USE OF COCONUT FIBRES AS AN ENHANCEMENT OF CONCRETE

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ABSTRACT
This research describes experimental studies on the use of coconut fibre as enhancement of concrete. The addition of coconut-fibres significantly improved many of the engineering properties of the concrete, notably torsion, toughness and tensile strength. The ability to resist cracking and spalling were also enhanced. However, the addition of fibres adversely affected the compressive strength. When coconut fibre was added to plain concrete, the torsional strength increased (by up to about 25%) as well as the energy-absorbing capacity, but there is an optimum weight fraction (0.5% by weight of cement) beyond which the torsional strength started to decrease again. Similar results were also obtained for different fibre aspect ratios, where again results showed there was an optimum aspect ratio (125). 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. Overall the study has demonstrated that addition of coconut fibre to concrete leads to improvement of concrete the toughness torsion and the tensile stress, Further work is however ,required to assess the long term durability of concrete enhanced with coconut fibres..

Keywords*: coconut fibres; compression and tensile strengths; torsion; toughness*

1.0 INTRODUCTION.

With the quest for affordable housing system for both the rural and urban population in Ghana and other developing countries, various proposals focussing 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 materials.

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. Coconut and sisal-fibre reinforced concrete have been used for making roof tiles, corrugated sheets, pipes, silos and tanks (Agopyan, 1988).

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 coconut fibres as an enhancement of concrete. Coconut fibres are not commonly used in the construction industry but are often discarded as wastes.

Coconut fibres obtained from coconut husk, belonging to the family of palm fibres, are agricultural waste products obtained in the processing of coconut 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.

Coconut 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). However, the problem of long term durability has not yet been solved. It has also been noticed that the degree of enhancement of concrete by coconut fibres depended on the type of coconut species and the sub-region that the coconut plant was cultivated.

The specific objective of experimenting on coconut fibre as an enhancement of concrete is two fold. Firstly, to assess if the fibres of the species grown in Ghana would improve the mechanical properties of concrete like the species in Latin America and South East Asia. Secondly, once it was proven that vital mechanical properties of concrete and mortar could be enhanced by coconut fibre from species grown in Ghana, then further investigation would be carried out on improving the long term durability of concrete and mortar with coconut fibres as an enhancement.

The coconut fibre used for this experiment is from Ghana and is from the coconut type known as the MYD+PT hybrid (combination of Malayan Yellow Dwarf and Penuate Tall). This is the type of coconut that is currently being cultivated after the devastating attack on the African tall spices by the Cape Saint Paul disease (since 1990).

2.0 EXPERIMENTAL STUDY

The experimental investigations was carried out on test specimens using one basic mix proportion with three variations of aspect ratio of coconut fibres, and different weight fraction of coconut fibre.

2.1 Materials

Ordinary Portland Cement conforming to BS 12, 1971 was used. The fine aggregate was natural sand from Swansea, UK conforming to BS 882 1975, while the coarse aggregate was crushed granite having a maximum size of 10mm (smaller size aggregate as suitable for the mould used for casting), also obtained from Swansea.

The fibres were coconut fibres with diameter ranging between 0.29mm and 0.83mm and length between 6mm and 24mm and approximate mean aspect ratio of 150. Eight fibre specimens were subjected to a tensile test in order to determine the ultimate strength. A graph of tensile strength against aspect ratio is plotted in Figure *9.*

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.

2.2 Preparation and testing of specimen In this study, a total of 60 specimens of a basic concrete mixes were selected. They were divided into four mixes in accordance with percentage weight fraction of fibres. Table 1 shows the proportion of various ingredients used for different mixes. The concrete was hand mixed. A number of specimen of cubes and cylinders were cast for each mix as follows:

Three 100mm cubes -subject to compression
Three 100x200mm cylinders -subject to tension splitting
Three 100x200mm cylinders -subject to torsion

Table 1 Mix ratio and percentage coconut fibre content

specimens		).25	).5	5
esign proportion	: 1.8 : 2.8 : 0.55 (ement : fine agg.: coarse agg.: water)			
eight fraction of fibre (%)	)0	25	50	7

Table 2 Detail of quantities of materials used per mix per mass fraction

aterials	ɔecimens									
		25/75	25/125	25/150	5/75	5/125	5/150	75/75	75/125	75/150
ement (kg)	0	2.0								
ınd (kg)	0	3.5								
ɔarse agg (kg).	.0	5.5								
/ater (kg)	0	1.0								
bre content (g)	0	10			20			30		

These specimens were cast for each of the mixes A, (the control specimen) and $C_{X/i}$, (i.e. specimens with x% fibre content and i fibre aspect ratio). A total of ten separate mixes were thus cast. Details of mixed proportion for each mix are shown in Table 1 and the total quantities of materials used per mix per weight fraction are listed in Table 2

2.3 Mixing of concrete with coconut fibres

In the previous research by the author, on concrete with coconut fibres the introduction of fibres to the concrete presented problem due to the way the mixer operated. To ensure complete distribution of fibres throughout the concrete mix, sometimes it became necessary to stop the mixer, remove the mixing paddles, sprinkled a layer of fibres onto the concrete surface and reactivated the machine for approximately five revolutions after each addition. 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.

2.4 Mixing procedure The dry cement and aggregates were mixed for two minutes by hand in a 0.1m^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 was continued for an additional two minutes. This ensured a complete distribution of fibres throughout the concrete mix. For each mix, a total of six cylinders with dimension of 100×200mm and three cubes of 100mm were cast.

2.5 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

2.6 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.

2.7. Details of test Three cubes and three cylinders from each mix were tested for compression and splitting tensile strength at day 28. after casting using a GD10A compression testing machine with a maximum capacity of 2500KN (Figure 1).

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.

In addition to the testing of compressive and split tensile strengths, three cylinders from each mix were tested for torsional strength. The samples for the torsional test were first roughened at the ends with grinder. Steel rings, with Polypaste applied to the inner perimeter, were fixed to each end of the samples. The polypaste then dried and hardened and formed a strong bond between the rings and the concrete. The samples were tested after one day of preparation. The steel rings had protruding radial arms, which could be pushed to induce a torque in the concrete cylinder. The cylinder was set up as shown in Figures 2 and 3. A twisting load was applied, and the load and respective angle of displacements were record.

