Synthesis and Characterization of Synthetic Sand by Geopolymerization of Industrial Wastes (Fly ash& GGBS) Replacing the Natural River Sand

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Abstract

The diminution of the natural sources in the form of dredging the riverbanks and blasting the mountain ranges has always dented the balance of the eco system which in turn results in disasters as well at times. This alarming situation accelerates the global warming, threatens the biota life in riverbanks, diminishes the ground water level, harms the aquatic life and affects the growth of agriculture. This study is an attempt to synthesis fine aggregates from the industrial byproducts such as fly ash and GGBS through the process of geopolymerization which enables the formation of aluminosilicate networks upon the addition of the alkaline activator solution (Na 2 SiO 3 + NaOH) into the byproducts which is then allowed for oven drying as well as air drying to accelerate the process. The Fly ash geopolymerized fine aggregate(F-GFA) and the GGBS geopolymerized fine aggregate(G-GFA) were noted to exhibit adequate physiochemical and mechanical properties in par with the natural sand. The production of GFA is considered as eco friendly process since it ceases the extensive usage of river sand and incorporates the effective usage of Industrial by products (Fly ash and GGBS) thereby minimizing the land pollution and its consequent harmful hazards. Though the F-GFA and G-GFA showcased higher water absorption ratio than the natural sand, owing to the unreacted fly ash and GGBS particles. Nevertheless, the same initiated the adequate compressive strength attainment up to 90% of natural sand, by reacting with the lime expelled out of the hydration process of cement in the mortar specimens developed in this experimental study. The microstructure of the samples was further examined through Optical microscope, Scanning Electron microscope (SEM) and X-Ray Diffraction (XRD) analysis in order to corroborate the experimental results of this study. The results thus obtained, strongly recommend the potential of the F-GFA and G-GFA as an ideal replacement material for natural sand.

1. Introduction

The construction industry is in high demand for the necessity of the fine aggregate in the recent era in both developing countries as well as the developed countries [Wu et al,2010] Depletion of the natural minerals and the over usage of the natural sources are the two main consequences of the usage of the M sand (Manufactured sand) and the natural sand respectively which in turn adversely affect the environmental balance that makes a call to identify the ideal replacement material for fine aggregate(binding material) in the concrete preparation. Though there are many outcomes for the replacement of the binding material [Mir et al,2015] still it unveils only the tip of the iceberg. Many of the studies were to replace the binding material partially [Ismail et al,2009; Siddique et al,2003] or up to a particular percentage only.

Geopolymer in concrete showed up us a boon in the construction industry as a consequence of its lower permeability, good fire resistance, enhanced chemical resistance and early attainment of the compressive strength [Davidovits,1991; Davidovits et al,1999; Duxon et al,2007; Komnitsas et al,2011]. Thus, the geopolymerization technique [Davidovits et al,2002] in concrete structures paved the way for the sustainable use of the by products in the synthesis of the other construction materials as well which is already well established in the synthesis of geopolymer cement [Davidovits,1994]. Fly ash and GGBS

(Ground granulated blast furnace slag) were incorporated in this study for the synthesis of the Geopolymer Fine aggregate (GFA). Both flyash and GGBS were generated about 450 million tons and 530 million tons respectively worldwide [Zhao et al,2015], out of which only 65% of GGBS [Tsakiridis et al,2008] and 25% of flyash [Ahmaruzzaman et al,2010] were currently used by other industries in various forms. Since the hazards and disposal process is rogue for both flyash and GGBS [Topcu et al,1997], these two industrial by-products were the high concern for the researchers and was reported that, the waste disposal and concrete production cost is considerably reduced by the inclusion of the same [Mo et al, 2017].

Fly ash being a prime material in the present construction industry as an optimum choice to be used in concrete batching, concrete pavement, construction blocks, bricks and in embankments too in some cases due to its highly favorable options such as low heat of hydration, good resistance to cold weather, resistance against chemical environment, no CO2 emission, lower water/ cement ratio, minimal shrinkage, higher later age strength and good workability[Ahmaruzzaman et al, 2010; Bouzoubaa et al, 2001; Fraay et al, 1989; Hemalatha et al, 2017; Mehta et al, 2004;Zhuang et al, 2016].Alike fly ash, being an industrial by product from iron and steel making industries, GGBS is highly cementitious and rich in calcium silicate hydrate (CSH) that enables it to improve the mechanical strength and durability of concrete. The other subsidies of GGBS such as reduction in porosity, negligible or no reinforcement corrosion, higher resistance to chlorides & sulphates attack and minimal damage by alkali-silica-reaction(ASR) relentlessly enables it as one of the remarkably used supplementary material in concrete. GGBS is also LEED (Leadership in Energy and Environmental Design) certified, since it improves the sustainability of the structures [Atis et al, 2007; Babu et al, 2000; Dhir et al, 1996; Domon et al,1995]

2. Materials

In view of the above literature study, it was chosen to develop polymerized sand with fly ash as well as Ground granulated blast furnace slag (GGBS) and study the characters along with the feasibility in both the cases. Fine aggregate particles were developed by both oven curing and air curing using fly ash as well as GGBS. Since it was noticed that the process of development of fine aggregate in the earlier studies were much tedious, an initiative was taken to cut down the procedure in the synthesis of the fine aggregates for construction. Fly ash were procured from the Coal power plant at tutucorin - 8.7642° N, 78.1348° E (Tamilnadu, India) for this study which is of lower calcium content (class F flyash), whereas GGBS were purchased commercially from the southern part of Tamilnadu (India). The chemical compositions and physical properties of the samples were listed in **Table 2.1** and **Table 2.2,** respectively. Sodium silicate solution and sodium hydroxide (pellets form) were acquired from the chemical industry in south Tamilnadu (India). Natural sand from the commercial market were incorporated in this study to compare the properties of the GFA, X-Ray Fluorescence test were conducted for the collected study materials and were categorized as per the ASTM standards.

Table 2.1: Chemical compositions of the Flyash Sample and GGBS Sample.

Oxide composition	Class F flyash composition, %	ASTM C 618 requirements for class F Flyash	GGBS-composition, %
Silicon Dioxide	62.6	-	29.54
Aluminium Oxide	24.5	-	13.44
Ferric Oxide	3.8	-	0.672
Silicon Dioxide+ Aluminium Oxide+ Ferric Oxide	90.9	Minimum 70.00	-
Calcium Oxide, CaO	2.7	-	36.72
Magnesium Oxide, MgO	3.1	-	7.12
Titanium Oxide, TiO_2	1.2	-	-
Pottasium Oxide, K_2O	0.9	-	-
Sodium Oxide, Na_2O	0.5	-	-
Sulphur trioxide, SO_3	1.9	Maximum 5	2.1
Loss on Ignition (LOI)	2.2	Maximum 6	2.4
pH value	11.24	-	10.98

Table 2.2: Physical properties of the Flyash Sample and GGBS Sample.

Physical property	Fly ash	GGBS
Specific gravity	2.27	2.98
Fineness (m^2/kg)	370 m^2/kg	400 m^2/kg

3. Experimental Program

In order to obtain GFA, repeated tests were carried out to optimize the curing period, temperature, solids:solution ratio and the $Na_2 SiO_3$/ NaOH ratio. Specimens of size 70.7mm x 70.7mm x 70.7mm cube were cast to monitor the compressive strength of the mortar specimens conforming to IS 2386(part VI):1986[15]. GFA was obtained by the addition of alkaline activator solution along with the byproducts (GGBS & Fly ash). Initially the sodium hydroxide pellets were allowed to dissolve in the distilled water after the complete dissolution of the pellets which is accelerated by a stirring rod, the sodium silicate solution is carefully poured in. The exothermic reaction generates heat and the solution is allowed to cool down. Consequently, the alkaline activator solution is then mixed with the byproduct (fly ash and GGBS)

and a homogeneous dry mixture is obtained by hand mixing for 10 minutes in a working area (**Fig 3.1**). The dry mixture obtained (**Fig 3.2**) is exposed for curing by both oven curing and air curing at room temperature 30^0 3 ^{0} c to obtain the geopolimerized sand (Thankam et al,2020) (**Fig 3.3**).

3.1 Optimization of the alkaline activator solution and dry mix ratio

The molarity of the alkaline solution is varied ranging from 6M, 8M, 10M, 12M to 14M (**Fig 3.1.1**) Na_2 SiO_3 / NaOH ratio is varied from 1:1 to 3:1 **(Fig 3.1.2)**, whereas the solid to solution ratio is varied from 2.5:1 to 3.5:1 by simultaneously altering the curing temperature from 80^oc to 130^0c with a varying curing period from 45 minutes to 105 minutes **(Fig 3.1.3)**. Based on the various experimental trials for fly ash maximum compressive strength is noted at 10m of alkaline solution with Na_2SiO_3 / NaOH ratio of 1:2 and solid to solution ratio of 2.8:1 when the mortar samples developed with F-GFA as fine aggregate are allowed for oven curing maximum compressive strength is obtained at 60 minutes for 120^0c(**Fig 3.1.4)**, whereas the fly ash samples which were noted to reciprocate the average compressive strength value at 30 3^0C for a duration of 7 days under air curing.

