International Journal of Recent Trends in Engineering & Research

ISSN (ONLINE) : 2455 – 1457 IMPACT FACTOR : 4.101

ICNSCET19- International Conference on New Scientific Creations in Engineering and Technology

Flexural Behavior of Geopolymer Ferro Cement Panels with the Incorporation of Crumb Rubber and Nano Fly Ash

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Abstract— This paper presents the application of geopolymer mortar incorporating into the Ferro cement panel with enhanced properties by incorporating crumb rubber and Nano fly ash. The cement free mortar is prepared by using industrial wastes such as fly ash and ground granulated blast furnace slag (GGBFS) called as geopolymer mortar which helps to reduce the level of CO_2 emission. Also, the recycled tyre crumb rubber is utilized as a sustainable construction material with partial substitution for sand. It helps to reduce land fill problems and air pollution. Crumb rubber having the capacity of absorbing more energy from static and other loads. In this research, geopolymer mortar is made by using the basic constituents such as fly ash, GGBFS, alkaline liquid made of NaOH and Na_2SiO_3, Nano fly ash. The effort has been made to enhance the strength of fly ash based geopolymer mortar by incorporation of GGBFS. The molarity of alkaline solution, solution to binder ratio and Na_2SiO_3 to NaOH ratio is fixed as 12, 0.4 and 1.5 throughout the process. The 5% crumb rubber is used instead of sand for enhancing the strength and for better ductility without affecting the strength. The panel was heat cured under hot air oven at 80^{o} C for 48 hours. The mechanical properties such as compressive and tensile strength and water absorption are investigated. The Ferro cement panel is made of high strength geopolymer mortar and expanded metal mesh for enhancing the ductility and energy absorption capacity. The 2 layers of expanded metal mesh and 2 layers of chicken mesh are used. The investigation involves finding the initial crack load, ultimate failure load and residual flexural strength ratio. The Nano fly ash helps in increasing the strength and durability of the element by its pore filling capability.

