (w_p) limits of 42% and 30% respectively. The less value of PI certainly relates to the presence of less clays and/or plastic silts. Considering the gradation data and the Atterberg's limits, laterite sample was classified as "SM-Silty sands, sand-silt mixtures". Further comparing the gradation curves of RS and laterite samples, the value of D_{50} (particle size corresponding to 50% finer) was observed to be very close with 0.6 mm and 0.81 mm respectively. This suggests about 50% of the samples in both RC and laterite are coarser than 0.6 mm. Moreover the gradation curves shows about 60% of the laterite to have sand sized particles. By these two observations it is clear that the laterite has sufficient resemblance (in terms of particle sizes) with RS. This perhaps is one of the key points to achieve successful replacement (partial or complete) of RS with laterites.

3. Experimental program

Mix design for M20 grade (1:1.5:3) concrete was used for preparing all the concrete samples in this study. This perhaps agrees with the conclusions reported by Balogun and Adepegba (1982),

Table 2 Mix proportions used for the concrete (in kg/m^3*)

Mix type	Control mix	GGBSC+RS+Laterite			
		No replacement	25% Laterite	50% Laterite	75% Laterite
Symbol used	CM	LR-0	LR-25	LR-50	LR-75
Cement	422.5	253.5	253.5	253.5	253.5
GGBS	-	156.5	156.5	156.5	156.5
RS	813.2	813.2	609.9	406.6	203.3
Laterite	-	-	203.3	406.6	609.9
Coarse aggregates	1214.5	1214.5	1214.5	1214.5	1214.5
Water	206.8	206.8	221.5	251.1	273.2
Water-binder ratio	0.49	0.50	0.54	0.54	0.54
Slump (mm)	69	71	65	57	44

*weight (kg) of the ingredients were measured in the laboratory approximately for one batch of casting (12 cubes+4 cylinders+4 beams) and later converted to kg/m^3 using the total volume per batch

however the water-cement-ratio (WCR) in this study was maintained close to 0.5. Table 2 tabulates the different mix proportions adopted in this study to prepare the concrete samples. The main variable considered in the experimental program was the replacement of RS with Laterites. For this purpose, concrete samples with five different mix proportions were prepared. First used the control mix (CM); that is prepared by only using PC, RS, course aggregates and water. Neither GGBS replacement in cement nor Laterite replacement in RS was done in the CM. The remaining mix were prepared using the GGBS-blended-cement (GGBSC) with 40% to 60% ratio of GGBS and PC respectively. The course aggregates and water were maintained unchanged throughout. The replacement of RS with Laterite was achieved at every 25% increment of laterite; that is 0% laterite (LR-0), 25% laterite (LR-25), 50% laterite (LR-50), and 75% laterite (LR-75). It should be noted that, LR-0 refers to only RS used as fine aggregates.

The test blocks were prepared by concrete samples casted in different molds depending upon the test requirements. A total of 60 cubes of dimension 150 mm×150 mm×150 mm accounting to 12 cubes per mix proportion were casted for the compression test. 20 cylinders of 150 mm diameter and 300 mm length were casted for the split tensile tests and 20 beams of dimension 500 mm×100 mm×100 mm were prepared for the flexural strength tests. Fresh concrete was used for the slump tests. It should be noted that among the 12 cubes prepared for compression tests, 4 cubes each were allowed for 3, 7 and 28 days of curing period prior to testing. While the cylinder and beam samples were allowed for 28 days of curing. The experiments in the laboratory were conducted with due care by following the procedures as per the recommendations from the respective Indian standards. The detailed procedure and methodology adopted in the study are available in Manjunath (2015).