In case of the mortar samples developed with G-GFA, maximum compressive strength is noted at 12M of alkaline solution with Na_2SiO_3 / NAOH ratio of 1:2 and a solid to solution ratio of 3:1. When the mortar samples developed with G-GFA are allowed for oven curing, maximum compression strength is obtained at 45 minutes for 100^0C, whereas the samples which were kept for air curing in the room temperature were noted to showcase good compressive strength at 30 3^oC for a duration of 48 hours(2 days).

4. Results And Discussion

4.1 Physical and Chemical Properties

The physical and chemical properties of the air dried F-GFA(AD-F-GFA), oven dried F-GFA(OD-F-GFA), air dried G-GFA(AD-G-GFA), oven dried G-GFA(OD-G-GFA) and natural sand(NS) were analyzed conforming to IS 2386-Part III(1963) and listed out below **(Table 4.1.1)**

Table 4.1.1 Physiochemical properties of the GFA's compared with natural sand

Parameter	AD-F-GFA	OD-F-GFA	AD-G-GFA	OD-G-GFA	NS
Water adsorption ratio	7.67%	7.02%	6.96%	6.25%	0.99%
Specific Gravity	1.98	1.96	2.4	2.2	2.62
pH value	10.9	10.7	11.5	11.7	8.2
Zone as per IS 383:2016	Zone I	Zone I	Zone I	Zone I	Zone I

4.2 Particle size Distribution

The particle size distribution curve for the G-GFA and F-GFA were developed **(Fig 4.2.1)** which is then compared with that of the natural sand as per the standards of IS 383:2016[16]. Three of the curves were noted to be within the limits of zone I with poor grading of the soil. The co-efficient of curvature (C_c) and the co-efficient of Uniformity (C_u) were evaluated for G-GFA, F-GFA and natural sand conforming to IS 1498:1970[17]. For the normal river sand, the values were C_u=1.59 and C_c =0.82. In case of the F-GFA, the observations were recorded as C_u=3.97 and C_c =1.09.Similiar but slightly higher values were noted in G-GFA with C_u=4.52 and C_c =1.32.Thus all the three types of fine aggregates were noted to be categorized as poorly graded soil(well graded soil: C_u>6 and C_c =1-3) as per IS 1498:1970 much similar to the earlier studies[Rao et al, 2014; Wanjari et al, 2011]

4.3 Optical Microscopy Analysis

In order to visualize the microstructure of the agglomerated particles of the fly ash **(Fig 4.3.1)** and GGBS (**Fig 4.3.2)**, the optical microscopy testing is conducted for the GFA developed and thus the polymerization in the GFA was corroborated. The samples of fly ash, GGBS, F-GFA and G-GFA were visualized with the help of optical microscope that generates the micrograph under visible light and an arrangement of system of lenses. The images seen in Optical microscope were captured by ordinary photosensitive camera to obtain the micrograph. The micrographs thus obtained clearly substantiate the agglomerated particles formed from the fly ash and GGBS along with the alkaline solution under the suitable conditions.

4.4 X-Ray Diffraction Analysis

The XRD patterns of the F-GFA and G-GFA (**Fig 4.4.1)** were obtained using X- ray diffractometer D8 Advance ECO XRCD systems with SSD160 1 D Detector and upon the further analysis of the results with the recent version of JCPDS software, the implications were procured accordingly. The XRD pattern of F-GFA showcased a high peak between 25.81˚ to 26.98˚ which is attributed to the presence of glassy phase [Ward et al, 2006]. Few other multiple average peaks were noted at 16.53˚, 20.95˚, 30.86˚, 33.29˚, 35.23˚,39.34˚, 40.91˚,45.92˚, 50.31˚, 60.69˚ and 66.94˚ indicating the presence of silica, sodium, aluminum, hydrogen & carbon compounds (plumbonacrite) and compounds of chlorides & oxides(chloranil) imparting the crystalline nature for the F-GFA and consequently initiates geopolymerization process in the same.

Whereas the XRD pattern of G-GFA exposed a broad hump between 24.50˚ and 34.90˚concentrated with calcium oxides, Alumina, Oxides, Iron and Sodium traces. The same traces were found throughout the diffraction pattern in lower peaks also depicting the amorphous nature in more portion. Few traces of Titanium, Calcined Alumina and Berilium were also noted in the G-GFA samples. Altogether, the G-GFA was noted to inhibit a crystalline combined with amorphous microstructure indicating the incomplete dissolution of the parent material which later imparts the hardened property in the developed mortar samples [Agrawal et al, 2017; Sharma et al, 2019].

4.5 SEM Analysis of the GFA

The GFA thus developed were analyzed for surface morphology with Scanning Electron Microscope EVO 18(CARL ZEISS) to corroborate the microstructure which can be further adapted to analyze the mechanical and durability studies of the mortar and concrete specimens. The samples of flyash, GGBS, F-GFA, G-GFA and NS were analyzed and presented in **Fig 4.5.1 to Fig 4.5.5**. Both F-GFA and G-GFA showcased the agglomerated crystal-like structures formed due to the polymerization process in the micrograph. In F-GFA, the glassy phase is turned out into crystal like grain structures whereas higher version of crystal-like grain structures with better pore structure is noted in the G-GFA ascertaining the formation of the geopolymerized sand through polymerization reaction. Few unreacted particles of fly ash as well as GGBS were noted in the F-GFA and G-GFA that remained as it is without reacting with the alkaline solution. These unreacted particles act as nucleation sites and as fillers also thereby contributing better binding nature due to the heterogeneous structure of the micrographs of F-GFA and G-GFA. These nucleation sites allow the reacted particles to amass it in the surroundings developed by the interlocking of the aluminum and silicon ions with the alkaline solution which apparently polymerize into aluminosilicate networks promoting the glassy phase into crystal like structure[Sharma et al, 2019]. Nevertheless, significantly similar micrographs were obtained in the GFA developed by both oven drying and air drying.

4.6 Compressive strength

Mortar cubes were casted to experimentally determine the compressive strength of the OD-F-GFA, AD-F-GFA, OD-G-GFA and AD-G-GFA which can be compared with the results **(Fig 4.6.1**) of the mortar specimens casted with NS. 15 mortar cubes were casted with a w/c ratio of 0.9, 0.85, 0.75, 0.7 and 0.4 for OD-F-GFA, AD-F-GFA, OD-G-GFA, AD-G-GFA and NS respectively. The higher water absorption of the F-GFA and G-GFA particles effectuated the respective mortar specimen to exhibit higher w/c ratio for the mortar mix. The compressive strength of the mortar samples was determined conforming to IS 2386(part 6):1986 by casting three replicate cubes of size 70.7mm×70.7mm×70.7mm. These specimens were allowed for ambient curing(32˚C) for a duration of 24 hours followed by water curing in a tank of tap water. Thus, the specimens were cured for 28 days.

A compressive strength of 19.9 N/mm^2 , 17.6N/mm^2, 20.11 N/mm^2 ,21.16 N/mm^2, and 23.5 N/mm^2 were obtained for OD-F-GFA, AD-F-GFA, OD-G-GFA, AD-G-GFA and NS respectively. The strength attained in F-GFA and G-GFA samples can be owed to the un reacted particles [Agrawal et al,2017] in fly ash and GGBS which later on reacts with the lime discharged from the hydration process of cement particles thus counterbalancing the effects of higher w/c ratio in the mortar samples[Rao et al, 2014]

5. Conclusion

The following conclusions were acquired upon the usage of OD-F-GFA, AD-F-GFA, OD-G-GFA and AD-G-GFA as fine aggregate which is then compared with the properties of NS. The physiochemical properties

such as the specific gravity, density, pH, fineness modulus and particle size distribution of F-GFA and G-GFA were noted to be appreciably in the adequate level with the natural sand. F-GFA are well graded with the oven drying preparation technique whereas G-GFA are ideally graded by the air-drying preparation itself, thus becoming the economical one. The higher w/c ratio in the F-GFA and G-GFA particles were owed to the porosity nature of the particles which is clearly seen in the micrograph obtained from SEM along with the un- reacted particles of fly ash and GGBS. The XRD patterns revealed the amorphous phase in most of the samples indicating the un reacted particles even after geopolymerization process, which later on plays the key role in the attainment of adequate compressive strength by reacting with the lime released after the hydration process of cement.AD-G-GFA was noted to achieve 90% of the compressive strength of the NS at 28 days, the same is also the most feasible GFA by means of economical production process as well as well gradation, blooming as the adequate complete replacement choice for the natural sand.

Future scope of the Study:

Researchers need to focus further in lowering the water absorption ratio of the GFA in the processing stage itself while executing the same in the larger scale too. Synthesizing machineries with lower cost units need to be established to manufacture GFA in industrial scale in factories similar to the M-Sand. The behavior of the GFA can be analyzed under various temperatures and environmental factors.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

All data generated or analysed during this study are included in this published article.

Competing interests

The authors declare that they have no competing interests.

Funding

The authors declare that no funding is received for this entire study to conduct the experimental study and for the collection of data.

