Pakistan Journal of Engineering and Technology, PakJET
Multidisciplinary & Peer Reviewed
Volume: 4, Number: 4, Pages: 57- 64, Year: 2021

Shear Behavior of End of Life Tyres Steel Fibrous Self Compacting Concrete Beams

Iffat Siddique[1,*], Zeshan Anwar[2], Umbreen Sahar[2] and Mifrah Ali[3]

[1]Civil Engineering Department, University of Management & Technology, Lahore, 54770, Pakistan
[2]Civil Engineering Department, University of Engineering & Technology, Lahore, 54890, Pakistan
[3]Mechanical Engineering Department, University of Management & Technology, Lahore, 54770, Pakistan

Corresponding author: Iffat Siddique (e-mail: iffat.siddique@umt.edu.pk+).

Abstract- **Self Compacting Concrete (SCC) presents lower shear strength due to its smaller aggregate size and lesser content. In addition, a large amount of hazardous vehicular tire waste is produced each year requiring a great deal of economy and land for its management. This work summarizes the results of a detailed investigation of the shear behavior of steel fibers reinforced self-compacting concrete (SFRSCC) beams. Steel fibers extracted from waste tires have been used in varying amounts and aspect ratios to study their impact on compressive, split tensile, and ultimate shear strengths and their corresponding deflections. The results indicate that the shear strength of SFRSCC beams is improved remarkably, and through the decision matrix, the results become more obvious and so the material can be recommended as a green shear enhancement material for SCC.**

Index Terms-- **Deflection Fiber, Aspect Ratio, Fiber dose, SFRSCC; Shear Strength.**

I. INTRODUCTION

The chemical admixtures (VMA & WRA) devised as an alternative to overcome the higher temperature rise in SCC due to greater cement content are very expensive and increase material cost [1], [2]. While on the other side, lesser small-sized aggregate content leads to weaker interlock mechanism and reduced shear strength [3]. Several researches have been carried out to formulate economical solutions to overcome these shortcomings of SCC. Metal including steel and plastic short fibers have been used in several experimental works in literature to improve mechanical properties (shear, flexure) [4-11]. The positive impact of commercial steel fibers on shear strength has also been investigated [11-15]. The sliding resistance offered by the fibers located at cracked shear surfaces is the primary reason for this improved behavior. Factors such as fiber content, their distribution, orientation, aspect ratio, shear span, and the concrete matrix proprieties play a key role in it.

A report published by the European Tyre and Rubber Manufacturers Association (ETRMA) in May 2018 based on data of 2016 of 32 countries revealed that there is an annual increase of 2% in the generation of waste tires [16]. A total of 3.9 Mt scrap tires each year while only 15.6% of it is recycled. The result will be an additional 100,000 tons each year waiting for their final fate to be decided. These alarming end-of-life tires (ELT) statistics demand discovering means of their suitable reuse in various sectors of life.

A lot of research is being carried out to discover materials that present less threat to the environment in terms of carbon footprint [17], [18]. Potential use of waste ELT fibers need to be assessed in this regard.

The main objectives of the present study are as follows:

- To check the possible use of waste from ELT for shear enhancement resulting in a green shear resistant SCC. To achieve the objectives shear strength tests on beams reinforced with steel fibers extracted from waste tires of heavy vehicles were conducted. Two fiber dosages (0.125% and 0.25% of total volume) and three different aspect ratios as 25, 35, and 45 were employed.
- To establish the optimum aspect ratio and dosage of these waste ELT fibers for the shear strength enhancement of SCC lost due to lesser and smaller aggregate being used.
- To report the cost-benefit achieved using a green material instead of commercial steel fibers while reducing the carbon footprint at the same time.

II. METHODS

A. Materials

The constituent materials included ASTM type (I) cement, locally available sand, ½” down coarse aggregates, steel fibers extracted from ELT, and tap water, Fig. 1. The properties of the aggregates are summarized in Table I and that of steel fibers are listed in Table II. The mix design proportion for SFRGSCC was 1:1.6:1.6 with a w/c of 0.4 as given in Table I. A high range water reducer (HRWR) Sika-Viscocrete 20HE was used (1.6% by weight of binder) meeting the ASTM C494/ C494M - 17 [19] requirements.

