Chemistry and Materials Research
ISSN 2224- 3224 (Print) ISSN 2225- 0956 (Online)
Vol.10 No.4, 2018

Investigation of the Bonding Characteristics of Termite Hill Clay in Akure, Ondo State, Nigeria for Use in Foundries

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Abstract

On annual basis, the activities of termites to man's habitat have been found to be destructive. Interestingly, man still goes in search of these insects day-in-day-out because of their usefulness in making life more convenient. In this work, the bonding characteristics of an active termite hill clay in the as – received state have been investigated. Three (3) different layers of clay: (Outermost layer -TCH 1; middle layer -TCHM 1 and innermost layer -TQH 1) from a termite colony were separately collected from a forest settlement in Akure, Nigeria, prepared and analyzed by means of compressive strength testing using an Instron Universal tester and mineralogical composition characterization using X-ray mini diffractometer.While results of the compressive strength testing showed that TQH 1, the innermost layer withstood the maximum compressive load of 3,370.27612N and absorbed 51.56948J in the process, results from the mineralogical composition characterization revealed that TQH 1 contained Sillimanite which melts around 1,850^{O}C.This work is of paramount importance to the use of locally available materials, and in large quantities in Nigeria at little or no cost. This has implication for the development of foundries and foundry activities in order to meet up with the increasing demands of the foundry.

Keywords: Mineralogical composition, compressive strength, as – received, colony, foundry, termite- hill clay.

1. Introduction

The destructive nature of termites renders so many products useless in many homes globally on annual basis, especially wood and concrete. Nevertheless, humans still find them very useful to their habitat based on their dynamism, without which man's survival would have been a bit difficult. For instance, the feeding and building activities of termites contribute majorly and positively to soils hosting their hills in many ecosystems by modifying them and improving their properties (Jouquet *et. al.,* 2002; Kaschuk *et. al*., 2006; Ackerman *et. al*., 2007; Mujinya *et. al.,* 2013; Ganguli *et. al*., 2014). This means that termites function as the sole decayer of plant and organic materials, thus serving as soils' nutrient recycler for further use by other living organisms (Orhue *et. al.,* 2007). Angier (2015) emphasized that termites play significant roles in the wellness of the soil. From their findings, Orhue *et. al* (2007) specified that termites' activities on soils lie solely on vegetation type and land use. As such, their dwellability in an environment is largely governed by soil, vegetation type and prevailing climatic conditions (Ata *et. al.,* 2006; Orhue *et. al.,* 2007). Therefore, the role of termites towards clay formation may be more significant than that of earthworms. Termites live abundantly on land and actively recycle the lignocellulose therein. Angier (2015) and Mackean (2016) reported that about 2,000 – 3,000 species of termites are in existence. While large species of the insects are evenly distributed across different ecosystems, some are peculiar to certain regions or belts (Ata *et. al.,* 2006). The type of termites in a particular colony determines the shape and size of the hill (Orhue *et. al.,* 2007). While some are hillock-shaped, others have different turrets or run in straight hollow tower, resembling a chimney. Little wonder they are generally referred to as master builders (Oberst *et. al*., 2016). Interestingly, the queen of the termites and her thousands of eggs and new babies, located in the centre of the termite mound are guarded by several armies and workers. Moreover, termites end up in the mouths of birds, lizards, small mammals and especially people as the insects are known to be rich in protein and fat. Even as termites continue to play important roles in the ecosystems of man and other living organisms, they build their hills from refractory material, cellulose material and a hardening secretion from their mouths or rectum, which make the walls of such hills to be hard and rigid (Ganguli *et. al,.* 2014; Adekola, 2016) . These hills overtime are still being put to other numerous uses by man. For example, Mijinyawa *et. al.* (2007) reported the use of termite hill clay as brick-making material for constructing the grain silo. Ata *et.. al.* (2006), while emphasizing that present housing policies in Nigeria encourages the sourcing of alternative, yet quality construction materials in order to cut down construction costs found the termite hill clay to be a suitable material for plastering purposes. Nwankonobi *et.. al.* (2014) reported the effects of blending rice husk-ash with termite clay in terms of physical and mechanical properties for housing purposes in the rural areas. While Folorunso *et. al.* (2015) evaluated the use of purified, alumina-reinforced termite hill clay as insulating bricks, Folorunso (2015) blended graphite and rice-husk into purified termite hill clay for the lining of furnaces. Furthermore, Omobowale *et. al.* (2015) investigated the thermal properties of the termite hill clay in relation to constructing grain silos. Assam *et. al.* (2016) assessed the use of processed termite hill clay as a stabilizing agent in some other clay soils. Otieno *et. al.* (2015) worked on uncalcined termite hill soil as partial replacement in cement for use as a sustainable material in Kenya (as roofing tiles). Adekola (2016) evaluated the compressive strength attainable, on reinforcing the termite hill clay with rice-husk. However, according to Hesse (1995), no known investigation has been reported concerning the characteristics of termite hills or the factors responsible for them. In this work, the bonding characteristics of the termite hill clays have been investigated in terms of compressive strength for subsequent use in foundries. The justification for this work was based on: (1) The need to develop suitable refractories for local fabrication of furnaces as well as kilns among others and (2) The folding up of small scale foundries in Nigeria due to high cost of importation of refractory materials to sustain such foundries. Therefore, the objective of this study was to examine the bonding characteristics of the different layers of the termite hill by evaluating their compressive strengths based on compression test, as well as mineralogical composition characterization based on XRD analysis.

