Feasibility Study of Natural Fibre Reinforced Mud Blocks as a Building Material

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ABSTRACT

Use of natural fibres is found to be an economical, eco-friendly, sustainable and efficient method of soil stabilization. The study investigates the improvements in compressive strength and crack resistance achieved by the introduction of banana fibres in mud blocks in locally available soil replaced with industrial residues. Among the natural fibres banana fibres are abundantly available in Kerala. Adobe samples were prepared with plain soil replaced with 10% industrial residues, reinforced with banana fibres of different percentages (0.25% to 1.00%) with an optimum fibre length of 60 mm and tested for strength and durability characteristics of the samples. Results show that the fibres greatly improved the compressive strength and the water absorption characteristics of stabilized mud blocks compared to the unreinforced soil. The effect of percentages of fibres on compressive strength and its influence on the post-fracture behaviour of the mud block compared to the unreinforced specimens of same size were also discussed in this paper.

KEYWORDS

Stabilized mud blocks, natural fibre, industrial residues, brick, building blocks

1.INTRODUCTION

Mud as a construction material offers the economic and effective alternative towards solving the large demand for low cost housing units. But the strength and durability of mud blocks is less and hence it is required to investigate on stabilizing mud blocks with admixtures, reinforcing them with natural fibres and checking its feasibility as sustainable alternative without compromising the strength and other functions. Again, residential sector has an enormous impact in the energy consumption and the CO_2 emissions. Buildings are responsible for the 40% of the final energy consumption and 36% of the total CO_2 emissions [1].

Traditional building materials like fired bricks, cement, concrete, steel, glass and tiles cause major environmental exertions like resources depletion and environmental damage. Their manufacturing process also demand high energy and result in release of carbon dioxide and other harmful pollutants like sulphur dioxide, carbon monoxide, nitrogen oxide and particulate matter polluting the environment. These emissions contaminate soil, water and air thus affecting the biotic environment and human health adversely.Therefore, the indiscriminate use of these traditional building materials demands a sustainable alternative that offers not only economic solutions but also sustainable development [2].

Soil building blocks enhanced with agricultural waste are one of the alternate building materials that have shown to provide social, environmental and economically sustainable building materials. These have been used to produce low-cost housing, improved thermal comfort and maintaining cultural heritage buildings [3]. The fibres that can be used are straw, tea residue, pineapple, date palm, oil palm and bagasse. Banana fibres will be a new bonus to construction materials. Adding banana fibres to the mix design is intended to increase the internal strength of the Compressed Earth blocks (CEB). These fibres prevent the deformations that may appear in the mud brick, thus preventing the shape of the brick and preventing the surface being falled off [4] .Various research works have shown that hygrometric shrinkage and associated cracking of earth –based materials can be greatly reduced by the introduction of fibres in to the mixture [5].

This paper deals with experimental investigation on the mechanical and durability properties of banana fibre reinforced mud blocks prepared from locally available soils replaced with industrial wastes that is energy saving, eco-friendly, imparting higher strength and sustainable development to help and develop technologies [6].

2 MATERIALS AND METHODS

2.1 Materials

The materials used for the study are Soil, Ground granulated blast furnace slag (GGBS), Fly Ash (FA) and Banana fibre.

2.2 Soil

Soil samples were collected from Thrissur town, Kerala. The preliminary site investigation of soil revealed that it was suitable for brick manufacture which was proved by conducting some typical field tests. The detailed material characterization of soil samples are given in Table 1.

2.3 Ground Granulated Blast Furnace Slag (GGBS)

GGBS was collected from Coimbatore Tamil Nadu, which is produced by quenching molten iron slag from a blast furnace in water or stream, to produce a glassy granular product that was then dried and ground in to fine powder. It was used to make durable concrete structures in combination with ordinary Portland cement or pozzolanic materials.

2.4 Fly Ash

Fly ash is also known as pulverized ash, is a combustion product that was composed of the particulates driven out of the fired boilers together with the flue gases. It is collected from ready mix concrete production centre near Thrissur district in Kerala.