a) Cement **b) Sand/Fine Aggregates**

c) Crush/Coarse Aggregates **d) Steel fibers in a waste tire piece**

FIGURE 1: Materials Used For Mix Design

TABLE I

PHYSICAL PROPERTIES OF AGGREGATES

Sr. No	Aggregate property		Results for Fine Aggregates	Results for Coarse Aggregates
1	Fineness Modulus		2.1	6.48
2	Specific Gravity	Oven-dried	2.68	2.61
		Apparent	2.75	2.65
		SSD	2.70	2.64
3	Water Absorption		1.01%	0.7%
4	Bulk Density		1650 Kg/m^3	1595 Kg/m^3

TABLE II

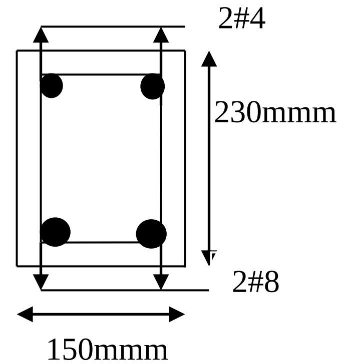
PROPERTIES OF WASTE STEEL FIBERS EXTRACTED FROM ELT

Sr No.	**Steel Fiber Properties**	**Test Results**
1	Average Lengths	(19, 25, 32) mm
2	Average Diameter	0.735mm
3	Aspect ratios	25, 35, 45
4	Tensile strength	3500 MPa
5	Density of steel fibers	7850 kg/m^3
6	Modulus of Elasticity	200 GPa

B. Test Sample Details

Cylinders of size (15 x 300)mm were used for the compression test and split tensile strength test. Beams of size (150 x 225 x 1250)mm dimension were cast for the shear strength test. A constant concrete cover of 40mm was provided. 2#8 and 2#4 bars were used as bottom and top reinforcement respectively, Fig. 2. The tests were performed on a UTM of 1000 KN. Two LVDTs (Linear Variable Differential Transducers) in the vertical direction to record deflection were used to note load values, see Figure (3).

a) Steel Reinforcement Cage



b) BeamX-Section

FIGURE 2: Reinforcement Details of Test Samples

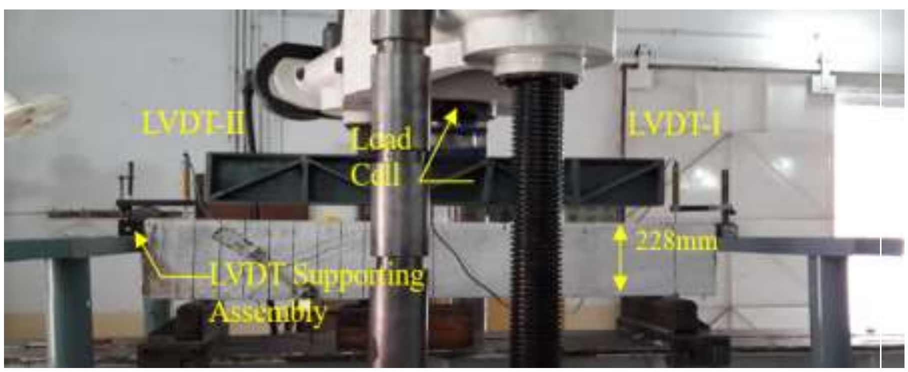


FIGURE 3:Test Setup for Shear Strength Test

The mix design ratio used for SFRSCC samples was 1:1.6:1.6 and that for NM was 1:1.45:2.45. Thereafter the results were normalized to eliminate the effect of compressive strength. Among the SFRSCC mixes, the only variable was the steel fiber dosage, which was varied from 0.125% to 0.25% of the total volume of concrete.

C. Experimental Program Details

Three samples for each of the tests were tested and an average of three has been reported in the results. The complete details about the number of samples and nomenclature used for various mix designs are given in Table III.

