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Effects of $CaCO_3$ and Kaolin Filler Loadings on Some Mechanical Properties of Poly Urethane Foams

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Authors' contributions

This work was carried out in collaboration between both authors. Author MBD designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author SDM managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

In Nigeria, the foam industries basically use $CaCO_3$ as filler in polyurethane (PU) foam manufacture. This has contributed to the high importation of this mineral, thereby, increasing dependency on imported goods. It is for this reason that, kaolin, a clay deposit commonly found on the upper Plateau in Central Nigeria is utilized as a potential filler in replacement or as a supplement for $CaCO_3$.Various masses (0,2,4,6,8,10,12,14, and 16 g) of the fillers ($CaCO_3$ or kaolin) were used in curing of PU foams and mechanical properties such as density, tensile strength, elongation at break, creep recovery and compression set were determined. Tensile strength values for $CaCO_3$ and kaolin filled conventional polymer (CPO) are far higher than for $CaCO_3$ and kaolin filled polymer polyol (PPO), generally. However, kaolin filled CPO foam display higher peaks at 2 g and 4 g compared to $CaCO_3$ filled CPO within the same range. Similarly, $CaCO_3$ filled CPO foams show higher peaks between 6 g and 12 g compared to kaolin filled CPO within the same concentration which seems to suggest that $CaCO_3$ exhibits better filler acceptance (compatibility) at higher concentration to a limiting value. In the same vein, kaolin filled PPO foams exhibit tensile strength properties higher than $CaCO_3$ filled PPO within the same concentration. Creep recovery for kaolin filled CPO are far higher than those of PPO, demonstrating that kaolin

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filled CPO exhibits far better % creep recovery property than $CaCO_3$ filled CPO, PPO and kaolin filled PPO. Results for the effects of filler loading on compression tests display the same trend as % creep recoveries. Generally, incorporation of between 2 – 8% of Kaolin as filler improves tensile strength, creep recovery and compression set over and above $CaCO_3$ even though it lowers the density of foams. Similarly, $CaCO_3$ incorporation between 2 – 14% also improves the mechanical properties at lower values. Kaolin filled foams can be used for light weight application such as upholstery, packaging, industrial filters, etcetera.

Keywords: Creep recovery; filler; compression set; tensile strength; conventional polyol; polymer polyol.

1. INTRODUCTION

Inorganic filler materials available as nano-, micro- and macro-scale crystals have effects on plastic foam materials which strongly depend on their particle sizes, filler/resin ratio, hybrid morphology, and dispersion quality. Raw materials are key drivers to any manufacturing industry. Nano-$CaCO_3$ have been found to influence production consistency, shrinkage and melt flow rates, as well as mechanical properties of polypropylene/$CaCO_3$ nano-composites [1]. Nano-materials have found application as fillers in materials. Among over twenty most important fillers, calcite ($CaCO_3$) holds the largest market volume and is mainly used in the plastic sectors. Other fillers include dolomite ($CaMg(CO_3)_2$), kaolin and talc [2].

Fillers are particles added to materials (such as plastics, concrete, composite materials) to lower the consumption of more expensive binder material or to better some properties of the material. They are ranked among the world's major raw materials and are contained in a variety of goods for daily consumer needs [3]. Historically, inorganic fillers such as barium sulfate and calcium carbonate have been used in flexible slab stock foams to achieve increased density and/or load bearing, and to reduce cost. Normal use concentration ranges from 20 to 150 parts per hundred parts polyol. Modification involving the use of fillers are to achieve desirable end use properties of polyurethane/filler composite products. It is also well known that fillers increase cell density and decrease cell size thereby affecting the macroscopic cell and in this way act as reinforcement materials in polyurethane foam composites [4].

The maximum benefit from nano layer dispersal and reinforcement was demonstrated by Javni and co-workers in 2002. In their study, they found that nano-silica used as filler in flexible polyurethane foam increased the hardness and compression strength, but decreased the rebound resilience of the foam. In the same study, micro-silica filler was found to decrease all the mechanical properties of the foam [5]. Effects of various organoclays of nanosizes on the thermo mechanical properties and morphology of polyurethane foam have been investigated [6]. The study shows that most clay layers were dispersed homogeneously into the matrix of the polymer. Moreover, the addition of only a small amount of organoclay was enough to improve the thermal stabilities and mechanical properties of the foam. Furthermore, some researchers have used nano- and micro- scaled calcium carbonate (calcite) to influence cell nucleation in the foaming process of polyethylene plastics. The nano-scaled calcite (ultra-flex $CaCO_3$) increased substantially the cell density of the foam thereby improving the mechanical properties, while the micro-scaled calcite (Hi-flex $CaCO_3$) has an effect that was less significant in reinforcing the strength characteristics of the foam [6].

With most, if not all foam industries utilizing $CaCO_3$ as fillers in foams, the importation of this raw material had greatly increased over the years. The Nigerian Guardian Newspapers [7] quoted the Director General of Raw Materials Research and Development Council (RMRDC) that, Nigeria loses over 1 billion naira annually on the importation of precipitated calcium carbonate (PCC).

Nigeria is naturally endowed with abundant basic raw materials for the chemical industry but these basic raw materials have not been given added values. Nigeria has depended on importation of these basic and finished materials at exorbitant cost depleting our foreign exchange earnings.

