STUDIES ON THE IMPACT BEHAVIOUR OF FIBER REINFORCED GEOPOLYMER CONCRETE

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ABSTRACT

Mechanical properties of geopolymer concrete with and without fibers were also determined. Comparisons were made in terms of compressive strength, split tensile strength, flexural strength and impact energy. The effect of impact loading on geopolymer concrete was investigated at three different energy levels. Impact response of geopolymer concrete was investigated under three-point bending configuration based on free-fall of an instrumented impact device for notched (25mm) and un-notched prisms. It was observed that reinforcing geopolymer concrete with 0.75% of crimped stainless steel improved the mechanical properties. Experimental investigation have shown that the orientation of fibers play a significant role in the determining the behavior of geopolymer concrete under impact loading.

Keywords : Alkaline Solution, Flyash, Geopolymer Concrete, Impact, Steel Fibers.

I INTRODUCTION

Geopolymers are members of the family of inorganic polymers. Davidovits first proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin resulting in a polymerization reaction and coined the term Geopolymer. The Polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals, that results in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al –O bonds. Thus, A geopolymer is essentially a mineral chemical compound or mixture of compounds consisting of repeating units . **Prabir etal** (2012) reported that the peak load of geopolymer concrete (GPC) was higher than that of ordinary Portland concrete (OPC) for similar compressive strength and failure modes of GPC are more brittle than OPC with relatively smooth fracture planes[1]. **Anjan etal (2010)** reported that reducing the size of the flyash particles from 30µm to below 10µm, the flow and strength properties of mortar and concrete were improved [2]. **Redmond etal (2008)** reported that unlike hydroxyl system, silicate activated system enables more homogeneous gelation process to take place throughout the inter-particle volume [3]. **Yip etal (2004)** reported that the formation of CSH gel together with the geopolymeric gel occurs only in a system at low alkalinity[4].**Gum Sung Ryu etal (2012)** reported from the study that the compressive strength increased with use of flyash as binder with higher concentration of NaOH and also with the use of sodium hydroxide to sodium silicate in 1:1 ratio[5].**Dey etal (2013)** reported that dynamic flexural strength under impact was more than 1.5 times higher than the static flexural strength and use of 0.5% volume fraction of polypropylene fibers resulted in more than three times higher flexural toughness[6]. **Bencardino etal (2010)** concluded that addition of fibers to concrete controls cracking and crack propagation and increase the overall ductility of the material[7]. **Atteshamuddin etal (2013)** reported that inclusion of steel fiber showed excellent improvement in mechanical properties of fly ash based geopolymer concrete[8]. **Ambily etal (2014)** reported that incorporation of steel fibers has improved the compressive strength and flexural strength of ultra high performance geopolymer concrete[9].

In this paper, the mechanical p roperties as well as the impact behavior of plain geopolymer concrete and fiber reinforced geopolymer concrete is investigated. The fiber reinforcement provided are 0.75% of crimped mild steel, 0.75% of crimped stainless steel and 0.75% of both crimped mild steel and crimped stainless steel (Hybrid). The compressive, split tensile and flexural strength of different mixes are investigated and compared. Further, the behavior of plain geopolymer concrete as well as fiber reinforced geopolymer concrete under impact loading is investigated under three – point – bending using instrumented drop weight system. The instrumentation included load cell to record the impact loading from the hammer. In the experiment the rebound of hammer is arrested. The variables in the experiment include the energy level provided and the corresponding drop heights. Time history of the load and energy time details are obtained and discussed in detail.

II EXPERIMENTAL INVESTIGATION

2.1 Materials Used

The fly ash used for the work was obtained from Ennor thermal power plant Tamil Nadu. The Ground granulated blast furnace slag (GGBFS) for the experimental work was from JSW, Vidyanagar, Karnataka. The chemical composition of fly ash and GGBFS are given in the Table 1 and Table 2.

