Eco. Env. & Cons. 26 (February Suppl. Issue) : 2020; pp. (S233-S241)

ISSN 0971–765X

Influence of industrial by-products in artificial lightweight aggregate concrete: An Environmental Benefit Approach

Kolimi Shaiksha Vali and S. Bala Murugan*

School of Civil engineering, Vellore Institute of Technology, Vellore, India

(Received 6 November, 2019; accepted 10 December, 2019)

ABSTRACT

Lightweight aggregate concrete manufactured from cold-bonded artificial lightweight aggregates with major amount of fly ash facilitates the use of high volume fly ash in aggregate with minimal energy use. This paper examines the influence of supplementary cementitious materials from industries on the strength behavior of cold-bonded artificial lightweight aggregate concrete due to partial replacement of cement. Replacing cement with granulated blast-furnace slag, silica fume and addition of glass fibres shows higher strength due to both matrix and matrix-aggregate interfacial bond densification with lesser cement content. Artificial lightweight aggregate concrete with a cement content of 249 kg/m^3 develops approximately 32.1 N/mm^2 compressive strength.

Key words *: Cold-bonded aggregate, Lightweight aggregate concrete, Supplementary cementitious material, Alkali Resistant glass fibre, Compressive strength.*

Introduction

The world cement production has increased dramatically over the past 15 years. This development is the most important part disturbing technological improvement and updating of cement industry manufacturing services. The requirement for cement was 5.02 billion metric tons in the year 2018. Existing technology for the manufacturing cement clinker is ecologically stressful as it needs huge energy natural resources usage and also results in pollutant emissions. Indeed, around 5% of the total carbon dioxide emitted and related with global warming is accountable for cement manufacturing. The cement industry has been recognized as one with a high potential for development. Assuming no or little substitute to portland cement clinker chemistry (Mehta *et al*., 1976 Ramachandran *et al*., 1981 Kolimi *et al*., 2019; Scrivener *et al*., 2008 Damtoft *et al*., 2008) and setting limits on the use of supplementary cementitious materials (SCMs), there is only option to reduce the carbon footprint, which is to increase the rates of diversity and utilization of cement clinker materials. Today, SCMs are broadly used in concrete either in mixed cements or in the concrete mixer added separately. A possible solution to partially replace Portland cement (PC) in the manufacturing of artificial lightweight aggregates (LWAs) and concrete is the use of SCMs such as ground granulated blast-furnace slag (GGBFS), a by-product from iron production, or fly ash (FA) from coal ignition (Kolimi *et al.,* 2019). The use of such materials in construction industry, where there is no additional clinkering procedure is involved, leads to a huge reduction in carbon dioxide emissions and is also a means of using by-products of industrial production processes. In concrete, aggregate occupies 60-70% of the volume, the utilization of cold-bonded artificial lightweight aggregate promotes high volume consumption of fly ash (Swamy *et al.*, 1984; Kolimi *et al.*, 2017; Swamy *et al.*, 1985; Wegen *et al.*, 1985; Zangh *et al.*, 1991; Zangh *et al.*, 1991; Chang *et al.*, 1996; Al-Khaiat *et al.*, 1998; Kolimi *et al.*, 2016; Kayali *et al.*, 1999; Baykal *et al.*, 2000; Haque *et al.*, 2004; Kayali *et al.*, 2005; Chi *et al.*, 2003; Gesoglu *et al.*, 2004; Gesoglu *et al.*, 2006; Kolimi *et al.*, 2019).

Using major part of fly ash in the manufacturing of LWAs and GGBFS and silica fume as a partial replacement of cement can further increase in lightweight aggregate concrete (LWAC) production. A systematic investigation on cold-bonded lightweight aggregate concrete was therefore carried out by incorporating super plasticizer (S.P) (Master Glenium SKY 8233), GGBFS, silica fume with addition of alkali resistant glass fibres (G.F) such as: (i) Optimizing the super plasticizer content based on trials with different percentage in water reduction (ii) Optimizing the GGBFS content based on strength and first trial (iii) Optimizing the silica fume content based on strength and second trial (iv) Addition of glass fibres based on third trial to get desired strength. In order to understand the influence of SCMs, cold-bonded artificial aggregate and partial replacement of cement with GGBFS, silica fume with addition of glass fibres, the compressive strength characteristic for 7days and 28days of LWAC were studied.