2. Literature Review

For centuries now, humans and termites have been carrying out diverse construction activities using clay. However, man still put this unique soil to several other uses, including industrial uses (Akinola and Obasi, 2014). Certain factors, such as deposition environment, geologic and geographical origin to mention a few determine whether the resulting soil will appear whitish (kaolin) or reddish to brownish (clay) (Akinyemi *et. al.*, 2014). Termite-hills are commonly built with the reddish/brownish clay types. The mineral, clay, is identified as a member of the phyllosilicate family and as a secondary mineral formed from the chemical weathering of the parent material (Williams and Haydel, 2011; Akinyemi *et. al.*, 2014). Clay is a unique mineral type with diverse applications and cannot be possibly described by just one definition (Irabor, 2002; Swedish Ceramic Institute, 2004; Shenoy and Shenoy, 2010; Johnson, Rautureau *et. al.*, 2017). Overtime, numerous types of clay have been discovered and reported, including the refractory clay (Rautureau *et. al.*, 2017). Alone in Nigeria, the mineral, clay, has been found in all the 36 States of the federation (Obaje, 2009).Towards the middle of the twentieth century, a scientific and reliable means of investigating the internal arrangement of clay particles known as X-ray diffraction was derived, but several other analytical techniques, including Scanning Electron Spectroscopy (SEM), X-ray Energy Dispersive Spectroscopy (EDS) and so on have since emerged (Rautureau *et. al.*, 2017).

3. Materials and Methods

Several trips were made to a forest settlement in search for an active termite colony in Akure, Ondo state, Nigeria. With the aid of a shovel, and in a matter of days, an active termite hill, about 2m high was carefully dug out and in layers. The first layer, known as the outermost layer (TCH 1) was collected in lumps and kept aside. Another layer, with white and black coloration and, referred to as the mid – layer (TCHM 1) was reached and also collected. Finally, though with some difficulty, the innermost compartment, known as the Queen house (TQH 1), inside which the termite Queen was embedded along with her newly born babies and surrounded by hundreds of soilder termites was reached and taken. On collection, these three (3) separate clay types in their lumps were taken to the laboratory for analyses using the XRD Mini Diffractometer 10 to run the X – Ray diffraction test and Instron universal tester to run the compression test.

Figure 1: The site of the termite hill with the outermost and mid layers.

Figure 2: The termite queen with some of her newly born babies in the innermost compartment.

4. Results and Discussion

From the XRD analysis, it was shown that the outermost layer (TCH 1) contained Microcline (Potassium Aluminium Silicate, **$KAlSi_3O_8$**) (Figure 3); the middle (mixed) layer (TCHM 1) contained Sodium dachlardite (Sodium Aluminium Silicate hydrate, **$Na_4(Al_4Si_2O)O_{48}I_{13}H_2O$**) (Figure 4) while the innermost layer, that is, Termite queen house (TQH 1) contained Sillimanite (Aluminium Silicate, **Al_2SiO_5**) (Figure 5).

