AKADÉMIAI KIADÓ

UNIVERSITY of DEBRECEN

International Review of Applied Sciences and Engineering

13 (2022) 1, 47–53

DOI:
10.1556/1848.2021.00302

ORIGINAL RESEARCH PAPER

GGBS based alkali activated fine aggregate in concrete - Properties at fresh and hardened state

G. Lizia Thankam*, T.R. Neelakantan and S. Christopher Gnanaraj

Department of Civil Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, 626126, India

Received: April 26, 2021 • Accepted: June 27, 2021
Published online: September 3, 2021

ABSTRACT

Scarcity of the construction materials, peculiarly the natural river sand has become a serious threat in the construction industry. Though many researchers of developed and developing countries are trying to find alternative sources for the same, the complete replacement of the fine aggregate in concrete is crucial. Geopolymer sand developed from the Industrial waste (Ground granulated blast furnace slag - GGBS) is an effective alternative for the complete replacement of the natural sand. The GGBS based geopolymer sand (G-GFA) was tested for physical and chemical properties. Upon the successful achievement of the properties in par with the natural river sand, the fresh properties (fresh concrete density & slump) and hardened properties (compressive strength, tensile strength & flexural strength) of the concrete specimens developed with G-GFA were studied. The G-GFA is obtained by both air drying (AD-G-GFA) and oven drying (OD-F-GFA) after the dry mixing of the alkaline solution and GGBS for about 10 min. Thus, developed fine aggregates were studied separately for the fresh and hardened concrete to optimize the feasible one. Superplasticizer of 0.4% is included in the concrete mix to compensate the sightly hydrophilic nature of the fine aggregates produced. The mechanical properties of the concrete with G-GFA are observed to be more than 90% close to that of the concrete developed with natural river sand. Thus, both the fresh and mechanical properties of the G-GFA concrete specimens resulted in findings similar to those of the control specimen developed with natural river sand reflecting the plausibility of G-GFA as a complete replacement choice to the fine aggregate in the concrete industry. The flaky GGBS particles merge well with the alkaline solution at room temperature itself since the former gets dried at elevated temperatures. Thus, more feasible fresh concrete properties and mechanical properties were recorded for the AD-G-GFA than the OD-G-GFA.

KEYWORDS

natural river sand, fine aggregate, GGBS, compressive strength

1. INTRODUCTION

Inevitably the use of concrete in the construction Industry is rapidly increasing and thus the depletion of natural resources too, since around 70% of the total mass of the concrete were procured from natural resources, like riverbeds and quarries [1]. The exploitation of natural resources paves way for the ecosystem imbalance through reduction of ground water table, soil erosion adjacent to the riverbeds, exhausting the flora & fauna and deforestation too in few cases. In view of these adversative effects, the researchers strive to involve the by-products, waste materials and recycled materials for the production of concrete in the form of no-cement concrete (Geopolymer Concrete) and also as replacement materials in both fine & coarse aggregates. The usage of the industrial by-products is always trending owing to its accompanying aids like limited usage of construction materials, conservation of natural resources (riverbeds & quarries) and prevention of dumping the by-products onto the fertile

*Corresponding author.
E-mail: g.liziathankam@klu.ac.in

AKJournals

soil swerving to a sustainable growth of the construction industry. One such industrial by-product, ground granulated blast furnace slag (GGBS) expelled out from the iron and steel industry, is always an ideal choice for researchers owing to its finer nature than cement which aided the same to possess good cementitious activity at early ages and increased rate of reaction at room temperature itself [2]. This LEED (Leadership in Energy and Environmental Design) certified industrial by-product also mitigates the pores thereby corrosion and provides good resistance to sulphate & chloride attack [3–6] owing to its primary contents like silica, calcium, aluminium, magnesium and oxygen, which together comprise for about 95% of its total composition. However, the composition may vary based on the parent mineral ore, the type of fluxing stone used and also the coke that is fed into the blast furnace at the manufacturing industry [7].

