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Sustainable Construction Materials: A Way Forward for the Protection of Ethiopian Environment

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Abstract

For past many hundred years, Ethiopia has been a blessed country of green cover, so its traditional house building technique hut (Chikka-Bet) has mainly depended on woods. However over past few decades, population explosion in Ethiopia has increased the dwelling demand which has led to cutting down of more trees. Deforestation has created several negative impacts in our environment. Soil erosion and sharp increase of the temperature has also been witnessed leading to extinction of many local flora, fauna and local animals. This is negatively impacted the livelihood of habitants as well. So, the only way forward to deal with such situation is using locally available sustainable materials in construction activities and cut down the dependency on woods for house construction. This research work presents several agro and industrial wastes that are found in Ethiopia which have been experimentally tested for their availability, suitability, economy, strength and durability to be used in construction activities as a sustainable construction material. From Agro-wastes perspective, rice husk ash, bagasse ash, teff straws, sisal fibres have been presented for their suitability and from industrial wastes perspective materials such as crusher dusts, crushed glasses, human hairs have been presented for their suitability as sustainable materials to be used in construction in place of conventional and traditional materials. The research results indicates that, the non-conventional materials have great potential to replace the traditional materials for construction activities. However it needs a great attention from the policy makers and win the confidence of local community by broadcasting the suitability of these non-conventional materials which will ensure a safe and clean environment for the generations to come.

Keywords: Sustainability, Environment, Materials, Non-Conventional, Economy

1. Introduction

Since ages, because of abundant availability of forests in Ethiopia, wood have been used as the primary material for building constructions. However, rapid population explosion in Ethiopia leading to increased dwelling demand have resulted in large scale deforestation in Ethiopia. A hundred years ago more than a third of Ethiopia was covered by forest, but in the year 2000 the forest covered area reduced to only three percentages which is a serious concern.

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There are clear evidences of climate change found in the Ethiopia over last couple of years caused predominantly due to the large scale deforestation. Climate change has resulted in several economic and social impacts in this region. Many local flora and fauna are in the verge of extinct and the viable living condition has gone down. Deforestation has also caused a vicious cycle of impoverishment of the soil and erosion as a result loosing rich minerals from the soil which are vital for a good crop which is an extremely serious threat to Ethiopia from food security perspective as it exacerbates the threat of famine. Studies performed in 2008 suggest that Ethiopia loses over 1.5 billion tons of topsoil from the highlands to erosion. This soil could have added about 1.5 million tons of grain to the country's crop production. This should be of good indication that soil erosion is a very serious threat to food security of the population and requires urgent attention.

	
Deforestation in Ethiopia	Soil erosion caused due to deforestation
	
Loss of green cover	Loss of local flora, fauna and species fall prey to deforestation

Figure 1. Deforestation related issues in Ethiopia

The traditional house building technology chikka-bets uses woods as the base material for prepare the frame of the house and mud is smeared over it to make the walls. Along with deforestation another major issue with this house construction method is durability issues for the houses. Termite attack and shrinkage cracks have been the common issues see in the traditional house which is a major concern.

	
Wattle and Daub Method: Ethiopian traditional house construction technique	Durability a concern for existing mud housing techniques in Ethiopia

Figure 2. Durability Issues in Traditional Houses

These traditional houses require frequent maintenance which is difficult to afford by the common man. Because of the durability issues in the earthen houses, people have started using modern technologies which utilizes cement as the base material which is definitely not sustainable. Cement is the major producer of greenhouse gases leading to destabilizing the ecosystem. So to deal with this major issue in Ethiopia, there must be a solution which utilizes the sustainable technology and materials for construction activities. When sustainability comes into picture, the focus must be on the locally available material which serves the purpose. In Ethiopia there are various agriculture products are being cultivated such as Coffee, Maize, Banana, Teff, Rice, Rice and Sugarcane etc. Once the food grains are extracted, the remaining wastes products have potential to be used as construction materials in various forms. Along with this there are waste products from industries such as ashes, slags, glass wastes, tire wastes and plastic wastes etc. which have potential to be used as construction materials.

	
Teff Straw: One of the major agro waste in Ethiopia	Wheat Straw: One of the major agro waste in Ethiopia
	
Banana Fibres: One of the major agro waste in Ethiopia	Wood Sawdust: One of the major waste in Ethiopia

Figure 3. Agro and Industrial wastes as sustainable building materials

This research paper presents various agro wastes such as Teff straws, Rice husk ash, Sugarcane bagasse ash and Sisal fibers, industrial and other wastes such as crusher dusts, crushed glasses and human hairs as alternative construction materials. There are various building construction technologies which uses soil as the base material such as compressed earth blocks, rammed earth, straw bale and adobe etc.

