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ASSESSMENT OF MECHANICAL PROPERTIES OF CEILING BOARD PRODUCED FROM GYPSUM REINFORCED WITH NATURAL FIBRES

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ABSTRACT

High performance demands and increase in cost of housing materials has pushed scientists and engineers to search for composites reinforced with cheap and eco-friendly materials. The mechanical properties of ceiling boards produced from gypsum reinforced with natural fibres were assessed. Twenty seven (27) medium board density of 600kg/m^3 having dimension 200 x 200 x 10mm were produced from Plaster of Paris (POP) at four different mixing proportion of 100%, 75%, 50% and 25% of *Cocos nucifera*, *Thaumatococcus danielli* and yarns. Flexural strength/ Modulus of Rupture (MOR), Modulus of elasticity (MOE), maximum compressive strength (MCS) and impact bending (IB) tests were carried out on the experimental boards. Data obtained were analyzed using descriptive statistical analysis and analysis of variance. Boards obtained from different mixing proportion of gypsum, natural and synthetic fibres displayed flexural strength, MOE, MCS and IB values which ranged from 0.92- 4.86 N/mm^2, 152- 856.8 N/mm^2, 16.12- 69.50 N/mm^2 and 1.58- 2.80J/mm^2 respectively. The results show that gypsum reinforced with natural fibres are reliable materials to be used for the production of ceiling boards which could be used in rural and municipal constructions.

Keywords: *Cocos nucifera*, Flexural strength, Impact bending, Plaster of Paris, *Thaumatococcus danielli*, yarn.

Introduction

The promotion of sustainable development has put pressure on all industries, including the construction industry to adopt and implement proper methods to protect the environment. Due to current global concerns for sustainable development that have arisen from extensive environmental problems such as climate change and the impoverishment of resources coupled with the rapid pace of technological advancement within the building sector, interest in alternative building materials has been developed (Ashour *et al*., 2015; Doukas *et al.*, 2006).The inclusion of fibre reinforcement in concrete, mortar and cement paste can improve many of the engineering properties of the basic materials, such as fracture toughness, flexural strength and resistance to fatigue, impact, thermal shock and spalling (Romildo *et. al*.,1999). Recently, there has been a great deal of interest globally on the potential applications of natural fibre reinforced, gypsum based composites

Plaster of Paris is a white powder obtained by heating Gypsum ($CaSO_4.2H_20$), which is a calcareous stone to about 300°F (150°C). Dry plaster powder reforms into gypsum when mixed with water (Colditz, 2002). Due to its availability in subsoil, relative low cost, ease of high usage and mechanical characteristics suitable for many uses, plaster is a widely used construction material, which can compete with cement. Where the latter is not eliminated completely but used rationally, structure like foundations and chaining must be strengthened. However, plaster appears to be heavy, permeable and too brittle (Gunasekaran *et al*., 2008). Heaviness and brittleness may be appreciably reduced by combining plaster with natural fibers (Dalmay *et al*., 2010)

There is great deal of interest in developing the technology of using natural fiber material as reinforcement in gypsum composites. Natural fibers exist in reasonably large quantities all over the world in different forms. There is a wide range of natural fibers, namely sisal, bamboo, coir (coconut fiber), jute, wood cellulose fiber, leaf stalk fibers and many others (Zain *et al*., 2015; Mulinari, 2011). Natural fibers are abundantly available and are comparatively cheap. Natural fiber composite are also claimed to offer environmental advantage such as lower pollutant emissions, lower greenhouse emission, enhanced energy recovery and end of life biodegradability, inexpensive, environmental friendly and easily available as reported by Xie *et al.,* (2010). Hence, the demands to utilize natural fibers for making good quality and low cost materials sustainable for housing and others are increasing. Vegetable fibres, including sisal, coconut, jute, bamboo and wood fibres, are prospective reinforcing materials and their use until now has been more empirical than technical (Romildo *et al*.,1999). However, most of these fibres were used mainly for the production of hard board and particle board.