Though there are many researches executed upon the replacement of fine aggregate in concrete with other industrial wastes and by-products such as waste foundry sand [8, 9], bottom ash [10, 11], waste glass [12, 13], marble waste [14, [15], crumb rubber [16–18], plastic PET fibres [19, 20], iron slag [21, 22], basaltic pumice [23, 24], rice husk [25, 26], waste tiles [27] and fly ash [28, 29], there are limited studies incorporating GGBS as fine aggregate [30] due to its finer nature. Nevertheless, in a detailed study [31] when granulated blast furnace slag (GFS), which has a particle size similar to river sand, is used as fine aggregate in concrete at 20%, 40% and 60%, better figures were noted in the quality of concrete when the GFS % is increased at both 0.45 and 0.5 water/cement ratio. Similar studies [32–34] using GFS reciprocated the betterment in compressive strength up to 75% replacement under controlled w/c ratio and controlled conditions.

It is evident from the past literatures that, though attempts were initiated to include GGBS as an alternative source for fine aggregate, due to the limited contribution to the mechanical properties as well as the finer particle size the complete replacement of the fine aggregate was hindered. Whereas, in the previous literatures in which polymerized sand is involved, fly ash was the base material for developing the fine aggregate and the synthesizing processes were also intricate. This is an intensive experimental attempt to investigate the potential of GGBS in concrete by geopolymerization process of this industrial waste into fine aggregates. Thus, synthesized fine aggregates from GGBS(G-GFA) were further incorporated in concrete to analyze the fresh concrete properties as well as the hardened concrete properties. Though comparable studies [35–37] were initiated recently in obtaining fine aggregates by geopolymerization of industrial wastes a refinement in the polymerization process was further mandatory for the potential use of the same [38] in concrete. A similar study [39] with flyash for the production of fine aggregate by geopolymerization process also noted the development of adequate strength in concrete.

2. MATERIALS AND TEST PROCEDURES

In order to synthesize fine aggregates from GGBS, it is allowed to geopolymerize through oven drying as well as air drying. Initially GGBS is manually dry mixed with alkaline medium of sodium hydroxide solution and sodium silicate solution for about 10 min. Thus, the obtained dry mix is used in concrete as geopolymerized fine aggregate after air drying (AD-G-GFA) and oven drying (OD-G-GFA). The optimum values for the compressive strength for the samples were noted at 12M of alkaline solution with a solid to solution ratio of 3:1 and Na_2SiO_3/NaOH ratio of 1:2. The 12M of alkaline solution is prepared by mixing 12 parts of sodium hydroxide pellets in a whole part of distilled water which is then allowed to cool and followed by the addition of the sodium silicate solution into it after the heat is settled down by the former reaction. The GGBS is procured from the locally available commercial market of south India. The air dried (30±3°) samples developed optimum strength at 7 days whereas the oven dried samples were optimized to be under 100 °C for about 45 min to obtain the maximum compressive strength. Thus, the developed synthetic sands were categorized under zone I as per the Indian standards-IS 383:2016 [40] and noted to have all required material properties (Table 1). A pH value of 11 and 8 is noted for G-GFA (Fig. 1) and natural sand (NS) (Fig. 2).

For the preparation of concrete in this study, a concrete slump of 75–100 mm is assumed as target slump and the

Table 1. Material properties of G-GFA compared with NS conforming to ASTM C128-15 [41] and IS 2386 [42]

Material Property	Type of Fine aggregate		
	AD-G-GFA	OD-G-GFA	NS
Water absorption	6.9%	6.2%	0.9%
Co-efficient of Uniformity (C_u)	4.51	4.53	1.59
Co-efficient of Curvature (C_c)	1.31	1.33	0.82
Compressive strength of mortar specimens (kN/mm^2)	20.10	21.11	23.56

Fig. 1. G-GFA

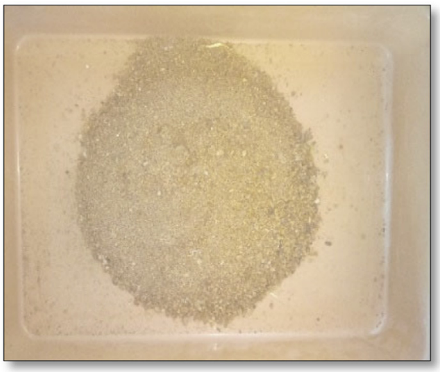

Fig. 2. Natural sand

mix proportioning (Table 2) is obtained. As per IS 456:2000 for moderate exposure of concrete, water/cement ratio of 0.6 is adopted in this study. The fine aggregate was completely replaced with geopolymerized sand and the following amounts of materials were calculated as per the IS standards. The material specifications incorporated in this study are also listed (Table 3).