Keywords—*geopolymer mortar, fly ash, GGBFS, Impact, Nano fly ash.*

I. INTRODUCTION

Geopolymer is a green innovative eco- friendly material for obtaining sustainable development with enhanced strength properties. This material not emits high amount o f carbon dioxide gas like cement manufacturing process [7]. It has too low level of loss on ignition values. The OPC manufacture also leads to the emission of nitrogen and sulphur oxide gases which creates global warming and acid rain problems. The cement manufacture alone creates 65% of global warming and it emits 1.35 billion tons of carbon dioxide gas into the environment. The geopolymer requires 1.6GJ energy with 80% reduction in CO2 emission whereas the cement manufacture needs 4GJ energy [1] & [3]. The geopolymerization process involves number of chains of inorganic molecule between polymer materials. The benefits of the geopolymer material are higher compressive strength, earlier strength development, acid resistance, fire resistance, low creep and shrinkage, crack reduction and lower porosity [6] & [9]. For the manufacturing of geopolymer mortar the alkaline solution preparation is most vital process. The alkaline solution can be made by sodium or potassium hydroxides and sodium or potassium silicates. The sodium-based materials are low cost but the potassium-based materials are slightly higher cost with increased strength. Alumina and Silica plays an important role in cementation process of geopolymer which forms two kinds of gel namely as C-A-S-H gel and N-A-S-H gel. The industrial byproducts mostly utilized in civil structural application is fly ash, GGBFS, metakaolin and RHA etc. [11] in which some of them are utilized and remaining are disposed into the land as a waste. This would create additional problems such as air pollution, ground water pollution and land pollution. Annually, 800 million tons of fly ash is produced in which only 50% is utilized [2]. The strength enhancement and increment in fly ash-based microstructure product is due to the presence of silica. GGBFS is a waste composed from iron ore industries which has high pozzolanic reactivity and alkali activation. It reduces the 93% of CO_2 emission of cement production [7]. The main composition of the fly ash and GGBFS are alumina, silica and oxygen. There are two kinds of fly ash namely low calcium (class-F) and high calcium (class-C) fly ash. The one ton of low calcium fly ash used to produce 2.5 m^3 of geopolymer concrete [6]. The fly ash based geopolymers are non-susceptible to alkali-aggregate reaction because of its lower calcium content. The compressive strength depends on the amount of calcium present in the fly ash. The high calcium fly ash is used for achieving early age strength development. The strength of binder can be enhanced by increasing the fineness and thermal treatment of fly ash [4]. The mineralogical classification of fly ash is amorphous/glassy (pozzolanic), inert, active, mixed phases and crystalline. The mix design of geopolymer binder involves molarity of NaOH, Na_2SiO_3/NaOH ratio, solution to binder ratio and water to binder ratio. These parameters directly affect the compressive strength of geopolymer binder. Usually 8 to 14 molarity of NaOH is preferred but for optimum results 12 to 14 molarity is followed. Totally there are three method of curing is usually followed for geopolymers. They are heat curing, steam curing and ambient curing. The heat curing efficiency is 1.5 times higher than steam curing. The temperature should be in the range of 60 ^oC to 80^oC. By increasing the curing period of geopolymer leads to strength increment. The ambient curing can be achieved by incorporating GGBFS into the fly ash based geopolymers. The annual tyre generation is reached 17 million [2]. The high mechanized ball mill is used to create shredded rubber, crumb rubber and powder rubber and the separation is done. When crumb rubber incorporating into the concrete or mortar, the problem due to tyre disposal on land is automatically reduced. The problem arises due to the tyre rubber disposal is follows: the presence of heavy metal affects the ground water quality standards and the non-bio-degradability of tyre leads to land pollution. The crumb is used instead of sand in many researches. It is an alternative way to reduce cost of natural sand and its transportation, over depletion of natural resources. The crumb rubber size can be in the range of 75μ to 4.75mm confirming to zone-II sand property. Crumb rubber having the ductile property and energy absorption capacity. Also, the thermal conductivity and permeability is reduced but compressive and flexural strength is reduced [7]. The crumb rubber bonding nature is the tedious one when dealt with the concrete micro structure. The self-compacting geopolymers are preferred for their reduced construction time, better quality and ease access with congested bars, homogeneity and higher strength [12]. The capability of absorbing energy is important for element when they may be subjected to static, dynamic and fatigue loads. Hence, there is a need for high ductile and energy absorbing element. Geopolymer mortar is quite popular due to its ease of mix preparation, superior performance as well as low carbon emission than the conventional OPC mortar. The primary objective of this flexure study was to investigate the effectiveness of mesh layers used at various combination of geopolymer mix.

II. EXPERIMENTAL PROCEDURE

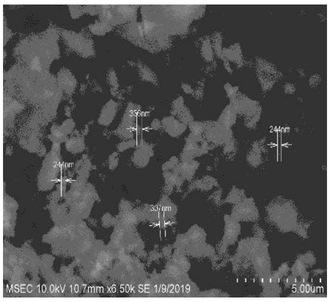
A. MATERIAL USED

Geopolymer is an inorganic polymeric homogeneous material which is produced by a material composed from industries such as fly ash, GGBFS, metakaolin, etc. with the alkaline activator liquid which induces alumino-silicate reaction. The material such as fly ash, GGBFS, crumb rubber, sand, alkaline liquid composed of sodium hydroxide and sodium silicate and water is used in this research work to produce geopolymer mortar. The fly ash is obtained from Tuticorin thermal power plant where the fly ash is produced by the combustion of coal in electric furnaces. Depending on the CaO content, there are two types class-C (high calcium) fly ash and class-F (low calcium) fly ash. In this research work low calcium class-F fly ash is used. The GGBFS is from by-product of steel and iron industries by quenching followed by grinding of coarser particle to get fine nature of angular particles with glassy form. The crumb rubber particles ranging from 75µ to 4.75mm is used. The river sand confirming to zone-II (IS 383-1987) with specific gravity and fineness modulus value 2.65 and 2.88 respectively is used.

Alkaline solution made of commercially available NaOH and Na_2SiO_3 is used to yield a process of geopolymerization. Sodium hydroxide flakes with 98% purity and sodium silicate with the silicate to sodium mass ratio (SiO_2/Na_2O) of two (Na_2O=14.7%, SiO_2=29.4% and H_2O=55.9%). The high fly ash amount and low Na_2O in activator gives high bond strength betwee n mesh and geopolymer, but high ash content increases the chances for brittle failure mode [35]. The ratio of sodium silicate to sodium hydroxide and solution to binder ratio is taken as 1.5 and 0.4 respectively. The NaOH flakes are mixed with demineralized water to prepare NaOH solution. The demineralized water doesn't affect the reaction in alkaline solution. For 1 molarity of NaOH solution 40g of NaOH solid is used for 1 liter of water. In this proposed work, the 12M of NaOH solution is made and left for 2 hours. After that the required amount of sodium silicate is added to NaOH solution to prepare an alkaline solution. The alkaline solution should be prepared 24 hours prior. This helps to ensure complete heat dissipation and proper dissolution of chemica ls in alkaline solution.