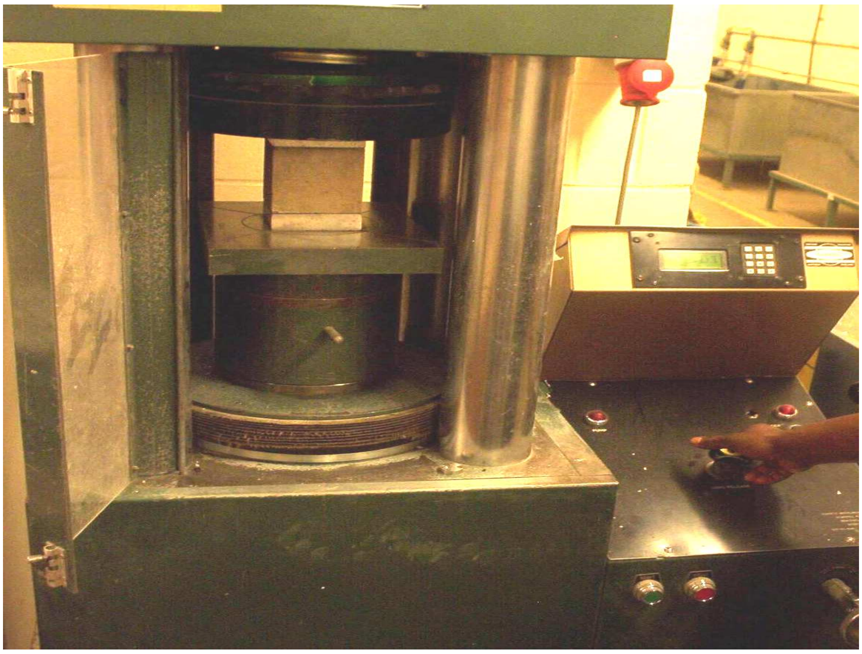


Figure 1 Compression testing machine setup

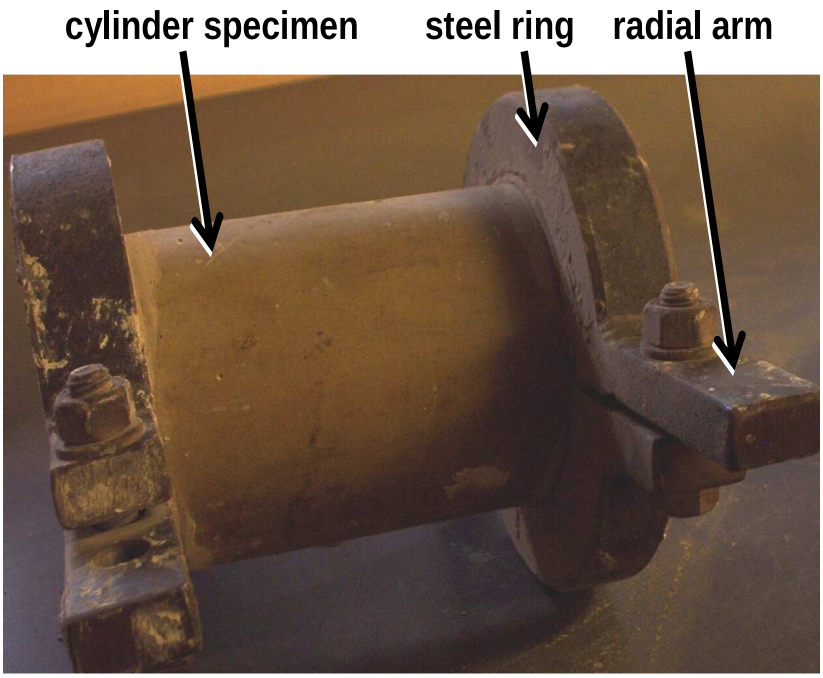


Figure 2 Prepared specimen for torsion testing

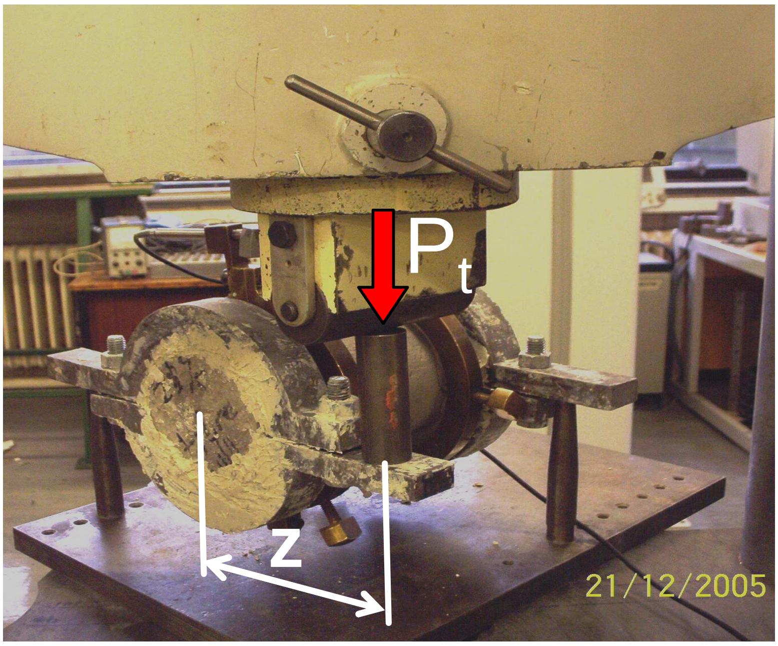


Figure 3 Torsion testing machine set up

2.8 Preparation of fibres
To facilitate the extraction of fibres, coconut husks 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 coconut fibre retained about 73% of its initial tensile strength when placed in NaOH for up to 60 days. Based of this knowledge, the coconut husks were further placed in NaOH for seven days to dissolve the lignin and hemicelluloses to facilitate extraction of fibres.

3.0 Test results and analysis
The analysis of the results from the laboratory experiments is in this section.

3.1 Surface morphology of the coconut husk
Husks soaked in fresh water and then in NaOH were observed to ascertain the effect of the soaking mediums. An electronic microscope was used to observe the surface structure of the fibre soaked in water and then in NaOH. Figures 4-8 show the changes of the fibre surface with soaking medium and soaking time.