Table 1. Material characterization of soil

Sl. No.	Properties of sample of soil	Observed Value	IS Code	Remarks
1	Atterberg limits		IS: 2720- (Part 5) 1985 [7]	For the experimental soil
	a. Liquid limit (%)	20.0		
	b. Plastic limit (%)	13.0		
	c. Plasticity index (%)	7.0		
2	Proctor compaction test		IS:2720 (Part 8)-1983	
	a. Maximum dry Density (kN/m^3)	19.60		
	b. Optimum Moisture Content (%)	10.30		
3	Specific gravity of soil	2.61	IS: 2720 (Part 3) – 1980[9]	Range of sp. gravity 2.65-2.85

2.5 Banana Fibre

Banana fibre is a naturally occurring fibre obtained from banana plant or plantain plant. The banana fibres of an optimized length of 60 mm [2] were collected from Kerala Banana Research Institute Peechi, Kerala for the present study (Figure 1.). The main advantage of banana fibre is its mechanical properties and its stiffness. It is a highly strong fibre with less weight. Table 2 shows the chemical and physical properties of banana fibre.

Figure 1. Banana fibres of 60 mm length (Optimized length)

Table 2. Chemical and Physical Composition of Banana fibre

Physical properties	Content	Chemical composition	Content
Optimum fiber length(mm)	60-70	Lignin	16.7%
Diameter(mm)	0.0142	Cellulose	57.60%
Density(g/cc)	1.35	Moisture	13%
Tensile strength (MPa)	115.5	-	-

Source: Mostafa & Uddin (2016) [2]

2.6 Sample Preparation

Mud blocks were prepared from plain soil in raw state and also from plain soil stabilized with GGBS and fly ash in varying proportions. Three specimens were prepared for each proportion. The ingredients such as raw soil, GGBS and fly ash were first dry mixed in the required proportions. Water to attain the uniform consistency (OMC) is then added to the dry mix and mixed well. The amount of water required to make soil balls without sticking in the hand is taken as the water required for attaining uniform consistency, the mix is then filled in to the moulds of size 210mm x 105mm x75 mm and compacted with hand in 3 layers. The moulds were then vibrated for 5 minutes in a table vibrator.

The blocks were hand molded, table vibrated and the top surface was finished and were allowed to dry in room temperature or in sun light of 27 degree centigrade and relative humidity of 72 % for 21 days. Mud blocks were prepared in varying percentages of fly ash and GGBS and with constant percentage of soil of 90% [3]. Table 3 shows the details of the mix proportions.

Table 3. Proportions of mix and quantity of materials

Sl. No.	Mix designation	% soil	Quantity of soil (kg)	% of Fly Ash	Quantity of fly ash (kg)	%of GGBS	Quantity of GGBS (kg)
1	PsF0G0	100	24	0	0	0	0
2	PSF10G0	90	24	10	2.4	0	0
3	PSF0G10	90	24	0	0	10	2.4
4	PsF9G1	90	21.6	9	2.16	1	0.24
5	PsF8G2	90	21.6	8	1.92	2	0.48
6	*PsF7G3	90	21.6	7	1.68	3	0.72
7	PsF6G4	90	21.6	6	1.44	4	0.96
8	PsF5G5	90	21.6	5	1.2	5	1.2

* (Ps-Plain soil; PsF7G3 –F7-Fly ash 7%; G3- GGBS 3%)

3 TESTS CONDUCTED

The mud blocks prepared from plain soil and those replaced with 10% industrial residues (combination of GGBS and fly ash) were tested under uni-axial compression testing machine of maximum load capacity of 2000kN. The rate of compression was set at 3 kN/s until failures. The percentage of GGBS and fly ash were optimized by preparing trial mixes of different percentages of fly ash and GGBS as per the table 3, and the compressive strength values were compared with control mix. To the optimized mix, banana fibres with 60 mm length in various percentages (0.25% -1.00%) were added as reinforcement. The effect of banana fibre content in density, compressive strength, shrinkage, and water absorption of mud blocks replaced with optimum combination of GGBS and fly ash were determined as per standard codes. Also dimension tolerance test was conducted as per standard IS:1077-1972 [10]to check whether the prepared mud blocks meet the standard dimensions.

