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Development of Building Material from Steel Industry by Products

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ABSTRACT: *We know that, in case of cement production equal amount of carbon-di-oxide (CO_2) was produced which causes some special type of environmental problems, like global warming, acid rain etc. apart from this every industrial activity required energy which comes from burning of fossil fuels like coal. Burning of coal causes or produces huge amount of carbon di oxide (CO_2) which again causes dis-balance in environmental activities. Ranchi is a core industrial city; it means that chance of pollution increases day by day in this city. In Ranchi major industry product is iron based materials. So major pollutants are the byproducts of iron industry like AOD slag, GBF slag, ETP sludge, fly ash and bottom ash. Hence, due to growing environmental concerns of the iron industry, there is a need to develop alternative materials to reduce pollution of fly ash, bottom ash, granulated blast furnace slag (GBFS), AOD slag & ETP sludge. Also there is a need to develop masonry units using these alternative materials for sustainability. This paper investigates the behavior of AOD and GBFS based geopolymer product. The composition of AOD and GBFS were fixed in mixture and only the percentage composition of fly ash and slime in the mixture were varied. The ratio of sodium hydroxide and sodium silicate 1:3 act as an activator solution were used for polymerization process. The samples were cured initially at 50 ^oC for 24 hrs and after 24 hours these samples were kept at normal temperature 35 ± 5 ^oC for 28 Days. The reaction products in different experimental conditions were characterized using Scanning electron microscope (SEM), X-Ray diffraction (XRD) and Furrier transmission of Infra red spectroscopy (FTIR) and automatic compressive test machine. The results of compressive strength of geopolymer products prepared at 35 ± 5 ^oC were in the range of 4 to 12 MPa. This result indicates for application in low strength geopolymer building block at room temperature.*

Key Words: Fly Ash, Slime, GBFS, AOD Slag, Geo-polymerization, Compressive Strength.

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Nomenclature:
FA: Fly ash
GBFS: Granulated blast furnace slag
AOD: Argan oxygen decarburization slag
ETP: Effluent treatment plant
SEM: Scanning electron microscope
XRD: X-Ray diffraction

I. INTRODUCTION

Fly ash is a by-products generated during the combustion of coal in thermal power plant and steel industry. Fly ash consists of smaller particles ranging from 200 µ to submicron size and is collected in electrostatic precipitator. Sludge refers to the residual, semi-solid material left from wire drawing industrial wastewater during clinging. AOD slag is a by product of Argon oxygen decarburization process for making steel and other high grade alloy and By-product from the production of pig iron GBFS formed by quenching the molten material with jets of water, 90-95% glass content, 450 kg of slag/1T of hot metal. Both of the slag (AOD & GBFS) contains mainly CaO and SiO_2. Chemically fly ash is SiO_2 and Ai_2O_3 based material and ETP sludge is chemically Iron rich material. Use of fly ash and GBFS as blending material in cement, as filler in concrete and for brick making is well established. Recent trend shows lots of interest in its use for geopolymer preparation.

Geopolymers are new class of binder materials formed due to reaction between various aluminosilicates, oxides and silicates under highly alkaline condition, yielding polymeric Si–O–Al–O bonds[1]. Due to its binding properties, it is considered as an alternative of Portland cement. The products formed as a result of geopolymerization exhibit good mechanical properties, excellent durability and longevity.

Fly ash, due to its aluminosilicate composition, fine size and significant amount of glassy content, is considered a suitable raw material for geopolymer synthesis. GBFS has been added to improve the reactivity of geopolymer[2–5]. Due to AOD slag and ETP sludge low reactivity, the application of AOD slag and ETP sludge has been discarded. Recently no paper reported the combined use of fly ash, AOD slag & ETP sludge and Fly ash, GBFS & ETP sludge for making geopolymer. The use of fly ash for making alternative of building materials[6] can reduce the carbon footprint. AOD slag and ETP sludge is used as a replacement of sand in building materials. These are the source material for geopolymerization with reasonable strength after being milled to a proper fineness. Some reported results suggested that the strength of fly ash based geopolymer is higher than the strength of Portland cement[7–10].

