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Shear Performance of Recycled Tyres Steel Fibres Reinforced Lightweight Concrete Beam using Palm Kernel Shear as Partial Replacement of Coarse Aggregate

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Abstract

This paper presents results of investigation of shear performance of recycled tyres steel fibres lightweight concrete beam. 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% 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 steel fibres reinforced lightweight concrete beam using palm kernel shells as partial replacement of coarse aggregates has a better load carrying capacity, minimum deflection at ultimate load and lower shear crack width. It was found that beam modified with the optimal mix has a 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 wastes emanating from the palm oil industry. The proper utilization of these wastes in the construction industry is lacking in Africa. In the field of civil engineering, studies have shown that palm kernel shells can be used as lightweight aggregates to produce structural lightweight concrete with a compressive strength ranged between of 17-35 MPa [1]. The high demand for concrete has resulted in an increase of aggregates production leading to an increase in environmental pollution and depletion of natural resources [2]. Efforts have been made to recycle 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. In addition, [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. The 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, steel fibres reinforced lightweight concrete is yet to be commonly applied in load bearing building structural elements. Steel fibres reinforced lightweight concrete has largely been limited to use in noncritical members, even though significant potential exists for full or partial replacement of costly, manually placed, shear reinforcement (stirrups).

This paper is an outcome of a research study that evaluated the effects of recycled tyres steels fibres on the compressive, splitting tensile and flexural strengths of structural lightweight concrete using palm kernel shells as partial replacement of coarse aggregates. The study showed that recycled tyres steel fibres obtained from pyrolysis can improve the compressive and splitting strengths of normal-weight concrete. It further suggested the optimal fibre aspect ratio, fibres content and palm kernel shells content to be used in lightweight concrete beams, which are 80, 0.50% and 25% respectively [13]. This paper reports an experimental programme that investigated the shear performance of recycled tyres steel fibres lightweight concrete beam with fibre aspect ratio of 80, fibres content of 0.50% and palm kernel shells content of 25% as partial coarse aggregate replacement and minimum amount of shear reinforcement.

II. EXPERIMENTAL PROGRAMME

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 [14] river sands and coarse aggregates crushed rocks were used as fine and coarse aggregate ranged in sizes of 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 [15]. The shells were used in density of 28 kg/m^3 as partial coarse aggregates replacement. As per requisite standards requirements, the river sand, crushed rocks and palm kernel shells 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, it was pre-soaked for 24 hours in portable water before mixing. Ordinary Portland cement (42.5 N), type CEM-I, conforming to [16]. 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 the fresh recycled steel fibres lightweight concrete. Portable water was used in all concrete mixes. Before used, the mechanical, physical and chemical properties of the materials were determined (Table 1).

The concrete mix proportion properties (Table 3) was designed as per [17]. Batching by volume incorporating mix ratio of 1:2:3 with a constant free water to cement ratio of 0.56 was adopted in this study. Concrete cubes (150 x 150 x150 mm) and cylinders (150 x 300 mm) were used to determine the optimum fibres aspect ratio, steel content, palm kernel shells content as partial replacement of coarse aggregates in recycled steel fibres reinforced lightweight concrete beams [13].

Fig. 1. Recycled tyres steel fibres

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	476.26	584	692.44
Yield **s**trength (MPa)	-	97.42	160	188.43

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

II.II Experimental Setup

Two reinforced concrete beams with identical cross-sectional area of 150x225 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 considered as the control specimen and Beam-II was the recycled tyres steel fibres reinforced lightweight concrete beam, using palm kernel shells as partial replacement of coarse aggregates. Two compression (Viz., hanger bars) and tension reinforcing bars of 8 and 12 mm diameters respectively, were used while the shear reinforcing bar were eleven 6 mm diameter plain steel bars. The shear reinforcement ratio of 0.64% and a concrete clear cover of 25 mm was used in all beams specimens. The fixed parameters (Table 4) used in this study were the shear reinforcing bars ratio ($r$sv = 0.64%), fibres aspect ratio (80), fibre volume fraction (0.50%). Super-plasticizer in 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 aspect ratio	Steel fibres content (%)	Stirrups ratio (%)	Shear span-depth ratio	28-days compressive strength (MPa.)	28-days splitting strength (MPa.)
Beam-I	0	0	0.64	4.0	28.3	2.1
Beam-II	80	0.50	0.64	4.0	31.3	1.8

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 tension reinforcing bars as well as at ends and sides of the concrete diagonally to measure the strain in the steels and tensile strain in the concrete respectively. The load was applied gradually and the deflections were measured at the mid-span of the beams till the ultimate failure occurred. The load and deflection at first crack was also noted. Cracks were detected at the end of load increment and mark with a marker pen. The companion average cubes and cylinders tests results were used to evaluate the compressive and splitting tensile strengths [13]. The load carrying capacity, load versus deflection, load versus strains, shear capacity, crack and failure pattern of all beam tested were investigated.