4 RESULTS & DISCUSSIONS

The compressive strength of mud blocks prepared from plain soil and that replaced with 10% industrial residues which is a combination of varying percentages of fly ash and GGBS are presented in Table 4.

Table 4. Optimization of compressive strength of mud blocks with industrial residues

Sl.No.	Mix designation	Max. Compressive Strength (N/mm²)	Remarks
1	PSF0G0	1.62	
2	PSF10G0	1.54	
3	PSF0G10	1.35	
4	PSF9G1	1.37	
5	PSF8G2	0.78	
6	**PSF7G3**	**2.34**	**Optimized mix (compressive strength 44% more than that of plain soil blocks)**
7	PSF6G4	0.83	
8	PSF5G5	0.74	

The maximum compressive strength of 2.34 N/mm^2 is obtained for the mud block prepared from plain soil replaced with 7% of fly-ash and 3 % of GGBS ($P_SF_7G_3$) as seen in Figure 2.

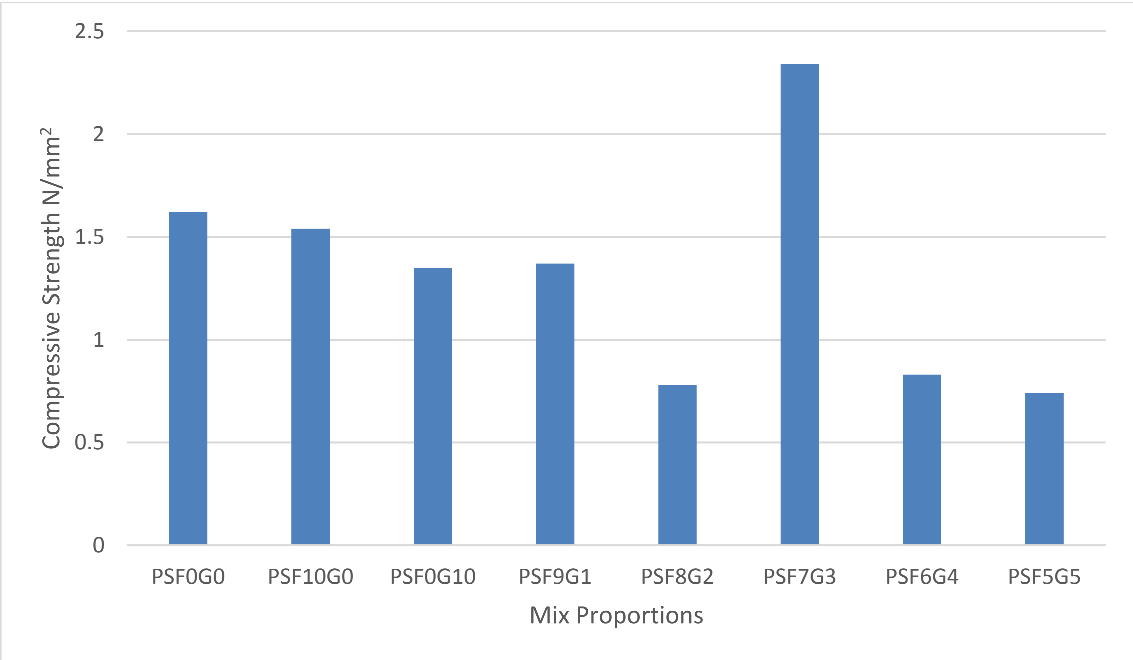

Figure 2. Average compressive strength of different mix proportions

Hence the mix designation PsF_7G_3 is selected for studying the effect of varying percentage of banana fibre (0.25% -1%) on density, compressive strength, shrinkage, water absorption and dimensions of mud blocks and the results are results are tabulated in Table 5.