For each mix combination, 100 mm cube specimens were casted for compressive strength determination. The specimens were cured at room temperature for 7-days and 28-days and tested through universal testing machine. Almost for all the mix combinations same trend in the compressive strength was followed in 7 and 28 days of curing, around 67% of compressive strength was achieved in 7days of normal water curing.

Experimental Programme

Materials and Mix proportions

Table 1 presents the physical and chemical properties of materials like fly ash, GGBFS, hydrated lime, cement, silica fume and Master Gelenium SKY 8233 super plasticizer (specific gravity: 1.08) was chosen in manufacturing of LWAC and added viz., 0.1%, 0.2% and 0.3% with different percentage in water reduction based on strength. Local river sand (spe-

Table 1. Chemical and physical properties of different binder materials utilized in this study

Observations	*FA (F)	C	HL	SF	GGBFS
Chemical Characteristics					
SiO_2	39.4	22.3	0.3	99.88	35
Fe_2O_3	18.54	3	0.23	0.040	0.95
Al_2O_3	17.9	6.93	0.42	0.043	17.7
CaO	17.45	63.5	69	0.001	41
MgO	2.88	2.54	0.5	-	11.3
TiO_2	0.95	-	-	0.001	-
Na_2O	0.28	-	-	0.003	0.2
K_2O	1.78	-	-	0.001	-
$Ca(OH)_2$	-	-	91	-	-
MnO_2	0.15	-	-	-	2.7
SO_3	1.70	1.72	-a	-	-
$CaCO_3$	-	-	-	-	10
P_2O_5	0.45	-	-	-	0.65
Glass content	-	-	-	-	92
Physical Characteristics					
Specific gravity	2.12	3.12	2.24	2.63	2.85
Appearance (powder)	Grey	Grey	White	White	Off-white
Specific surface area (m^2/kg)	407	290	-	819	409
Loss on ignition	1.76	0.84	-	0.015	0.26
pH Value	-	6.3	12.4	6.90	-
Moisture (%)	0.5	-	-	0.058	0.10

FA (F): Fly ash (F-Type); C: Cement; HL: Hydrated lime; SF: Silica fume; GGBFS: Ground granulated blast furnace slag cific gravity: 2.54, water absorption: 1 %) was used as a fine aggregate and GGBFS and silica fume was used to replace cement with addition of glass fibres.

Manufacturing of cold-bonded artificial aggregate

Cold-bonded artificial coarse aggregate was manufactured using 80% Class-F fly ash, 10% GGBFS, 10% hydrated lime and 0.17% glass fibres by pelletization method. The disc pelletizer was fabricated with a diameter of 0.5m and 0.25m depth as shown in Fig. 1. The aggregates were pelletized for 17 min in order to achieve maximum pelletization efficiency, maximum strength and minimum water absorption, based on different trials the pelletizer speed and angle were maintained at 55 rpm and 36^0 respectively along with a 28% water content (by total weight of material added at the time of pelletization). The cold-bonded coarse aggregate size fraction passing 16 mm and retained in 4.75 mm sieve was water cured (Cold-bonded) for 28 days at room temperature as shown in Fig. 3. The physical and mechanical characteristics of cold-bonded coarse aggregate is tested as per IS: 2386 – 1963 which satisfies the structural demand as per IS: 9142 (part 2) – 2018 are given in Table 3 and Table 4. To achieve workability artificial aggregate was presoaked for 30 min before it mixed in to concrete.

