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Full Length Research Paper

An Experimental Investigation on Sustainable Construction Materials and Technologies in Ethiopia

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Abstract

Ethiopian rural traditional house construction technique called chikka-bet is primarily dependent on woods which causes large scale deforestation. People have started looking for alternative materials and technologies such as concrete housing. However, cement, the primary material of concrete is a major producer of greenhouse gases. This paper presents an alternative construction technology for rural mud housing called Adobe which utilizes locally available soil and agro wastes. In addition, materials that are abundantly available in Ethiopia such as bermuda grass ash, granite powder, crusher dust, and sisal fibres possess the potential to be used as sustainable cementing materials, fine aggregates, and fibres. In this research, these materials have been experimentally tested for their suitability as construction materials by conducting several strength and durability. It is evident from the experimental results that adobe prepared with soil, 3.5% cement, and 1.5% teff straws possess excellent strength and durability. Experimental results have also revealed that the addition of bermuda grass ash and granite powder up to 10% of cement volume enhances the strength and durability of conventional concrete. Utilization of crusher dust 50% of the replacement of sand has been proved to enhance the mechanical properties and durability of concrete. The addition of sisal fibre which is up to 1% by volume has been proved to resist the tensile cracks in concrete. So the researchers and policymakers must ensure that these alternative techniques and materials reach the common man and construction industry for a sustainable solution for construction activities in Ethiopia.

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1. INTRODUCTION

Since ages, because of the abundant availability of forests in Ethiopia, wood have been used as the primary material for building constructions. However, the rapid population explosion in Ethiopia was leading to increased dwelling demand has resulted in large-scale deforestation. Hundred years ago more than a third of Ethiopia was covered by forest, but in the year 2000 G.C, the forest-covered area reduced to only three percentages which is a serious concern. There is clear evidence of climate change found in Ethiopia over the last couple of years caused predominantly due to large-scale deforestation. Climate change has resulted in several economic and social impacts in this region. Many local flora and fauna are on the verge of extinction and the viable living condition has gone down. Deforestation has also caused a vicious cycle of the impoverishment of the soil and erosion as a result of losing rich minerals from the soil which are vital for a good crop which is an extremely serious threat to Ethiopia from a food security perspective exacerbates the threat of famine. Studies conducted in 2008 reported 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 a good indication that soil erosion is a very serious threat to the 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-bet* 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 seen 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 earthen houses, people have started using modern technologies which utilize cement as the base material which is 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 that utilizes sustainable technology and materials for construction activities. Sharma et al. (2015), experimentally investigated the strength and durability properties of Adobe units by using locally available soil as a base material along with agro wastes as reinforcing agent and cement as a binder. The experimental results revealed that the addition of fibres and cementing agents improves the strength and durability of mud blocks because of the reduction in shrinkage. When sustainability comes into the picture, the focus must be on the locally available material which serves the purpose. In Ethiopia, there are various agricultural products are being cultivated such as Coffee, Maize, Banana, Teff, Rice, and Sugarcane, etc. Once the food grains are extracted, the remaining wastes products have the 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, tyre wastes, and plastic wastes, etc. which have the potential to be used as construction materials.

Figure 3: Agro and Industrial wastes as sustainable building materials

This research paper presents various agro wastes such as teff straws, bermuda grass ash, and sisal fibres and industrial wastes such as granite powder and crusher specks of dust as alternative construction materials which have got pozzolanic properties that are responsible for adding strength to concrete. As per ASTM C618, a "pozzolan" is defined as siliceous or siliceous and aluminous materials, which in itself possesses little or no cementing property, but will in a finely divided form and the presence of moisture chemically react with calcium hydroxide to form CSH gel which is responsible for strength enhancement in concrete. Ibrahim et al (2015), investigated the influence of Pozzolanic Materials on Properties of Concrete. The research addressed some of the pozzolanic materials such as Fly ash, Ground Granulated Blast Furnace Slag (BBBFS), Silica Fume (SF), Metakaolin (MK), and Rice Husk Ash (RHA). The experimental results revealed that the pozzolanic materials help in enhancing the strength of concrete thereby consuming the Ca (OH)2 and creating CSH gel in concrete. Various building construction technologies use soil as the base material such as compressed earth blocks, rammed earth, straw bale, and adobe, etc.