Gypsum composites could be reinforced with some of these natural fibres to produce ceiling boards which could be a substitute to asbestos-cement composite, which is a serious hazard to human and animal health and is prohibited in industrialized countries. Fibres of *Cocos nucifera* and *Thaumatococcus danielli* are agricultural waste products that are readily available and often times constitute nuisance to the environment if they are not properly disposed. This work, therefore, examined the mechanical properties of ceiling boards produced from gypsum reinforced with *Cocos nucifera* and *Thaumatococcus danielli* and synthetic fibres.

Materials and Methods

Collection and preparation of natural fibers and Plaster of Paris (POP)

Coconut husks were collected from Ibode area, Ibadan, the husks were washed properly and air dried for five days under ambient temperature. The coconut husks were chopped with sharp scissors maintaining a length from 15 to 35mm. The coconut fibers were pre-treated in hot water at 80°Cfor one hour to remove water soluble sugars and other chemicals that can affect the setting and curing of the plaster. Then, the fiber was washed thoroughly in cold water and air dried to 12% moisture content and was stored in polythene bag prior to use.

Thaumatococcus danielli stalks used for this study were harvested from Ikeji-Ile, Osun State. The stalks were cut to short lengths of 50mm, and the fibres were removed with a sharp knife and dried for20 hours at 60°C to constant moisture content.

80kg of Plaster of Paris (POP) and Synthetic Fibre (Yarn) were purchased from Supreme Interior Decoration NIG LTD, Iwo road Ibadan, Oyo State Nigeria.

Mixing proportion of the Board

Medium density board of 600kg/m^3 having dimensions 200 mm x 200mm x 10mm were cast for both synthetic and natural fibres using the mixing ratio: 5g of fibres + 235g of Plaster of Paris (POP) + 300ml of water. The percentage of each mixing proportion is given in Table 1 for the following levels: Level 1: (Yarn/POP); Level 2: (*Thaumatococcus danielli*/POP); Level 3*: (Cocos nucifera*/POP)

Table 1: Mixing proportion of the Plaster of Paris and the natural fibres and synthetic fibres

FIBRES	MIXING PROPORTION
100%	$P_{235g}: C_{5g}$ $P_{235g} : T_{5g}$ $P_{235g} : Y_{5g}$
75%	$P_{235g} : C_{3.5} : Y_{1.5}$ $P_{235} : T_{3.5} : Y_{1.5}$
50%	$P_{235} : C_{2.5} : Y_{2.5}$ $P_{235} : T_{2.5} : Y_{2.5}$
25%	$P_{235} : C_{1.5} : Y_{3.5}$ $P_{235} : T_{1.5} : Y_{3.5}$

Note: P- POP; C- coconut husk; T- *Thamautococcus danielli*; Y- Yarn

Board Formation and Setting

Mold of 200mm × 200mm × 10mm was placed on flat metal and was lubricated to prevent the sticking of the formed boards on the plates. The POP, yarn and natural fibres were measured using the sensitive scale accordingly, the measured water was poured gradually into the bowl containing the gypsum and stirred gradually. The POP mixture was turned gradually into the mold and the fibers was spread equally onto it, another mixture of POP was added to the surface thereby making the fibers to be in between the plaster. The casting was done quickly because it is the nature of POP to harden quickly. After all the process, the board was allowed to set for five (5) minutes and was removed gently from the mold and kept in a well-ventilated place to dry over a period of 7days. The board was further cut into various test specimens for evaluation in accordance with BS 5669: (1979). The parameters tested for are water absorption and thickness swelling.