4. Results and discussion

Table 3 tabulates the results obtained from the laboratory experiments. The slump values for the concrete sample prepared using the GGBSC showed a decreasing trend with increasing per cent

Table 3 Tabulation of results from the experimental program

Test parameter	CM	LR-0	LR-25	LR-50	LR-75
Slump (mm)	69	71	65	57	44
Compressive strength (MPa), Curing period 3 days	14.8	13.8	13.0	12.6	11.0
Compressive strength (MPa), Curing period 7 days	19.1	18.5	17.3	16.0	15.5
Compressive strength (MPa), Curing period 28 days	28.0	27.1	25.2	23.9	20.2
Flexural strength (MPa), Curing period 28 days	3.31	3.25	2.88	2.38	1.56
Split tensile strength (MPa), Curing period 28 days	2.44	2.34	2.19	2.02	1.70

Note: Values in table are the average of four trials for each test

replacement of RS with laterite. The slump values in the current study ranged between 71 mm and 44 mm. LR-0 showed an increased slump value in comparison to CM. This perhaps relates to the smooth surface texture of the GGBS particles as thoroughly discussed in the literatures - refer to review article by Khan *et al*. (2014). However the influence of increasing laterite content may relate to the water holding capacity of laterite soil particles, with more emphasis on clays and silts. Perhaps the additional water absorbed by the clay content of laterite results in lower WCR thereby resulting in stiffer concrete mix. Similar results were presented by Balogun and Adepegba (1982) where the slump values dropped from 65 mm from 40% laterite to “zero slump” at 100% laterite for a 1:1.5:3 concrete mix at WCR of 0.55. At 25% laterite content the results from Balogun and Adepegba (1982) showed a collapse, whilst the current study showed higher slump values. The presence of 40% GGBS in the cementitious fraction of the concrete samples in this study could be one of the reasons. However further study on the physical-chemical interaction of the material is mandatory to confirm this variation. Fig. 2 also compares the slump values for concrete samples with different materials used as replacement for fine aggregates from the literatures. The other alternatives considered include the crushed ceramic-1:1.5:3 mix with WCR of 0.47-0.48 (Binici 2007); crushed basaltic pumice-1:1.5:3 mix with WCR of 0.49-0.50 (Binici 2007); and waste glass-WCR of 0.53 (Ismail and Al-Hashmi 2009). The overall observation shows decreasing trend in the slumps values with increasing replacement content for all the other alternatives as well.

Fig. 3(a) shows the comparison of compressive strength (f_c) between the concrete samples with increasing laterite content and control mix for 3, 7 and 28 days curing period. The observations present a decreasing trend with increasing laterite content in the concrete. This trend seems not be influenced by the replacement of cement with GGBS adapted in this study. Because similar decreasing trends with increasing laterite content have been reported in the literatures conventionally with only Portland cement; for example Balogun and Adepegba (1982), Udoeyo *et al*. (2006). Fig. 3(b) shows and compares the influence of increasing laterite contents. The decrease in f_c with increasing laterite is well explained as the weak cementation behaviour of the laterite particles (Udoeyo *et al*. 2006). However to judge the strength of a particular mix proportional it’s rather crucial to have a relative comparison with the conventional practise, that is CM in this study. Hence the term “relative strength” defined as the ratio of f_c for a particular mix to that of CM is used in the analysis. Fig. 3(c) shows the relative strength for different mix proportions adapted in this study with curing period. As expected, lower relative strengths were observed at 3 days curing period for LR-0 and LR-25 mixes. This can be related to the presence of

