SINK FABRICATION FROM LIMESTONE-CLAY REINFORCED POLYESTER COMPOSITE

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ABSTRACT

Different materials had been used for sink fabrication in recent years. In this study ceramic filled polyester composite material has been developed by adding micro-fine limestone and clay ceramic particulates with particle size of <134 µm to unsaturated polyester resin with a loading weight of 20% limestone and 30% limestone/clay and fixed amount of catalyst (1% weight). The reaction temperature lies within 95.8 – 150 ° C. Resin Transfer Molding (RTM) technique has been used to fabricate a prototype sink using wooden and Plaster of Paris (POP) mold with a view to examine surface finish. The prototype sink produced shows durability with smooth surface finish and can be customized to satisfy end user's preference and choice.

Keyword: Resin Transfer Molding, Sink, Limestone, Clay, Polyester.

INTRODUCTION

The need to use technology in ceramic raw materials to enhance their potentials for product development is necessary for the economics of a developing country like Nigeria. Akinbogun (2003) reported that the modern world is experiencing various new use of ceramic materials with a growing recognition of ceramic raw materials and their superior engineering and technological properties fit for varied applications. Structural materials such as plastics and ceramics appear to be the dominant materials amongst composite materials over the past decades. The number of composite applications have grown steadily with new market demand. Composite materials in today's modern world are composed from carefully engineered materials ranging from everyday products to advanced applications. The composite industry has experienced innovative manufacturing versatility as a result of attempts made to produce components that are economically appealing. Composite have enabled new product development that are used in our everyday lives, such as bathtubs, countertops, windmills and car bumpers which have addressed the disadvantages in traditional material design and raised functional level (Tanaka, 1986).

For composites to be competitive with other materials such as metals, it is however necessary that coordinated efforts should be made in material processing, design, tooling, quality assurance and fabrication (Mishra et al., 2002). With the global technological improvement in the manufacture of composite materials, the cost barrier is yet to be subdued.

1. Literature Survey

In recent years', composites filled with particulates have been found to be of commercial importance as manufacturers sought after new and efficient materials for specific applications (Ma et al., 2007; Shonaike & Advani, 2003).

Compounding ceramic particulates into polymer is a familiar operation in the plastic industry, being utilized to improve the properties of polymers, such as strength and to cut-down the production cost of shaped products (Rai & Singh, 2003). Amongst usually used ceramic fillers are clay, granite, alumina, silica, calcium carbonate, talc and kaolin (Chew & Tan, 2011; Hanna et al., 2011; Ishid, 1979). Different academic researchers have apprised the strength outcome and modification of interfacial bonding between fillers and polymer matrix (Abdal razaq et al., 2013; Kiruthika et al., 2014). The combination of clay particles modifies the modulus properties of polymer composite (Gao, 2004), thermal, flexural and tensile strength (Gao et al., 2009). The flow, thermal and tensile properties of $CaCO_3$-filled low density polyethylene composites has been investigated by Liang (2007). Fine micro size calcium carbonate particulate increases the hardness properties of flexible polyurethane foam compositions of up to 35 weight % (Gonzalez et al., 2002; Latinwoet al., 2010).

The objective of this study has been established based on the intensifying need for an alternative sink product for low income housing units in Nigeria. This is done by using clay and limestone powder as ceramic filler and unsaturated polyester (UP) resin as a binder. This has emerged as a need to expand the structural applications of ceramic filled polymer composite within the circumference of its economic viability for the fabrication of kitchen sink.

2. Materials

2.1 Okpella Limestone

The Okpella limestone deposit in Edo state is currently being utilized for the manufacture of cement and calcium carbonate. It is located in the northern part of Edo state in Nigeria. It lies between latitude 7° and 7.25° North and longitude 6.15° and 6.38° East, covering an area of about 231.2 km^2 (Fadugba et al., 2015).

2.2 Ikere Ball Clay

Ikere-Ekiti, is a city in Ekiti State of Nigeria in Ikere Local

Elements	Average
SiO_2	1.7938 %
Al_2O_3	0.3420 %
Fe	0.2210 %
CaO	52.4857 %
MgO	0.4157 %
K_2O	0.0771 %
Na_2O	0.0055 %
SO_3	0.2053 %
Lime Saturation Factor (LSF)	942.3120 %
Alumina Moduli (ALM)	1.5473 %
Silica Moduli (SIM)	5.4666 %
Cementation Index (CI)	0.1059

Table 1. Typical Percentage Composition of Limestone (Adedamola, 2014)

Oxides	Ikere Ekiti Ball Clay
SiO_2	57.82
Al_2O_3	32.40
TiO_2	1.80
Fe_2O_3	2.21
CaO	0.37
MgO	0.07
K_2O	2.33
Na_2O	0.41
LOI	7.24

Table 2. Typical Percentage Composition of Ikere Ball Clay (Atanda & Oluwole, 2012)

Government. It is located 7.50° latitude and 5.23° longitude and it is situated at elevation 381 meters above sea level. It is an agrarian and mine centre for the locals.