The ball mill is used for synthesizing Nano fly ash. It is a cylindrical device used for grinding or mixing of materials such as ores, chemicals, ceramic raw materials and paints, etc. This apparatus is works under the impact and attrition principle. The 50 numbers of tungsten carbide balls each consists of 8 grams weight were employed to ground 40-gram fly ash for 4 hours. This process is made by following fly ash: ball ratio of 1:10. The fly ash taken was sieved through 45- micron sieve to get particle range below 45 microns. After and before the synthesis process, the SEM analysis is done to identify the size ranges of particles. The Nano fly ash is obtained with sub - micron particle ranges as shown in Figure 1.

The Scanning Electron Microscope (SEM) image of fly ash and Nano fly ash is given below;



Figurer 1. Nano fly ash

From SEM images, the fly ash particle size distribution ranges from 5µm to 50µm with spherical particle is obtained. The treated crumb rubber ranges from 5µm to 50µm with granular size particle is obtained.

For Ferro cement construction, the steel meshes used are expanded metal mesh (EMM) for their high ductility with chicken mesh (CM) layers. The meshes are made of galvanized iron material shown in fig.4 and fig.5 respectively. The crack pronouncement is more during the loading condition but the ductile capacity of the specimen is superior in performance of loading. EMM make an improvement in the structural indicators such as cracking loads, ultimate loads and ductility of panel [19]. The number of mesh layer contributes to the effective strength achievement upto a certain limit thereafter there will be no effect.

Table 1. Dimensions of meshes

Mesh type	Shape	LWD (mm)	SWD (mm)	Thickness (mm)
EMM	Diamond	17	09	0.75
CM	Hexagonal	26	20	0.4

LWD - long way dimension, SWD – short way dimension.

Table 2. Chemical composition of GGBFS and fly ash in percentage

material	CaO	Al_2O_3	Fe_2O_3	SiO_2	MgO	MnO	Sulphide Sulphur	Insoluble residue	Loss on ignition	Glass content
GGBFS	37.34	14.42	1.11	37.73	8.71	0.02	0.39	1.59	1.41	92
Fly ash	3.45	24.61	6.47	61.75	1.53	-	trace	-	-	-

B. MORTAR MIX PREPARATION

The mortar mix ratio of 1:2 (i.e. one part of cementitious materials and 2 parts of fine aggregate) is followed throughout the process. The solution to binder ratio, Na2SiO3/NaOH and molarity of NaOH is fixed as 0.4, 1.5 and 12 respectively throughout the entire process of work. The sand is replaced by optimized amount of 5% crumb rubber. The additive selected as Nano fly ash of 10% is decided to use for enhancing the microstructure property. Also, the control specimen was made with the water-cement ratio of 0.30. The 2.0% super plasticizer by the cement weight is added to increase the workability of mix. Higher sand content with lesser binder content results in reducing geopolymerization process. By optimizing the alkali content, the efficient mortar with better strength can be achieved [6]. The increase of molarity of NaOH, curing temperature with reduced solution to binder ratio leads to improved mechanical strength of GP specimen [7]. The higher carbonation resistance will be achieved by increasing GGBFS ratio and its fineness, NaOH content with non-room temperature curing, decreased solution to binder and water to solid ratio [9].

C. SURFACE ALTERATION OF CRUMB RUBBER

The crumb rubber surface can be altered by oxidation followed by sulphonation using. Following methods of treatment: 1. Acid etching method, 2. Plasma pretreatment, 3. Coupling agent methods.

Usually followed treatment methods are NaOH treatment, Organo clay treatment, $KmnO_4$ treatment and Silane coupling agent method, etc. In this research, the NaOH treatment is done because of its high effective surface modification, simplicity and minimal cost. Treated crumb rubber incorporation into the mix result in higher compressive and flexure strength ra ther than that of non-treated rubber included specimen. The followed NaOH solution concentration is one normality. The crumb rubber is immersed in NaOH solution for 30 minutes. After completion of immersion time the rubbers are washed in water to remove the presence of NaOH residue. The moist rubber is dried under sun light with ambient condition to make dry crumb rubber. 1lit of NaOH solution may require for treating 1kg of crumb rubber. The SEM image of treated crumb rubber is shown in Figure 2.