Table 1 : Chemical composition of Fly ash

COMPOUND	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	Mn_2O_3	SO_3	P_2O_5
FLY ASH	49.45	29.61	10.72	3.47	1.3	0.31	0.54	1.76	0.17	0.27	0.53

Table 2 : Chemical composition of GGBFS

COMPOUND	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	Mn_2O_3	SO_3
GGBFS	33.45	13.46	0.31	41.7	5.99	0.16	0.29	0.84	0.40	2.74

The alkaline solution used was a combination of sodium hydroxide and sodium silicate in 1:2 ratio.. River sand passing through 4.75mm sieve was used as fine aggregate and 10mm angular aggregates were used as coarse aggregate. The water used for the entire work was portable water. Crimped mild steel fibers as well as crimped stainless steel fibers of aspect ratio 60 and diameter 19mm were used.

2.2 Synthesis

Sodium hydroxide pellets was mixed with water as per the mix proportion and kept overnight for cooling as the reaction between sodium hydroxide and water is a highly exothermic reaction. About one hour before the casting work the sodium hydroxide solution was mixed with sodium silicate gel and the activator (alkaline) solution of 3.5M was made.

Four different mixes of geopolymer concrete has been prepared for the entire experimental work. The four mixes include a geopolymer control mix, crimped stainless steel fiber geopolymer mix, crimped stainless steel fiber geopolymer mix and a hybrid geopolymer mix.

The fly ash and GGBFS were thoroughly blended along with coarse aggregate and fine aggregate in a drum mixer. The activator solution was then added with the dry mix at small intervals. The complete component materials were made to form a homogeneous mix by thorough mixing in the drum mixer. The mix proportion of the materials used is given Table 3:

Table 3: Mix proportions for geopolymer mix of 3.5M

MIX	FlyAsh (kg/m^3)	GGBS (kg/m^3)	F.A (kg/m^3)	C.A (kg/m^3)	SH (kg/m^3)	SS (kg/m^3)	CSS (kg/m^3)	CMS (kg/m^3)	WATER (kg/m^3)
CM	204	204	635	1113	24	48	-------	-------	175
GP-1	204	204	635	1113	24	48	59	--------	175
GP-2	204	204	635	1113	24	48	---------	59	175
GP-3	204	204	635	1113	24	48	29.5	29.5	175

Where CC is the geopolymer control mix,GP-1 is the geopolymer mix reinforced with 0.75% crimped stainless steel fibers, GP-2 is the geopolymer mix reinforced 0 with 0.75% crimped mild steel fibers and GP-3 is the hybrid geopolymer mix containing both 0.75% crimped stainless steel and crimped mild steel fibers.

2.3 Preparation of specimens

For each geopolymer mix, cubes of size 100*100mm, small cylinders of size 100*200mm, large cylinders of size 150*300mm and prisms of size 100*100*500mm were casted and kept for curing under ambient (room) temperature. The prism specimens for impact test has been provided with a notch of 25mm prior to the test.

III RESULTS AND DISSCUSSION

3.1 Compression test

The compression test was conducted on all the four mixes to determine the 3rd, 7th and 28th day compressive strength. The compression testis done on 100mm*100mm*100mm cubes using Universal Testing Machine (UTM). The compressive strength of the specimen is calculated as:

$$\text{Compressive strength} = \text{load/area} = P/A$$

The 3rd, 7th and 28th day compressive strength of geopolymer is given in Table 4:

Table 4:Compressive strength of geopolymer mixes

MIX	3rd day (MPa)	7th day (MPa)	28th day (MPa)
CM	20.05	34.8	42.25
GP-1	35.98	36.04	51.78
GP-2	33.32	37.48	51.29
GP-3	31.978	37.013	49.01

3.2 Split tensile strength

The split tensile strength of the cylindrical specimen of size 100mm*200mm was tested as per ASTM 109 standard. The split tensile strength of the specimen was calculated as:

$$\sigma sp = 2P / \pi \text{ d l}$$

The split tensile strength of different mixes is given in Table 5 :

Table 5: Split tensile strength of different geopolymer mixes

MIX	SPLIT TENSILE STRENGTH (MPa)
CM	4.22
GP-1	5.17
GP-2	5.12
GP-3	4.90

3.3 Flexural Strength

Prisms of size 100m*100mm*500mm were tested for flexure. The prisms were tested as per ASTM 109 standard using Universal Testing Machine (UTM). The flexural strength of the specimen was calculated as:

$$\text{Flexural strength} = Pl/bd^2$$

The flexural strength of different mixes is given Table 6:

Table 6: Flexural strength of geopolymer mixes

MIX	FLEXURAL STRENGTH (MPa)
CM	4.55
GP-1	5.03
GP-2	5.01
GP-3	4.90

3.4 Instrumented Impact Loading Test

The effect of impact loading on geopolymer concrete is investigated under three – point – bending using an instrumented drop weight system. Geopolymer prisms (both with and without fibers) of size 100*100*500mm were tested for impact. The test was conducted for both notched and un-notched specimens. The total mass of drop (including tup weight) was 20 kg. The variable parameter used is energy level. The different energy levels adopted were 20J, 30J and 40JThe Force – time graph and Energy – time graph were plotted and compared.

