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# EFFECTS OF LIME AND $CaCl_2$ ON IMPACT STRENGTH AND DIMENSIONAL STABILITY OF BANANA FIBRE- REINFORCED COMPOSITE ROOFING TILES

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## ABSTRACT

This study examined the effects of partial replacement of cement with lime and $CaCl_2$ addition on impact strength and sorption properties of banana fibre-reinforced concrete roofing tiles. Fibres were extracted from banana *(Musa acuminata*) pseudo-stems, while lime was obtained from welder's carbide waste (lime). Cement was replaced at 10, 20 and 30% levels, while $CaCl_2$ was added at 0 and 3% respectively by mass of cement in the production of the tiles. The Water Absorption (WA), Thickness Swelling (TS) and impact resistance of the roofing tiles were determined. The density of the samples ranged between 1.63 and 2.02g/cm$^3$. Partial replacement of cement with lime led to a reduction in density. WA values ranged from 0.8 to 3.13% at 2 h, and 0.84 to 3.18% at 24 h, with corresponding TS values of 0.84 - 1.60%, and 1.63 - 2.55% respectively. Partial replacement of cement with lime up to 20 % coupled with the addition of $CaCl_2$ led to a reduction in WA, while partial replacement of cement with lime up to 10 % led to a reduction in TS. Positive correlations were observed between the density and 24 WA of $CaCl_2$- treated and un-treated samples. However, the 24 WA and TS of only the samples treated with $CaCl_2$ were positively correlated, thus suggesting a need for further investigations on the role of $CaCl_2$ in the water resistance behaviour of banana fibre-cement composite. The use of $CaCl_2$ and partial substitution of Portland cement with carbide waste lime had no significant effect on the impact resistance of the roofing tiles.

**KEYWORDS:** banana fibre; lime; roofing tiles; impact resistance

## INTRODUCTION

Banana (*Musa acuminata)* is a perennial crop that grows quickly and can be harvested all year round. It is grown in all tropical regions and plays a key role in the economies of many developing countries where the bulk of the production is self-consumed or locally traded. The plant does not only give delicious fruit, but also provides the fibre. Nigerian farmers however often face the problem of disposal of the banana stem which are accumulated in banana growing areas. The fruitful utilization of these stems is therefore an important issue related to banana cultivation. Since waste banana stems is posing a big problem of disposal, they are available almost free of cost for fibre-reinforced composite production in Nigeria.

The three basic procedures that are used in extracting the banana fibres are retting, chemical treatment and mechanical decortication. In the retting process, the banana stems are soaked in water and the combined action of microbial enzymes and water decomposes the non-fibrous material surrounding the fibre bundles, enabling them to be loosened for manual extraction. The fibres can also be subjected to chemical treatments in order to remove the gummy material known as mucilage. Mechanical decortication takes place by passing the fibres through decortication machines that crush them between layers and scrape them against a bladed drum. Where decortication machine is not available, the fibres can be extracted manually with the use of hand (Wood, 1997). Banana fibre has relatively good mechanical strength (Maleque *et al.* 2007, Mukhopadhyay, *et al.* 2008). It is also bio-degradable and has no negative effect on environment and thus can be considered as an eco-friendly fibre. What was previously considered as agricultural waste is now used as a non-conventional material in cement composites Coutts (1990, 2005).

The ideal roof cladding material is one which should have relatively low self-weight and adequate strength to support different types of loads including its weight and loads due to wind pressure or any other imposed force. It should be impervious to rain, prevent excessive heat gain or loss, have good resistance to fire and require little maintenance during its life span. Given these conditions, it is not surprising that only a few materials (such as galvanized-iron sheets, aluminium sheets, clay, and concrete tiles) have become the recognized roof cladding materials. These materials are often imported and are invariably scarce and/or costly in most developing countries. Sometimes they are not available at all.

