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Modelling Predicting the Effect of Palm Bunch Fibres on the Strength Properties of Concrete

Yalley, P. P.[1], Osei Poku[2], M. and Zievie, P.[3]

[1]*Department of construction Technology Education, College of Technology Education, University of Education, Winneba. Ghana, Email:<yalleypp@gmail.com >.*

[2]*Department of Building Construction, Methodist Technical Vocational School, Kumasi, Ghana. Email :< moplysa@yahoo.com>.*

[3]*Department of Building Technology and Estate, Wa Polytechnic, Ghana, Email: < zppat74@gmail.com>.*

ABSTRACT

This research describes experimental studies on the use of palm bunch fibre as enhancement of concrete. The addition of palm bunch-fibres significantly improved many of the engineering properties of the concrete, notably toughness and tensile strength. The ability to resist cracking and spalling were also enhanced. However, the addition of fibres adversely affected the compressive strength. An increase in fibre weight fraction provided a consistent increase in ductility up to the optimum content (0.5%) with corresponding fibre aspect ratio of 125. The increase in toughness, could be attributed to the fact that, the fibre presence in the concrete contributed greatly in offering restrain to early twist in the concrete hence, much energy was needed to debond and stretch the fibres. Palm bunch fibres have been used to enhance concrete, and have proven to improve the toughness and the tensile stress of the concrete of which concrete with fibres as enhancement seems to address. However, the problem of long term durability has not yet been solved in this study.

INTRODUCTION

With the quest for affordable housing system for both the rural and urban population in Ghana and other developing countries, various proposals focusing on cutting down conventional building material costs have been put forward. One of the suggestions in the forefront has been the sourcing, development and use of alternative, non-conventional local construction materials including the possibility of using some agricultural wastes as construction material Natural reinforcing materials can be obtained at low cost and low levels of energy using local manpower and technology. Utilisation of natural fibres as a form of concrete enhancement is of particular interest to less developed regions where conventional construction materials are not readily available or are too expensive. Some of the materials under consideration are agro waste as reinforcement materials in the construction are available in literature (Mohr; El-Ashkar & Kurtis, 2004). Concrete made with Portland cement has certain characteristics: it is strong in compression but weak in tension and tends to be brittle. The weakness in tension can be overcome by the use of conventional steel bar reinforcement and to some extent by the inclusion of a sufficient volume of certain fibres. The use of fibres also alters the behaviour of the fibre-matrix composite after it has cracked, thereby improving its toughness.

The overall goal for this research is to investigate the potential of using waste and low energy materials for domestic construction, principally in Ghana. The objective of this research is to experiment on the use of palm bunch fibres as an enhancement of concrete. Palm bunch fibres are not commonly used in the construction industry but are often discarded as wastes. Two main factors that were taken into account in the search for new construction materials were ecological impact and production costs. The incorporation of recycle materials originating from renewable sources into a cementitious core is a feasible alternative that this research would investigate. In Brazil, vegetable fibres have been used as reinforcement in cementious material. For instance, building component was developed with coir and sisal fibres (Agopyan, 1998; Fowler, & Koehler, 2004).

Mostly, palm tree is one of the most important agricultural and commercial plantation crop in Ghana. People recognized it as a tree of life because, every part of the palm tree such as fruits, trunks, leaves, shells of the fruits can be effectively utilized for living (Ahmad, Saman & Tahir; 2010; Eichhorn &Young, 2004). Palm bunch fibres obtained from palm bunch of palm fruit belonging to the family of palm fibres, are agricultural waste products obtained in the processing of palm oil, and are available in large quantities in the tropical regions of the world, most especially in Africa, Asia and southern America. In Ghana, they are available in large quantities in the southern part of the country. Natural fibre has been used to enhance concrete and mortar, and has proven to improve the toughness of the concrete and mortar (Gram, 1983, and Ramakrishna, et al., 2005). It has also been noticed that the degree of enhancement of concrete by natural fibres depended on the type of fibre species. The specific objective of experimenting on palm bunch fibre as an enhancement of concrete is two fold. Firstly, to assess if the fibres improve the mechanical properties of concrete like other natural fibres like sisal, jute, coir, etc. Secondly, once it was proven that vital mechanical properties of concrete and mortar could be enhanced by palm bunch fibre then further investigation would be carried out on improving the long term durability of concrete and mortar with palm bunch fibres as an enhancement.

EXPERIMENTAL STUDY

The current experimental investigations on palm bunch fibres as enhancement of concrete, was thus carried out on test specimens using one basic mix proportion with three variations of aspect ratio of palm bunch fibres, four different weight fraction of palm bunch fibre and three different water/cement ratios.