The objective of the present work is to use fly ash as reactive material to produce geopolymer binder, and ETP sludge as replacement of sand/filler material. AOD slag and GBFS has been added to improve the reactivity of geopolymer. The focus of the study is to see the role of AOD slag and GBFS on ETP Sludge geopolymerization behaviour with 6 molar NaOH with sodium silicate (Na_2SiO_3). The reaction product has been identified using XRD and SEM-EDAX analyses. Attempt has been made to relate the structure with properties.

II. EXPERIMENTAL

Materials

Fly ash and AOD slag used in this study were collected from Tata jindal steel plant, jajpur, Orisa. To improve the rate of geopolymerization, GBFS obtained from Electrosteel, Bokaro, Jharkhand was used. ETP sludge obtained from Usha Martin, Wire drawing industry, Tatisilwe, Ranchi Jharkhand. Chemical compositions of fly ash, GBFS and AOD slag are given in Table I and chemical composition of ETP sludge was given in table II. Fly ash was mainly aluminosilicate in nature with SiO_2/Al_2O_3 ratio 1.736. The major oxides (SiO_2, Al_2O_3 and Fe_2O_3) of fly ash. Chemical characteristics revealed that the fly ash belonged to class F fly ash (ASTM C 618). Fly ash was used as feedstock to form aluminosilicate gel during geopolymerization whereas ETP sludge was used as filler material to replace sand in the geopolymer paste. GBFS was milled in a ball mill for 1 h to get the desirable particle size. The particle size distributions of fly ash, AOD slag and GBFS were determined by sieve analysis (IS-460-1962*) and the results are given in Table III. Sodium hydroxide (NaOH) solutions were used as alkali activators. The 6 molar NaOH solution was prepared and Sodium silicate, with composition Na_2O 14.7%, SiO_2 29.4% and H_2O 55.9%, was also used for the study. In this study the NaOH/ Sodium silicate ratio was 3:1.

Raw Material Characterization:

The physical properties of raw materials are presented in Table IV. The specific gravity of fly ash, AOD slag, GBFS and ETP sludge was 1.97, 3.03, 2.88 and 3.78 respectively. Figure 1, 2, 3 and 4 shows XRD patterns of fly ash, GBFS, AOD slag and ETP sludge respectively. The major peaks identified in fly ash and AOD slag are quartz and mullite, in case of GBFS major identified phase is gehlinite and sebrodolskite is the identified phase present in the ETP sludge. Sodium silicate solution with 14.7% Na2O, 29.4% SiO2 and 55.9% H2O, and 6M NaOH solutions were used as alkaline activators.

Mix Proportion

Fly ash, AOD slag, GBFS and ETP sludge were mixed with various proportions as given in Table V(a) and V(b). NaOH solution was prepared at least 24 h before use. Alkaline activator was prepared using different ratios of the prepared NaOH solution and Na2SiO3 solution. A total 18 mix proportions were made. The Fly ash and ETP sludge of each mix was varied in the percentage of 0% to 50% in one condition and 20% to 80% in second condition. Value of AOD slag and GBFS was fixed in condition one it was 10% and 20% in second condition. Samples were vibro-cast in 43 mm diameter cylindrical mould. The samples, after casting, were kept at 50^{o}C for 24 h. The samples were demoulded after heat curing and kept in sealed condition at ambient temperature for 28 days duration. Compressive strength of the samples was determined on 28 day using automatic compression testing machine (AIMIL COMPTEST 2000, India).

Geopolymer Characterization

The phase present in raw materials and products were analysed by powder X-ray diffraction technique using CuKα radiation with Fe filter (X-ray BRUKER diffractometer, model: D8 Discover). The morphological characterization of the fractured surfaces was done by a NOVA scanning electron microscope (FEI-430, NOVA) with an EDAX attachment for X-ray microanalysis.

III. RESULTS AND DISCUSSION

Figure 5a, 5b and 6a, 6b shows the result of compressive strength of all batches prepared. Results shows that as the fly ash content increases in each condition the compressive strength increases and also increase in AOD slag and GBES percentage increases the compressive strength. Figure 7, 8, 9 and 10 shows the XRD pattern of compositions, major peaks of qurartz and mullite are observed which were derived from parent fly ash. The products have been formed due to the reaction between reactive glassy fraction of fly ash and AOD slag. The hump between 10^o and 30^o indicates the presence of low crystalline phases.