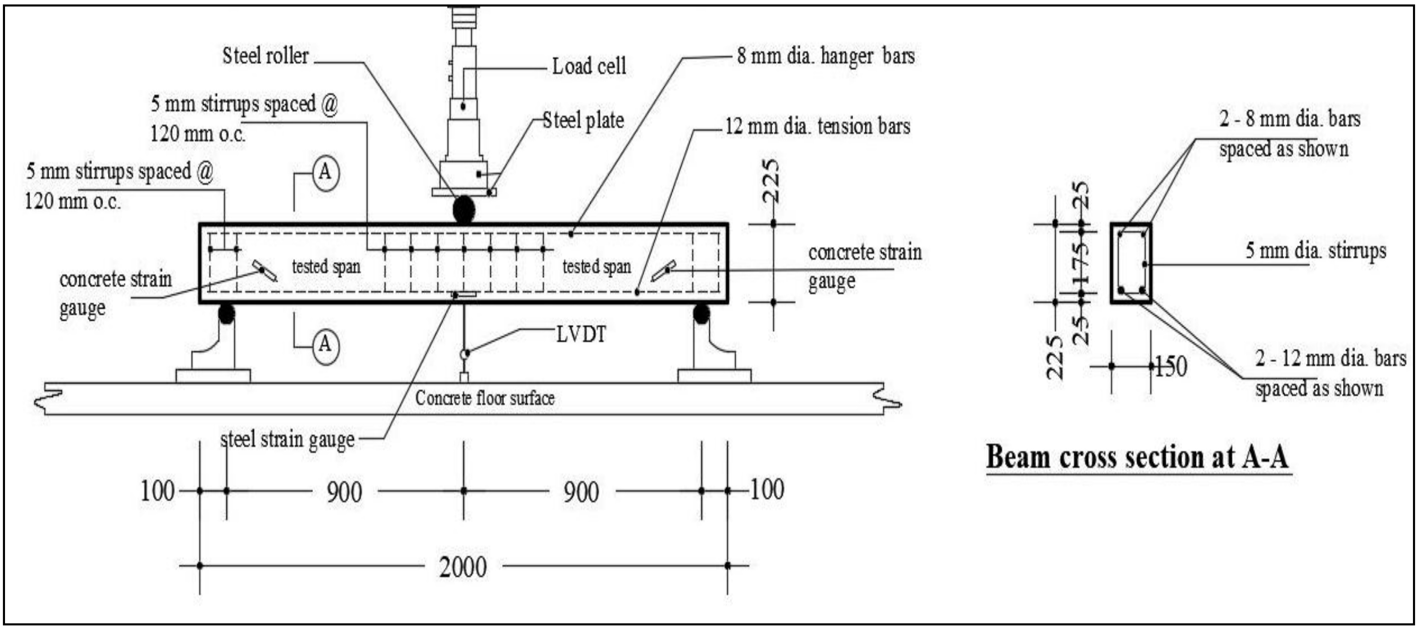

Fig. 2. Experimental setup and reinforcing bars details for Beam-I and Beam-II specimens

III. EXPERIMENTAL RESULTS AND DISCUSSION

III.I Load Carrying Capacity

Fig. 3 depicts that for Beam-I, the first crack appears at a load of 38 KN and delays for Beam-II. Considering the loads at ultimate failure for the two beams specimens, it can be seen that the ultimate load (i.e. strength) of Beam-II slightly increased than Beam-I. It can therefore be confirmed that recycled tyre steel fibres reinforced lightweight beam made palm kernel shells as partial replacement of coarse aggregates had a higher load carrying capacity compared to recycled tyres steel fibres reinforced concrete beams.

