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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

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Abstract

The improper handling and disposal of waste tyres in many African countries is still a serious problem which has caused environmental and health hazards. Like waste tyres, the proper reuse of agricultural wastes, such as palm kernel shells, is also a challenge as the production has increased over the years. In the field of civil engineering, effort have been made to recycle waste tyres and palm kernel shells in concrete production to mitigate some of the environmental problems arising from these wastes. The recycling of such waste for civil engineering applications has been heightened with the development of new technologies. This study was carried out to evaluate and assess the effects of recycled tyre steel fibres and palm kernel shells on the compressive, splitting tensile and flexural strengths of structural lightweight concrete, using recycled tyre steel fibres for reinforcement and palm kernel shells as partial replacement of coarse aggregates. Recycled tyres steel fibres were added in normal-weight concrete at 0.25, 0.50 and 0.75% (Viz., 6, 12 and 18 kg/m^3) content and aspect ratio of 20, 40, 60, 80 and 100% to determine the optimal fibres content and aspect ratio. The results show that recycled tyres steel fibres obtained from pyrolysis can improve the compressive and splitting strengths of normal-weight concrete. The optimal fibres content and aspect ratio were used with palm kernel shells at 25, 50, and 75% content to determine the optimal partial replacement of coarse aggregates with palm kernel shells. The maximum compressive and splitting tensile strengths values were obtained at an aspect ratio of 80, palm kernel shell content of 25% and steel content of 0.50%. Normal-weight concrete strength values in flexure were higher than lightweight concrete made with optimal values. Additionally, beams with 25 and 50% content of palm kernel shells with optimal fibre content and aspect ratios qualified as structural lightweight concrete.

Keywords: palm kernel shells, recycled tyres steel fibres, waste tyres, lightweight concrete, normal-weight concrete, compressive strength, splitting tensile strength and flexural strength.

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1. Introduction

Construction of roads remains an essential aspect for national, industrial and socio-economic development in many African countries. Improvement in the living standards of people has witnessed them buy vehicles for transporting goods and for services. This has resulted in a rapid increased in the number of vehicles over the last few decades and has led to increase in waste tyres in the environment. The problem of waste tyres management in Africa is severe, particularly in large urban cities like Nairobi (Achankeng, 2003). The improper handling and disposal of waste tyres cause environmental damage, health and fire-related problems (UNEP, 2013). It is worth noting that in 2016, 2.01 billion tonnes of solid waste were generated globally amounting to a footprint of 0.74 kg per person per day. Out of the global waste generated, 9.1% are from used vehicles tyres (Environmental Protection Agency, 2014). With an increase in population and urbanization, annual solid waste generation was expected to increase by 70% from 2016 levels to 3.40 billion tonnes in 2050 (Kaza et al. n.d.). The increase in population has resulted in high demand for food and this has led to increase in agricultural and construction activities, which enhance national, industrial and socio-economic development. One of the agricultural activities that has thrived in Africa is palm production. It was reported by Global Palm Oil Conference (2015), that the world production of palm oil and palm kernel oil has grown rapidly in recent decades (viz., from about 2 million metric tonnes in 1961 to over 56 million tonnes in 2012). The World Bank also reported an estimated consumption of palm oil could double by 2020 to about 112 million tonnes (Global Palm Oil Conference, 2015).