The present study compares and contrasts the effects of filler loading on the mechanical properties of foams formulated using calcium carbonate (a rock mineral and a conventional filler presently in use by foam industries in Nigeria) and kaolin (a clay mineral locally abundant and cheaper on the Jos – Plateau, Nigeria) as fillers. Therefore, exploring and exploiting alternative local raw materials for the foam industry will reduce manufacturers' cost and invariably the prices of these goods [8]. This research focuses on the utilization of kaolin, as a potential filler in replacement or as a supplement for $CaCO_3$ in which some mechanical property advantages of the kaolin fiiied foams were investigated. Extracted of map of Riyom LGA of Plateau state, Nigeria showing deposits of kaolin has been earlier reported [9]. Moreover, kaolin is much cheaper than Calcium Carbonate as 2 kg of kaolin processed in Jos costs between 400 and 500 naira (Nigerian currency) while a corresponding weight of processed calcium carbonate costs much higher. Therefore, cost can be minimized and calcium carbonate can be freed for use in leather, paint, and water treatments, e.t.c. Furthermore, it has been earlier reported that, the utilization of kaolin, a clay mineral with high refractory temperature of 1785℃ as compared to $CaCO_3$ with 400℃ is locally abundant as a filler which improves curing rates by ease of absorption of exotherms generated during foaming process and also enhances some important mechanical properties such as tensile strength, creep recovery and compression set of urethane foams for light weight, packaging and cushioning applications over and above the conventional $CaCO_3$ filler presently used by foam industries in Nigeria [9].

2. MATERIALS AND METHODS

2.1 Sample Collection

Polymer polyol (PPO), conventional polyol (CPO), toluene diisocyanate, (TDI 80/20), stannous octanoate, dimethyl ethanolamine, polysilicone, methylene dichloride (MC), and $CaCO_3$ were graciously obtained from Vitafoam Nig. Plc, Jos Mega Factory. Pure white powdered commercial kaolin was purchased at Katako market in Jos Plateau State, Nigeria.

2.1.1 Sample treatment

The kaolin and $CaCO_3$ were dried at 100℃ for 2 hours and thereafter sieved to 150 µm particle sizes.

2.2 Determination of Moisture Content of Fillers

3.0 g of sample was weighed and dried at 103℃. Repeat weights were carried out at intervals of 30mins until constant weights were obtained. Moisture content was calculated using the formula:

$$\text{Moisture content} = \frac{W_2 - W_1}{W_1} X\ 100 \qquad (1)$$

Where W_1 = Initial weight of sample
W_2 = final weight of sample after drying.

2.3 Determination of Apparent Bulk Density of Fillers [10]

100 g of filler was weighed and transferred into 250 cm^3 measuring cylinder and kept on a flat horizontal surface. The measuring cylinder was tapped 50 times and repeated 4 times to obtain a constant the volume of sample. Apparent Bulk Density (ABD) was calculated as:

$$\text{ABD} = \frac{weight\ of\ \ filler}{tapped\ volume} X\ 0.6253 \qquad (2)$$

Where 0.6253 is the correction factor for filler loading.

2.4 Foam Formulations

One-shot technique of urethane foam formulation was used. The ingredients were measured accurately using syringes, micro-syringes, pipettes and measuring cylinders into moulds of dimensions (21.5 cm x 13.7 cm x 14.5 cm), using the recipes on Table 1. The components were thoroughly stirred and TDI added with continuous stirring until the system creamed. The foams were then allowed to rise undisturbed and left to cure for 24 hours after which physico-mechanical properties of the foams were determined.

Table 1. Formulations with variations of $CaCO_3$ or Kaolin filler loading for CPO or PPO

Sample identity	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
CPO or PPO (g) [polyfunctional monomers]	100	100	100	100	100	100	100	100	100
$CaCO_3$ or Kaolin (g) [fillers]	0	2	4	6	8	10	12	14	16
Silicone (g) [lubricant]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Amine (g) [catalyst]	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Stannous(g) [catalyst]	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Water (g) [primary blowing agent]	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30
M.C (g) [auxiliary blowing agent/fire retardant]	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
TDI (g) [polyfunctional monomer]	50	50	50	50	50	50	50	50	50

2.5 Determination of Density of Foams [11]

The rises (h), widths, breadths and the weights of the foams were measured and their volumes and densities were calculated using the expressions;

Volume V = base area of mould x foam rise (h)

Where base area = base of mould (breadth) x width of mould

$$Density = \frac{weight}{volume\ of\ \ foam\ (v)} \quad (3)$$

2.6 Determination of Stress and Strain [11]

Each foam was trimmed and cut into 3 pieces using band knife splitter CV-02. From each cut piece, three test samples measuring 10cm x 5cm x 1cm were cut randomly using a special knife and their extensions (mm) (elongation at break) with loadings were read from a computer coupled Tensometric Testing Machine with a cell load of 500kgf (5000N), at a speed of 60mm/min at constant rate of extension method at Standard, Organization of Nigeria (SON) Laboratory Kaduna. Mechanical properties were calculated from the expressions;

$$Tensile\ strain = \frac{extension}{original\ length} = \frac{I - I_0}{I_0} \quad (4)$$

Where l = extended length

l_o = original length (mm)

$$Tensile\ stress = \frac{force\ (loadatbreak)\ Ncm^{-2}}{cross - sectional\ area\ (cm^2)} \quad (5)$$

Where cross sectional area = length x thickness.

$$Tensile\ strerngth = \frac{tensile\ stress\ (Ncm^{-2})}{tensile\ strain} \quad (6)$$

$$\%\ elongation\ at\ break = \frac{I - I_0}{I_0} X\ 100 \quad (7)$$

2.7 Determination of Creep Recovery/ Resilience [11]

From the trimmed samples, tests samples measuring 10 cm x 5 cm x 1 cm were cut and subjected to a tensile force of 20N using a computer coupled Universal Tensile testing machine with a cell load of 250 N at a speed of 60 mm/min under ambient condition (67 $\pm$ 2% Relative Humidity and 27℃) using the method of constant rate of extension. The total extension (mm) on application of load (20N) and the relaxation (mm) on removal of load after 5 seconds of each test piece were noted and the percentage recovery of each sample was calculated using the expression:

$$\%\ creep\ recovery = \frac{creep\ recovery\ or\ resilience}{extension\ on\ application\ of\ load} X\ 100 \quad (8)$$

Where creep recovery/resilience = Total extension (mm) on application of load – Relaxation (mm) on removal of load after 5 seconds.

