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IMPROVING ENERGY CONSUMPTION AND DURABILITY OF THE CLAY BAKEWARE (MITAD)

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ABSTRACT

properties and production systems of some clay and sandy clay deposits used for mitad making in Tigray region, Ethiopia were investigated with a view to determine their suitability for use as energy efficient bakeware. The samples were collected from three different commercial pottery mitad centers around Tigray; they are Adi-harta from samre, akatsil from Selekleka, Romanat from Enderta. Two varieties of soil samples from each Centre were collected from all of the three selected areas. The samples were crushed, pulverized, sieved and their chemical compositions were determined. The clay samples were treated separately and blended together in different proportions then moulded into 12 cm diameter clay disks. Samples with different thickness and grain size were also prepared. The clay disks were dried and fired to 900 oC. Tests for thermal conductivity, water absorption rate, and compressive strength were carried out on each sample.

The results showed that the samples from Romanat having the highest SiO2 content with a lesser clay composition displayed the highest thermal conductivity. The samples with a smaller thickness and smaller grain size also possess higher thermal conductivity, diffusivity and compressive strength but, Cement addition was found to decrease these properties.

*The sample with 0.7 cm thickness, 45µm grain size, and 10% clay to sandy clay ratio were found to have thermal conductivity of 0.417 W/mK, thermal diffusivity of 2.71*10-7m2/s, and compressive strength of 12.89 MPa. This mitad has reduced the energy lost after baking of the local mitad by 56.39%. This mitad also has improved the thermal conductivity, thermal diffusivity, compressive strength of the local mitad by 30.72%, 10.7% and 46.96% respectively.*

Keywords

Keywords: Mitad, Clay, Ceramics, Pottery, Energy Efficiency, Enjera,

1. INTRODUCTION

The Enjera pan (Mitad) is made of clay and has a diameter of 45-60 cm. Enjera, large pancake-like bread, is the staple food of Ethiopia. Mitad is the cultural bakeware of Enjera in Ethiopia, since enjera is the most preferable food of Ethiopian's, mitad is the main energy consuming material among the household utensils used for cooking or baking. According to the research done by the embassy of Japan, Only 10% of the total energy consumption in Ethiopia is supplied by electric power and the rest is from primitive resources, such as wood fuel and dung [1]. The household sector takes up nearly 90% of the total energy supplies. Access to energy resources and technologies in rural Ethiopia is highly constrained. Physical and economic access to biomass resources is deteriorating because the resources are exploited beyond their carrying capacity. This results in higher household expenditures of labour, time or cash, while modern energy services are totally unavailable. The energy infrastructure is underdeveloped because of the low-economic capacity of the government and other development agents and users [2].

Researches show that rural households use an estimated 50 million m3 of wood per year for cooking and lighting. This has contributed to rapid loss of tree resources. This in turn has caused loss of soil nutrients and decline in agricultural productivity [3].

Research done in southern part of Ethiopia reveals that In all settlement typologies, baking enjera consumes the most fuel wood and accounts for about 60 percent of total household fuel consumption [2]. This being the fact, new development and improvements on this area has been started scientifically in 1983, which most of them are done on enhancing the efficiency of the stove. But, no research was being conducted to improve the energy efficiency of the clay disk pan (MITAD).

2. MATERIALS and METHODS

2.1. Study Area Selection and Data Collection

Romanat from Enderta, Adi-Harta from Samre and Akatsil from Selekleka were selected according to the variation in their geographical occasion, product quality and price. The raw materials, the production steps they follow, and their finished products were observed, recorded and taken for further investigation.

2.2. Sample Preparation

2.2.1. Physical and chemical properties of raw clay and sandy clay samples

The chemical composition of the soil samples were analyzed by X ray fluorescence (XRF 3000 Bruker ax5 with spectra phase) with pressed pellets in Addis Ababa geotechnical survey and that of the pozolana cement that has been used was also taken from Messobo cement factory.