In the field of civil engineering, efforts have been made to recycle waste tyres and agricultural wastes for concrete production (Basri et al. 1999; Centonze et al. 2012; Mannan & Ganapathy 2004; Okafor 1988). These efforts have been directed towards the use of recycled steel fibres and palm kernel shells. The use of recycled steel fibres from waste tyres in concrete improves the mechanical properties of concrete. Therefore, there is high prospect for using them for structural and non-structural concrete elements (Dinh 2009; Kwak et al. 2003; Lim & Oh 1999). Hamid Behbahani & Behzad Nematollahi, (2011) reports that the addition of steel fibres in concrete increases flexural strength, energy absorption capacity, ductile behaviour before the ultimate failure and durability, and reduces cracking. In addition, Teo et al. (2006) observed that flexural and ductility behaviour of concrete made with palm kernel shells as aggregates can be compare with other types of lightweight aggregates. Aggregates used in concrete production account for about 60-80% of the total volume of concrete depending on the mix design. The reduction can be achieved in many ways, such as the use of smaller sections and lightweight aggregates Okpala (1990). The use of lightweight aggregates from agricultural wastes like palm kernel and coconut shells can be sustainable in Africa if there is requisite technology for their extraction. The high demand for concrete has resulted in an increase in aggregates production leading to increase environmental pollution and depletion of natural resources (Alengaram et al. 2013). The use of lightweight aggregates is cost-effective compared to natural aggregates. This study aims at determining the compressive, splitting tensile and flexural strengths of reinforced lightweight concrete with recycled tyre steel fibres using palm kernel shells as partial replacement of coarse aggregates.

2. Materials and Methods

2.1. Materials acquisition and characterisation

The materials used in this study were recycled tyre steel fibres, ordinary Portland cement (class 42.5N), super-plasticizer, fine and coarse aggregates, palm kernel shells, and portable water. The steel fibres, cement, super-plasticizer, fine and coarse aggregates, were procured locally while the palm kernel shells were procured from Uganda, Buggala Island in Kalangala (a district composed of eight-four different islands in Lake Victoria). The steel fibres were produced through pyrolysis. Ten (10) samples of the fibres were selected randomly and were tested for tensile strength using a Hounsfield tensometer as per ACI Committee 544 (2002). The mean diameter and tensile strength values were recorded as 1.17 mm and 1032.35 MPa, respectively. The fibres were cut into different sizes in order to obtain desired aspect ratios (Viz., length/diameter) of 20, 40, 60, 80, and 100. The cement conformed to British Standard Institution (2011). It was dry, powdery and free of lumps. The physical and chemical compositions of the cement were determined before use (Tables 1 and 2). 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.

Palm kernel shells were obtained after oil extraction from fresh palm fruit bunches. The palm kernel shells and aggregates were prepared in conformity with European Standard (En, 2002) and European Standard (BS-EN-12620, 2013), respectively, which requires that they are 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. The sizes of the shells ranged from 2.36-15 mm while those for fine and coarse aggregates ranged from 0.15-10 mm and 2.36-20 mm, respectively. The physical and mechanical properties of the fine and coarse aggregates are shown in Table 3.

Table 1: Physical properties of the ordinary Portland cement (42.5N)

Characteristics	**Property**
Specific gravity	3.15
Standard consistency	41.25%
Initial setting time	153 minutes
Final setting time	274 minutes

Table 2: Chemical composition of the ordinary Portland cement

Chemical Composition	**Percentage by mass (%)**
Calcium oxide (CaO)	61.48
Silica (SiO_2)	25.79
Aluminium oxide (Al_2O_3)	5.60
Iron (Fe)	2.34
Sulphur (S)	2.60
Potassium oxide (K_2O)	1.00
Phosphorous pent oxide (P_2O_5)	0.52
Chloride (Cl)	0.23
Titanium (Ti)	0.21
Strontium (Sr)	0.14

Table 3: Physical and mechanical properties of fine aggregates, coarse aggregates and palm kernel shells

Property	Fine aggregates	Coarse aggregates	Palm kernel shells
Maximum aggregate size (mm)	5	20	10
Fineness modulus	2.82	2.86	2.38
Apparent specify gravity	2.48	2.56	1.44
Moisture content (%)	0.06	1.03	13.68
24 hours of 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)	1644.67	1424.48	580.50
Loose bulk density (kg/m^3)	1485.93	1411.46	515.28