To ascertain the feasibility of the G-GFA developed in this study both the fresh concrete studies and hardened concrete studies were carried out. Fresh concrete studies such as the workability and fresh concrete density were studied. Whereas for the hardened concrete, the dry density, compressive strength, tensile strength, and flexural strength were studied to conclude the mechanical properties of the concrete specimens developed with AD-G-GFA and OD-G-GFA, which were then compared with the control concrete specimens developed with NS. The different tests carried out in both fresh concrete and hardened concrete are listed below (Table 4).

3. RESULTS AND DISCUSSION

3.1. Fresh concrete

Initially the fresh concrete properties of the developed samples were studied. The fresh concrete mixes obtained

Table 2. Mix proportioning of the concrete specimens of NS and G-GFA

Type of fine aggregate	Water (kg/m^3)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Plasticizer (kg/m^3)	Total quantity (kg/m^3)
NS	196.37	327.28	683.32	1124.86	2.61	2334.83
AD-G-GFA	196.37	327.28	574.20	1124.86	2.61	2225.77
OD-G-GFA	196.37	327.28	626.40	1124.86	2.61	2277.97

Table 3. Material specifications for concrete

Serial number	Material	Specification	Code Standards
1	Water	Potable tap water	IS 456-2000 [43]
2	Ordinary Portland cement (53 Grade)	Specific gravity – 3.15	IS 12269: 2013 [44]
3	Coarse aggregate	Specific gravity – 2.6 Size – 10 mm–12.5 mm	IS 383: 2016 [40]
4	Admixture	Polycarboxylate based super-plasticizer (up to 0.8%)	IS 9103: 1999 [45]
5	Fine aggregate – natural sand	Specific gravity – 2.62 Zone – I	IS 383: 2016 [40]. IS: 2386 (Part- III) – 1963 [46]

Table 4. Tests on hardened concrete and Fresh concrete

S.No	Test on concrete	Specimen details	Formulae
Test on fresh concrete			
1.	Workability	Slump cone	Slump value = total height of the slump – height of the slumped concrete.
2.	Density	100 mm cube	Density = mass/volume
Tests on harden concrete			
1.	Compressive strength	100 mm cube	Compressive strength $= \frac{\text{load at point of failure}}{\text{cross sectional surface area}}$
2.	Splitting tensile strength	150 mm diameter and 300 mm height cylinder	Splitting tensile strength = $2P/\pi$ DL Where, P = applied load D = diameter of the specimen
3.	Flexural strength	$100 \times 100 \times 500$ mm beam	Flexural strength = PL/bd^2 P = Failure load L = Effective span of the beam b = Breadth of the beam

with AD-G-GFA and OD-F-GFA were experimentally tested for workability and density.

3.1.1. Workability and fresh concrete density. The well graded G-GFA resulted in a steadily falling slump for a water/cement ratio of 0.6. The mix initially appeared dry. Upon the addition of poly carboxylate-based superplasticizer of 0.4% into the mix, good flowability and workability is noticed in the concrete. No bleeding or segregation is visualized in the developed concrete due to the uniform grading of the fine aggregate and hence the concrete too.

The density (Fig. 3) of the fresh concrete matrix is noted to be more for the AD-G-GFA than the OD-G-GFA. The denser matrix resulted in easily workable concrete with no excess water for the AD-G-GFA similar to that of the concrete specimens developed with NS. The fresh concrete density of NS is 9% and 3% higher than the OD-G-GFA and AD-G-GFA, respectively, indicating the feasibility of usage of this particular mix for the further study.

3.2. Harden concrete parameters

To define the mechanical properties of the concrete specimens, the dry density, compressive strength, flexural strength and split tensile strength were studied and then compared with that of the specimens obtained with NS. To conduct the study experimentally three replicate specimens were casted for each parameter for every type of fine aggregate and the average value is noted for further analysis.