Table 1. Chemical composition of clay and sandy clay samples

Field name	Oxides in (%)										
	SiO_2	AlO_2	FeO_2	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	LOI (%)
C.S(Samre)	55.35	13.16	9.06	1.91	9.61	0.69	2.12	0.86	0.11	0.15	6.98
C.S(selekle)	50.23	16.08	17.39	1.57	2.66	0.73	1.80	1.87	0.16	0.08	7.44
S.S(selekle)	45.70	8.44	13.92	11.31	6.72	3.20	1.69	1.62	0.19	0.84	6.38
S.S(Roman)	61.10	19.70	4.91	0.27	0.89	5.19	4.33	0.04	0.22	0.03	3.34
S.S(samre)	49.75	12.48	12.81	9.01	5.85	3.28	1.39	1.58	0.15	0.26	3.44

*s.s = sandy clay sample, c.s = clay sample

Table 2. Chemical composition of cement from Messobo cement factory

	Oxides in (%)										
Name	SiO2	AlO2	Fe2O3	CaO	MgO	Na2O	K2O	TiO2	Mn2O3	P2O5	SO3
Cement	19	6	3	62	3	0.3	0.7	0.5	2.5	1.5	1.3

The physical behaviours of the samples especially their Atterberg limit has been done and recorded; the liquid limit of the samples is measured using a standard casagrande cup

Table 3. Atterberg limit of clay and sandy clay samples

Sample name	Sandy clay Samre	Sandy clay Selekleka	Sandy clay Romanat	Clay Samre	Clay Selekleka
Liquid limit	26	42.7	30	48	53.3
Plastic limit	12	29.1	22.5	29	31.1
Plasticity index	14	13.6	7.5	19	22.2

2.2.2. Baking or Forming Of Mitad Sample

After samples were crushed down and sieved with an electrical sifter having 9 different sieve numbers i.e. 1mm sieve, 45 µm, 90 µm, 150 µm,180 µm, 250 µm, 355 µm, 500 µm, 710 µm sieves. Samples of 12cm in diameter with varying thickness, composition, and grain size were prepared. On doing so, a 300 g of sandy clay is weighed and an appropriate percentage of clay is calculated and weighed and is then mixed with optimal amount of water. The mixtures were baked in to the prepared circular split pattern made from steel and fixed using a C-clamp.

2.2.3. Drying

After the samples are baked they are allowed to stay in a room for an average of 8 hours and are later splitted from their clamp and exposed to sun light on the following manner for up to an average of 3 days which largely depends on the condition of the sunlight.

Fig.1. Mitads Collected

Fig.2. Sample Baking

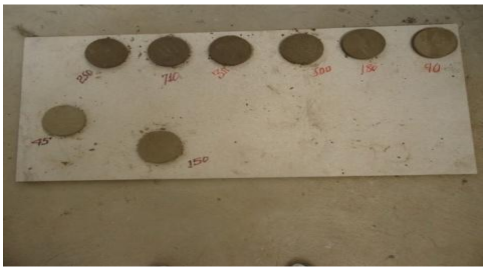

Fig.3. Drying Using Sun Light

2.2.4. Firing

The samples were fired up to 900^{o}C in a heat treatment furnace (C.E 612) that can reach a maximum temperature of 12000C with a 10oC increase per minute.

2.3. Thermal conductivity of the prepared sample mitad and the local mitad

The thermal conductivity were determined using A lee's disc apparatus with 12 cm aluminium disk and a 5 cm deep aluminium chamber which works on a heat source from the steam that comes from heated water [4].

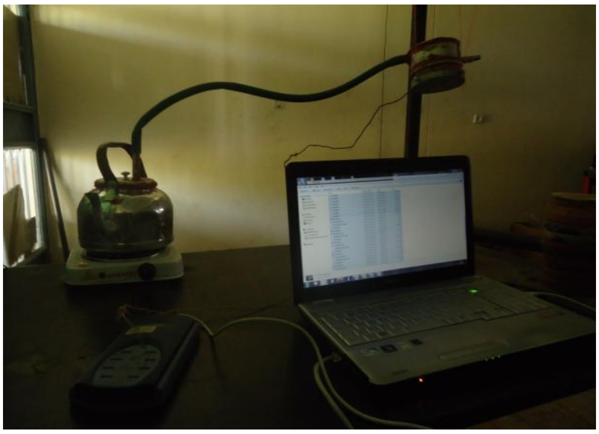

Fig.4. Lee's disk apparatus

Procedures

1. The clay disk was put in between the aluminium disk and aluminium chamber connected to the heat source by a plastic tube to transport the steam and heat the chamber.
2. the stove was switched on slowly so as to feed heat to the steam chamber
3. Two thermocouples of type K were connected each one to the heat chamber and aluminium disk for reading the input temperature T1 and disk temperature T2.
4. Then the thermocouples were connected to a pico-loger which in-turn is connected to a computer so that the temperature T1 and T2 are read every 30 seconds in the software installed in the computer. The temperature T1 and T2 are recorded at steady state (temperature changes less than 10C in 5 minutes).
   Then, the clay disk is removed and the heat chamber is put directly over the aluminium disk. T2 (82.6 OC) which is the temperature of the aluminium disk is recorded at its steady state. Consequently the heat source is closed and the drop in temperature is recorded every thirty seconds until the temperature reaches 50C below the steady state temperature.
5. Using the recorded cooling temperatures the cooling curve is plotted. From the curve the rate of cooling of the metallic disk $(\frac{dT}{dt})$ is determined to be 0.028 K/s.