The materials utilized for this study are limestone obtained from Okpella in Edo State. Ball Clay has been obtained from Ikere Ekiti, in Ekiti state. Unsaturated Polyester Resin (UPR), Methyl Ethyl Ketone Peroxide (MEKP) and cobalt Naphthanate has been purchased from a local chemical store in Lagos, Nigeria. Plaster of Paris and Wood plank were purchased from a local store and saw-mill in Ado Ekiti respectively. Representative samples of the fillers used in the study are presented in Figure 1.

3. Method

3.1 Processing of Limestone Powder

5 kg of limestone has been obtained from Okpella, in Edo state, Nigeria. It has been crushed and pulverized into a powdery form as shown in Figure 1 (d), and then screened with <134-micron meter 200 Tyler mesh sieve shaker.

3.2 Preparation of The Clay

Ball Clay used for this research has been mined from Ikere Ekiti, in Ekiti state and it has been processed to remove exfoliated impurities. The ball clay has been soaked in a container of water for two days and then sieved using a

(a) (b) (c) (d)

Figure 1. (a) Raw Clay (b) Processed Clay Powder (c) Limestone Hard-Core (d) Limestone Powder

sieving mesh. It has been allowed to settle for four days after which excess water has been decanted from the surface of the clay and then poured into clay drying pit made from Plaster of Paris (POP) which helped to absorb excess water from the clay. The clay has been then oven dried at 108 °C for 48 hours to remove inherent water in it and then sieved using a 134-micron meter 200 Tyler mesh ASTM-E11 NO. 200. The clay has been used in a dried powdery form Figure 1 (b).

3.3 Variables for Evaluation

In the course of this experiment, the following parameters were varied (a) clay powder (b) limestone powder and (c) polyester resin.

Limestone filler varied between 140 g, 280 g and 420 g representing 10 weight % and 10 weight % loading respectively; while the hybrid composite has a mixture of clay and limestone fillers at 30% loading at a weight of 420 g. The volume of catalyst and accelerator used throughout the experiment has been the same. The volume of polyester used for each composition varies with change in the percentage of clay and limestone powder used, which decreases as the volume of the fillers increases as shown in Table 3. In every composite mixture prepared, the total mass of ceramic filler (i.e., clay and limestone powder) and polyester is 1.4 kg. The sink fabrication has been carried out according to the process in Figure 2.

4. Design of Kitchen Sink Prototype Mould

4.1 Material Selection

For mold fabrication, both wood and Plaster of Paris (POP) were selected as they are abundantly available and relatively very cheap. The main advantage of wood is that it can be easily shaped and it possesses low weight as compared to metal. Wood and Plaster of Paris (POP) are optimal for casting and small quantity production.

Limestone Powder (%) - (g)	Hybrid Powder (%) – (g)	Polyester Resin (%) – (g)	Catalyst (%) – (g)	Accelerator (%) – (g)
10 – 140	-	88 – 1232	1 – 14	1 – 14
20 – 280	-	78 – 1092	1 – 14	1 – 14
-	30 - 420	68 – 952	1 – 14	1 – 14