3.2.1. Dry density. The mass of the specimens was recorded with the weighing balance and then the dry density is obtained for each specimen. The dry density (Fig. 4) of the samples was recorded for 7, 28, 56 and 90 days of curing period to study the variation of the same with respect to the curing days.

At 28 days and 56 days the OD-G-GFA specimens attained 83% and 87% density to that of the NS specimens. Whereas at 28 days and 56 days, the AD-G-GFA specimens developed 93% and 94% dry density of the NS specimen indicating the high chance of usage of the G-GFA in the concrete specimens. Not many variations are observed for the dry density at 7 days and 90 days for the concrete specimens since the GGBS did not contribute to the later age strength.

3.2.2. Compressive strength. For the analysis of the compressive strength (Fig. 5) of the samples, three replicate

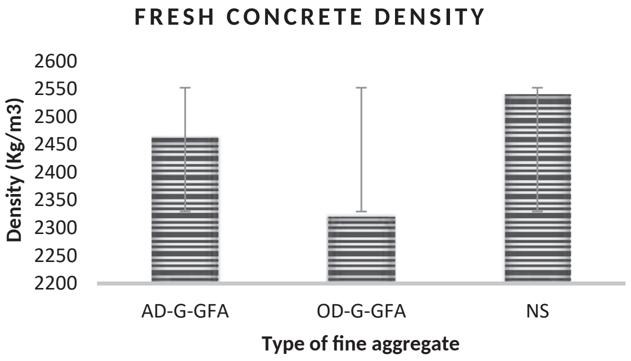

Fig. 3. Fresh Concrete Density of G-GFA compared with NS

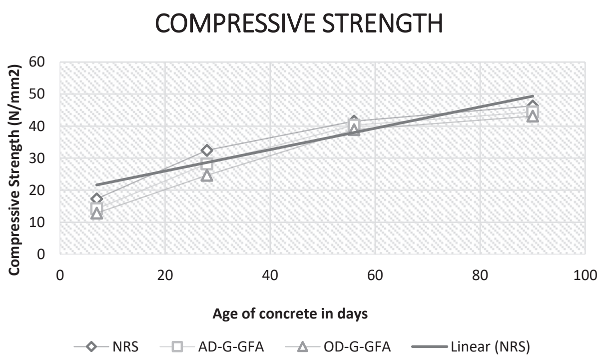

Fig. 5. Compressive strength of G-GFA compared with NS

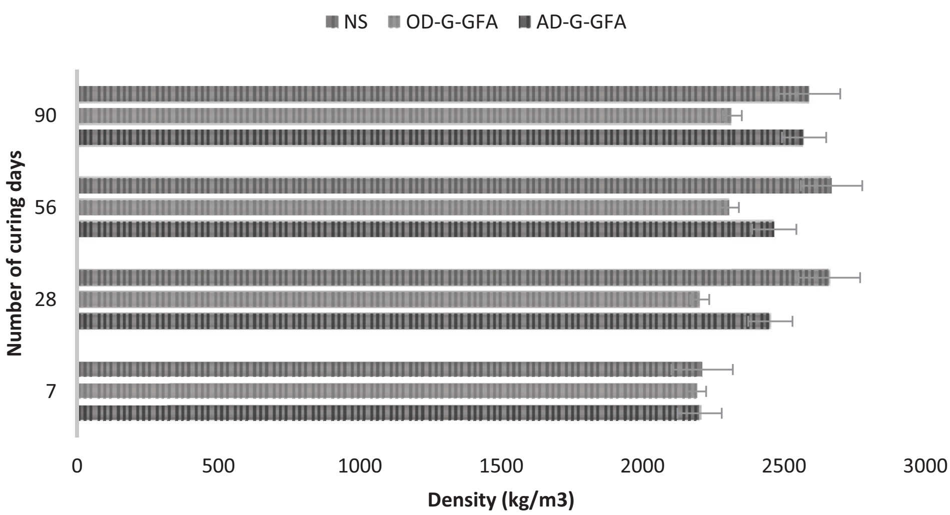

Fig. 4. Dry density of G-GFA compared with NS

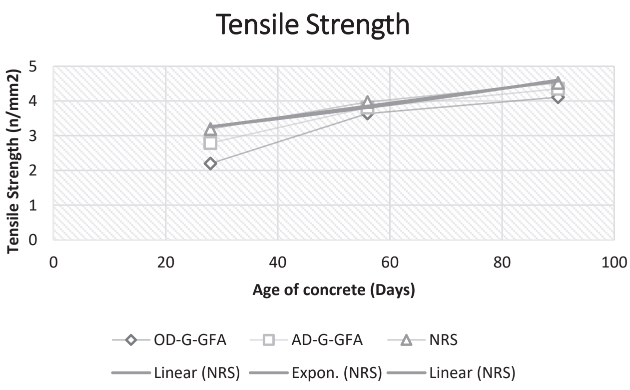

Fig. 6. Tensile strength of G-GFA compared with NS

samples were casted for a single type of concrete and were tested at curing of 7 days, 28 days, 56 days and 90 days. Concrete specimens of size 100 mm × 100 mm × 100 mm were adopted for testing the compressive strength using the universal testing machine. The results indicated maximum strength gain at 56 days of curing for AD-G-GFA concrete and OD-G-GFA concrete, which is 97% and 94%, respectively, compared to the concrete developed with NS. Nevertheless at 90 days of curing also, considerable rise in compressive strength was noted for the G-GFA specimens when compared with the NS specimens.