Investigations on the development of alternative low cost roofing materials from fibre-cement composites have been going on for over three decades. Given the relatively high cost of Portland cement in many developing countries, coupled with the negative environmental impact of cement manufacture, one possible option is to develop fibre-cement composites in which cement can be partially replaced. A potential material is carbide waste (lime). The Nigerian Automobile Technicians Association has about twenty-five thousand members (commonly referred to in the Nigerian parlance as *panel beaters*) who use calcium carbide for vehicle body repairs. Each *panel beater* produces an average of 30 kg of carbide waste (lime) daily which is dumped indiscriminately resulting in environmental problems and health hazard (Chukwudebelu *et al*. 2013). The utilization of waste carbide for cement mortar production was investigated by Al-Khaja (1992), while its potential uses for rattan cane fibre-cement and wood-cement composite manufacture have been explored by Olorunnisola and Ogundipe (2014) and Nta and Olorunnisola (2016) respectively. Also, banana contains carbohydrates that could inhibit cement hydration. The inhibitory effect can, however, be minimized by various means, including the use of chemical accelerators such as dilute Sodium Hydroxide (NaOH), Sodium Silicate ($Na_2SiO_3$), Calcium Chloride ($CaCl_2$) and Aluminum Sulphate $Al_2(SO_4)_3$. However, $CaCl_2$ is often preferred given the fact that it is relatively cheaper than other accelerators and it tends to enhance not just cement hydration, but also the mechanical properties of fibre-cement composites (Moslemi and Pfister 1987). The main objective of the study was to investigate the effects of $CaCl_2$ and lime on banana fibre-reinforced cement composite properties.

## METHODOLOGY

Decomposing banana *(Musa Acuminata)* stems obtained from a banana farm (Figure 1) were washed with water to remove the slimy material binding the cellulosic fibres together. The fibres were then separated from each other with the use of plastic comb to obtain straight fibres (Figure 2). The fibres were washed again and sun-dried for 2 days (Figure 3). The dried fibres were then cut into 25mm length and kept in a polythene bag prior to use to prevent moisture absorption. Carbide waste (lime) was air-dried for 7 days, pulverized and screened with 75nm British Standard sieve. The screened lime was further sun-dried for another 21. River sand was washed, sun-dried and sieved with a 2mm mesh size sieve.



**Figure 1: Decomposing Banana stems** **Figure 2: Fibre Extraction** **Figure 3: Dried Banana Fibres**

Fibre-cement composite samples were produced using cement: sand ratio of 1: 2, water: cement ratio of 0.5, 3%banana fibre (by mass of cement), lime (0%, 10%, 20% and 30% replacement of cement) and red oxide (2% by mass of cement). $CaCl_2$ was dissolved in distilled water in the following percentages: 0% (control) and 3% by mass of cement and added to the fibre-cement mixture. The mixture was then vibrated for 50 seconds. Each vibrated composite was carefully placed on a corrugated mould (Figure 4), covered with polythene sheet and de-moulded after 24 h. The dry corrugated roofing tile was then de-moulded and cured under water in a plastic reservoir at a temperature of 20 ± 2°C for 6days, and then kept in a ventilated room at room temperature for 21 days before being tested.

**Figure 4: Moulding of Roofing Tiles**

**Figure 5: The Fully-Cured Roofing Tiles**

The average mass and volume of three samples of each treatment were used to compute the average density. The water absorption test was carried out by immersing the samples in water at room temperature for 2 h and 22 h respectively after taking their initial masses and thicknesses, measured using a vernier calliper at four points, midway along each side of each sample. The average thickness was then calculated. The samples were withdrawn from the water to allow for water to drain before taking the final masses and thicknesses. The water absorption (WA) and thickness swelling (TS) were then calculated.

The impact strength test was carried out in accordance with RILEM (1984) specifications. A steel ball of mass 153g was used to determine the impact strength of the samples. The steel ball was dropped on a supported panel of board from increasing heights, each drop being made at the centre until the sample fails. Two replicate samples of each treatment were used and the mean value was determined. At each impact, the face of the sample was checked and the maximum height of drop of the steel ball that causes rupture is recorded. The impact energy was computed using equation 1:

$$E = mgh \quad (1)$$

Where: $E$ = Energy required to break the sample;
$m$ = mass of steel ball;
$g$ = acceleration due to gravity and
$h$ = maximum height of steel ball to rupture sample.