Authors Contribution

1. Lizia Thankam Gnana Durai: Major contributor in conducting the experiments in the laboratory and drafted most of the research article.
2. Neelakantan Thruvas Renganathan: Suggested most of the technical tools and analysis means for the entire study. Contributed to the final revision of the research article.
3. Christopher Gnanaraj Selvaraj: Supported the laboratory works and proposed technical tools.

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Conflict of interest

There is no conflict of interest

References

1. Agrawal, U. S., S. P. Wanjari, and D. N. Naresh. "Characteristic study of geopolymer fly ash sand as a replacement to natural river sand." *Construction and Building Materials* 150 (2017): 681-688.
2. Ahmaruzzaman, M. "A review on the utilization of fly ash." *Progress in energy and combustion science* 36, no. 3 (2010): 327-363.
3. Atis¸ , C.D., Bilim, C., 2007. Wet and dry cured compressive strength of concrete containing ground granulated blast-furnace slag. Build. Environ. 42 (8).
4. Babu, K. Ganesh, and V. Sree Rama Kumar. "Efficiency of GGBS in concrete." *Cement and Concrete Research* 30, no. 7 (2000): 1031-1036.
5. Bouzoubaa, N., Zhang, M.H., Malhotra, V.M., 2001. Mechanical properties and durability of concrete made with high-volume fly ash blended cements using a coarse fly ash. Cem. Concr. Res. 31 (10)
6. Davidovits, J., 2002. 30 years of successes and failures in geopolymer applications, Market trends and potential breakthroughs. In: Geopolymer 2002 Conference. Saint-Quentin (France), Melbourne (Australia): Geopolymer Institute
7. Davidovits J. Geopolymers: inorganic polymeric new materials. J Therm Anal 1991;37:1633–56.
8. Davidovits J, Buzzi L, Rocher P, Marini DGC, Tocco S. Geopolymeric cement based on low cost geologic materials – geocistem. In: second international conference geopolymer 99, France; 1999.
9. Davidovits, Joseph. "Properties of geopolymer cements." In *First international conference on alkaline cements and concretes*, vol. 1, pp. 131-149. Kiev State Technical University, Ukraine: Scientific Research Institute on Binders and Materials, 1994.

10. Dhir, R. K., M. A. K. El-Mohr, and T. D. Dyer. "Chloride binding in GGBS concrete." *Cement and Concrete Research* 26, no. 12 (1996): 1767-1773.
11. Domone, P. L., and M. N. Soutsos. "Properties of high-strength concrete mixes containing PFA and ggbs." *Magazine of Concrete Research* 47, no. 173 (1995): 355-367.
12. Duxon P, Fernandez-Jiminez A, Provis JL, Luckey GC, Palomo A, Van Deventure JSJ. Geopolymer technology: the current state of the art. J Mater Sci 2007;42:2917–33.
13. Fraay, A. L. A., J. M. Bijen, and Y. M. De Haan. "The reaction of fly ash in concrete a critical examination." *Cement and concrete research* 19, no. 2 (1989): 235-246
14. Hemalatha, T., and Ananth Ramaswamy. "A review on fly ash characteristics–Towards promoting high volume utilization in developing sustainable concrete." *Journal of cleaner production* 147 (2017): 546-559.
15. IS: 2386-1963, Methods of test for aggregates for concrete–Part 1: Particle size and shape, Bureau of Indian Standards, New Delhi.
16. IS 383-1970, Coarse and Fine Aggregate for Concrete – Specification , Bureau of Indian Standards, New Delhi.
17. IS1498-1970, Classification and identification of soils for general engineering purposes, Bureau of Indian Standards, New Delhi.
18. Ismail, Zainab Z., and Enas A. Al-Hashmi. "Recycling of waste glass as a partial replacement for fine aggregate in concrete." *Waste management* 29, no. 2 (2009): 655-659.
19. Komnitsas KA. Potential of geopolymer technology towards green buildings and sustainable cities. In: International conference on green buildings and sustainable cities, procedia engineering, vol. 21; 2011: p.1023–32.
20. Li C, Sun H, Li L. A review: the comparison between alkali-activated slag (Si+Ca) and metakaolin (Si+Al) cements. Cem Concr Res 2010;40:1341–9.
21. Mo, K.H., Ling, T.C., Alengaram, U.J., Yap, S.P., Yuen, C.W., 2017. Overview of supplementary cementitious materials usage in lightweight aggregate concrete.Constr. Build. Mater
22. Mehta, P.K., 2004. High-performance, high-volume fly ash concrete for sustainable development. In: Proceedings of the International Workshop on Sustainable Development and Concrete Technology. Iowa State University, Ames, IA, US
23. Mir, Anzar Hamid. "Replacement of natural sand with efficient alternatives: recent advances in concrete Technology." *J. Eng. Res. Appl. www. ijera. com* (2015).
24. Provis JL, VanDeventer JSJ, editors. Geopolymers, structure, processing, properties and application. UK: Woodhead Publishing Limited; 2009.
25. Rao, S. M., & Acharya, I. P. (2014). Synthesis and characterization of fly ash geopolymer sand. *Journal of materials in civil engineering*, *26*(5), 912-917.
26. Sharma, Anil Kumar, and K. B. Anand. "Comparative study on synthesis and properties of geopolymer fine aggregate from fly ashes." Construction and Building Materials 198 (2019): 359-367.

27. Siddique, Rafat. "Effect of fine aggregate replacement with Class F fly ash on the mechanical properties of concrete." *Cement and Concrete research* 33, no. 4 (2003): 539-547.
28. Song, H.W., Saraswathy, V., 2006. Studies on the corrosion resistance of reinforced steel in concrete with ground granulated blast-furnace slag-an overview. J. Hazard. Mater. 138
29. Thankam, G. Lizia, 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, p. 012039. IOP Publishing, 2020.
30. Topcu, I.B., 1997. Physical and mechanical properties of concretes produced with waste concrete. Cem. Concr. Res. 27 (12)
31. Tsakiridis, P.E., Papadimitriou, G.D., Tsivilis, S., Koroneos, C., 2008. Utilization of steel slag for Portland cement clinker production. J. Hazard. Mater. 152 (2)
32. Wanjari, S. P., 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, p. 092011. IOP Publishing, 2018.
33. Ward, Colin R., and David French. "Determination of glass content and estimation of glass composition in fly ash using quantitative X-ray diffractometry." *Fuel* 85, no. 16 (2006): 2268-2277.
34. Wu, Wei, Weide Zhang, and Guowei Ma. "Optimum content of copper slag as a fine aggregate in high strength concrete." *Materials & Design* 31, no. 6 (2010): 2878-2883.
35. Zhao, H., Sun, W., Wu, X., Gao, B., 2015. The properties of the self-compacting concrete with fly ash and ground granulated blast furnace slag mineral admixtures.J. Clean. Prod. 95
36. Zhuang, Xiao Yu, Liang Chen, Sridhar Komarneni, Chun Hui Zhou, Dong Shen Tong, Hui Min Yang, Wei Hua Yu, and Hao Wang. "Fly ash-based geopolymer: clean production, properties and applications." *Journal of Cleaner Production* 125 (2016): 253-267.