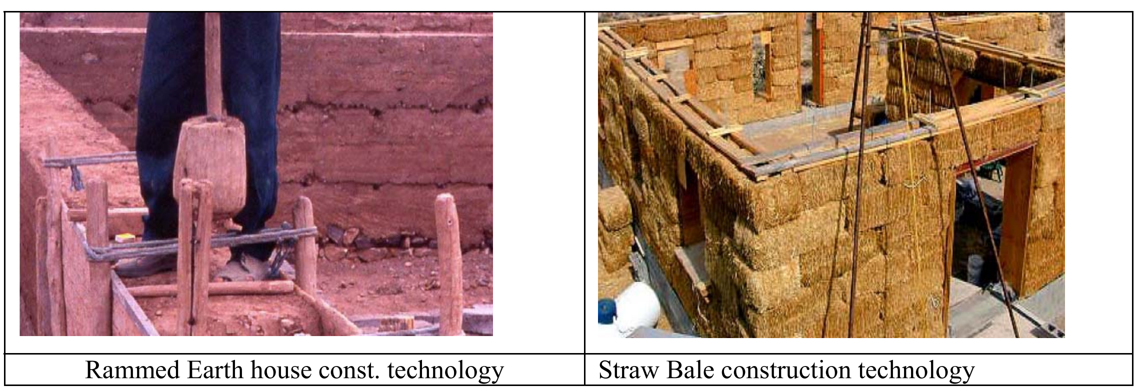

Figure 4: Building technologies with soil as base material

However from an Ethiopian perspective, the best-suited one is the Adobe technique which uses soil, a 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 that utilizes soil as a base material. To stabilize the soil, various natural/artificial binders and reinforcing agents such as banana fibres, sisal fibres, wood specks of dust, rice husk, bagasse, cement, and lime can be used. However, this research work presents adobes that use a major agro waste in Ethiopia called teff straw as a binder. From an 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, a standard proctor compaction test was conducted. Once the soil and binder were finalized, the reinforcing agent i.e. teff straw was 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

<u>Bermuda Grass Ash</u>

Bermuda grass is one of the major weeds found in Ethiopia predominantly in the sugarcane, coffee, and other cultivation lands. These weeds do not only impact the production of the crops but also cause several negative impacts on the surrounding it grows. To avoid its negative impacts, the local community often has to cut down these weeds and use them as fuel for household cooking and other small factories. When this bermuda grass burns at a controlled temperature at about 650° C, the final product comes out in form of ash which has the potential to be used as a cementing material in concrete because of its pozzolanic properties. In this research, an extensive study was conducted on the fresh, mechanical, and durability properties of concrete by partially replacing cement with bermuda grass ash using carrying out various experiments.

		
Fresh Bermuda Grass	Dry Bermuda Grass	Bermuda Grass Ash

Figure 7: Bermuda grass ash an alternative cementing material

<u>Sisal Fibre</u>

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

		
Sisal plant	Fibre extraction process	Sisal fibres

Figure 8: Sisal fibre a natural fibre for arresting tensile cracks in concrete

2.3. Industrial wastes as alternative construction materials

Granite Powder

Granite powders are the waste materials generated during the resizing of the granite plates used in construction activities. These wastes are generally unutilized and either thrown out or used as a filling material. However, these wastes having pozzolanic properties possess a great potential to be used as an alternative cementing material in the manufacturing of concrete. In this experimental investigation, these granite powders have been tried as a partial replacement of cement in the manufacturing of concrete. In this research, concrete with granite powders as a cementing material has been tested for their strength and durability properties to prove its suitability it as an alternative cementing material.