Table 5 Variation of parameters with change in fibre content of $P_SF_7G_3$ mud block

% fibre	Density (kg/m^3)	Compressive strength (N/mm^2)	% linear shrinkage	% water absorption	Dimension tolerance		
					Length (mm)	Breadth (mm)	Depth (mm)
0	2100	2.34	5 .60	Dissociated fully	4210	2036	1580
0.25	2000	1.34	5.46	30.00	4200	2026	1540
0.50	1900	2.03	5.16	25.00	4310	2135	1610
0.75	1700	3.06	3.99	16.42	4340	1586	1586
1.00	1600	2.43	3.19	21.42	4366	2173	1600

4.1 Density Test

The density was determined as per IS: 1077-1992 [10]. It is the ratio of mass of bricks to the total volume of specimen. The density was found to decrease with the increase in percentage of fibres. The variation in density with respect to percentage fibre content for the mix PsF7G3 is shown in Figure 3.

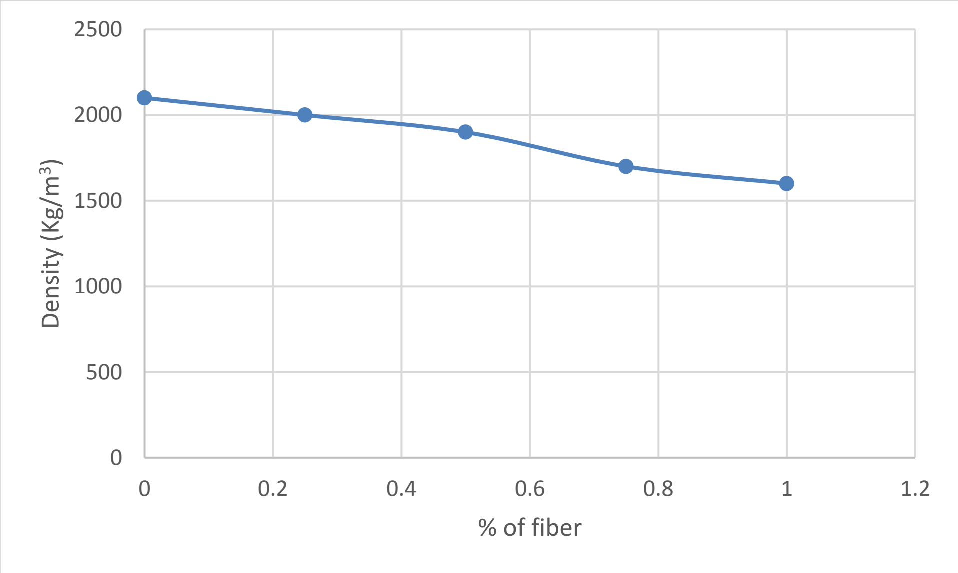

Figure 3. Variation in density with percentage of fibre for mix $P_SF_7G_3$

4.2 Compressive Strength Test

The compressive strength was tested as per IS: 3495 (Part 1)-1992 [11]. It was observed from the study that 0.75 % of fibre shows maximum compressive strength 3.06N/mm^2 which is 34.4 % more than the standard value for sundried brick (2.5N/mm^2). With further increase in fibre content to 1%, reduction in compressive strength was noted but the value was greater than that of the unreinforced mud block. 0.75% is thus found to be the optimum fibre content for $P_SF_7G_3$ mud block (Figure 3.). The compressive strength of 0.75% banana fibre reinforced $P_SF_7G_3$ mud block resembles the values obtained in the study conducted by Bougerra et al., (1998); Kumar et al., (2006) [12,13] on fibre reinforced clay. The failure of mud blocks were gradual indicating the ductile property of the banana fibres which was added as reinforcement. Figure 4. shows the variation in average compressive strength of $P_SF_7G_3$ mud block with 60 mm optimized length banana fibres of varying percentages from 0.25% -1%.

