Direct Research Journals

Direct Research Journal of Chemistry and Material Science
Vol.7 (1), pp. 12-19, March 2020
ISSN 2354-4163
DOI: https://doi.org/10.26765/DRJCMS12129868
Article Number: DRJCMS12129868

https://directresearchpublisher.org/drjcm/

*Full Length Research Paper*

# Compatibility Test of Hybrid Cement with Sawdust and Water Mixes in the Production of Cement Bonded Composite

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Received 3 February 2020; Accepted 26 March, 2020

**ABSTRACT:** The suitability of hybrid cement, Obeche sawdust and water using the hydration test were investigated. The effect of calcium chloride ($CaCl_2$) incorporation on the hydration parameters was examined. The hydration parameters considered in this project are maximum hydration temperature ($T_{max}$), setting time ($t_{max}$), time ratio ($t_R$) and inhibitory index. Two sets of sawdust (without and with hot water extraction) were used as fiber reinforcement/filler in the cement matrix. Hot water treatment maintained at 80°C for about 2 h was conducted. Coconut shell ash was reacted with 5% calcium hydroxide to produce coconut shell pozzolana. After the production of the pozzolan, two different formulations of hybrid cement were considered which were 80:20 and 60:40 (% basis) of Portland cement to pozzolan. The control was 100% Portland cement. The increase of pozzolan in the hybrid cement showed considerable differences in the hydration reaction. Calcium chloride treatment considerably improved the compatibility of the various hybrid cement with wood particles. The combination of all the hydration parameters employed in this project was evidenced that the two hybrid cement formulated from Portland cement and coconut shell ash pozzolan are compatible with Obeche wood for the production of cement bonded composites.

**Keywords:** Hybrid cement, pozzolan, hydration, compatible, inhibitory

## INTRODUCTION

Cement bonded composites (CBC) are very important and indispensable product produced from strands, particles or fibres of wood, mixed together with Portland cement. These are manufactured into panels, bricks, tiles and other products used in the construction industry and are of high demand all over the world (Beutel, 1996). The incorporation of wood elements in the composites greatly improves the mechanical properties (especially the brittle fracture strength) of the matrix material (cement) while retaining the excellent fire resistance associated with the matrix (Moslemi, 1989). However, CBC is not a novel concept, having been on the market for over 70 years (Moslemi and Pfister, 1987) but the introduction of hybrid cement which are made from natural pozzolan and Portland cement for the production of CBC is novel. Despite of the advantages associated with CBC, its production still faces some challenges. According to Fabiyi, (2013), the production of CBC for floor tiles, ceiling, wall partitioning, etc. is becoming expensive because of the increasing cost of Portland cement procurement in Nigeria. In the year 2016, the cost of Portland cement was almost 50% higher than that of 2013. Unfortunately, the needs for shelter by both the rich and the poor, during the economic abundance or recession makes it a must not to neglect the task of making housing an affordable for all. One of the practical approaches is to produce low-cost building materials. Since cement is a major ingredient in the manufacturing of the CBC, the production of a low-cost "hybrid cement," commonly known as pozzolana cement, would serves as a good program. Reducing the cost of CBCs production is of great interest and this can be done by finding an alternative way of substituting Portland cement with natural pozzolana cement. A pozzolan has been defined as a siliceous or aluminosiliceous material that, in finely divided form and in the presence of moisture, chemically reacts with the calcium hydroxide released by the hydration of Portland cement to form calcium silicate hydrate and other cementitious compounds (Detwiler *et al*., 1996). Therefore, natural pozzolana cement could be produced from any biomaterials with high silica content. An example of such biomaterials is coconut shell, which is also a very common agricultural food crop. It was reported that many tonnes of coconut shells are generated annually worldwide while about 2 million are generated in Nigeria annually (Oyetola and Abdullahi, 2006). Out of the total coconut produced, the shell constitutes approximately 20%. Unfortunately, recycling of agricultural residues like coconut shells may not be commensurate with the increase in coconut shells generation. Large quantity of the coconut shells generated in developing countries are normally burnt off or dumped in landfills, while the insignificant portion is used as fuel. Burning in the open air is likely to cause environmental pollution as carbon dioxide ($CO_2$) and carbon-monoxide (CO) would be released into the atmosphere as a result of insufficient oxygen in the heap of the coconut shell. The release of these gases into the atmosphere changes the climate, thereby resulting in global warming, which is now one of the greatest threats to our world (Fabiyi, 2003). Blending pozzolan with Portland cement could be referred to as “green cement” because it reduces carbon dioxide emissions and also encourages the use of waste materials in the case of the recycling of wastes (Wilson and Ding, 2007). Bilodeau and Malhotra (2003) estimated that the production of 1 tone of ordinary Portland cement (OPC) led to the release of 1 tone of $CO_2$, a major contributor to the greenhouse effect and the global warming of the planet. Decrease in the amount of $CO_2$ released into the atmosphere during Portland cement production can be achieved with the use of natural pozzolans. Based on this fact, using coconut shell for the production of pozzolan would help reduce CBC production cost, minimize environmental pollution, enhance municipal solid wastes management, and also contribute positively to the economic growth of our society.

