HYDRATION CHARACTERISTICS AND STRENGTH PROPERTIES OF CEMENT BONDED CONCRETE COMPOSITES REINFORCED WITH PARTICLES OF TECTONA GRANDIS WOOD AND WASTE POLYETHYLENE TEREPHTHALATE BOTTLES

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ABSTRACT

Particles of waste Polyethylene terephthalate bottles (PET) and Tectona grandis were tested for compatibility in cement bonded composites production using the hydration approach. The fabricated cement bonded concrete composites from the PET and T. grandis particles and their mixtures were tested for flexural strength. The hydration test revealed that the PET, T. grandis particles and their mixtures were compatible with cement having maximum hydration temperature (Tmax) of 47.0 - 50.6 oC, maximum hydration time (tmax) of 7.9 - 8.0 h and temperature dependent ratio index (tR) of 0.9. The flexural properties i.e. Moduli of rupture and elasticity were between 7.2 and 45.9 N/mm2 and 653.1 and 1,641.4 N/mm2, respectively. The fabricated composites are suitable for use as low-cost building components.

KEYWORDS:

Waste PET bottles, Tectona grandis, Hydration test, flexural properties.

INTRODUCTION

A lot of waste is generated worldwide due to daily human activities. Prominent amongst these are synthetic polymeric materials and wood wastes. Synthetic polymeric materials (SMP) waste estimated as 100 million tons has a significant part recycled while majority is untouched being inseparable from household garbage (Sanchez et al., 2014). Wood wastes on the other hand occur due to usage of old mill equipment, lack of expertise, low capital input, improper processing methods and low log recovery factor is estimated to be about 1.8 million tons (Ogunbode et al, 2013;Ogunwusi, 2014, Oluoti et al., 2014). These items oftentimes litter the environments and are commonly disposed by land filling or open air incineration. Improper disposal of these wastes result in emission of toxic and non-toxic particulates, pollution of inland and ground water due to leaching of chemicals, reduction in water percolation and may also contribute to health hazards (Oluoti et al., 2014; Malik, 2015).

The deleterious effects of these wastes can be curtailed by incorporating these items in the production of value added composite products. This can be achieved by deploying the wood and SMP wastes in cement bonded composites production for low cost building components. Cement bonded composites (CBCs) are known lightweight, low-cost, durable and environmentally friendly products. They have been and can be utilised in building construction for interior/exterior wall cladding, partitioning, decking, ceiling, roofing and shuttering (Badejo 1987, 1998; Mrema, 2006) and also for the full construction of schools, theatres, hospitals and residential homes in many countries in North and Central America and Europe (Badejo, 1989; Ramirez-Coretti et al., 1998). This is more so due to the increasing demand for high quality building materials to replace the conventional ones and the need for cost effective and durable materials for low cost structures. Therefore, there is the need for the development of a variety of new and innovative low-cost building materials (Mijinyawa, 2010).

However, the low level compatibility problems between wood, an organic substance and cement/SMP inorganic compounds hinder the formation of strong crystalline bond (Olorunnisola, 2005). Therefore, the suitability of using wood and SMP wastes as aggregates in CBC production need to be ascertained. This can be achieved by adopting the hydration test approach and evaluation of the flexural properties of the composites products.

This work therefore examined the suitability of saw dust of teak (Tectona grandis) wood and particles derived from Polyethylene terephthalate bottles (PET) for the production of cement bonded concrete composites.

MATERIALS AND METHODS

The suitability of using particles of waste PET bottles and wood in concrete production was determined by the hydration test approach. 200 g of the cement (32.5R grade) and 15 g of PET/wood particles ((particle size < 0.6 mm) were manually mixed with 0.48 water:cement ratio until homogenous slurries were formed. This was in accordance with procedures of Adefisan and Olurunnisola (2007) and Adefisan *et al.* (2014). The mixtures were placed in thermally sealed thermos flasks at room temperature (25 ± 3 ºC) and the rise in temperature was recorded at an interval of 10 min until maximum temperature was attained using a Data logger Omega OM-DAQPRO-5300 (Plate 1). Three replicates of each mixture were prepared. The parameters measured were: Maximum temperature (T_{max}) and time to reach the maximum temperature (t_{max}). This procedure was also carried out with cement mixes containing 50:50 weights of wood and PET particles.

The suitability/compatibility of the wastes (wood/PET) with cement were assessed using the temperature dependent time ratio index (t_R) developed by Adefisan and Olorunnisola (2010) which relates the time ratio index (Olorunnisola, 2008) with the minimum hydration temperature (40 ºC). The temperature dependent time ratio index states that:

i. composites with T_{max} less than 40 ºC are inhibitory irrespective of the t_R values;

ii. composites with T_{max} greater than 40 ºC and $1 \leq t_R \geq 1.5$ are suitable, further pre-treatment unnecessary;

iii. composites with T_{max} greater than 40 ºC and $1.5 < t_R \geq 2.0$ are acceptable, further pre-treatment recommended and;

iv. composites with T_{max} greater than 40 ºC and $t_R > 2.0$ are inhibitory, further pre-treatment is highly recommended.

$$t_R = \frac{t_{WC}}{t_{NC}} \quad \text{.......................................} \; (1)$$

where:

T_{max} is the maximum hydration temperature (ºC)

t_{max} is the time to reach maximum temperature (T_{max}) (h)

t_{WC} is the setting time of wood: cement composite (h)

t_{NC} is the setting time of neat cement

Figure 1: Hydration Experiment

For the flexural test, concrete mix ratio 1:2:3 was used for the cement (32.5R Grade), fine aggregate (sand: particle size 0.4 mm), coarse aggregate (granite: particle size 12.5 mm) using a water/cement ratio of 0.6. Milled particles of *T. grandis* wood passing through sieve with aperture size of 4.76 mm was used for composites production while those passing through sieve of size 6.0 mm were used for the PET bottles. The variables used in the production of the concrete mixes are shown in Table 1. The composites were produced in accordance with ASTM D 1037-96a in three replicates, conditioned at room temperature 25 ± 3 ºC, de-moulded after 24 h, cured in water for 14 days and air-dried for another 14 days. The samples were loaded perpendicularly at midspan at a uniform speed of 2 mm/min by a movable crosshead on a 600 KN Okhard Universal Testing Machine (UTM) until definite failure occurred. The maximum load that produced failure was noted and the Moduli of Rupture (MOR) and Elasticity (MOE) were evaluated.

$$\text{MOR} = \frac{3PL}{2bh^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

$$\text{MOE} = \frac{PL^3}{4bh^3Y} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Where P is the maximum load (N)

P is the load at the proportional limit (N),

Y is the deflection corresponding to P (mm,

b is the width of the specimen (mm)

h is the thickness of the specimen (mm) and

L is the span (mm), respectively.

Table 1: Concrete Mixing ratio used for Production

Cement	Sand	Coarse Aggregates	PET particles	Wood Particle
1	2	3	0	0
1	1.5	3	0.5	0
1	1.5	3	0	0.5
1	1	3	0.5	0.5
1	0	3	1	1

RESULTS AND DISCUSSION

Hydration Test

The results of the hydration tests are shown in Table 2. The T_{max} of the neat cement was 50.6 ^oC while those of concrete + PET (CP), concrete + wood (CW) and concrete + wood and PET(CPW) were 50.6, 48.3 and 47.0 ^oC, respectively. The t_{max} ranged from 7.9 to 8.0 h as against 8.6 h for neat cement while the t_R of the composites was 0.9 in comparison with 1.0 for neat cement. Based on the Adefisan and Olorunnisola (2010) criterion, the particles of the PET bottles, *T. grandis* wood and their combinations are compatible with cement no further pre-treatment needed since the composites had T_{max} greater than 40 ^oC and $t_R \leq 1$. Statistical analyses (Duncan's Range Test) revealed no significant differences ($P \leq 0.05$) in the hydration parameters of the cement mixes tested (Table 2).

Flexural Test

The MOR and MOE of the composites ranged between 7.2 and 45.9 N/mm^2 and 653.1 and 1,641.4 N/mm^2 respectively (Table 3). These values are comparable with those of Joshi (2013) and Ghernouti et al. (2015) and suggest that the waste PET bottle and *T. grandis* particles are suitable as aggregates in cement bonded concrete composites formation.

As shown (Table 3), composites substituted with 25% *T. grandis* particles recorded the highest significant MOR and MOE (45.9 and 1641.4 N/mm^2) while the 100% PET-wood substitution had the least (7.2 and 899.0 N/mm^2). What this suggests is that incorporation of wood particles in the composite mix enabled better interfacial bonding and enhanced the flexural properties more than those of PET. This could possibly due to the differences in the particle size of the wood and PET (i.e. 4.76 vs 6.0 mm) in which smaller particles seal the void spaces in the concrete mix than larger particles (Adefisan, 2010). However, since the flexural properties recorded for the PET cement composites and the 50% PET and wood substitution are not significantly different from the control, these composites can also be considered suitable for use in low-cost building construction purposes

Table 2: Hydration Parameters of Cement-Plastic-Wood Mixes

Cement Mixes	t_{max} (h)	T_{max} (^oC)	t_R
Neat Cement	8.6^a (0.77)	50.6^a (2.63)	1.0^a (0.0)
Cement + PET (CP)	8.0^a (0.44)	50.6^a (3.68)	0.9^a (0.03)
Cement + Wood (CW)	7.9^a (0.09)	48.3^a (0.50)	0.9^a (0.08)
Cement + PET +Wood (50 : 50) (CPW)	7.9^a (0.19)	47.0^a (1.88)	0.9^a (0.07)

* Means with the same letters and in the same column are not statistically different

Standard deviation in parentheses

Table 3: Flexural Properties of the Cement Concrete Composites

Samples	MOR	MOE
Control	18.6^{b} (11.3)	1467.1^{ab} (701.4)
Concrete + 25% PET Substitution	12.2^{b} (1.2)	731.4^{c} (38.5)
Concrete + 25% Wood Substitution	45.9^{a} (2.4)	1641.4^{a} (175.8)
Concrete +PET + Wood (50% Substitution)	18.2^{b} (6.3)	899.0^{bc} (154.6)
Concrete + PET + Wood Substitution (100%)	7.2^{b} (1.7)	653.1^{c} (32.6)

* Means with the same letters and in the same column are not statistically different

Standard deviation in parentheses

CONCLUSIONS

Cement bonded concrete composites were successfully produced from particles of waste Polyethylene terephthalate bottles (PET) and *Tectona grandis* wood. The composites possessed adequate strength properties. Incorporation of *T. grandis* wood in the composites mix enhanced the flexural properties (MOR and MOE) more than those of PET bottles. The fabricated composites are suitable for use as low-cost building components.

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