Table 3. Selected Recipe Formulation

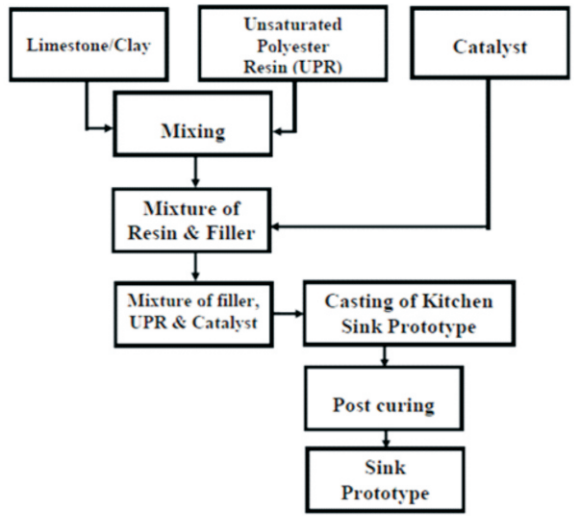


Figure 2. Flow Chart Showing Kitchen Sink Composite Fabrication Process

4.2 Wireframe of Kitchen Sink Mould

A wireframe (also known as 'skeleton') is a static, low-fidelity representation of different layouts that form a product as shown in Figure 3. It's a visual representation of an interface using only simple shapes. Wireframes are used to communicate structure (how the pieces of the kitchen sink mould will be put together) and functionality (how the interface will work).

The wireframe specifies the details of the kitchen sink mould at the initial stage of design description, because it is simple and fast to draw. Figures 4 and 5 shows the representative outlook of detail dimensions of the designed kitchen sink prototype mould while Figure 6 is the 3D design of the wooden mold.

4.3 Mold Fabrication

- *Wooden Mold:* The kitchen sink mold has been fabricated in the wood workshop of the department of Building Technology at Federal Polytechnic Ado Ekiti. Fabrication has been tailored after the predetermined

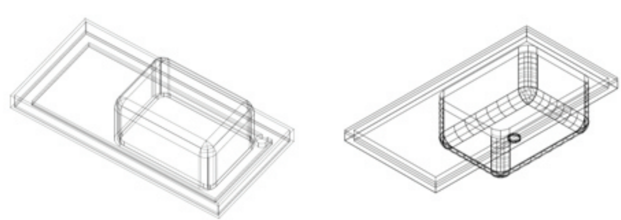
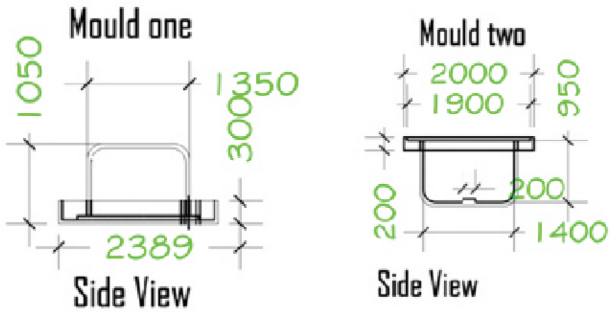
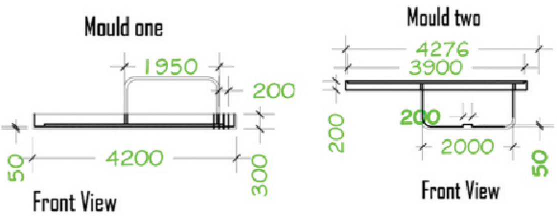


Figure 3. Wireframe of Mold One



(a) (b)

Figure 4. Side View Dimensions (a) Mould One, (b) Two Mould



(a) (b)

Figure 5. Front View Dimension (a) Mould One, (b) Two Mould

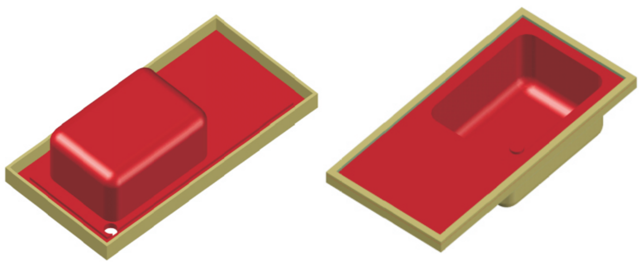


Figure 6. 3D Design of a Two-part, Matched Prototype Wooden Mold

design details with a volume capacity of 1400 ml or 1400 gram.

- *Plaster Mold:* The mold has been produced using Plaster of Paris (POP). Powdered POP has been dissolved in water at a ratio 2:1 with a setting time of 15 minutes. The primary wooden model sink has been covered with a separator made from a dissolved bar soap in hot water. Model sample has been laid halfway on a plastic clay slab boxed with wood plank. Stripes of rubber has been used to hold the wooden plank box together. All forms of undercut were closed for smooth removal after casting. The POP slip has been poured half way on the enclosed table ware and allowed to set. Afterwards, the solid POP had taken the form of the mould, key holes were made and it has been trimmed by scraping and the procedure has been repeated to cast the other half of the model. Eventually, the model has been carefully removed from the POP and the mould cast has been ready for use.