2.2. Data collection and analysis

The data was collected and analysed in order to: (i) evaluate the compressive and splitting tensile strengths of structural lightweight concrete using recycled tyre steel fibres and palm kernel shells as partial replacement of coarse aggregates, and; (ii) assess the effects of recycled tyre steel fibres and palm kernel shells on the compressive, splitting tensile and flexural strengths of structural lightweight concrete. In order to achieve the first objective, recycled tyre steel fibres of 20, 40, 60, 80 and 100 aspect ratios were used in a concrete mix design of 1:2:3 (viz., cement 383 kg/m^3; sand 632 kg/m^3 and ballast 1111 kg/m^3) at a constant water-cement ratio of 0.56 and for each aspect ratio, 0, 0.25, 0.50 and 0.75% (0, 6, 12 and 18 kg/m^3) steel fibre content were added. Thereafter, compressive and splitting tensile strengths were determined on three cubes and cylinder for each mixes after 7 and 28 days of curing in conformity to European standard (En, 2011) and European standard (En, 2009), respectively. In total, 96 cubes (150x150x150mm) and 96 cylinders (150x300mm) were used. From the test results, the optimum aspect ratio and steel fibre content were established. The specimens for each concrete mixes were tested on a 1500/150 kN capacity Automatic Compression Machine, model Y1MC109NS using a loading rate of 0.05MPa/sec for all tests. The load was applied slowly until the specimen failed.

For the second objective, 18 cubes (150x150x150 mm) and 18 cylinders (150x300 mm) of lightweight concrete mix of 1:2:3 (Viz., cement 383 kg/m3; fine aggregates 632 kg/m3 and coarse aggregates 1111 kg/m3) with a cement-water ratio of 0.56 corresponding to the established optimum aspect ratio and steel fibre content were used. However, the coarse aggregates were partially replaced with 0, 25, 50 and 75% by weight of palm kernel shells. From this tests, the optimum content of palm kernel shells to be used in the concrete was established. The flexural strength was determined using 6 prismoidal beams (150x150x520mm) as per European standard EN 12390-6 (2009). The beams were prepared using the optimum aspect ratio, steel fibre content and palm kernel shell content as partial replacement of coarse aggregate in concrete mix of 1:2:3 (Viz., cement 383 kg/m3; fine aggregates 632 kg/m3 and coarse aggregates 1111 kg/m3) with a cement-water ratio of 0.56.

The test were conducted on a centre-point loading after 28 days of curing. The load was arranged such that, one load-applying roller was positioned at the mid-span and the load was applied as all loading and supporting rollers were resting evenly against the test specimen. Specimens were tested on a 1500/150 kN capacity Automatic Compression Machine, model Y1MC109NS. The average of the three replicates was taken.

3. Results and Discussion

The results of compressive strength for recycled tyre steel fibres with normal-weight concrete at different aspect ratios are presented in Figures 1-3. The maximum average compressive strength obtained was observed for concrete mixes with 0.50% (12 kg/m^3) content of steel fibres for all aspect ratios at 7 and 28 days. The compressive strength increases as the fibres aspect ratio increases from 20-80 and decreases thereafter. On the hand, Figure 4 presents the compressive strength for optimal aspect ratio of 80 and steel fibre content of 0.50% (12 kg/m^3) at various palm kernel shells content. The results show that as the content of the shells increases the compressive strength decreases. However, since the objective was to partially replace the coarse aggregates, a content value of 25% was selected as it produced the highest compressive strength. Additionally, the result obtained shows that concrete made with optimal aspect ratio of 80, steel fibre content of 0.50% (12 kg/m^3), 25 and 50% content of palm kernel shells as partial replacement of coarse aggregates can be qualified as structural lightweight concrete (Li, 2011). Figure 5-7 shows the results of splitting tensile strength for recycled tyre steel fibres with normal-weight concrete at different aspect ratios and steel fibre content. The average splitting tensile strengths obtained was observed to a slight increase for all concrete mixes for all aspect ratios at 28 days and a high increase at 7 days. The maximum average splitting tensile strength for concrete mixes was observed at 0.50% (12 kg/m^3) content of steel fibre. Figure 8 presents the splitting tensile strength for optimal aspect ratio of 80 and steel fibre content of 0.50% (12 kg/m^3) at various palm kernel shells content. The results show that as the content of the shells increases the splitting tensile strength decreases. However, since the objective was to partially replace the coarse aggregates, a content value of 25% was selected as it produced the highest splitting tensile strength as well. Table 4 presents the flexural strength for control mix and concrete mix made with optimal aspect ratio of 80 and steel fibre content of 0.50% (12 kg/m^3) and palm kernel shells content of 25%. From the results, the average flexural strength for beam specimens made with optimal aspect ratio, steel fibre content and palm kernel shell content decreases by 26% as compared to the control specimens. It was further observed that the fibres were unable to resist the propagation of cracks thereby causing it to fail suddenly.