Evaluation of Mechanical Properties

Flexural Strength (Modulus of Rupture)

Flexural strength is a parameter for measuring static bending strength of material. The test samples were cut into dimension 50 mm × 195 mm× 10mm in accordance with British Standard, 1989.The test was carried out using Electronic Universal Testing Machine, Model: wDw-50 (2018).The test specimens were mounted one by one on the jig and the load was applied at the center with the aid of an electro mechanical motor till the point where failure occurred. The recording of the ultimate failure load (P) was estimated on the mercury meter. The Flexural strength (s) was calculated using equation 1.

$$s = \frac{\frac{3PL^3}{2\Delta bd^2N}}{mm^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, P = Load that failed the test sample (N); I = span for the test sample (mm); b = Width of the test sample (mm); d = Thickness of the test sample (mm)

Modulus of Elasticity (MOE)

This is the measure of stiffness property of the board i.e. the ability of materials to regain its original shape and size after being stressed (Panshin and Dezeewo, 1980). MOE was determined from the deflection test carried out during the test. This was calculated from the values obtained from the load -deflection graph during the test. The formula employed is given as MOE in equation 2.

$$MOE= \frac{\frac{3PL^3}{4\Delta bd3} N}{mm^2} \dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

Where, P = Maximum load at failure (N); L = Span of the material (mm); d = Depth; b= width of the board sample (mm); Δ = Deflection of beam Centre at proportional load (ASTM 2003)

Compressive Strength

The test was carried out using an Electronic universal testing machine, with a tension focus on the maximum load causing failure. The test samples were cut into dimension 30 × 30 × 10mm and the test procedures of the electro-mechanical was used. The test was placed between a supporting base and a flat steel plate above it, on to which a plunger that applied a compressive load will rest. The maximum load (Newton) was recorded per test specimen and the compressive stress was calculated as force per unit area according to equation 3.

$$C = \frac{F}{A} \dots\dots\dots\dots\dots\dots\dots\dots (3)$$

Where, C= compression (N/mm^2); F= Force applied; A= Area of the board (ASTM 2003)

Impact Bending Test

For impact test, sample of size 150 × 150 × 10mm was used. The impact bending test was carried out using the tensiometer machine. The height was recorded in metre as the height of maximum hammer drop. The purpose of impact bending test is to observe the impact resistance or bending strength of the ceiling, (ASTM, 2003) the impact bending strength was calculated according to equation 4.

$$s_a = \frac{3L_2F}{2bh} \dots\dots\dots\dots\dots\dots\dots\dots(4)$$

Where, s_a= impact bending; L=Span; b=Width; h=Depth; f=Maximum load

Statistical Analysis

Data collected were subjected to analysis of variance (ANOVA) at 95% level of significance. For each data, significantly different groupings were obtained using Duncan Multiple Range Test (DMRT).

Results and Discussion

Effect of Fibre Reinforcement on Flexural strength (Modulus of Rupture) of Gypsum-bonded Boards

The graphical representation of the flexural strength readings are as shown in Figure 1. The flexural strength values ranged from 0.92- 4.86 N/mm^2. The 50% mixing proportion ($P_{235:}T_{2.5}$: $Y_{2.5}$) has the lowest values of 0.92N/mm^2 while the highest values of 4.86N/mm^2 is observed in 75% mixing proportion ($C_{3.5:}$ $Y_{1.5}$).The decrease in the flexural strength for 50% mixing proportion may be as a result of equal volume of conventional and natural fibre used.Table 3 shows that **t**here is a significant difference in the flexural strength value between different proportions of the fibers as well as between the fibers. Flexural strength is also known as modulus of rupture, is a mechanical parameter which is defined as a material's ability to resist deformation under load. The flexural strength represents the highest stress experienced within the material at its moment of rupture (Chinta*et. al.* 2013).