4.4 Kitchen Sink Fabrication Process

The ever-increasing demand for faster production rates has pressed for alternative fabrication processes and has encouraged fabricators to use those processes wherever possible. Resin Transfer Molding (RTM) is one of the most efficient, attractive and economical processes for high performance composite materials with low cost manufacturing. RTM's ability to produce a wide variety of shapes at moderate cost makes it a very attractive process. RTM is a fairly simple process. It begins with a two-part, matched, closed mold that has been made of wooden material and Plaster of Paris (POP). Limestone, clay, resin and catalyst are metered and mixed in a dispenser, then poured into the mold through mold cavity ports as shown in Figure 7 and 8, following predesigned paths which then preforms quickly and evenly before cure. The reaction temperature lies within 95.8 – 200 °C and the

(a) (b)

Figure 7. (a) Pouring Limestone Polyester Composite into Wooden Mold (b) Sink Cast

(a) (b)

Figure 8. (a) POP Sink Mold (b) Pouring of Limestone-Clay Composite into Plaster Mold

formed prototype sink has been demoulded as shown in Figure 9 (a) and (b).

5. Property Characterization

5.1 Flexural Test

Flexural strength is the ability of the material to withstand bending forces applied perpendicular to its longitudinal axis. The test specimens were conditioned in accordance with the ASTM D 790. Three-point bending tests were carried out using a universal material testing machine 1000 N. At least three rectangular beam specimens were tested with specimen dimensions 0.5 mm × 3 mm × 7 mm and the test speed was 2 mm/minute. Flexural strength, flexural modulus, and elongation at break values were obtained and evaluated according to ASTM D790M.

Bending strength has been calculated according to Equation 1,

$$\sigma = \frac{3FL}{2bd^2} \quad (1)$$

where, σ is the Bending strength (N/mm^2), F is the load (N), *L* is the span (mm), *b* is the specimen width (mm) and *d* is the specimen thickness (mm).

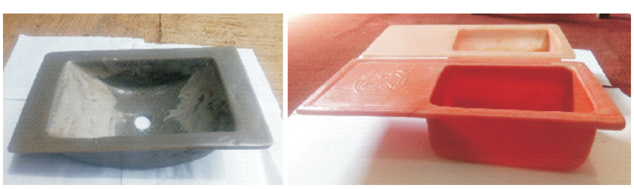
Flexural modulus has been calculated according to Equation 2,

$$E_n = \frac{FL^3}{4bd^3D} \quad (2)$$

where, E_n is the flexural modulus of elasticity (N/mm^2), *L* is the span (mm), *b* is the specimen width (mm), *d* is the specimen thickness (mm), and D is the maximum deflection at the center (mm).

5.2 Water Absorption Tests

Water absorption studies were performed following the ASTM D 570-98 method (Memmert water bath). Water absorption of the composites has been determined after 4 hours and 24 hours' immersion in distilled water at 90 °C.



(a) (b)

Figure 9. (a) Fabricated Hybrid Prototype Sink Composite (b) Fabricated Limestone Prototype Sink Composite

Three specimens of each formulation were dried in an oven for 24 hours at 103±2 °C. The dried specimens were weighed with a precision of 0.001 g and were immersed in distilled water. At the end of the immersion periods, the specimens were removed from the distilled water, the surface water has been wiped off using blotting paper, and wet weight values were determined.

Water absorption percent has been calculated according to Equation 3,

$$M(\%) = \frac{m_t - m_o}{m_o} x100 \quad (3)$$

where, m_o and m_t denote the oven-dry weight and weight after time *t*, respectively.

5.3 Micro Hardness Measurements

The hardness values of the composites were evaluated using Vicker Hardness Tester (Model MV1-PC) with the load of 0.1 kgf having a maximum and minimum limit of 100 and 0.05 HV at Finlab Nigeria Limited, Lagos Nigeria. The samples were exposed to a direct load of 0.1 kgf for 10 seconds on the mounted transverse sections to determine the hardness profile through the depth. Multiple hardness tests were performed on each sample and the average value has been computed.

5.4 Wear Test

Wear test has been performed according to ASTM D4060-14 standard. Disc-shaped samples with 100 mm diameter and thickness of 6.4 mm were affixed to a turntable platform that rotates vertically on its axis at a fixed speed of 2.36 m/s. There are two abrading arms on the turntable that are precision balanced. Each arm has been loaded for 250 g pressure against the test samples and lowered onto the specimen surface. Characteristic rub-wear action is produced by contact of the test sample against the sliding rotation of the two abrading wheels.