Figures

Figure 1

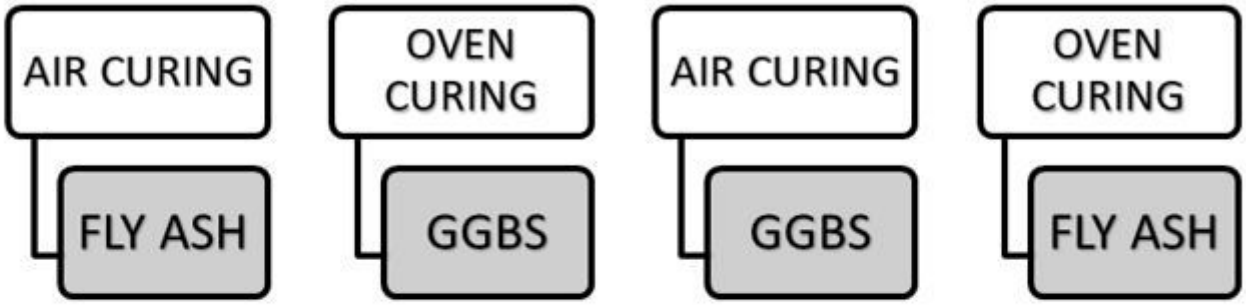
Hand mixing the dry mix for 10 minutes

Figure 2

Dry mix just after mixing

Figure 3

Geopolymerized sand



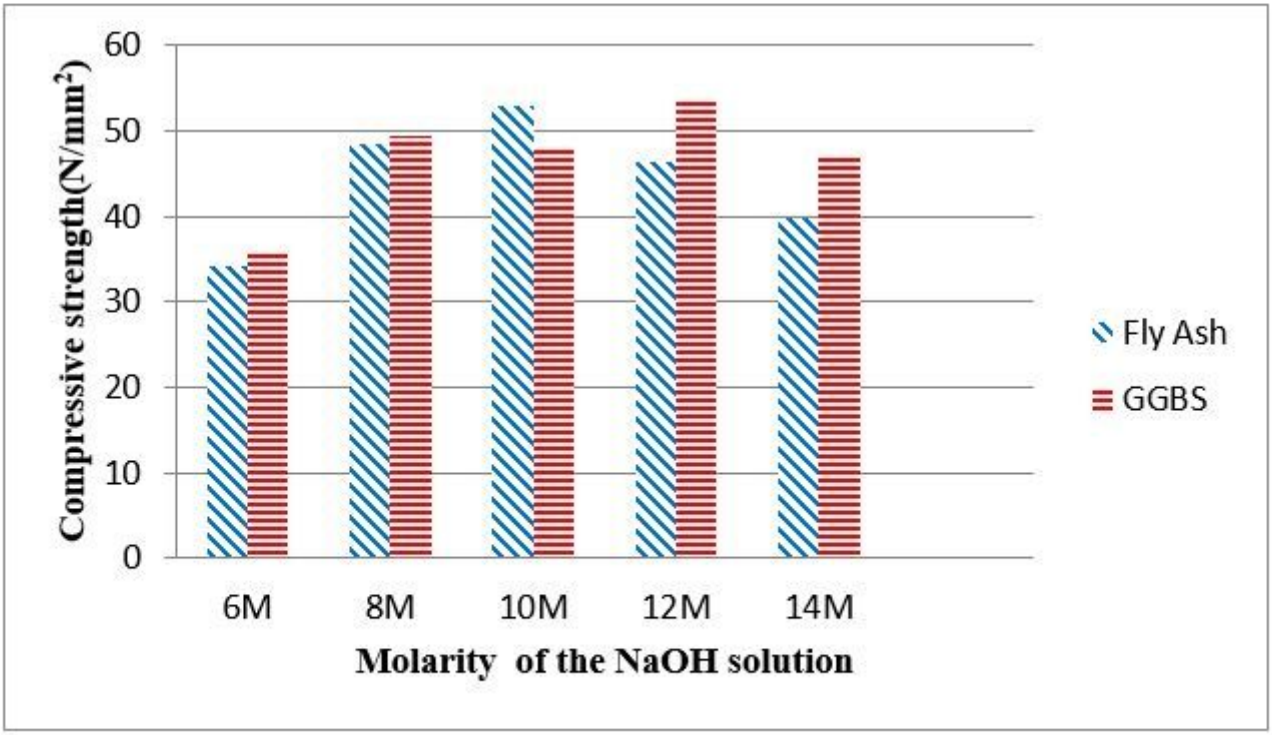


Figure 4

Optimization of the Molarity of the NaoH solution for Fly ash and GGBS based GFA

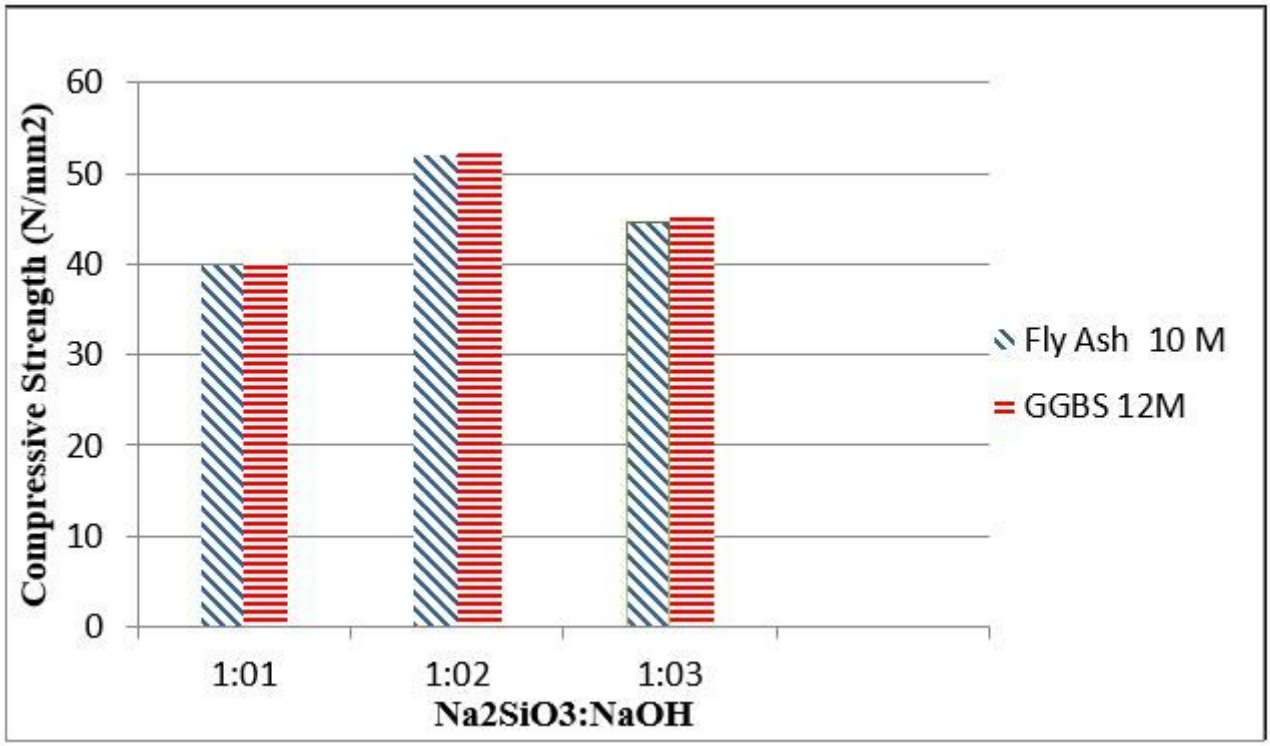


Figure 5

Optimization of the Na2SiO3 / NaOH ratio for Fly ash and GGBS based GFA

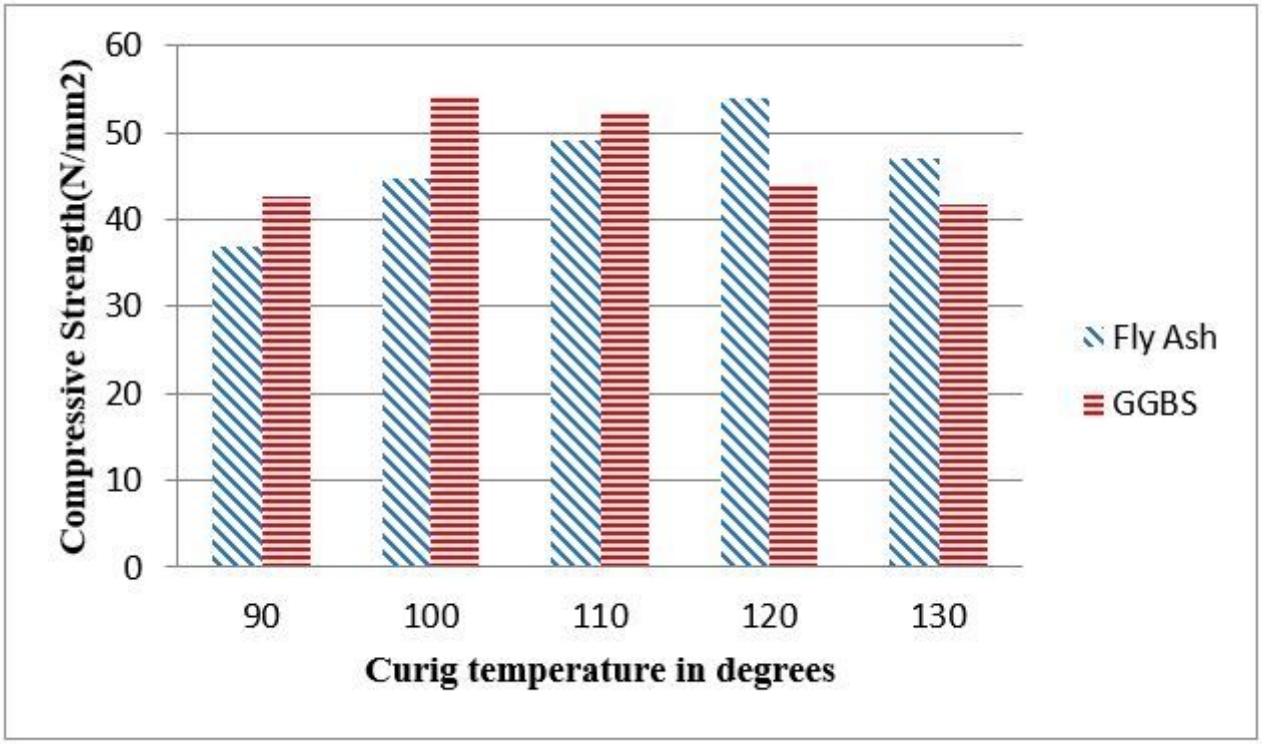