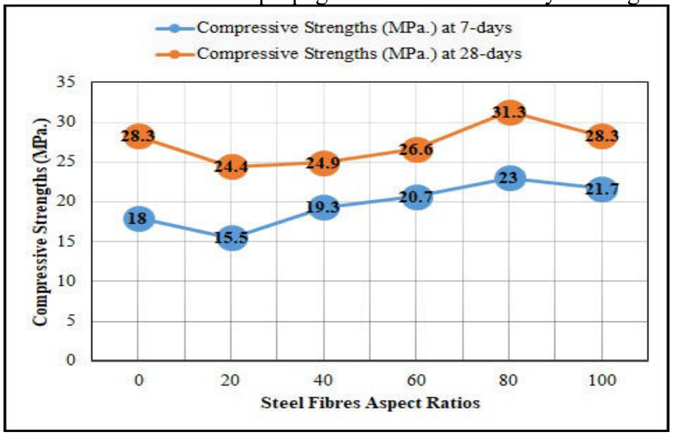

Figure1: Compressive strength for 0.25% recycled steel fibres for various aspect ratios

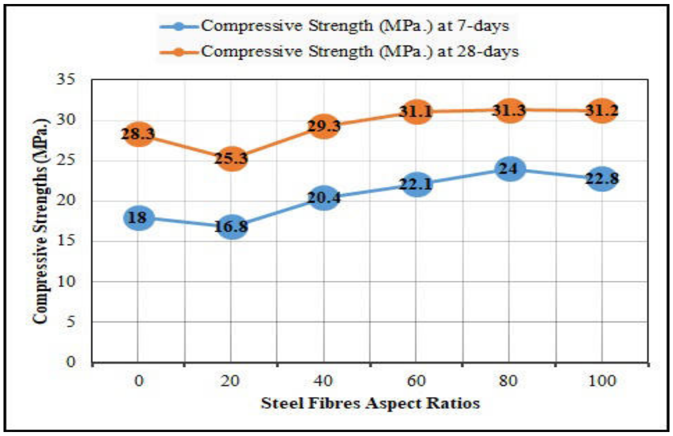

Figure 2: Compressive strength for 0.50% recycled steel fibres for various aspect ratios

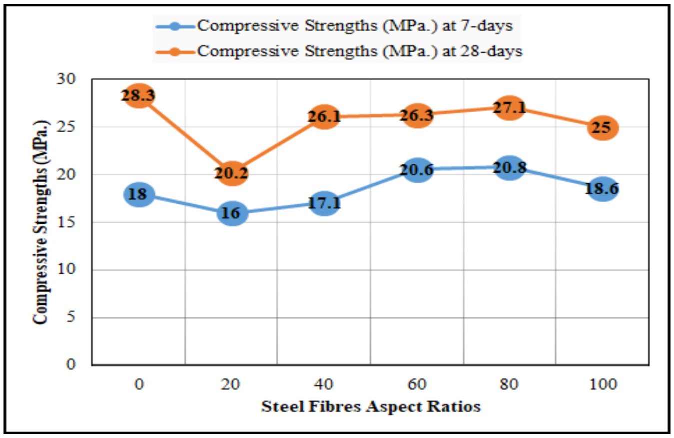

Figure 3: Compressive strength for 0.75% recycled steel fibres for various aspect ratios