Figure 1: Instrumented impact testing machine

For the impact test, three prisms from each geopolymer mix were tested for each condition (notched and un-notched). Each beam was given a particular energy level and the force time history and energy time history was plotted and compared.

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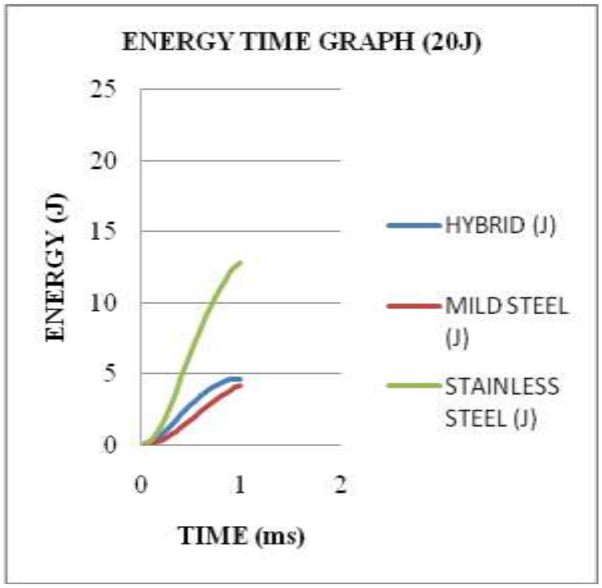
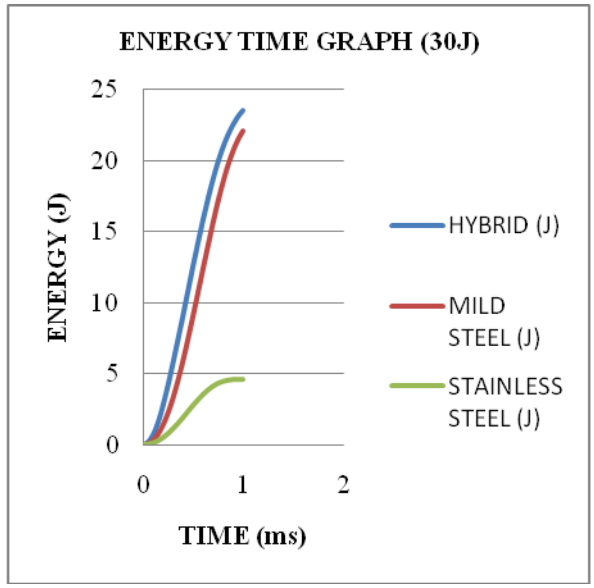
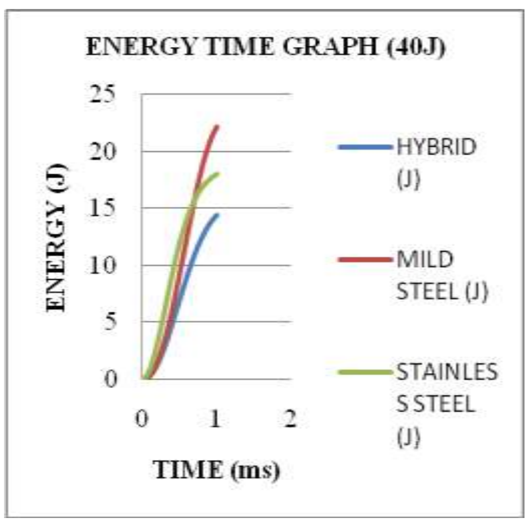
Fig 2(a), 2(b) and 2(c) shows the energy time history for different energy levels for un-notched prisms. From energy time history , it was observed that for energy level of 20J,geopolymer with 0.75% of crimped stainless steel fibers has given higher result, for 30J energy level geopolymer with 0.75% hybrid fibers has given higher result and for 40J energy level, geopolymer with 0.75% of crimped mild steel fibers has given the higher result.