## RESULTS AND DISCUSSION

### Density of the Banana Fibre-Reinforced Roofing Tiles

As shown in Figure 6, the density of the banana fibre-reinforced composite roofing tile samples ranged between 1.63 and 2.02g/cm$^3$. Partial replacement of cement with lime resulted in a reduction in density in conformity with the findings of Nta and Olorunnisola (2016). The reduction in density with increase in lime content was most likely due to the differences in the specific gravity and porosity of carbide waste lime and Portland cement. The specific gravity of carbide waste lime is about 40 - 50% lower than that of Portland cement and it has been reported in literature that the porosity of carbide waste lime could be as high as 66%, while the capillary porosity of Portland cement, on the other hand, could be as low as 11 – 17% (Al-Khaja 1992). Also, though the addition of $CaCl_2$ slightly lowered the densities of the composites, the observed differences were not significant ($p<0.05$). These results suggest that partial replacement of cement with lime coupled with the use of $Cacl_2$ may be an effective strategy for decreasing the density and hence the weight of banana fibre –reinforced composite roofing tiles.

**Water Absorption by the Banana Fibre-Reinforced Roofing Tiles**

Figures 7 and 8 show the values obtained for WA by the composites after 2 and 24 h respectively. The values ranged from 0.8 to 3.1 % for 2 h WA, and from 0.9 to 3.2 % for 24 h WA. Partial replacement of cement with lime up to 20 % coupled with the addition of $CaCl_2$ led to a reduction in WA at 2 and 24 h respectively. Also, the 24 h WA was expectedly higher than the 2 h WA and that most of the WA by the composites occurred during the first 2 h. As shown in Figures 9 and 10, positive correlations were observed between the density and 24 WA in the composite samples un-treated and treated with $CaCl_2$ respectively. However, the correlation observed in the untreated samples was quadratic while that for treated samples was linear, suggesting that $CaCl_2$ addition played an intervening role in the WA behaviour of the samples. The actual nature of this role has to be further investigated.