Fig 1. Disc Pelletizer

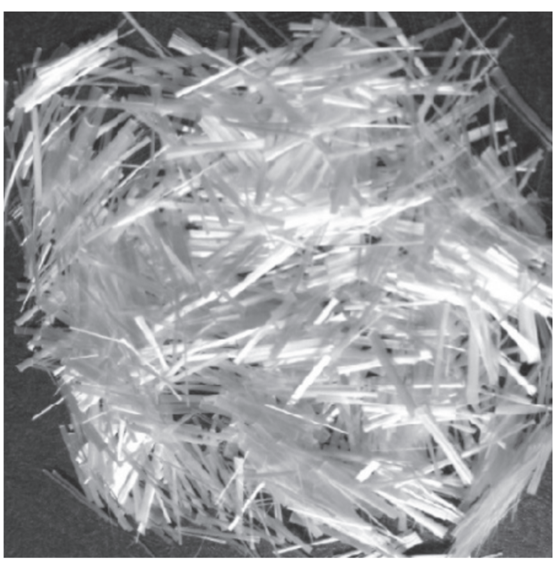

Fig 2. Glass fibres

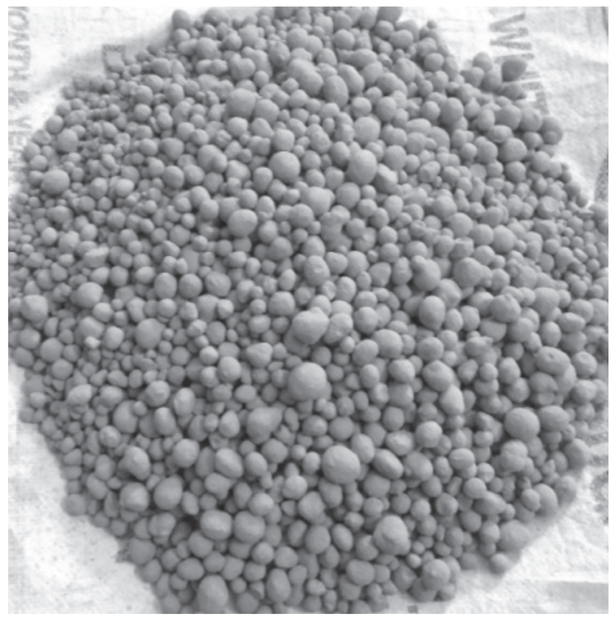

Fig 3. Cold-bonded aggregate

Alkali Resistant glass fibre

Alkali Resistant glass fibres were added to the manufacturing of lightweight aggregates and characteristics are given in Table 2 which is evaluated as per ASTM C1579-13.

Cement replacement with GGBFS and Silica fume

Lightweight concrete manufactured with cement content of 438kg/m^3 was selected as control mix. Based on the first trial five levels of cement replacement with GGBFS viz., 10%, 20%, 30%, 40% and 50% by weight of cement were selected and noted as second trial. In third trial optimum mix in second trial was chosen and four levels of cement replacement with silica fume viz., 2.5%, 5%, 7.5% and 10%

by weight of cement were adopted. In fourth trial, the optimum mix in third trial was selected and added Alkali resistant glass fibres viz., 0.1%, 0.2% and 0.3% by total volume of concrete to achieve compressive strength. The different trial mix combinations of LWAC were calculated by absolute volume method with slump values is presented in Table 5-8.

Results and Discussion

Fresh concrete properties

Super plasticizer dosage with different percentage in water reduction

The dosage of super plasticizer required to maintain a constant workability increases with percentage decrease in water reduction, which is connected to the increase in the mix's specific surface. For the reduction of cement content super plasticizer was used and to fix the exact dosage of super plasticizer based on strength with different percentage in water reduction. Table 4 shows that the increase in workability of concrete as the increasing in dosage of super plasticizer. As the water reduction increases workability getting decreased even if increase in dosage of super plasticizer.