Several studies all over the world today are focusing on ways of utilizing agro-wastes as a source of raw materials for the production of natural pozzolan (cementious ash) in the CBC industry. These wastes utilization would not only be economical, but can also result to foreign exchange earnings and environmental pollution control. Waste wood and other lignocellulosic materials are abundant. The annual global production of lignocellulosic residues is about 4 billion tons, of which roughly 60% comes from agricultural crops and 40% from forests (Olesen and Plackett, 1999).

The use of chemical additives such as $Cacl_2$ improves wood to cement bond and CBC properties due to its effect of accelerating the hydration of wood cement mixtures (Olorunnisola, 2007). It also improves the bonding between particles of lignocellulosic materials and cement (Badejo, 1989; Fabiyi, 2003; Olorunnisola, 2006). Therefore, this study was designed to investigate the compatibility of hybrid cement, obeche sawdust and water by employing the hydration test.

## MATERIALS AND METHODS

Portland cement was purchased from a local cement distributor in Akure., Coconut shell (CNS) was collected from coconut chips producers, Obeche sawdust was collected from a local sawmill, while $CaCl_2$ was purchased at a local scientific chemical store in Akure Ondo state Nigeria. Obeche sawdust was subjected to hot water treatment (maintained at 80°C for about 2 h) to remove water-soluble extractives. The coconut shell was then air dried and then converted to ash as described by Fabiyi, (2013). The ash was reacted with 5% calcium hydroxide (lime, by weight of coconut shell ash) in order to produce coconut shell pozzolana. After the production of the pozzolan, two different formulations of hybrid cement were considered which are 80:20 and 60:40 (% basis) of Portland cement to pozzolan. The control was purely 100% Portland cement. The 80:20 and 60:40 hybrid cement were referred to as hybrid cement type A and type B, respectively. For the hydration test, 15 g of sawdust ( untreated and treated with 3% $CaCl_2$), 200 g of hybrid cement (PC: pozzolan of 100:0, 80:20,and 60:40) and 93 ml of distilled water was measured and then mixed in a polyethylene bag to form homogenous slurry following the method developed by Adefisan and Olorunshola (2007). The test was performed in well insulated thermos flasks. The temperature rise was monitored for 24 hours using thermocouples (J-type) connected to an 8-channel data logger (USBTC-08, Pico Technology). Four specimens of each mixture were tested. The compatibility of Obeche wood sawdust with the hybrid cement was assessed based on the compatibility indices developed by Sandermann and Kohler, (1964), Hofstrand *et al*. (1984), Olorunnisola, (2002) and Weatherwax and Tarkow, (1964).