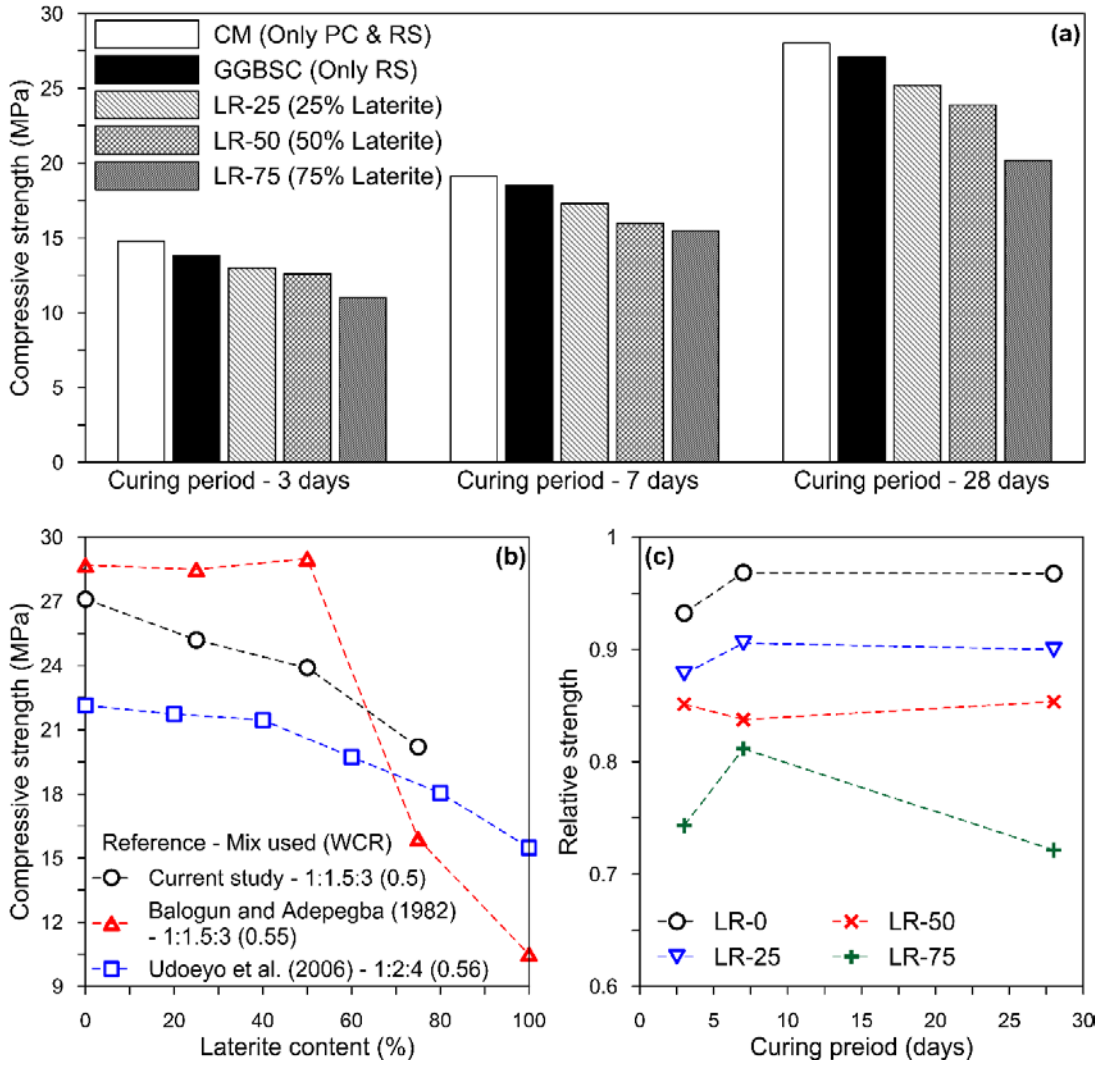

Fig. 3(a)-(c) Comparison of the compressive strengths of concrete samples; with (a) variation of mix proportions; (b) influence of laterite content after 28 days curing; (c) relative strength with respect to CM

GGBS which imparts lower strength for early curing periods-generally 3 days (Hogan and Meusel 1981, Oner and Akyuz 2007). While the trends presented by the mixes LR-50 and LR-75 are not in confirmation with these trends; this may require further investigation focussing on the physical-chemical interaction of the mixes. Nonetheless considering the scope of the current paper, it can be clearly observed that a relative strength of about 0.9 and 0.85 was achieved with a replacement of 25% and 50% of RS with laterite respectively, in the GGBS-blended-concrete. This suggests that f_c of about 85% can be achieved by replacing 50% by weight of RS with Laterite in GGBS (40% by weight) blended concrete; hence saving on cost and the depleting resources for fine sand. The marginal decrease (relative strength of about 0.97) observed in LR-0 in comparison to CM perhaps relates to the replacement of PC with GGBS (for example, Babu and Kumar 2000).