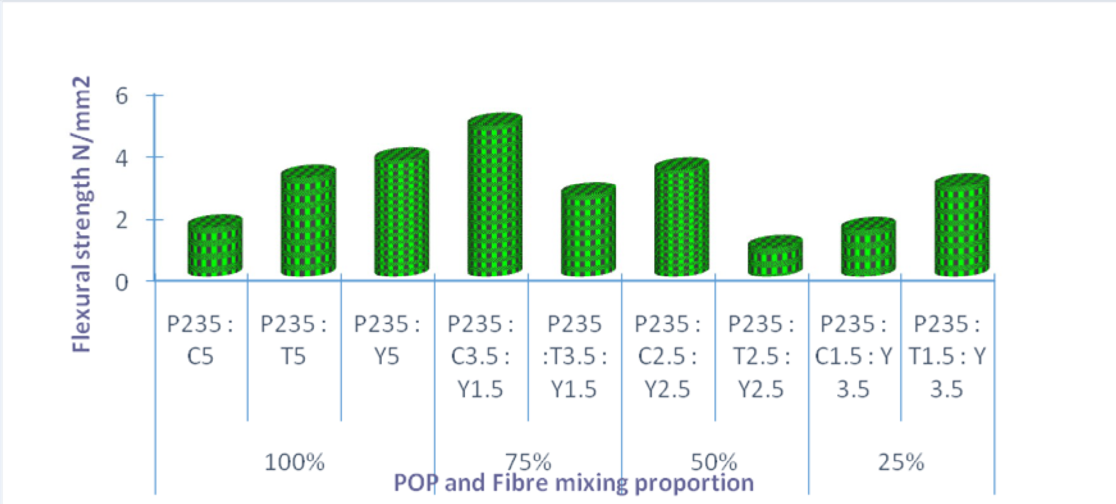

Figure 1: Flexural Strength of Gypsum-Bonded Boards from Natural and Synthetic Fibers.

From figure 1, it is observed that there is a significant difference on the flexural strength of different fibres used. For 100% mixing proportion of fibres, the plaster reinforced with yarn has value that is significantly higher than other with 100% natural fibre in the composite. However, the combination of 75% coconut fibre with 25% yarn produces a board that has a flexural strength that is significantly higher than all the boards produced from other mixing proportion. From this result it is obvious that the strength of the board reached a maximum value at 75% ($C_{3.5:}$ $Y_{1.5}$) and then decreased. This drop in strength of the board may be due to decrease in the strength of the board with increasing synthetic fibre content ratio to the natural fibres.

Effect of Fibre Reinforcement on Modulus of Elasticity (MOE) of Gypsum-bonded Boards

The graphical representation of the Modulus of Elasticity (MOE) of the board produced is presented in Figure 2. The mean value ranges from 152N/mm^2 to 856.8N/mm^2. The highest MOE values is observed in board produced at 75% fiber with mixing P $_{135g}$: C $_{3.5g}$: Y $_{1.5g}$ while the lowest MOE values is seen in the board with 50% with mixing proportion of P $_{135g}$: T $_{2.5g\,:}$ Y $_{2\cdot5}$ g. However, follow –up results (Table 2) indicated that there is a significant difference in the MOE values between different proportions of the fibers as well as between the fibers. For 100% mixing proportion of the fibres, the plaster reinforced with yarn has the MOE value that is significantly higher than other with 100% natural fibre in the composite. However, the combination of 75% coconut fibre with 25% yarn produces a board that has the MOE (856.80 N/mm^2) that is significantly higher than the boards produced from *T. danielli.* This could be as a result of the high tensile strength of the coconut fibre as previously reported (Noor *et al.*, 2012).The combination of 50% coconut fibre with 50% yarn also produces a board with MOE (755.15 N/mm^2) that is significantly higher than the board produced from 50% mixing proportion of the *T. danielli* with the yarn. From the results, it could be observed that all the boards produced from the combination of natural and synthetic fibres produced boards with MOE that are significantly higher than other boards with just one fibre combination.