Table 2. Physical characteristics of Alkali resistant glass fibre

Characteristics	
Specific gravity	2.68
Density	2.7
Elastic modulus (Gpa)	72
Tensile strength (Mpa)	1700
Fibre filament diameter (microns)	14
Length (mm)	12

Table 3. Sieve analysis of cold-bonded artificial aggregate

Size of aggregate (mm)	Percentage of aggregates produced
16	5.1
12.5	35.6
10	45.1
4.75	14.2

Table 4. Physical and Mechanical Properties of cold-bonded artificial aggregate

Properties	Units	Value
Fineness modulus	-	6.44
Production efficiency	%	95.5
Specific gravity	-	2.48
Water absorption (24h)	%	16.3
Loose bulk density	Kg/m^3	855
Rodded bulk density	Kg/m^3	898
Impact strength	%	16

Individual aggregate compressive strength N/mm^2 16 mm: 44.212.5mm: 47.810mm: 52.34mm: 58.1

Cement replacement with GGBFS and Silica fume

The increase in workability of lightweight concrete with an increase in GGBFS alone and the combination of GGBFS and silica fume as well is associated to the lower specific surface area (SSA) of GGBFS, silica fume as compared to cement is presented in Table 5 and 6. For binder content, due to the circular shape of cold-bonded artificial aggregate, the workability increases significantly with cold-bonded aggregate content. With the increase in percentage addition of glass fibres the workability decreases which is more than control concrete.

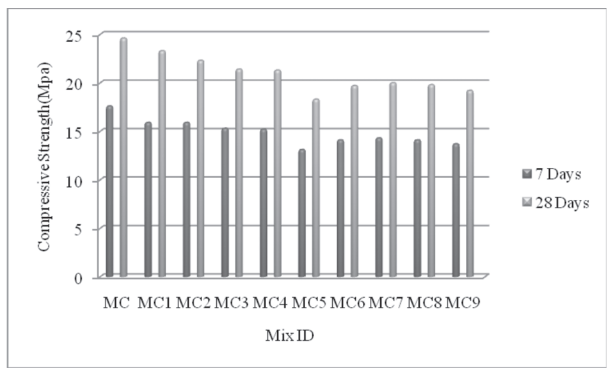

Fig 4. Compressive strength values for Trial-1

Fig 5. Universal Testing Machine

Compressive strength

Super plasticizer dosage with different percentage in water reduction

The compressive strength test was conducted in universal testing machine as shown in Fig. 5. As the percentage increase in water reduction compressive strength decreases, irrespective in increasing in dosage of super plasticizer. The highest compressive strength of 24.6 N/mm^2 was achieved without super plasticizer (MC) as shown in Fig. 4 and failure pattern of specimen in Fig. 6. An average of 16.3% of strength was decreased with dosage of super plasticizer with different percentage in water reduction. The optimum dosage of super plasticizer was fixed after different trials based on strength and cement replacement with GGBFS in second trial.

Cement replacement with GGBFS

The cold-bonded aggregate concrete compressive strength for different percentage of cement replacement with GGBFS is represented in Fig. 7 as second trial. The optimum mix in first trial (MC and MC1) was taken and cement replacement levels from 10% to 50% with GGBFS was done. The highest compressive strength of 29.3 N/mm^2 was achieved at 40% cement replacement with GGBFS without super plasticizer (MCG4) which is 19.1% more than control mix and failure pattern of specimen is shown in Fig. 9. Similarly compressive strength of 28.4 N/mm^{2}was attained at 20% cement replacement with GGBFS with 0.1% super plasticizer (MCG7) which is 15.5% more than control mix. At any replacement level of GGBFS, the compressive strength of concrete was higher than that of the corresponding control mix due to more CaO but significantly less Al_2O_3 which forms pozzolanic reaction. The optimum mix combination in second trial was chosen and further replaced cement with silica fume in third trial.

Table 5. Mixture compositions with super plasticizer content with water reduction (TRIAL-1)

Mix ID	Mix Combinations	Cement (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Cold-bonded aggregate (kg/m^3)	Super plasticizer (kg/m^3)	Slump (mm)
MC	0%S.P Control	438	197.2	640	1077	-	105
MC1	0.1%S.P(16%WR)	369	166	690	1161	0.369	110
MC2	0.2%S.P(16%WR)	369	166	690	1161	0.738	110
MC3	0.3%S.P(16%WR)	369	166	690	1161	1.107	112
MC4	0.1%S.P(19%WR)	356	160	701	1179	0.356	105
MC5	0.2%S.P(19%WR)	356	160	701	1179	0.712	110
MC6	0.3%S.P(19%WR)	356	160	701	1179	1.068	110
MC7	0.1%S.P(21%WR)	346	156	707	1191	0.346	100
MC8	0.2%S.P(21%WR)	346	156	707	1191	0.692	107
MC9	0.3%S.P(21%WR)	346	156	707	1191	1.038	109

