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Investigating the Shear Performance of Lightweight Concrete Beams Reinforced with Recycled Tyres Steel Fibres

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Abstract

This study investigated the shear performance of lightweight concrete beams reinforced with recycled tyre steel fibres. Two simply-supported beams, subjected to a monotonically-increased, concentrated loading were tested to failure. Recycled tyres steel fibres of aspect ratio 80 and content of 0.50% (Viz., 12 kg/m^3 per concrete volume) were incorporated, while palm kernel shells were used in volume content of 25% as partial coarse aggregates replacement in the beam other than the control. The results demonstrated that lightweight concrete beams reinforced with recycled tyres steel fibres using palm kernel shells as partial replacement of coarse aggregates has a better load-carrying capacity, minimum deflection at ultimate load and higher shear capacity than the control beam.

Keywords: waste tyres, recycled tyres steel fibres, palm kernel shells, lightweight concrete, shear performance

I. INTRODUCTION

Palm kernel shells are lightweight aggregates obtained from the agriculture sector and one of the several types of waste resulting from the palm oil industry. The proper utilization of these wastes in concrete members is lacking in Africa. In the field of civil engineering, studies have shown that palm kernel shells can be used as lightweight aggregate to produced structural lightweight concrete with a compressive strength in the range of 17-35 MPa [1]. The high demand for concrete has resulted in an increase in aggregates production leading to an increase environmental pollution and depletion of natural resources [2]. Fewer efforts have been made to recycle waste tyres and agricultural wastes for concrete production [3]–[6]. These efforts have been directed towards the use of recycled steel fibres and palm kernel shells. Experimental investigations have shown that adding steel fibres in concrete improves the mechanical properties such as; the shear resistance of beams by increasing the tensile and post-cracking or energy absorption capacity, ductile behaviour before the ultimate failure and durability, and reduces cracking of the concrete element [7]–[10]. Steel fibres can delay the formation and propagation of cracks by improving the effectiveness of the crack-arresting mechanisms present in beams when applied under high shear stresses. Also, [11] observed that flexural and ductility behaviour of concrete made with palm kernel shells as aggregates can be compared with other types of lightweight aggregates. Beams with 0.52 and 0.75% reinforcement ratios satisfied the maximum allowable deflection at service loads as per [12] requirement. Despite the increased awareness in practice and research, there is not much information on the application of recycled tyres steel fibres as shear reinforcement in lightweight concrete for load-bearing building structural elements. Recycled tyres steel fibres reinforced lightweight concrete has largely been limited to use in noncritical members, even though the significant potential exists for full or partial replacement of costly, manually placed, shear reinforcement (stirrups).

II. MATERIALS AND METHODS

II. I Materials and Mixture Proportions

The materials used in this study were recycled tyre steel fibres, conventional reinforcing bars, fine aggregates, coarse aggregate, palm kernel shells, ordinary Portland cement (class 42.5N), superplasticizer and portable water.

The steel fibres were extracted from waste tyres through pyrolysis, as shown in Fig. 1 (fibres mean diameter of 1.17 mm, aspect ratio of 80, density of 12 kg/m^3, and average tensile strength of 1032.35 MPa). Reinforcing bars (Table 1) of 8 and 12 mm diameters deformed bars were used as hanger and tension reinforcements respectively, and 6 mm diameter plain bars were used as shear reinforcement. As per [13] river sand and crushed rocks were used as fine and coarse aggregates with sizes ranging from 0.15-10 and 2.36-20 mm, respectively. Palm kernel shells were obtained after oil extraction from fresh palm fruit bunches. The size of the palm kernel shells ranged from 2.36-15 mm conforming to [14]. The content of the shells used was 25% as partial replacement of coarse aggregates in the beam. As per requisite standards requirements, the crushed rocks and palm kernel shells were washed and allowed to air-dry under ambient temperature for 30 minutes to achieve saturated surface dried state and later graded. Due to the high water absorption of the shells, they were pre-soaked for 24 hours in portable water before mixing. Ordinary Portland cement (42.5N), type CEM-I, conforming to [15] was used. It was dry, powdery and free of lumps. A high-performance super-plasticizer I was used at 1.5% of the cement content to control workability and reduce the high water absorption of palm kernel shells of fresh-made recycled steel fibre lightweight concrete. Portable water was used in all concrete mixes. Before use, the physical and mechanical properties of the materials were determined (Table 2).