TABLE III

TEST MATRIX FOR EXPERIMENTATION

Mix No.	Mix ID	Fiber Aspect Ratio	Steel Fiber Quantity	Compressive Strength Test	Split Tensile Strength Test	Shear Strength Test
-	**-**	**%**	**(Kg)**	**#**	**#**	**#**
1	**SM1**	F0.125-AR25	9.81	3	3	3
2	**SM2**	F0.25-AR25	19.62	3	3	3
3	**SM3**	F0.125-AR35	9.81	3	3	3
.4	**SM4**	F0.25-AR35	19.62	3	3	3
5	**SM5**	F0.125-AR45	9.81	3	3	3
6	**SM6**	F0.25-AR45	19.62	3	3	3
7	**NM7**	F0.0- AR0	0.00	3	3	3

In Table III, F125-AR25 indicates that fibers dosage is 0.125% and aspect ratio is 25. 2.0 was the used shear span over effective depth (a_v/d) ratio. Three different tests were performed in fresh state; slump flow test, J-ring test, and V-funnel test; see Figs. 4 and 5. Although the addition of fibers decreased the workability to some extent, it remained within the prescribed limits of SCC for both the volumes of fibers used in the presented work, Fig. 5.

a) Slump Flow b) J-Ring c) V- Funnel

FIGURE 4: Fresh SCC Tests of Prepared Mixes

a) Slump Flow b) J-Ring c) V- Funnel

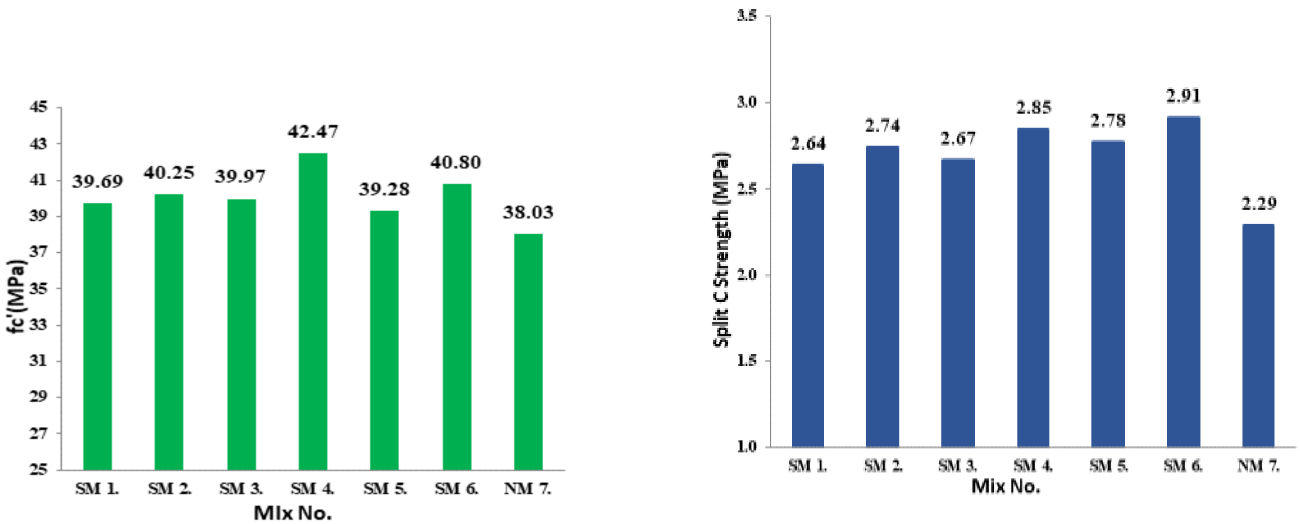
FIGURE 5: Fresh SCC Tests of Prepared Mixes

III. RES

ULTS

A. Compressive Strength:

Compressive strength [20] tests were conducted on hardened cylinder samples and the results are presented in Figure (6).



a) Compressive Strength

b) split tensile strength Test

FIGURE 6: Results of Mechanical Properties

Compressive strength test results indicate that all the mixes with fibers gave more strengths than NM7 mix without fibers, Fig. 6. But increase in fiber aspect ratio beyond a certain value results in a reduction of compression strength due to the congregation effect of long steel fibers. In this research, SM4 with maximum dosage and aspect ratio 35 gave maximum compressive strength as 42.47 MPa and a split tensile strength of 2.85 (v.close to a maximum of 2.91). This is 11.6%, 4.4%and 7% greater than SM2, SM6, and NM7 mixes respectively. It can be inferred that although the fibers increase the elastic modulus of concrete, but the height of the compressive zone decreases at the same time, resulting in its very small effect on compressive strength as observed by many researchers in the past [21]–[23].