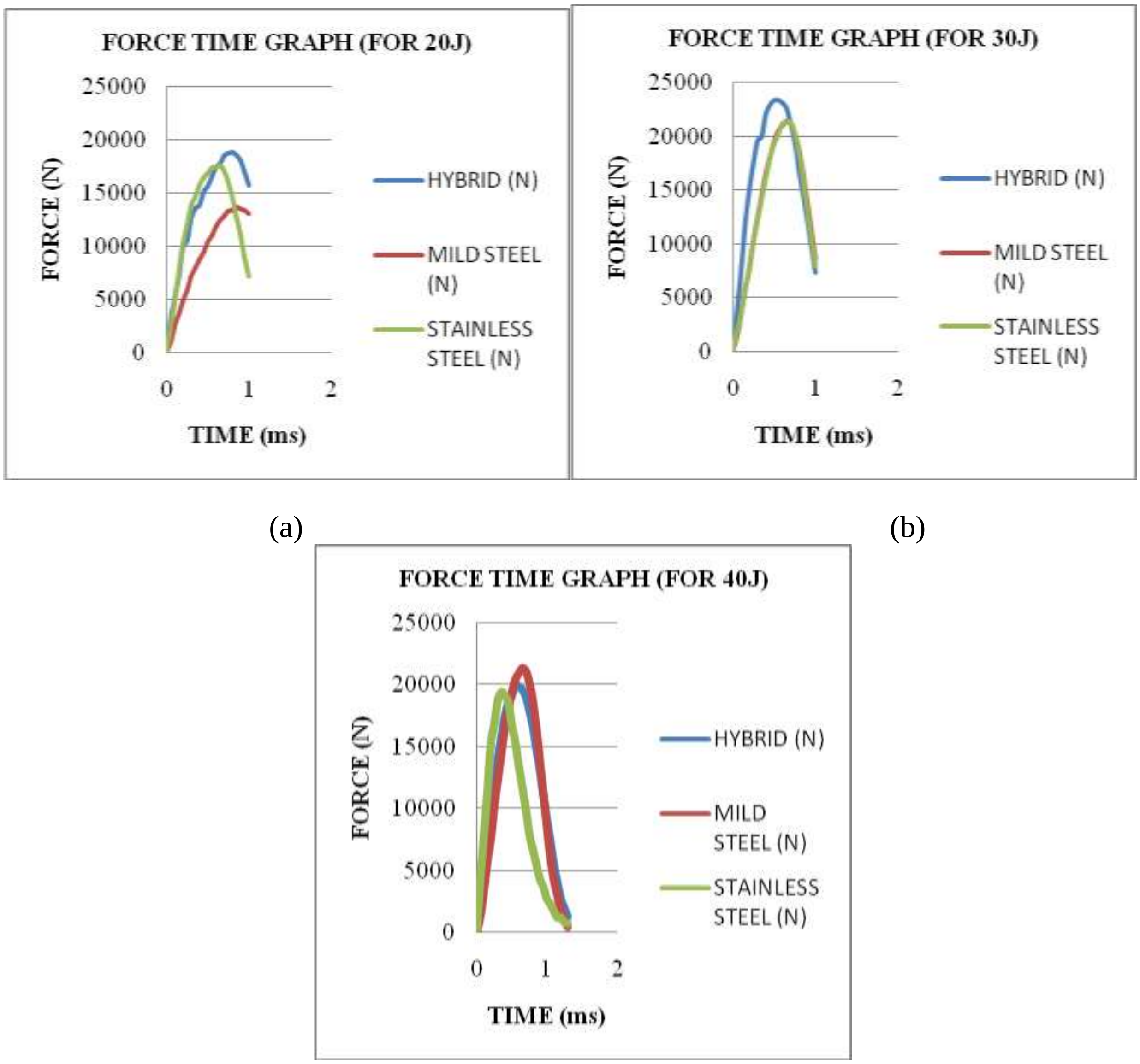
(a) (b)



(c)

Figure 2:Energy time history of un-notched geopolymer prisms : (a) 20J (b) 30J and (c) 40J

Fig 3(a), 3(b) and 3(c) show the force time history for different energy levels for un-notched prisms. From force time history, it was observed that for 20J and 30J energy level, geopolymer with hybrid fibers has shown highest energy absorption capacity and for energy level of 40J, geopolymer with 0.75% of crimped mild steel fibers has higher energy absorption capacity.