## RESULTS AND DISCUSSION

The hydration curves of the mixes of Portland cement, coconut shell ash pozzolan, wood particles of Obeche

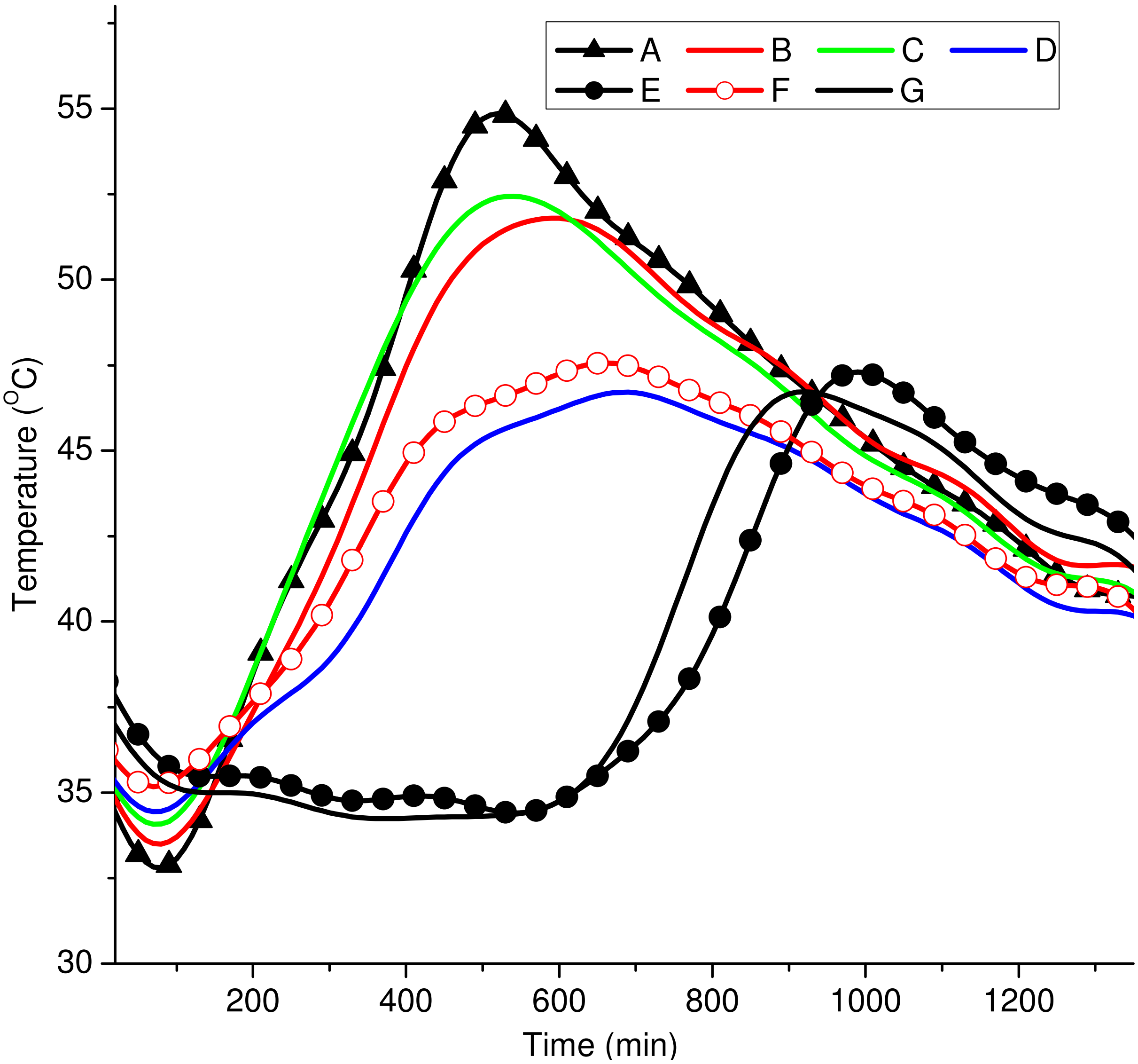


**Figure 1.** Exothermic reactions (temperature versus time) for (A) neat cement-water mixed, (B) wood without hot water extraction-Portland cement-water mixed, (C) wood with hot water extraction-Portland cement-water mixed, (D) wood without hot water extraction -hybrid cement type A-water mixed, (E) wood without hot water extraction -hybrid cement type B-water mixed, (F) wood with hot water extraction- hybrid cement type A-water mixed and (G) wood with hot water extraction-hybrid cement type B-water mixed.

and water are shown in Figures 1 and 2. These curves show the temperature behaviour that occurred during the curing of the control and the hybrid cement (either type A or B), Obeche wood particles (without and with hot water extracted) a distilled water in order to ascertain the suitability of the compounded materials for cement bonded composites production. Various hydration parameters like maximum hydration temperature ($T_{max}$,°C), maximum setting times ($t_{max}$, h), time ratio ($t_r$) and inhibitory index were calculated from the data obtained from (Figures 1 and 2) which are presented in (Tables 1 and 2).

**Maximum hydration temperature**

From Table 1, the maximum hydration temperature ($T_{max}$) for neat cement, control, hybrid cements and wood particle (without and with hot water extraction ranged between 46.29±0.48 and 58.74±0.88 °C. The mixture of control cement, wood particles without hot water extraction and 3% $CaCl_2$ had the maximum hydration temperature ($T_{max}$) while the hybrid cement “type B”, wood particles with hot water extraction and 3% $CaCl_2$ had the lowest. The substitution of Portland cement with 20 and 40% coconut shell pozzolan caused reduction in

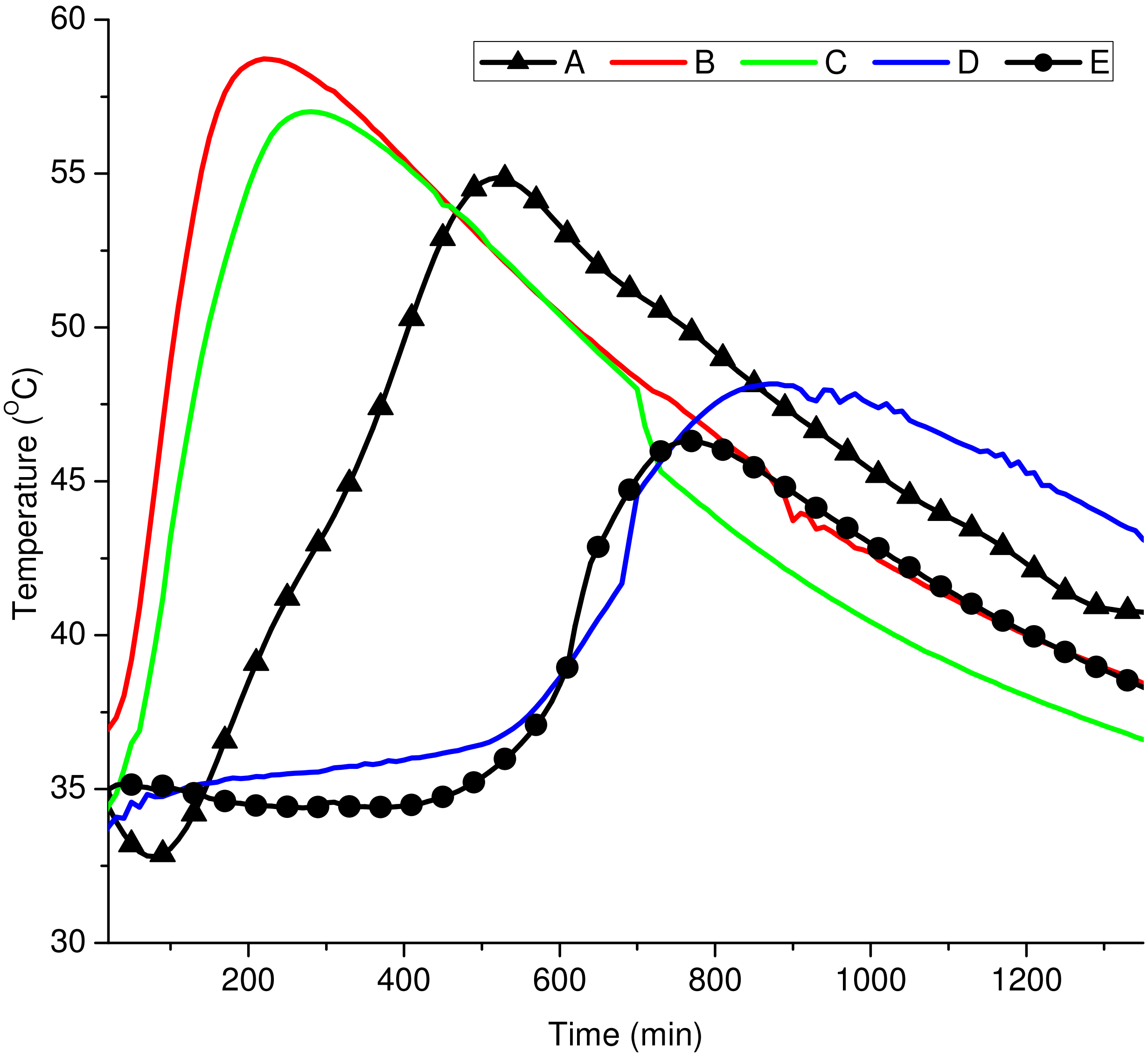


**Figure 2.** Exothermic reactions (temperature versus time) for (A) neat cement-water mixed, (B) $CaCl_2$ treated wood without hot water extraction-Portland cement-water mixed, (C) $CaCl_2$ treated wood with hot water extraction-Portland cement-water mixed, (D) $CaCl_2$ treated wood with hot water extraction- hybrid cement type A-water mixed and (E) $CaCl_2$ treated wood with hot water extraction-hybrid cement type B-water mixed.

the maximum hydration temperature). The analysis of variance presented in (Table 2) shown that there was a significant different at $p \leq 0.05$ for the maximum hydration temperature of the various cement-wood-water mixes.

The suitability classification of the hybrid cement formulated for cement bonded composites (CBC) in this study could be established based on the study of Sandermann and Kohler (1964), where three suitability classes based on maximum hydration temperature were developed for any lignocellulosic materials with $T_{max}$<50°C, $T_{max}$=50-60°C and $T_{max}$>60°C as unsuitable, intermediately suitable and suitable, respectively. Therefore, none of the hybrid cement formulated was suitable for the cement bonded composites production when considering only the maximum hydration temperature. The wood particles with and without hot water extracted whether incorporated with $CaCl_2$ or not, were intermediately suitable for CBC production. Generally, incorporation of calcium chloride increased the maximum hydration temperature except for the mixture of hybrid cement “type B” and wood particles with hot water extraction. This is not surprising because $CaCl_2$ has been identified as a good accelerator that helps cement setting (Arum and Olotuah, 2006). Also, increased in the pozzolan proportion caused decrease in the $T_{max}$. According to Zhou and Kamdem (2002), the $T_{max}$

**Table 1:** Hydration parameters (maximum hydration temperature and setting time at maximum hydration temperature) of Obeche-cement –water systems.

| Treatment | Maximum temp. ($T_{max}$, °C) | Remark | Setting time max. ($t_{max}$, h) | Remark |
|---|---|---|---|---|
| Neat Portland cement | 55.202±0.77 | IS | 6.88±0.00 | S |
| Control + wood without hot water extraction | 52.09±0.61 | IS | 8.21±0.10 | S |
| Control + wood with hot water extraction | 52.67±0.30 | IS | 8.67 | S |
| Hybrid cement "A" + wood without hot water extraction | 46.64±0.54 | US | 10.5 | S |
| Hybrid cement "B" + wood without hot water extraction | 47.22±0.66 | US | 16.33 | US |
| Hybrid cement "A" + wood with hot water extraction | 47.52±0.97 | US | 10.17 | S |
| Hybrid cement "B" + wood with hot water extraction | 46.95±0.91 | US | 15.5±0.67 | US |
| Control + wood without hot water extraction +$CaCl_2$ | 58.74±0.88 | IS | 3.78±0.19 | S |
| Control + wood with hot water extraction + $CaCl_2$ | 57.02±0.69 | IS | 4.67±0.17 | S |
| Hybrid cement "A" + wood with hot water extraction + $CaCl_2$ | 48.21±0.69 | US | 14.55±0.43 | S |
| Hybrid cement "B" + wood with hot water extraction + $CaCl_2$ | 46.29±0.48 | US | 12.22±0.10 | S |

reduction may be caused by a reduced value of cement hardening or by the presence of a determined mass of lignocellulosic material which did not contribute to heat generation but, on the contrary, absorbed it.