2.8 Determination of % Compression Set [11]

The test pieces were cut into dimensions. The samples were placed in the compression device which consisted of two flat plates with parallel to each other was ensured and the space between plates was adjusted to the required deflected height. The test piece was compressed by 50%, maintained at ambient temperature of 27^{o}C for 22 hours. At the end of the 22 hours, the test piece was removed from the device and placed on a wooden surface since wood is of low thermal conductivity. The test piece was allowed to recover for 30 minutes after which its thickness was measured as (Tr)

$$\%\ compressio\ n\ set = \frac{T_0 - T_r}{T_0}\ X\ 100 \qquad (9)$$

Where T_o = initial thickness, Tr = thickness after removal of load after 30 mins.

3. RESULTS AND DISCUSSION

Table 2 shows the particle sizes, moisture contents and apparent bulk densities of $CaCO_3$ and kaolin fillers. The result indicates that $CaCO_3$ has a much lower moisture content of 0.6% compared to kaolin with 1.3%. Similarly, $CaCO_3$ has a higher apparent bulk density of 0.75 g/cm^3 than kaolin with 0.4 g/cm^3. This means that, $CaCO_3$ filled foams are denser than kaolin filled ones. However, the later displays other superior mechanical properties then the former.

Fig. 1 shows variations of density with $CaCO_3$ and kaolin filler loadings for CPO and PPO foam formulations. Density generally increases with filler loadings but higher increases are displayed by $CaCO_3$ filled CPO and PPO than kaolin filled CPO and PPO due to differences of their bulk densities (see Table 2). However, $CaCO_3$ filled CPO displays higher increases than $CaCO_3$ filled PPO. Kaolin filled CPO exhibits lower values up to 10 g compared to kaolin filled PPO, because PPO is denser than CPO. This agrees with the report by Ikeh (1991) that, foam density is a rating applied to PU which may be based in part on the chemical composition of polyols and in part on the additives such as fillers [12]. However, at higher values above 10 g, density values show little or no significant differences between $CaCO_3$ filled PPO and kaolin filled CPO and PPO as a result of molar ratio compatibility [13].

Table 2. Results of moisture content and apparent bulk density of fillers

Fillers	Particle size (µm)	Apparent bulk density (g/cm^3)	Moisture content (%)
$CaCO_3$	150	0.75	0.60
Kaolin	150	0.40	1.30

Fig. 2 shows variations of tensile strength with $CaCO_3$ and kaolin filler loadings of CPO and PPO. The values for $CaCO_3$ and kaolin filled CPO are far higher than the values for $CaCO_3$ and kaolin filled PPO generally. $CaCO_3$ filled CPO shows tensile strength peaks at; 2 g = 119.39 N/mm^2, 4 g = 130.24 N/mm^2, 6 g = 141.80 N/mm^2, and 12 g = 138.66 N/mm^2 with depressions at 0 g = 40.35 N/mm^2, 5 g = 89.76 N/mm^2, 10 g = 90.47 N/mm^2 and 14 g = 40.87 N/mm^2. On the other hand, kaolin filled CPO shows tensile strength peaks at; 2g = 141.68 N/mm^2, 4 g = 142.13 N/mm^2, 6 g = 132.12 N/mm^2, 8 g = 119.34 N/mm^2, and 12 g = 121.02 N/mm^2 with depressions at; 0 g = 40.35 N/mm^2, 10 g = 91.97 N/mm^2 and 14 g = 104.81 N/mm^2.

These results show that tensile strength generally increases with filler loading, however, kaolin filled CPO displays higher peaks at 2g and 4 g compared to $CaCO_3$ filled CPO within the same range. This is because the level of filler compatibility has to be considered and controlled to attain optimum results. It has been reported by several investigators that particle size distribution influences the extent of reinforcement, that is, the smaller the particle size, the better the reinforcement. Particle sizes of 70 – 150 µm have been considered as better as fillers. Furthermore, particle size analysis of some clay minerals indicates that purified kaolin has a limited grain size range of about 95%, with particles between 2 - 0.3μm in size. Sedimentary kaolin such as ball clays of the best qualities contains 60% or more of particles with less than 0.05μm and up to 90% with less than 1μm [14]. Therefore, surface area is better for kaolin than $CaCO_3$ because of high foam/kaolin interfacial area, which makes kaolin a better filler acceptor, exhibiting higher tensile strength values at lower concentrations than $CaCO_3$ [15]. Its low plasticity and apparent bulk density, high dry shrinkage and refractory properties are added advantages over $CaCO_3$. Similarly, $CaCO_3$ filled CPO shows higher peaks between 6 g and 12 g compared to kaolin filled CPO within the same concentration