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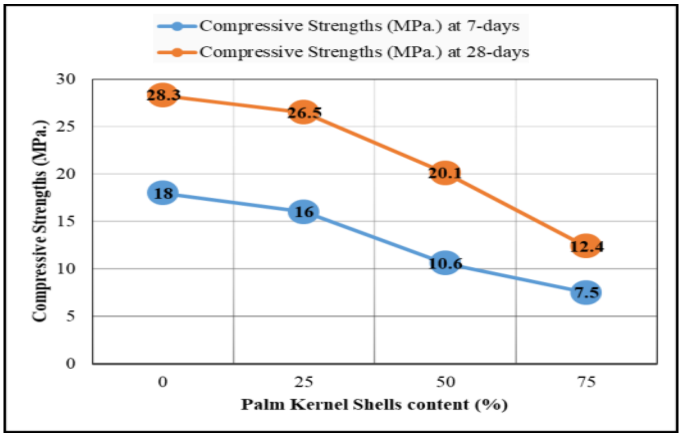

Figure 4: Compressive strength for optimal aspect ratio of 80 and steel fibre content of 0.50% at various palm kernel shells content

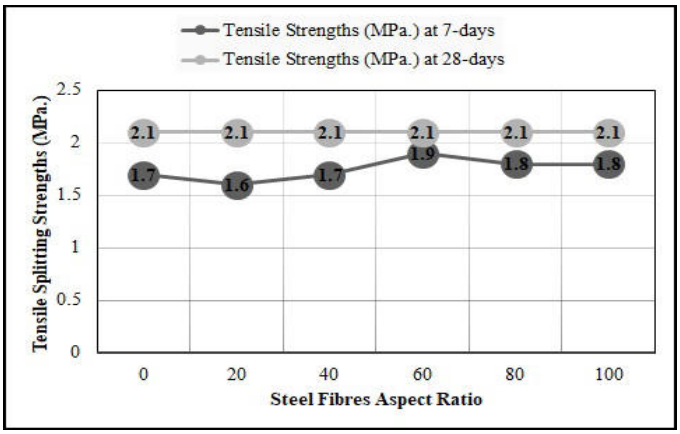

Figure 5: Splitting tensile strength for 0.25% recycled steel fibres for various aspect ratios

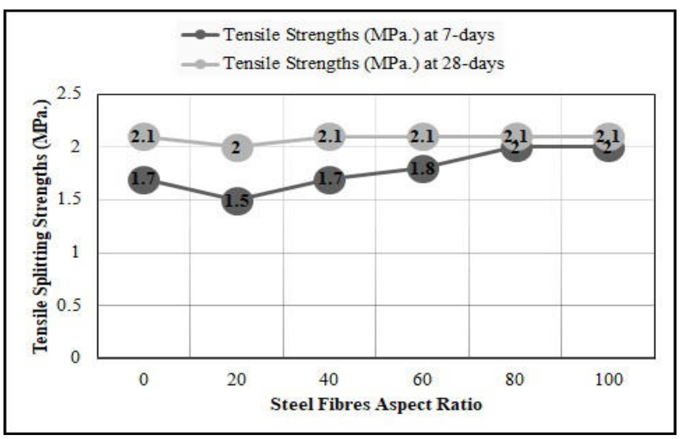

Figure 6: Splitting tensile strength for 0.50% recycled steel fibres for various aspect ratios