The concrete mix proportion properties (Table 3) was designed as per [16]. Batching by volume incorporating mix ratio of 1:2:3 with constant free water to cement ratio of 0.56 was adopted. Concrete cubes (150 x 150 x 150 mm) and cylinders (150 x 300 mm) were used to determine the optimum fibres aspect ratio, fibres content, and palm kernel shells content as partial replacement of coarse aggregates in lightweight concrete beams [17].

Fig. 1. Recycled tyre steel fibre

Table 1. Properties of recycled steel fibres and conventional reinforcing bars

Characteristics	**Recycled steel fibres**	**Conventional reinforcing bars**		
		6 mm Ø	8 mm Ø	12 mm Ø
Cross **s**ectional **a**rea (mm^2)	0.86	28.27	50.26	113.10
Tensile **s**trength (MPa)	1032.35	436.26	476.26	692.44
Yield **s**trength (MPa)	-	416.33	404.58	588.43

Table 2. Physical and mechanical properties of fine aggregates, coarse aggregates and palm kernel shells

Properties	**Fine aggregates**	**Coarse aggregates**	**Palm kernel shells**
Maximum aggregate size (mm)	5	20	10
Fineness modulus	2.82	2.74	2.38
Apparent specify gravity	2.48	2.56	1.44
Moisture content (%)	0.06	1.03	13.68
24 hours water absorption (%)	0.45	0.98	34.07
Aggregate crushing value (%)	-	22.69	2.30
Aggregate impact value (%)	-	15.51	4.74
Compacted bulk density (kg/m^3)	1644.53	1424.48	580.50
Loose bulk density (kg/m^3)	1485.93	1411.46	515.28

Table 3. Concrete mixture proportion

Materials	Cement	Fine aggregates	Coarse aggregates	Palm kernel shells	Water
Content (Kg/m^3)	383	632	833	278	214

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II. II Experimental Setup

Two reinforced concrete beams with identical cross-sectional areas of 150 x 225 mm, span length of 2000 mm, shear span length of 900 mm and a shear span-depth ratio of 4 were designed, constructed and tested in this study. The beams were designed as per [12] and designated as Beam-I and Beam-II. Beam-I was taken as the control with 0% recycled tyre steel fibres and 100% coarse aggregate, while Beam-II was reinforced with recycled tyre steel fibres and palm kernel shells were used as partial replacement of coarse aggregates. 2T8 compression and 2T12 tensile bars, respectively, and 11R6 shear reinforcing bars were used in the beams. The concrete clear cover was taken as 25 mm. The fixed parameters (Table 4) that were used in this study corresponded to shear reinforcing bars ratio ($r$sv = 0.64%), fibres aspect ratio (80) and fibre volume fraction (0.50%). Super-plasticizer content of 1.5% per weight of cement and palm kernel shells in volume content of 25% as partial replacement of coarse aggregate was used only in Beam-II.