Materials. Ordinary Portland cement conforming to BS 12, 1971 was used. The fine aggregate was natural sand conforming to BS 882 1975, while the coarse aggregate was crushed granite having a maximum size of 10mm. The fibres were palm bunch fibres with diameter ranging between 0.29mm and 0.83m m and length between 6mm and 24mm and approximate mean aspect ratio of 150. Sufficient moulds in accordance with BS 1881 were available to enable simultaneous casting of all specimens. This eliminated discrepancies such as variation in mix proportion, water content etc., which might have arisen if more than one mix was required per casting.

Preparation of Fibres. To facilitate the extraction of fibres, palm bunch were soaked in water for one month and later placed in 10% concentration of sodium hydroxide (NaOH) for seven days, before physical extraction of the fibres by hand. Fibres were separated while minimising structural damages during the extraction process. The fresh water was meant to remove the pith particles and the lignin from the surface of the fibres (Nanayakkrar et al., 2005). Studies conducted by Ramakrisma el al. (2004) on the durability of natural fibres, indicated that NaOH is also a good solvent for both lignin and hemicelluloses, and also palm bunch fibre retained about 73% of its initial tensile strength when placed in NaOH for up to 60 days. Based on this knowledge, the palm bunch were further placed in NaOH for seven days to dissolve the lignin and hemicelluloses to facilitate extraction of fibres.

Mixing of Concrete with Palm Bunch Fibres. In an endeavour to ensure that the fibres were well distributed and randomly orientated, and thus prevent balling or interlocking, the concrete together with the fibres were mixed by hand in this investigation.

Mixing Procedure. The dry cement and aggregates were mixed for two minutes by hand in a $0.3m^3$ laboratory mixer pan. The mixing continued for further few minutes while about 80% of the water was added. The mixing was continued for another few minutes and the fibres were fed continuously to the concrete for a period of 2–3 min while stirring. Finally, the remaining water along with superplasticizer was added and the mixing continued for an additional two minutes. This ensured a complete distribution of fibres throughout the concrete mix. For each mix, a total of five cylinders with dimension of 100×200mm and three cubes of side 100mm were cast. These specimens were cast for each of the mixes A, (the control specimen) and $B_{x/y/z}$, (i.e. specimens with x% w/c ratio, y% of fibre content and z fibre aspect ratio). A total of 39 separate mixes were thus cast.

Method of Compaction. The moulds with half-filled fresh concrete were vibrated vertically on the vibrated table while casting for about 30 seconds. The moulds were then fully filled with fresh concrete and vibrated further for about 60 seconds. This method of compaction was to align the fibres normal to the direction of vibration (Parameswaran et al., 1975)

Curing. The specimens were stripped from the moulds 24 hours after casting and submerged in water until testing. Some of the specimens were removed from the water after 28 days of submersion in water for testing the 28-day strength.

Details of the Test. Five cubes and five cylinders from each mix were tested for compression and splitting tensile strength at 28-day curing age, using a GD10A compression testing machine with a maximum capacity of 2500KN (Figure 1).

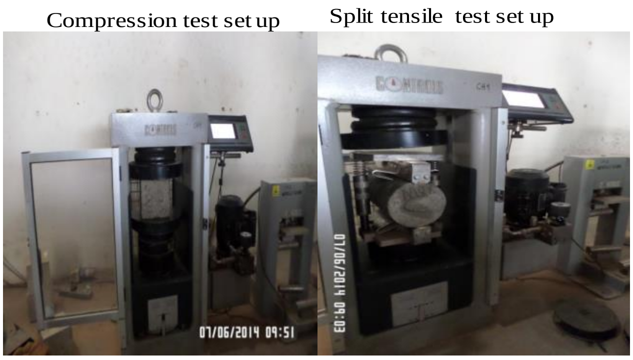

Figure 1. Testing set up for compression and tensile strength

In order that the cylinders could be tested to obtain the split tensile strength in accordance with BS1881, additional plywood packing strips (10mm wide) were used at point of load contact to prevent stress concentration.

RESULTS AND DISCUSSION

It was observed for all levels of fibre addition and for all fibre aspect ratio the mechanical properties namely: compressive. Tensile strength and toughness decreased with increased in W/C ratio. In other words specimen with W/C ratio of 0.5 had the highest mechanical propertied compared with corresponding specimens with W/C ratio of 0.55 and 0.6. For simplification of the descriptive analysis specimen with W/C ratio of 0.5 was used while varying fibre content and fibre aspect ratio.