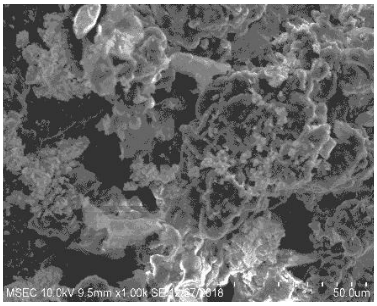


Figure 2. Treated crumb rubber

Figure 3. Crumb rubber treatment

D. METHODS

Fly ash, GGBFS and sand is used as a binder material to produce geopolymer mortar. These materials are dry mixed for 3 to 4 minutes followed by wet mix for 4 to 6 minutes to produce homogeneous mixture paste. The geopolymerization is activated by alkaline activator solution composed of sodium-based silicate and hydroxide. The calculated free water is added for obtaining workable and flowable mix with the addition of 2% super plasticizer. Then, the mortar is filled in cube (volume=7.06cmX7.06cmX7.06cm) by 3 layers and each layer is ramped 25 times for achieving well compaction. The hot air oven curing method is followed for 48 hours at $80^{o}C$. After completion of curing process, compression test and water absorption test are done.

The Ferro cement panel is made by using expanded metal mesh (2 layers), chicken mesh (2 layers) and geopolymer mortar. The panel mold is made of steel L angle with the size of 230mmX230mmX25mm with open top and bottom is rest on steel base plate. The mold is connected by bolted connection. The chicken mesh and expanded metal mesh is bundled with binding wire without gap. Initially grease followed by oil is applied over mold surface to obtain good finishing surface of panel. Then the mortar is applied and mesh is placed with the cover of 5mm followed mortar layer. For achieving proper compaction of the mortar in the panel, the fresh mortar layer is well compacted with the help of trowel. Finally, the panel is finished with a thin mortar layer to obtain a smooth surface. Then the panel is demolded and allowed for curing process.

Figure 4. Mortar cubes

Figure 5. Heat curing

E. COMPRESSIVE STRENGTH

This test is performed to check the required compressive strength is attained for GP mortar when compared to control specimen. The GP mortar cube was heat cured and control specimen are water cured for 28 days at room temperature. After completion of curing period, the cubes are dried in an air and tested on 1000KN capacity universal testing machine as shown in Fig.11. The compression loading is continued upto the failure of the specimen. The test is conducted as per IS 4031 (part 6)-1988 guidelines.

F. WATER ABSORPTION TEST

This test is made in accordance with ASTM C 642 code provisions. Initially, the cubes were set in oven at 100°C for 24 hours. Then the weight is taken with the accuracy of one gram. Then the specimen is immersed in water for 24 hours. The cubes are taken out from water and wipe out with a cloth and the weight of is taken. From these two weights, the percentage of water absorption percentage is calculated.

G. FLEXURE TEST

The center point flexural loading is decided to apply on a panel. The conventional compression or universal testing machine is used for performing this flexure test. The concentrated load is applied at middle portion of the panel. The loading is continued until the failure of the panel.

The load resisting capacity and corresponding deflection at the middle of the span is recorded. The test procedure is done according to ASTM D 3043 – 00e guidelines. The investigation involves first crack load, failure load, deflection, cracking pattern, etc. The influencing factors of first crack strength are type, geometry and specific surface of the reinforcement used in the panel fabrication.

III. RESULTS and DISCUSSION

A. Bonding behavior

From the previous literature, the geopolymer composed of fly ash, GGBFS and alkaline liquid gives excellent bonding nature. The crumb rubber incorporation would reduce the bonding between the geopolymer materials. Hence there is a need to modify the surface of the crumb rubber particles. The NaOH treatment is used for modifying the surface of crumb rubber as rough to achieve efficient bonding nature. Then, the bonding is automatically enhanced between crumb rubber and geopolymer substrate. Also, there is a presence of NaOH in geopolymer alkaline liquid; it will make some effect on crumb rubber surface modification.

