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Utilizing wood wastes as reinforcement in wood cement composite bricks

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Abstract: This paper presents the research work undertaken to study the properties of Wood Cement Composite Bricks (WCCB) from different wood wastes and cement / wood content. The WCBBs with nominal density of 1200 kg m^{-3} were produced from three tropical wood species and at varying cement and wood content of 2:1, 2.5:1 and 3:1 on a weight to weight basis. The properties evaluated were compressive strength, Ultra Pulse Velocity (UPV), water absorption (WA) and thickness swelling (TS). The Compressive strength values ranged from 0.25 to 1.13 N mm^{-2} and UPV values ranged from 18753 to 49992 m s^{-1}. The mean values of WA after 672 hours (28 days) of water soaking of the WCCBs ranged from 9.50% to 47.13% where there were no noticeable change in the TS of the bricks. The observed density (OD) ranged from 627 to 1159 kg m^{-3}. *A. zygia* from the three wood/cement content were more dimensionally stable and better in compressive strength than the other two species where *T. scleroxylon* had the best performance in terms of UPV. All the properties improved with increasing cement content. WCCBs at 3.0:1 cement/wood content are suitable for structural application such as panelling, ceiling and partitioning

Keywords: Tropical wood species, portland cement, composite bricks, UPV

Ahşap çimento kompozit tuğlalarında güçlendirici olarak ahşap atıklarının kullanılması

Özet: Bu çalışma, farklı ahşap atıklarından ve çimento / ahşap içeriğinden elde edilen Ahşap Çimento Kompozit Tuğlaların (WCCB) özelliklerini incelemek üzere gerçekleştirilen araştırmayı temsil etmektedir. Üç tropik ağaç türünden ve ağırlık bazında 2:1, 2,5:1 ve 3:1 olmak üzere değişen çimento ve ahşap içeriğiyle 1200 kg m^{-3} nominal yoğunluğa sahip WCCB'ler üretilmiştir. Basınç dayanımı, ultra atım hızı (UPV), su emilimi (WA) ve kalınlık şişmesi (TS) özellikleri değerlendirilmiştir. Basınç dayanımı değerleri 0,25 ila 1,13 N mm^{-2} arasında değişiklik gösterirken, UPV değerleri ise 18.753 ila 49.992 m s^{-1} arasında değişmiştir. WCCB'lerin 672 saat (28 gün) suya batırılmasının ardından elde edilen ortalama WA değerleri %9,50 ile %47,13 arasında değişiklik gösterirken, tuğlaların TS'sinde fark edilir bir değişiklik olmamıştır. Gözlemlenen yoğunluk (OD) 627 ila 1.159 kg m^{-3} arasında değişiklik göstermiştir. UPV açısından *T. Scleroxylon*'un en iyi performansı göstermiş olduğu diğer iki türe oranla, basınç dayanımı açısından üç adet ahşap/çimento içeriğinden elde edilen *A. zygia* ölçüsel olarak dengeli ve daha iyi olmuştur. Tüm özellikler, arttırılan çimento içeriği ile iyileştirilmiştir. 3,0:1 çimento / ahşap içeriğine sahip WCCB'ler panel, tavan ve bölümlere ayırma gibi yapısal uygulamalara uygundur.

Anahtar Kelimeler: Tropik ağaç türleri, portland çimentosu, kompozit tuğlalar, UPV

1. INTRODUCTION

Over the decades, there has been a growing interest in utilizing wood for making low-cost building materials (Udoeyo and Dashibil, 2002; Li et al., 2003; Soroushian et al., 2003 and Galetakis and Raka, 2004). Increasing demand for forest products in various applications has led to the shortages of wood supply. Besides, large volume of wood wastes is produced in the wood industries as a result of poor wood conversion skill. Every day large volume of wood wastes is mounted up and usually burnt or land filled. Wood wastes constitute a very important residue in wood industries in Nigeria. The methods of disposal

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are no doubt waste of a primary natural resource which constitute a huge economic loss and also pose a serious danger to the environment in the form of air pollution, emission of greenhouse gases and occupation of useful land. Many attempts have been made to recycle these ever increasing waste into production of value-added products by both industries and researchers (Elinwa and Mahmood, 2002 and Manning, 2004). Results of a study conducted by Wolfe and Gjinolli, (1999) on the durability and strength of cement-bonded wood particle composites made from construction wastes showed that they have the potential for structural applications. Low density wood-cement bonded composites have been employed in the areas where strength is not a major factor such as internal partitioning, ceiling panels and so on. Despite their relatively low strength compared to other structural materials, wood cement composites can have sufficient strength for interior applications to resist a wide range of threats common to wood composites such as rot, borers, termites and fire (Stahl et al., 2002). The mechanical properties and dimensional stability of composites can be improved with increasing amounts of additives as reported by Wei and Tomita (2000). This research investigated some of the characteristics of Wood-cement Composite Brick from three tropical wood species and Cement/Wood content. This is in the view to determine the suitability of wood wastes as a replacement for fine aggregates in building brick production. This will ensure full utilization of wood wastes and cut cost incurred in procuring sand which is a conventional material for block production in Nigeria. The flexural strength and shear values were not determined in this research. The other engineering properties (compression and ultrasonic pulse velocity) were investigated.

2. MATERIALS AND METHODS

2.1 Technical Data on The Cement-Wood Composite Bricks

1. Three wood species were used: *Triplochyton scleroxylon*, *Meliacea excelsa* and *A. zygia*
2. Cement/wood mixing proportion of 2:1, 2.5:1 and 3:1 based on the weight of cement to wood
3. Brick nominal density of 1200 kg m^{-3}
4. Water pre-treatment temperature of 80°C for the wood samples
5. Brick dimension = 50 x 50 x 50 mm and 105 x 225 x 75 mm
6. Pressing pressure = 1.23 N mm^{-2} for 30 mins.
7. Additive concentration; Calcium chloride ($CaCl_2$) = 1.5% (based on the weight of the cement).

The quantity of water required for the mix was measured using a formula by Simatupang, (1979)

$$Water\ (g) = 0.60C + (0.30 - MC)\ W \qquad (1)$$

Where
W = weight of oven-dry wood (kg), MC = moisture content (%) and C = weight of cement (kg)

2.2 Method

Wood particles of *Melicia excelsa* (Iroko), *Triplochyton scleroxylon* (Obeche) and *A. zygia* were collected from a wood mill in Akure, Ondo State. The wastes were sieved with 2mm sieve to obtain a uniform particle size, thereafter they were pre-treated with hot water at 80°C and stirred for 10 minutes and was allowed to stand for 30 minutes. After this, the water was drained off and then soaked in cold water for 10 minutes and then drained, this was repeated for three times after which the wood particles were dried until attaining a constant moisture content. The pre-treatment was mainly to facilitate adequate removal of all traces of inhibitory chemical substances which may hinder the setting of the cement (Badejo (1989) (Oyagade, 1992) and Ajayi (2000) and Olorunsola, (2009).

Manual moulders of dimension 105 x 225 x 75 mm and 50 x 50 x 50 mm were fabricated to produce composite blocks of dimension 105 x 225 x 75 mm and 50 x 50 x 50 mm according to ASTM C 67-03 (2003). The wood particles, calcium chloride, cement and water were thoroughly mixed manually and packed into the manual mould before the cement starts to set and then transferred to the press and compacted by a combination of vibration and low pressure of 1.23 N mm^{-2} for 15 to 20 minutes to compress the mix to achieve good compaction after which they were removed from the mould. The formed brick samples were carefully removed from the mould so that no damage will occur on the bricks while demoulding. All the bricks were appropriately and adequately labelled for easy identification. All brick samples were cured at room temperature for 24 h. After which they were cured for 28 days in a tank filled with tap water at 27°C. At the end of the 28 days, samples for water absorption and thickness swelling were immediately tested while the samples for compressive strength and ultrasonic pulse velocity (UPV) were dried for 24 h in a ventilated oven at 105°C before testing.

2.3 Property Testing

2.3.1 Physical Properties

After 28 days of curing, the brick samples were tested for water absorption, thickness swelling and unit weight in accordance with ASTM D 1037-96 (1998). The bricks were taken out of the curing tank and the samples were drained off any surface water and were then weighted and measured instantly. After obtaining the saturated weight and dimension, they were oven dried to constant weight at 105°C to get the oven dry weight and dimension. These values were used in the calculation of the absorbed water and swelling rate in percentage for the brick samples. Also, their unit weights were obtained by dividing the mass of the bricks by their overall volume.