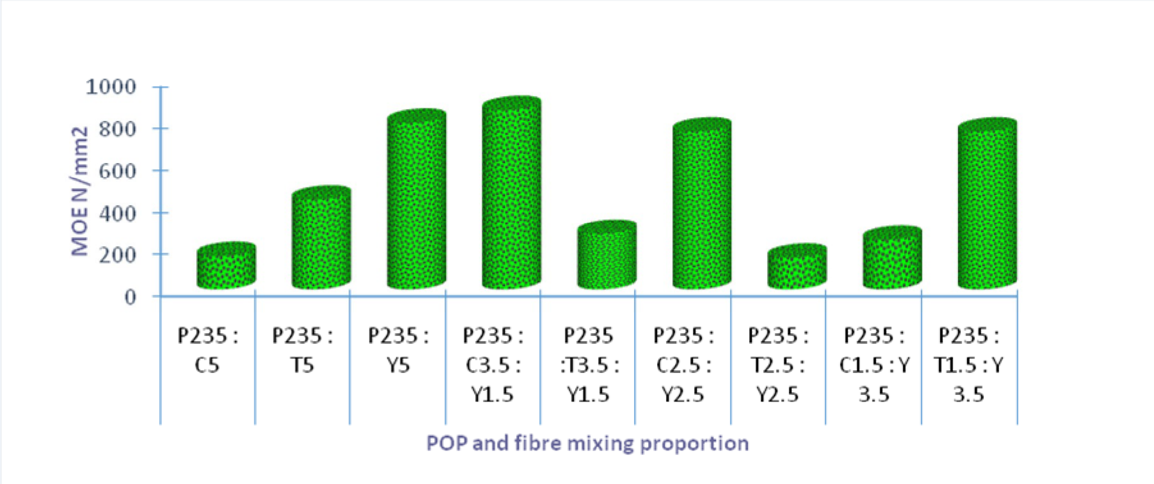

Figure 2: Modulus of Elasticity of Gypsum-Bonded Boards from Natural and Synthetic Fibers.

The result revealed that, strongest boards were produced at the highest levels of coconut fibres combined with 15% of the yarns. Greater compaction of boards achieved might be as a result of bonds and the equal proportion of fibers to binder produced stiffness boards. MOE property of samples decreased with increase in binder loading and this might be due to reduction in stiffness of the composite specimens also suggest that reinforcing fibers gave higher stiffness than the binder matrix .This result is contrary to what Mehmet and Ayhan (2008) and Lou *et al.*(2007) reported.

Table 2: Follow up test for MOE and flexural strength of Gypsum-Bonded Boards from Natural and Synthetic Fibers.

FIBRE MIXING RATIO		MOE(N/mm^2)	Flexural strength (N/mm^2)
100%	$P_{235} : C_5$	160.79 ± 132.27^a	1.59 ± 1.20^a
	$P_{235} : T_5$	428.16 ± 138.56^c	3.19 ± 0.86^c
	$P_{235} : Y_5$	796.86 ± 220.54^d	3.74 ± 0.84^c
75%	$P_{235} : C_{3.5} : Y_{1.5}$	856.8 ± 663.6^d	4.86 ± 0.36^d
	$P_{235} : T_{3.5} : Y_{1.5}$	265.72 ± 118.59^b	2.62 ± 1.24^b
50%	$P_{235} : C_{2.5} : Y_{2.5}$	755.15 ± 134.87^d	3.42 ± 0.59^c
	$P_{235} : T_{2.5} : Y_{2.5}$	152.80 ± 27.18^a	0.92 ± 0.18^a
25%	$P_{235} : C_{1.5} : Y_{3.5}$	237.00 ± 39.92^b	1.51 ± 0.14^a
	$P_{235} : T_{1.5} : Y_{3.5}$	700.20 ± 133.60^d	2.91 ± 1.69^b

Means of the different alphabet are significantly different at ($p < 0.005$)

Effect of Fibre Reinforcement on Impact Bending

The graphical representation for Impact bending (IB) of the boards produced are presented in Figure 3. The impact bending of the board ranges from 1.58J/mm^2 - 2.80 J/mm^2. The board produced at 100% fibre mixing proportion has the highest IB while the least is observed in board with 50% ($P_{235} : C_{2.5} : Y_{2.5}$) fibre mixing proportion. The high impact bending observed in the 100% ($P_{235} : Y_5$) mixing proportion could be as a result of higher ductility and lesser susceptibility to embrittlement of the yarn fibres which resulted in high impact resistance of the board reinforced with yarn. However, follow –up results (Table 3) shows that there is no significant difference in IB of the boards produced from all the mixing ratio except the boards with 100% (P_{235} : Y_5) which is significantly different from the other boards. The results of this study indicated that there is no significant difference in the impact bending of various fibre combination used.