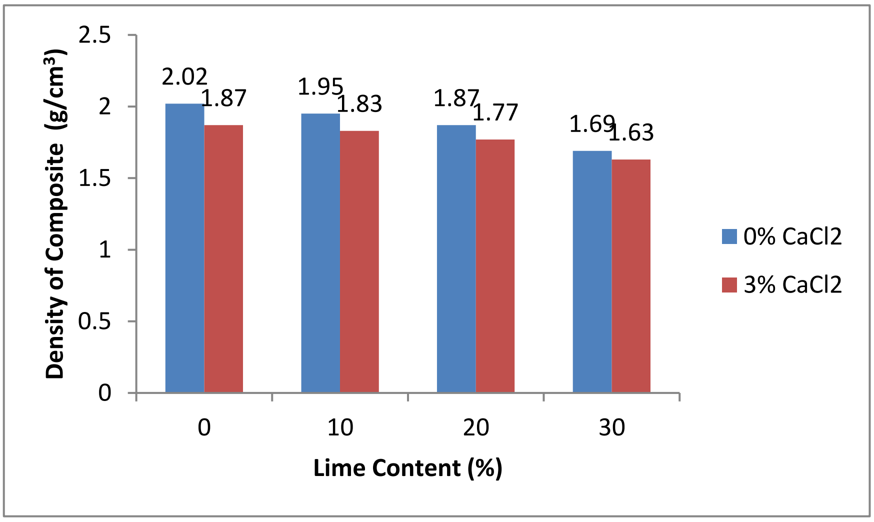


**Figure 6: Effect of $CaCl_2$ and Lime on the Density of the Roofing Tiles**

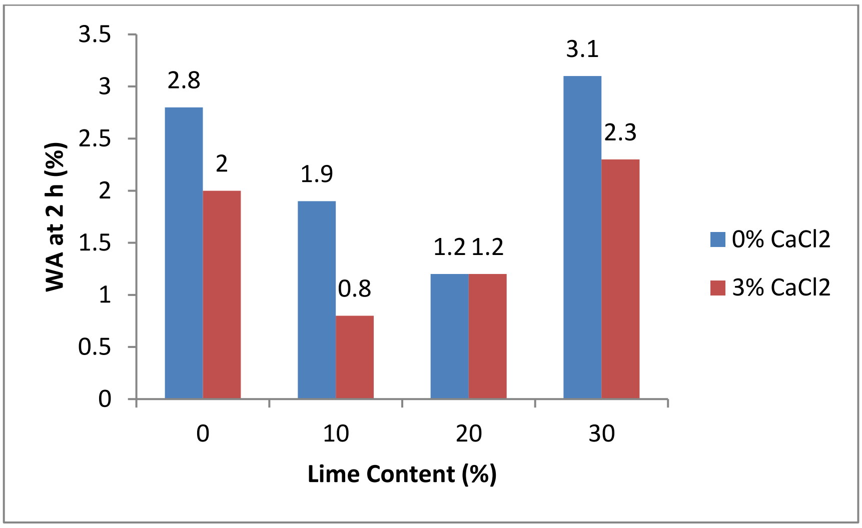


**Figure 7: Effect of $CaCl_2$ and Lime on the 2 h WA of the Roofing Tiles**

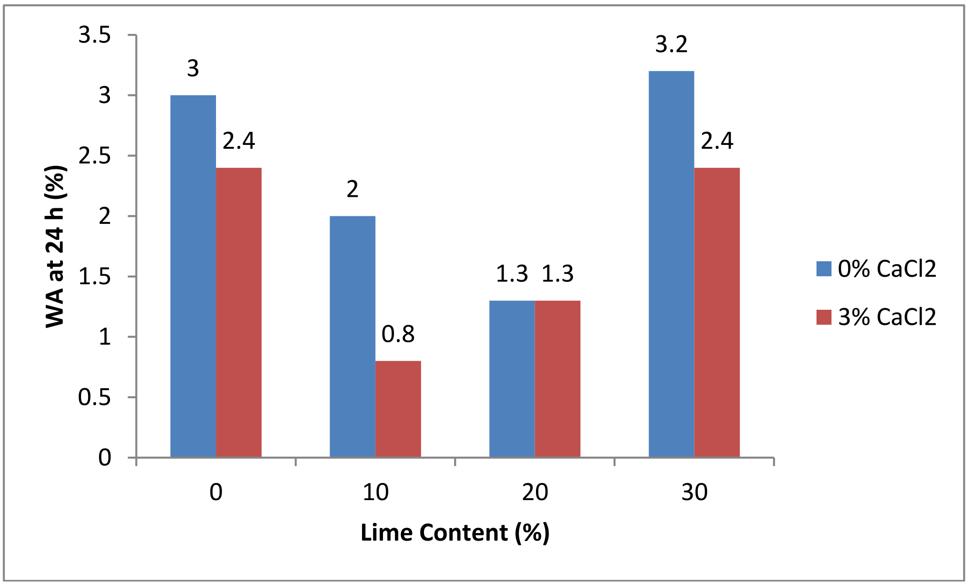


**Figure 8: Effect of $CaCl_2$ and Lime on the 24 h WA of the Roofing Tiles**

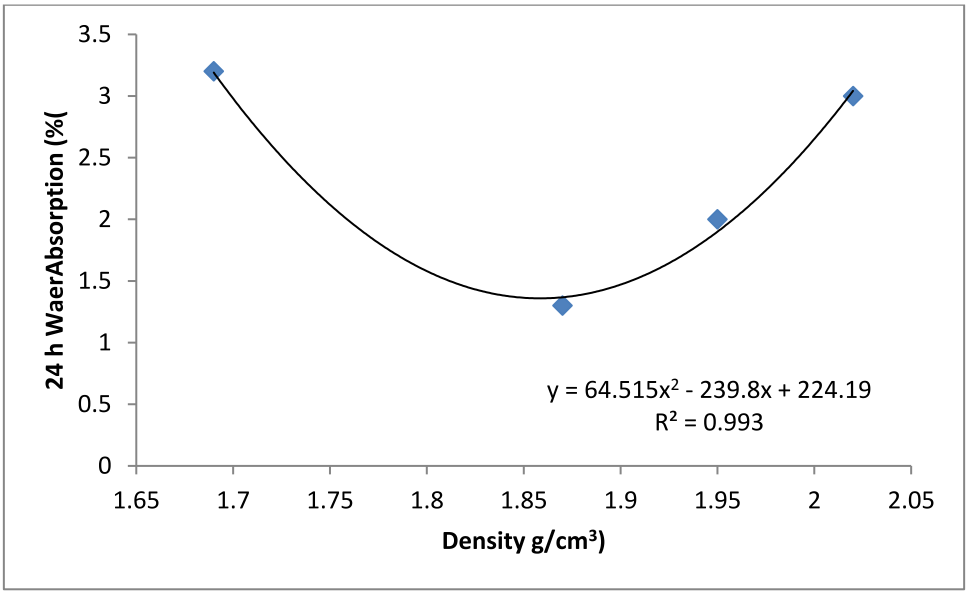


**Figure 9: Correlation between Density and 24 h WA of the Roofing Tiles Un-Treated with $CaCl_2$**

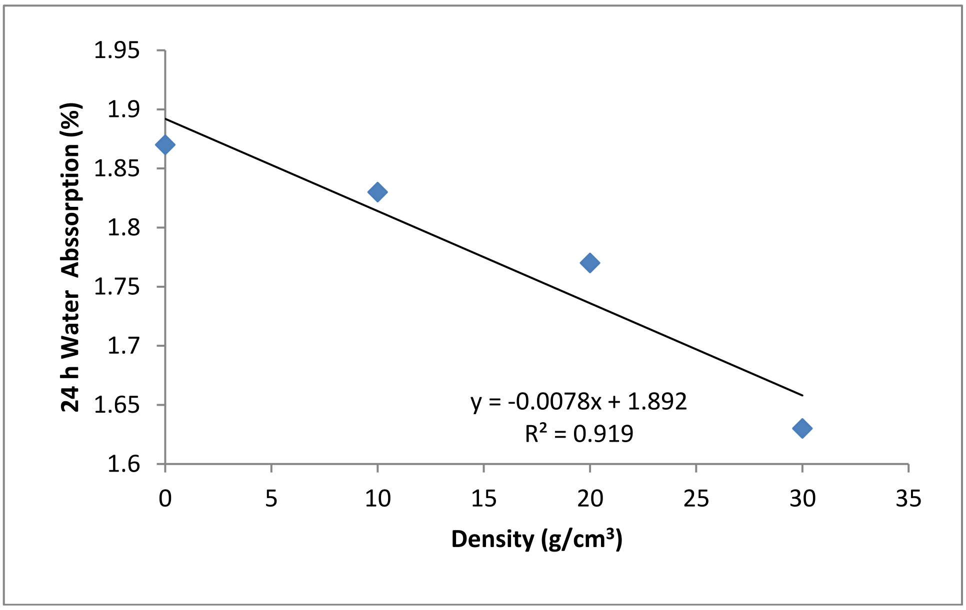


**Figure 10: Correlation between Density and 24 h WA of the Roofing Tiles Treated with $CaCl_2$**

### Thickness Swelling of the Banana Fibre-Reinforced Roofing Tiles

Thickness swelling is a measure of the dimensionally stability of cement-bonded composite materials when exposed to water. Samples with TS lower than 2 % after 24 h WA have been recommended for commercial use by ISO 8335 (1987). Figures 11 and 12 show the mean TS values obtained after 2