Microline: belongs to the group of Potassium feldspars, in the silicate class and tectosilicate subclass. Its hardness varies between 6 and 6.5 and with specific gravity of 2.6. At normal pressures, the melting temperature is 1,250. However, when pressure is varied, it melts between 593.5 and 1,093^{o}C. Its origin is traceable to the Igneous – rock forming tectosilicate mineral and with a molecular weight of 278.33gm.

Sodium dachlardite: belongs to the Zeolite group, in the silicate class and tectosilicate subclass. Its hardness varies between 5 and 5.5 and with specific gravity of 3.2. Melting point is well below 900°C. It usually associates with minerals like quartz, calcite serandite, apophylite, natrolite, stilbite, heulandites and other zeolites.

Sillimanite: Its hardness varies between 6 and 7.5 and with a specific gravity of 3.2. The melting temperature is 1,850°C. It is normally used as a refractory material in the form of mullite and its properties are similar to that of mullite. The Sillimanite – to – Mullite transformation occurs between 1,350 – 1540°C. It undergoes a volumetric change of about 2 – 3% between 1545 – 1550°C. It has a molecular weight of 162.05gm.

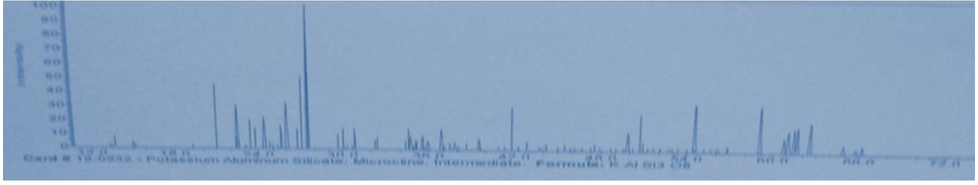

Figure 3: Graph showing the Peak values from the outermost layer.

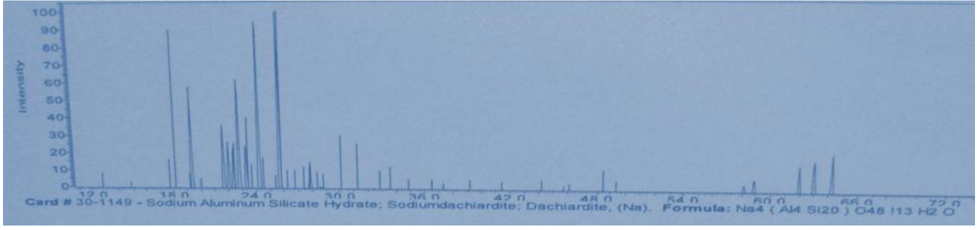

Figure 4: Graph showing the Peak values from the middle/mixed layer.

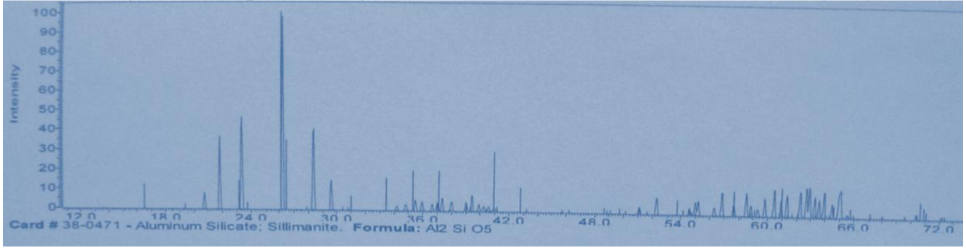

Figure 5: Graph showing the Peak values from the innermost layer (Queen house).

Shown in Table 1 is a standard on the properties of some common ceramics derived from the Engineering tool box (200aa