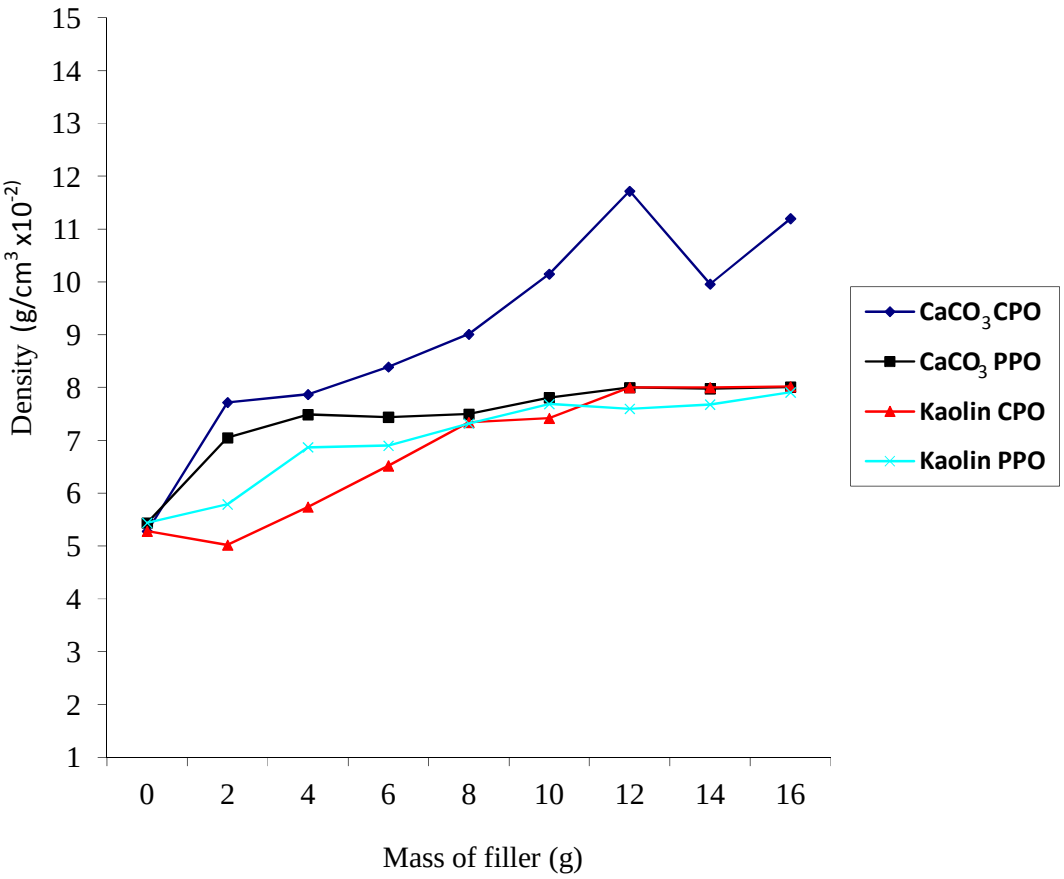

Fig. 1. Results of variations of $CaCO_3$ and kaolin filled CPO and PPO filler loadings with density

which seem to suggest that $CaCO_3$ exhibits better filler acceptance (compatibility) at higher concentration to a limiting value. The valleys (depressions) at 10 g for both fillers are convergent which seems to suggest a limiting concentration, but the values at 14g are divergent with kaolin filled CPO displaying a value of 104.81 N/mm^2 which is far higher than $CaCO_3$ filled CPO with a value of 40.77 N/mm^2. This observation is in disagreement with the findings of Babalola and Dominic, (2012), who reported a higher value for $CaCO_3$ filled CPO, between 1 – 30 g filler loading in parts per hundred resin (polyols) [16]. Depressions or low tensile strengths indicates areas of little or no compatibility since strength properties are influenced by particle size, coarse aggregates introduces non – compatibility (no – cohesion between the two phases) [17].

Comparing and contrasting $CaCO_3$ and kaolin filled PPO show that tensile strength for $CaCO_3$ filled PPO increases gradually from 40.00 N/mm^2 at 0 g to 50.95 N/mm^2 at 4 g, with a sharp peak at 8 g = 73.89 N/mm^2 and lower peaks at 12 g = 59.34 N/mm^2 and 14 g =60.09 N/mm^2, displaying valleys (depressions) at 6g = 49.54 N/mm^2 and 10 g = 52.68 N/mm^2 as against kaolin filled PPO which shows sharp peaks at; 4g = 79.33 N/mm^2, 12 g = 73.87 N/mm^2 with an interface value of 47.06 N/mm^2 with 6 g $CaCO_3$ filled PPO (= 49.54 N/mm^2) on the chart and a steep descend to an overall lowest depression at 8 g = 21.84 N/mm^2 and a steep rise again to 57.15 N/mm^2 at 10 g which finally peaks at 12 g = 73.87 N/mm^2. It however, descends slowly to 59.48 N/mm^2 at 14 g. This observation demonstrates that, for PPO formulations, kaolin influences tensile strength properties better at; 2 g, 4 g, 10 g, 12 g