	
Rammed Earth house const. technology	Straw Bale construction technology

Figure 4. Building technologies with Soil as base material

However, from Ethiopian perspective the best suited one is Adobe technique which uses soil, small amount of stabilizer and locally available agro wastes as reinforcing which are not only sustainable but also excellent from the economical and local tradition perspective.

2. Materials and Methods

2.1. Adobe as an alternative construction technology

Adobe is a mud brick building technology which utilizes soil as a base material. To stabilize the soil, various natural/artificial binders and reinforcing agents such as banana fibers, sisal fibers, wood dusts, rice husk, bagasse, cement and lime can be used. However, this research work presents adobes which uses a major agro waste in Ethiopia called teff straw as a binder. From artificial stabilizer perspective, based on the type of soil the stabilizer is generally chosen such as cement or lime etc. For the red-soil which is the most common and preferred soil for house construction in Ethiopia, cement has been chosen as the best stabilizer in this research.

Figure 5. Teff Straw as artificial reinforcing agent for Adobe

	
Adobe brick preparation	Adobe samples for strength testing

Figure 6. Adobe brick sample preparation and testing

As a first step, several soil tests were carried out to understand the physical properties of the soil used in this research work and the type of soil from USCS classification. Based on the type of soil the most suitable binder was chosen. To find the optimum percentage of binder, standard proctor compaction test was conducted. Once the soil and binder was finalized, the reinforcing agent i.e. teff straw were added in different percentages by volume of the soil (0% to 2%) and adobe test samples of size 19 cm x 9 cm x 9 cm were prepared. The test samples were sun dried for 28 days after which their compressive strength was measured to find the best adobe sample and its compositions.

2.2. Agro-wastes as alternative construction materials

Rice Husk Ash

Production of rice has expanded in Ethiopia from the beginning of 1970 and total rice cultivation has risen from about 10,000 ha in 2006 to 50,000 ha in 2018. The major areas which produce rice in Ethiopia are Gambella, West central highland of Amhara region, South and South west lowland of SNNPR and Somali region etc. Once the rice is extracted from the seeds, the remaining product is called as rice husk. The rice husk is basically a waste product which doesn't have any notorious value and are at times used as a filler material or used as a fuel in some industries. However, when the rice husk is burnt in a controlled temperature the ash comes out which is called as rice husk ash has a pozzolanic property and can be used as a cementing material in concrete production by replacing the conventional cementing material i.e ordinary portland cement which is a major producer of CO_2. This research work, the rice husk ash was procured from local factory from Hawassa and tested for their suitability as an alternative cementing material.

Rice husk Burning of RHA Rice husk ash

Figure 7. Rice Husk Ash an alternative cementing material

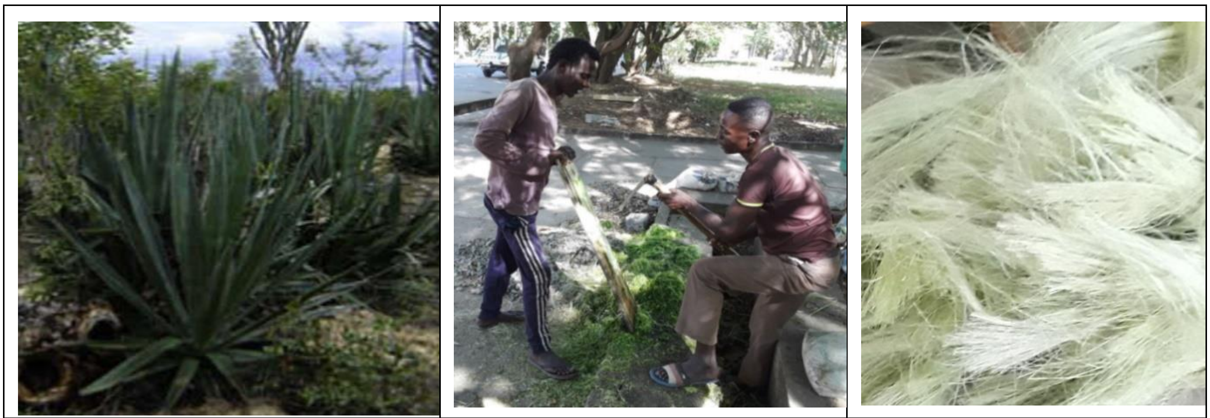
Bagasse Ash

Sugarcane is a major crop in Ethiopia. Currently there are about eight sugar producing factories, which produce 3.5 to 4 million quintals of sugar annually. Once the sugar is extracted from the sugarcane, the waste product is generally used as a fuel in the sugar plants which further produces ashes known as bagasse ash. The bagasse ash being a pozzolanic material have the potential to be used as an alternative cementing material. This research work presents the suitability of bagasse ash procured from Omo-Kuraz factory-II as an alternative cementing material.