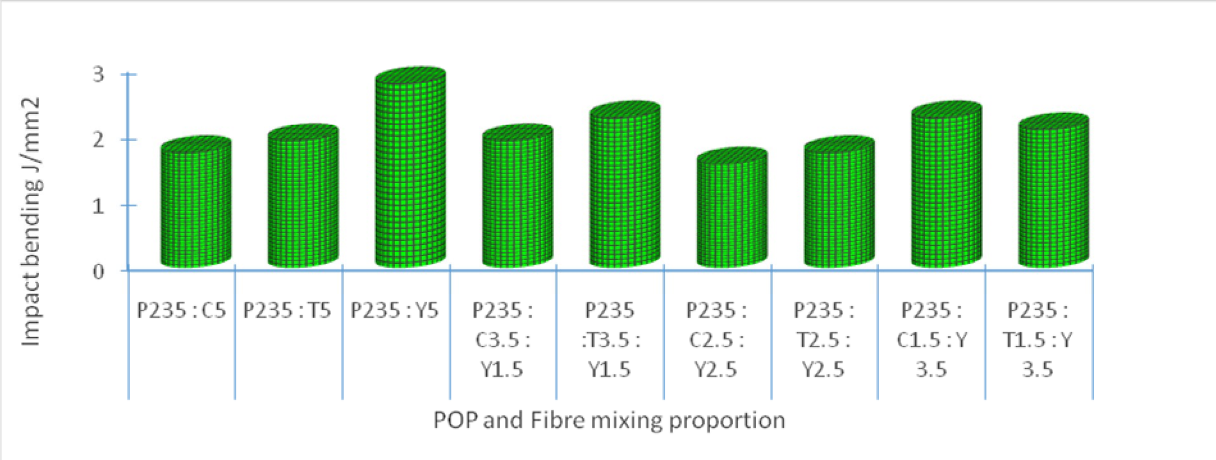

Figure 3: Impact Bending of Gypsum-Bonded Boards from Natural and Synthetic Fibres

As reported by Ramakrishna and Sundararajan (2005), crack resistance increases with increase in fibre content irrespective of the type of fibre used. This could be responsible for the similarity in the impact resistance of boards produced from different fibre combination for all the mixing proportions.

Effect of Fibre Reinforcement on Compressive Strength

The graphical representation of the compressive strength is given in figure 4 and the follow up result is presented in table 3. The compressive strength of the board ranges from 16.12N/mm^2 to 69.50N/mm^2. The least compressive strength of the boards is produced from the 75% (P_{235g}: $T_{3\cdot5g}$: $Y_{1\cdot5g}$) fibre mixing proportion. And the highest compressive strength is observed in the boards with 25% (P_{235g}: $T_{1\cdot5g:}Y_{3.5g}$) mixing proportion. There is a significant difference between the values between different mixing proportions of fibres and POP. Compressive strength is the capacity of a material to withstand axially directed pushing force verses deformation for the test method (Chinta *et. al.* 2013).Strength decreased with increase in the mixing ratio of the synthetic fibres. The compressive strength of the board also competes favourably with the reported ones, according to Gong *et. al.* (2004) the compressive strength values required for the material to be used as pavements ranged from 20-25N/mm$^{2.}$