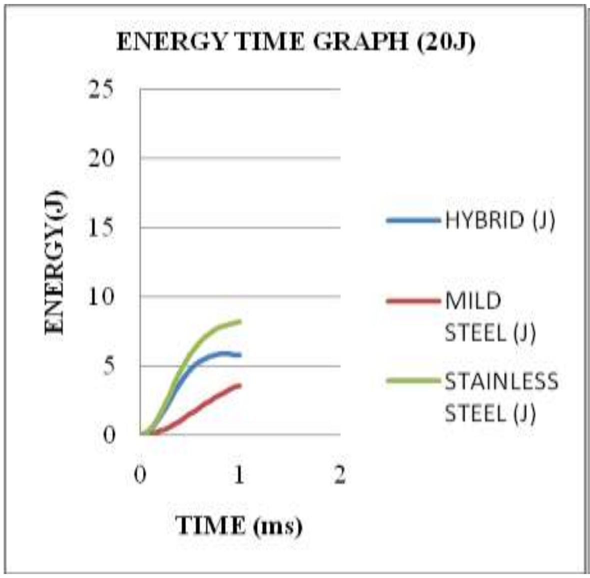
(a) (b)

(c)

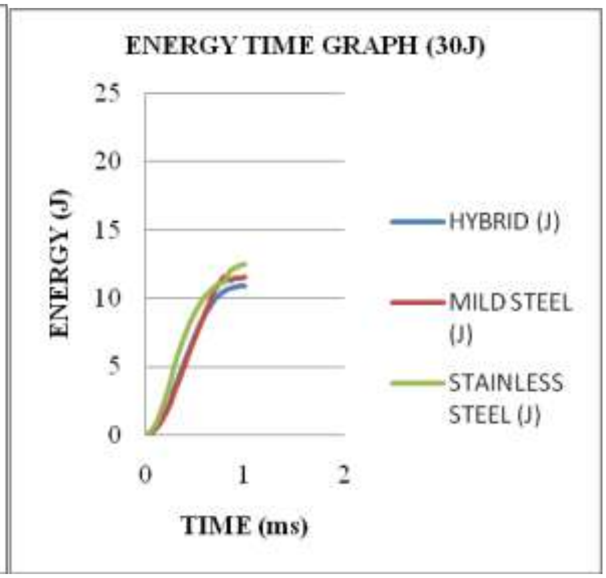
Figure 3:Force time history of un-notched geopolymer prisms (a) for 20J (b) for 30J and (c) for 40J

The time history results obtained from the experiments do not show any particular pattern or consistency. This inconsistency in time history results for un-notched prisms may be due to the random orientation of fibers in the geopolymer mixes. Thus, it can be inferred from the present experimental results that orientation of fibers in the concrete mix plays an significant role. Further experimental studies need to be done to determine which fiber gives higher impact energy taking into account the effect of orientation of fibers.

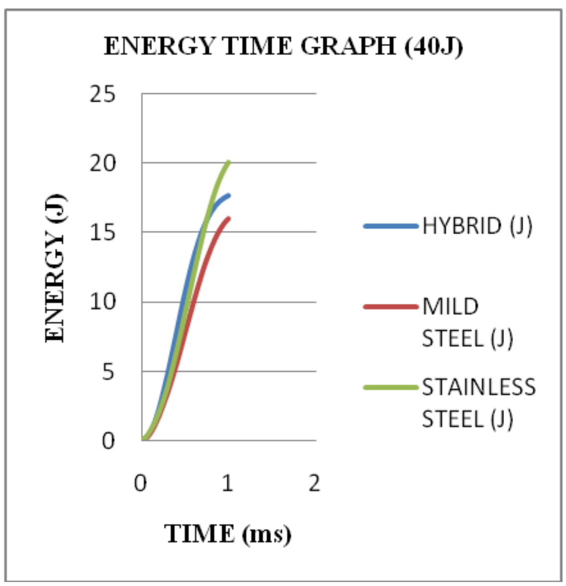
Fig 4(a), 4(b) and 4(c) shows the energy time history results for notched beams. From the energy time history results it was observed that geopolymer with 0.75% of crimped stainless steel fibers has shown higher energy absorption capacity.