Figure 8: Bagasse Ash an alternative cementing material

Sisal Fiber

It is a well-known fact that tensile cracks are the major issues in concrete construction and the addition of fibers enhances the tensile strength of the concrete. Several artificial fibers such as steel fibers, glass fibers are in use which are not sustainable because of their higher embodied energy. So the use of natural fibers such as Jute, Banana and Sisal make them sustainable. In this research paper, suitability of Sisal fiber procured from SNNPR region have been presented as a sustainable fiber for concrete construction to arrest the tensile cracks.



Sisal plant	Fibre extraction process	Sisal fibres

Figure 9. Sisal fibre a natural fibre for arresting tensile cracks in concrete

2.3. Industrial wastes as alternative construction materials

Glass Wastes

River sand is the common form of fine aggregate use for concrete construction in Ethiopia. However, the large scale dependency on river sand has resulted in depletion of the riverbeds leading to floods and damage to the agriculture lands. So alternative non-conventional fine aggregates are the need of the hour. In Addis Ababa, Ethiopia more than 15% of solid waste generated is glass waste which has the potential to be used as a fine aggregate in concrete by partially replacing the river sand. In this research work, the suitability of glass wastes procured from Addis Ababa, Ethiopia as a fine aggregate in concrete have been presented.

Figure 10. Glass wastes from Addis Ababa as fine aggregate

Crusher Dusts

Similar to glass wastes stated above, crusher dusts are waste products from stone crushers which are mostly used as filling materials. However, with careful selection these crusher dusts can be used as a fine aggregate in concrete there by reducing the dependency on river sand. In this research work, the suitability of crusher dusts procured from Hawassa Monopol, Ethiopia as a fine aggregate in concrete have been presented.

Figure 11. Crusher dusts from Hawassa Monopol as fine aggregate

Human Hairs

Among several natural and artificial fibers to arrest the tension cracks there by enhancing the tensile strength of concrete construction, human hairs also possess the capability to arrest the tensile cracks if used well treated and with appropriate aspect ratio. Use of human hairs not only enhances the tensile strength of concrete but also helps in utilizing a major waste product for a good reason. In this research paper, the suitability of treated human hair as a fiber in concrete has been presented.

	
Waste natural human hair as fibres in concrete	Concrete beams test samples

Figure 12. Processed human hairs as fibres in concrete

2.4. Experiments for evaluating the properties of the materials

To evaluate the suitability of the waste products stated in the previous section, concrete cube test samples of size 150 mm x 150 mm x 150 mm and beam samples of size 150 mm x 150 mm x 800 mm were prepared with usual the ingredients and these wastes in various percentages by their weight. The concrete samples were cured in potable water for 28 days after which they were taken out and their strength were measured and compared with that of normal concrete. Several durability studies were also carried out to find out the suitability of these materials under different climatic conditions.

	
Compressive strength testing	Flexural strength testing

Figure 13. Strength testing on concrete

Water absorption testing

Resistance to elevated temperature testing

Chloride penetrability testing

Resistance to carbonation testing

Figure 14. Durability testing on concrete

3. Results and Discussions

3.1. Adobe as an alternative building technology

The compressive strength of adobe blocks tested at various sundried curing period has been presented in Table 1.