Before soaking the husk in water, pith cells remained tightly attached to the fibre surface, (see Figure 4). The pith (or dust) is non fibrous tissues surrounding the fibre and are bonded by lignin. After soaking the husk for thirty days in water, the surface became clearer due to the removal of pith cells adhering to the fibres. The fibres display many "pin-hole" like structures on the surface of the husk, known as pits. The pits are variously arranged in between the fibres on the husk surface (see Figure 5), and are not uniformly spaced. The pit shape is somewhat irregular in its facial view. The soaking process thus facilitates the removal of pit particles from the husk surface. In addition white crystal-like structure could be seen on the pits, which according to Bowlike and Debnath (1984) are reported to be silicate crystals. Silicate usually occurs in plant in the form of its oxide, silicon dioxide (Lanning et al., 1958). These structures give roughness to the fibre surface.

The water was drained from the husks and then replaced with a sodium hydroxide solution. The husk was observed after three hours under electronic microscope. It could be seen from Figure 6 that the silicate crystals had almost disappeared. The silicate crystal could not be completely dissolved by the sodium hydroxide as some of the crystals could be seen under the microscope even after seven days of soaking in sodium hydroxide solution. With soaking time in sodium hydroxide solution (Figures 6-8), the fibre became clearer and thinner. This indicated that the vascular bundle surrounded the fibre had dissolved. This vascular bundle is believed to be lignin. Lignin is a complex constituent of plant that cements the cellulose fibres together. In all cases the fibres themselves were not affected with soaking mediums and soaking time.

Figure 4. Coconut husk before being soaked in water

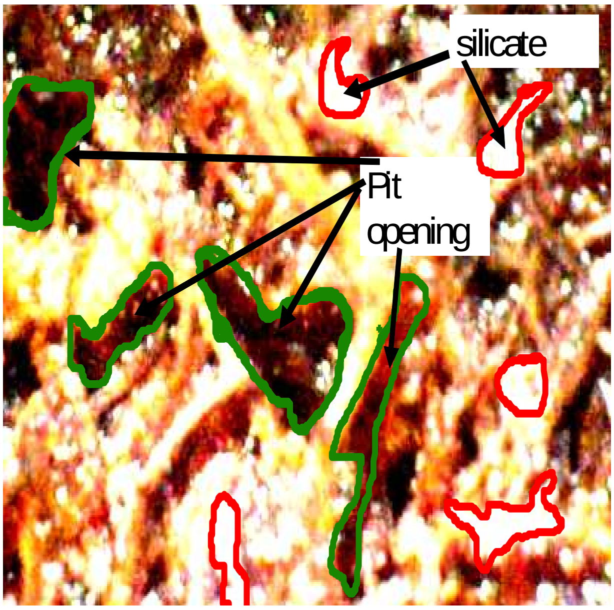


Figure 5. Coconut fibre after being soaked in water for 30 days

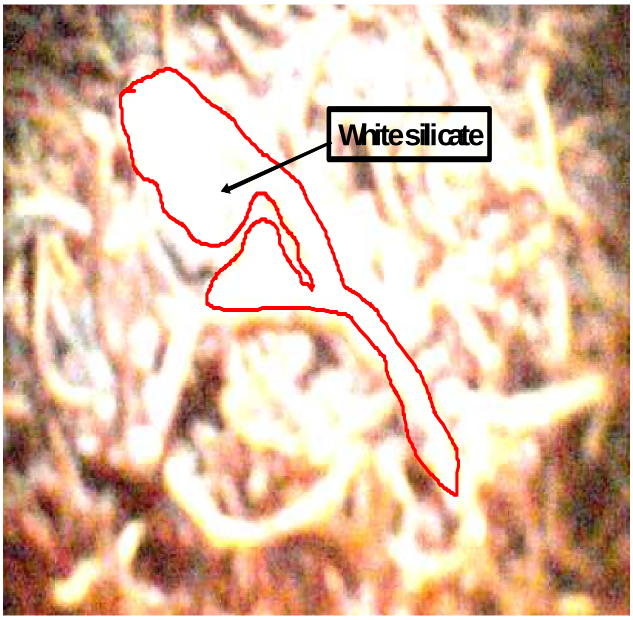


Figure 6. Coconut husk after being soaked in NaOH for 3 hours

Figure 7. Coconut husk after being soaked in NaOH for 6 hours

Figure 8. Coconut husk after being soaked in NaOH for 7 days

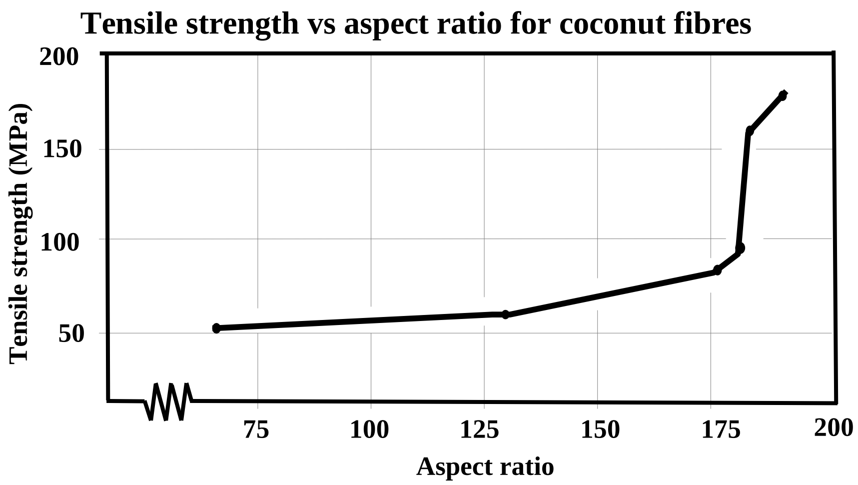
3.2 Tensile strength of coconut fibre The tensile strength of the coconut fibre was tested with the view of comparing its value with tensile strength of coconut fibre in literature by other researchers in the field of natural fibres. The results are recorded in Table 3. On the basis of these tests it could be said that increase in the aspect ratio also increased the tensile strength, but the increase was not linear as could be seen in Figure 9. This is because there was no consistent numerical pattern in the selected aspect ratio, since the coconut fibres were randomly picked, and hence non-linear shape of the graph of tensile strength verses aspect ratio was observed.