5.5 Microstructure Examination (SEM)

Micro-structural analysis of the samples has been carried out using a PhenomProx Scanning Electron Microscope (SEM). The accelerating voltage of the microscope is 15 kV.

6. Results and Discussion

6.1 Flexural Behavior of the Composite

Flexural strength is defined as the ability of the composite to

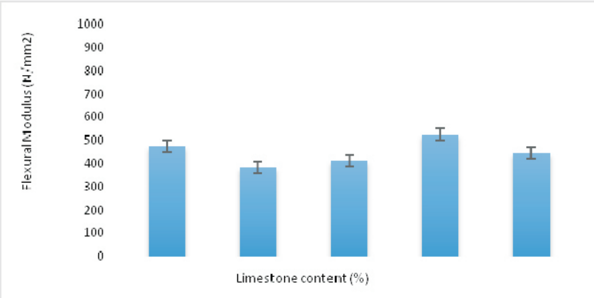


Figure 10. Limestone Variation on the Bending Modulus of Composite

resist deformation under load. Figures 10, 11 and 12 shows the result of bending modulus of the samples reinforced with limestone, clay and the hybrid. Figures 13, 14 and 15 shows the result of flexural modulus of the samples reinforced with limestone, clay and the hybrid. The effect of ceramic filler content on the flexural modulus shows that as the volume fraction of limestone particles increased at 10%, flexural modulus of the composite is decreased, with the modulus found to be 382 N/mm^2 (Figure 10). 9% percentage reduction has been observed. However, it began to increase as limestone content increased from 20% to 30%, with a flexural modulus of 411 N/mm^2 and 526 N/mm^2 respectively. The bending strength at peak however increased as limestone content increased from 21.78 N/mm^2 to 41.53 N/mm^2, which represent 90% increase in the strength of the composite. Figure 11 shows that as the volume fraction of clay particles increased at 10%, 30% and 40% flexural modulus of the composite decreased with the flexural modulus of 451 N/mm^2, 464 N/mm^2 and 472 N/mm^2 respectively. The highest flexural modulus value of the composite samples has been observed to be 729