Table 6. Mixture compositions with GGBFS as cement replacement (TRIAL-2)

Mix ID	Mix Combinations	Cement (kg/m^3)	GGBFS (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Cold-bonded aggregate (kg/m^3)	Super plasticizer (kg/m^3)	Slump (mm)1
MCG1	0%S.P+90C+10G	394.2	43.8	197.2	640	1077	-	105
MCG2	0%S.P+80C+20G	350.4	87.6	197.2	640	1077	-	107
MCG3	0%S.P+70C+30G	306.6	131.4	197.2	640	1077	-	110
MCG4	0%S.P+60C+40G	262.8	175.2	197.2	640	1077	-	110
MCG5	0%S.P+50C+50G	219	219	197.2	640	1077	-	120
MCG6	0.1%S.P+90C+10G(16%WR)	332.1	36.9	166	690	1161	0.369	115
MCG7	0.1%S.P+80C+20G(16%WR)	295.2	73.8	166	690	1161	0.369	115
MCG8	0.1%S.P+70C+30G(16%WR)	258.3	110.7	166	690	1161	0.369	121
MCG9	0.1%S.P+60C+40G(16%WR)	221.4	147.6	166	690	1161	0.369	125
MCG10	0.1%S.P+50C+50G(16%WR)	184.5	184.5	166	690	1161	0.369	129

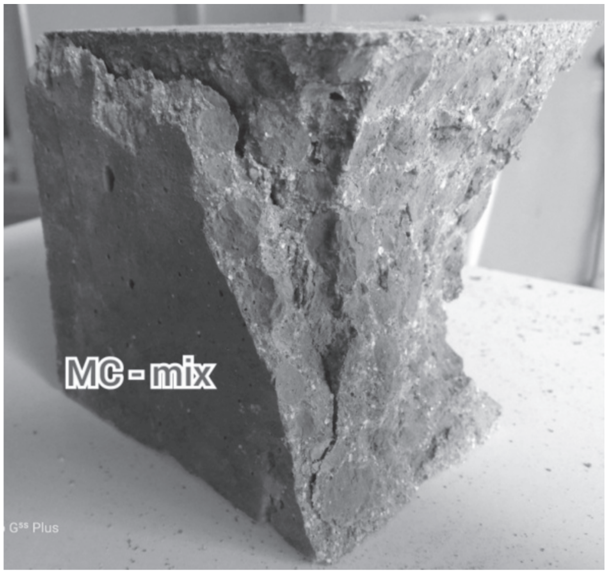

Fig 6. MC – Tested Specimen

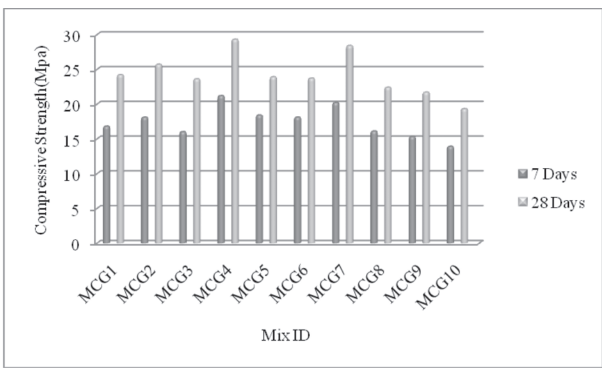

Fig 7. Compressive strength values for Trial-2

7 Cement replacement with Silica fume

The Lightweight aggregate concrete compressive strength for different levels of cement replacement with silica fume is given in Fig. 8 as third trial. The best mix in second trial (MCG4 and MCG7) was taken and cements replacement levels from 2.5% to 10% with silica fume. The highest compressive strength of 30.7 N/mm^2 was achieved at 40% cement replacement with GGBFS and 5% cement replacement with silica fume, without super plasticizer (MCGS2) which is around 25% more than control mix and failure pattern of specimen is shown in Fig.10. Silica fume have totally very fine particles size of silicon dioxide which is relatively high pozzolanic nature which is responsible for high strength in concrete. The optimum mix combination in third trial was selected and further added with