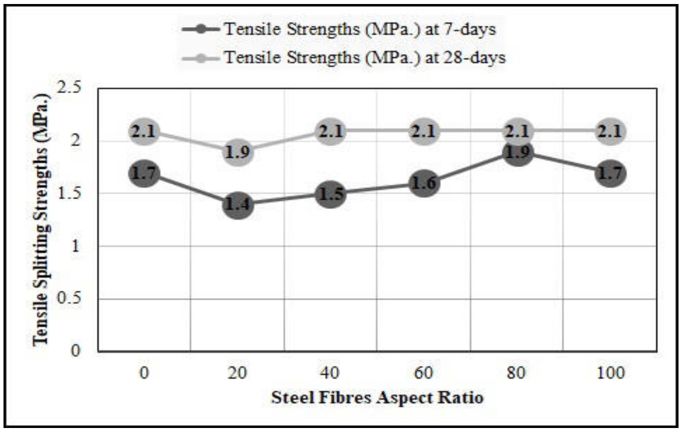

Figure 7: Splitting tensile strength for 0.75% recycled steel fibres for various aspect ratios

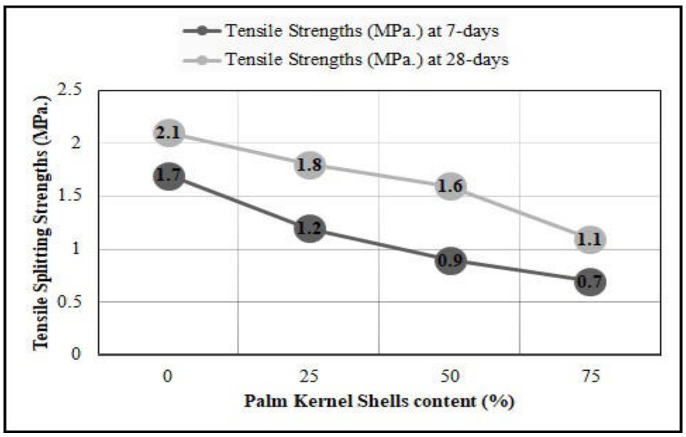

Figure 8: Splitting tensile strength for optimal aspect ratio of 80 and steel fibre content of 0.50% at various palm kernel shells content

Table 4: Flexural strengths for hardened concrete mixes at 28 days

Specimens	Steel fibres		Kernel shells content (%)	Flexural strengths (MPa.)	Average flexural strength (MPa.)
	Aspect ratio	Content (%)			
Beam-1A	0	0	0	4.383	4.250
Beam-1B	0	0	0	4.124	
Beam-1C	0	0	0	4.244	
Beam-2A	80	0.5	25	3.031	3.139
Beam-2B	80	0.5	25	3.162	
Beam-2C	80	0.5	25	3.223	

4. Conclusions

The results of this study show that an increase in recycled steel fibres from 20-80 aspect ratios increases the compressive strength and splitting tensile strengths of normal weight concrete. The maximum values are obtained at an aspect ratio of 80, palm kernel shell content of 25% and steel content of 0.50%. And, the average splitting tensile strength for normal-weight concrete reinforced with recycled steel fibres meet the minimum requirement for structural grade lightweight aggregates as per ASTM International, (2009). Further, it was observed that normal-weight concrete strength values in flexure are higher than those for lightweight concrete made with an optimal aspect ratio of 80, steel content of 0.50% and palm kernel shell content of 25% used as partial replacement of coarse aggregates.

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References

Achankeng, E. (2003) 'Globalization , Urbanization and Municipal Solid Waste Management in Africa Eric Achankeng , University of Adelaide', *African on a global stage*, pp. 1–22.

ACI Committee 544 (2002) 'ACI 544.1R-96: Report on Reinforced Concrete (Reapproved)', *ACI Structural Journal*, 96(Reapproved), pp. 1–66. doi: 10.1177/0733464813512180.