Table 1. Compressive strength of adobe blocks

Sr. No	Mix	14^{th} day strength (MPa)	28^{th} day strength (MPa)	56^{th} day strength (MPa)
1	Soil	4.6	4.8	4.9
2	Soil + 3.5% cement	2.3	4.9	5.1
3	Soil + 3.5% cement + 0.5% teff straw	3.4	4.9	5.2
4	Soil + 3.5% cement + 1% teff straw	4.1	4.9	5.3
5	Soil + 3.5% cement + 1.5% teff straw	4.3	5.1	5.5
6	Soil + 3.5% cement + 2% teff straw	2.9	3.6	3.9

The experimental test results shown in the Table 1 clearly shows that, with the soil and cement of 2.5% as binder when the teff straw is added from 0.5% up to 1.5%, the compressive strength of Adobe blocks increases. However, with further increase in the teff straw the compressive strength decreases. The decrease in compressive strength is because of the balling effect of fibers in soil samples. So it can be concluded that the optimum mix for adobe to be used are red soil with 2.5% of cement and 1.5% of teff straws. The general requirement of compressive strength of earthen bricks is 3 – 3.5 Mpa. From the experimental investigation it can be clearly seen that for optimum adobe composition, the strength achieved was 5.5 Mpa which is well beyond the general requirement. Further several durability studies have also indicated that the use of teff straws reduces the shrinkage of the adobes there by increasing the durability of the adobes.

3.2. Rice husk ash as an alternative cementing material

The compressive strength of concrete with rice husk ash as cementing material at various curing period has been presented in Table 2. The effect of rice husk ash on water absorption which is an important durability measure is presented in Table 3.

Table 2. Effect of rice husk ash on compressive strength of concrete

Mix	% rice husk ash replacement with cement	Density (Kg/m^3)	Compressive Strength at Different Age (MPa)		
			7 days	14 days	28 days
C20	0%	2036	18.26	20.64	23.72
	10%	2013	11.60	18.27	24.97
	20%	1992	11.36	15.84	20.32
	30%	1975	11.10	13.16	15.22
	40%	1950	8.45	9.70	10.90

The experimental test results shown in the Table 2 clearly indicate that with increase in the dosages of rice husk ash a partial replacement of cement up-to 10% in concrete, the compressive strength increases. With further addition of rice husk ash reduces the compressive strength. The reduction in strength is because of low workability of concrete with rice husk ash in concrete beyond 10% of partial replacement with cement. Hence the optimum dosages of rice husk ash as a partial replacement of cement in concrete from strength perspective is 10%.

Table 3. Effect of rice husk ash on water absorption of concrete

Grade	% RHA	Weight of Oven-Dried Sample(kg)	Weight of Saturated Sample (kg)	Saturated Water Absorption at 28 Days (%)
C-20	0%	7.99	8.17	2.1%
	10%	7.98	8.14	1.9%
	20%	7.94	8.07	1.6%
	30%	7.77	7.96	2.4%
	40%	7.65	7.91	3.4%

The experimental test results shown in the Table 3 clearly indicate that with increase in the dosages of rice husk ash a partial replacement of cement up-to 20% in concrete, the resistance to water absorption increases. This is because of the pozzolanic action of rice husk ash which reduces the porosity of concrete. Hence the optimum dosages of rice husk ash as a partial replacement of cement in concrete from water resistance perspective is 20%.

3.3. Bagasse ash as an alternative cementing material

The compressive strength of concrete with bagasse ash as cementing material at various curing period has been presented in Table 4. The effect of bagasse ash on resistance to chloride penetrability is presented in Table 5.

Table 4. Effect of bagasse ash on compressive strength of concrete

Mix	% bagasse ash replacement with cement	Density (Kg/m^3)	Compressive Strength at Different Age (MPa)		
			7 days	14 days	28 days
C35	0%	2359	25.3	40.7	46.2
	10%	2360	26.9	45.7	48.7
	20%	2351	20.3	35.6	38.2
	30%	2461	18.7	20.6	32.6
	40%	2335	8.8	11.6	16.2

The experimental test results shown in the Table 4 clearly indicate that with increase in the dosages of bagasse as a partial replacement of cement up-to 10% in concrete, the compressive strength increases. With further addition of bagasse ash reduces the compressive strength. The reduction in strength is because of low workability of concrete with bagasse ash in concrete beyond 10% of partial replacement with cement. Hence the optimum dosages of bagasse ash as a partial replacement of cement in concrete from strength perspective is 10%.

Table 5. Effect of bagasse ash on chloride penetrability of concrete

% bagasse ash replacement with cement	Charge passed in coulombs	Chloride ion penetrability as per ASTM C1202
0%	2637.77	Moderate
10%	1885.61	Low
20%	1384.64	Low
30%	2121.05	Moderate
40%	2823.25	Moderate

The experimental test results shown in the Table 5 clearly indicate that with increase in the dosages of bagasse ash a partial replacement of cement up-to 20% in concrete, the resistance to chloride penetrability increases. This is because of the pozzolanic action of bagasse ash which reduces the porosity of concrete. Hence the optimum dosages of bagasse ash as a partial replacement of cement in concrete from chloride penetration resistance perspective is 20%.