3.2.3. Tensile strength. The tensile strength (Fig. 6) of the G-GFA specimens were tested and compared with the NS specimens to ascertain the ability of the concrete to withstand the tensile stress. Both AD-G-GFA and OD-G-GFA soundly contributed to improving the concrete against the tensile stress. Particularly, at 56 days of curing 96% and 91% of tensile strength was attained by the AD-G-GFA and OD-G-GFA specimens. The G-GFA particles consisted of unreacted particles even after the geopolymerization process during the synthesis of the fine aggregate which then reacted with the cement particles and enhanced the mechanical strength.

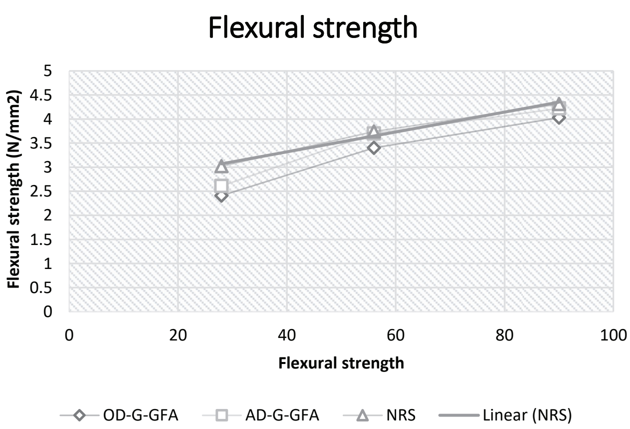

Fig. 7. Flexural strength of G-GFA compared with NS

3.2.4. Flexural strength. The maximum stress that occurred on the tension face of the concrete bean (unreinforced) was calculated by using a concrete specimen of size 100 × 100 × 500 mm. The flexural strength (Fig. 7) developed in the G-GFA specimens were appreciable and closer to the NS specimens. At 56 and 90 days of curing, the OD-G-GFA samples acquired 91% and 94% of tensile strength compared to the NS concrete. On the other hand, the AD-G-GFA specimens developed 99% and 98% of flexural strength of the NS concrete. The results are evident that the air dried geopolymer sand developed improved concrete compared to the oven dried geopolymer sand.

4. CONCLUSION

This experimental investigation is concluded as follows:

1. For obtaining the GGBS based geopolymer sand, an alkaline solution of 12M, solid:solution ratio of 3:1 and Na_2SiO_3/NaOH ratio of 1:2 is optimized based on the required compressive strength.
2. The AD-G-GFA can geopolymerize in room temperature (30±3 °C) whereas the OD-G-GFA is kept in hot air oven for about 45 min at a temperature of 100 °C for attaining the optimum compressive strength.
3. Both AD-G-GFA and OD-G-GFA acquired higher water absorption ratio than the natural river sand, however, the uniform grading of the G-GFA along with the usage of superplasticizer initiated a workable concrete mix.
4. The mechanical properties of the AD-G-GFA are comparatively higher than the OD-G-GFA owing to the ability of GGBS to polymerize under room temperature itself without the necessity of additional heat. The oven dried polymerized sand specimens developed comparatively lower mechanical strength due to the stiffening nature of the GGBS under higher temperature due to further drying, that resulted in degradation of the microstructure in OD-G-GFA, apparently for the concrete specimens too.
5. Though the G-GFA samples demands higher water absorption ratio compared with the normal river sand, the unreacted particles in the G-GFA even after the geopolymerization process gets hydrated upon concreting and promotes the formation of C-S-H gel too, thus enhancing the microstructure and the mechanical properties of the G-GFA concrete.
6. The OD-G-GFA developed better workability with concrete than the AD-G-GFA. The flaky nature of GGBS particles polymerizes with the alkaline solution at room temperature itself in AD-G-GFA and becomes adoptable in the concrete. This also enhanced the mechanical properties of the AD-G-GFA concrete specimens, since the left out unreacted particles in GGBS react with cement and contribute to the formation of C-S-H gel also.
7. When the same results are compared with the European standards of concrete – EN206, since the concrete type is

classified based on the characteristic compressive strength as well as the density of the materials. The obtained values of compressive strength in this study were also noted to satisfy the prescribed compressive strength values based on the cube compressive strength values and cylindrical specimens compressive strength values.

8. Thus, the AD-G-GFA becomes the most feasible alternative construction material instead of the natural river sand in the construction industry.

5. FUTURE SCOPE OF THE STUDY

- Synthesis of G-GFA in large scale can be further studied by framing the proper guidelines.
- Partial replacement of the G-GFA in various types of concrete can be analyzed for developing a high strength concrete.
- Behavior of G-GFA concrete at elevated temperature is still a research lag.
- The feasibility of G-GFA in extreme conditions (seashore structures, colder regions, etc.) can be further studied.
- Since this study aims international researchers, a comparative study by using the G-GFA concrete can be executed, which involves a correction factor also to validate the results with a few other well-known codal standards for concrete.

Data availability: All the data, techniques and codes involved in this study are available within this article.

ACKNOWLEDGEMENT

The authors would like to acknowledge the Kalasalingam Academy of Research and Education for their full-fledged support throughout the entire study. We also acknowledge the technical team and faculty members who backed this experimental investigation.

REFERENCES

[1] K. Vardhan, R. Siddique, and S. Goyal, “Influence of marble waste as partial replacement of fine aggregates on strength and drying shrinkage of concrete,” *Construction Building Mater.*, vol. 228, p. 116730, 2019.

[2] ACI 233 R03, Slag Cement in Concrete and Mortar. Detroit, Michigan,2000.

[3] C. D. Atiş, and C. Bilim, “Wet and dry cured compressive strength of concrete containing ground granulated blast-furnace slag,” *Build. Environ.*, vol. 42, no. 8, 2007.

[4] K. G. Babu, and V. Sree Rama Kumar, “Efficiency of GGBS in concrete,” *Cement Concrete Res.*, vol. 30, no. 7, pp. 1031–6, 2000.

[5] R. K. Dhir, M. A. K. El-Mohr, and T. D. Dyer, “Chloride binding in GGBS concrete,” *Cement Concrete Res.*, vol. 26, no. 12, pp. 1767–73, 1996.

[6] P. L. Domone, and M. N. Soutsos, “Properties of high-strength concrete mixes containing PFA and ggbs,” *Mag. Concrete Res.*, vol. 47, no. 173, pp. 355–67, 1995.

[7] E. Özbay, M. Erdemir, and H. İbrahim Durmuş, “Utilization and efficiency of ground granulated blast furnace slag on concrete properties–A review,” *Construction Building Mater.*, vol. 105, pp. 423–34, 2016.

[8] Y. Aggarwal, and R. Siddique, “Microstructure and properties of concrete using bottom ash and waste foundry sand as partial replacement of fine aggregates,” *Construction Building Mater.*, vol. 54, pp. 210–23, 2014.