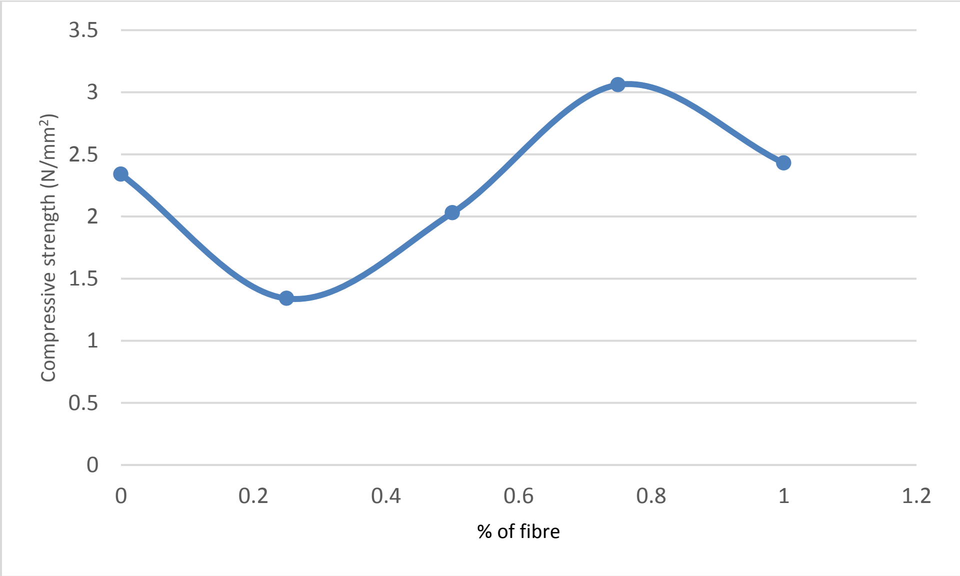

Figure 4. Compressive Strength with banana fibre 60 mm optimized length

4.3 Shrinkage Test (Appropriate building codes for specifications for Adobe Construction

Shrinkage test was conducted as per the Appropriate building codes for specifications for Adobe Construction [14] .Shrinkage ratio is the change in length to original length. Some bricks show reduction in dimension due to drying shrinkage and due to the plastic nature of soil. Shrinkage increases with time as drying increases. Fibres present in the soil matrix resist deformation through friction and reduce the linear shrinkage to a great extent. It is observed that with increase in fibre percentage, percentage shrinkage got reduced stating the fact that fibres are effective in arresting the shrinkage cracks (Table 5). Similar trend was observed in the study conducted by Bougerra et al., (1998); Bouhicha et al., (2005) [12, 15] on fibre reinforced clay with natural aggregates. As per the Table 5, mud blocks reinforced with 0.75 % and 1% fiber content have moderate shrinkage value [2]. Fibres not only arrest the cracks but also bridge the cracks width. Shrinkage cracks are commonly found in unreinforced mud blocks usually.

4.4 Water Absorption Test

Water absorption test was determined as per IS: 3495 (Part 2)-1992 [16]. This test is conducted to determine durability property of bricks such as degree of burning, quality and behavior of bricks in weathering. A brick with water absorption of less than 7% provides better resistance to damage by freezing. Water absorption increases with increase in pore space. The voids in the fibers create a path, allowing more water absorption in the bricks.

The mud block with composition 90% plain soil, 7% fly ash and 10% GGBS dissociated fully in water. With the addition of 0.25%, 0.5% and 0.75% banana fibre the percentage water absorption was found to decrease to 30%, 25% and 16.42%. With further increase in fibre content to 1%, water absorption increased again to 21.42% (Figure 5.).

As per IS Specification, the water absorption capacity of the brick shall not be more than 20% by weight for I class, 22% for II class and 25% for III class. PsF_7G_3 mud block with 0.75% fibre content was found to have percentage water absorption conforming to class I brick whereas that with 1% fibre content conforms to water absorption capacity of class II bricks as per IS specifications.