(a)



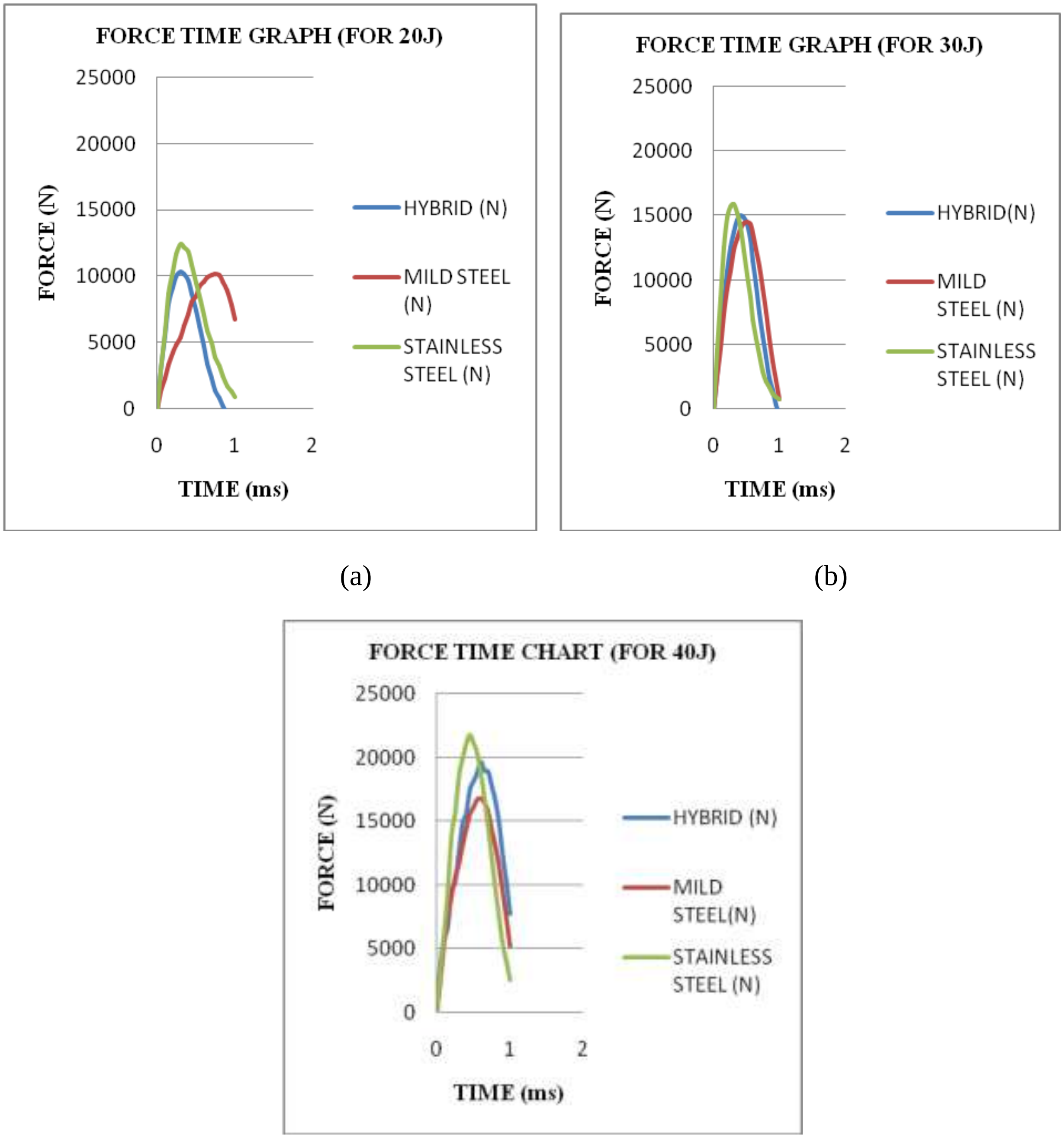
(b)



(c)

Figure 4: Energy time history of notched geopolymer prisms : (a) 20J (b) 30J and (c) 40J

Fig 5(a), 5(b) and 5(c) shows the force time history for different energy levels for notched prisms. From the force time history results it was observed that geopolymer with 0.75% of crimped stainless steel fibers has given higher value.



