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RESEARCH ARTICLE

Experimental study of reinforced geopolymeric paper blocks with different ways of placing fiber reinforcement

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Abstract

This experimental study investigated various characteristics of "geopolymeric paper blocks" with and without fiber reinforcement. Five tests were performed in order to identify this material's feasibility to use in construction works. The five tests performed were – compressive strength test along with the plotting of stress verses strain curve , tensile strength test for ropes , bond test between ropes and blocks , tensometer test along with plotting of load verses deflection curve and flexural test. The results of these tests along with the conclusions are articulated in this paper with the description of all the tests. For casting of all the blocks two types of proportions were used as 'fly ash: paper: foundry sand' – 1:2:0.75 and 1:1.5:1. In case of compression test, proportion 1:1.5:1 gave highest strength i.e., 2.2 Mpa as amount of foundry sand in it was comparatively higher. In tensile test of ropes, sisal fiber strands were tested which gave strength of 1.2KN with gradual failure pattern. In case of bond test of sisal strands with blocks, breaking point was observed at a point along that length of strand which is not inserted inside the blocks leading to a conclusion that the length of strand inserted in the block is still intact and possess good bonding with the material. In case of flexural test, blocks with fiber reinforcement that has been prestressed while casting gives highest result i.e., 2.325 Mpa. In tensometer test, the material was observed getting stretched to a large extent, evident from the graph, hence could be said to possess some "elasticity".

Introduction

Geopolymeric paper block is made up of waste paper , foundry sand , fly ash , sodium silicate and sodium hydroxide . To recommend its use as a construction material , it not only requires to be structurally sound but also appropriate in its behavior . Being a construction material it should have enough compressive and tensile strength from structural point of view to bear the loads coming on it . To ensure its stability in a structure various tests needed to be performed.

In construction works, mostly steel / comparable materials are used as reinforcement. It poses problem not only by increasing the carbon footprint [1] but also being one of the costly material in any construction work . Also steel being heavy as compare to fibers increases the dead load of the structure . The tensile strength of geopolymeric paper blocks can be increased with reinforcement , but having made up of light weight raw materials and demanding average tensile strength for its intended application in construction, fiber reinforcement can be think upon as a solution to it . Sisal fibers being light in weight , economical, resistant to chemical attack , manufacturing process has least carbon footprint and most importantly having good tensile strength can be incorporated in these blocks as reinforcement for increasing the tensile strength . Flexural testing is done in order to check the tensile strength of the reinforced geopolymeric paper blocks .

The material during its service life experiences compression along with the tensile force where the extent of the these forces coming on the material depends on its intended use in the structure . The blocks have been tested for compressive strength using compressive testing machine . After ensuring the safety of the material against the loads a basic foundation needs to be developed as a parameter for designing . Hence to provide ease for designing and to know materials characteristics stress verses strain graph in both compression and tension has been plotted from the results of compression testing and tensile testing of the geopolymeric paper blocks.

Therefore the present experimental study was conceived following the general purpose of testing new sustainable building material , aimed not only at saving natural raw materials and reducing energy consumption , but also to reuse industrial by – products.

Material and Methods

a. Waste paper : For this study the waste paper has been procured from "Padamji paper mill situated in pune , India " . The waste paper generated from this mill contains all the impurities and is wet in nature but still works out to be good for making these blocks which is well supported by the results of the tests in the following sections.

b. Fly ash : When coal is burned in a coal fired boiler , it leaves behind ash , some of which is removed from the bottom of the furnace known as bottom ash , and some of which is carried upward by the hot combustion gases of the furnace , and removed by collection devices (fly ash)[2]. Hence use of this fly ash not only helps in reducing its adverse effect on environment but also reduces the amount of land required for its storage as a idle resource . The fly ash used for the study was low calcium Fly ash (ASTM type F) [3]..