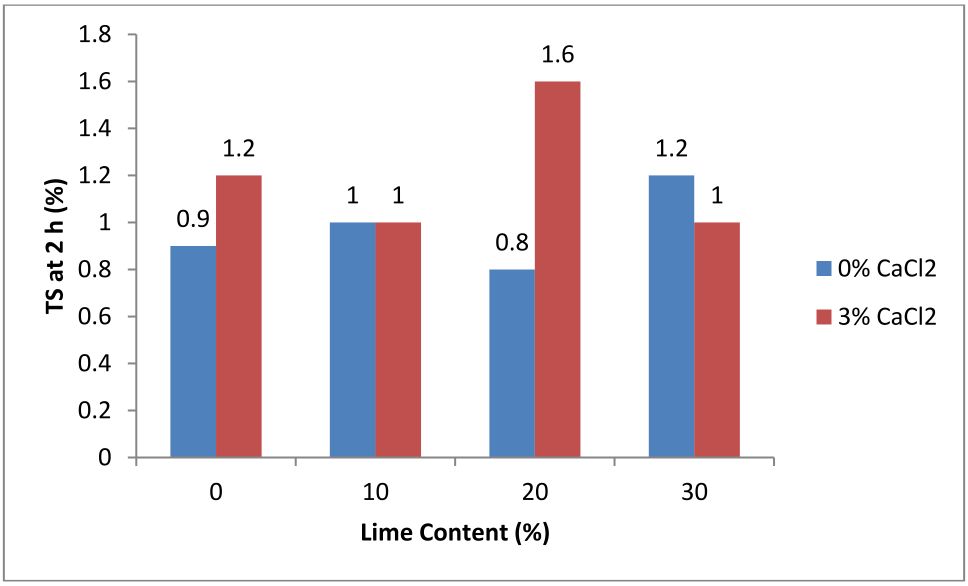


**Figure 11: Effect of $CaCl_2$ and Lime on the 2h TS of the Roofing Tiles**

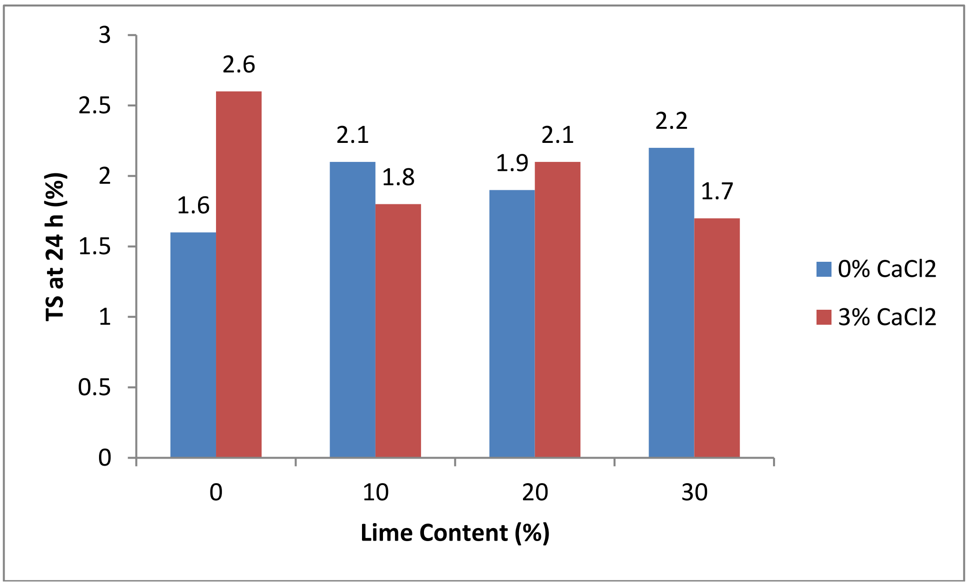


**Figure 12: Effect of $CaCl_2$ and Lime on the 24 h TS of the Roofing Tiles**

and 24 h respectively. The values are generally in conformity with the stated ISO standard except for the control samples treated with $CaCl_2$. Partial replacement of cement with lime up to 10 % led to a reduction in TS at 2 and 24 h respectively, suggesting that the threshold for partial replacement of cement with lime should be about 10% for the banana fibre-reinforced roofing tiles. A positive correlation was observed between the 24 WA and TS of the samples treated with $CaCl_2$ (Figure 13). On the contrary, there was no correlation between the 24 WA and TS of the un-treated samples. This result again suggests a need for further investigations on the role of $CaCl_2$ in the water resistance behaviour of the banana fibre-cement composite.