Table 4. Major testing perimeter of Beam-I and Beam-II

Specimens	**Steel fibres**		**Stirrups ratio**	**Shear span-depth ratio**	**28-days compressive strength** (MPa.)	**28-days splitting strength** (MPa.)
	aspect ratio	content (%)	(%)			
Beam-I	0	0	0.64	4.0	28.3	2.1
Beam-II	80	0.50	0.64	4.0	20.1	1.6

II. III Test Procedures and Data Collection

Fig. 2 illustrates the schematic diagram of the loading of the beams specimens. The beams were simply-supported, subjected to a monotonically-increased concentrated load. Deflections were measured using Linear Variable Differential Transducers (LVDT) and strain gauges (viz., PFL-30-11 and PL-60-11) were placed on the bottom of the tension reinforcing bars and diagonally at ends and sides of the concrete to measure the strain in the steels and tensile strain in the concrete. The load was applied gradually and the deflections were measured at the mid-span of the beams until ultimate failure. There were four concrete strain gauges along the diagonal section of the hardened surface of each beam, and two steel strain gauges on tension reinforcing bars. The load and deflection at first crack were also recorded. Cracks were detected at the end of load increment and marked with a marker pen. Tests results on concrete cubes and cylinders conducted by [17]. were used to evaluate the compressive and splitting tensile strengths of the concrete mixes. The load-carrying capacity, load versus deflection, load versus strains, shear capacity, crack and failure pattern of all beams tested were analysed.

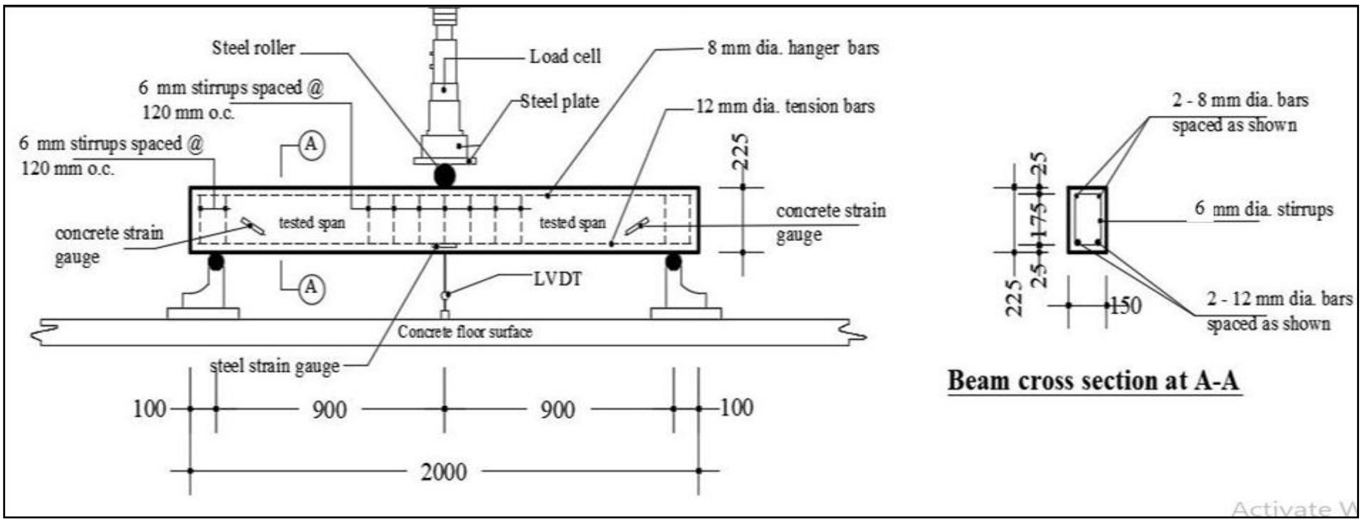

Fig. 2. Experimental setup and reinforcing bars details for Beam-I and Beam-II specimens

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III. EXPERIMENTAL RESULTS AND DISCUSSION

III. I Load Carrying Capacity

From Fig. 3, it can be noted that the initial crack appears at a load of 36 kN for Beam-I and a load of 41 kN for Beam-II, indicating that there was a delay in cracking in Beam-II. Considering the loads at ultimate failure for the two-beam specimens, it can be seen that the ultimate load (i.e., strength) of Beam-II slightly increased than of Beam-I. It can, therefore, be deduced that beams reinforced with recycled tyre steel fibre and using palm kernel shells as partial replacement of coarse aggregates have a higher load-carrying capacity than those with 0% steel fibres and 100% coarse aggregate.