Material	**Specific Gravity**	**Coefficient of Linear Expansion** *(10^6 ppm/°C)*	**Maximum Safe Operating Temperature** *(°C)*	**Thermal Conductivity** *(10^{-3} cal/cm^2/ cm/sec/°C)*	**Tensile Strength** *(psi)*	**Compressive Strength** *(psi)*	**Flexural Strength** *(psi)*	**Modulus of Elasticity** *(10^6 psi)*
Porcelain	**2.2-2.4**	**5.0-6.5**	**400**	**4-5**	**1500-2500**	**25000-50000**	**3500-6000**	**7-10**
Alumina Porcelain	**3.1-3.9**	**5.5-8.1**	**1350-1500**	**7-50**	**8000-30000**	**8000-25000**	**20000-45000**	**15-52**
High-Voltage Porcelain	**2.3-25.5**	**5.0-6.8**	**1000**	**2-5**	**3000-8000**	**25000-50000**	**9000-15000**	**7-14**
Zirconia Porcelain	**3.5-3.8**	**3.5-5.5**	**1000-1200**	**10-15**	**10000-15000**	**80000-150000**	**20000-35000**	**20-30**
Lithia Porcelain	**2.3-4**	**1**	**1000**			**60000**	**8000**	
Cordierite Refractory	**1.6-2.1**	**2.5-3.0**	**1250**	**3-4**	**1000-3500**	**20000-45000**	**1500-7000**	**2-5**
Alumina Silicate Refractory	**2.2-2.4**	**5.0-7.0**	**1300-1700**	**4-5**	**700-3000**	**13000-60000**	**1500-6000**	**2-5**
Magnesium Silicate	**2.3-2.8**	**11.5**	**1200**	**3-5**	**2500**	**20000-30000**	**7000-9000**	**4-5**
Steatite	**2.5-2.7**	**8.6-10.5**	**1000-1100**	**5-6**	**8000-10000**	**65000-130000**	**16000-24000**	**13-15**
Forsterite	**2.7-2.9**	**11**	**1000-1100**	**5-10**	**8000-10000**	**60000-100000**	**18000-20000**	**13-15**
Titania/Titanate Ceramics	**3.5-5.5**	**7-10**		**8-10**	**4000-10000**	**40000-120000**	**10000-22000**	**0.3-0.5**

1 psi (lb/in^2) = 6,894.8 Pa (N/m^2)

On comparing the results obtained from the XRD analysis with Table 1, it was seen that Microcline, with a melting temperature of 1,250^{0}C is above the safe operating temperature of refractories like high voltage porcelain, Lithia porcelain, Zirconia porcelain, Steatite, Magnesium silicate and Fosterite but matches exactly with that of Cordierite refractory.

Sodium Dachlardite, with a melting temperature well below 900^{0}C will only perform within the safe operating temperature of porcelain, which is 400^{0}C.

Sillimanite has a melting temperature of 1,850^{0}C and is thus well above the safe operating temperature of refractories like high voltage porcelain, Lithia porcelain, Zirconia porcelain, Steatite, Magnesium silicate, Fosterite and even those of other refractories like Alumina porcelain and Alumina silicate refractory.

Results from the Compression test (Figure 6) include the graph of all the parameters under consideration, such as compressive extension, compressive load, energy, compressive stress and strain all at yield. Most prominent is the compressive load at yield withstood by each of the layers of the termite clay hill.

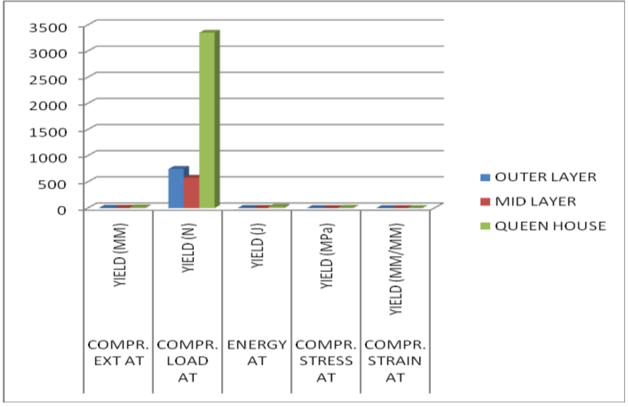

Figure 6: Graph of Sample type versus Compressive extension (mm), Compressive load (N), Energy (J), Compressive stress (MPa) & compressive Strain all at yield.

Shown in Figure 7 is the graph of sample type versus compressive load (N) and energy (J) at yield. It could be seen that some amount of energy was absorbed by each layer of the termite hill in demonstrating a particular amount of load, so that while the Queen house (TQH 1) absorbed 24.02843J of energy to display a load of 3,352.05347N, only 1.49632J of energy was consumed by the middle (mixed) layer (TCHM 1) to display a load of 578.93970N. The outermost layer absorbed 1.89846J of energy to display a load of 747.79181N.