B. Split Tensile Strength:

The split tensile strength test results represent quite a similar trend as that of compressive strength test results, Fig. 6. SM6 gave maximum split tensile strength in the conducted research as it contained maximum amount and maximum fibers length. The impact of aspect ratio in the case of split tensile strength remains enhancing with increasing fiber aspect ratio contrary to compressive strength test results. This is because when the load is applied the sample splits and the bridging effect of fibers causes the sample to continue taking more load due to the bridging action of fibers. And this bridging effect is more when fibers have more aspect ratio. The enhancement is 6.2%, 2.1%, and 27.1% w.r.t. SM2, SM4, and NM7 mixes respectively. While on the other hand, SM4 with a maximum dosage and aspect ratio of 35 gave a split tensile strength of 2.85 MPa (very comparable to a maximum of 2.91MPa).

C. Shear Strength:

The shear strength of beams was found by performing a four-point loading test, Fig. 5. Three beams from each concrete mix were tested. The results of varying fibers (dosage and aspect ratio) are listed in Table IV.

TABLE IV

SHEAR STRENGTH TEST RESULTS OF BEAMS

Mix. No.	Mix Detail	Shear Span (a_v/d)	Cracking Load (P_{cr})	Maximum Load (P_u)	P_u-P_{cr}	Deflection	Ultimate Shear Strength
	-	-	(KN)	(KN)	(KN)	(mm)	(MPa)
SM1	F125-AR25	2.0	117.7	132.7	15.0	6.6	2.32

SM2	F25-AR25	2.0	120.3	179.0	58.7	7.3	3.14
SM3	F125-AR35	2.0	123.3	157.6	34.3	6.8	2.76
SM4	F25-AR35	2.0	119.3	187.5	68.3	7.5	3.29
SM5	F125-AR45	2.0	130.3	180.4	50.1	7.2	3.16
SM6	F25-AR45	2.0	129.5	210.5	81.0	7.9	3.69
Nm7	NM2.0	2.0	179.3	197.3	18.0	6.4	2.29

In Fig. 7, Normalized shear strength was obtained by dividing the shear strength by their respective compressive strengths to eliminate the reflection of compressive strength in the results. And so the results truly depict only the change of the shear strengths due to fiber addition.