Behavior under compression. The results of the compressive strength shows that at a constant fibre content and fibre length, the compressive strength decreases as the water cement ratio increases for all batches. From Figure 2 there was a reduction of about 62% in compressive strength from 42 N/mm^2 for plain concrete with 0.5 w/c ratio to 16 N/mm^2 for concrete with one percent of fibre addition with fibre aspect ratio of 150 and w/c ratio of 0.5. Again keeping w/c ratio and fibre content constant, the compressive strength decreases with increased in fibre length (Figure 2). On another hand when the w/c ratio and the fibre aspect ratio remains unchanged the compressive strength of PBF enhanced concrete increases with increased in the fibre content up to the level of 0.5% (by weight of cement) addition. The compressive strength started declining when the fibre addition was beyond 0.5%.

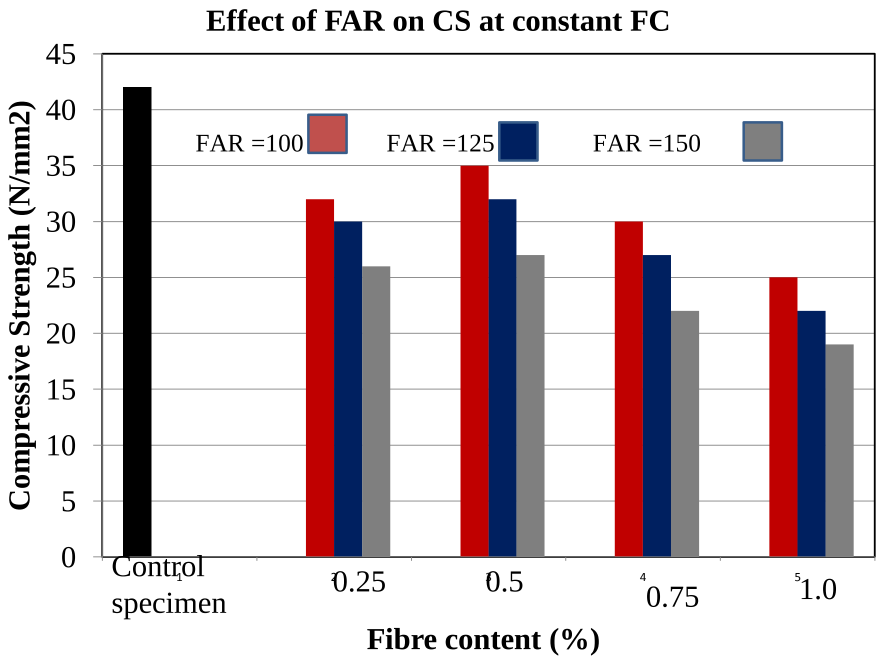

Figure 2. Effect of FAR on CS at constant FC and W/C =0.5

Regression analysis was performed using Minitab 17 project to assessing the relative contribution of water/cement ratio (w/c), fibre content (FC) and fibre aspect ratio (FAR) in the prediction of the compressive strength of concrete enhanced with palm bunch fibre. From the regression equation (1) when FAR and w/c ratio is held constant, beyond 0.5% level of fibre addition, a percentage increased in the fibre content would decrease the compressive strength by about 11 N/mm^2. In the same vein when FC and w/c ratio remain unchanged, a increased in the w/c ratio by one unit would decreased the compressive strength by approximately 49 N/mm^2. The contribution of the fibre aspect ratio to the variance in compressive strength when other predictors are held constant is 0.06 N/mm^2 when the length of the fibres is decreased by 1mm. Water/cement ratio, fibre content and fibre aspect ratio collectively explained about 80% (R^2adjusted) = 79.40%) of the variance in compressive strength. This would suggest that the present regression model is a good predictor of compressive strength. It would appear that the fibre content explained the bulk of the variance in the compressive strength ($t=-7.01$, $p<0.001$)

$$CS\ (N/mm^2) = 42.00 - 11.12\ \text{Fibre content (\%)} - 0.0602\ \text{Aspect Ratio} - 48.5\ \text{w/c ratio} \qquad (1)$$

Table 2. Minitab data showing the effect of FC, FSR and W/C ratio on compressive strength (n=39)

Variable	B	R^2	R^2 Adjusted	T- value	P -value
Constant	64.38	80.03	79.40	10.54	0.00
Fibre content (%)	-11.12			-7.09	0.00
Aspect Ratio	- 0.0602			-4.70	0.00
w/c ratio	-48.5			0.00	1.00