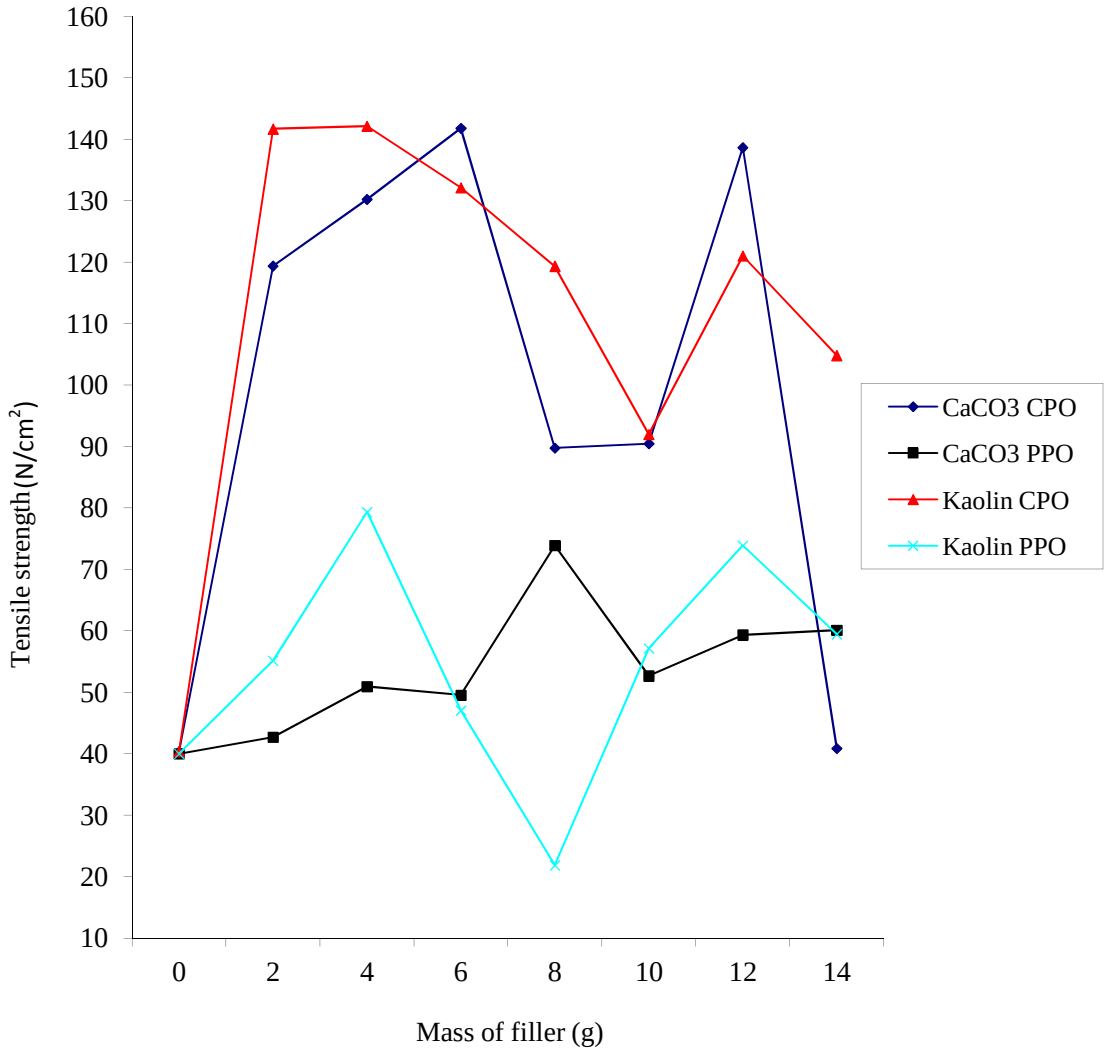

Fig. 2. Results of variations of Tensile strength with CPO and PPO filler loading

and 14 g with the highest values at 4 g and 12 g, compared to $CaCO_3$ filled PPO which only peaks at 8 g = 73.89 N/mm^2 while kaolin filled PPO depresses to 21.84 N/mm^2 at this concentration. It also suggests that kaolin filled PPO exhibits tensile strength properties higher than $CaCO_3$, the traditional filler used in the foam industry in Nigeria. This observation compliments and reaffirm values obtained for kaolin filled CPO at 2 g and 4 g concentrations earlier observed. This trend again indicates areas or regions where the molecules are arranged randomly ('disordered' or 'amorphous' regions), that is, there are no regular or ordered packing. These amorphous regions can be distinguished from the regions where the molecules are arranged in regular arrays giving areas of three-dimensional order, with very little molecular 'imperfections' or 'dislocations'. These regions are described as crystalline regions. The co-existence of these two phases in polymeric substances has important effect on the physical and mechanical properties of these substances. The amorphous/crystalline content or ratio has important implications for polymer properties. For example, highly crystalline polymers can be manipulated to give materials with high tensile and impact strengths. Conversely, polymers with large amorphous content will usually give soft polymers with relatively lower strength [18]. Furthermore, it has also been observed by the Menter's dislocation model evidenced by electron microscope that,

bond dislocations movement (migration) lowers tensile strength by plastic deformation. However, strengthening of materials can be achieved by obstructing dislocation movements by barriers i.e. pockets of disorder in the lattice which the addition of fillers introduces in foam formulation [19].

Fig. 3 shows variations of % elongations at break with filler loading. For $CaCO_3$ filled CPO, peaks are observed at; 2 g = 90.9%, 4 g = 93.8%, 8 g = 79.3%, 10 g = 73.3%, and 12 g = 73.9% and depressions at; 6 g = 60.9% and 14 g = 55.9% which are lower than the values at 0 g = 63.2%, while kaolin filled CPO shows peaks at; 4 g = 94.0%, 8 g = 89.4% and 14 g = 80.8% with depressions at; 2 g = 19.3% (the lowest overall), 6 g = 82.4% and a sloping value at 10 g = 70.6% and a final fall at 12 g = 59.3%. Interestingly, there is an interface at 4 g = 94.0% for both $CaCO_3$ and kaolin filled and another triple convergence at 10 g = 73% for $CaCO_3$ and kaolin filled CPO and kaolin filled PPO. It is also observed that at 2 g kaolin filled CPO with 19.3% elongation, exhibit a very high tensile of strength of 141.68 N/mm^2. This is in agreement with our