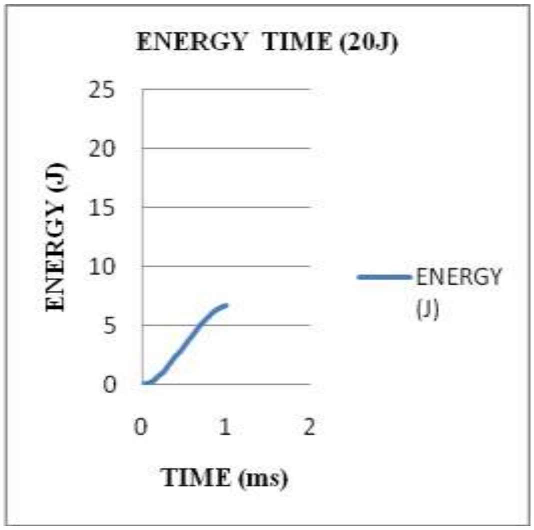
(a) (b)

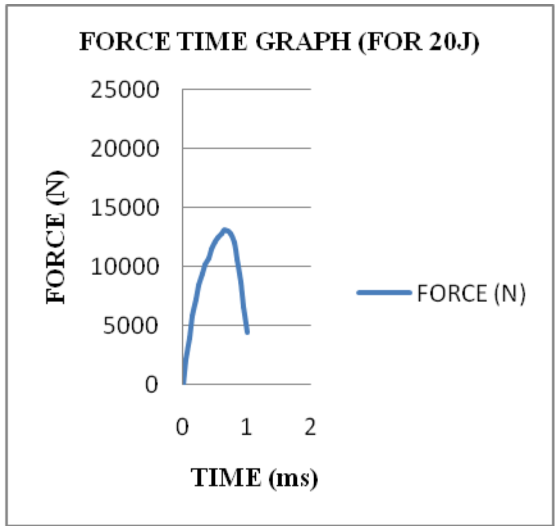
(c)

Figure 5: Force time history of un-notched geopolymer prisms (a) for 20J (b) for 30J and (c) for 40J

From the time history results obtained from impact testing of notched geopolymer prisms, geopolymer mix with 0.75% of crimped stainless steel fibers showed higher impact energy. This implies that crimped stainless steel fiber has higher energy absorption capacity and higher bond strength. In case of notched beams the probability of effect of random orientation of fibers is less since by notching the prism the failure is forced to occur at the notch rather than any other part of the specimen.

Fig 6(a) and 6(b) shows the time history result of un- notched prisms without fibers (control mix).

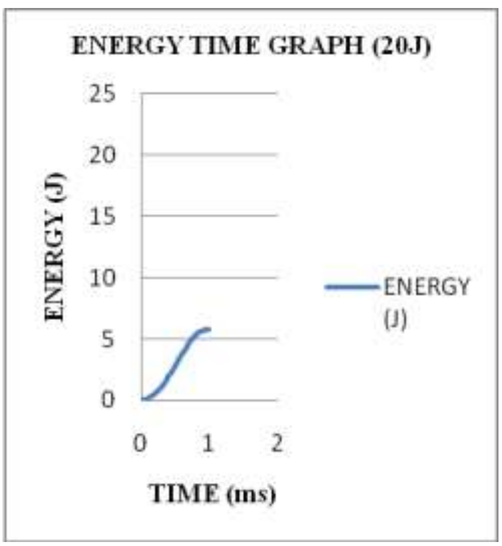




(a) (b)

Figure. 6: Time history results of control mix (un-notched): (a) Energy time graph (b) Force time graph

Fig 7(a) and 7(b) shows the time history result of notched prisms without fibers (control mix).