Behaviour under tension. In the splitting tensile tests cylindrical specimen were subjected to splitting tension along their axis. The method for calculating the split tensile test is give as

$$\sigma_t = \frac{2F}{\pi Ld} \qquad (2)$$

where, F = Applied force L =Height of cylinder D =Diameter of cylinder

On average there was an increase of about 15% when 0.5% of PBF was added to the concrete However, beyond 0. 5%, the tensile strength again decreased. Addition of 0.75% and 1.0% did not improve the splitting tensile strength; there was a reduction of an average about 41% as compared with the control specimens when the fibre content was increased to 1.0% as shown in Fugure 3. It was established that the optimum fibre aspect ratio of 100 provided the best performance in splitting tensile strength in all weight percentage and all w/c ratio.

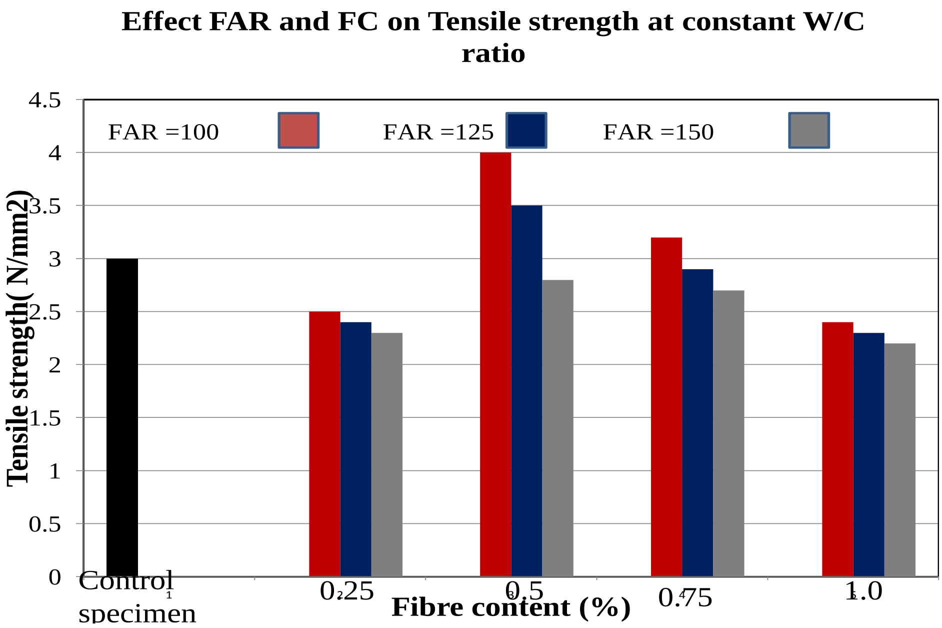

Figure 3. Effect of FC and FAR on Tensile strength at constant W/C ration

It is expected that, composites with the highest fibre aspect ratio would have higher tensile strength than those with smaller fibre aspect ratios as evidence in Mohr, et. al. (2005) but this is not the case in this study. It appears that the critical fibre aspect ratio is 100, and any increase of the critical fibre length leads to a corresponding decrease in tensile strength. One of the reasons could be attributed to the fact that in the short fibre-enhanced composite there are more end points which allowed faster penetration of cement hydration products into the fibre lumen walls and voids and therefore, accelerating the loss of flexibility of the fibres.

From Table 3 FAR, FC and w/c ratio could explain 17% of the change in the tensile strength of the specimens enhanced with PBF. Fibre content is not significant in the prediction of the tensile strength at a significant level of 0.05 (T- value = -0.04, P-value = 0.97). It could be said that w/c ratio highly influenced the variance in the tensile strength (T- value = -0.26, P-value = 0.026). This is evidence in equation 3, where the tensile strength decreased by 4.54 N/mm^2 when the w/c ratio is increased by one unit.

$$\text{Tensile strength (N/mm}^2\text{)} = 5.56 - 0.012\ \text{FC (\%)} - 0.00478\ \text{FAR} - 4.54\ \text{w/c} \quad (3)$$

Table 3. Minitab data showing the effect of FC, FSR and W/C ratio on Tensile strength (n=39)

Variable	B	R^2	R^2 Adjusted	T- value	P –value
Constant	5.56	23.7	17.2	5.04	0.00
Fibre content (%)	- 0.012			-0.04	0.97
Aspect Ratio	-0.04			-2. 06	0.04
w/c ratio	-4.54			-2.32	0.026