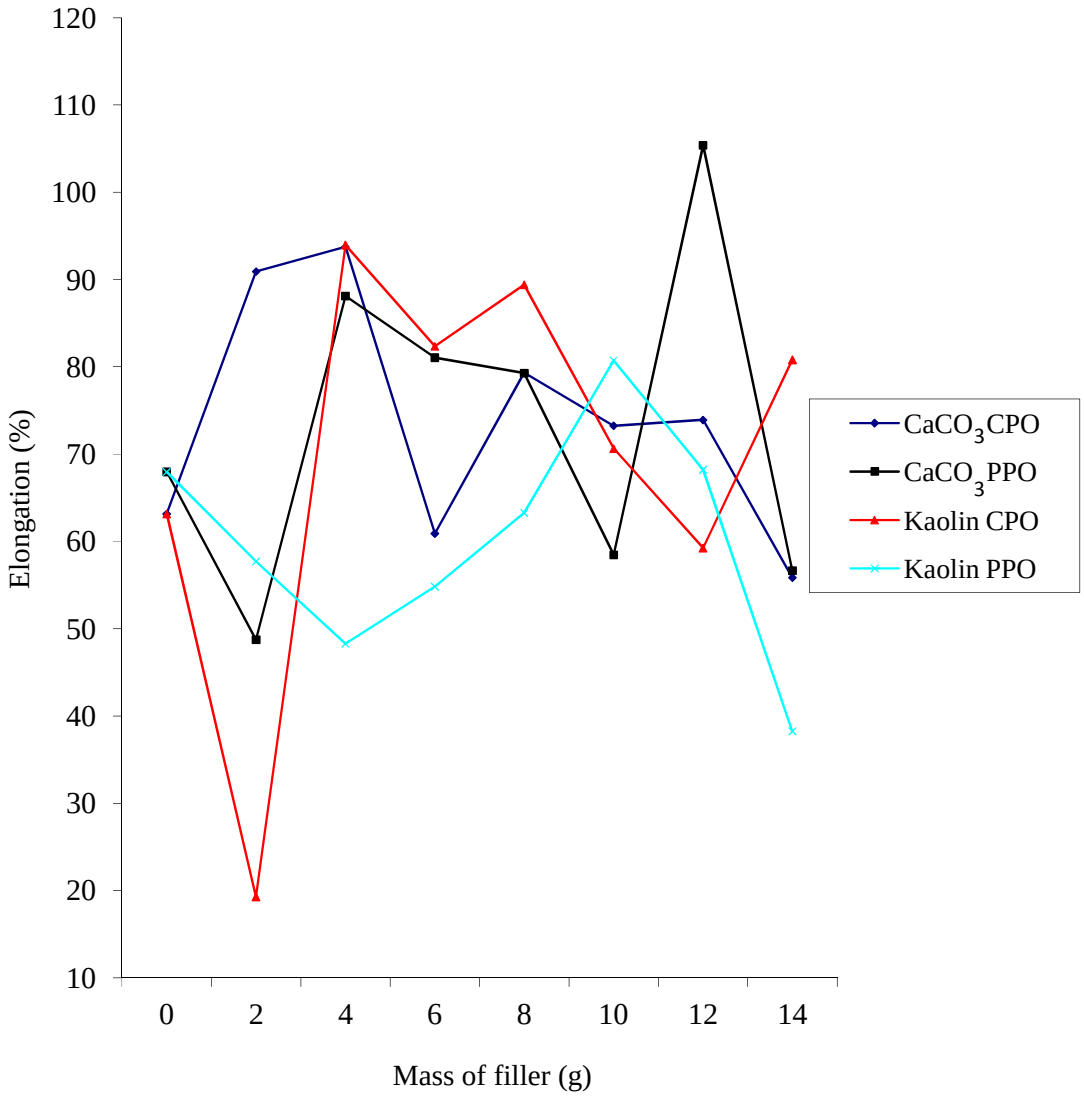

Fig. 3. Results of variations of Elongation with CPO and PPO filler loading

earlier observation in this present study that tensile strength correlates inversely with % elongation. Several researchers have reported that greater plasticization effects over crystallization effect (stretching orientation) alters the crystalline texture of the polymers by re-ordering and re – orienting the crystallites [20]. Plasticization due to diluents fillers (weak intermolecular forces between the polymer matrix and fillers) introducing amorphous (non-compatibility) regions decrease tensile strength [15]. What is evident here is the predominance of plasticization effect over stretching orientation which decreases tensile strength and modulus of elasticity but increases elongation at break. The factors that affect the reinforcing potential of fillers include; filler dispersion, surface area, surface reactivity, particle size, bonding quality between the filler and polymer matrix. Stiffness of filler effect reduces % elongation [21].

For $CaCO_3$ filled PPO, the results show peaks at; 4 g = 93.8% and 12 g = 105.4%, with sloping values at; 10 g = 81.1%, 8g = 79.3% and 14 g = 56.7% which are higher than the value at 0 g = 68% except the value at 14 g = 56.7% shown above. For kaolin filled PPO, the chart shows a high peak at 10 g = 80.7%, sloping peak at 12 g = 68.2% with valleys at; 4 g = 48.3% and 14 g = 38.3%, while values at; 6 g = 54.8% and 8 g = 63.3% fall below 68% value for 0 g filler.

Generally, % elongations are expected to increase with decrease in tensile strength values and vice versa. This is not strictly observed here probably due to a balance of plasticization and stretching orientation effects of the fillers except for 2 g kaolin filled CPO and 14 g kaolin filled PPO which indicate values of 19.3% and 38.3% elongation respectively, while other values show high increases or little decreases from values at 0 g $CaCO_3$ or kaolin filled CPO (= 63.2%) and 0 g $CaCO_3$ or kaolin filled PPO (= 68%) as observed by Okafor and Chukwu [20].

Fig. 4 shows the effects of filler loadings on % creep recovery. The results show that generally, % creep recovery decreases with filler loading, but these decreases are sharper for $CaCO_3$ filled CPO, PPO and kaolin filled PPO compared to kaolin filled CPO considering the values at 0 g filler with 41.7% and 6.4% for PPO and CPO in that order. Generally, kaolin filled CPO displays far higher increases in % creep recovery with filler loading compared to 6.4% at 0 g filler loading. For $CaCO_3$ filled CPO, % creep recovery peaks are observed at; 4 g = 7.4%, 8 g = 6.7% and depressions at; 2 g = 3.3%, 6 g = 1.3% and 10 g = 3.0% with slopes at 12 g = 2.8% and 14 g = 1.7%. For kaolin filled CPO, the highest peak is observed at 4 g = 34.2%, while lower peaks are observed at 6g (24.6%) and 8 g (24.7%). Depressions are displayed at; 10 g = 15.5%, 12g = 14.3% and 14 g = 12.2% and a rising peak at 2 g = 20.6%. For $CaCO_3$ filled PPO, sloping peaks are observed at 4 g = 16.5% 10 g = 5.0% and 14 g = 4.0%, with valleys at; 2 g = 6.8%, 6 g = 5.3%, 8 g = 1.5% and 12 g = 3.0% while kaolin filled PPO shows two creep recovery peaks at 10 g = 11.6% and 14 g = 7.8% with a trough between; 2 g = 1.9%, 4 g = 1.4% and 6 g = 0.8% and a rising peak at 8 g = 6.2% and a valley at 12 g = 4.1%. Generally, $CaCO_3$ filled CPO and PPO show much lower decreases in % creep recovery with filler loading compared to values at 0 g = 6.4% for CPO and 41.7% for PPO, while values for CPO loading show greater decreases than those for PPO except those at 8 g $CaCO_3$ filled CPO (= 6.7%) and PPO (= 1.5%) respectively. For kaolin filled CPO and PPO, results indicate that all CPO values are far higher than those of PPO, demonstrating that kaolin filled CPO exhibits far better % creep recovery property than $CaCO_3$ filled CPO, PPO and kaolin filled PPO. This observation is anchored on the fact that increases in filler loading increase degree of stiffness thereby reducing the springiness (creep recovery) of the foams while tensile strength increases at the expense of elongation [21]. The variations in the magnitude of the decreases in % creep recovery is due largely to either predominance of plasticization over stretching orientation effects or vice versa. The higher creep recovery characteristics of kaolin filled CPO can be explained based on ease of filler dispersion (low apparent bulk density), larger surface area, surface reactivity, particle size, better bonding quality between the filler and polymer matrix compared to $CaCO_3$. Furthermore, because CPO is less viscous than PPO, filler dispersion is easily achieved [22].