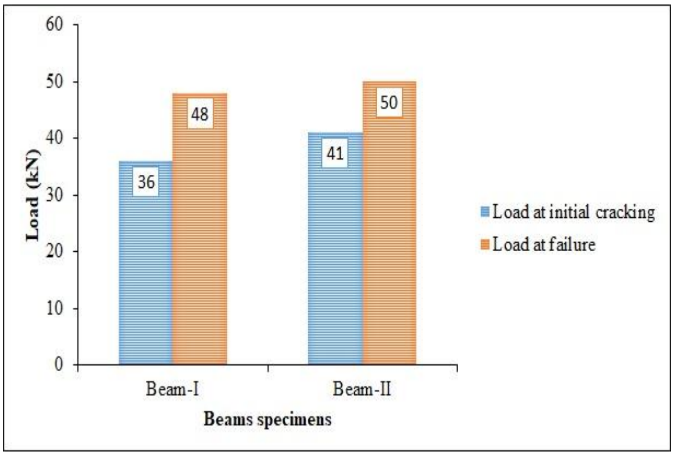

Fig. 3. Load-carrying capacity for Beam-I and Beam-II

III. II Load-Deflection Relation in the Beams

As shown in Fig. 4 from the load-deflection relationship concerning the mid-span deflection for all tested beams, revealed that all beams experienced diagonal shear failure. At the beginning of the loading procedure, the specimens behave elastically. When diagonal cracks develop, the curves become nonlinear and the stiffness degrades. It can also be observed that the peak load deflection for recycled tyre steel fibre reinforced concrete beam without palm kernel shells as partial replacement of coarse aggregates is less than that for recycled tyre steel fibre reinforced concrete beams made using palm kernel shells as partial replacement of coarse aggregates. This indicates that the addition of the fibres in the beam with palm kernel shells as partial replacement of coarse aggregate increases the shear capacity regardless of the stirrups ratio and deformation capacity of beams. It can also be stated that the area under the load versus deflection curve of Beam-II is higher. The deflection curve for Beam-II is slightly steeper than Beam-I in the pre-peak stage. This indicates an increment in the stiffness of the beams. The overall results show that the use of recycled tyres steel fibres increases the stiffness and deformation a failure of the beams, which means it reduces the brittleness of diagonal shear failure.