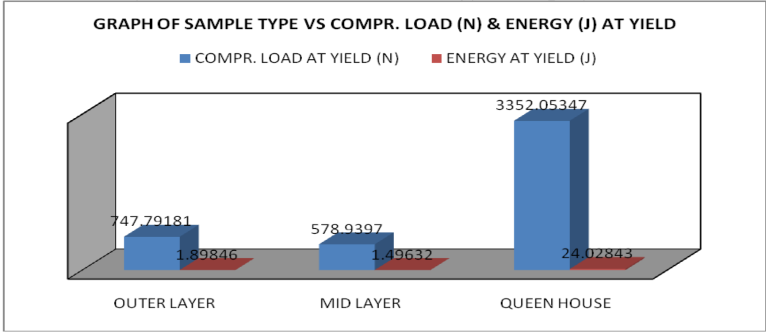

Figure 7: Graph of Sample type versus Compressive load (N) & Energy (J) at yield**.**

Figure 8 is the graph of sample type versus compressive stress and strain at yield point. It was noted that the relationship between the compressive stress and strain is directly proportional. For instance, a compressive stress of 0.926 MPa in (TCH 1) produced a corresponding compressive strain of 0.35799. It dropped a little in (TCHM 1), so that a compressive stress of 0.77037 MPa correspondingly produced a strain of 0.27954. It finally rose sharply in (TQH 1) so that a compressive stress of 4.37737MPa produced a corresponding strain of 0.83834.

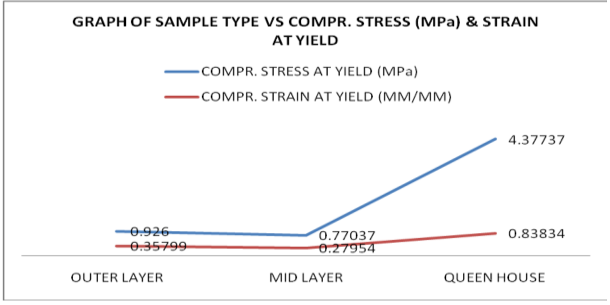

Figure 8: Graph of Sample type versus Compressive stress (MPa) &Strain at yield.

In Figure 9, the graph of sample type versus compressive extension at yield (mm) is shown. (TQH 1) recorded the longest compressive extension at yield, followed by (TCH 1). The least extension was recorded in (TCHM 1).

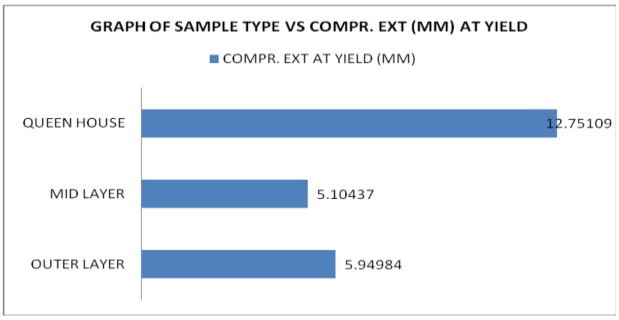

Figure 9: Graph of Sample type versus Compressive extension (mm) at yield.

Shown in Figure 10 is the graph of sample type versus compressive strain and extension (mm) produced at yield. It could be deduced that as the compressive strain produced increased, the resulting compressive extension for the different layers of termite hill specimens increased and vice – versa.

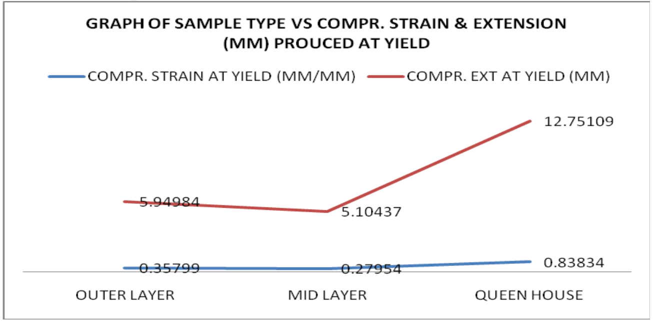

Figure 10: Graph of Sample type versus Compressive strain & extension (mm) produced at yield.