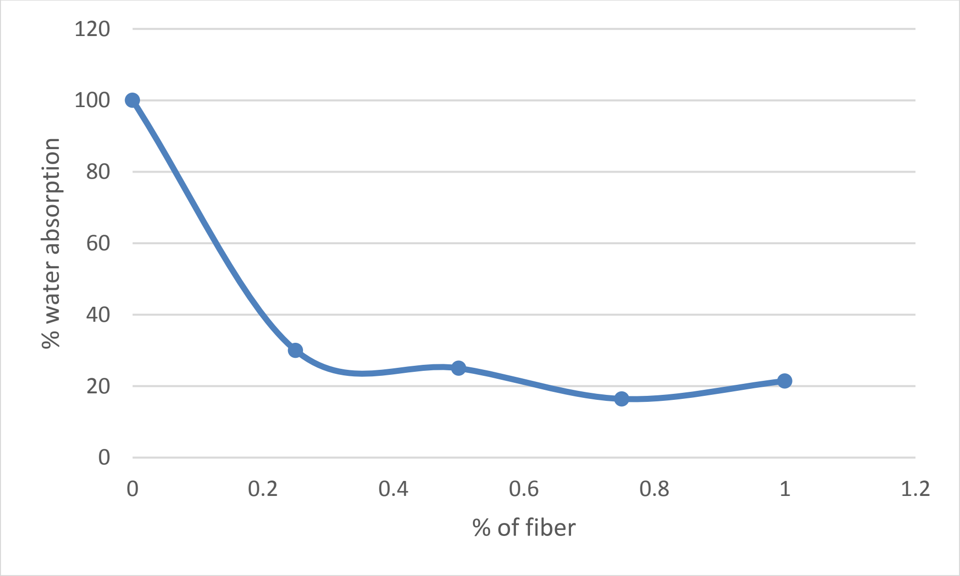

Figure 5. Percentage water absorption

In the case of all other natural fibres water absorption increases with increase in fiber content. But in the case of banana fibres a decrease in water absorption with increase in fibre content was observed. Hence it is proved that banana fibers are effective in mitigating water absorption to a certain limit.

4.5 Dimension Tolerance Test (IS 1077-1972)

Twenty samples were taken and are laid flat on table. The size of bricks is fixed by giving maximum and minimum dimensions on individual bricks but on batches of 20 bricks chosen at random. Batches are likely to contain, bricks outside the prescribed limit of tolerance, to avoid complaints about the variation of perpends. The standard dimension tolerance limits for 20 blocks are presented in Table 6.

Table 6. Dimension Tolerance Max and Min. values as per standard

Dimension	**Standard values (mm)**	**Tolerance**	
		Max.(mm)	**Min.(mm)**
Length	4200	4280	4120
Width	2100	2140	2060
Height	1500	1540	1460

It is noticed that bricks with 0.50% fibre content confirms to the standard value in length, breadth and depth of specimens (see Figures 6-8). The dimension tolerance values for 0.75% and 1% reinforced $P_SF_7G_3$ mud block are slightly out of range in terms of length, width & height (see table 6).