c. Foundry sand : Waste foundry sand is high quality silica sand with uniform physical characteristics. It is a by-product of ferrous and non-ferrous metal casting industries, where sand has been used for centuries as a molding material because of its thermal conductivity. Foundries successfully recycle and reuse the sand many times. When the sand can no longer be reused in the foundry, it is removed from the foundry and is termed as waste foundry sand . The foundry sand has been procured from a metal casting industry was waste foundry sand which was available locally. [2]

d. Chemicals : Sodium hydroxide (NaOH) and sodium silicate(Na_2SiO_3) are the two chemicals used for the formation of geopolymer along with fly ash [4] to act as a binder to hold waste paper and foundry sand to make the material homogenous and compact . Sodium hydroxide is used in the pellet form and sodium silicate is used in the liquid forms which are available in the local mark.

e. Sisal fibers (fig.1)[5][6] : Sisal fibers have been used as a reinforcement in the blocks for increasing its tensile strength . Sisal fibers possesses properties such as good tensile strength , less percentage water absorption , economic and resistant to chemical attacks . Use of these fibers in geopolymeric paper blocks is well justified by the properties these fibers possess and the requirement for the blocks to be called environment friendly material .Sisal fibers are obtained from Agave Sisalana, a native of Mexico . The hardy plant grows well all year round in hot climate and arid regions which are often unsuitable for other crops . Sisal can be cultivated in most soil types except clay and has low tolerance to very moist and saline soil conditions

f. Environmental benefits of using sisal fibers : Sisal is a renewable resource par excellence and can form part of the overall solution to climate change. Measured over its life-cycle, sisal absorbs more carbon dioxide than it produces. During processing, it generates mainly organic wastes and leaf residues that can be used to generate bioenergy , produce animal feed, fertilizer and ecological housing material and , at the end of its life cycle , sisal is 100 percent biodegradable. [7]

Fig.1 Sisal Fibers

Mix proportioning and preparation of blocks:

The mix proportion was decided by considering 16M concentration NaOH solution, by keeping ratio of sodium silicate(Na_2SiO_3) to sodium hydroxide(NaOH) as 1.5 and ratio of solution(combine NaOH and Na_2SiO_3) to fly ash as 0.66 by taking reference from research paper on geopolymer[8].In the research papers till now, geopolymer has been used for concrete production as a substitute for cement but in this study it was used with paper. Hence the above mentioned ratios might seem to be little deviated from the one specified in research studies on geopolymer concrete in order to adjust and gain proper workability of geopolymer with paper. Waste paper pulp with water content in the range of 60-70% was used. Class F type fly ash and foundry sand from locally available RMC plant and metal casting industry was used respectively. In order to utilize paper to the maximum extent without hampering the workability of the mix and strength two types of proportions have been tried and tested. The two proportions are shown in table 1.

Table 1. Proportioning of the ingredients

PROPORTION	FLY ASH (IN Kg)	PAPER (IN Kg)	FOUNDRY SAND (IN Kg)	NaOH (IN Kg)	SODIUM SILICATE (IN Kg)
1: 2: 0.75	2.4	4.8	1.8	0.64	0.96
1:1.5:1	2.4	3.6	2.4	0.64	0.96

Therefore for all these mix proportions, required quantities of material were weighed as per the table 1. The mixing procedure adopted was as follows:

- The solution mix of sodium silicate and sodium hydroxide was mixed 24 hours prior to making the mix. In those 24 hour after every 3to 4 hour the mix was stirred thoroughly in order to avoid precipitation at the bottom.[9]
- After 24 hours of prior mixing, foundry sand and fly ash were dry mixed in a rotating drum till a uniform color was obtained without any clusters of foundry sand and fly ash (fig.2).
- Then the solution mix was added in the dry mix and allowed to rotate in the drum till the homogeneous mix was obtained.
- At the end waste paper was added in the mix and rotated for thorough mixing of all the ingredients (fig.3).