B. Compressive strength test

The compressive strength can be increased by increasing the concentration of NaOH solution and percentage of GGBFS in geopolymer mortar [10]. The GGBFS incorporated geopolymer form the more compacted microstructure [14]. The increment in compressive strength is due to the formation of N-A-S-H gel and C-S-H gel formation along with the silico-aluminate structure. The rubber addition modifies the failure of panel from brittle to ductile with small reduction in strength [23].

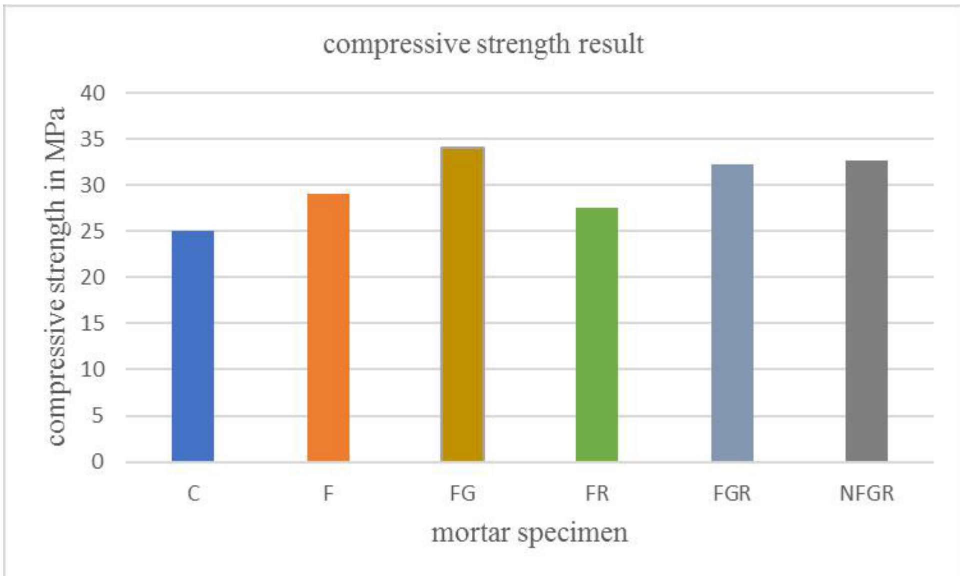


Figure 6. Compressive strength results

C. Water absorption test

Water absorption test are used to find the permeability and porous medium of a structure. It is also used to indirectly evaluate the durability of a homogeneous material. The water absorption test results obtained are shown below for different geopolymer material and control specimen.

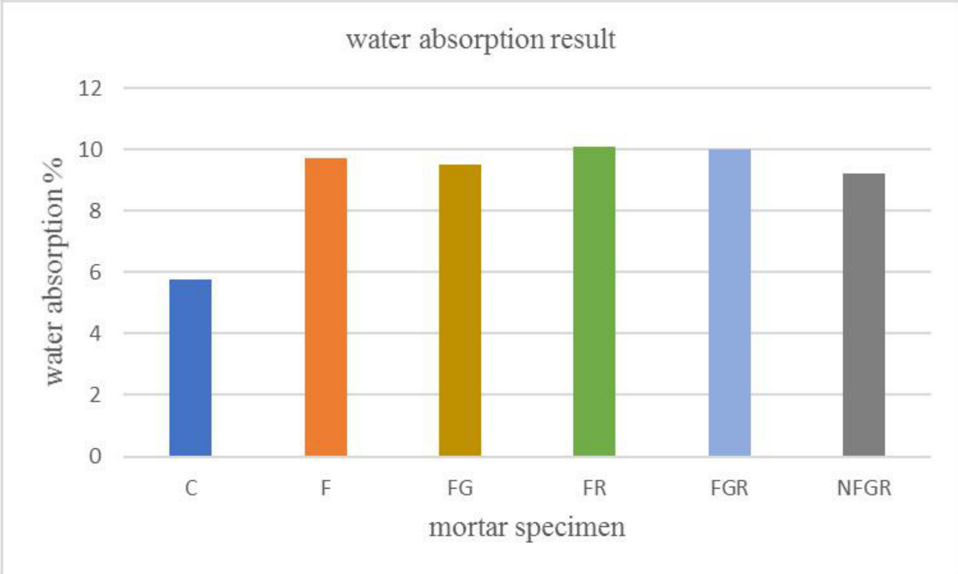


Figure 7. Water absorption percentages

D. FLEXURE TEST

The flexure strength test involves the findings of first crack strength and ultimate strength to cause initial crack generation and failure of panel. The deflection at mid span is measured during the failure of panel. Based on the flexure test results the residual flexural strength is calculated for each panel.