As reported in the literature (Agopyan, 1988 and Resi, 1988), the tensile strength of coconut fibre ranges from 15MPa to 220MPa. The coconut fibre in this study which has an average tensile strength of 88.5MPa which is within the expected range.

Table 3 Tensile strength of coconut fibre

ngth (mm)	iameter (mm)				spect ratio	ax. pplied load)	nsile rength Pa)
				ve.			
.15	64	73	82	73	.85	.3	0.45
.16	46	43	38	42	8.67	.87	65.07
.06	29	42	49	39	6.80	.70	0.02
.25	61	53	54	57	8.00	.30	.80
.46	54	58	61	58	1.50	.20	.60
.22	56	48	46	49	1.88	.10	.68
.85	51	48	47	48	6.80	.40	1.68

Average tensile strength =88.9MPa



Fugure 9. Tensile strength against fibre aspect ratio

3.3 Density of coconut fibres One hundred different fibres of average length of seven centimetres and average diameter of 0.48cm were weighed and the density calculation performed. The average mass of 100 fibres was 10.65g and a volume of 100(Л 0.48^2x7/4) was used to give a density of 0.084g/cm^3

The density of the MYD+PT species (0.084 g/cm^3) used in this studies is much less than the species from Latin America and South East Asia origin which is recorded in literature as 1.25 g/cm^3.

3.4 Mechanical and physical properties coconut fibre enhanced concrete

It has been observed in previous work by the author that the addition of up to one percent of coconut fibre could improve the strength performance of concrete. The extent of improvement of the properties of concrete could be expected to depend upon the fibre content and fibre geometry (diameter and length of fibre). Various combinations of these parameters would give rise to different strength characteristics. However, there was limited information regarding the quantitative influence and relative importance of fibre aspect ratio on the strength of concrete. Therefore the introduction of fibre aspect ratio and fibre weight percentage between 0.25% and 1% in these experiments would add a further dimension to this study of coconut fibre in concrete.

3.4.1 Slump test

Slump test values showed concrete workabilities ranging from medium (25-50mm) to high (51mm and over). Using water and cement ratio of 0.5 (for normal concrete) the slump value obtained was 125mm which indicates high workability. This value deceased progressively as percentage of fibre added to the concrete increased. Superplasticizer was added to the mix with higher fibre content so as to obtain a slump test value of 125 ± 25 mm. The result is recorded in Table 4.

Table 4 Fresh concrete test results of coconut fibre enhanced concrete

ix	itial slump height nm)	djusted slump height nm)	emarks
	!5	il	itially assumed a high orkability value
).25	)5	il	high workability range was

			hieved.
).5	;	.5	ıperplasticizer was added .5% by wt of cement.
).75	}	.5	ıperplasticizer was added .75% by wt of cement)

3.4.2 Behaviour under Compression Figures 10 and 11 show variation of compressive strength for plain concrete and concretes with different aspect ratios containing three different coconut fibre contents. The results of compressive strengths are presented in Table 5. Discussions are based on the average results of three samples. The addition of fibres did not increase the compressive strength. Figure 10 shows that there is a loss in compressive strength for higher aspect ratio for all percentage of added coconut fibre content.

i) Influence of fibre weight fraction on compressive strength

There was an average reduction of 40%, 24% and 28% respectively in compressive strength for concrete with 0.25%, 0.5% and 0.75% fibre content as shown in Figure 10.

ii) Influence of fibre length on compressive strength For all weight fractions, the compressive strength decreased as the aspect ratio of fibre increased. The fibres with lower aspect ratios provided better performance in compressive strength. For this investigation the best aspect ratio was about 75 for all fibre contents as shown in Figures 10 and 11 though if the smaller aspect ratio had been tried, a higher compressive strength (closer to plain concrete) might yet have been obtained)

In general, the addition of fibres adversely affected the compressive strength, as expected; this might be due to the difficulties in compaction which consequently created voids. This is reflected in the increase in the air content with increase in the fibre length; hence at the same fibre content specimens with highest aspect ratio have the lowest compressive strength as shown Table 5

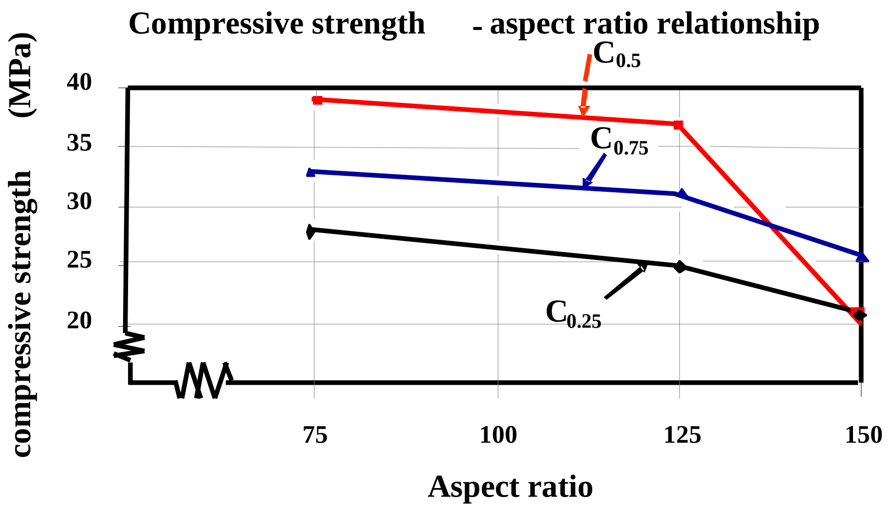


Figure 10 Compressive strength verse aspect ratios for coconut fibre enhanced concrete