The coefficient of thermal conductivity of the samples is calculated as follows

$$K = \frac{MC\frac{dT}{dt}}{\pi r^2 (T_1 - T_2)} * \frac{(r-2h)d}{2(r+h)} \quad [4]$$

Where

M is the mass of the aluminium disk, K is the coefficient of thermal conductivity of the clay disk,C is the specific heat capacity of aluminium, $\frac{dT}{dt}$ Is the rate of cooling of the metallic disk,

r is the radius of the sample, h is the thickness of the metallic disk,

T1-T2 is temperature difference of the sample at steady state, d = thickness of sampleparameters of the lee's disk apparatus are shown here below.

Specific heat of aluminium = 910 J/ kg. K, Mass of the aluminium disk = 0.85 kg

Thickness of the metallic disk = 0.019 m, Radius of the samples = 0.06 m

2.4. Compressive strength of sample mitad and local mitad

After the samples were fired to 900°C they were put in a mechanical compressive strength machine as shown below. The compressive strength of the samples is calculated as follows.

Compressive strength = $\frac{\textbf{load (force) applied}}{\textit{cross sectional area}}$ [5]

2.5. Water absorption rate of sample and local mitad

Testing for water absorption of the samples is done first weighing the dry weight of the samples and immersing them in cold water for 24 hours. After they come out of the water, they are polished and dried to remove the water not basically absorbed. And are then weighed so that their absorption rate is calculated as follows

Water absorption rate in (%) =

$$\frac{\textbf{total weight} - \textbf{dry weight}}{\textbf{dry weight}} * 100\%$$ [5]

3. RESULTS AND DISCUSSION

The thermal conductivity of the mitad has increased while thickness decreases, it has increased from 0.38 W/m K for 0.019 m thickness to 0.409W/m K for 0.007 m thickness of sample. Its thermal conductivity has increased by 7.63%. The sample with the thickness of 0.005m has better thermal conductivity than 0.007 m thickness sample. But, during drying the sample 0.005m thickness has cracked and was out of need. So, it can be said that the sample with thickness of 0.007m is the thickness that can be done with the available raw materials to give the required strength and durability.

And also, it is observed from all the samples that there is an increase of thermal conductivity as the percentage of clay (binder) composition decreases. The best thermal conductive of all the samples having the same thickness (0.015m) is the sample from Romanat with 10% clay to sandy clay and 1mm grain size. Its thermal conductivity is 0.385 W/m k as show in fig below.

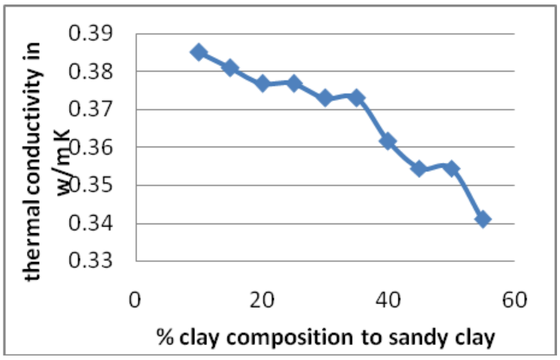

Fig.5. Thermal conductivity versus % clay to sandy clay composition of samples from Romanat

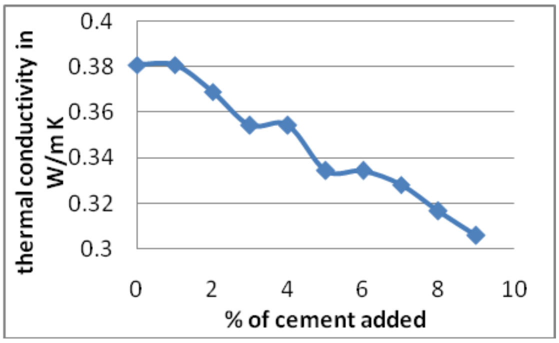

Fig.6. Thermal conductivity versus % cement to sand composition of samples from Selekleka

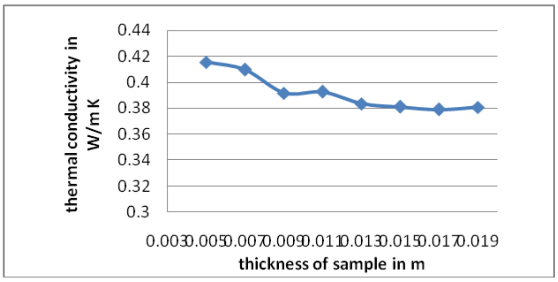

Fig.7. Thermal conductivity versus thickness of samples (30% clay to sandy clay composition) from Selekleka

Adding cement for the samples has brought with lesser thermal conductive fig.6. and unexpectedly its compressive strength was also less than the cement free samples. So; adding cement to cookware and bakeware has a negative effect on thermal conductivity and durability.