[9] R. Siddique, G. Singh, R. Belarbi, and K. Ait-Mokhtar, “Comparative investigation on the influence of spent foundry sand as partial replacement of fine aggregates on the properties of two grades of concrete,” *Construction Building Mater.*, vol. 83, pp. 216–22, 2015.

[10] T. Bakoshi, K. Kohno, S. Kawasaki, and N. Yamaji, “Strength and durability of concrete using bottom ash as replacement for fine aggregate,” *Spec. Publ.*, vol. 179, pp. 159–72, 1998.

[11] P. Aggarwal, Y. Aggarwal, and S. M. Gupta, “Effect of bottom ash as replacement of fine aggregates in concrete,”, pp. 49–62, 2007.

[12] Z. Z. Ismail, and E. A. Al-Hashmi, “Recycling of waste glass as a partial replacement for fine aggregate in concrete,” *Waste Manag.*, vol. 29, no. 2, pp. 655–9, 2009.

[13] M. I. Malik, M. Bashir, S. Ahmad, T. Tariq, and U. Chowdhary, “Study of concrete involving use of waste glass as partial replacement of fine aggregates,” *IOSR J. Eng.*, vol. 3, no. 7, pp. 8–13, 2013.

[14] R. Rodrigues, J. De Brito, and M. Sardinha, “Mechanical properties of structural concrete containing very fine aggregates from marble cutting sludge,” *Construction Building Mater.*, vol. 77, pp. 349–56, 2015.

[15] M. Sardinha, Jorge de Brito, and R. Rodrigues, “Durability properties of structural concrete containing very fine aggregates of marble sludge,” *Construction building Mater.*, vol. 119, pp. 45–52, 2016.

[16] C. A. Issa, and S. George, “Utilization of recycled crumb rubber as fine aggregates in concrete mix design,” *Construction Building Mater.*, vol. 42, pp. 48–52, 2013.

[17] K. Bisht, and P. V. Ramana, “Evaluation of mechanical and durability properties of crumb rubber concrete,” *Construction Building Mater.*, vol. 155, pp. 811–7, 2017.

[18] M. K. Batayneh, I. Marie, and I. Asi, “Promoting the use of crumb rubber concrete in developing countries,” *Waste Manag.*, vol. 28, no. 11, pp. 2171–6, 2008.

[19] K. Ramadevi, and R. Manju, “Experimental investigation on the properties of concrete with plastic PET (bottle) fibres as fine aggregates,” *Int. J. emerging Technol. Adv. Eng.*, vol. 2, no. 6, pp. 42–6, 2012.

[20] M. Frigione, “Recycling of PET bottles as fine aggregate in concrete,” *Waste Manag.*, vol. 30, no. 6, pp. 1101–6, 2010.

[21] G. Singh, and R. Siddique, “Effect of iron slag as partial replacement of fine aggregates on the durability characteristics of self-compacting concrete,” *Construction Building Mater.*, vol. 128, pp. 88–95, 2016.

[22] A. S. Ouda, and H. A. Abdel-Gawwad, “The effect of replacing sand by iron slag on physical, mechanical and radiological properties of cement mortar,” *HBRC J.*, vol. 13, no. 3, pp. 255–61, 2017.

[23] H. Binici, "Effect of crushed ceramic and basaltic pumice as fine aggregates on concrete mortars properties," *Construction Building Mater.*, vol. 21, no. 6, pp. 1191–7, 2007.

[24] H. Bınıci, M. Yasin Durgun, T. Rızaoğlu, and M. Koluçolak, "Investigation of durability properties of concrete pipes incorporating blast furnace slag and ground basaltic pumice as fine aggregates," *Scientia Iranica*, vol. 19, no. 3, pp. 366–72, 2012.

[25] K. Kunchariyakun, S. Asavapisit, and K. Sombatsompop, "Properties of autoclaved aerated concrete incorporating rice husk ash as partial replacement for fine aggregate," *Cement and concrete composites*, vol. 55, pp. 11–6, 2015.

[26] I. O. Obilade, "Experimental study on rice husk as fine aggregates in concrete," *Int. J. Eng. Sci.*, vol. 3, no. 8, pp. 9–14, 2014.

[27] A. A. Adekunle, K. R. Abimbola, and A. O. Familusi, "Utilization of construction waste tiles as a replacement for fine aggregates in concrete," *Eng. Technol. Appl. Sci. Res.*, vol. 7, no. 5, pp. 1930–3, 2017.