3.4. Sisal Fibre as a natural fibre in concrete

The compressive strength of concrete with sisal fibers as tension crack resisting materials at various curing period has been presented in Table 6.

Table 6. Effect of sisal fibres on compressive strength of concrete

Mix	% sisal fiber of entire volume of concrete	Compressive Strength at Different Age (MPa)		
		7 days	14 days	28 days
C35	0%	25.2	30.7	40.8
	0.5%	25.8	35.7	41.1
	1%	26.3	36.6	43.9
	1.5%	21.7	34.4	42.1
	2%	17.6	27.6	35.1

The experimental test results shown in the Table 6 clearly indicate that with increase in the dosages of sisal fibers up-to 1% of entire volume of concrete, the compressive strength increases. With further addition of sisal fibers, the compressive strength decreases. The reduction in strength is because of balling effect of the fibers in concrete beyond 1% addition. Hence the optimum dosages of sisal fiber as a tension crack resisting material in concrete can be taken as 1% of entire concrete volume.

3.5. Waste glass as fine aggregates in concrete

The compressive strength of concrete with waste glass as fine aggregate as a partial replacement of river sand at various curing period has been presented in Table 7. The effect of elevated temperature on concrete with waste glass as fine aggregate has been presented in the Figure 15.

Table 7. Effect of waste glass as fine aggregate on concrete strength

Mix	% waste glass as partial replacement of river sand	Compressive Strength at Different Age (MPa)		
		7 days	14 days	28 days
C50	0	39.6	46.1	54.3
	20	39.7	47.3	55.3
	40	40.4	47.8	55.7
	60	40.1	48.8	56.6
	80	42.1	49.7	58.7
	100	34.9	43.2	52.1

The experimental test results shown in the Table 7 clearly indicate that with increase in the dosages of waste glass up-to 80% of partial replacement of river sand, the compressive strength of concrete increases. Hence up-to 80% of river sand, the waste glasses can be partially replaced as a fine aggregate in concrete for achieving a superior strength.

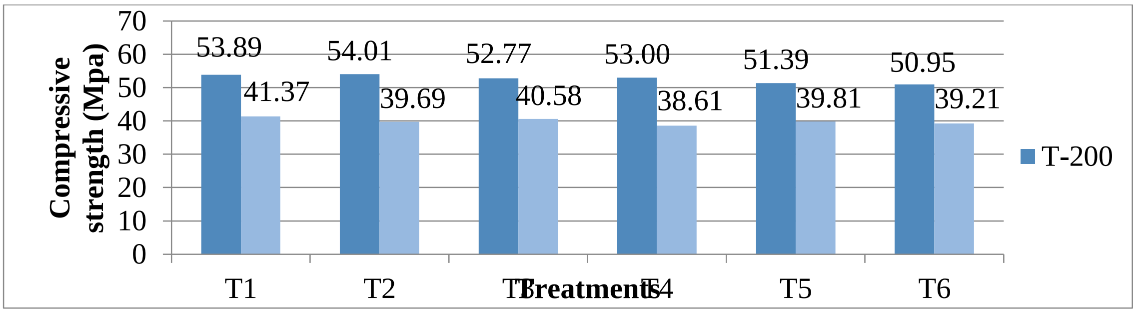


Figure 15. Residual compressive strength of concrete with crushed glasses as fine aggregate exposed to elevated temperature

The experimental test results shown in the Figure 15 clearly indicate that with inclusion of waste glass as fine aggregate doesn't impact the performance of concrete under elevated temperature and behaves similar to controlled concrete. However, the strength loss of concrete at 600° exposures is higher compared to 200°. This higher strength loss is due to blasting effect of the internal moisture at higher temperature.

3.6. Crusher dust as fine aggregate in concrete

The compressive strength of concrete with crusher dust as fine aggregate as a partial replacement of river sand at various curing period has been presented in Table 8. The effect of acids on concrete with crusher dust as fine aggregate has been presented in the Table 9.