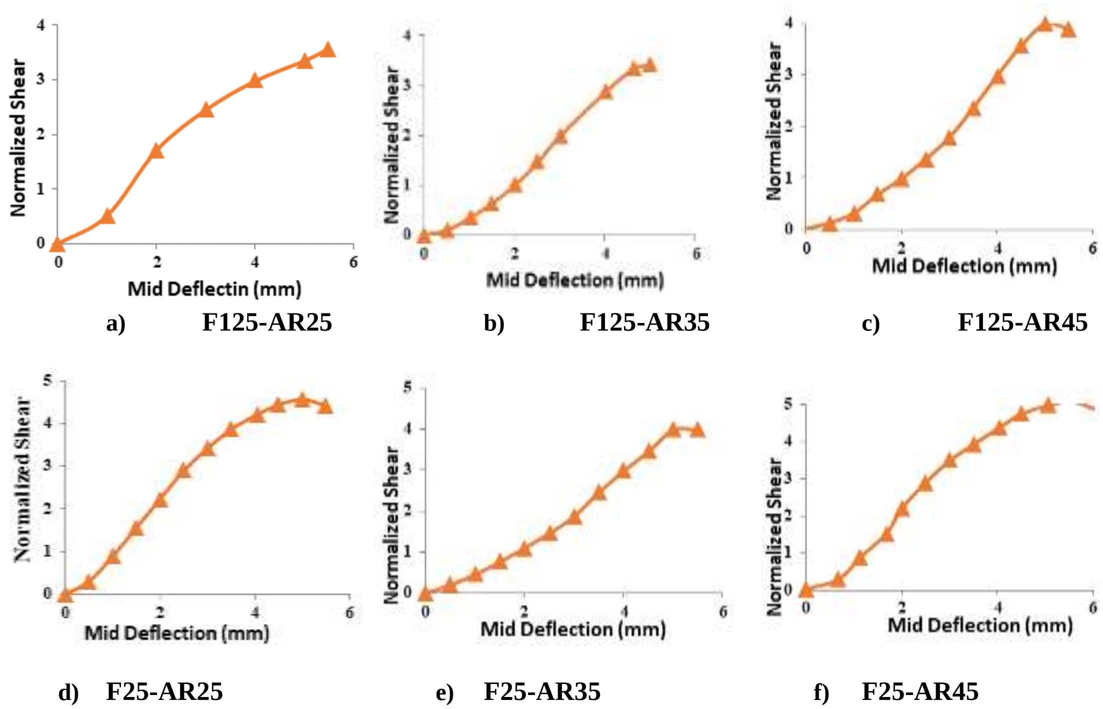


FIGURE 7: Load Deflection Curves For Shear

All the mixes with fibers showed better performance in shear than that of the samples without fibers indicating the effectiveness of fibers in the shear enhancement of SCC. The maximum shear strength improvement was observed from 2.32 MPa to 3.69 MPa (59%) when the fiber dosage was increased from 0.125% to 0.25% with the aspect ratio increasing from 25 to 45 respectively. The shear strength increased from 2.32MPa to 3.16MPa (36.2%) when the fiber was aspect ratio was changed from 25 to 45. While changing the fiber content from 0.125% to 0.25% resulted in further improvement. The maximum shear strength obtained was for SM4 as 3.69MPa which is 35.3% more than SM2 and 59% more than SM1 and 61.1 more than the mix without fibers NM7. Although increasing fiber dose increases shear strength but this trend is more dominant when the aspect ratio is less and vice versa in accordance with the compressive strength test (35.3% for SM1& SM2 while 19.2% and 16.8% for SM3 & SM4 AND SM5& SM6 respectively). The increased fiber dosage improves the no. of steel fibers that hinders the formation of shear cracks. While on the other hand, the greater fiber aspect ratio results in the slenderness effect of the fibers which tend to buckle and lumps up together causing a drop in the shear capacity of the members.

IV. DECISION MATRIX & RESEARCH SIGNIFICANCE

The ever-growing environmental problems demand for discovering of new efficient environmentally friendly construction materials and techniques. The current research focuses on this aspect. And so a waste material is employed that will help not only eliminate the waste management cost but also shuns useful land from being a dump. To elucidate how successfully this objective is achieved, a decision matrix is developed, Table V, which is one of the best ethical aids for determining the best among the available options. The tensile strength was determined using a UTM with a least count of 0.01 kN.

TABLE V

DECISION MATRIX FOR ELT FIBERS USE FOR SHEAR ENHANCEMENT

Shear Strength			ELT Fibers			Commercial Steel Fibers		
Objective	Weighing Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Material Cost	0.25	PKR/Kg	50-70	10.0	2.5	150-170	3.3	0.8
Tensile Strength	0.25	MPa	3500	10	2.5	2000	5.71	1.4
Material Availability	0.10	Experience	Good	10.0	1.0	Great	10	1.0
Manufacturing Time	0.10	Experience	Good	8.0	0.8	Great	10	1.0
Green Material	0.30	Experience	Great	10.0	3.0	Poor	2	0.6
Overall Value					9.8			4.8

LEGEND:

Qualitative Score	Great	Good	Okay	Fair	Poor
Assignment	10	8	6	4	2

In this Matrix, first of all, the objectives which are important for the selection of the materials are selected and are given weighing factors according to their importance in the decision of material selection with the sum of all equal to 1. Magnitude represents the actual quantities in terms of selected units while **Score** is a relative comparative value out of 10 concerning the maximum magnitudes among the resources. The **Value** represents **the** weighted value obtained by score times the weighing factor. The overall value thus obtained by summing all the values of the particular material ranks ELT fibers as the first choice to overcome the shortcoming of reduced shear strength of SCC.

V. CONCLUSIONS

The major outcomes of this present study are as follows:

- By using steel fibers the ultimate shear strengths of SFRSCC beams were remarkably increased (maximum 59%). Hence, the material can be used as a green material for shear improvement.
- The increased fiber aspect ratio results in a reduction of shear and compressive strength. Among the tested mixes, F25AR25 gives the maximum compressive and shear strength indicating that 0.25% dosage and 25 aspect ratio as the best mix design proportions.
- The strength of these used waste steel fibers is 75% more than the commercial steel fibers with a cost-effectiveness of 61%.
- And finally, using waste is not only helpful for solid waste management but also a part of green construction which is the need of the hour.

ACKNOWLEDGMENT

The authors gratefully acknowledge the use of service and facilities of the Civil Engineering Department, UMT Lahore. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

REFERENCES

[1] T. Akram, S. A. Memon, and H. Obaid, "Production of low cost self compacting concrete using bagasse ash," *Constr. Build. Mater.*, vol. 23, no. 2, pp. 703–712, Feb. 2009, doi: 10.1016/j.conbuildmat.2008.02.012.