[28] W. Tariq, S. Q. Hussain, D. A. Nasir, N. Tayyab, S. H. Gillani, and R. Adeel, "Experimental study on strength and durability of cement and concrete by partial replacement of fine aggregate with fly ash," *Earth Sci. Pak*, vol. 1, pp. 10–4, 2017.

[29] R. Siddique, "Effect of fine aggregate replacement with Class F fly ash on the mechanical properties of concrete," *Cement Concrete Res.*, vol. 33, no. 4, pp. 539–47, 2003.

[30] G. Singh, S. Das, A. Abdullahi Ahmed, S. Saha, and S. Karmakar, "Study of granulated blast furnace slag as fine aggregates in concrete for sustainable infrastructure," *Procedia-Social Behav. Sci.*, vol. 195, pp. 2272–9, 2015.

[31] R. K. Patra, and B. Bhusan Mukharjee, "Influence of incorporation of granulated blast furnace slag as replacement of fine aggregate on properties of concrete," *J. Clean. Prod.*, vol. 165, pp. 468–76, 2017.

[32] M. C. Nataraja, P. G. D. Kumar, A. S. Manu, and M. C. Sanjay, "Use of granulated blast furnace slag as fine aggregate in cement mortar," *Int. J. Struct. Civil Engg. Res.*, vol. 2, pp. 60–8, 2013.

[33] I. Yüksel, Ö. Özkan, and T. Bilir, "Use of granulated blast-furnace slag in concrete as fine aggregate," *ACI Mater. J.*, vol. 103, no. 3, p. 203, 2006.

[34] D. S. Shi, P. Han, M. Zheng, and J. B. Wang, "Report of experimented on compressive strength of concrete using granulated blast furnace slag as fine aggregate," in *Advanced Materials Research*, vol. 575, Trans Tech Publications Ltd, 2012, pp. 100–3.

[35] S. M. Rao, and I. P. Acharya, "Synthesis and characterization of fly ash geopolymer sand," *J. Mater. civil Eng.*, vol. 26, no. 5, pp. 912–7, 2014.

[36] A. K. Sharma, and K. B. Anand, "Comparative study on synthesis and properties of geopolymer fine aggregate from fly ashes," *Construction Building Mater.*, vol. 198, pp. 359–67, 2019.

[37] S. P. Wanjari, U. S. Agrawal, and D. N. Naresh, "Geopolymer sand as a replacement to natural sand in concrete," in *IOP Conference Series: Materials Science and Engineering*, vol. 431, no. 9, IOP Publishing, 2018, p. 092011.

[38] G. L. Thankam, T. R. Neelakantan, and S. Christopher Gnanaraj, "Potential of fly ash polymerized sand as an alternative for river sand in concrete-A state of the art report," in *IOP Conference Series: Materials Science and Engineering*, vol. 1006, no. 1, IOP Publishing, 2020, p. 012039.

[39] G. L. Thankam, T. R. Neelakantan, and S. Christopher Gnanaraj, "Effect on the properties of fresh and hardened concrete made using fly ash geopolymer sand," *Int. Rev. Appl. Sci. Eng.*, 2021.

[40] IS 383:2016, Coarse and Fine Aggregate for Concrete – Specifications. Bureau of Indian Standards.

[41] ASTM C128–15, *Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate*. West Conshohocken, PA, ASTM 2015 International.

[42] Bureau of Indian Standards (BIS), *Method of Test for Aggregate for Concrete Particle Size and Shape*. IS 2386 (Part-I), New Delhi, India, 1963.

[43] IS 456, *Plain and Reinforced Concrete*. Bureau of Indian Standards, 2000.

[44] IS 12269, *Ordinary Portland Cement, 53 Grade – Specification*. Bureau of Indian Standards, 2013.

[45] IS 9103, *Specification for Concrete Admixtures*. Bureau of Indian Standards, 1999.

[46] IS 2386-3, *(R2016) Methods of Test for Aggregates for Concrete - Part 3: Specific Gravity, Density, Voids, Absorption and Bulking*. Bureau of Indian Standards, 1963.