Fig. 2Dry mixing

Fig. 3 Mixing of all the ingredients in rotating drum

After the preparation of the geopolymeric paper slurry sisal fibers were placed during the casting of the blocks in the moulds in the following ways:

Forms of reinforcement used: Fiber reinforcement has been done in following ways:

1. Mesh(fig.4) :

The mesh was prepared by keeping the single fibers of a strand of sisal rope in longitudinal and cross directional direction in the form of layers there by making all the fiber interlocked between each other. The mesh is shown in fig.4.While making mesh care was taken to keep its length and breadth from all the sides at least 20mm less than the size of blocks to allow for cover requirement. Further before placing the mesh in position some cover of 20mm was left from the nearest face of block.

Fig.4 Mesh

2. Strands:

a. Strands kept in position individually :

The fibers were used as strands as shown in fig.5. Fiber rope used for this study consisted of 4 strands tangled in each other to form a rope, hence the rope was untangled in to 4 strands of average diameter 3.5mm and then each strand was kept in required position .The length of the strands was kept such that it will have some cover from the faces of blocks.

Fig.5 Strands of fibers

b. Strands inserted in the moulds throughout and stressed by stretching it(fig.6) :

Here the strands of fibers were passed through the holes in the mould and from both the ends the protruding strands were stretched in order to ensure positioning of the fiber strands in straight and stressed way unlike the strands put in a position 20mm from the bottom individually (i.e., without stretching).

Fig.6 Strands inserted in the moulds throughout

c. Homogenous mixing of small fiber elements :

Here the fibers were cut into small units. These units were then randomly mixed in geopolymer paper slurry and then casted.

Placing of fibers:
The cover requirement for all the cases was kept as 20mm from the nearest face.

- Mesh :

The placement of mesh had been done in following three ways:

a. Single mesh: Single mesh layer were kept horizontally at the bottom by keeping approximately 20mm cover from the bottom face of block.

b. Double mesh: Two mesh layers, one at top and other at bottom were kept in a horizontal position accounting for cover requirement during its placement.

Triple mesh: Three mesh layers at equal interval in horizontal position were kept accounting for cover requirement during its placement

- Strands : strands are reinforced in following forms :

a. Singly reinforced: In this case three strands were kept at bottom in straight position leaving required cover from bottom face.

b. Doubly reinforced : Three strands in upper part and three at bottom were placed by leaving required cover form both the faces .

c. Throughout Strands(fig.7) : Here the strands were placed through the holes provided in the mould and had been stretched as shown in figure below.

Fig.7 Strands Positioned in a mould throughout

- During random mixing the fibers were cut in small units and added in the slurry and mixed.
- However if this method is to be adopted for large scale production, it was observed that while mixing lumps were formed(balling like effect). So it may become difficult later on to cast. So proper workability should be achieved for use of this form of reinforcement.
- For strand and mesh if it is placed as it is(not wetted before placing) (Fig.8) in mould then required binding will not be achieved and purpose of reinforcement would not be fulfilled and will lead to failure of block as shown in fig.9.

Fig.8 Fibers placed in a mould without being wetted in a geopolymeric paper slurry

Fig.9 Failure of blocks due to the dry placement of fibers during casting

- To ensure proper bonding with the geopolymeric paper slurry the mesh and strand were dipped in liquid slurry of geopolymer paper as shown in fig.10.So that it will get completely covered by the wet mix and thereafter kept at desired position.

Fig.10 Application of geopolymeric slurry thoroughly to the fibers

- **Casting and curing of the blocks:**
  Following type of mould were prepared and geopolymeric paper blocks with and without fiber reinforcement were casted according to the size requirement of the tests.

- Casting for all the tests mould except tensometer test (fig.11): After the preparation of mix it was casted in wooden moulds of size 20 x 10 x 10cm. The moulds are made up of four different parts as shown in .This moulds were provided with sheets of mica from inside which makes the inner surface non-sticky and helps during removal of blocks after curing. As these moulds consist of detachable parts so it can be easily dismantled and connected together.