Fig. 5 shows the effects of filler loading on compression tests. These test values display the same trend as observed for % creep recoveries shown on Fig. 4. Compression (mm) generally decreases with filler loading, however these decreases are sharper for $CaCO_3$ filled CPO, PPO and kaolin filled PPO compared to kaolin filled CPO, with respect to the values at 0 g filler for PPO (= 17.2 mm) and CPO (=3.0 mm). For

$CaCO_3$ filled CPO, compression peaks are observed at; 4 g = 3.5 mm, and 8 g = 3.3 mm with depressions at; 2 g = 1.8 mm, 6 g = 1.5 mm and 10 g = 2.2 mm and slopes at; 12 g = 1.6 mm and 14 g = 1.2 mm. For kaolin filled CPO, the highest compression peak is observed at; 4 g = 14.7 mm, coming from a rising one at 2 g = 8.5 mm and sloping peaks at; 6 g = 10.5 mm, 8 g = 10.4 mm, 10 g = 7.2 mm, 12 g = 7.0 mm and 14 g = 5.5 mm. These values show the same trend with the corresponding % creep recovery values shown on Fig. 4. 24 with the same reasons explained above.

For $CaCO_3$ filled PPO, sloping peaks are observed at; 4 g = 6.6 mm, 10 g = 3.0 mm and 14 g = 2.1 mm, with depressions at; 2 g = 3.2 mm, 6 g = 2.6 mm, 8 g = 1.1 mm and 12 g = 1.7 mm as against kaolin filled PPO with sloping peaks observed at; 10 g = 5.2 mm and 14 g = 3.1 mm and a rising peak at 8 g = 3.0 mm, with a trough between 2 g = 1.2 mm, 4 g = 1.1 mm and 6 g = 0.7 mm. Again, values for kaolin filled CPO are far higher than those for $CaCO_3$ filled CPO, PPO and kaolin filled PPO, displaying the same trend observed for % creep recovery charts shown on Fig. 4. due to the same reasons, earlier stated.