SEM and EDAX Analyses:

Figures 11a to 11c show the SEM images of geopolymer samples and their characteristics are given in Table VI. The compactness of the microstructure improved with increasing Si/Al ratio which may be described by the formation of greater amount of calcium aluminosilicate gel. EDAX study revealed that most common gel phases were present as ASH (aluminium silicate hydrate) and CSH (calcium silicate hydrate) with Na in the structure.

IV. CONCLUSIONS

Geopolymerization behaviour of AOD and GBFS were studied with addition of Fly ash and ETP sludge. It was observed that fly ash has reactive with alkaline solution, whereas ETP sludge was inert. Addition of GBFS and AOD slag enhanced the rate of geopolymerization by formation of A-S-H and C-S-H gel in samples. The strength development was influenced by the formation of compact microstructure with reinforcement of gel structure with reacted surface. Based on compressive strength data, compositions F, G and H for GBFS based samples and sample P and Q can be used for brick making where the desired strength is 7 MPa. Study of mechanical properties, it is assumed that the samples prepared will be more sustainable in terms of environmental performance, economic viability and potential for waste utilization.

ACKNOWLEDGEMENTS

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Chemical composition	Fly ash	GBFS	AOD slag
SiO_2	51.06	14.20	33.39
Al_2O_3	29.71	2.69	3.52
Fe_2O_3	9.60	25.34	0.48
CaO	2.14	42.83	47.78
MgO	0.75	5.05	2.40
Na_2O	0.56	--	--
K_2O	0.40	--	11.02
Cr_2O_3	--	--	0.92
LOI	2.51	8.91	5.77

Table I: Chemical Composition of raw materials

Chemical composition	ETP Sludge
MnO_2	0.727
CdO	0.005

Fe_2O_3	85.000
ZnO	10.057
PbO	4.041
Cr_2O_3	0.056
CuO	0.012

Table II: Chemical Composition of ETP sludge

Sieve No	Fly ash	GBFS	AOD slag	ETP sludge
+229µ	20	42	80	Not done due to its sticky nature
-229µ, +149µ	38	10	12	
-149µ, +74µ	30	26	6	
-74µ, +44µ	6	8	--	
-44µ	2	10	--	

Table III: Retained weight (in %), fineness of raw materials

Physical Property	Colour	Form	Plasicity	A. Sp. Gr.
Fly ash	Gray	Powder	Non plastic	1.97
GBFS	Light Gray	Powder	Non plastic	2.88
AOD slag	Dark gray	Powder	Non plastic	3.03
ETP sludge	Red	Sticky	Non plastic	3.78

Table IV: Physical Property of raw materials

Sample No.	Fly ash %	ETP Sludge %	GBFS %
A	40	50	10
B	30	60	10
C	20	70	10
D	10	80	10
E	--	90	10
F	30	50	20
G	20	60	20
H	10	70	20
I	--	80	20

Table V(a): Batch Composition with GBFS

Sample No.	Fly ash %	ETP Sludge %	AOD Slag %
J	40	50	10
K	30	60	10
L	20	70	10
M	10	80	10
O	--	90	10
P	30	50	20
Q	20	60	20
R	10	70	20
S	--	80	20

Table V(b): Batch Composition with AOD slag

Fig. no.	Microscopic Character	EDAX result	Remarks
15a	Needle shaped microstructure radial towards the centre and geopolymer gel phase	Si/Al = 2	Presence of ASH Gel phase
15b	Thick gel phase	--	
15c	Reacted geopolymer surface and filamentous structure		