Table 5 Results of compressive strength of coconut fibre enhanced concrete

ecimen	aximum pplied force		ompressive rength MPa	ecrease in mpressive rength
	alues	verage		
	8.0 0.0	9.0	.9	
).25/75	1.0 7.0	9.0	.9	3.0%
).25/125	0.0 3.0	1.5	.2	9.9%
).25/150	2.8 0.7	1.8	.2	9.0%
).5/75	3.6 0.4	2.0	.2	1.0%
).5/125	5.3 4.2	9.8	.0	1.6%
).5/150	0.8 7.4	4.0	.4	1.0%
).75/75	2.4 4.0	3.2	.3	0.5%
).75/125	3.3 6.9	6.6	.7	6.7%
).75/150	7.2 3.4	0.3	.1	.0%

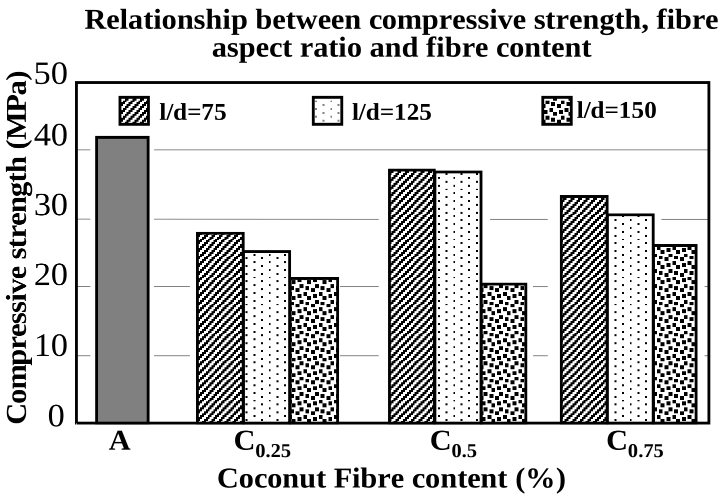


Figure 11 Compressive strength verse aspect ratios for coconut fibre enhanced concrete

c) Behaviour under tension In the splitting tensile tests cylindrical specimen were subjected to splitting tension along their axis. Figures 12 and 13 compare tensile strength values for three fibre aspect ratio and three fibre weight fractions. The method for calculating the split tensile test is give as

(1)

where,

F = Applied force

L = Height of cylinder

D =Diameter of cylinder

The results of tensile strengths are presented in Table 6.

Influence of fibre weight fraction on tensile strength For a higher percentage (0.5% and 0.75%) of coconut fibre the cylindrical specimens had only cracked in the specimen, but did not split into two halves like those of the plain concreteas shown in Figure 14.

In this investigation the fibre weight fraction of 0.25% did not improve the splitting tensile strength, there was a reduction of an average about 34% as shown in Table 6 and Figures 12 and 13. The better bond in the specimens with higher weight fraction resulted in higher splitting tensile strength. On average there was an increase of about 15% and 3.2% for concrete with fibre content of 0.5% and 0.75% respectively. However, beyond 0.75%, the tensile strength again decreased from the authors previous work .

ii) Influence of fibre length on tensile strength It was established that the optimum fibre aspect ratio of 125 (length/diameter) provided the best performance in splitting tensile strength in all weight percentage,

Table 6 Results of tensile strength of coconut fibre enhanced concrete

ecimen	aximum applied load(kN) at -day curing age		nsile strength Pa) at 28-day ring age	crease in tensile ength
	'est	verage		

	lues	alue		
	92.0			-
	87.0	91.0	2.9	
).25/75	68.3			-27%
	60.7	64.5	2.1	
).25/125	75.4			-21%
	69.0	72.2	2.3	
).25/150	50.3			-48%
	45.7	48.0	1.5	
).5/75	124.0			+30%
	110.0	117.0	3.4	
).5/125	112.0			+17%
	104.0	108.0	3.9	
).5/150	104.0			-3%
	82.4.0	88.2	2.8	
).75/75	96.4			0%
	87.0	91.7	2.9	
).75/125	104.0			+10%
	96.0	100.0	3.2	
).75/150	93.0			0%
	86.8	89.9	2.9	

except for 0.5% although the value for 0.75% was only marginally higher than that for 0.5% in the case of aspect ratio of 150. It is also observed in this experiment that, at the same fibre content, composites with the fibre aspect ratio of 125 have higher tensile strength than those of fibre aspect ratio of 75 (see Figure 13).

It is expected that, at the same fibre content, composites with the highest fibre aspect ratio of 150 would have higher tensile strength than those with smaller fibre aspect ratios as evidence in Romildo et al. (1999), as cited in Mohr, et. al. (2005) but this is not the case in this study. It appears that the critical fibre aspect ratio is 125, and any increase of the critical fibre length leads to a corresponding decrease in tensile strength. This fact suggests that the shorter fibres became mineralised, in other words embrittled earlier than the critical fibres length (aspect ratio of 125). One of the reasons could be attributed to the fact that in the short fibre-enhanced composite (e.g. fibre aspect ratio of 75) 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. Coconut fibre, like many natural fibres, is originally flexible and become stiffer when in contact with hydration products of concrete (Mohr et al., 2004)

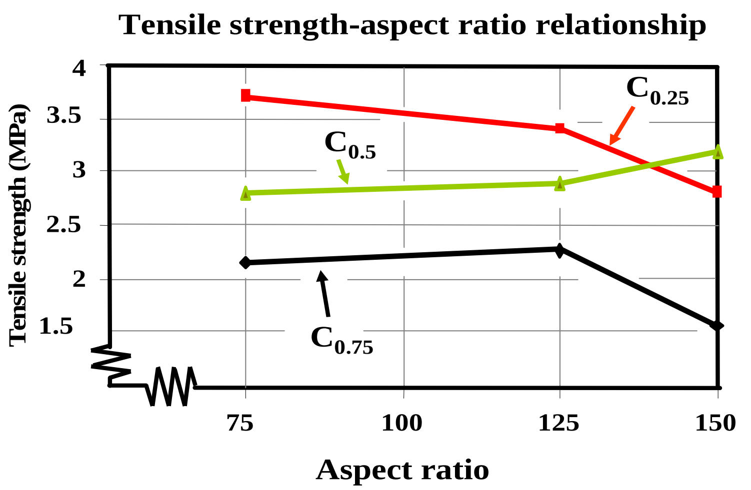


Figure 12 Tensile strength verse aspect ratio
For coconut fibre enhanced concrete

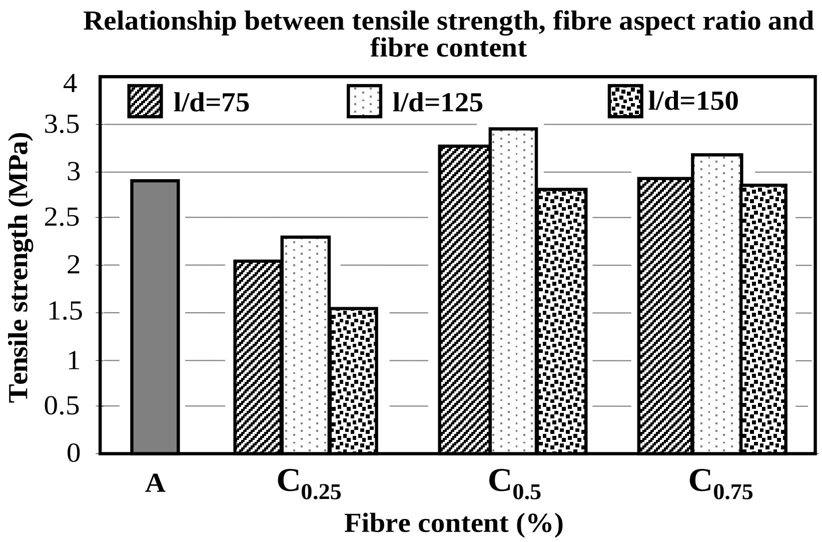


Figure 13 Tensile strength with respect to aspect ratio for different fibre content

Figure 14.Specimen after splitting test for concrete fibre concrete

d) Behaviour under torsion

The key parameters normally used to characterise a torque-twist curve are in Table 7 These values represent the average for the respective groups of specimens. To verify whether aspect ratios has influence on the torsion-twist curves and subsequently on the toughness of the concrete, individual specimens of a typical group ($C_{0.25}$, $C_{0.5}$ and $C_{0.75}$) are presented in Figures 15.

The applied torque T is given by:

$$T = P_T Z \quad (2)$$

where, P_T = applied load causing torsion (N), (see Figure 3).
Z = Distance between the point of application of the load and the centre of the cylinder (mm). (Z= 0.13m) and the twist rotation (radian) of the cylinder due to the torque.

$$\Phi = \frac{Y}{Z} \quad (3)$$

Y= angular displacement

The behaviour of coconut fibre–enhanced concrete under pure torsion was investigated. When fibre was added to plain concrete the torsional strength increased by between 26 and 77Nm which is an increase between 10% and 20% (Table 7). There is an optimum weight fraction beyond which the torsional strength started to decrease again. Similar pattern are also obtained for different fibre aspect ratios for the same fibre content, where again results showed there is an optimum aspect ratio as seen in Figure 15.

Table 7 Torsion characteristics of coconut fibre enhanced concrete at 28-day curing age

ecimen	plied torsional ce (kN)	gular Displacement, n)	imate torsion (Nm)	gle of twist at max. que ($x10^{-3}$ rad)	dulus of resilience n)	dulus of toughness n)
	2	.0	5.0	57	13	66
.25/75	5	3.0	2.0	87	66	87
.25/125	6	3.0	7.5	18	87	07
.25/150	4	.0	1.5	33	64	06
.5/75	5	.0	5.0	50	90	09
.5/125	8	8.0	2.5	35	98	27
.5/150	8	5.0	2.2	16	98	18
.75/75	5	.7	8.8	49	84	07
.75/125	4	.1	8.8	53	81	09
.75/150	1	.6	3.0	72	63	08

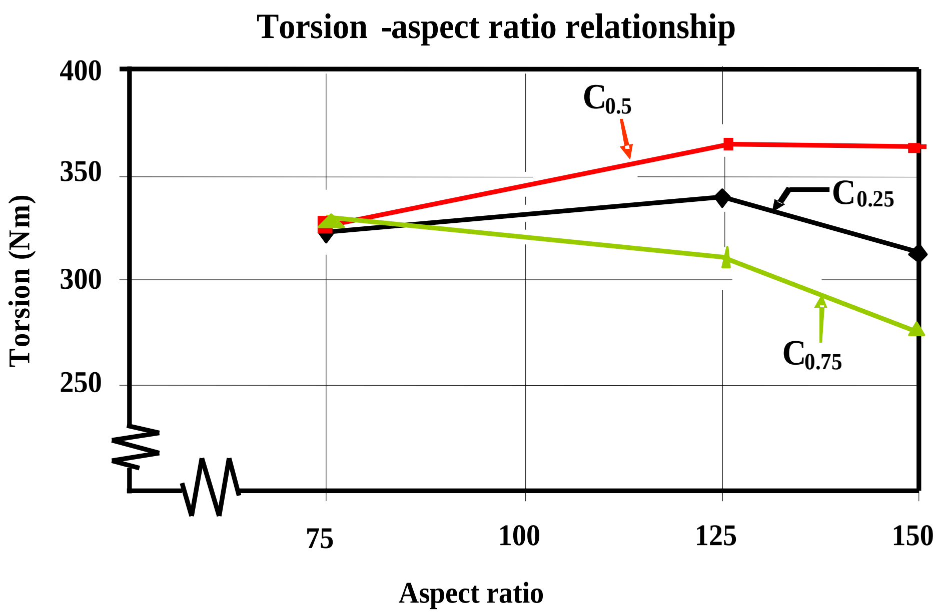


Figure 15 Torsion with respect to aspect ratio for different coconut fibre content

e) Toughness The addition of fibres increased the angle of twist corresponding to the peak torsion. Increase in peak angle of twist at peak torsion is maximum for concrete having 0.5% fibre weight fraction with aspect ratios of 125 and 150, and resulted in the highest value of energy absorption without creating a permanent distortion (modulus of resilience) (see Table 7). The twist capacity and the elastic deformation capability of the concrete matrix just before failure increased considerably with the inclusion of coconut-fibres. However the relative magnitude of energy increase up to the elastic limit (modulus of resilience) in 0.5% fibre weight fraction is on average about 30% and 24% greater than energy increase in 0.25% and 0.75% fibre contents respectively. Overall coconut fibre enhanced concrete could absorb much more energy before failure compared with the plain concrete counterpart. The optimum weight percentage of fibre and aspect ratio for this investigation are 0.5% and 125 respectively. The total area under torsion-twist curve, which measures toughness, increased substantially with the addition of coconut fibre, by between 1.3 and 1.9 times, resulting in a more ductile behaviour. The increase in toughness of the concrete could be attributed to the probable increase of fibre-cement contact of the coconut fibres due to higher lignin content (about 30%) of the coconut fibres (Nanayakkra et al., 2005) 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 (Table 7 and Figures 16-17). It was further established from this experiment that with a constant weight fraction, the toughness is higher with specimens having an aspect ratio of 125 (Table 7) and (Figures 16 a-c). Again it is clear from the investigation that, at a constant aspect ratio, 0.5% fibre content had the highest modulus of toughness and 0.25% fibre had the least toughness (see figures 17a-c). 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 75 become mineralised earlier, therefore causing earlier embrittlement of the fibre.

In short, the addition of coconut fibre to concrete enhanced the toughness, torsion and to some extent the tensile strength of the concrete. The increase in toughness, torsion and the tensile strength could be attributed to the fact that, the fibre presence in the concrete contributed greatly in offering restrain to early twist or strain in the concrete. It is also clear that the coconut 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.

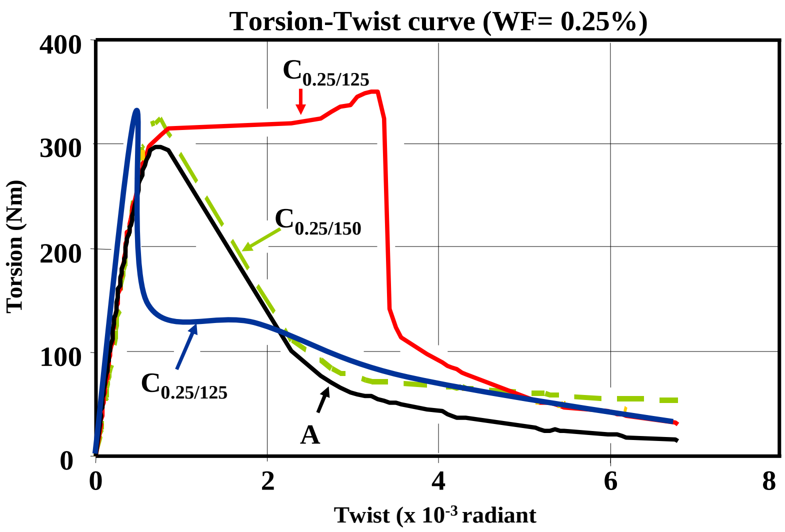


Figure 16a torsion- twist curves for concrete enhanced with 0.25% coconut fibre with fibre different aspect ratios

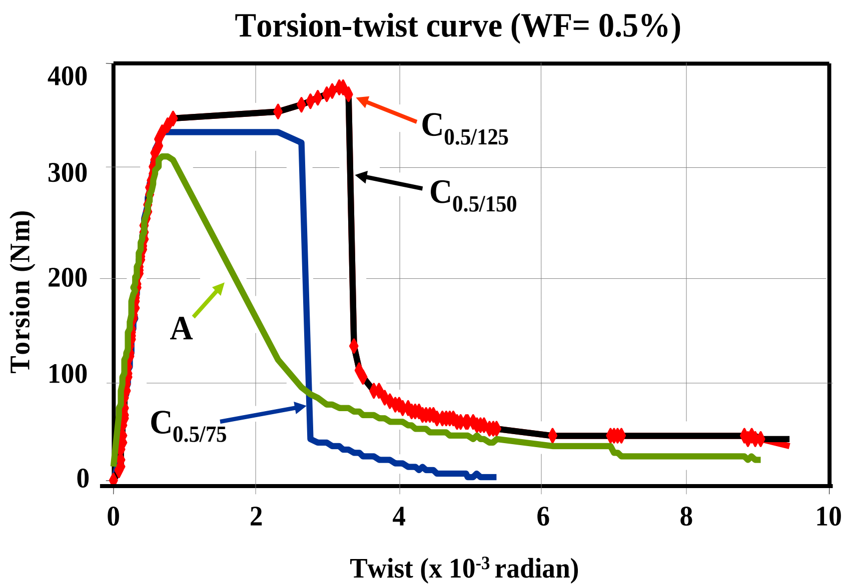


Figure 16b torsion- twist curves for concrete enhanced with 0.5% coconut fibre with fibre different aspect ratios

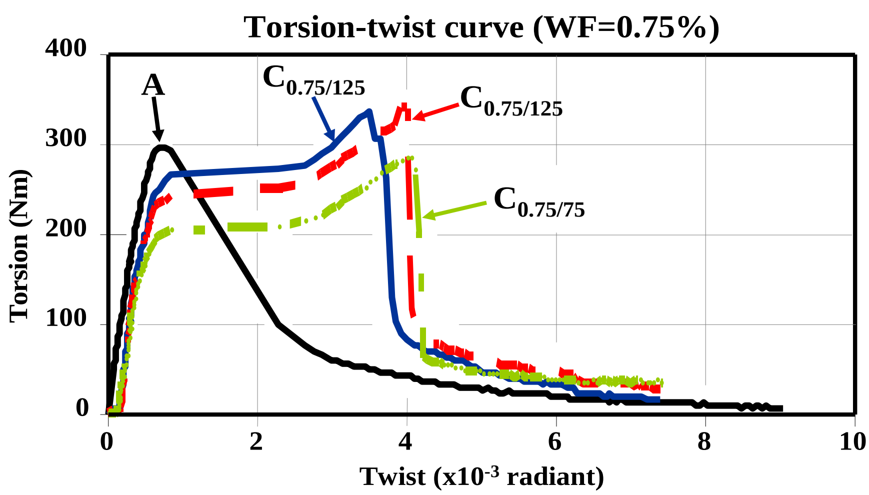


Figure 16c torsion- twist curves for concrete enhanced with 0.75% coconut fibre with fibre different aspect ratios