Alengaram, U. J. *et al.* (2013) 'Utilization of oil palm kernel shell as lightweight aggregate in concrete – A review', *Construction and Building Materials*. Elsevier Ltd, 38, pp. 161–172. doi: 10.1016/j.conbuildmat.2012.08.026.

ASTM International (2009) 'ASTM C330-09. Standard Specification for Lightweight Aggregates for Structural Concrete', *Annual Book of ASTM Standards*, 552(18), p. 4. doi: 10.1520/C0330.

Basri, H. B., Mannan, M. A. and Zain, M. F. M. (1999) 'Concrete using waste oil palm shells as aggregate', *Cement and Concrete Research*, 29(4), pp. 619–622. doi: 10.1016/S0008-8846(98)00233-6.

British Standard Institution (2011) 'BSI Standards Publication Cement Part 1 : Composition , specifications and', (November).

BS-EN-12620 (2013) 'BSI Standards Publication Aggregates for concrete'.

BSEN 12390-6 (2009) 'Testing hardened concrete', *British Standards Institution BSI*.

Centonze, G., Leone, M. and Aiello, M. A. (2012) 'Steel fibers from waste tires as reinforcement in concrete: A mechanical characterization', in *Construction and Building Materials*. Elsevier Ltd, pp. 46–57. doi: 10.1016/j.conbuildmat.2012.04.088.

Conference, G. P. O. (2015) 'Global Palm Oil Conference'.

Dinh, H. H. (2009) 'SHEAR BEHAVIOR OF STEEL FIBER REINFORCED CONCRETE BEAMS by', *Design*. doi: 10.4172/2165-784X.1000292.

En, B. S. (2002) '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 —', (1).

En, B. S. (2009) 'Testing hardened concrete'.

En, B. S. (2011) 'Testing hardened concrete', (August).

Environmental Protection Agency, U. (2014) 'Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures A Methodology Document Municipal Solid Waste in the United States Facts and Figures A Methodology Document', (April). doi: 10.1080/13642980902948926.

Hamid Behbahani and Behzad Nematollahi (2011) 'Steel Fiber Reinforced Concrete: A Review (PDF Download Available)'. Available at: https://www.researchgate.net/publication/266174465_Steel_Fiber_Reinforced_Concrete_A_Review.

Kaza, S. *et al.* (no date) *What a waste 2.0*.

Kwak, Y. *et al.* (2003) 'Shear Strength of Steel Fiber-Reinforced Concrete Beams without Stirrups', (99), pp. 1–9.

Li, Z. (2011) *Advanced Concrete Technology*. Hoboken, New Jersey: John Wiley & Sons, Inc.

Lim, D. H. and Oh, B. H. (1999) 'Experimental and theoretical investigation on the shear of steel fibre reinforced concrete beams', *Engineering Structures*, 21(10), pp. 937–944. doi: 10.1016/S0141-0296(98)00049-2.

Mannan, M. A. and Ganapathy, C. (2004) 'Concrete from an agricultural waste-oil palm shell (OPS)', *Building and Environment*, 39(4), pp. 441–448. doi: 10.1016/j.buildenv.2003.10.007.

Okafor, F. O. (1988) 'PALM KERNEL SHELL AS A LIGHTWEIGHT AGGREGATE FOR CONCRETE', *CEMENT and CONCRETE RESEARCH*, 60(8), pp. 27–30.

Okpala, D. C. (1990) 'Palm Kernel Shell as a Lightweight Aggregate in Concrete', 25(4), pp. 291–296.

Teo, D. C. L., Mannan, M. A. and Kurian, J. V. (2006) 'Flexural Behaviour of Reinforced Lightweight Concrete Beams Made with Oil Palm Shell (OPS)', *Journal of Advanced Concrete Technology*, 4(3), pp. 459–468. doi: 10.3151/jact.4.459.

UNEP (2013) *The Environment in Numbers*.