As recorded in Figures 6-10, at yield point, in terms of compressive load, energy and compressive extension, the Queen house recorded the highest set of values, followed by the outermost layer. The mixed layer recorded the lowest set of values. Also, at yield point, as the compressive stress increased, the compressive strain increased and vice–versa. Likewise, a directly proportional relationship exists between compressive strain and extension at yield. Extension was longest in termite Queen house and shortest in the mixed layer at the yield point.

In Figure 11 is shown the graph of sample type versus compressive extension (mm), loading (N), energy (J), compressive stress (MPa) and strain all at break for the three (3) layers of the termite hill collected. As in fig.6, the compressive load at break is the most conspicuous of all the parameters under consideration. However at break, higher results have been obtained than at yield.

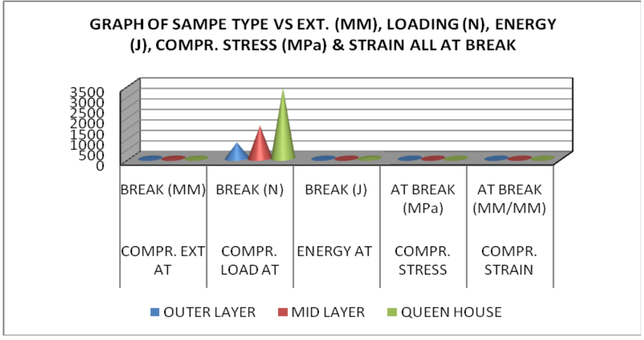

Figure 11**:** Graph of Sample type versus extension (mm), loading (N), energy (J), Compressive stress (MPa) & strain all at break.

In Figure 12, the graph of sample type versus compressive load (N) and energy (J) at break is shown. While (TCH 1) withstood the lowest compressive load of 765.25092N, (TCHM 1) withstood 1,166.85657N and (TQH 1) withstood 3,370.27612N. On the contrary, it was not so in the corresponding absorbed energy values as (TCH 1) absorbed 13.86601J of energy, (TCHM 1) absorbed 6.49275J and (TQH 1) absorbed up to 51.56948J of energy.

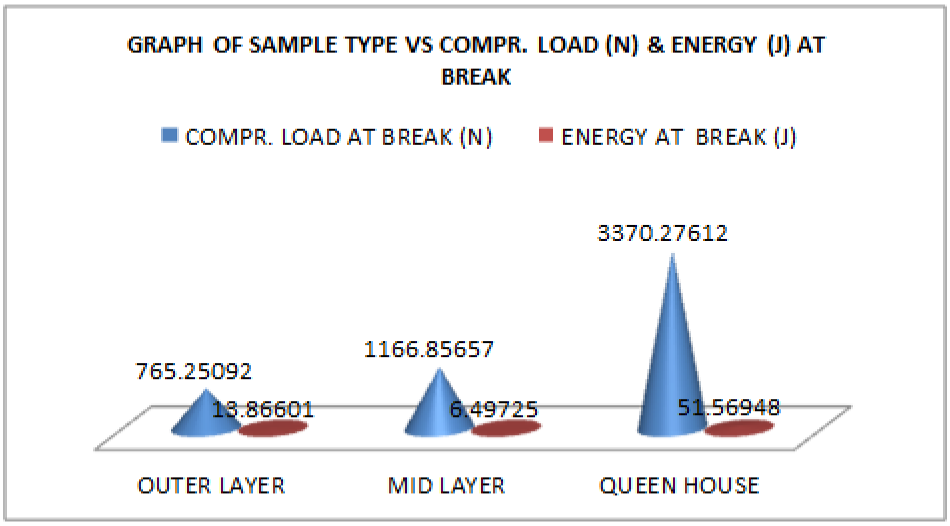

Figure 12**:** Graph of Sample type versus Compressive load (N) & energy (J) at break.

In Figure 13, the graph of sample type versus compressive stress (MPa) and compressive strain at break is shown. It was noted that the relationship between the compressive stress and strain was inversely proportional, such that as the compressive stress increased from (TCH 1) through (TCHM 1) to (TQH 1), the compressive strain decreased correspondingly.