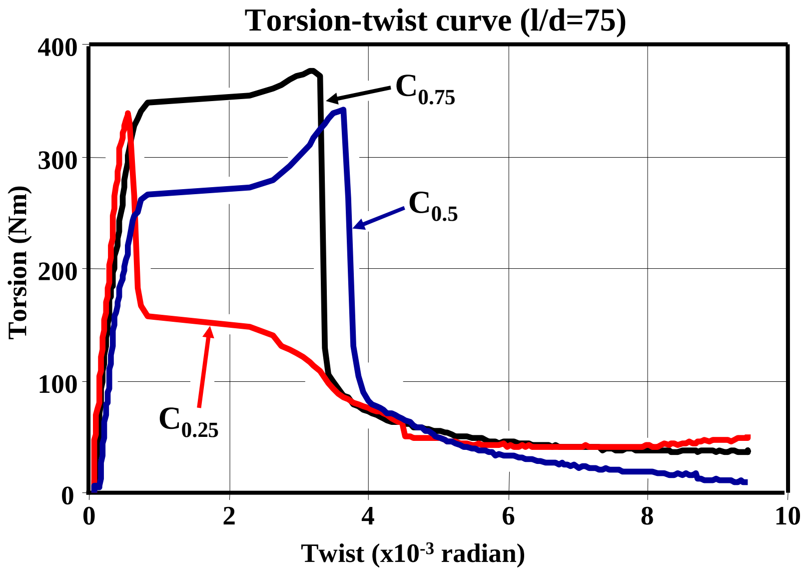


Figure 17a torsion- twist curve for concrete with different coconut fibre content with aspect ratio of 75

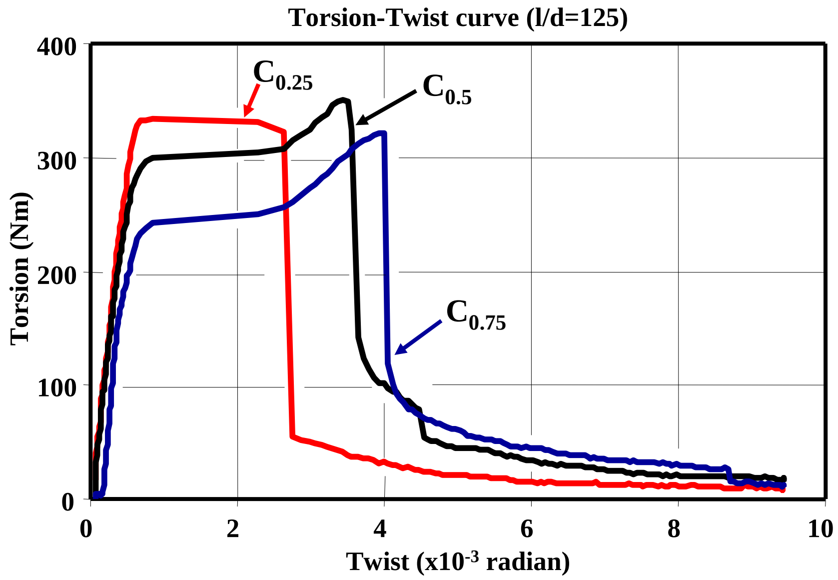


Figure 17b torsion- twist curve for concrete with different coconut fibre content with aspect ratio of 125

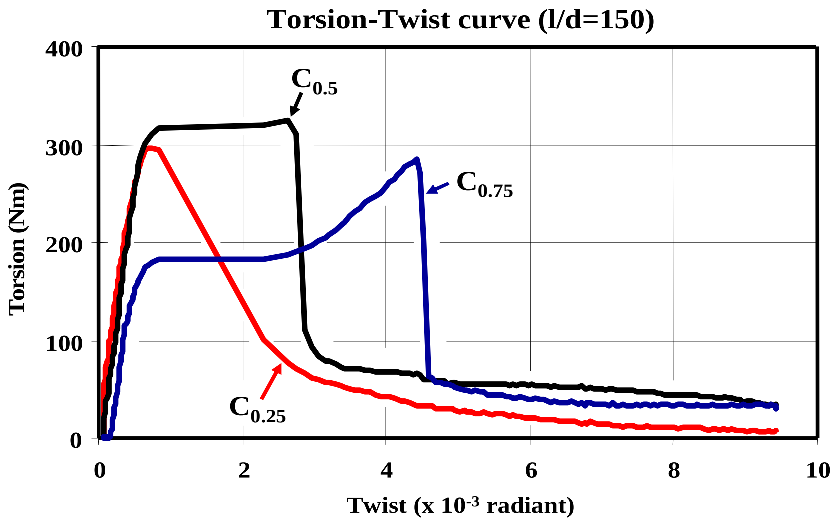


Figure 17c torsion- twist curve for concrete with different coconut fibre content with aspect ratio of 150

4.6 Conclusion and Future Research Needs

4.6.1 Conclusion

The findings of experimental investigations on the strength characteristics of concrete enhanced with coconut fibres are reported. The following conclusions can be derived.

The addition of coconut-fibres significantly improved many of the engineering properties of the concrete, notably torsion, 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.

Despite its excellent properties, coconut fibre as an enhancement of concrete is unlikely to replace steel for the vast majority of structures. 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.

Previous researchers like Gram (1983), Le Huu Do et al. (1995) Romildo et al. (2000) Savastano (2000) and Ramkrisha et al. (2004) have identified the following disadvantages in using natural fibres in cement based composite:

a) high water absorption of natural fibre causes unstable volume and low cohesion between fibre and matrix; and
b) natural fibre decomposes rapidly in the alkaline environment of cement and concrete.

Based on the above disadvantages future work on coconut fibre-enhanced concrete and mortar should concentrate on minimising the impact of these disadvantages.

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.

Applications for coconut fibre enhanced concrete and mortar composite for housing need to be expanded. Since cement-based materials are well known insulators, another avenue for future research and product development would be the use of coconut fibre-cement composites for sound and heat insulation. Such products might be composed wholly of fibre-cement or use the fibre-cement as one component in an insulating member. It must be acknowledged that aerated concrete would be better, cheaper and easier than the proposed coconut fibre composite insulator however, it could be used as replacement where aerated concrete might not be available or comparatively expensive to produce.

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