Table VI: Summary of microstructure

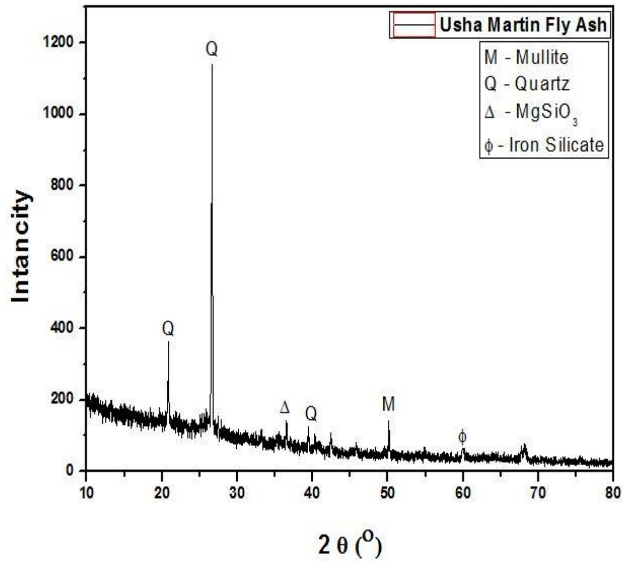

Figure 1: XRD of Fly ash

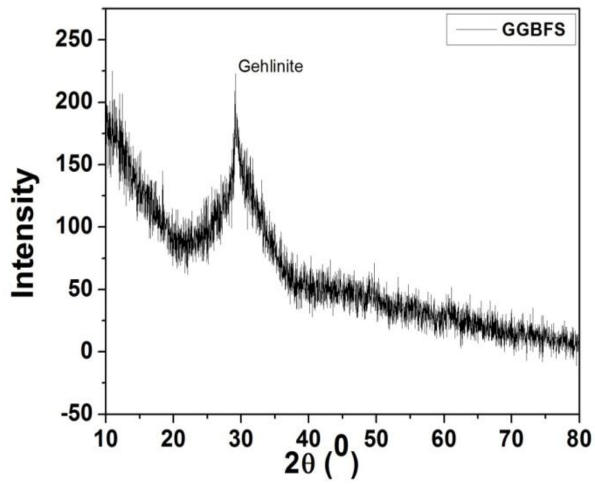

Figure 2: XRD of GBFS

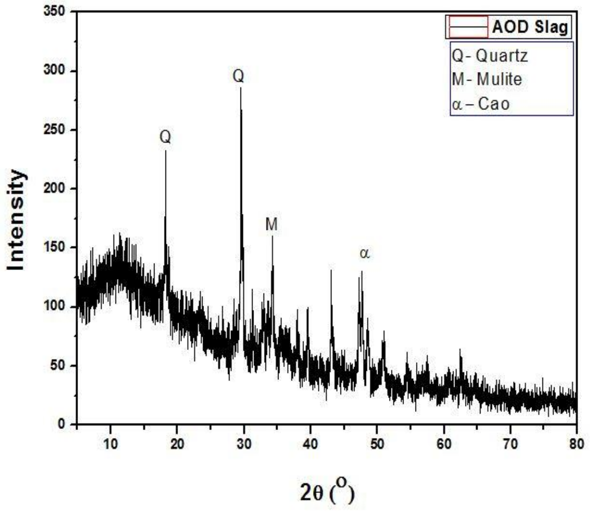

Figure 3: XRD of AOD slag

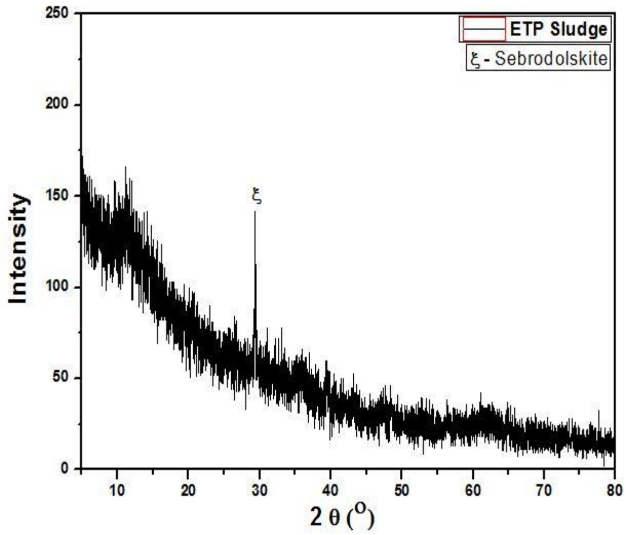

Figure 4: XRD of ETP sludge.