Size reduction of the raw samples for making mitad has come with increasing the thermal conductivity of the composite. The thermal conductivity has increased from 0.381 W/m K to 0.407 W/m K from 700μm to 45μm grain size for Selekleka mitadas shown in fig.7. There is 6.82% increase in thermal conductivity.

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So, a sample from Romanat having 10% clay to sandy clay composition, 0.007m thickness, 45µm grain size has:-

Sample thermal conductivity for Romanat = thermal conductivity of sample from Romanat having 10% clay to sandy clay ratio with 0.015 m thickness + increase in thermal conductivity due to thickness reduction to 0.007m + increase in thermal conductivity due to grain size reduction to 45µm.

= 0.385 W/m K + 0.385 W/m K *0.0763+0.385 W/m K * 0.0682

= 0.417 W/m K is the thermal conductivity of the new mitad developed.

3.1. Mitad Energy Consumption

3.1.1. Mitad Local Energy Consumption

The energy consumption of mitad depends mainly on its thermal conductivity, heat capacity and thermal diffusivity. The thermal conductivity and thermal diffusivity also influences the heating up time of the utensil. Here below calculated is the energy consumption of the local mitad. For the local mitad the heating up time and the baking temperature of enjera is found through field testing.

Basic Data

About Injera

- Mass of one Injera 349 gm, Average number of Injera for one family at one session is 30
- Mass of dough for 30 Injera is 16kg (70% of it is water and 30% of it is cereal)
- Cp of wheat is 3.65KJ/Kg 0K ...[6], Baking temperature of Injera = 1800c-2100c.
- Mass of water that evaporates during baking = mass of liquid dough – mass of enjera = 0.5333kg - 0.349kg = 0.184 kg

About Mitad

- Diameter of Mitad = 60 cm, Thickness of mitad = 1.9 cm, Mass of Mitad average = 7kg
- Cp of Mitad 0.92KJ/Kg 0k-1KJ/Kg 0k ...[7],
- Thermal conductivity of local mitad 0.319 W/m K

Other accessory data

- Time needed to reach the electric Mitad from room temperature to cooking temperature is 5 min. and is 20 min average for the wood firing local mitad.
- Time needed to bake one Injera 2 min, The time gap between successive Injera is 30sec.

3.1.2. Calculation of Energy needed for heating up

Heat needed to reach the temperature of baking is

Q = Mc (Th -Ta) [5]................................ (1)

Using the input data

Q = 7 kg * 1KJ/Kg 0k * (210 – 22) k = 1313 KJ

The heat loss during heating up is calculated as follows

$$Q = \frac{k*A*(T_h - T_a)*t}{d} \quad [5]............................(2)$$

Known values

Area of mitad = $\frac{\pi D^2}{4} = \frac{\pi 60^2}{4}$ = 0.2827 m2;

K= 0.319 W/m K; d = 1.90cm = 0.019m; t = 300 Sec; Th = 210 oC; Ta = 22 oC;

Substituting the above values in equation (2);

Heat loss through mitad during heating up for electric mitad is;

$$Q = \frac{0.319\frac{W}{mk}*0.2827m^2*(210-22)k*300\ sec}{0.019\ m} = 267.696\ kJ;$$

Heat loss through mitad during heating up for local mitad is;

$$Q = \frac{0.319\frac{W}{mk}*0.2827m^2*(210\ oC - 22\ OC)*1200\ sec}{0.019\ m} = 1070.784\ KJ$$

The amount of heat needed for heating up is the sum of the energy stored and the energy lost.

Energy needed (for local wood mitad) = 1313 KJ + 1070.784 KJ = 2383.784 KJ

Energy needed for heating up (electric mitad) =**1313 KJ + 267.696 kJ = <u>1580.696 kJ</u>**

3.1.3. Energy required to raise the food ingredient from ambient to cooking temperature

Dough is a mixture of cereal (now wheat powder) and water, so two of the mixtures should come to the baking temperature.