The $T_{max}$ for the neat Portland cement revealed that the cement used was not even suitable but intermediately suitable for the CBC production based on Sandermann and Kohler, (1964) suitability classification. It could therefore be deduced that there are some yet to discover reason for the low the $T_{max}$ in this study whether for the Portland cement- or hybrid cement- wood mixes. Oyagade (1993) explained that chemical composition of cement which may vary from country to country and from one manufacturer to the other dictates the maximum hydration temperature attainable. Therefore, absolute comparison of wood-cement-water mixes solely on the maximum hydration temperature for compatibility classification by researcher who did not purchase cement from the same source where Sandermann and Kohler, (1964) bought their own may be misled. More importantly, judging the suitability of hybrid cement (combination of Portland cement and coconut shell ash pozzolan) based on maximum hydration temperature alone may not be enough reason for rejecting it. Adefisan and Olorunnisola (2010) reported that the maximum hydration temperature for an admixture of cement, lignocellulosic material and water may be equal or greater than 40°C and still be suitable for CBC production. This implies that it should not be a hard rule to set minimum allowable maximum hydration temperature to above 50°C suggested by Sandermann and Kohler, (1964). Therefore, going by the report of Adefisan and Olorunnisola (2010), the hybrid cement formulated in this study are suitable for CBC production as the $T_{max}$ is greater than 40°C.

## Setting time

The maximum setting times (time to reach maximum temperature, $t_{max}$) for neat cement, control, hybrid cement

**Table 2:** Hydration parameters (time ratio index and inhibitory) of Obeche-cement–water systems.

| Treatment | Time ratio index ($t_R$) | Remark | Inhibitory | Remark |
|---|---|---|---|---|
| Neat Portland cement | 1 | S | 0 | LI |
| Control + wood without hot water extraction | 1.19 | S | 19.21 | MI |
| Control + wood with hot water extraction | 1.26 | S | 25.91 | MI |
| Hybrid cement "A" + wood without hot water extraction | 1.53 | A | 52.54 | HI |
| Hybrid cement "B" + wood without hot water extraction | 2.37 | I | 137.29 | EI |
| Hybrid cement "A" + wood with hot water extraction | 1.48 | S | 47.69 | MI |
| Hybrid cement "B" + wood with hot water extraction | 2.25 | I | 125.18 | EI |
| Control + wood without hot water extraction +$CaCl_2$ | 0.55 | S | -45.11 | LI |
| Control + wood with hot water extraction + $CaCl_2$ | 0.68 | S | -32.2 | LI |
| Hybrid cement "A" + wood with hot water extraction + $CaCl_2$ | 2.11 | I | 111.38 | EI |
| Hybrid cement "B" + wood with hot water extraction + $CaCl_2$ | 1.78 | A | 77.56 | HI |

Where S = suitable, A = acceptable, I = inhibitory, LI = low inhibitory, MI = medium inhibitory, HI = high inhibitory and EI = extreme inhibitory

and wood particles (without and with hot water extraction) ranged from 3.78 and 16.33 hours (Table 1). The highest and lowest maximum setting time were observed for the mixes of hybrid cement "type B" and wood particles without hot water extraction as well as control, wood without hot water extraction and $CaCl_2$, respectively. Hofstrand *et al.* (1984) classified cement-wood mix based on maximum setting time where $t_{max}$<15h and $t_{max}$>20h are grouped as suitable and unsuitable, respectively. Based on this classification, only the hybrid cement "type B" and wood particles (without and with hot water extraction) without the incorporation of $CaCl_2$ were unsuitable for the CBC production; all other mixes were suitable.