Table 8. Effect of crusher dust as fine aggregate on concrete strength

Mix	% crusher dusts as partial replacement of river sand	Compressive Strength at Different Age (MPa)		
		7 days	14 days	28 days
C25	0	24.5	26.4	27.6
	30	28.5	27.3	31.6
	50	30.2	28.8	34.3
	70	27.9	26.8	30.8

The experimental test results shown in the Table 8 clearly indicate that with increase in the dosages of crusher dust up-to 50% of partial replacement of river sand, the compressive strength of concrete increases. Hence 50% of river sand can be partially replaced with the waste glasses as a fine aggregate in concrete for achieving a superior strength.

Table 9. Effect of crusher dust as fine aggregate on acid resistance of concrete strength

Sr. No	% of crusher dust as partial replacement of river sand	% wt. loss for 28 days acid curing	% strength loss for 28 days acid curing
1	0	4.4	8.1
2	30%	1.3	4.9
3	50%	0.5	13.3
4	70%	0.2	21.1

The experimental test results shown in the Table 9 clearly indicate that with inclusion of crusher dusts as fine aggregate up-to 30% of partial replacement of river sand, the strength loss of concrete exposed to acids reduces. However, the weight loss is lowest up to 70% of replacement of river sand with crusher dusts. This is solely because of the high density of the crusher dusts compared to the river sands.

3.7. Waste human hairs as fibres in concrete

The compressive strength of concrete with human hairs as tension crack resisting materials at various curing period has been presented in the Figure 16.

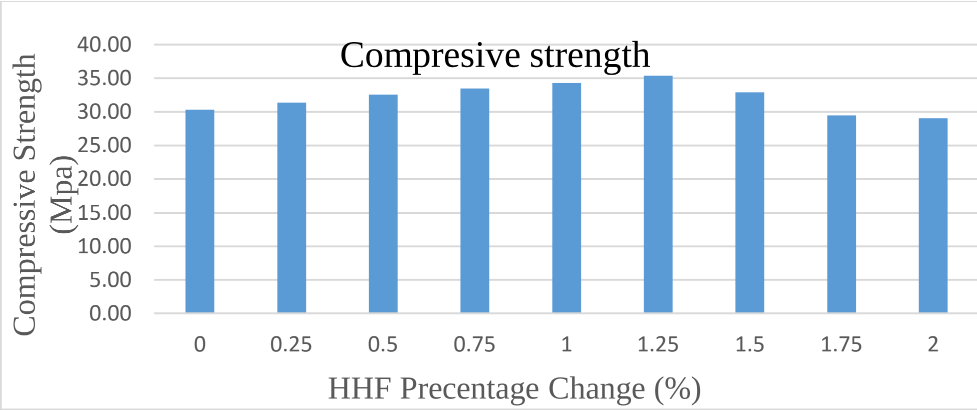


Figure 16. Effect of human hairs on compressive strength of concrete

The experimental test results shown in the Figure 16 clearly indicate that with increase in the dosages of human hair fibers up-to 1.25% of entire volume of concrete, the compressive strength increases. With further addition of human hair fibers, the compressive strength decreases. The reduction in strength is because of balling effect of the fibers in concrete beyond 1.25% addition. Hence the optimum dosages of human hair fiber as a tension crack resisting material in concrete can be taken as 1.25% of entire concrete volume.

4. Conclusions and Recommendations

Based on the various literature review, observations and experiments the following conclusions have been made.

- Adobe blocks prepared with red soil, 2.5% cement and 1.5 % of teff straws are the best suited alternative construction technique which can replace the traditional construction technique hut (Chikka-bets). Adobe technique will also help in proper utilization of the agro wastes.
- By using Adobe technology for construction, the deforestation and soil erosion can be controlled to some extent there by reducing the negative impact on our environment.
- Addition of rice husk ash and bagasse ash as a cementing material in concrete enhances the strength and durability properties of concrete there by reducing the dependency on ordinary portland cement which is a major producer of greenhouse gases.
- Rice husk ash and Bagasse ash being pozzolanic materials enhances the resistance to water and chloride penetration in concrete thereby improving the durability of concrete.
- Use of Sisal fiber and human hairs in concrete helps in stopping the propagation of tensile cracks there by enhancing the tensile strength of concrete. The use of the natural fibers helps in eradicating the dependency on artificial fibers such as glass fibers, steel fibers and plastic fibers which are not sustainable because of their higher embodied energy.

- Crusher dusts and glass wastes can be the best suited alternative to be used as fine aggregate in concrete by partially/fully replacing river sand. This will help in eradicating the over dependency on river sand as a fine aggregate. This will further help in stopping the depletion of river beds and floods damages to the agriculture lands.

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6. Conflict of Interests

The authors state that they have no conflicting interests.

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