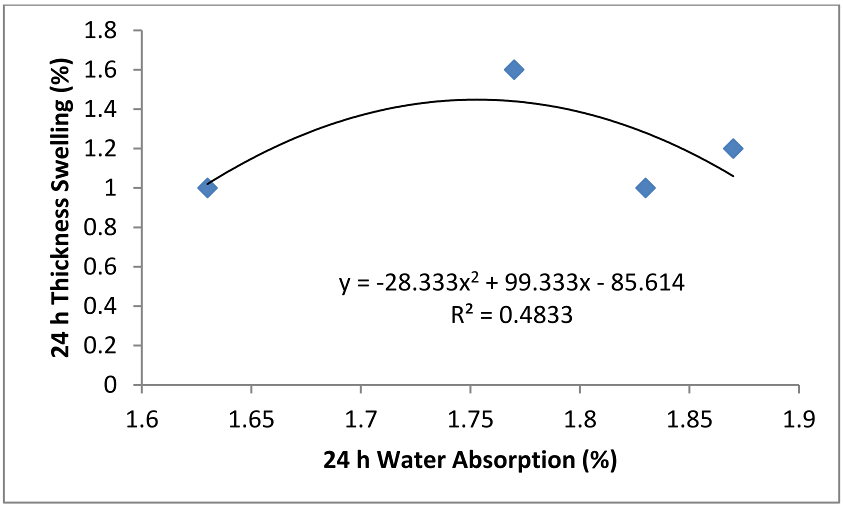


**Figure 13: Correlation between 24 h WA and TS of the Roofing Tiles Treated with $CaCl_2$**

**Impact Resistance**

The results of the impact energy test are presented in Figure 14. The mean impact energy of the roofing tiles ranged from 0.19 to 0.22Nm. There was an insignificant decrease in the impact energy as the lime content increased. However, the addition of $CaCl_2$ to samples in which cement was partially replaced with lime resulted in a slight but insignificant ($p<0.05$) increase in impact energy absorption capacity of the roofing tiles. A similar finding was reported by Olorunnisola and Ogundipe (2014) for rattan fibre-reinforced roofing tiles in which cement was partially replaced with carbide waste lime. Al-Khaja (1992) had also reported an insignificant decrease in compression strength when carbide waste lime was mixed with cement in making mortars. What these findings suggest is that partial substitution of Portland cement with carbide waste lime in small quantities would not have negative effects the strength properties of the resulting lime-cement product.

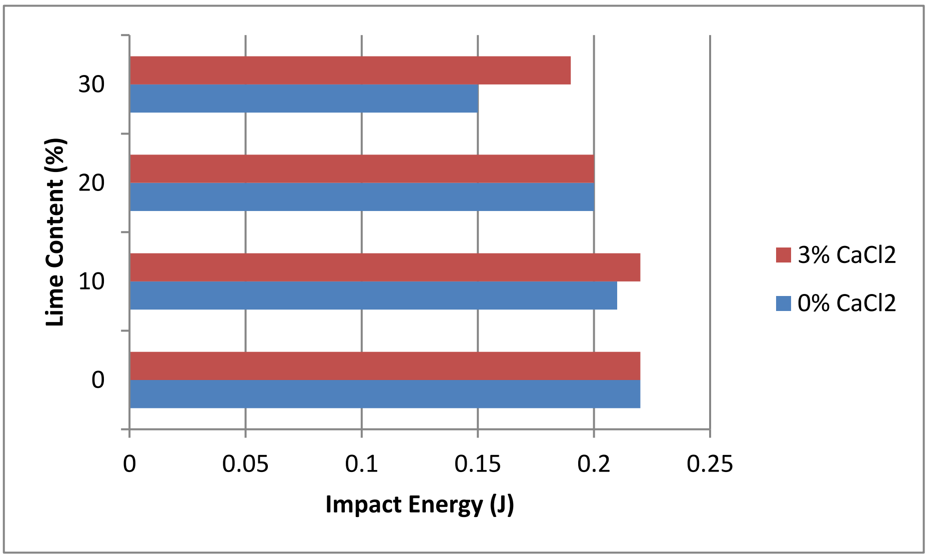


**Figure 14: Effect of $CaCl_2$ and Lime on Impact Resistance of the Roofing Tiles**

## CONCLUSION

Based on the findings of this study, it was concluded that it is possible to partially replace cement with about 10% waste carbide lime in the production banana fibre-reinforced roofing tiles to reduce cost, weight, and thickness swelling without significantly compromising their impact energy absorption capacity. Addition of 3% $CaCl_2$ would further enhance the properties of the roofing tiles.

## ACKNOWLEDGEMENTS

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