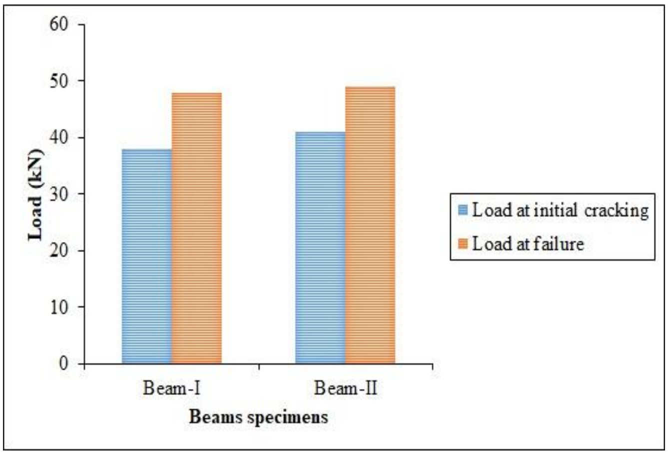

Fig. 3. Load carrying capacity for Beam-I and Beam-II

III.II Load versus Deflection Behaviour

As shown in Fig. 4 from the load versus deflection behaviour with respect to the mid-span deflection for all tested beams, revealed that all beams experienced diagonal shear failure as designed. At the beginning of the loading procedure, the specimens behaved in an elastic manner. When diagonal cracks develop, the curves became non-linear and the stiffness degraded. The peak load deflection for recycled tyres steel fibres reinforced concrete beams without palm kernel shells as partial replacement of coarse aggregates is less than recycled tyres steel fibres reinforced concrete beams made using palm kernel shells as partial replacement of coarse aggregates, which indicates the addition of the fibres increases the shear capacity regardless of the stirrups ratio and deformation capacity of Beam-II increases. It can also be 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 steel fibres increase the stiffness and deformation at failure of the beams, which means it reduces the brittleness of diagonal shear failure.

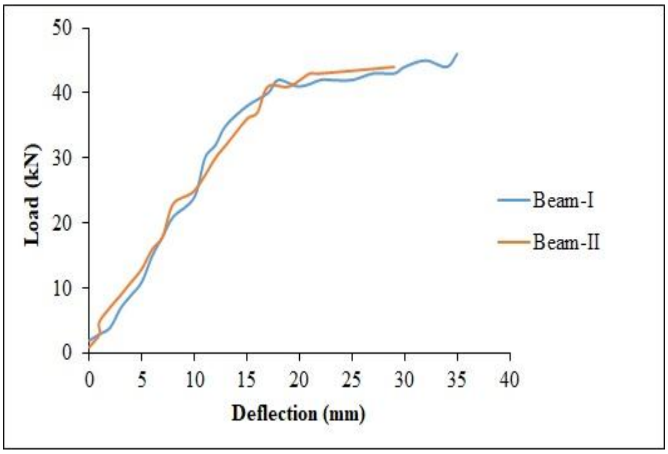

Fig. 4. Load versus deflection curves for Beam-I and Beam-II specimens

III.III Load versus Tension Reinforcing Bars Strain

The strains in the tension reinforcing bars (Fig. 5) of Beam-I and Beam-II was recorded and analyzed during the loading procedure. The results show that the average yield and tensile strengths of tension reinforcing bars in Beam-I was 301 and 371 MPa., respectively, and the average yield and tensile strengths of tension reinforcing bars in Beam-II was 287 and 354 MPa., respectively. It can be observed that the results obtained for the yield strength is higher than calculated yield strength and the tensile strength is lower than the calculated strength for the 12 mm diameter reinforcing bars. Therefore, the reinforcing bars experienced a plastic deformation longer than excepted and permanently failed sooner than expected. This could be due to the fact that the beams specimens were not fully shear reinforced to resist the early cracks.