Toughness. The result indicates that with a constant weight fraction, the toughness is higher with specimens having an aspect ratio of 100. Again it is clear from the investigation that, at a constant aspect ratio, 0.5% fibre content had the highest modulus of toughness. The above phenomenon could be explained by suggesting that there is a better alignment of fibres with a certain critical fibre length. Beyond the critical length, any increase in fibre length, or fibre aspect ratio, worsen fibre-fibre interactions thus reducing toughness, strength and modulus. On the other hand, fibres with fibre aspect ratio of less than100 would become mineralised earlier, therefore causing earlier embrittlement of the fibre. The increase in toughness of the concrete could be attributed to the probable increase of fibre-cement contact of the palm bunch fibres due to higher lignin content (about 30%) of the palm bunch fibres which stiffened the cell-wall of the fibre preventing embrittlement of the fibres. The improvement in ductility is more pronounced in specimen with fibre weight fraction of 0.5% and an aspect ratio of 125). The increase in toughness could be attributed to the fact that, the fibre presence in the concrete contributed greatly in offering restrain to early strain in the concrete. It is also clear that the palm bunch fibres suffered no harm in the alkaline pore water in the concrete; hence, much energy is needed to debond and stretch the fibres, and hence, higher concrete toughness.

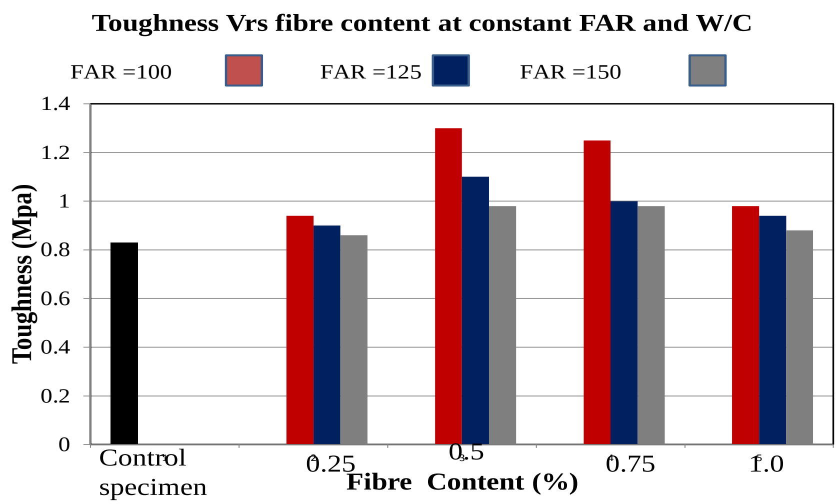

Figure 4. Effect of FAR on Toughness at a constant w/c and FC

Using Minitab regression analysis; from Table 4 FAR, FC and w/c ratio could explain 20% of the change in the toughness of the specimens enhanced with PBF. It could be said that fibre content highly influenced the variance in the toughness (T- value = -0.3.41, P-value = 0.002). This is evidence in equation 4, where the toughness increased by 0.6 N/mm^2 when the fibre content is increased by one percent.

$$\text{Toughness (MPa)} = 0.917 + 0.568\,Fc\,(\%) - 0.00094\,FAR - 0.01\,w/c \qquad (4)$$

Table 4. Minitab data showing the effect of FC, FSR and W/C ratio on Toughness (n=39)

Variables	b	R	R^2 Adjusted	T- value	P –value
Constant	5.56	26.44	20.13	5.04	0.00
Fibre content (%)	0.568			-3.41	0.02
Aspect Ratio	-0.00094			-0.69	0.494
w/c ratio	-0.01			-0.01	0.995

CONCLUSION

The findings of the study supports the following conclusions: The addition of palm bunch-fibres significantly improved many of the engineering properties of the concrete, notably toughness and tensile strength. The ability to resist cracking and spalling were also enhanced. However, the addition of fibres adversely affected the compressive strength, as expected, due to difficulties in compaction which consequently led to increase of voids.

RECOMMENDATIONS

Experiments and demonstration projects around the world have shown that natural fibre enhancement is a viable and cost effective alternative to conventional building materials. However, the construction industry is extremely conservative, and so the most likely development route is the use of the new materials in non-structural applications or in ones where the consequences of failure are not too severe.

Given the variety of fibre materials, the number of mix constituent and method of production, it is evident that product development should be the prime future research objective. Economic methods of natural fibre extraction, handling, and economical and automated methods of dispersing fibres at a batching plant is needed if large quantities of fibres are going to be used in construction.

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