Figure 6

Optimization of the curing temperature for Fly ash and GGBS based GFA

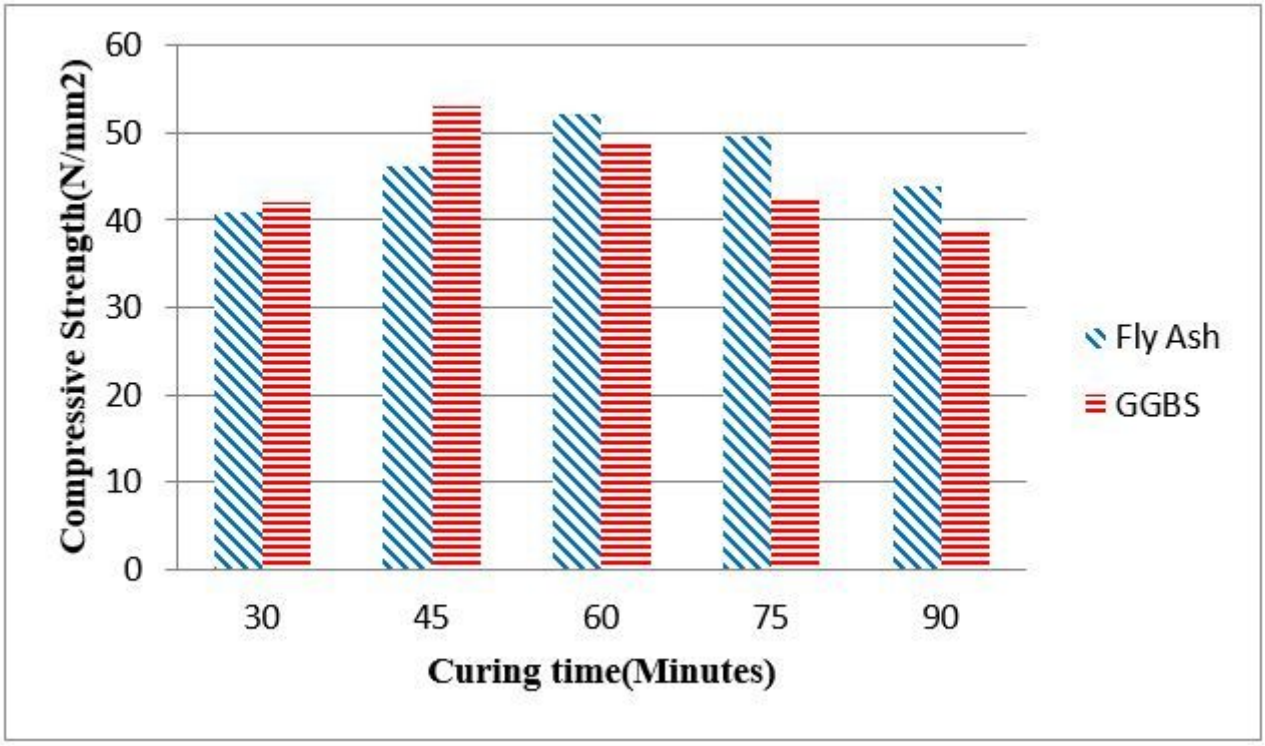


Figure 7

Optimization of the curing time for Fly ash and GGBS based GFA

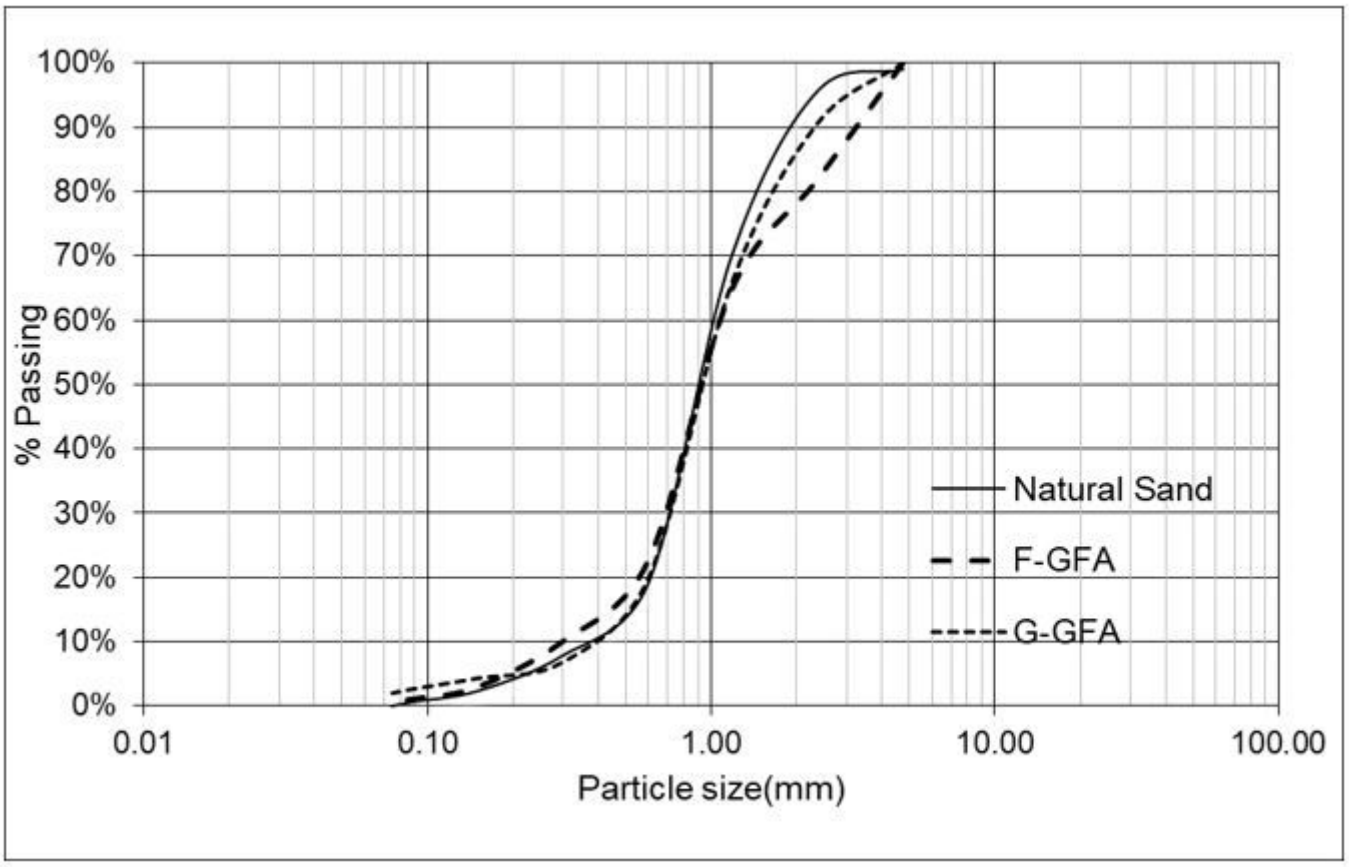


Figure 8

Particle size distribution of the NS, F-GFA and G-GFA.

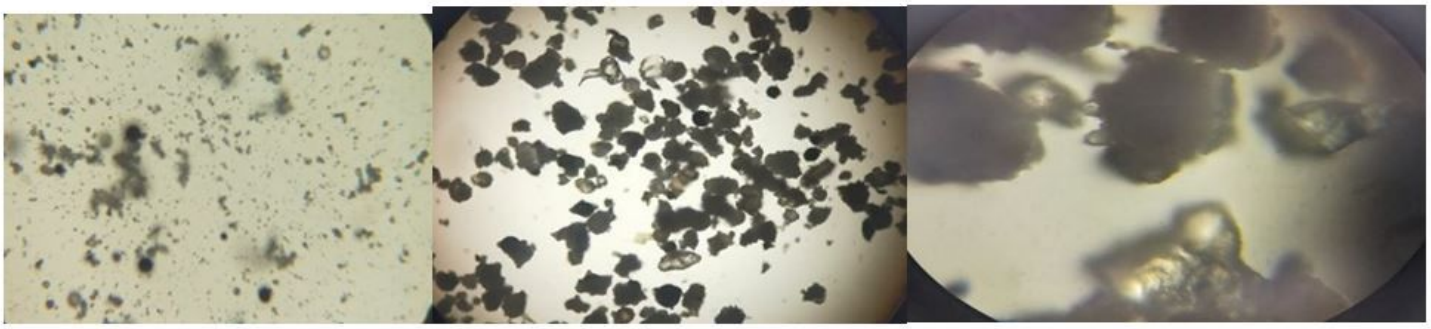


Figure 9

(a)Fly ash under 40x magnification (b)F-GFA under 10x magnification (c) F-GFA under 40x magnification