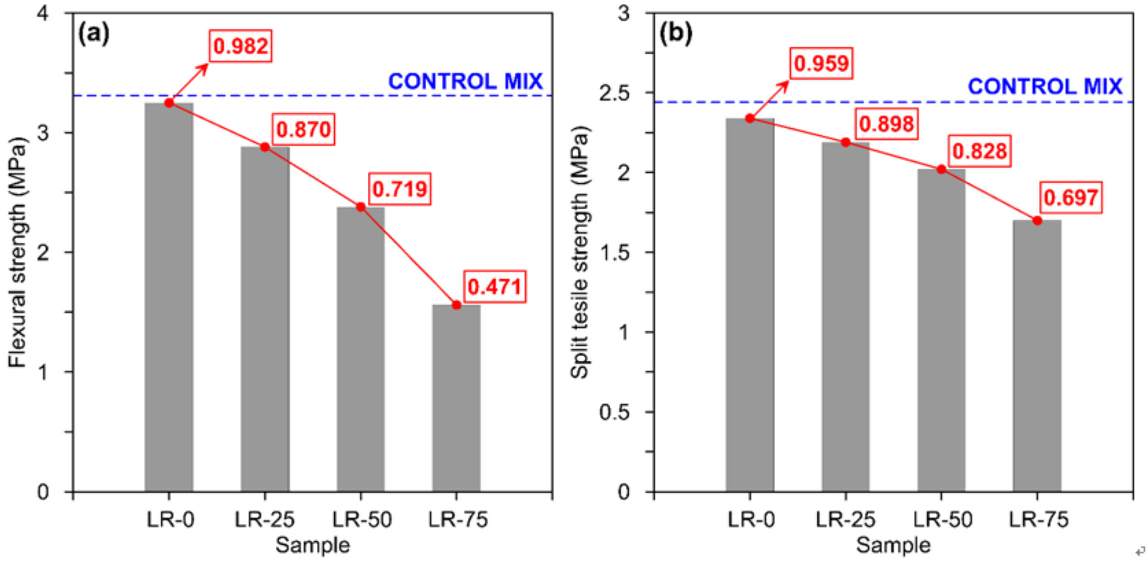

Fig. 4(a)-(b) Effect of increasing laterite content on the; (a) flexural strength, and (b) split tensile strength of the concrete samples

Fig. 4(a) shows the effect of increasing laterite content on the flexural strength (f_b) after a curing period of 28 days. The trend of f_b with increasing laterite content was much comparable to that of compressive strength. However a twofold decrease in the f_b was noted between LR-0 and LR-75. This was further quantified using the relative strength for f_b values, with 0.471 for LR-75. Nonetheless the relative strength of about 0.87 and 0.719 was noted with 25% and 50% replacements respectively (refer to Fig. 4(a). Similar numbers were observed with the split tensile strength (f_s) values as well; while the rate of decrease in f_s values was relatively low when compared with the f_b values. The relative strengths for f_s at 25% and 50% replacements were observed to be at 0.898 and 0.828 respectively. Therefore based on the observation and the experimental results, replacement of RS with laterite in GGBS-blended-concrete could be considered in order to adapt a cost effective concrete mix, provided the laterite is available in abundance; however with a slight decrease in the strength. Therefore the per cent of laterite replacement certainly depends upon the nature of construction and strength requirements. Further research focussing on the physical-chemical interaction of laterite in GGBS-blended-concrete is crucial to comment on its utilization in practise. Also considering the effect of varying clay content in laterite would be ideal as this study is limited to laterite obtained from one particular source.

5. Conclusions

Based on the experimental results presented in this study, the following conclusions can be drawn:

• Observation from the slump tests showed decreasing trend in slump values with increasing replacement content of RS with laterite in GGBS-blended-concrete. This perhaps relates to the water holding capacity of laterite, with more emphasis on clays, thereby reducing WCR.

• Replacement of about 25% by weight of RS with laterite in GGBS-blended-concrete showed to have around 87% to 90% of the strength (f_c, f_b, and f_s) being achieved by CM mix after 28 days curing. Further 50% replacement showed 85% and 82% of f_c and f_s achieved by CM mix after 28 days curing; whilst lower f_b values close to 72%.

• As evident from the results and discussion presented, increasing laterite content in GGBS-blended-concrete showed decreasing trends in the strength parameters. Hence, the amount of laterite content to be adopted in the mix certainly depends on the nature of construction and strength requirements.

• Further research focusing on the physical-chemical interaction of laterite in GGBS-blended-concrete is crucial to decide its utilization in practice. Especially considering the clay content in laterite, as this study is limited to laterite obtained from one particular source.

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