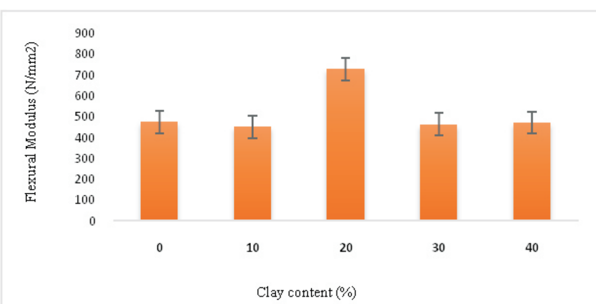


Figure 11. Clay Variation on the Bending Modulus of Composite

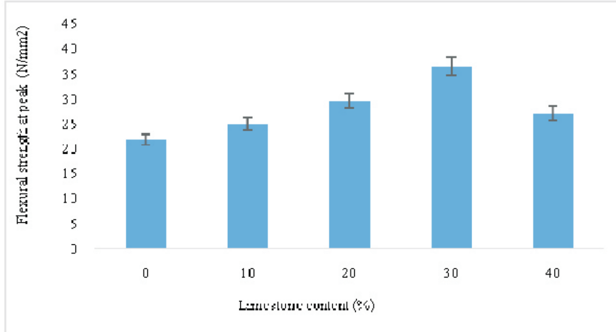


Figure 13. Limestone Variation on the Flexural Strength at Peak

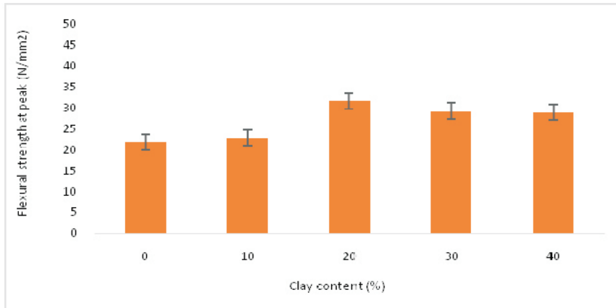


Figure 14. Clay Variation on the Flexural Strength at Peak

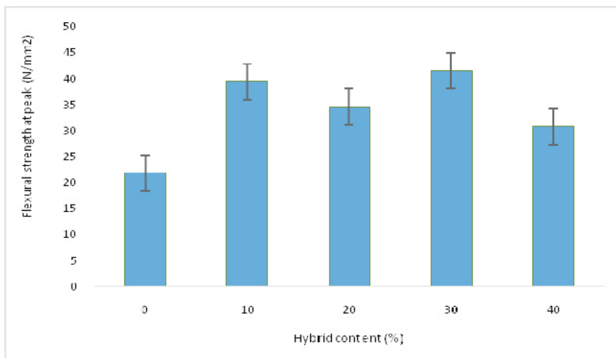


Figure 15. Hybrid Variation on the Flexural Strength at Peak

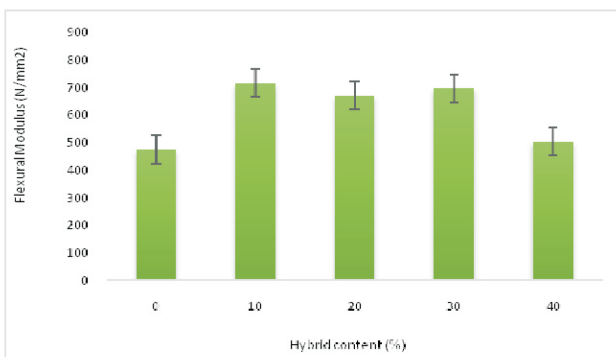


Figure 12. Hybrid Variation on the Bending Modulus Composite

N/mm² which is a 53% increase in flexural modulus of the composite at 20% volume fraction. The value of the highest bending strength has been 31.52 N/mm² at 20% volume fraction of clay particles addition, the strength of the composite increased by 44%. In Figure 12, the flexural modulus of the polymer composite increased with increased hybrid addition with modulus value of 504 N/mm² to 717 N/mm² which has been observed to be 33% reduction in the flexural modulus of the composite. The value of the bending strength increased by 90% with the highest and lowest value has been observed to be 41.53 N/mm² and 30.73 N/mm² respectively at 30% and 40% volume fraction of hybrid addition. The increase in the bending strength of the composite has been achieved by the presence of strong interfacial adhesion between the ceramic filler particles (i.e., clay and limestone) and the polyester matrix because of uniform dispersion. The interfacial bonding between the fillers and polymer matrix

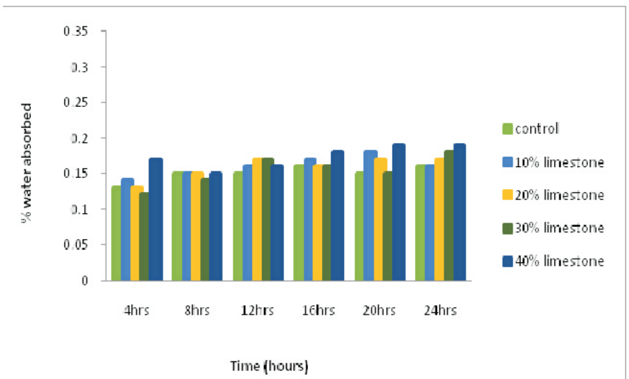


Figure 16. Water Absorption Profile of Limestone Variation Against Time at 90 °c

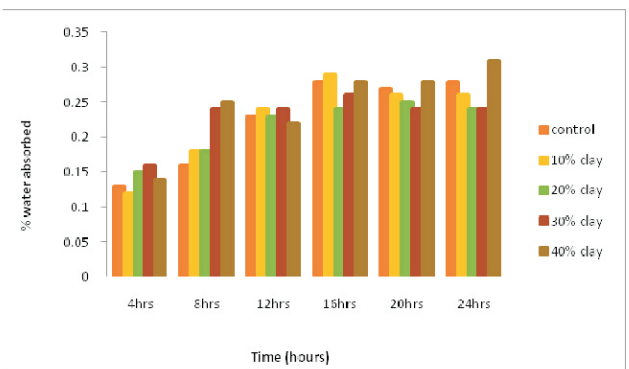


Figure 17. Water Absorption Profile of Clay Variation Against Time at 90 °c

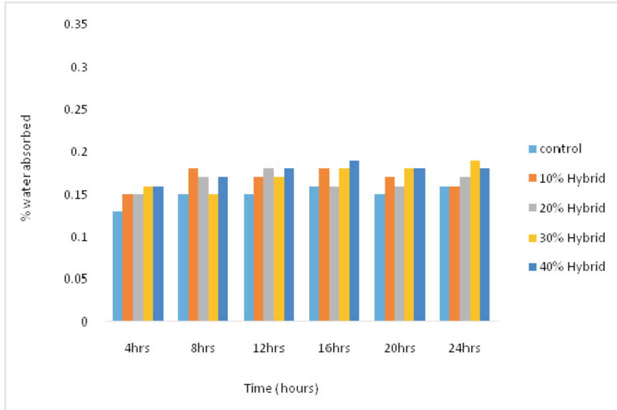


Figure 18. Water Absorption Profile of Hybrid Variation Against Time at 90 °c

facilitates efficient and proper load transfer according to Sarojini (2013).