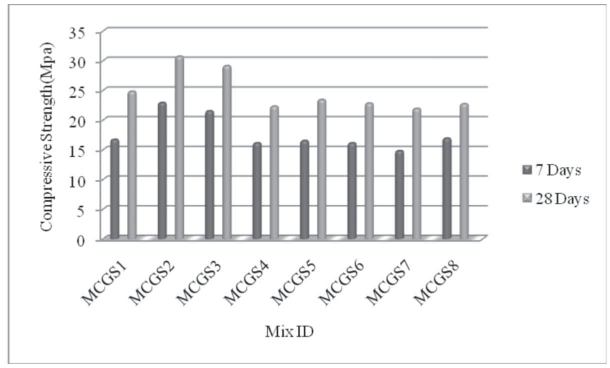

Fig 8. Compressive strength values for Trial-3

Fig. 9. MCG4 – Tested Specimen

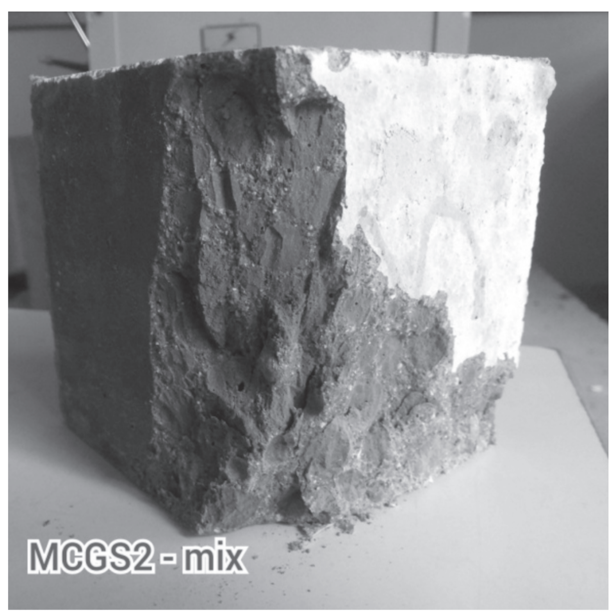

Fig 10. MCGS2 – Tested Specimen

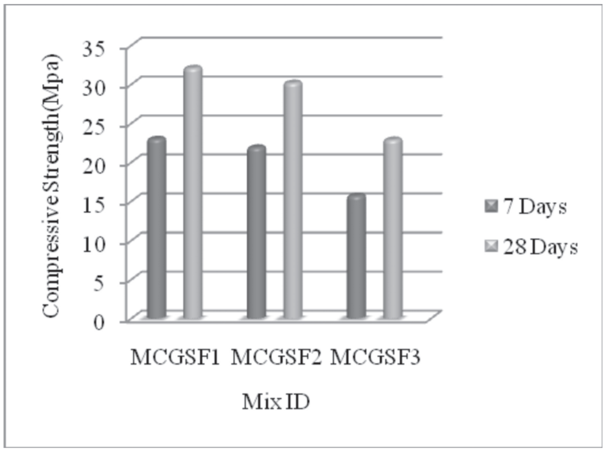

Fig 11. Compressive strength values for Trial-4

glass fibres on total volume basis in fourth trial.