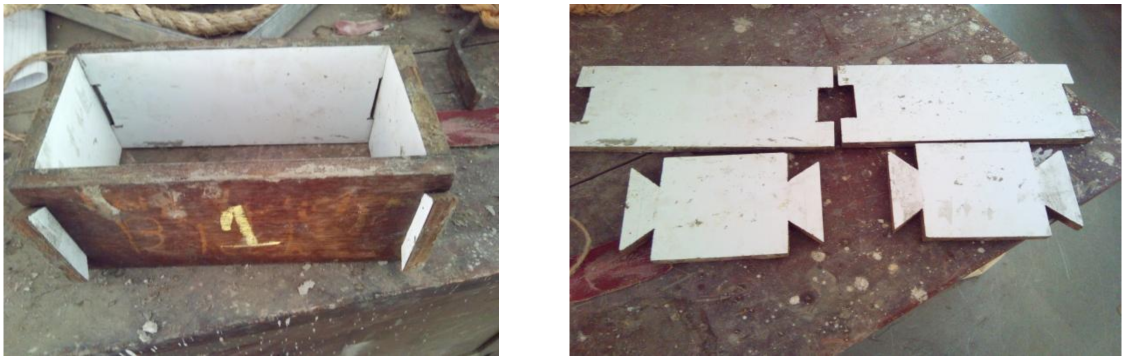

Fig.11 Casting mould for reinforced geopolymeric paper blocks

- Casting of briquettes for tensometer test(fig.12) : Two Briquettes of sizes150 x 35 x 15 mm were casted for tensometer test. The dimensions were achieved by giving shape to the semi-solid geopolymeric paper mix using cutting tools and measuring scale.

Fig.12 Geopolymeric paper briquettes

CURING: In case of this blocks the extent of completion of geopolymerisation reaction and thus achieving strength depends on the proper curing of the blocks done as follows:

- After casting of the blocks they were kept under sun exposure for around 7 days because if they are directly steam cured then it leads to loosening of the blocks and also it was observed that the chemicals starts oozing out of blocks.

- Once the blocks were cured under sun exposure they were kept in steam curer for 0.5-1 hr at 60^0c [10][11]depending upon any adverse effect on its state after 0.5 hr.

- After steam curing, the blocks were kept under sun exposure until they totally dry up (this depends on local environment)and then they were tested.

Result and Discussion

Testing:

Following tests were carried out for blocks :

1. Compression Test(fig.13) :This test was carried out in accordance with IS code standard specifications [IS:516-1959].The block with proportion of 1:2:0.75(Fly ash: paper: foundry sand) was taken as a representative sample for plotting of the stress vs strain graph while for the proportion of 1:1.5:1 peak load was noted. This test gives idea about the compression strength of geopolymeric paper blocks and results of the same are shown in the table below (table 2) along with the stress versus strain graph (fig.14)plotted from the results.

Fig.13 failure of block in Compression(left side), compressive testing apparatus setup(right side)