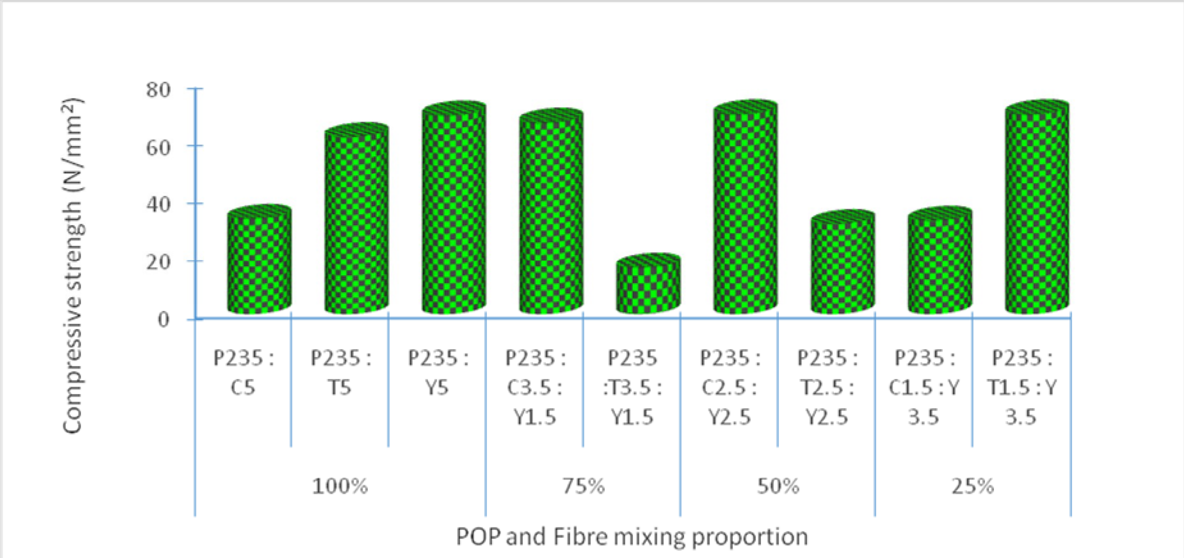

Figure 4: Compressive strength of Gypsum-Bonded Boards from Natural and Synthetic Fibres

The reason for this according to Bentur and mindness (1990) could be attributed to the fact that fibres are generally not used to improve the compression of cement bonded composite. The low strength values could also mean that the boards may not be suitable for structural applications but only non-loading bearing ceiling boards.

Table 3: Follow up test for Impact bending and Compressive strength of Gypsum-Bonded Boards from Natural and Synthetic Fibers.

FIBERS	MIXING RATIO	IMPACT BENDING(J/mm^2)	COMPRESSIVE STRENGTH(N/mm^2)
100%	$P_{235} : C_5$	$1.75{\pm}0.30^a$	$33.14{\pm}3.5^b$
	$P_{235} : T_5$	$1.93{\pm}0.30^a$	$61.65{\pm}1.17^c$
	$P_{235} : Y_5$	$2.8{\pm}0.61^b$	$69.07{\pm}0.00^c$
75%	$P_{235} : C_{3.5} : Y_{1.5}$	$1.93{\pm}0.30^a$	$66.59{\pm}7.05^c$
	$P_{235} :T_{3.5} : Y_{1.5}$	$2.28{\pm}0.31^{ba}$	$16.12{\pm}0.65^a$
50%	$P_{235} : C_{2.5} : Y_{2.5}$	$1.58{\pm}0.52^a$	$69.47{\pm}0.41^c$
	$P_{235} : T_{2.5} : Y_{2.5}$	$1.75{\pm}0.30^a$	$31.33{\pm}9.5^b$
25%	$P_{235} : C_{1.5} : Y_{3.5}$	$2.28{\pm}0.31^{ba}$	$32.52{\pm}8.2^b$
	$P_{235} : T_{1.5} : Y_{3.5}$	$2.10{\pm}0.5b^a$	$69.50{\pm}0.37^c$

Means with different alphabets in same column are significantly different at ($p < 0.05$)

Conclusion

Ceiling boards were successfully produced from natural fibers and synthetic fibres with mixing ratio of100%,75%,50% and 25%. It was observed that the mechanical properties of the boards produced from combination of natural fibres and synthetic fibres at different mixing ratio compete favorably with the boards produced from conventional fibres (yarn) of mixing ratio 100% (P_{235}:

Y_5).This establishes the fact that combination of natural fibres with the synthetic fibres produced boards with best mechanical properties.

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