Cement replacement with GGBFS and Silica fume with Glass fibres

Fibre reinforced cold-bonded aggregate concrete compressive strength for cement replacement with GGBFS and silica fume with addition of glass fibres as shown in Fig.11 as fourth trial. The optimum mix in third trial (MCGS2) was chosen and added with 0.1%, 0.2% and 0.3% of glass fibres by total volume of concrete. The highest compressive strength of 32.1 N/mm^{2}was achieved at 40% and 5% cement replacement with GGBFS and silica fume with addition of 0.1% glass fibres (MCGSF1) which is 35.1% more than control mix combination and failure pattern of specimen is shown in Fig.12. From all the four trials, compressive strength results suggested

Fig 12. MCGSF1 – Tested Specimen

Table 7. Mixture compositions with GGBFS and silica fume as cement replacement (TRIAL-3)

Mix ID	Mix Combinations	Cement (kg/m^3)	GGBFS (kg/m^3)	Silica fume (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Cold-bonded aggregate (kg/m^3)	Super plasticizer (kg/m^3)	Slump (mm)
MCGS1	0%S.P+57.5C+40G+2.5SF	256.23	175.2	6.57	197.2	640	1077	-	110
MCGS2	0%S.P+55C+40G+5SF	249.66	175.2	13.14	197.2	640	1077	-	113
MCGS3	0%S.P+52.5C+40G+7.5SF	243.09	175.2	19.71	197.2	640	1077	-	120
MCGS4	0%S.P+50C+40G+10SF	236.52	175.2	26.28	197.2	640	1077	-	125
MCGS5	0.1%S.P+77.5C+20G+2.5SF	287.82	73.8	7.38	166	690	1161	0.369	117
MCGS6	0.1%S.P+75C+20G+5SF	280.44	73.8	14.76	166	690	1161	0.369	120
MCGS7	0.1%S.P+72.5C+20G+7.5SF	273.06	73.8	22.14	166	690	1161	0.369	120
MCGS8	0.1%S.P+70C+20G+10SF	265.68	73.8	29.52	166	690	1161	0.369	127

Table 8. Mixture compositions with GGBFS and silica fume as cement replacement with glass fibres (TRIAL-4)

Mix ID	Mix Combinations	Cement (kg/m^3)	GGBFS (kg/m^3)	Silica fume (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Cold-bonded aggregate (kg/m^3)	Glass fibre (kg/m^3)	Slump (mm)
MCGSF1	0%S.P+55C+40G+5SF+0.1GF	249.66	175.2	13.14	197.2	640	1077	2.35	110
MCGSF2	0%S.P+55C+40G+5SF+0.2GF	249.66	175.2	13.14	197.2	640	1077	4.7	100
MCGSF3	0%S.P+55C+40G+5SF+0.3GF	249.66	175.2	13.14	197.2	640	1077	7.06	95

that the cement replacement percentage can be controlled based on the target strength.

Conclusion

The conclusions drawn from the present investigation on cold-bonded artificial lightweight aggregate concrete are summarized below:

1. The mix combination of well-researched mineral admixtures such as fly ash, GGBFS and silica fume does not only manufacture concrete but also improve fresh and hardened properties with economic efficiency.
2. Workability of cold-bonded artificial aggregate concrete increases with increasing in dosage of super plasticizer, irrespective of water reduction content.
3. By partial replacement of cement with GGBFS, the workability of cold-bonded artificial aggregate concrete increased, while it again increased when cement was partially replaced with silica fume and decreased with the addition of glass fibres.
4. From all the trial mix combinations, it is noticed that compressive strength results suggested that the cement replacement percentage can be controlled based on the target strength.
5. The compressive strength for 28-days, cement replacement mixes with GGBFS and silica fume was higher than the corresponding control mix. The strength enhancement was higher with lower cement content as 249 kg/m^3.

References

Al- Khaiat, H. and Haque, M.N. 1998. Effect of Tested Specimen initial curing on early strength and physical properties of lightweight concrete. *Cem Concr. Res.* 28 : 859–866.

ASTM International C1579-13. 2013. Standard Test Methods for Evaluating Plastic Shrinkage Cracking of Restrained Fiber Reinforceds (Using a Steel Form Insert.

Baykal, G. and Doven, A.G. 2000. Utilization of fly ash by pelletization process; theory, application areas and research results. *Resour Conserv Recy.* 30: 59–77.

Chang, T. and Shieh, M.M. 1996. Fracture properties of lightweight concrete. *Cem Concr Res.* 26 : 181–188.

Chi, J.M., Huang, R., Yang, C.C. and Chang, J.J. 2003. Effect of aggregate properties on the strength and stiffness of lightweight concrete. *Cem Concr Comp.* 25 : 197–205.