Table 3. Flexure strength results

Panel		First crack load (KN)	Ultimate failure load (KN)	Deflection (mm)	Residual flexure strength ratio
Control C		1.67	2.19	2	1.31
Geopolymer	F	1.5	2.1	2.5	1.4
	FG	1.75	2.54	4	1.45
	FR	1.3	1.65	4.5	1.27
	FGR	1.9	2.7	5	1.42
	NFGR	2.05	3.12	9	1.52

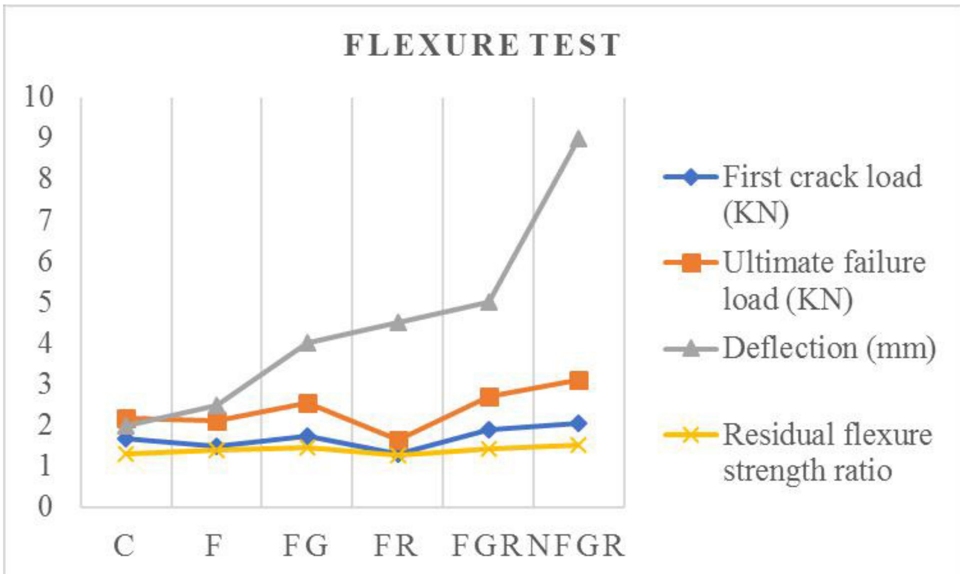


Figure 8. Flexure strength results

E. Effect of GGBFS in curing condition

The fly ash based geopolymer needs heat curing or steam curing for gaining effective strength. There is a reduction in strength of fly ash based geopolymer when cured it on ambient temperature and it prolongs to take more time for its setting due to the slow dissolution of Al and Si coordinate and condensation process. It requires high temperature curing to start polymer chain reactions. It makes some restriction while the geopolymer are applied into the field. When us ing fly ash-GGBFS based geopolymers, this problem can be solved due to the capability of curing in ambient temperature [11]. When incorporating GGBFS into the fly ash based geopolymer mix, the specimen will have a capability to cure even at ambient tempera ture. The fly ash-GGBFS based mix can be set in one day but the fly ash-based mix cannot set in one day. It takes 3days for their setting. When compared to fly ash based geopolymer, the fly ash-GGBFS based geopolymer give superior quality in both strength and setting parameters.

IV. CONCLUSION

The water absorption percentage of all the geopolymer mortars is in the acceptable range according to ASTM C642 provisions. But these values are slightly higher than that of control specimen.

The GGBFS based geopolymer compressive strength is 17% higher than fly ash based geopolymer mortar. The addition of rubber reduces 5% of strength which could be compensating by adding Nano fly ash into the mix. The problem of application of geopolymer concrete in site due to difficulties in heat curing can be solved by addition of GGBFS, which make it to behave better even under ambient curing.

The rubber addition in mix reduces the flexural strength of fly ash and fly ash-GGBFS based panel by 9.29% and 2.07% respectively. The residual impact strength ratio of Nano fly ash based geopolymer panel is 1.52, which is higher than all other panel category.

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