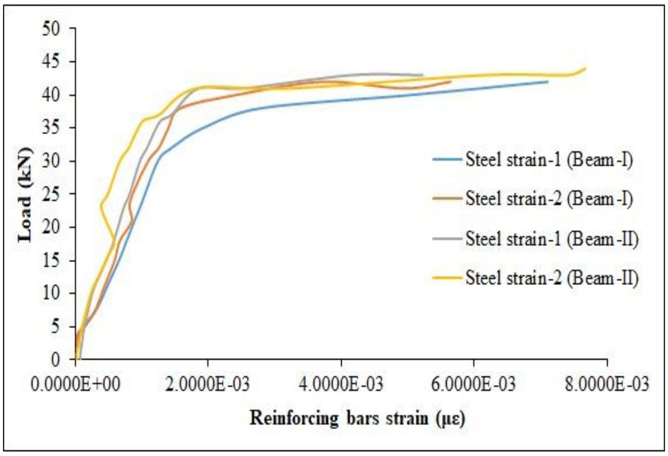

Fig. 5. Load versus reinforcing bars strain for Beam-I and Beam-II specimens

III.IV Load versus Concrete Strain

The load versus the concrete strain curves for Beam-I and Beam-II are shown in Fig. 6 and Fig. 7 respectively. There were four strain gauges along the diagonal section of each beam. In the test, it was observed that the diagonal crack at appeared at the left side of the beam near the fixed support. With the increase of load, the crack simultaneously extended to the direction of the applied load. The corresponding loads of Beam-I was 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. Besides, the growing degree of concrete strains were further enlarged. This indicates that the expansion and extension of the diagonal crack at near the support was restrained.

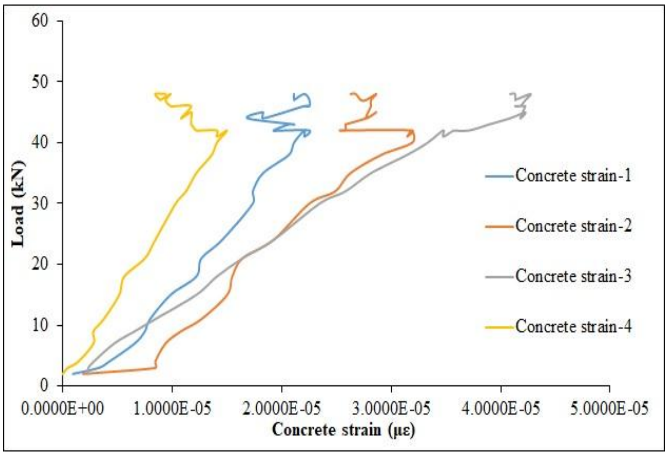

Fig. 6. Load versus concrete strain for Beam-I

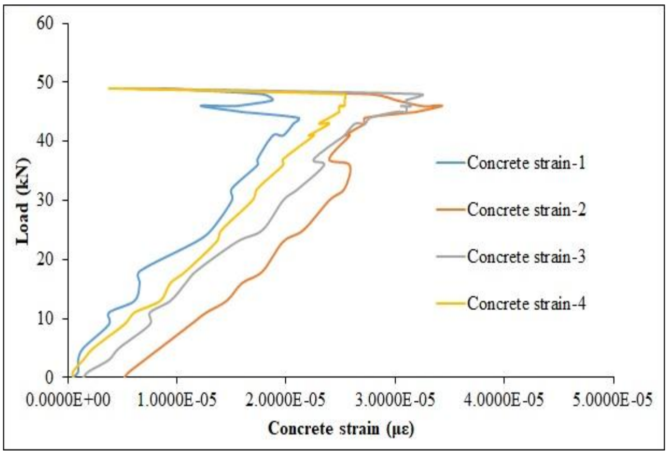

Fig. 7. Load versus concrete strain for Beam-II

III.V Crack and Failure Patterns

Fig 8 and Fig 9 shows the cracks and failure patterns of the beams. inclined cracks was observed on one side of the shear span region, and the mode of failure for both beams specimens was a combination of shear-tension and diagonal tension as designed. The cracks which formed initially have widened during the ultimate failure.

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

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

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 (1), 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

$$V_{Rd,3} = V_{cd} + V_{fd} + V_{wd} \tag{1}$$

Since there were stirrups bars, the shear resistance of member without shear reinforcement is equal to zero. The formula in equation (1), is thus reduced to equation (2).

$$V_{Rd,3} = V_{fd} + V_{wd} \tag{2}$$

From the calculated results shown in Table 5 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 5. 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	3∅6	5.55	-
Beam-II	0.50	3∅6	6.25	13

IV. CONCLUSION

Based on the experimental results, the following conclusions were established:

- Recycled tyres steel fibres reinforced concrete beam made with optimal mix of fibres aspect ratio of 80, fibres content of 0.50% and palm kernel shells content of 25% as partial replacement of coarse aggregates has better load carrying capacity than recycled tyres steel fibres reinforced concrete beam made without the optimal mix. The shear load carrying capacity at both initial crack and failure for the former increases by 8% and 2% respectively as compared to the latter.