Damtoft, J.S. Lukasik, J. Herfort, D. Sorrentino and Gartner, E.M. 2008. Sustainable development and climate change initiatives. *Cement Concrete Research.* 38 (2) : 115–127.

Gesoglu, M., Ozturan, T. and Guneyisi, E. 2006. Effects of cold bonded fly ash aggregate properties on the shrinkage cracking of lightweight concretes. *Cem Concr Comp*. 28: 598–605.

Gesoglu, M., Ozturan, T. and Guneyisi, E. 2004. Shrinkage cracking of lightweight concrete made with cold-bonded fly ash aggregates. *Cem Concr Res*. 34: 1121–1130.

Haque, M.N., Al-Khaiat, H. and Kayali, O. 2004. Strength and durability of lightweight concrete. *Cem Concr Comp.* 26 : 307–314.

Indian Standard IS: 9142 (Part 2) – 2018. Artificial Lightweight Aggregate for Concrete Specification.

Kayali, O. Zhu, B. 2005. Chloride induced reinforcement corrosion in lightweight aggregate high-strength fly ash concrete. *Constr Build Mater.* 19: 327–336.

Kayali, O., Haque, M.N. and Zhu, B. 1999. Drying shrinkage of fibre- reinforced lightweight aggregate concrete containing fly ash. *Cem Concr Res*. 29 : 1835–1840.

Kolimi Shaiksha Vali and Abdul Rahim, 2016. Mechanical Properties of Light Weight Engineered Cementitious Composites. *International Journal of Engineering and Technology.* 8 (6): 2937-2945.

Kolimi shaiksha vali and Bala Murugan, S. 2017. Overview of Artificial Lightweight Aggregates-A Review. *International Journal of Civil Engineering and Technology.* 8 (6): 360-369.

Kolimi shaiksha Vali and Bala Murugan, S. 2019. Effect of Water and Accelerated Curing on Impact and Compressive Strength of Artificial Aggregates with Nano Silica. *Ukieri Concrete Congress Conference*. NIT Jalandhar. Indian Standard IS: 2386 – 1963. Standard Test Method for aggregates properties.

Kolimi shaiksha vali and Bala Murugan, S. 2019. Utilization of Cementitious Materials with Cold-bonded Artificial Aggregate in Concrete. *International Journal of Engineering and Advanced Technology*. 9 (1): 385-388.

Kolimi Shaiksha Vali and Bala Murugan. 2019. Impact of Nano SiO2 on the Properties Cold-bonded Artificial Aggregates with Various Binders. *International Journal of Technology.* 10 (5): 897-907.

Mehta, P.K. and Polivka, M. 1976. Use of highly active pozzolans for reducing expansion in concrete containing reacting aggregates, living with marginal aggregates. *ASTM STP.* 597 : 25–35.

Ramachandran, V.S. and Feldman, R.F. 1981. Beaudoin JJ. Concrete science: treatise on current research. Heyden & Son Ltd, London.

Scrivener, K.L. and Kirkpatrick, R.J. 2008. Innovation in use and research on cementitious material. *Cement Concrete Research*. 38: 128–136.

Swamy, R.N. and Lambert, G.H. 1985. Mix design and properties of concrete made from PFA coarse aggregates and sand. *Int J Cem Comp Lightweight Concr.* 3: 191–208.

Swamy, R.N. and Lambert, G.H. 1984. Flexural behaviour of reinforced concrete beams made with fly ash coarse aggregates. *Int J Cem Comp Lightweight Concrete*. 6 : 189–200.

Wegen, V.G.J.L. and Bijen, J.M.J.M. 1985. Properties of concrete made with three types of artificial PFA coarse aggregates. *Cem Concr Comp.* **7**: 159–167.

Zhang, M.H. and Gjorv, O.E. 1991. Mechanical properties of high strength lightweight concrete. *ACI. Mater J*. 88 : 240–247.

Zhang, M.H. Gjorv, O.E. 1991. Permeability of high strength lightweight concrete. *ACI Mater J*. 88 : 463–469.