[2] N. Bouzoubaâ and M. Lachemi, "Self-compacting concrete incorporating high volumes of class F fly ash: Preliminary results," *Cem. Concr. Res.*, vol. 31, pp. 413–420, Mar. 2001, doi: 10.1016/S0008-8846(00)00504-4.

[3] J. A. Khafaji, I. A. Shaarbaf, and W. H. Sultan, "Shear Behavior of Fibrous Self Compacting Concrete Deep Beams," *J. Eng. Dev.*, vol. 18, no. 6, Nov. 2014.

[4] D. Bjegovic, A. Baricevic, S. Lakusic, D. Damjanovic, and I. Duvnjak, "Positive interaction of industrial and recycled steel fibres in fibre reinforced concrete," *J. Civ. Eng. Manag.*, vol. 19, no. sup1, pp. S50–S60, Dec. 2013, doi: 10.3846/13923730.2013.802710.

[5] B. Boulekbache, M. Hamrat, M. Chemrouk, and S. Amziane, "Influence of yield stress and compressive strength on direct shear behaviour of steel fibre-reinforced concrete," *Constr. Build. Mater.*, vol. 27, pp. 6–14, Feb. 2012, doi: 10.1016/j.conbuildmat.2011.07.015.

[6] E. Cuenca, J. Echegaray-Oviedo, and P. Serna, "Influence of concrete matrix and type of fiber on the shear behavior of self-compacting fiber reinforced concrete beams," 2015, doi: 10.1016/J.COMPOSITESB.2015.01.037.

[7] J. Echegaray-Oviedo, J. Navarro-Gregori, E. Cuenca, and P. Serna, "Modified push-off test for analysing the shear behaviour of concrete cracks," *Strain*, vol. 53, no. 6, p. e12239, 2017, doi: 10.1111/str.12239.

[8] A. Khaloo and N. Kim, "Influence of Concrete and Fiber Characteristics on Behavior of Steel Fiber Reinforced Concrete under Direct Shear," 1997, doi: 10.14359/344.

[9] A. Khanlou, G. A. MacRae, A. N. Scott, S. J. Hicks, and G. C. Clifton, "Shear Performance of Steel Fibre-Reinforced Concrete," 2012, Accessed: Jan. 20, 2022. [Online]. Available: https://ir.canterbury.ac.nz/handle/10092/10654

[10] M. A. Mansur, T. Vinayagam, and K.-H. Tan, "Shear Transfer across a Crack in Reinforced High-Strength Concrete," *J. Mater. Civ. Eng.*, vol. 20, no. 4, pp. 294–302, Apr. 2008, doi: 10.1061/(ASCE)0899-1561(2008)20:4(294).

[11] F. Minelli, A. Conforti, E. Cuenca, and G. Plizzari, "Are steel fibres able to mitigate or eliminate size effect in shear?," *Mater. Struct.*, vol. 3, no. 47, pp. 459–473, 2014, doi: 10.1617/s11527-013-0072-y.

[12] F. Minelli and G. Plizzari, "On the Effectiveness of Steel Fibers as Shear Reinforcement," *Aci Struct. J.*, vol. 110, pp. 379–390, May 2013.

[13] A. A. Mirsayah and N. Banthia, "Shear strength of steel fiber-reinforced concrete," *ACI Mater. J.*, vol. 99, pp. 473–479, Sep. 2002.

[14] R. Narayanan and I. Y. S. Darwish, "Use of Steel Fibers as Shear Reinforcement," *Struct. J.*, vol. 84, no. 3, pp. 216–227, May 1987, doi: 10.14359/2654.

[15] J. Navarro-Gregori, E. J. Mezquida-Alcaraz, P. Serna-Ros, and J. Echegaray-Oviedo, "Experimental study on the steel-fibre contribution to concrete shear behaviour," *Constr. Build. Mater.*, vol. C, no. 112, pp. 100–111, 2016, doi: 10.1016/j.conbuildmat.2016.02.157.

[16] 2017 ETRma, "ETRma Annual Report 2017." European Tyre and Rubber manufacturers assosciation, 2017. [Online]. Available: https://www.etrma.org/wp-content/uploads/2019/09/20170905-etrma-annual-report-2016-17-final.pdf

[17] M. Saleem and N. