Flexural and Water Sorption Properties of Cement Bonded Composites Produced From Pozzolan and Portland Cement

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Abstract

The suitability of substituting Portland cement (PC) with palm kernel shell and sawdust pozzolan in the production of cement bonded composites (CBC) at various ratios was investigated. Pozzolan was produced by the addition of lime and the ash of each of the biomaterial residues. The combination of PC and biomaterial pozzolan called "hybrid cement" was produced by mixing Portland cement with the pozzolan at the ratio of 100:0, 90:10 and 80:20 of PC: pozzolan. The hybrid cement was used to produce CBC. The water absorption (WA), thickness swell (TS), modulus of rupture (MOR) and modulus of elasticity (MOE) of the CBC were determined. An increase in the pozzolan content caused an increase of WA for the whole 28 days of water soak, hence CBC with a mixing ratio of 100:0 was the most water resistant composites. The MOR decreased with an increase in the proportion of the pozzolan in the hybrid cement of both palm kernel shell and sawdust. The MOE of the CBC produced from palm kernel shell hybrid cement decreased with and increase in the pozzolan proportion. However, the MOE increased from 10% to 30% pozzolan, but dropped at 40% pozzolan. From these data, it was observed that the bending strength was affected by the incorporation of the pozzolana cements. The CBC with the highest MOR were produced in the proportion of pozzolana cement (100:0). The CBC produced from the hybrid cement are suitable for ceiling, floor unit and other applications.

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Keywords: *palm kernel shell, sawdust, pozzolan, hybrid cement, cement bonded composites.*

1. Introduction

Cement-bonded board (CBC) is an engineered particle composite produced from wood or other lingocellulosic raw materials bonded with inorganic binder (such as cement), chemical additives and water and then pressed under regulated pressure (Fabiyi *et al*. 2010). Among the features outlined by Frybort *et al*. (2008), which can make any CBC superior to conventionally bonded composites are durable, high dimensional stability, toughness, as well as availability of raw material. However, the increase interest of less-developed countries in CBC was attributed to low costs and the availability of raw materials. The raw materials for the production of CBC ranges from agricultural products or residue to forest biomass and wood waste (Rowell 2007, Thygesen *et al*. 2005, Zhou and Kamdem 2002 and Kim *et al* 2002). These materials have constituted a disposal problem in Nigeria as the country faces the waste management problem. For example, it was documented that less than 40% of round logs from the forest is actually used at industrial level while the rest are disposed as waste (Ogunwusi, 2014). Luangkiattikhun *et al*. (2008) and Pansamut *et al*. (2003) reported that about 0.070, 0.103, and 0.012 tons of palm shell, palm fibre and palm kernel, respectively, are produced as the solid wastes for every ton of oil-palm fruit bunch that is being fed into the palm-oil processing plant. Okoroigwea and Saffron (2012) recommended that palm kernel shell be used for energy production through direct combustion processes during palm oil processing. In addition, the proposition for the use of palm kernel shell as concrete reinforcement in the construction industry has been around for almost two decades now (Okafor, 1988, Okpala, 1990, Alemgaram *et al* 2008, Mahmud, *et al* 2009, Otunyo 2011). Ganiron (2013) stated that it is more environmentally safe and friendly to use agricultural and forest residues for industrial purposes than any other method of wastes disposal being commonly adopted nowadays.

The need to use biomaterial residues for the production of pozzolan has been motivated by the availability of agricultural commodities in Nigeria as reflected in Central Bank of Nigeria's report (CBN, 2007). Apart from the use of these biomaterials as fibrous raw materials, some of them contain silicon that makes them to be cementous in nature when ashed, thereby reducing the cost of Portland cement procurement (Fabiyi 2013). The main components of OPC are Calcium Oxide (CaO), Silica (SiO_2), Alumina (Al_2O_3) and Iron Oxide (Fe_2O_3) (PCA, 2014). Environmental pollution is a great challenge that is being faced during OPC production. About 50% of CO_2 emissions occur during the calcination process at mining stage (Hasanbeigi *et al*. 2012). Therefore, partial replacement of OPC with palm kernel shell and sawdust pozzolan is expected to yield a significant reduction in CO_2 emissions associated with OPC production. In addition, the production of CBC produced from natural pozzolanic cement will encourage the construction of environmentally friendly buildings, increases waste management, provides alternatives to cement in the construction industry and enhances sustainability.
The main objective of this study was to investigate the physical and mechanical properties of CBC produced from hybrid cement (Portland cement and natural pozzolan).

2. Materials and Method

2.1 Procurement of Cementious Materials

Portland cement was purchased from a local cement store in Akure, Ondo State, Nigeria. Palm kernel shells (PKS) were collected from a local farm at Igbimo, Ekiti State, Nigeria while sawdust was collected from a local sawmill at Akure. The PKS and sawdust were air dried prior their conversion to ash. These biomaterial residues were ashed at 800°C in a kiln in the absence or limited amount of air through carbonization in the presence of nitrogen gas in a well controlled chamber. The ash was reacted with 2% calcium hydroxide (lime, by weight of ash) in order to produce pozzolana. Thereafter, it was mixed with Portland cement at certain percents in order to reduce the cost of production that Portland cement The hybrid cement was produced by mixing Portland cement with the pozzolan at the ratio of 100:0, 90:10, 80:20, 70:30 and 60:40; named as control, hybrid A, hybrid B, hybrid C and hybrid D, respectively.

2.2 Mat Formation and Board Production

The dimension of CBC produced were 10 mm (thickness) × 360 mm (length) × 360 mm (width). The quantities of sawdust, hybrid cement used to produce the CBC in this study were weighed based on the mixing ratio of 70% of hybrid cement and 30% of wood particles and on a nominal density of 1000 kg/m^3, which was then compounded. Quantity of water used for the mixing was calculated using the formula developed by Simatupang (1979), which is expressed as:
Water (l) = 0.35C + (0.03 – MC)W,
where C is the hybrid cement weight (kg), MC is the particle moisture content (oven-dry basis) and W is the oven-dry particle weight (kg).
Prior to board production, sawdust was subjected to hot water treatment (maintained at 80°C for about 2 h) to remove water-soluble extractives

prior board formation. The pre-treated sawdust was further treated with $CaCl_2$ (3% of the cement). The required hybrid cement, treated sawdust and distilled water were thoroughly mixed until a homogenous mixture is attained in a mixer. The mixture was felted into the mould on a caul plate laid with polyethylene sheet. When the mould is removed, another polythene sheet was placed on top of the mat prior pressing to prevent the sticking of the board on the plate. Then, another caul plate was placed on the top of the mat and pressed to the required thickness size of 10 mm on a manual hydraulic press with a pressure of 1.23 N/mm^2. After pressing, the CBC was removed from the mold and wrapped with a polythene sheet and kept in the laboratory for 28 days for proper curing so that the CBC can reach its full strength and to achieve a moisture balance between the atmosphere and the inherent board material.

Water Absorption and Thickness Swelling

The CBCs were cut into test specimens according to a modified ASTM D 1037 (2003) standard. Specimens of 10 mm × 50 mm × 50 mm were used to determine the water absorption (WA) and thickness swelling (TS). The test specimens were soaked in water (at room temperature) for moisture uptake for a total of 360 h while data were collected at 2, 24, 72, 144, 216, 288 and 360 h; then the weight was recorded. WA was computed as follows (equation 1):

$$WA(\%) = \frac{W_2 - W_1}{W_1} \times 100 \quad (1)$$

Where:
WA = Water Absorption (%)
W1 = Initial Weight (g)
W2 = Final Weight (g)

The thickness of the CBC was measured using veneer calipers before and after water soak. The thickness swell was computed as expressed in equation 2.

$$T_S(\%) = \frac{T_2 - T_1}{T_1} \times 100 \quad (2)$$

Where:
TS = Thickness Swelling (%)
T1 = Initial Thickness (mm)
T2 = Final Thickness (mm)

Mechanical Properties

The CBC for mechanical properties were cut into test specimens according to a modified ASTM D 1037 (2003) standard. Specimens of 10 mm × 50 mm × 150 mm were used for flexural MOR and MOE determination. The specimens were subjected to a force/load on the Universal Tensiometer machine. The force exerted on the specimen that caused its failure was recorded; thus, MOR and MOE were calculated using the following equations 3 and 4, respectively:

$$MOR = \frac{3PL}{2bd^2} \quad (3)$$

Where:
MOR = Modulus of rupture (N/mm^2)
P = the ultimate failure load (N)
L = the span of board sample between the machine supports (mm)
b = width of the board sample (mm)
d = thickness of the board sample (mm)

$$MOE = \frac{PL^3}{4bd^3H} \quad (4)$$

Where:
MOE = Modulus of elasticity (N/mm^2)
P = the ultimate failure load (N)
L = the span of board sample between the machine supports (mm)
b = width of the board sample (mm)
d = thickness of the board sample (mm)
H = Increase in deflection.

3. Results and Discussion

3.1 Physical Properties

Water absorption (WA) and Thickness swelling (TS)

The water absorption and thickness swell of the cement bonded composites produced from the control and the three hybrid cement after 2, 24, 72, 144, 216, 288 and 360 h of water soak are presented in Tables 1 and 2. The variations in the Portland cement to pozzolan (palm kernel shell ash) ratio showed the effect on the reaction of boards to water absorption. It was observed that as the pozzolan proportion increases, water absorption also increase at all the durations of water soaking while thickness swell varies at each level of water soaking. The CBC produced at the highest ratio of pozzolana cement (60:40) has the highest water absorption and this could be due to the high quantity of pozzolana cement. This is an indication that dimensionally stable CBC improves with a decrease in the quantity of palm kernel shell pozzolan incorporation. While the highest thickness swell is at formulation 90:10 at 24 h and this may be due to fact that additive concentration and mixing ratio had a strong influence on the boards' physical properties (Adedeji and Ajayi, 2008). Portland and wood sawdust ash pozzolan cement showed that the CBC's water absorption increased with an increase in pozzolana cement while the thickness swell of the CBC's decreased at the highest mixing ratio of 60:40. This is an indication that dimensionally stable CBC produced with sawdust pozzolana cement improved with the increase in the quantity of sawdust pozzolana incorporation. While CBC produced with a mixing ratio of 100:0 was found to be the most dimensionally stable from the water absorption test. The increase in the proportion of pozzolan caused an increase in water absorption in all the boards produced with pozzolanic cement. However, Renato *et. al.* (2002) attributed higher water absorption and thickness swell in CBC to the lower density, which results in higher voids that can be filled, most probably due to the presence of fewer void spaces within the panel and the affinity of $CaCl_2$ for water.

The analysis of variance conducted on the WA and TS of the boards between 2- 360 h of water soaking are presented in Table 3. The results showed that the water absorption for 2 h and thickness swell for 288 h and 360 h had significant difference ($p<0.05$). Table 4 presented the Duncan multiple range tests which show that there is a significant difference at mixing ratio of 100:0 and 60:40 of Portland cement to that of the biomaterial residues (rice husk, palm kernel shell and sawdust) pozzolan for both water absorption and thickness swell.

3.2 Mechanical Properties

3.2.1 Modulus of rupture (MOR) and modulus of elasticity (MOE)

The modulus of rupture and modulus of elasticity of CBC produced are presented in Figures 1 and 2. MOR ranged from 3.25 to 8.66 N/mm^2 for both hybrid cement produced from the palm kernel shell and sawdust pozzolana cement (Figs. 1 and 2). While The MOE of the CBC ranged from 1597.2 N/mm^2 to 4052.4 N/mm^2 and 1471.6 N/mm^2 to 4052.4 N/mm^2 for both hybrid cement produced from the palm kernel shell and sawdust pozzolana cement, respectively (Figs. 1 and 2). From these data, it was observed that the bending strength was affected by the incorporation of the pozzolana cements. The CBC with the highest MOR were produced at the proportion of pozzolana cement (100:0). This may be due to the higher quantity of solid materials per unit volume. The high proportion of Portland cement in the CBC might have improved the flexural property of the board. It is well-known that Portland cement is stiffer than pozzolana cement, so low amount of Portland cement reduce the stiffness of the boards. Therefore, to obtain better MOE properties of CBC made from Portland cement-pozzolan, the quantity of cement, mixing ratio and additive concentration should be considered. However, Renato *et al* (2003) reported that the presence of additive improved the bending strength values (MOE and MOR).

The maximum MOR of hybrid cement produced from sawdust ash (6.1 N/mm^2) was less than the minimum MOR (13.0 N/mm^2) specified by BS 5669:1989 Part 2 for General Purpose Board. However, the minimum MOR requirement specified in DIN 1101:1989 for sandwich composite panels for use as insulating materials is 0.7 N/mm^2, which far less than the MOR of any of the CBC produced from the hybrid cement. Therefore, the CBC produced in this study can be used in floor units, ceilings, shuttering, and partitioning.

The result of analysis of variance carried out to test the significant difference among the boards produced at different formulations are presented in Table 3. It showed that the bending strength values (MOE and MOR) are not significantly affected by Portland cement - pozzolana ratio, quantity of cement and additive concentration at 0.05 significance level for all the formulations for each of the pozzolanic materials. Therefore, since there is no significant difference in the MOE and MOR, the substitution of Portland cement with 40% pozzolan (i.e. 60:40 Portland cement to pozzolan) can be employed to produce CBC.

4. Conclusions

Cement bonded composites were successfully produced by using hybrid cement (Portland cement and pozzolana cement), sawdust and chemical additive as raw materials. The hybrid cement/sawdust formulations do not significantly influence the MOR, MOE, WA and TS of the experimental CBC. Therefore, it is possible to produce CBC at a density of 1000 kg/m^3 to meet modulus of rupture and modulus of elasticity requirements by orienting hybrid cement. However, the boards were dimensionally unstable, with high values for water absorption and thickness swell possibly due to the particle geometry in the boards. Further research is needed to overcome these limitations. Based on the MOR and MOE, the CBC produced from the hybrid cement are suitable for applications in the ceiling, floor units, shuttering and other places.

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Table 1: Water absorption (WA) and thickness swelling (TS) of cement bonded composites produced with palm kernel shell ash

Parameter	Submersion duration (h)	Hybrid cement (Portland cement: Palm kernel shell)				
		100:0	90:10	80:20	70:30	60:40
Water absorption (WA)	2	24.27±2.50	38.63 ± 2.62	46.49 ± 1.93	56.93 ± 5.22	59.25 ± 8.77
	24	28.84 ± 1.79	44.65 ± 2.65	48.18 ± 2.21	63.69 ± 2.61	62.73 ± 8.67
	72	31.26 ± 1.02	47.02 ± 3.17	49.48 ± 1.71	65.83 ± 3.57	66.43 ± 10.45
	144	33.73 ± 1.74	48.45 ± 3.16	51.27 ± 1.72	65.31 ± 5.78	70.41 ± 11.48
	216	34.11 ± 1.71	49.06 ± 0.16	52.30 ± 2.49	67.43 ± 6.64	71.08 ± 14.48
	288	34.29 ± 1.67	50.90 ± 0.33	53.82 ± 2.55	69.37 ± 4.19	71.95 ± 14.79
	360	41.15 ± 2.14	52.61 ± 0.38	55.11 ± 2.69	69.93 ± 7.17	72.53 ± 14.64
Thickness swell (TS)	2	1.40 ± 0.20	3.20 ± 0.60	3.10 ± 0.60	3.80 ± 1.50	4.60 ± 0.80
	24	8.40 ± 0.20	10.41 ± 0.60	13.60 ± 10.60	19.60 ± 1.80	23.50 ± 9.90
	72	10.70 ± 0.50	13.80 ± 0.80	14.30 ± 0.80	26.40 ± 1.20	26.90 ± 0.50
	144	12.29 ± 1.79	14.20 ± 0.60	16.10 ± 0.80	30.80 ± 1.50	33.60 ± 0.90
	216	24.26 ± 1.46	25.98 ± 8.19	27.90 ± 0.65	34.04 ± 1.97	36.13 ± 0.36
	288	24.36 ± 1.50	27.76 ± 0.10	30.11 ± 1.19	42.56 ± 1.60	41.47 ± 1.16
	360	24.53 ± 1.66	28.96 ± 0.10	38.24 ± 1.06	42.57 ± 1.61	43.99 ± 1.56

Table 2: Water absorption (WA) and thickness swelling (TS) of cement bonded composites produced with wood sawdust ash

Parameter	Submersion duration (h)	Hybrid cement (Portland cement: wood sawdust ash)				
		100:0	90:10	80:20	70:30	60:40
Water absorption (WA)	2	24.27±2.50	46.01 ± 0.64	50.64 ± 0.76	57.09 ± 0.26	63.27 ± 1.90
	24	28.84 ± 1.79	53.77 ± 0.75	54.98 ± 0.27	62.35 ± 0.35	69.04 ± 1.56
	72	31.26 ± 1.02	54.32 ± 0.90	56.29 ± 0.61	65.15 ± 0.85	71.83 ± 1.38
	144	33.73 ± 1.74	55.75 ± 0.77	56.81 ± 0.89	66.16 ± 0.67	73.29 ± 1.70
	216	34.11 ± 1.71	57.08 ± 14.48	57.22 ± .53	66.42 ± 0.88	73.49 ± 1.80
	288	34.29 ± 1.67	57.16 ± 0.08	57.84 ± .57	69.63 ± 0.35	74.31 ± 1.66
	360	41.15 ± 2.14	57.44 ±0.07	59.14 ± 0.45	67.08 ± 0.58	74.63 ± 1.73
Thickness swell (TS)	2	1.40 ± 0.20	3.40 ± 2.60	3.40 ± 0.90	4.90 ± 0.70	5.70 ± 1.00
	24	8.40 ± 0.20	9.50 ± 1.50	13.30 ± 1.70	13.70 ± 3.00	20.80 ± 5.30
	72	10.70 ± 0.50	12.60 ± 1.10	13.00 ± 0.40	14.00 ± 0.70	22.70 ± 0.60
	144	12.29 ± 1.79	13.40 ± 2.60	17.40 ± 0.90	18.90 ± 0.70	28.90 ± 1.90
	216	24.26 ± 1.46	25.77 ± 1.34	26.36 ± 1.19	28.39 ± 6.13	34.78 ± 1.51
	288	24.36 ± 1.50	26.67 ± 0.10	28.23 ± 1.03	29.95 ± 0.30	41.54 ± 0.63
	360	24.53 ± 1.66	26.68 ± 0.09	35.30 ± 1.03	39.00 ±0.17	42.23 ± 0.24

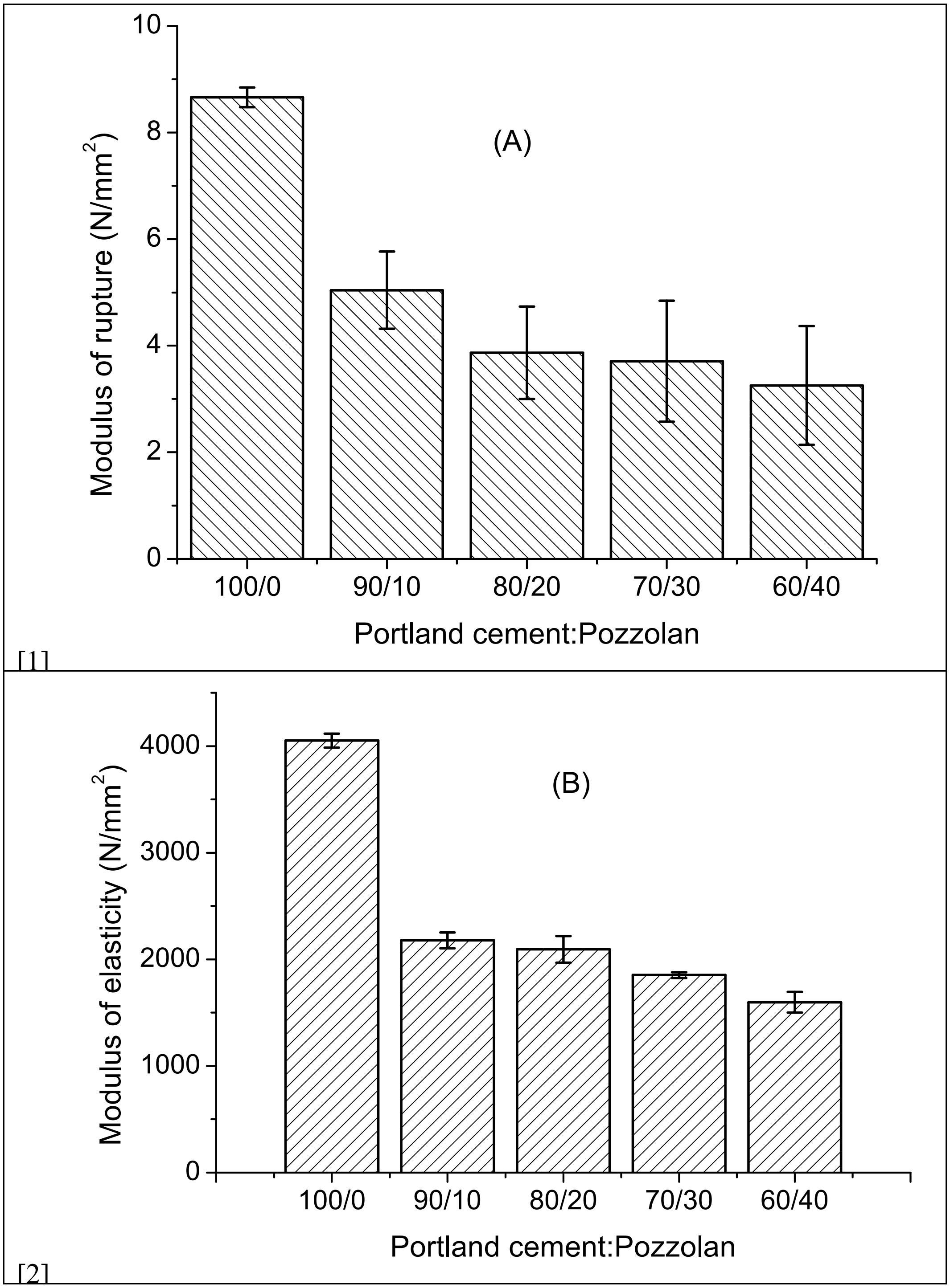

Fig.1 Effect of ordinary Portland cement replacement with palm kernel shell ash pozzolan on the flexural (A) modulus of rupture and (B) modulus of elasticity of cement bonded composites.

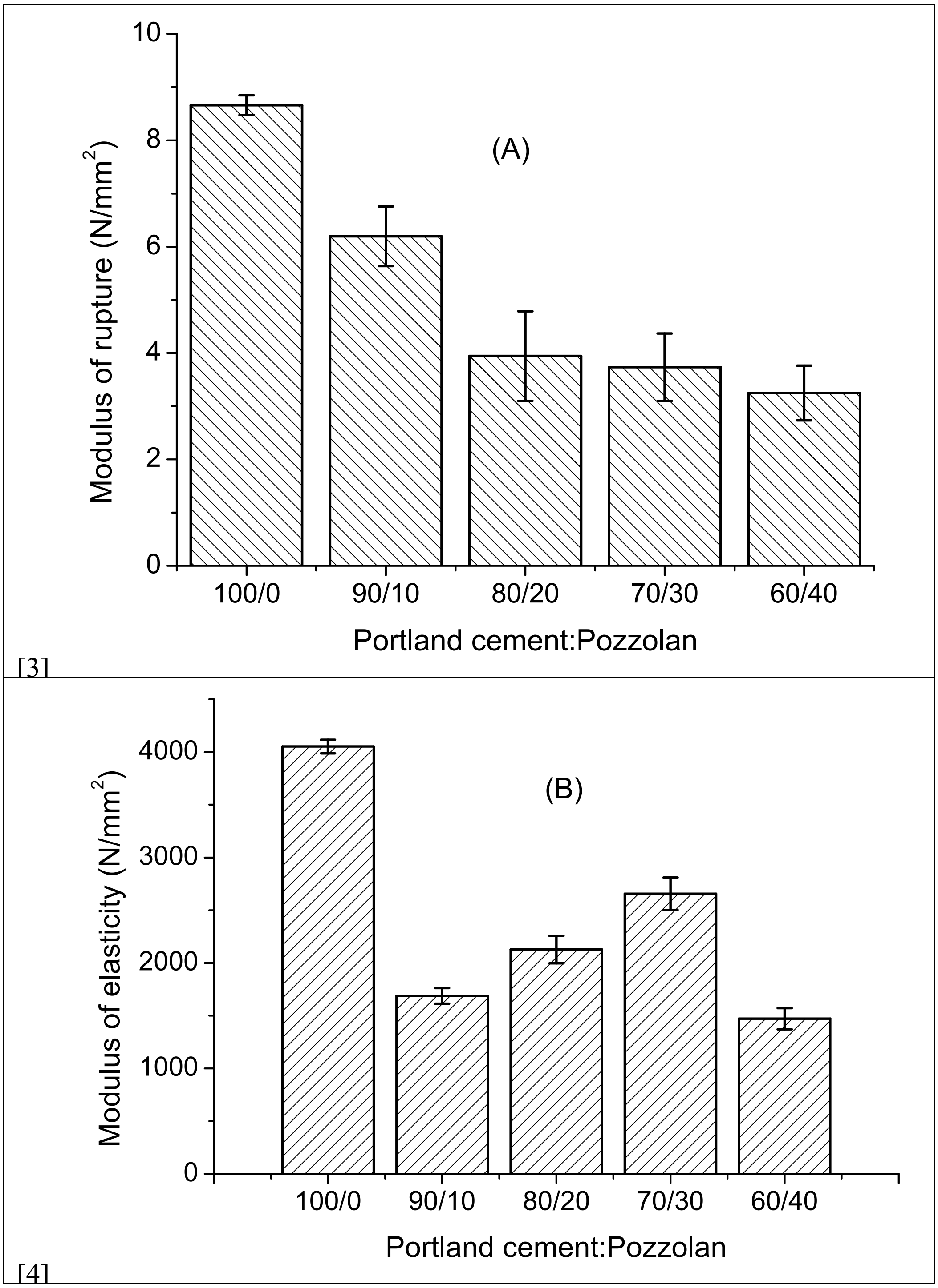

Fig. 2. Effect of ordinary Portland cement replacement with sawdust ash pozzolan on the flexural (A) modulus of rupture and (B) modulus of elasticity of cement bonded composites.