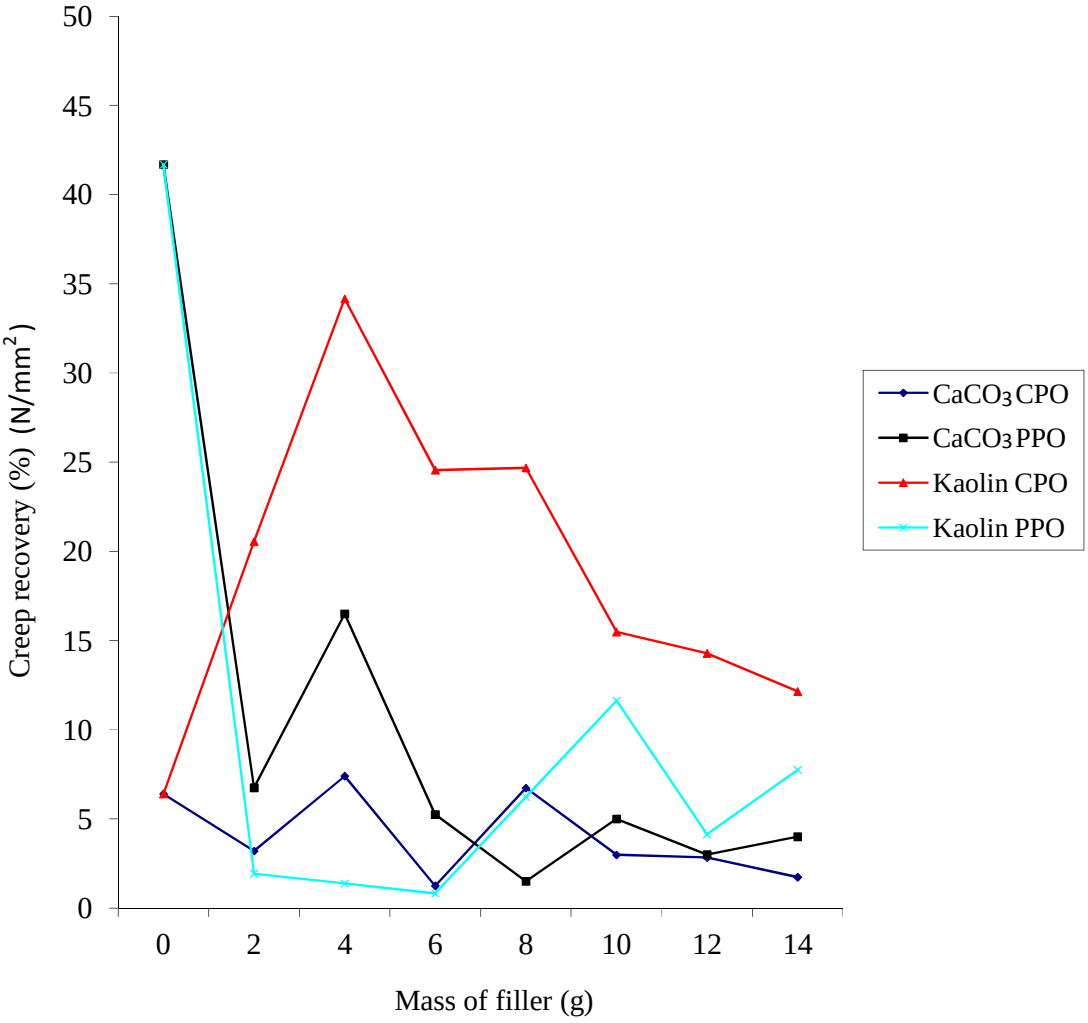

Fig. 4. Results of variations of Creep recovery with CPO and PPO filler loading at 20N applied compression load

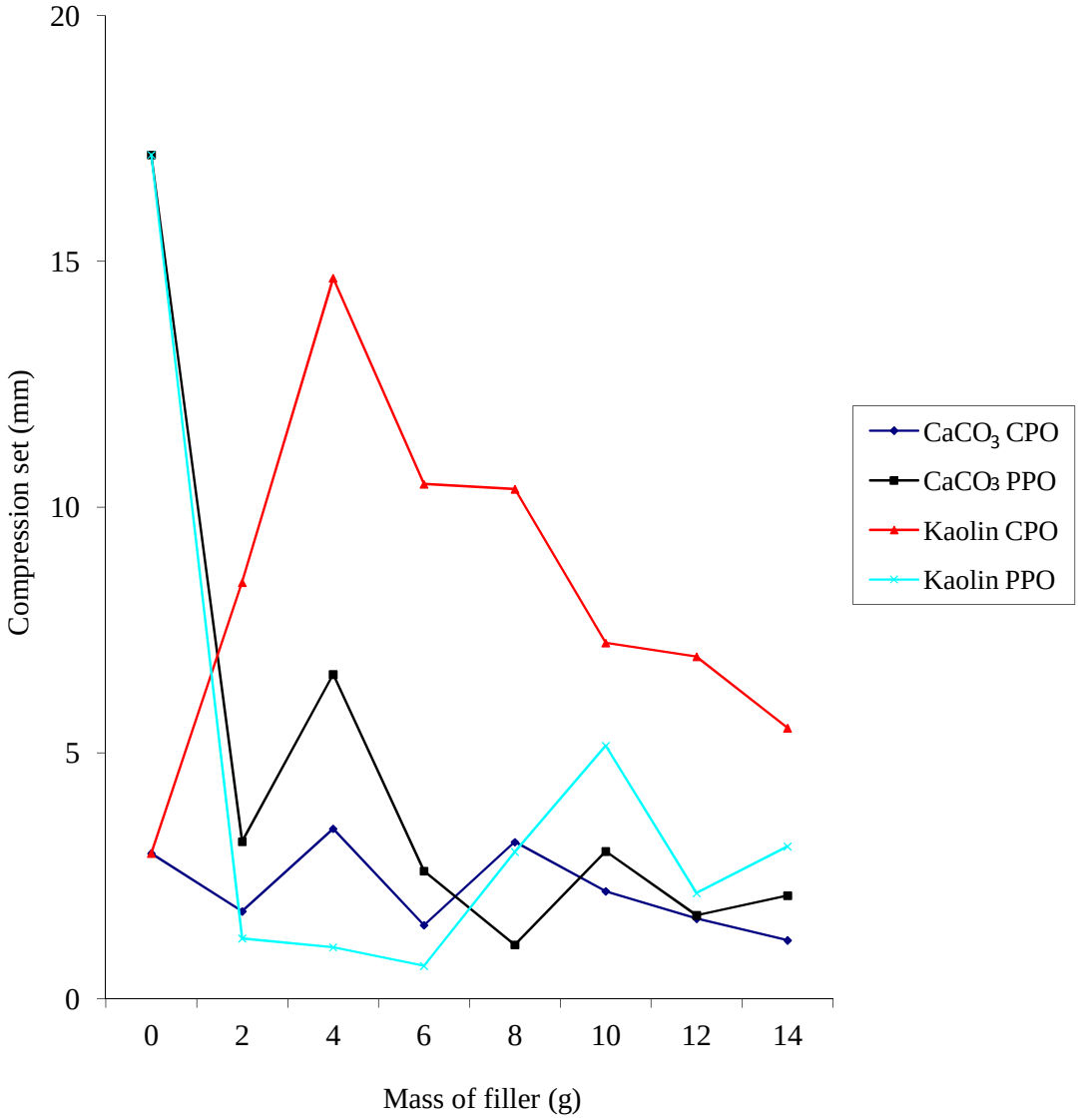

Fig. 5. Results of variations of compression testing with CPO and PPO filler loading at 20N applied compression load

4. CONCLUSION

Incorporation of between 2 – 8% of kaolin as filler improves tensile strength, creep recovery and compression set over and above $CaCO_3$ even though it lowers the density of foams while calcium carbonate incorporation between 2 – 14% also improves the mechanical properties mentioned above at comparatively lower values. This percentage incorporation of kaolin was seen to also improve the curing rates far above $CaCO_3$ [9]. Kaolin filled foams can be used for light weight application such as upholstery, packaging, industrial filters, etcetera [8]. Kaolin is much cheaper than $CaCO_3$ as 2 kg of kaolin processed in Jos costs between N400 and N500 while a corresponding weight of processed $CaCO_3$ costs much higher. Therefore, cost can be minimized and $CaCO_3$ can be freed for other uses. This is because kaolin being a clay mineral is abundant naturally and cheaper with large deposits on the Jos Plateau [9].

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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