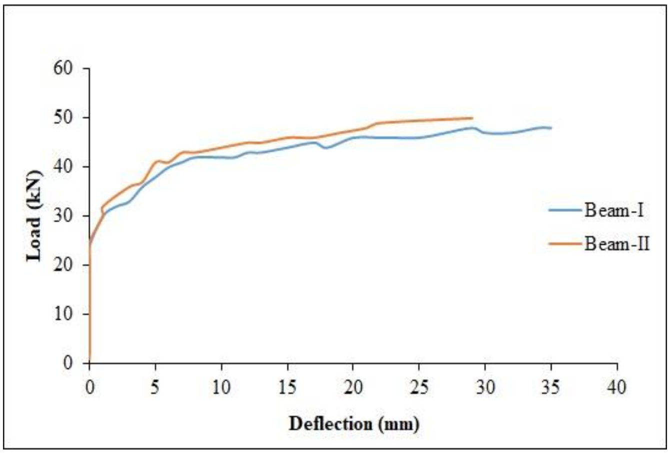

Fig. 4. Load-deflection relationship for Beam-I and Beam-II

III. III Load-Strain Relation in Reinforcing Bars

The load-strain relationships (Fig. 5) in the tensile reinforcing bars for Beam-I and Beam-II which was measured by the strain gauges attached to the bottom of the tension reinforcing bars. It can be seen that the development of the tension strain is almost similar for the two test beams. The tension strains in Beam-II was little as compared to Beam-I before the initial diagonal cracking, which means that the bending stress in Beam-II was mainly resisted by the concrete at this stage. When the diagonal section cracked in Beam-I, the tension strains increased suddenly. Therefore, the reinforcing bars experienced a plastic deformation for a longer time than was expected and that they permanently failed sooner than was expected. This is mainly because the concrete around the tension reinforcing bars cracked and no longer was able to carry the applied load, resulting in a sudden increase in bending. As the load increased, the tensile strain increased rapidly for Beam-I. After yielding, as the load increased slightly, the tensile strains increase rapidly. In contrast, for Beam-II, the tensile strain increased slowly, and the strain value was small when the steel yielded.

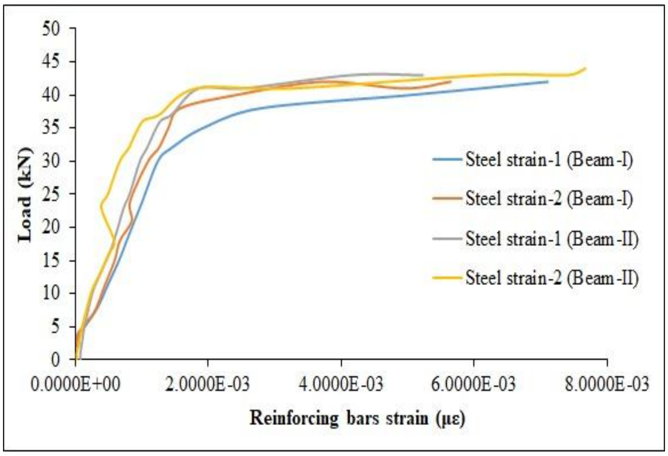

Fig. 5. Load-strain relation in the tension reinforcing bars for Beam-I & Beam-II

III. IV Load-Strain Relation in Concrete

Fig. 6 and Fig. 7 present the load-strain relationship in concrete for Beam-I and Beam-II, respectively. During testing, it was observed that the diagonal crack appeared at the left side of the beam near the fixed support. The crack continuously extended in the direction of the applied load with an increase in load. The corresponding loads of Beam-I were great when the two concrete strains at the left side of the beam entered the rapid growth stage, and the difference between the cracking loads was more obvious than Beam-II. This indicates that the expansion and extension of the diagonal crack near the support were restrained.