6.2 Water Absorption

The following observations were made from the results obtained in the water absorption test as shown in Figures 16, 17 and 18 for limestone, clay and hybrid respectively. The percentage of water absorption depended on the volume fraction of particulate present, the number of hours' composites were immersed in water and the ambient temperature. It has been observed that increase in immersion time from 4 hours to 24 hours at a temperature of 90 °C had increased the amount of water uptake from 0.13% to 0.19%. Limestone/polyester composite has been observed to have the highest percentage water absorption value of 0.19% at 40% volume fraction of limestone addition at 90 °C after 24 hours' as shown in Figure 16. The highest value of percentage water absorption of clay/polyester composite has been 0.19% at 40% volume fraction of clay content at a temperature of 90 °C after 24 hours' as shown in Figure 17. Similar trend has been observed in the hybrid composite, the value of percentage water absorption increased as hybrid particle addition increased. After 24 hours the highest value has been observed to be 0.19% at 40% volume fraction of hybrid particulate at 90 °C as shown in Figure 18. This result suggested that the composite will probably perform better in areas were low water absorption is expected.

6.3 Wear Characteristics

It has been observed from this result that content of the filler is highly influential in enhancing the wear resistance of the composites. The volume loss of the three composites increase as the sliding moment increases. Initially, the change in volume loss is minimal for the composites, but as the sliding distances increased, volume loss in the wear also increases. The wear resistance of the limestone powder reinforced polyester matrix increased minimally compared to the unreinforced polyester matrix at all sliding distances. Thus, the volume loss of the virgin polyester sample, clay, limestone and hybrid composite increased with increase in sliding moment at 30% volume fraction of ceramic filler from 0.08 – 0.19%. The volume loss of hybrid composite filled with 30% volume of hybrid powder is inferior to both limestone and clay reinforced polyester composite as shown in Figure 19. This indicates improvement in the wear resistance of polyester as it is reinforced with hybrid particulate both at low and high speeds. This behavior can be attributed to the high strength of interfacial adhesion between the polyester matrix and the ceramic fillers used (i.e., clay and limestone) which is due to increased surface area and surface energy of the particles.

6.4. Micro Hardness Characteristics of Composite

The Vicker hardness values of the composites increased gradually with increase in contents of the ceramic fillers in the matrix from 6.56 VHN to 11.6 VHN, with limestone/ polyester composite having the highest hardness value of 10.2 VHN at 20% volume fraction representing 55% improvement in resistance to abrasion. While clay/polyester and hybrid/polyester composite also have 66% and 76% respectively. These peak hardness values of the reinforced composites have significant improvement over virgin polyester at 30% volume fraction as shown in Figure 20. Previous researches has shown that increase in hardness of composites may be attributed to the hardening effect of the filler particles. However, as the volume fraction increases beyond 40%, the composite hardness decreases at higher volume fraction of the filler. Pores may result due to agglomeration of the particles leading to lower surface resistance (Ataiwi & Abdul-Hamead, 2012; Bartczaket al., 1999).

6.5 Microstructure Analysis

The extent of dispersion of limestone particles into the virgin polyester has been observed using Scanning Electron Microscope (SEM). The virgin polyester (control sample) represents the matrix without ceramic filler addition as shown in Figure 21. As the magnification increases localized dispersion of the limestone particles is seen in the composites. The white spot in the SEM micrograph represents the reinforcement while the black spot is the polyester matrix as clearly depicted in 21 (a) and (b). The reinforcement has been evenly distributed in the matrix with few agglomerations. The agglomeration of the reinforcement in the polyester matrix has been minimal and the level of agglomeration did not affect the mechanical property of the composite (Amdouniet al., 1992; Najera, 2008). The properties of composites used in this study is given in Table 4.