Figure 9: Granite Powder as an Alternative Cementing Material

Crusher Dusts

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

Figure 10: Crusher dusts from Hawassa Monopol as fine aggregate

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 were prepared with usual 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 was 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

Water absorption testing

Resistance to acids attack testing

Resistance to carbonation testing

Figure 11: Strength and 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

SN	Mix	14th day strength (MPa)	28th day strength (MPa)	56th 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 are shown in Table 1 clearly indicate that with the soil and cement of 2.5% as a binder when the teff straw is added from 0.5% up to 1.5%, the compressive strength of Adobe blocks increases. However with a further increase in the teff straw the compressive strength decreases. The decrease in compressive strength is because of the balling effect of fibres in soil samples. So it can be concluded that the optimum mix for adobe to be used is 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 thereby increasing the durability of the adobes. This proved that the inclusion of locally available fibres as reinforcing agents and a binder enhances the strength and durability of mud bricks as researched by Sharma et al. (2015).

3.2. Bermuda grass ash as an alternative cementing material

The density and compressive strength of concrete with *bermuda* grass ash as cementing material at various curing period has been presented in Table 2. The effect of *bermuda* grass ash on water absorption which is an important durability measure is presented in Table 2.

Table 2: Effect of *bermuda* grass ash on compressive strength of C30 concrete

Mix	% of bermuda grass ash	Density (Kg/m^3)	Compressive Strength at Different Age (MPa)		
			7 days	14 days	28 days
C30	0%	2316	21.54	24.45	26.62
	5%	2248	22.78	27.94	32.03
	10%	2219	26.41	30.92	33.98
	15%	2209	18.18	21.70	23.83
	20%	2202	15.62	18.01	19.81

The experimental test results are shown in Table 2 clearly indicate that with the increase in the dosages of bermuda grass ash a partial replacement of cement decreases the density of concrete making it lightweight compared to the controlled concrete. The reduction in density is related to the low specific gravity of the bermuda grass ash compared to cement. The results also show that with up to 10% replacement, the compressive strength of concrete is increasing, and further addition of bermuda grass ash reduces the compressive strength. The reduction in strength is because of the low workability of concrete with bermuda grass ash in concrete beyond 10% of partial replacement with cement. Hence the optimum dosages of bermuda grass ash as a partial replacement of cement in concrete from a strength perspective is 10%.

Table 3: Effect of bermuda grass ash on water absorption of C30 concrete

Grade	% RHA	Weight of Oven-Dried Sample(kg)	Weight of Saturated Sample (kg)	Saturated Water Absorption at 28 Days (%)
C30	0%	7.99	8.17	2.1%
	5%	7.98	8.14	1.9%
	10%	7.94	8.07	1.6%
	15%	7.77	7.96	2.4%
	20%	7.65	7.91	3.4%

The experimental test results are shown in Table 3 clearly indicate that with the increase in the dosages of *bermuda* grass ash a partial replacement of cement up to 10% in concrete, the resistance to water absorption increases. This is because of the pozzolanic action of *bermuda* grass ash which reduces the porosity of concrete. Hence the optimum dosages of *bermuda* grass ash as a partial replacement of cement in concrete from a water resistance perspective is 10%. This proves that the inclusion of pozzolanic materials enhances the strength and durability of concrete as researched by Ibrahim et al. (2015).

3.3. Sisal fibre as a natural fibre in concrete

The compressive strength of concrete with sisal fibres at various curing period has been presented in Table 4.

Table 4: Effect of sisal fibres on compressive strength of C40 concrete

Mix	% sisal fibre of entire volume of concrete	Compressive Strength at Different Age (MPa)		
		7 days	14 days	28 days
C40	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 are shown in Table 4 clearly indicate that with the increase in the dosages of sisal fibres up to 1% of the entire volume of concrete, the compressive strength increases. With the further addition of sisal fibres the compressive strength decreases. The reduction in strength is because of the balling effect of the fibres in concrete beyond 1% addition. Hence the optimum dosages of sisal fibre as a tension crack resisting material in concrete can be taken as 1% of the entire concrete volume.

3.4. Granite powder as a cementing material in concrete

The compressive strength of concrete with granite powder as cementing material as a partial replacement of ordinary Portland cement at various curing period has been presented in Table 5. The effect of acids on concrete with granite powder as cementing material has been presented in the Figure 12.