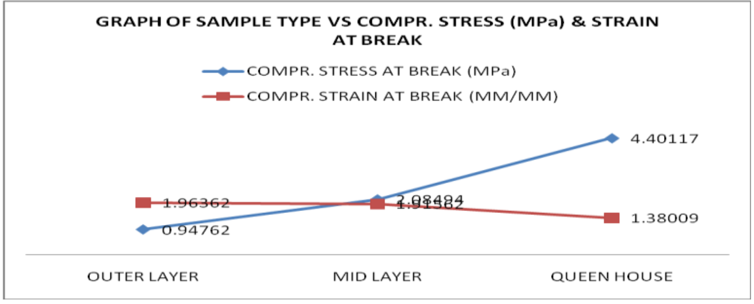

Figure 13: Graph of Sample type versus Compressive stress (MPa) & Strain at break.

Shown in Figure 14 is the graph of sample type versus compressive extension (mm) at break, in which (TQH 1) has the least extension of 20.99109mm, followed by (TQH 1) with an extension of 32.63531mm.Highest extension of 34.97922mm was recorded by (TCHM 1).

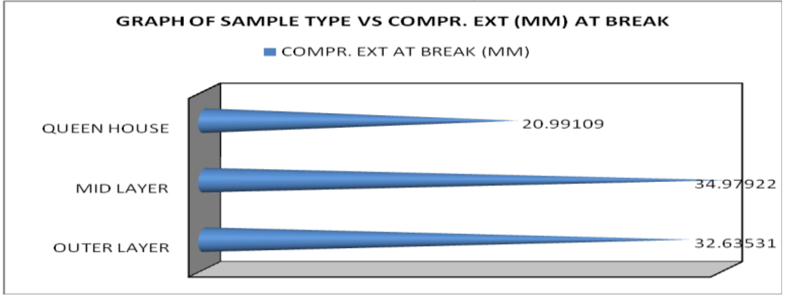

Figure 14: Graph of Sample type versus Compressive extension (mm) at break.

Figure 15 shows the graph of sample type versus compressive strain and extension (mm) produced at break. The compressive strain was 1.96362 in (TCH 1) but dropped to 1.91562 in (TCHM 1). It further dropped down to 1.38009 in (TQH 1). However, for the extensions produced, it initially rose from 32.63531mm in (TCH 1) to 34.97922 in (TCHM 1) but thereafter dropped down to 20.99109mm in (TQH 1).

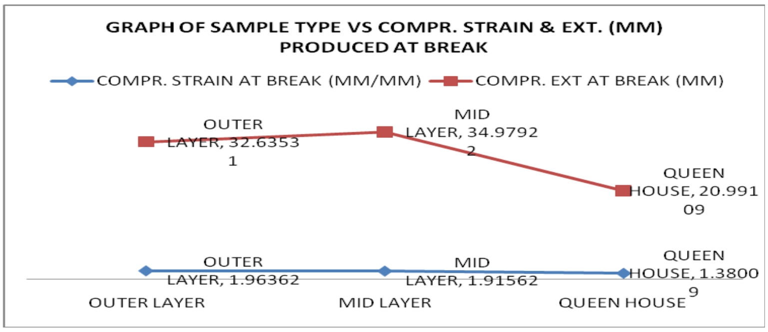

Figure 15: Graph of Sample type versus Compressive strain & extension (mm) at break.

As shown in Figure 16, at break, TCH 1 underwent an extension of 32.63531 in withstanding a load of 765.25092N.

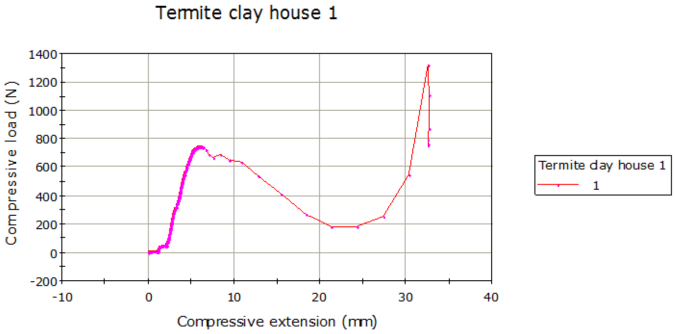

Figure 16: Graph of the compression test for the outermost layer of the Termite hill.