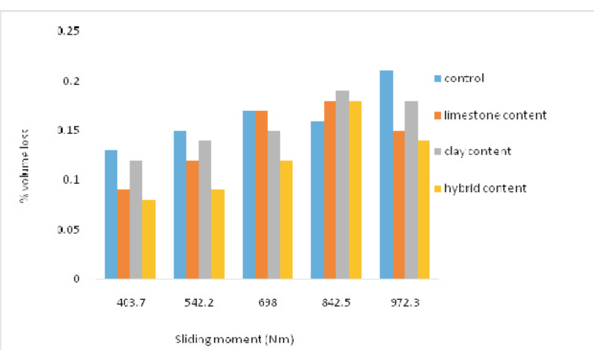


Figure 19. Wear Behavior of Composite at 30% Volume Fillers and Speed of 2.36 m/s

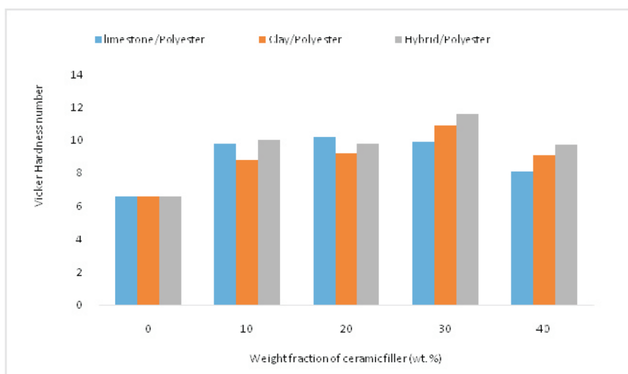
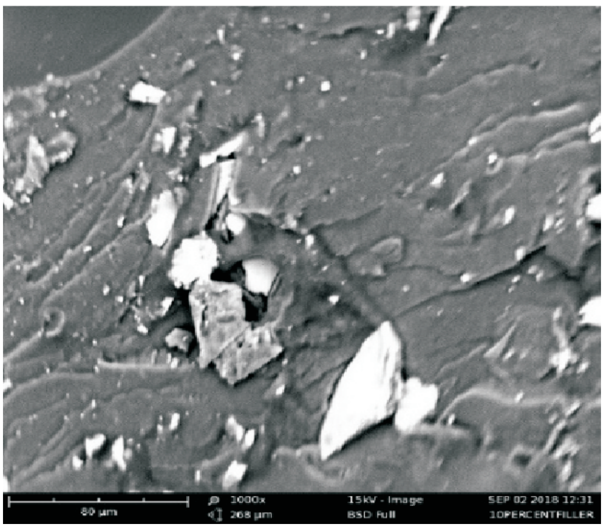


Figure 20. Hardness Behaviour of Composite at 0, 10%, 20%, 30% and 40% Volume Fraction of Filler

(a)



(b)

Figure 21. (a) Microanalysis of polyester composite without filler addition at 500x magnification, (b) SEM micrograph of 10% limestone variation against polyester composite at 1000x magnification

Properties	Limestone	Polyester Composite	Limestone-Clay Hybrid Composite
Mass weight	10%	20%	30%
Flexural modulus (N/mm^2)	382	411	697
Bending strength (N/mm^2)	24.93	29.62	41.53
% water absorption - 8 hours at 90°C	0.15	0.17	0.15
% volume loss at 403.7Nm sliding moment	0.09	0.09	0.08
Vicker hardness value	9.8	10.2	11.6

Table 4. Properties of the Composite Formulations used in this Study

Conclusion

In the present research work, Resin Transfer Moulding (RTM) technique has been used to fabricate a prototype sink from limestone and clay particulate (reinforcement) and unsaturated polyester resin (matrix). Results from the mechanical properties of sample specimens showed the composition for the fabrication of the prototype sink. The product showed good surface finish. The prototype can be customized to satisfy customer's preference and choice.

Based on the results obtained from this research, the following conclusions were drawn:

- This research has successfully fabricated a kitchen sink made from clay and limestone filler reinforced polyester composites by simple Resin Transfer Molding (RTM) technique.
- This research has established the importance of clay and limestone as ceramic filler in polymer matrix composite within the circumference of its economic viability for sink fabrication.
- Fabricated sink has been durable, technically efficient and could serve as an alternative substitute sink.
- It has established the fact that composite kitchen sink can be produced locally by industrial designers and entrepreneurs with a view to create job opportunity for sustainable development.
- It has created opportunity for industrialist to reduce the need for imported sinks through local production.

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