Table 5: Effect of granite powder on compressive strength of C30 concrete

Mix	% granite powder as partial replacement of ordinary portland cement	**Compressive Strength at Different Age (MPa)**		
		7 days	14 days	28 days
C30	0	24.5	25.4	34.9
	5	26.6	27.3	35.2
	10	27.4	28.8	36.1
	15	23.2	24.3	29.6
	20	21.9	22.8	27.9

The experimental test results are shown in Table 5 indicate that with the increase in the dosages of granite powder up to 10% of partial replacement of ordinary portland cement, the compressive strength of concrete increases. Hence 10% of ordinary portland cement can be partially replaced with granite powder as cementing material in concrete for achieving superior strength.

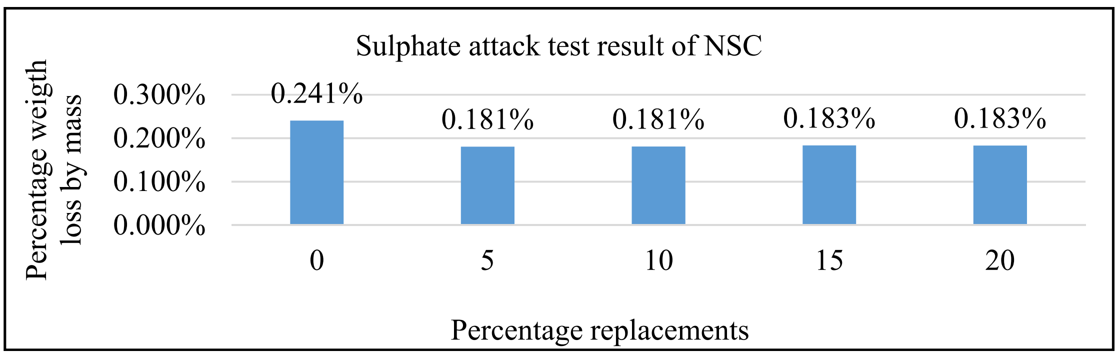

Figure 12: Effect of granite powder on acid resistance of concrete strength

The experimental test results shown in Figure 12 indicate that with the inclusion of granite powders as cementing material as partial replacement of ordinary Portland cement, the weight loss of concrete exposed to acids reduces. Hence the granite powder-based concrete can be considered for concrete construction in structures exposed to acids.

The granite powder-based concrete was also tested for its resistance to carbonation by spraying phenolphthalein indicator solution on the fracture surface of concrete followed by measuring the carbonation depth. The carbonation depth was found to be zero which indicates that the granite powdered-based concrete doesn't have any impact on carbonation.

3.5. 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 periods has been presented in Table 6. The effect of acids on concrete with crusher dust as fine aggregate has been presented in Table 7.

Table 6: Effect of crusher dust as fine aggregate on strength of C25 Concrete

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 are shown in Table 6 indicate that with the 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 waste glasses as a fine aggregate in concrete for achieving superior strength.

Table 7: 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 Table 7 indicate that with the inclusion of crusher specks of dust 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 the replacement of river sand with crusher specks of dust. This is sole because of the high density of the crusher specks of dust compared to the river sands.

3.7. Conclusions and Recommendations

Based on the various literature reviews, 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 i.e. Chikkabet. 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 bermuda grass ash and granite powder as cementing materials 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.
- Bermuda grass ash and granite powder being pozzolanic materials enhances the resistance to water penetration in concrete thereby improving the durability of concrete.
- Use of Sisal fibre in concrete helps in stopping the propagation of tensile cracks

there by enhancing the tensile strength of concrete. The use of the natural fibres helps in eradicating the dependency on artificial fibres such as glass fibres, steel fibres and plastic fibres which are not sustainable because of their higher embodied energy.

- Crusher dusts can be the best suited alternative to be used as fine aggregate in concrete by partially 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.

Disclosure statement

No potential conflict of interest was reported by the authors

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Declarations

This article is not published anywhere and under consideration for publication. There is no conflict of interest.

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