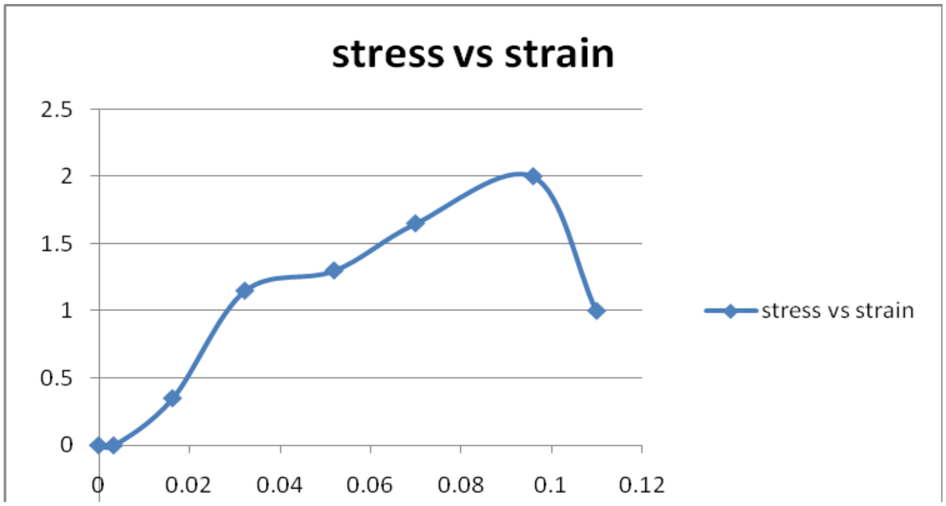

Fig.14 Graph of stress Vs strain for a geopolymeric paper block

	Table 2.Compression test results				
Proportion	**load(kN)**	**deflection(mm)**	**stress(Mpa)**	**Strain**	**E (Mpa)**
1:2:0.75	0	0	0	0	0
	0	0.33	0	0.0033	0
	7	1.63	0.35	0.0163	21.472
	23	3.23	1.15	0.0323	35.603
	26	5.2	1.3	0.052	25
	33	7	1.65	0.07	23.571
	40	9.6	2	0.096	20.833
	20	11	1	0.11	9.090
1:1.5:1	44	9.8	2.2	0.098	22.448

The stress and strain for the blocks have been found out using following formula :

Stress = Load/ Area, where for the blocks casted the area was= 20*10 sqcm.

Strain=change in dimension/actual dimension,

for example, for the 3^{rd} result in the above table:

Stress=7*1000/(20*10*100)= 0.35Mpa

Strain=1.63/100=0.0163

From the graph it can be seen that the peak load is 40KN and then the stress starts declining with little increase in strain resulting in the failure load of 20KN.

Out of the two proportions mentioned in the table above, paper being less and foundry sand being comparatively more in 1:1.5:1 proportion then 1:2:0.75, maximum stress obtained was in 1:1.5:1 i.e., 2.2Mpa.The samples taken for the test were wet from inside which can be seen in the fig.13 (left) where it was crushed and the internal part is visible. Hence it can be conclude that, if the samples would have been cured for further more days it would have given higher strength

2. Tensile test of strands: In order to know tensile strength of sisal fiber strands of average diameter 3.5mm this test was performed. Test set up is as shown in fig.15.This test gives inference about fibers compatibility to use as reinforcement at places where element will be subjected to tension and was performed according to standard code for this test[ASTM D4595-09]. Also test gives idea about maximum tensile load it can bear. The tensile strength of the sisal fiber strands was observed to be 1.2 KN at failure. Failure of the strand was not sudden. The failure initiated with the breaking of few fibers until the complete strand of fibers broke thereby taking the load till the last few fibers break.

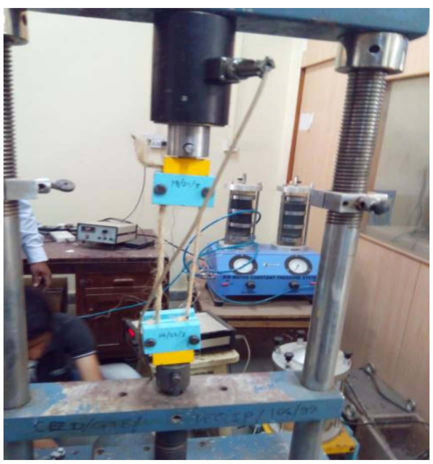

Fig.15 Apparatus arrangement for tensile test of strands

3. Bond test of strands with block : This test was performed in order to check the bonding of reinforced fibers with the geopolymeric paper composite. The test set up is as shown in fig.16. The strands of fibers were reinforced as full length of block,3/4th length of block and half length of block so as to get an idea regarding length effect of it inside the blocks. The results are as per table 3. It also helps in design part to ensure the development length to be provided.

Fig.16Bond test of ropes reinforced with geopolymeric paper blocks

Table 3. Results of bond test of strands with blocks

Fiber type	Extent of reinforcement	Tensile load
		(KN)
Sisal	full length	1.2
	3/4th Length	0.9
	Half length	0.6

During test it was observed that the breakage occurred in the strand but the strand was still intact with block which shows that strands have good bonding with the geopolymer paper composite.