2.3.2 Strength Properties

The samples for the compressive strength as well as ultrasonic velocity were tested in accordance with ASTM C 67-03 (2003) using a compression testing and pulse testing machines in the Department of Civil Engineering, Federal University of Technology Akure. The dry compressive strength of brick samples was determined using a servo-controlled compression test machine with a maximum capacity of 800 kN. The compression load was applied onto the face of the sample having a dimension of 50 x 50 x 50 mm. The compressive strength was determined by dividing the maximum load with the applied load area of the brick samples. The direct UPV was also measured for each brick sample of dimension 105 x 225 x 75 mm according to BS 1881 (1997). The direct path length for the direct UPV was measured through the brick length of 225 mm. A total of 54 bricks samples were casted, twenty seven bricks of dimension 50 x 50 x 50 mm were used for water sorption and compressive strength test while twenty seven bricks of dimension 105 x 225 x 75 mm were used for the UPV test.

2.4 Statistical Analysis of Data

The experimental design was a completely randomized one with 3 treatment levels for both wood species and cement to wood ratio making a total of 9 treatment combinations. Analyses of Variance (ANOVA) using SPSS 16 were used to evaluate the variability in the properties of the WCCBs while Duncan Multiple Range Test (DMRT) was used in separation of means.

3. RESULTS

The mean values obtained for WA, TS, compression and UPV for all the WCCBs are shown in Table / Tablo 1 while Table / Tablo 2 shows the result of the analysis of variance for the data obtained for all the properties evaluated.

3.1 Physical Properties

The nominal brick density was 1200 kg m^{-3}, but the measured densities of the composites ranged between 627 and 1159 kg m^{-3} (Table / Tablo 1). The lowest density being 627 kg m^{-3} was found in brick samples made from *Meliacae excelsa* where the highest density 1159 kg m^{-3} was found in bricks made from wood species of *A. zygia*. From the result of this work, it seems that the observed density depended on the cement/wood ratio, which explains the trend in the observed density across the three cement/wood content. The bricks' water absorption ranged from 9.50% to 47.13% with the highest and lowest occurring in bricks made from *M. excelsa* at cement/wood ratio of 2:1 and 3:1 respectively compared to bricks from the other two species and cement/wood ratio. Where that of the control was 1340 kg m^{-3} and

4.08% for OD and WA respectively. The results were similar to those gotten from literature (Badejo, 1987; Oyagade, 1995; Ajayi, 2003 and 2004; Del Meneéis et al., 2007 and Erakhrumen et al., 2008).

The thickness-swelling (TS), ranged from 0.01 to 0.61% compared to that of the control which is 0.01%. There was no appreciable change in the dimensions of the brick. OD (R = 0.99 and R^2 = 0.99), WA (R = 0.99 and R^2 = 0.993) and TS (R = 0.877 and R^2 = 0.770) showed a strong relationship with cement-wood content. The result of ANOVA shows that there are significant variations in the OD and WA from each of the species and cement-wood content. Their interactions were also significant. Only significant variation exists in TS of *M. excelsa* from the three cement-wood content while there was no significant variation in TS of *T.scleroxylon* and *A. zygia* and their cement-wood content.

3.2 Strength Properties of WCCBs

The results of the strength test are shown in Table / Tablo 1, the compressive strength and the UPV ranged from 0.25 to 1.13 N mm^{-2} and 18753 to 49992 m s^{-2} respectively. The highest compressive strength and UPV were recorded in *A. zygia and T. scleroxylon* at cement-wood content of 3:1 with values of 1.13 N mm^{-2} and 49992 m s^{-2} respectively, while the lowest compressive strength and UPV were recorded in *T. scleroxylon* (0.25 N mm^{-2}) *and M. excelsa* (18753 m s^{-2}). These values were incomparable to that of control (cement-sand brick) whose compressive and UPV values were 2.23 N mm^{-2} and 87500 m s^{-2} respectively. Compressive strength (R = 0.99 and R^2 = 0.993) and UPV both showed a strong relationship with cement-wood content (R = 1.000 and R^2 = 1.000). The result of ANOVA showed significant differences at $P<0.05$ in strength properties (compression and UPV) among the three cement-wood content (Table / Tablo 2).

4. DISCUSSION

4.1 Physical Properties

From the result of this work, it seems that the observed density depended on the cement/wood ratio, which explains the trend in the observed density across the three cement/wood content. The bricks with higher cement content had higher observed density values. The bricks' water absorption ranged from 9.50% to 47.13% with the highest and lowest occurring in bricks made from *M. excelsa* at cement/wood ratio of 2:1 and 3:1 respectively compared to bricks from the other two species and cement/wood ratio. This high sorption value at 2:1 cement/wood content may be attributed to incomplete encapsulation of the wood particles by the cement as the wood content is high, this result in lower internal bonding and free internal spaces which may allow inflow of water into the cement-wood matrix. Moreover, when wood content is increased, density decreases, but water absorption increases (Savastano et al., 2000). Generally, the WA of the various bricks was higher where there was reduced proportion of cement in the WCCB matrix. Badejo, (1987); Oyagade, (1995); Ajayi, (2003) and (2004); Del Meneéis et al., (2007) and Erakhrumen et al., (2008) got similar results.

The thickness-swelling (TS), ranged from 0.01 to 0.61%. There was no appreciable change in the dimensions of the brick. This may be as a result of fine particle used as well as pressure for compacting the cement/wood matrix which ensures proper encasement of the wood particles thereby restricting hydro-expansion. (Hachmi, et al, 1990; Zhou and Kamdem, 2002). Although, TS is highly correlated with the cement/wood ratio with little or no effect of the wood species used. When wood content increases, water absorption is expected to increase. From table 1, the highest swelling (0.61%) was observed in *A. zygia* at cement-wood content of 2:1 followed by *M. excelsa* (0.57%) at cement-wood content of 2:1. The result indicates that no significant change was observed in the length, breadth and width of the bricks.

4.2 Strength Properties

The results of the strength properties are showed in Table / Tablo 1. It was observed that both the compressive strength and the UPV increased with increasing concentration of cement in the WCCB matrix. Reducing the cement content negatively affected the values. These values were incomparable to that of control (cement-sand brick) where the compressive and UPV values were 2.23 N mm^{-2} and

87500 m s^{-2}. Generally, the compression strength was greater in WCCB with higher cement content (3:1). Also from the result, it can be seen that the strength of the bricks increased with the density of the bricks (Table / Tablo 2) meaning that the greater the proportion of cement in the composite, the stronger it would be.

Table 1. Mean values of the WCCBs properties from three species and cement/wood content (Three replicates per each WCCB type).
Tablo 1. Üç farklı türden üretilen WCCB özelliklerine ait ortalama değerler ve çimento / odun içerikleri (Her WCCB tipinde üç tekrarlı ölçüm yapılmıştır).

Species	**Wood / cement content**	**OD (kg m^{-3})**	**WA (%)**	**TS (%)**	**COMP (N mm^{-2})**	**UPV (m s^{-1})**
T. scleroxylon	2:1	728 ± 6.25a	37.33 ± 1.53a	0.01 ± 0.00 a	0.25 ± 0.02c	26280 ± 26.46*a*
	2.5:1	932 ± 4.36b	25.07 ± 1.91b	0.01 ± 0.00 a	0.26 ± 0.04ab	33879 ± 7.09*b*
	3:1	1131 ± 8.02c	13. 87 ± 2.29c	0.01 ± 0.00 a	0.27 ± 0.59a	49992 ± 7.64*c*
M. excelsa	2:1	627 ± 5.86a	47.13 ± 0.45a	0.57 ± 0.00 a	0.49 ± 0.02c	18753 ± 5.51*a*
	2.5:1	711 ± 3.22b	31.80 ± 1.40b	0.31 b	0.54 ± 0.04ab	22829 ± 2.52*b*
	3:1	963 ± 3.79c	9.50 ± 0.40c	0.12 ± 0.00 c	0.66 ± 0.03a	40386 ± 2.71***c***
A. zygia	2:1	938 ± 7.00a	13.80 ± 0.36a	0.61 ± 0.00 a	1.06 ± 0.03ab	30005 ± 14.57a
	2.5:1	1009 ±10.02b	13.67 ± 0.41ab	0.11 ± 0.00 b	1.07 ± 0.03a	32812 ± 1.18b
	3:1	1159 ± 60.75c	12.43 ± 0.50c	0.02 ± 0.00 c	1.13 ± 0.04c	40387 ± 2.25c
Control		1340 ± 0.0	4.08 ± 0.00	0.01	2.23	87500.00

Means with different letters are significantly different at $p \leq 0.05$
OD = Observed density; WA = Water absorption; COMP = Compressive strength and UPV = Ultrasonic-pulse velocity

Table 2: Anova for the WCCBs properties assessed
Tablo 2: WCCB özelliklerine ait Anova sonuçları

Parameters	**Source of Variation**	**SS**	**df**	**MS**	**F-value**	**Sig**
Observed density (kg m^{-3})	W/C	470000.22	2	235000.11	525.90	0.000**
	Spp	329864.00	2	164932.00	369.098	0.000**
	W/C*Spp	32735.11	4	8183.78	18.314	0.000**
	Error	8043.33	18	446.85		
	Total	2.324E7	27			
Water absorption (%)	W/C	1959.21	2	979.60	624.84	0.000**
	Spp	1275.35	2	637.67	406.74	0.000**
	W/C*Spp	1019.46	4	254.87	162.57	0.000**
	Error	28.22	18	1.57		
	Total	18235.96	27			
Thickness swelling (%)	W/C	0.110	2	0.055	1.801	0.306ns
	Spp	0.168	2	0.084	2.758	0.209ns
	Error	0.091	18	0.030		
	Total	0.755	27			
Comp. strength (N mm^{-2})	W/C	0.030	2	0.02	11.87	0.001**
	Spp	3.142	2	1.57	1.259E3	0.000**
	W/C*Spp	0.026	4	0.007	5.292	0.005**
	Error	0.022	18	0.001		
	Total	14.126	27			
UPV (m s^{-1})	W/C	1.672E9	2	8.361E8	7.023E6	0.000**
	Spp	4.312E8	2	2.156E8	1.811E6	0.000**
	W/C*Spp	1.734E8	4	4.335E7	3.641E5	0.000**
	Error	2142.980	18	119.054		
	Total	3.135E10	27			

SV = Source of variation; * = interaction; ** = highly significant ($p \leq 0.05$),
W/C = wood/cement content, spp = species, ns = not significant

According to Gong et al., (1983) the compression strength values required for materials to be used as pavements range from 20-25 N mm^{-2} while that of beams ranges from 20-35 N mm^{-2} and up to 65 N mm^{-2} depending on the expected loads. Increasing the quantity of cement resulted into increased compressive strength and higher UPV. The result further showed that the ultrasonic pulse velocity is higher in bricks with high compressive strength. With the values of the compressive strength and UPV, the bricks can only be utilized in areas where strength is not a major requirement. The result of this work shows that not all the treatment combination can be used for the manufacture of bricks for the same application. The cement/wood content will largely dictate the applications for which these bricks will be put compared to species of wood used. Considering the economic aspect, decreasing the cement-wood ratio is advantageous as wood is less expensive than cement (Zhou and Kamdem, 2002). The cost of the binding component which is cement, is also a determining factor in choosing the mixing proportion in relation to properties of the bricks to be manufactured for specific uses (Erakrumeh et al., 2008).

5. CONCLUSION

The physical and mechanical properties of brick samples using wood particles as reinforcement were investigated. All the properties were incomparable to that of sand-cement brick. The bricks were higher in moisture, but lower in strength properties than that of the control. Increasing the amount of cement in the WCCB matrix increases both the compressive strength and Ultrasonic pulse velocity in each brick. The result of the experiment shows that not all the treatment combination can be used for the manufacture of bricks for the same application. The cement/wood content will largely dictate the applications for which these bricks will be put. The cost of the binding component which is cement, is also a determining factor in choosing the mixing proportion in relation to properties of the bricks to be manufactured for specific uses. The brick material usage is limited to certain areas in a structure because of its low strength and high WA such as in interior wall panelling, in-fill wall panels, and general interior applications where no wetting occurs. Their usage will be more efficient and economical for internal structural application than for outdoor use. The test result showed that wood waste is a potential material for production of lighter and economical brick material. WCCBs from cement-wood content of 3:1 proved to be the best treatment for the manufacture of WCCBs. The mechanical properties and dimensional stability of composites can be improved with increasing amounts of additives.

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