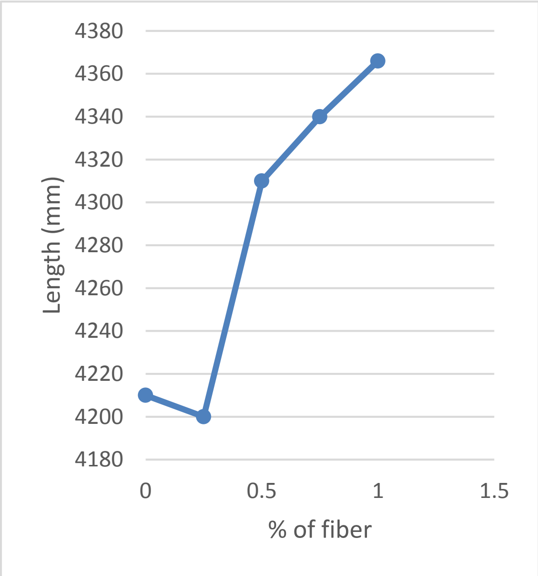

Figure 6. Tolerance - Stacking stretcher wise

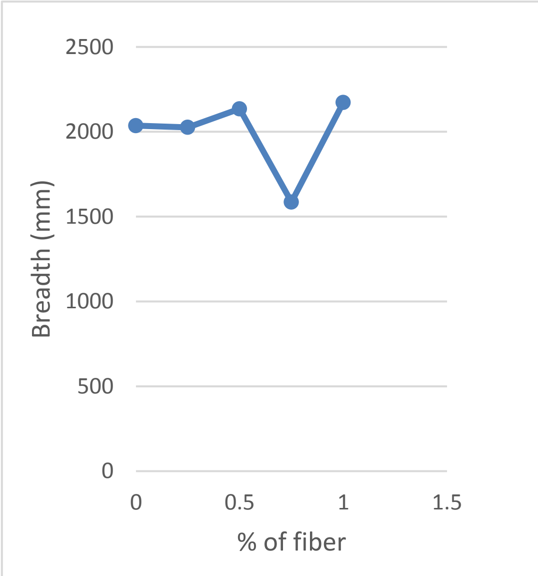

Figure 7. Tolerance – Stacking Header wise

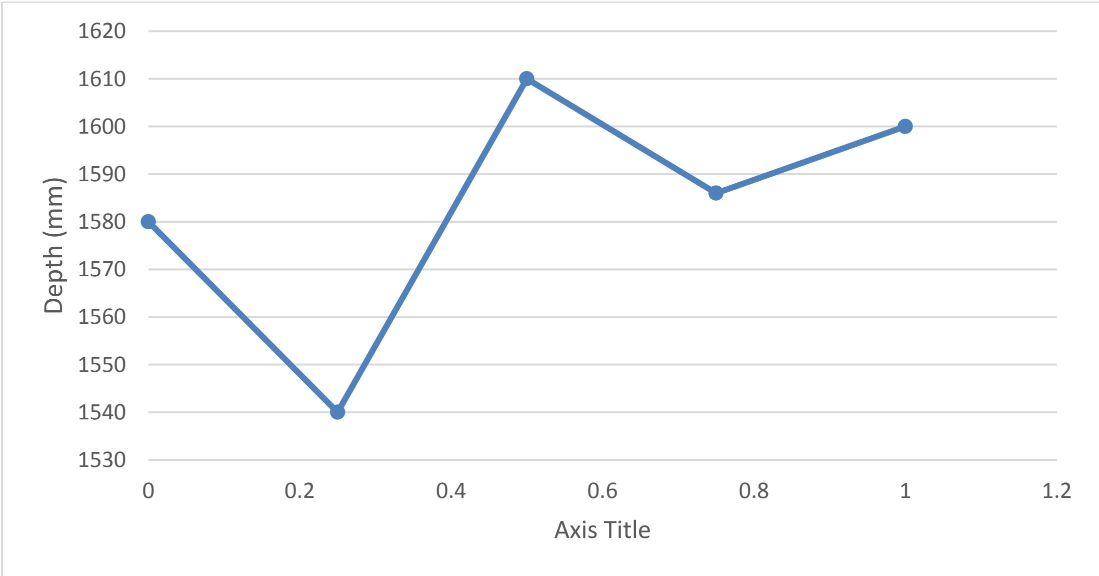

Figure 8. Tolerance - Depth wise Stacking

Considering density, maximum compressive strength (31% more than unreinforced mud blocks), percentage shrinkage and percentage of water absorption (less than 20%) $P_SF_7G_3$ mud blocks reinforced with 0.75 % banana fibres 60 mm length is recommended for mud block construction.

5 CONCLUSIONS

The present study was conducted to investigate the feasibility of adding natural fiber like banana fiber to stabilized mud blocks. The following conclusions are derived from the study

- Addition of mineral admixtures to the locally collected red earth has some impact on the soil properties in the case of compressive strength.
- Compressive strength was increased to about 44% with industrial residue combination of 7% fly ash and 3% GGBS in plain soil compared to the un-stabilized sundried bricks.
- Among the different percentage of fibres, 0.75 % fibre shows better result n compressive strength. The compressive strength increased 31% more than the unreinforced soil blocks. Further studies are recommended in studying property of yielding or ductile property of fibres.
- The replacement by industrial residues was not sufficient to reduce water absorption. Addition of fibers shows improvement in water absorption characteristics within the standard limit of country burnt bricks (less than 20 %).
- The density is inversely correlated with strength and water absorption.
- Mud blocks reinforced with 0.75% banana fiber showed moderate values in density and shrinkage, maximum compressive strength (31% more than unreinforced mud blocks) and percentage of water absorption within the range of standard bricks (less than 20%).

This case study aims to use locally available raw earth in combination with industrial residues and natural fibre reinforcements as a building material which can be used as a local resource which is energy efficient, eco-friendly, higher strength and thus contribute to sustainable development for low cost housing, In addition, with its improved ductile property, it may be used for earth quack resistant low cost housing units in earth quack prone areas.

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