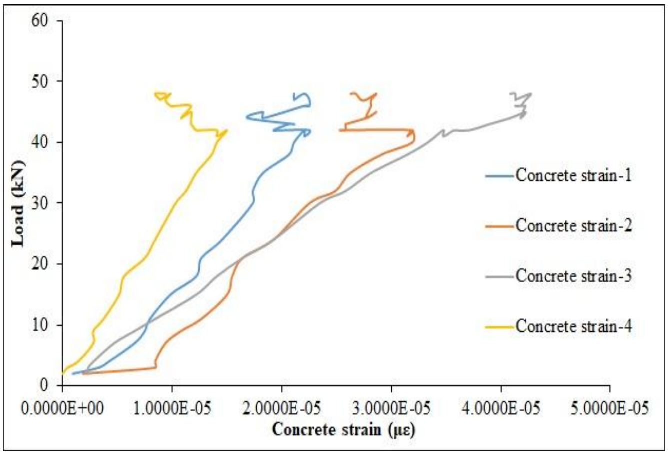

Fig. 6. Load-strain relation in concrete for Beam-I

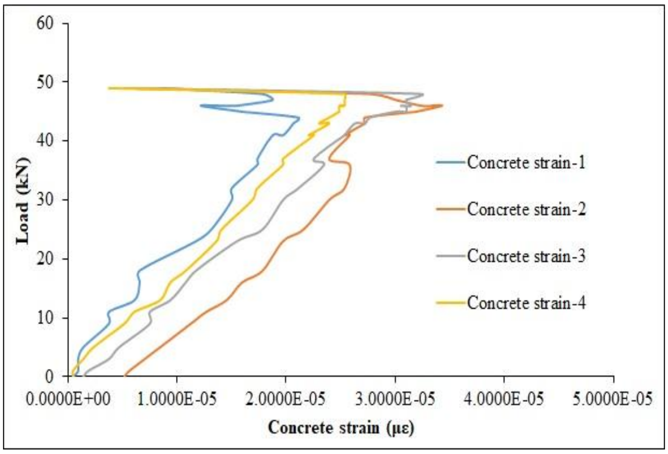

Fig. 7. Load-strain relation in concrete for Beam-II

III. V Crack and Failure Patterns

Fig. 8 and Fig. 9 present the cracks and failure patterns of Beam-I and Beam-II, respectively. The results show that the inclined cracks occurred on one side of the shear span region, and the mode of failure for both beams was a combination of shear-tension and diagonal tension. The cracks which formed initially widened at the ultimate failure.

Fig. 8. Crack and failure pattern of Beam-I

Fig. 9. Crack and failure pattern of Beam-II

III.VI Shear Capacity

The shear capacity for Beam-I and Beam-II was calculated with the recommendation of [18], where it is clearly stated that the given method is only valid for beams and plates reinforced with traditional reinforcement bars. In the presence of axial compression forces, this method is also applicable for pre-stressed members and columns. The proposed design method for shear resistance given by [18] can be seen in Equation (2.0), In the equation $V_{Rd,3}$ is the shear capacity; V_{cd} is the shear resistance for members without shear reinforcement given in equation; V_{fd} is the contribution of stirrups or inclined bars to shear resistance; and V_{wd} is the contribution of fibres to shear resistance; and

$$V_{Rd,3} = V_{cd} + V_{fd} + V_{wd} \quad (2.0)$$

Since there were stirrups bars, the shear resistance of member without shear reinforcement is equal to zero. The formula in equation (2.0) is thus reduced to equation (3.0).

$$V_{Rd,3} = V_{fd} + V_{wd} \quad (3.0)$$

From the calculated results (Table 6) for all beams specimen, it can be concluded that the shear resistance increases using the optimal fibres aspect ratio, fibres content and palm kernel shells content as partial replacement of coarse aggregates.

Table 6. Shear resistance for Beam-I and Beam-II

Series	Fibre volume (%)	Shear reinforcement	Shear resistance (KN)	Increase of capacity due to fibre volume (%)
Beam-I	0	3Ø6	5.55	-
Beam-II	0.50	3Ø6	6.25	13

IV. CONCLUSION

The results of this study show that concrete beams reinforced with recycled tyre steel fibres with an aspect ratio of 80, fibre content of 0.50% (Viz., 12 kg/m^3 per concrete volume) and palm kernel shells content of 25% as partial replacement of coarse aggregates has better load carrying capacity than concrete beams reinforced made with 0% fibres content and palm kernel shells content as partial replacement of coarse aggregate. The shear load-carrying capacity at both the initial crack and failure for the former increases by 13.88 and 4.17%, respectively, as compared to the latter.

The results further show that the behaviour of the concrete strain show that recycled tyre steel fibres increase diagonal crack at the shear span of the beam, and also increase the degree of concrete bearing in tension, but it is not effective to control the extension of the crack. In addition, the shear resistance of beams made with an aspect ratio of 80, the fibre content of 0.50% (Viz., 12 kg/m^3 per concrete volume) and palm kernel shells content of 25% as partial replacement of coarse aggregates increased by 13% compared to beam made with 0% fibres content and palm kernel shells content as partial replacement of coarse aggregate. Next, recycled tyre steel fibres at an aspect ratio of 80 and content of 0.50% (Viz., 12 kg/m^3 per concrete volume), along with palm kernel shells content of 25% as partial replacement of coarse aggregates can be used in structural lightweight concrete beams. Finally, recycled tyres steel fibres obtained from pyrolysis can be used as shear reinforcement in lightweight concrete beams

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