The heat needed to raise the cereal from ambient temperature to baking temperature is given from equation 8;

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$Q1 = M\ C\ (Th - Ta)$ [5] ;
Known values
M = 349 gm = 0.349kg; C = 3.65 KJ/kg K; Th = 210 oC; Ta = 22 oC;
Substituting the known values
Q1 = 0.349 kg * 3.65 kJ/kg k (210 oC -22oC) = 239.484 KJ.

239.484 KJ is the heat needed to raise the cereal fraction from ambient to baking temperature.

The heat needed to raise the temperature of water fraction from ambient to baking temperature from equation 8.

$Q2 = Mc\ (Th - Ta)$ [5]
Known values
M = 184 gm = 0.184kg, C = 4.220 KJ/kg k, Th = 210 oC, Ta = 22 oC
Substituting the known values
Q2= 0.184kg * 4.220kJ/kg k (210 oC -22 oC) = 145.987 KJ

145.987 KJ is the heat needed to raise water fraction from ambient to baking temperature.

Total heat energy needed to bake one enjera

Q1+Q2 = 239.484KJ +145.987KJ = 385.46 KJ

Total heat needed to bake 30 enjera = 385.46KJ*30 = 11563.867 KJ

3.2. Energy consumption of the current/new mitad

Calculation of Energy needed for heating up

Heat needed to reach the temperature of baking is using equation 1

$Q = Mc\ (Th - Ta)$;[5] Where

Q = the heat needed to reach the temperature of baking enjera;

M = mass of mitad with a thickness of 0.007m, 45µm grain size from Romanat is 3.266kg;

The density of the sample with 45µm grain size is 1538.887kg/m3 and area of mitad is 0.2827m2, thickness of the sample is 0.007m;

Then inserting this value to the equation below gives;

M = 1538.887 kg/m3 * 0.007m*0.2827m2 = 3.045kg;

c = Specific heat of mitad (0.9- 1 KJ/Kg K); Th = temperature of baking = 210 oC;

Ta = ambient temperature = 22 oC; Using the input data

Q = 3.045 kg * 1KJ/Kg 0k * (210 – 22) k = 572.517KJ

This result shows that the heat stored in the mitad during heating up time is decreased from 1313 KJ to 572.517 KJ due to the decrease in the thickness of mitad from 1.9 cm to 0.7 cm which decreases the mass of mitad from 7 Kg to 3.045 Kg.

The amount of heat stored in the heating up time is almost equal to the amount of heat left after baking is finished. That is; the amount of heat lost to the environment. So, it can be said that decreasing the heat stored in the bakeware by 740.48 kJ is saving this amount of energy from that was to be lost to the environment.

740.48 KJ of energy is saved in each period of baking enjera by using the newly proposed mitad.

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3.3. Summarized comparison of the current and the local Mitad

The comparison of the local electric, wood burning and current proposed mitad are summarized in the table below

Table 4. Comparison of properties between the local mitad and the new mitad

	Wood burning mitad	Electric mitad	Current mitad in wood burning stove	Current mitad in electric stove	Percentage improvement(%)
Thermal conductivity in W/m K	0.319	0.319	0.417	0.417	30.72
Heat diffusivity in m^2/s	$2.448*10^{-7}$	$2.448*10^{-7}$	$2.71*10^{-7}$	$2.71*10^{-7}$	10.7
Heat lost after baking in KJ	1313	1313	572.517	572.517	56.39
Thickness in cm	1.9	1.9	0.7	0.7	63.16
Density In Kg/m^3	1303.22	1303.22	1538.887	1538.887	18.03
Compressive strength in MPa	6.87	6.87	12.89	12.89	46.7
Water absorption rate in %	17.21	617.21	6.03	6.03	minimum of 64.96

4. CONCLUSION

- Due to lesser thermal conductivity coefficient and higher specific heat capacity of clay; the addition of more clay to sandy clay has displayed lesser thermal conductivity and higher specific heat capacity. This characteristic of the local mitad has made it a high energy consuming utensil. It was also found to be less durable.
- The addition of cement has a negative effect on the quality of mitad, that is, it has lowered the thermal conductivity, thermal diffusivity and compressive strength as well.
- Out of the 58 samples prepared and analysed, the sample with 0.7 cm thickness, 45μm grain size, and 10% clay to sandy clay ratio were found to have thermal conductivity of 0.417 W/m K, thermal diffusivity of 2.71*10-7m2/s, and compressive strength of 12.89 MPa. This mitad has reduced the energy lost after baking of the local mitad by 56.39%. This mitad also has improved the thermal conductivity, thermal diffusivity, and compressive strength of the local mitad by 30.72%, 10.7% and 46.96% respectively.

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