As shown in Figure 17, at break, TCHM 1 underwent an extension of 34.97922mm to withstand a load of 1,166.85657N.

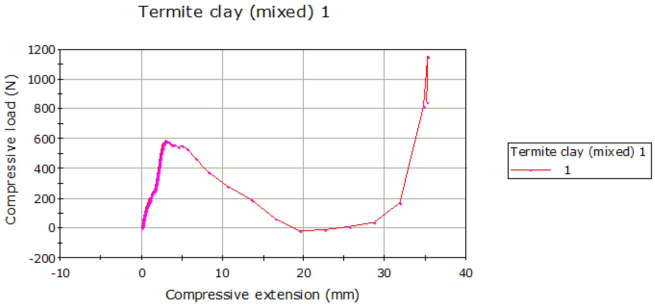

Figure 17: Graph of the compression test for the middle/mixed layer of the Termite hill.

As shown in Figure 18, at break, TQH 1 underwent an extension of 20.99109mm in withstanding a load of 3,370.27612N.

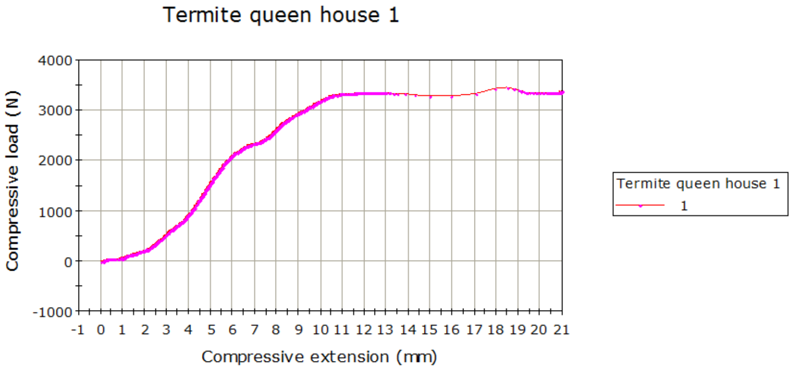

Figure 18: Graph of the compression test for the innermost layer (Queen house) of the Termite hill.

At break, (Figure 18) compressive load applied was lowest in the outermost layer, followed by the mixed layer and highest in the termite Queen house. Energy absorbed was highest in the Queen house and lowest in the mixed layer with 6.49725J.

An inversely proportional relationship exists between the compressive stress and strain at break. In addition, at the breaking point, extension was shortest in the termite Queen house and longest in the mixed layer. Also, an inversely proportional relationship exists between compressive strain and extension at break.

5. Conclusion

The bonding characteristics of an active termite hill have been investigated in terms of XRD analysis and compression test.

XRD analysis revealed that the Queen house (innermost layer) contained sillimanite which melts around 1850°C even without any reinforcing additives like graphite and asbestos. This layer will serve as a very good refractory material for foundry usage. The mixed layer contained sodium dachlardite, a low temperature material that will not be ideal for use as foundry refractory material. The outermost layer contained microcline which melts around 1250°C. This layer will need additives like graphite and asbestos to raise the melting temperature and make it quite suitable for foundry use.

Moreover, as the compressive strength (that is, strength resulting due to the bonding together of the particles of each of the different layers of the termite hill clay), deduced by means of compression test increased, the refractoriness, deduced by means of X-ray diffraction analysis correspondingly increased and vice-versa. This shows that a directly proportional relationship exists between the compressive strengths and refractoriness of the different layers of the termite hill clay. Furthermore, it can be said that as the bonding of the particles increased, the resulting compressive strength increased. This shows that a directly proportional relationship also exists between the bonding of the termite hill clay particles and compressive strength. Therefore, it is safe to conclude that the higher the bonding characteristics of the termite hill clay, the higher the resulting compressive strength, together with corresponding refractoriness and vice-versa.

6. Acknowledgement

The author acknowledges the support of the members of staff of Engineering Materials Development Institute (EMDI), Akure, Ondo State, Nigeria, particularly, Mr Silas Anamu (Foundry Unit)for rendering assistance in the course of sample collection and preparation. She also wishes to express her profound gratitude to Dr Supo Ogundare (Instron Room) for the compression test and Miss Thereza Nwankwor (XRD Room) for assisting with the X-Ray Diffraction analysis.

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