- The behaviour of the concrete strain show that recycled tyres steel fibres increases diagonal crack at the shear span of the beam, and also increases the degree of concrete bearing in tension, but it is not effective to control the extension of the crack.

- The shear resistance of beam made with the optimal mix increased by 13% compared to beam without the optimal mix.

- Recycled tyres steel fibres at aspect ratio 80 and content of 0.50%, along with palm kernel shells content of 25% as partial replacement of coarse aggregates can be used in structural lightweight concrete beams.

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REFERENCES

[1] P. Shafigh, M. Z. Jumaat, and H. Mahmud, “Mix design and mechanical properties of oil palm shell lightweight aggregate concrete: A review,” *Int. J. Phys. Sci.*, vol. 5, no. 14, pp. 2127–2134, 2010.

[2] U. J. Alengaram, B. Abdullah, A. Muhit, and M. Zamin, “Utilization of oil palm kernel shell as lightweight aggregate in concrete – A review,” *Constr. Build. Mater.*, vol. 38, pp. 161–172, 2013.

[3] F. O. Okafor, “PALM KERNEL SHELL AS A LIGHTWEIGHT AGGREGATE FOR CONCRETE,” *Cem. Concr. Res.*, vol. 60, no. 8, pp. 27–30, 1988.

[4] H. B. Basri, M. A. Mannan, and M. F. M. Zain, “Concrete using waste oil palm shells as aggregate,” *Cem. Concr. Res.*, vol. 29, no. 4, pp. 619–622, 1999.

[5] M. A. Mannan and C. Ganapathy, “Concrete from an agricultural waste-oil palm shell (OPS),” *Build. Environ.*, vol. 39, no. 4, pp. 441–448, 2004.

[6] G. Centonze, M. Leone, and M. A. Aiello, “Steel fibers from waste tires as reinforcement in concrete: A mechanical characterization,” in *Construction and Building Materials*, vol. 36, Elsevier Ltd, 2012, pp. 46–57.

[7] D. H. Lim and B. H. Oh, “Experimental and theoretical investigation on the shear of steel fibre reinforced concrete beams,” *Eng. Struct.*, vol. 21, no. 10, pp. 937–944, 1999.

[8] Y. Kwak, M. O. Eberhard, W. Kim, and J. Kim, “Shear Strength of Steel Fiber-Reinforced Concrete Beams without Stirrups,” no. 99, pp. 1–9, 2003.

[9] Hamid Behbahani and Behzad Nematollahi, “Steel Fiber Reinforced Concrete: A Review (PDF Download Available),” 2011.

[10] H. H. Dinh, “SHEAR BEHAVIOR OF STEEL FIBER REINFORCED CONCRETE BEAMS by,” *Design*, 2009.

[11] D. C. L. Teo, M. A. Mannan, and J. V. Kurian, “Flexural Behaviour of Reinforced Lightweight Concrete Beams Made with Oil Palm Shell (OPS),” *J. Adv. Concr. Technol.*, vol. 4, no. 3, pp. 459–468, 2006.

[12] British Standard Institution 8110-1, “Structural use of concrete —,” no. December, 1997.

[13] B. J. Dorr, R. O. Onchiri, and C. L. Kanali, “Effects of Recycled Tyre Steel Fibres on the Compressive , Splitting Tensile and Flexural Strengths of Structural Lightweight Concrete Using Palm Kernel Shells as Partial Replacement of Coarse Aggregates,” vol. 11, no. 6, pp. 35–41, 2019.

[14] BSI Standards Publication and BS EN 206, “BSI Standards Publication Concrete — Specification , performance , production and conformity,” *Br. Stand.*, no. May, p. 30, 2013.

[15] B. S. En, “B R I T I S H S T AN D AR D L ig h t w e ig h t a ggr ega t es —,” no. 1, 2002.

[16] British Standard Institution, “BSI Standards Publication Cement Part 1 : Composition , specifications and,” no. November, 2011.

[17] B. Standard, “British Standard is licensed to,” 1990.

[18] F. Recommendation, “RILEM TC 162-TDF: ‘Test and design methods for steel fibre reinforced concrete’ σ-ε-design method,” *Mater. Struct. Constr.*, vol. 36, no. 262, pp. 560–567, 2003.