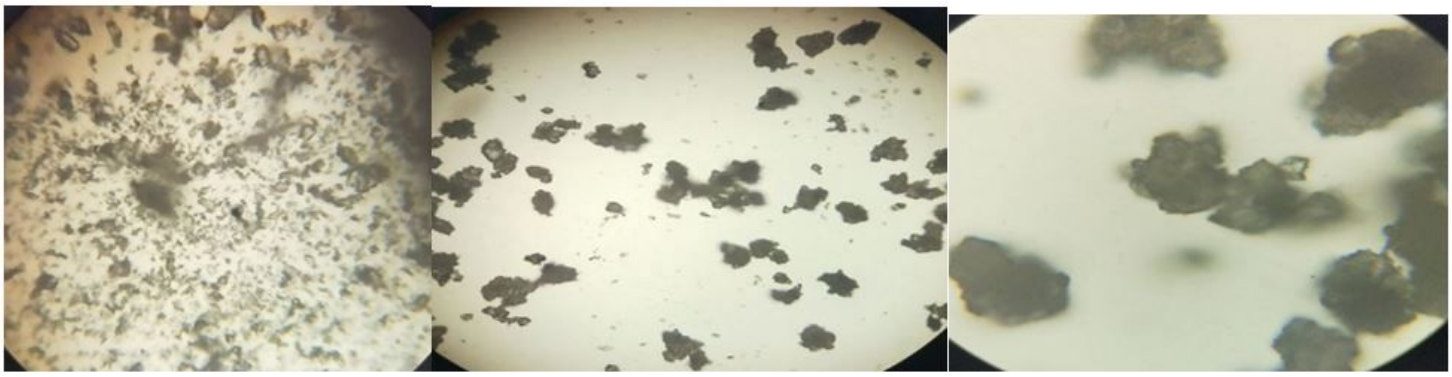


Figure 10

(a) GGBS under 40x magnification (b)G-GFA under 10x magnification (c)G-GFA under 40x magnification

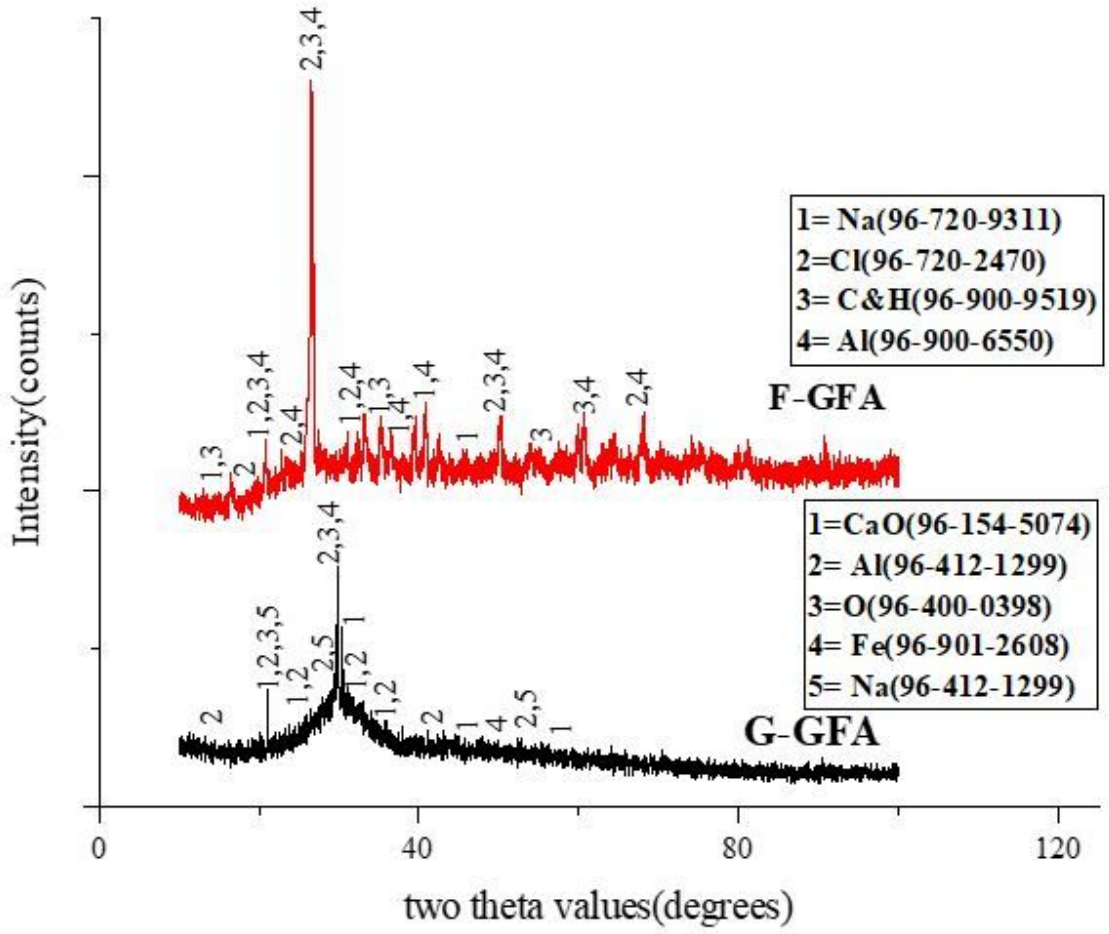


Figure 11

XRD patterns of G-GFA and F-GFA indicating the mineral composition along with their respective JCPDS card number.