4. Flexural Test: This test was performed in order to determine the tensile strength of the reinforced geopolymeric blocks[IS :516-1959][IS:9399-1979]. After comparing two proportions on the basis of amount of paper being used and compressive strength results, 1:2:0.75(fly ash: waste paper: foundry sand) proportion works out to be optimum as there is not much difference in compressive strength of both the proportions and also it is economical as more waste paper is used in this proportion. Hence maximum test samples with different ways of reinforcement have been tested for 1:2:0.75 proportion. One point loading was applied on the blocks and the arrangement for it is shown in fig.17. The span was kept as 160mm.In this

test, tensile strength of fibers helps in sustaining the tensile load on the blocks coming at the bottom. The results of it are shown in table 4.

Fig.17 Flexural test arrangement

Table 4 Results of flexural test

SR. NO.	PROPORTION	TYPE OF REINFORCEMENT	LOAD (KN)	FLEXURAL STRENGTH (MPa)
1	1-2-0.75	No reinforcement	3.18	0.763
2	1-2-0.75	Singly reinforced	6.39	1.533
3	1-2-0.75	Mesh	5.19	1.245
4	1-2-0.75	Triple Mesh	5.9	1.416
5	1-2-0.75	Doubly reinforced	7.6	1.824
6	1-2-0.75	Prestress	9.8	2.352
7	1-2-0.75	Random mix	3.75	0.900
8	1-1.5-1	No reinforcement	6.9	1.656
9	1-1.5-1	Singly reinforced	5.6	1.344
10	1-1.5-1	Mesh	4.2	1.008

Flexural strength was found out using following formula:

Flexural strength = M*y/I,

Where,M-moment ,

y-distance of extreme fiber from neutral axis

I-moment of inertia about neutral axis

Example : for the 1^{st} result in the following ,

M=(3.18*1000/2)*80= 127200 N-mm, I=bd^3/12= 100*100^3/12=8333333.33 mm^4

Flexural strength = 127200*50/8333333.33= 0.7632012Mpa

From test it was observed that blocks without reinforcement got completely failed. Mesh reinforced showed fine crack and strand reinforced showed distinguishable crack. . Prestressed one showed more good results but from practical point of view it is difficult to caste. Multi strand and multi mesh shows improvement in flexural strength.

5. Tensometer Test(fig.18) : This test was performed on briquettes of geopolymeric paper having dimension of 150 x 35 x 15 mm[IS:2380(Part v)-1977]. It gives inference regarding the tensile strength of geopolymeric paper material without reinforcement. The graph of load versus displacement is plotted as shown in fig.19. Rate of loading was kept as 10mm per minute.