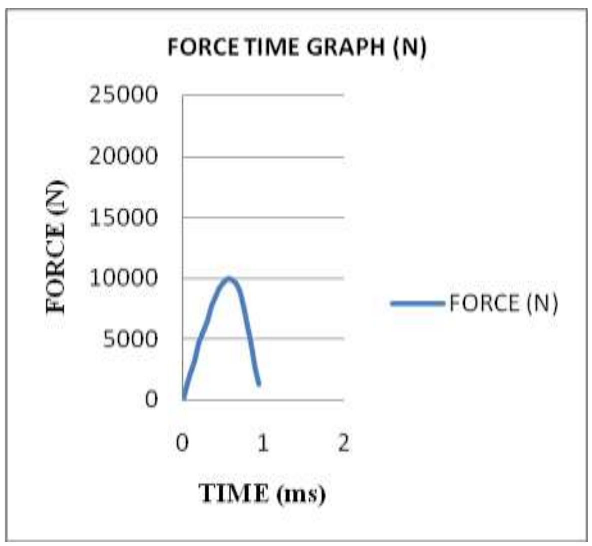


Figure 7: Time history results of control mix(notched): (a) Energy time graph (b) Force time graph

The control specimens which are geopolymer prisms (notched and un-notched) without fibers cannot be compared with the specimens with geopolymer with fibers since the maximum energy level that can be provided to the specimen was only 20J. At an energy level of 20J the complete failure of control mix specimen occurred.

IV CONCLUSIONS

Compressive strength, split tensile strength and flexural strength of geopolymer concrete was determined. It was observed that use of 0.75% of crimped stainless steel fibers in geopolymer concrete increased the mechanical properties of geopolymer concrete due to the higher bond strength characteristics of stainless steel fibers. Impact response of geopolymer concrete was studied for an instrumented test using a three point bending configuration. Time history results are obtained for geopolymer concrete with and without notch at energy levels of 20J, 30J and 40J. It can be concluded from the experimental investigation that for un-notched beams the effect of impact energy mainly depends on the orientation of fibers in concrete. Geopolymer prisms with crimped stainless steel reinforcement have shown higher time history results due to higher energy absorption capacity and bond strength of stainless steel fibers. It was also observed from the experiment that the maximum energy level that can be provided for a geopolymer concrete without fiber reinforcement is 20J. More detailed studies need to be done to determine the effect of orientation of fibers affecting the impact behavior of geopolymer concrete.

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REFERENCES

1. Prabir. K. Sarker, Rashedul Haque, Karamchand. V. Ramgolam “Fracture behavior of heat cured fly ash based geopolymer concrete.”Materials and Design 44(2013) 580-586
2. Anjan. K. Chatterjee “Indian fly ashes,their potential formechano-chemical activation for enhanced usability”. Second International Conference on Sustainable Construction Materials and Technologies.
3. Redmond. R. Lloyd, John. L. Provis, Jannie. S. J. van Deventer “Microscopy and microanalysis of inorganic polymer cements.” J Mater Sci (2009) 44:620-631
4. C.K.Yip, G. C. Lukey, J.S.J. van Deventer “The coexistence of geopolymeric gel and calcium silicate hydrate at the early stage of alkaline acyivation” Cement and Concrete Research 35 (2005)1688-1697
5. Gum Sung Ryu, Young Bok Lee, Kyung Taek Koh, Young Soo Chung “The mechanical properties of fly ash based geopolymer concrete with alkaline activators.”Construction and Building Materials 47 (2013) 409-418
6. V. Dey, A. Bonakdar, B. Mobasher “Low-velocity flexural impact response of fiber-reinforced aerated concrete.” Cement & Concrete Composites 49 (2014) 100-110

7. F.Bercardino, L.Rizzuti, G.Spadea, R.N.Swamy "Experimental evaluation of fiber reinforced fracture properties" Composites:Part B 41 (2010) 17-24
8. Atteshamuddin.S.Sayyad, Subhash.V.Patnakar "Effect of steel fibers and low calcium flyash on mechanical and elastic properties of geopolymer concrete composites" Indian Journal of Material Science (2013)
9. Parukutty.S.Ambily,Kapali Ravisankar, Chockkalingam Umarani, Jamboor.K Dattatreya, Nagesh.R. Iyer "Development of ultra-high-performance geopolymer concrete" Magazine of Concrete Research (2014), 66(2), 82-89