## Time ratio

The time ratio for neat cement, control, hybrid cement and wood particle (without and with hot water extraction are presented in (Table 2). The value ranges from 0.55 to 2.25. The time ratio for the wood particles without hot water extraction and wood particles with hot water extraction were 1.19 and 1.26, respectively. Time ratios for mixture of control (100% Portland cement), wood without hot water extraction and $CaCl_2$, control, wood without hot water extraction and $CaCl_2$, wood particle with hot water extraction, hybrid cement type "A" and $CaCl_2$, wood particle with hot water extraction, hybrid cement type "B" and $CaCl_2$ and wood particles without hot water extraction with $CaCl_2$ incorporation were 0.55, 0.68, 2.11 and 1.78, respectively. It is also noted that the value increased from 1.53 to 2.37 for un treatedwood + hybrid cement type "A" and untreated wood+ hybrid cement type "B"; from 1.48 to 2.25 for treated wood+ hybrid cement type "A" and treated wood+ hybrid cement type "B". Olorunnisola, (2008) used time ratio to classify the suitability of lignocellulosic fiber for CBC production: $1 \leq t_R \geq 1.5$, $1.5 < t_R \geq 2.0$ and $t_R > 2.0$ as suitable, acceptable and inhibitory, respectively. Based on this, the mixture of wood particle without and with hot water extraction, hybrid cement type "A" and wood particle with hot water extraction, hybrid cement type "B" and $CaCl_2$ were all inhibitory. The other mixture types are either suitable or acceptable for CBC production.

### Inhibitory index

The inhibitory indices calculated for all the mixes in this study are presented in (Table 2). The inhibitory indices were found to range from -45.11 and 137. The lowest value was recorded for wood particle without hot water extraction but incorporated with $CaCl_2$ while the highest value was recorded for wood particle without hot water extraction, hybrid cement type "B". The inhibitory index in accordance with Okino *et al*. (2004) can be classified as $I \leq 10$, $10 < I \leq 50$, $50 < I \leq 100$ and $I > 100$, such raw material is graded as having low, medium, high and extreme inhibition, respectively. Comparing the inhibitory indices obtained in this study with the values assigned to different inhibitory indices by Okino *et al.* (2004), the inhibitory index results showed that mixtures of wood particle without hot water extraction and hybrid cement type "B", wood particle with hot water extraction and hybrid cement type "B" as well as wood particle with hot water extraction, hybrid cement type "A" and $CaCl_2$ are with extreme inhibition. Mixtures of wood particle without hot water extraction and hybrid cement type "A" and mixtures of wood particle with hot water extraction, hybrid cement type "B" and $CaCl_2$ also show high level of inhibition while mixtures of wood particle without and with hot water extraction and control cement and mixtures of wood particle with hot water extraction and hybrid cement type "A" had medium level of inhibition. But it is to be noted that wood particle without or with hot water extraction, control cement and with or without $CaCl_2$ had negative inhibitory value. This is an indication that these two mixes are highly compatible.

### Conclusion

From this study, incorporation of coconut shell ash pozzolan at certain proportions to ordinary Portland cement when mixed Obeche wood particles showed that pozzolan supplementary is suitable for cement bonded composites (CBCs) production based on hydration testing conducted. The substitution of Portland cement with 20 and 40% coconut shell ash pozzolan caused reduction in the maximum hydration temperature but incorporation of calcium chloride increased the maximum hydration temperature. Hydration behaviour showed that incorporation of $Cacl_2$ into the mixes is suitable for CBC production based on its setting time. The classification of the suitability of the hybrid cement based on the maximum setting times and ratio of setting time of wood: cement mix to neat cement are more favourable than using the maximum hydration temperature. Both the maximum setting times and ratio of setting time of wood: cement mix to neat cement revealed that increasing the proportion of CSA pozzolan in the hybrid cement enhance considerable improvement on their suitability both for untreated and treated wood particles. Inhibitory index shown that wood particle without or with hot water extraction, control cement and + $CaCl_2$ had negative inhibitory value which indication that these mixes are highly compatible. In addition, the outcome of this project revealed the validity of the suitability of the hybrid cement for cement bonded composites production cannot solely be judged based on only one hydration parameters especially the maximum hydration temperature. Generally, combination of all the hydration parameters employed in this project showed that the two hybrid cement formulated from Portland cement and coconut shell ash pozzolan are compatible with Obeche wood for production of cement bonded composites.

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