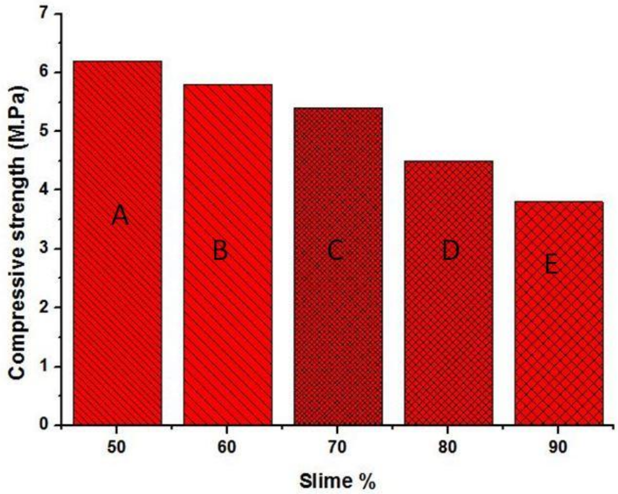

Figure 5a: Compressive strength results of 10% GBFS based samples

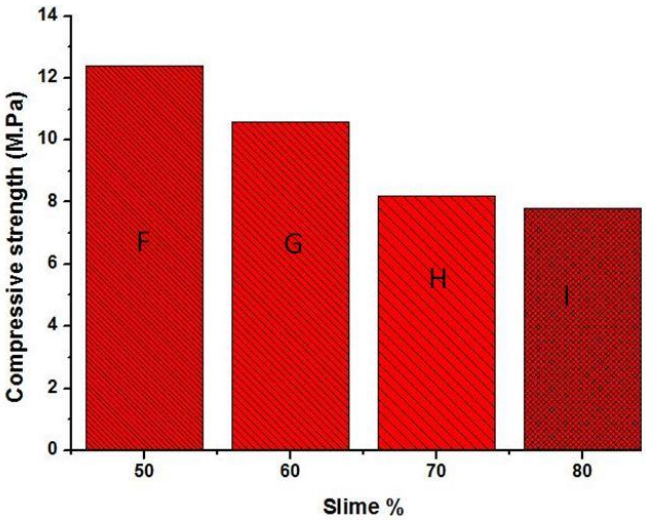

Figure 5b: Compressive strength results of 20% GBFS based samples

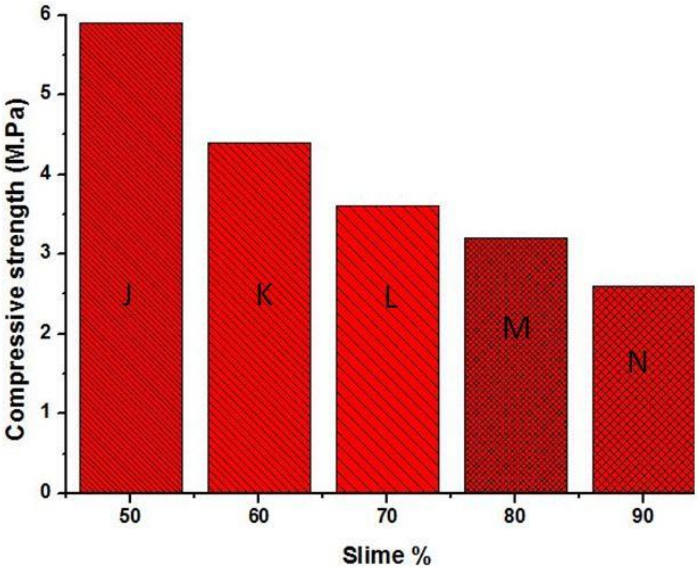

Figure 6a: Compressive strength results of 10% AOD slag based samples

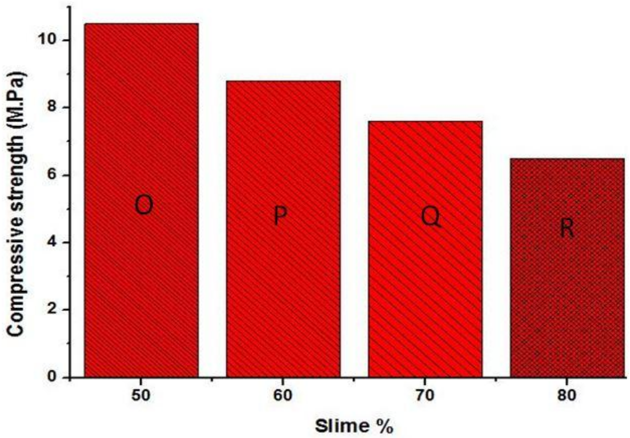

Figure 6b: Compressive strength results of 20% AOD slag based samples

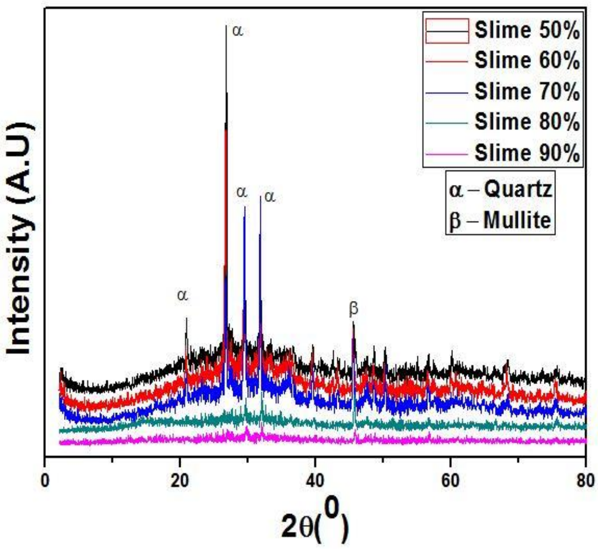

Figure 7: XRD of 10% GBFS based samples.

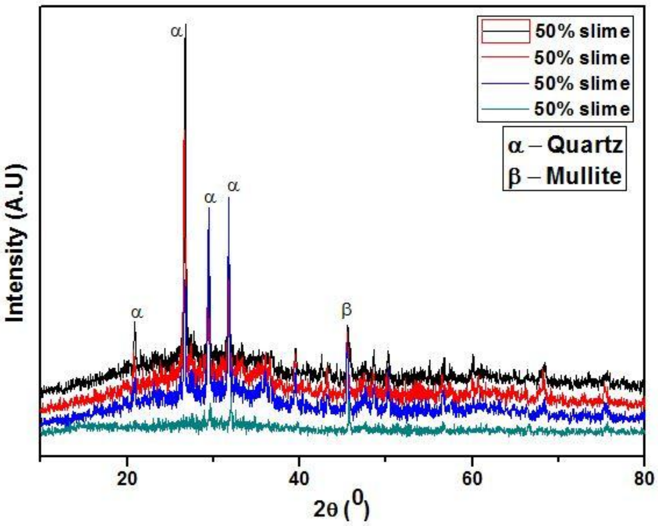

Figure 8: XRD of 20% GBFS based samples.

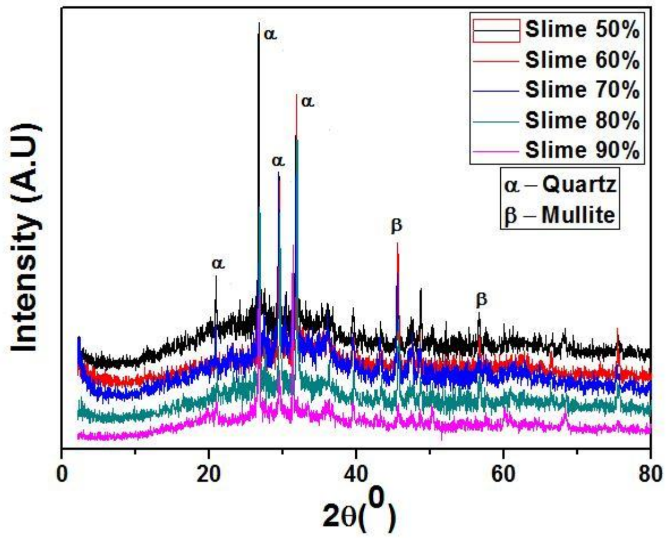

Figure 9: XRD of 10% AOD slag based samples.

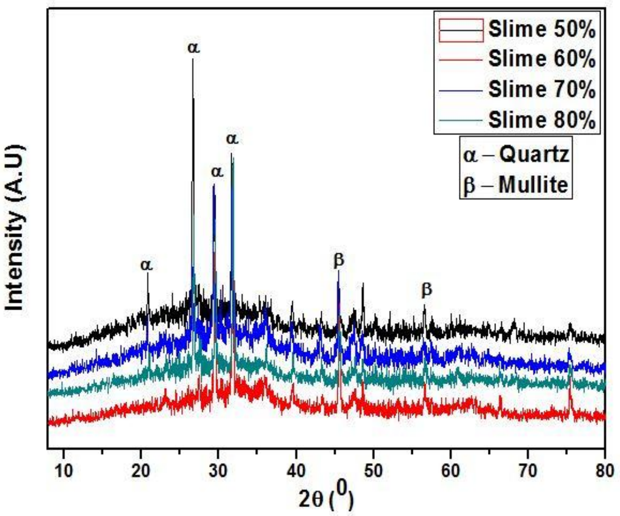

Figure 10: XRD of 20% AOD slag based samples.

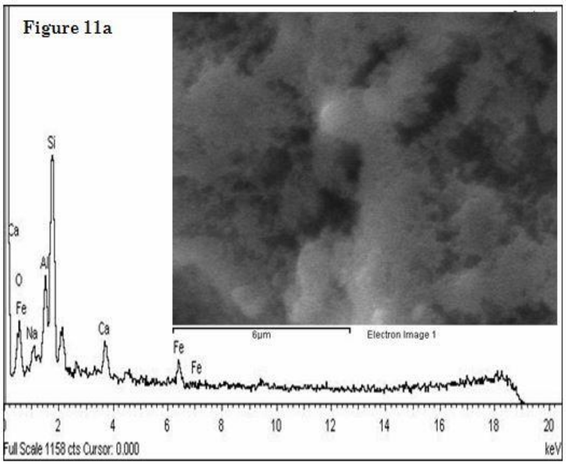

Figure 11a: Needle shaped microstructure radial towards the centre and geopolymer gel phase

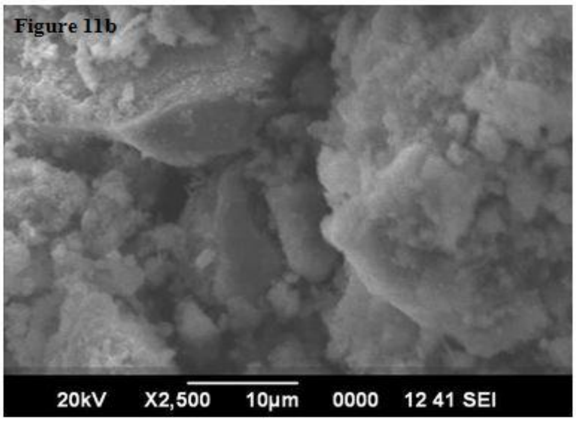

Figure 11b: Thick gel phase present in sample

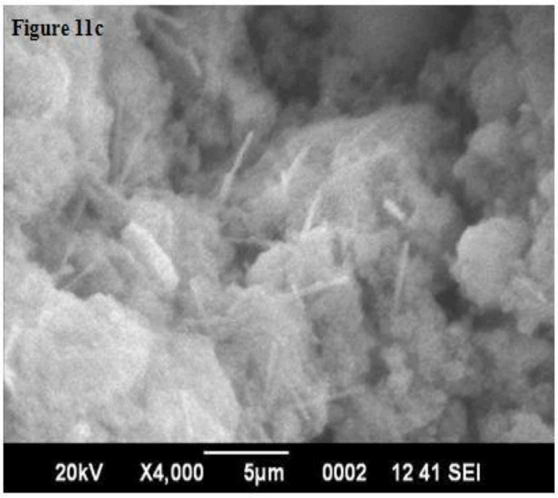

Figure 11c: Reacted geopolymer surface and filamentous structure

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