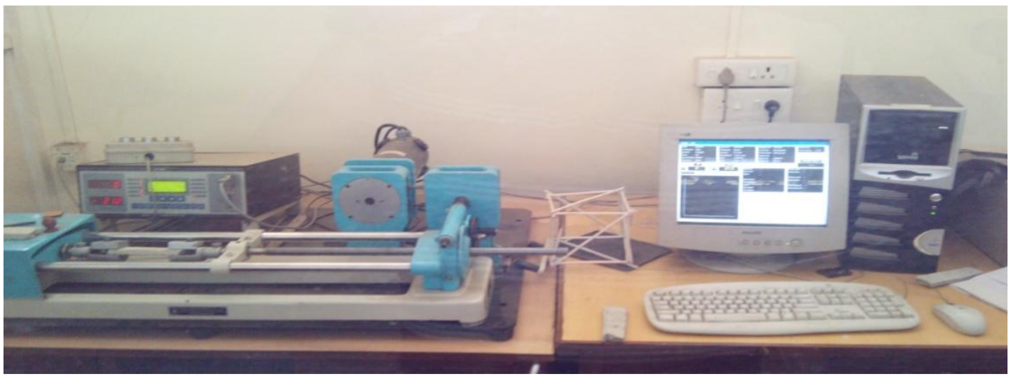

Fig.18 Tensometer apparatus

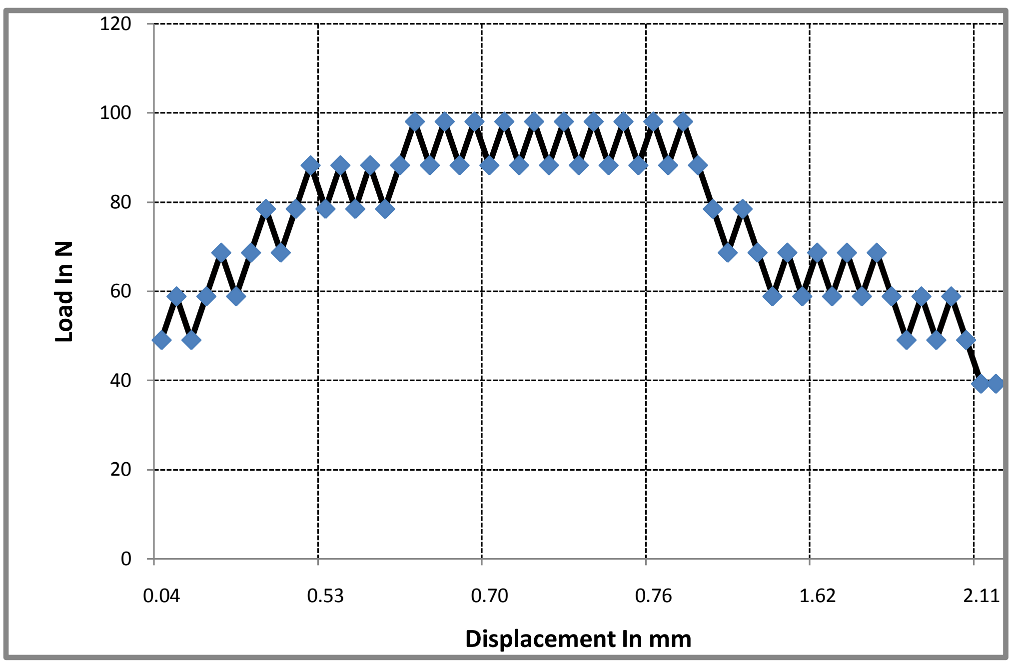

Fig.19 Graph of load Vs deflection (Tensometer Test)

From this test it was observed that the material has good axial tensile strength. During test it was observed that material gets elongated to large extent which was evident from the load vs displacement graph .So the material could be said to possess some elasticity.

Conclusion: Following conclusions were drawn from the study:

1. The studies carried out indicate the viability of using waste material i.e., waste paper, fly ash and foundry sand along with sisal fibers as reinforcement in the production of reinforced geopolymeric composite for construction purposes.
2. More homogeneity and uniformity can be obtained by using proper mixer and compaction.
3. In order to maintain the straightness of the fiber reinforcement while placing strands inserted throughout the mould and stretched works out to provide desired position to reinforcement.
4. Fibers in any form (strands or mesh) have proper bonding with the prepared mix when they are completely wetted in geopolymeric paper slurry.
5. Moulds should be removed once it is assured that the composite is self sustainable with a point of view of maintaining its desired shape.
6. The two proportions used for the casting and preparation of mix does not have a remarkable difference in their compressive strength hence the proportion which can give more economy by using more waste paper i.e.,1:2:0.75 can be considered to be the optimum one for the use.
7. The blocks should be put in to use after they get completely dried or cured otherwise it will lead to low compressive and tensile strength .Therefore the period of curing should be increased.
8. Strands which are placed by stressing them while casting gives higher tensile strength
9. Blocks with fiber reinforcement leads to development of fine cracks when mesh is used while distinctive cracks were observed when strands are used .Hence use of strands helps in getting prior warning before failure.
10. Bonding between sisal fibers and geopolymer paper composite is strong hence sisal fibers can be used as reinforcement in these blocks.
11. The material not being brittle in nature gives remarkable elongation.
12. Big sections should not be casted as a single unit as its curing period will be too much and hence can be made by adhering small units together to form a big section.

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