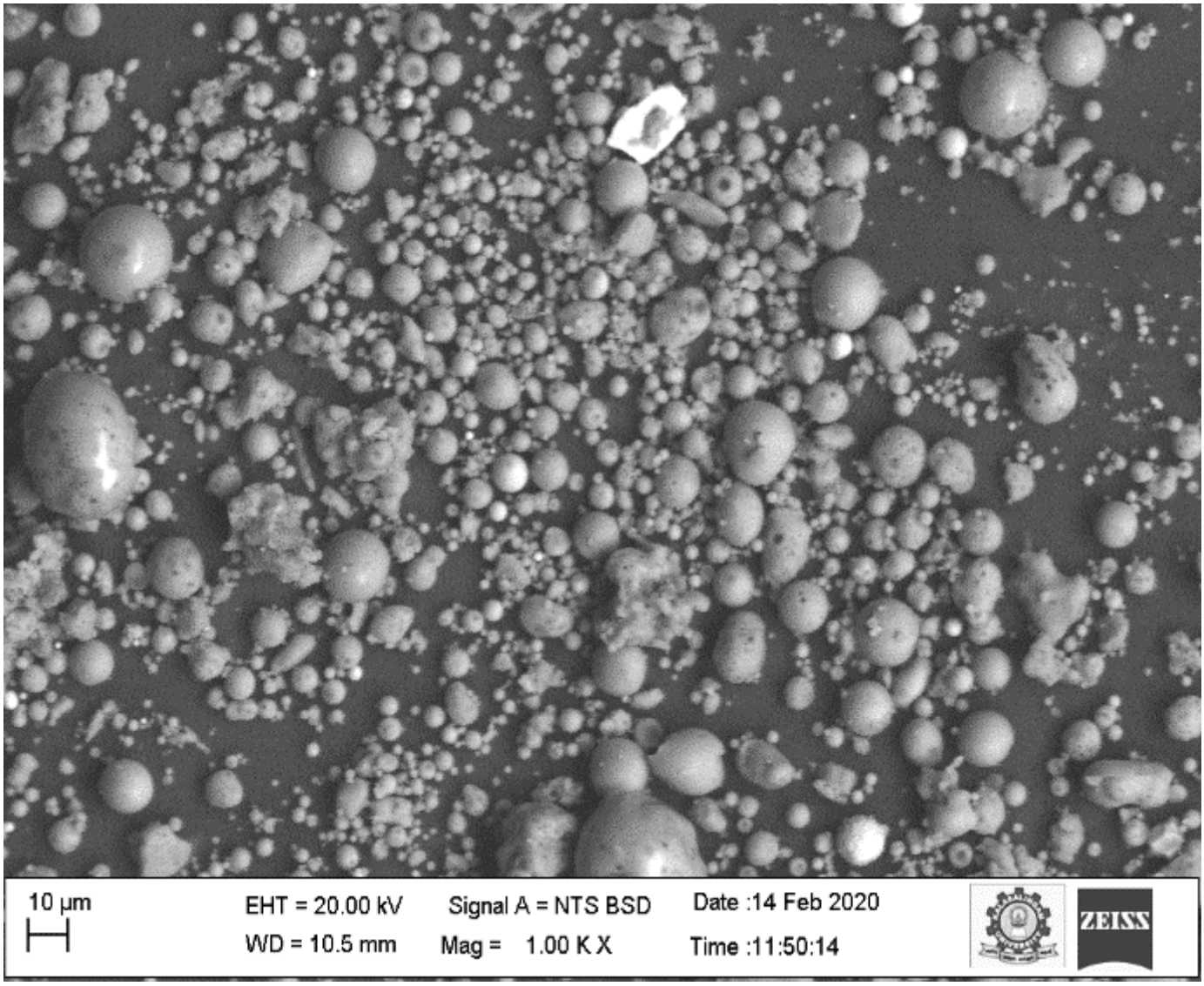


Figure 12

SEM micrograph of the Fly ash

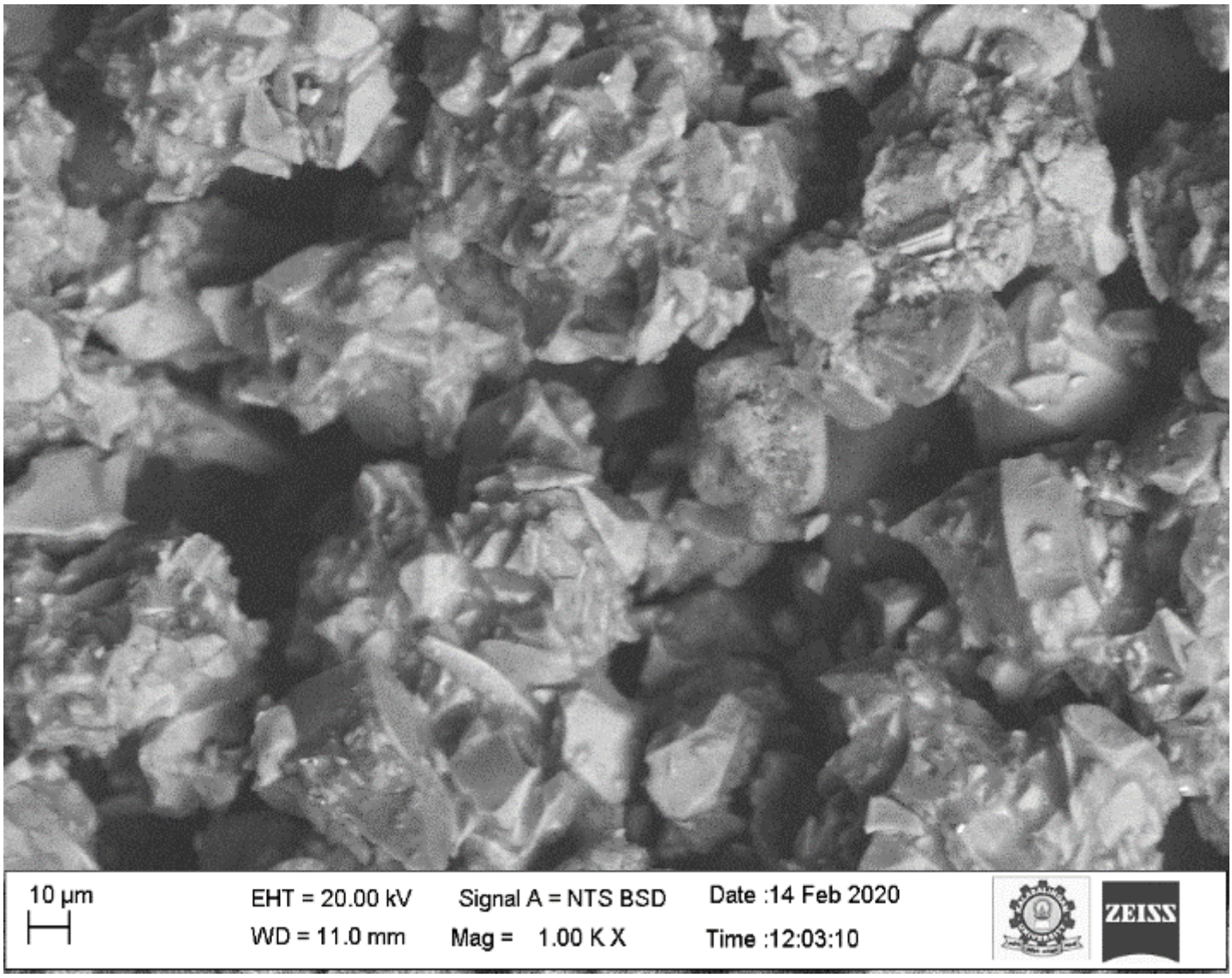


Figure 13

SEM micrograph of the F-GFA

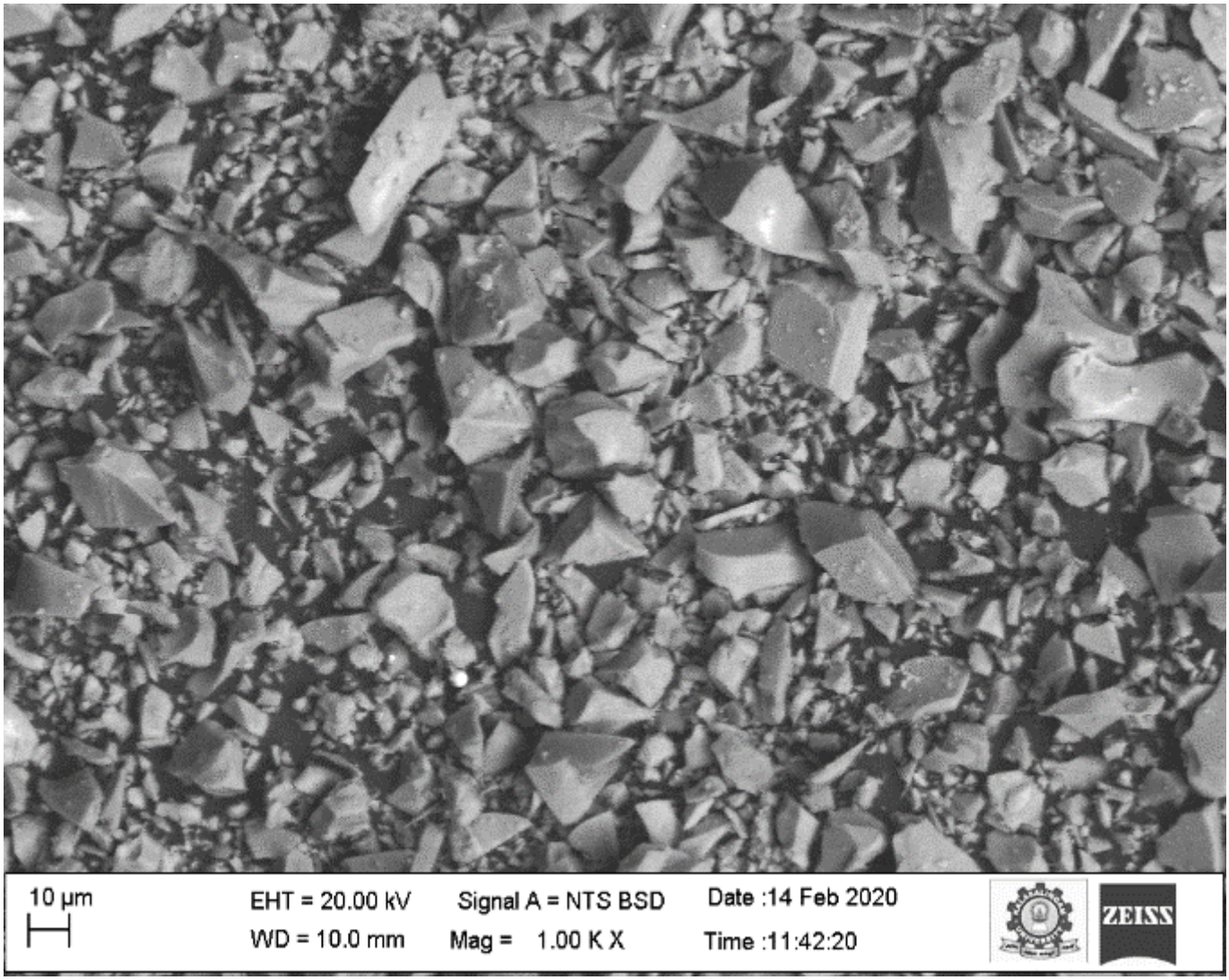


Figure 14

SEM micrograph of the GGBS

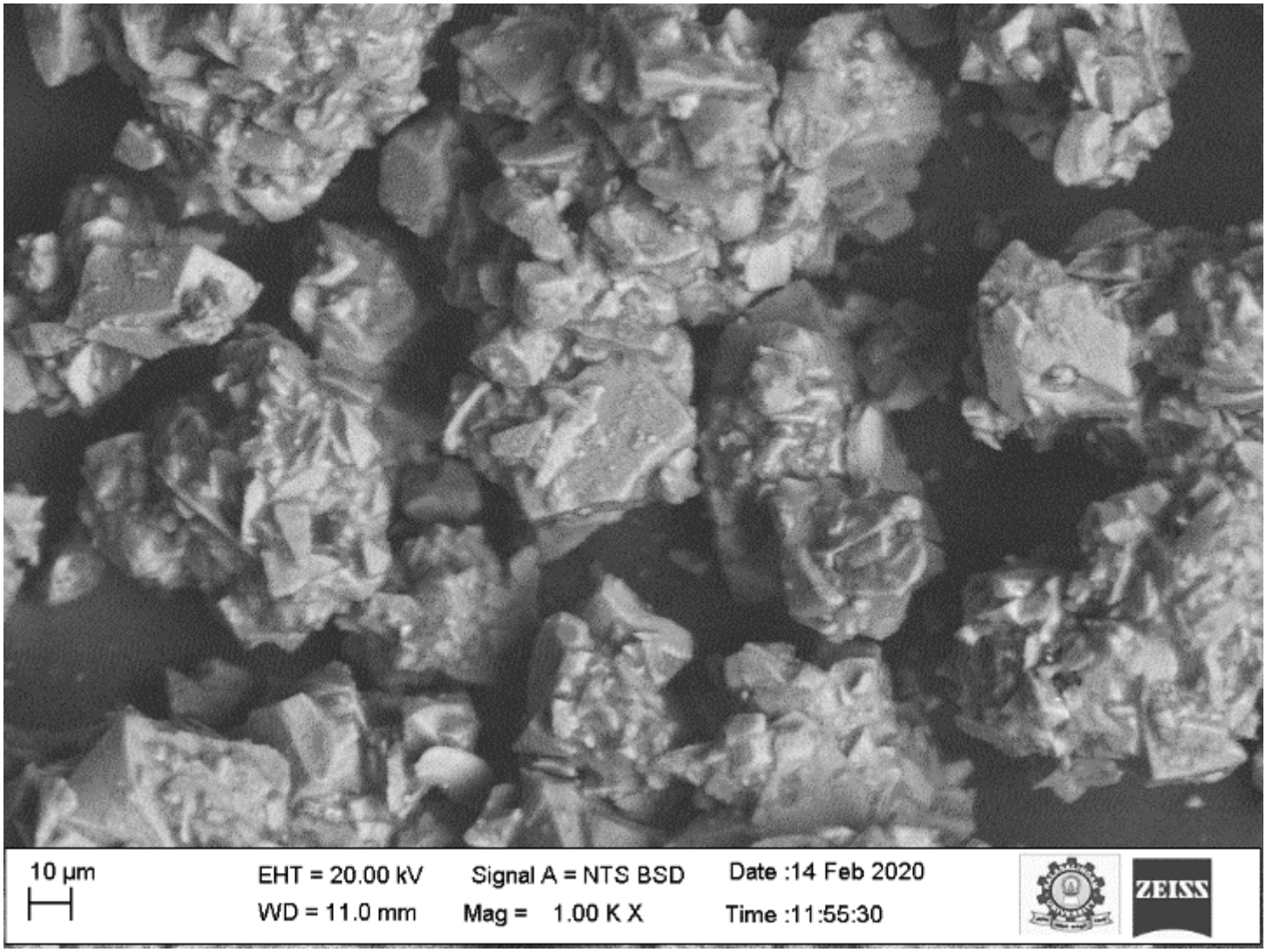


Figure 15

SEM micrograph of the G-GFA

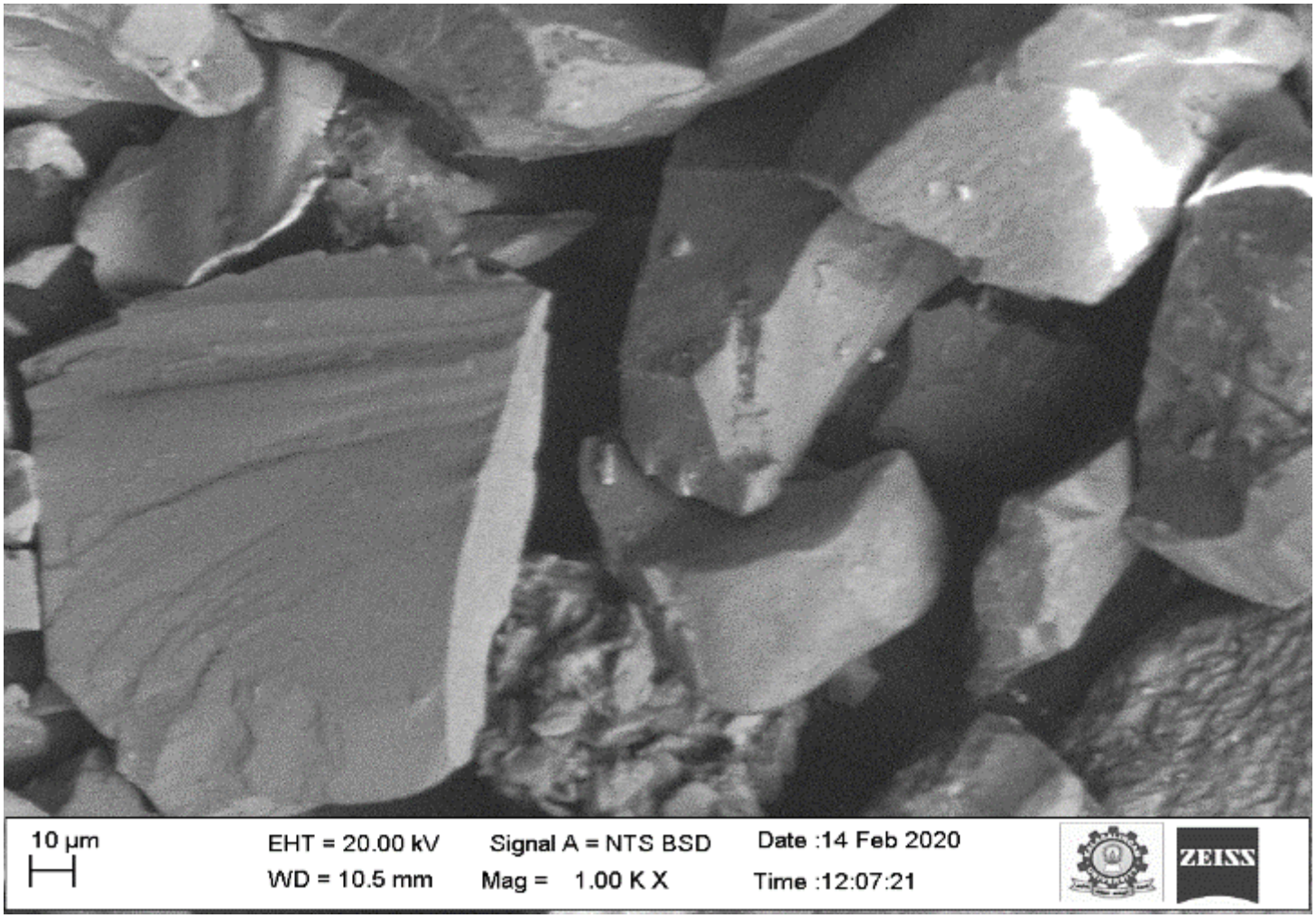


Figure 16

SEM micrograph of the NS

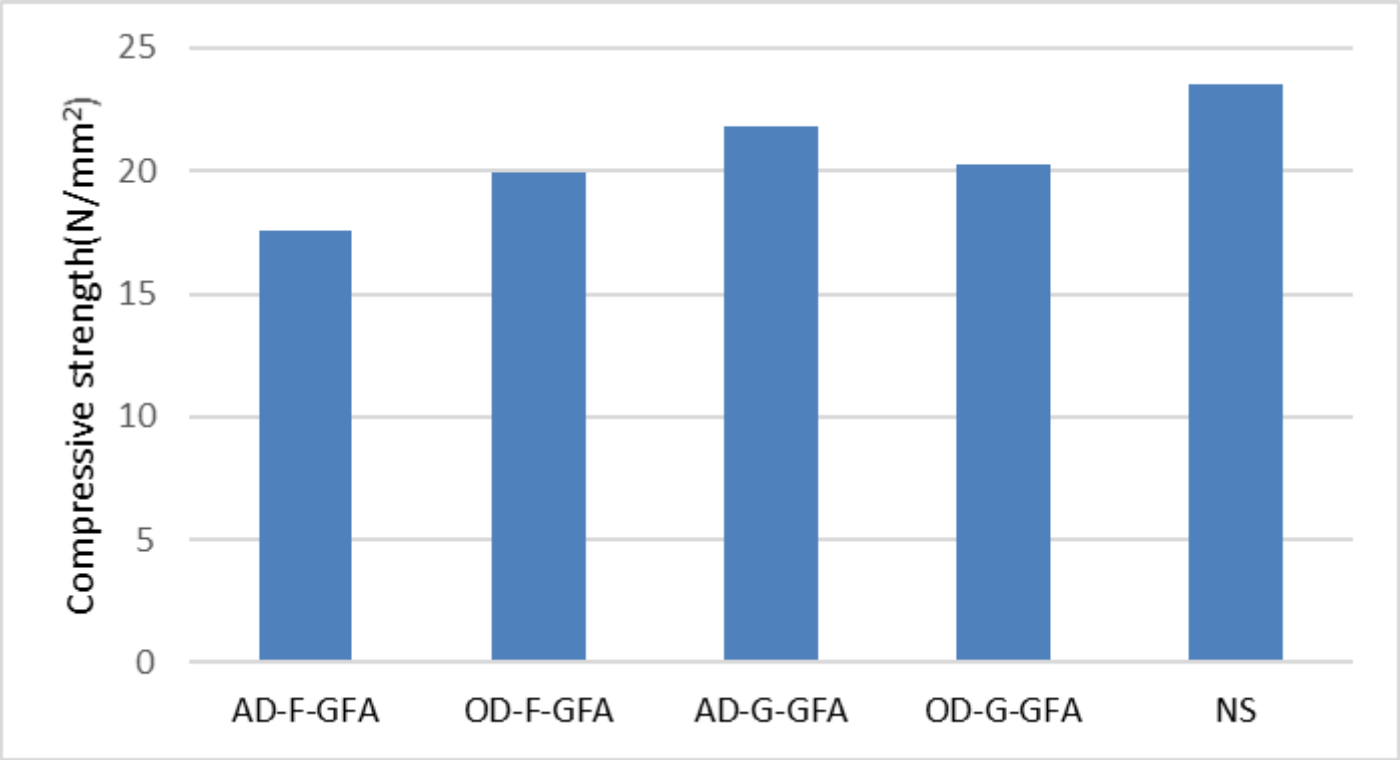


Figure 17

compressive strength test results of the mortar samples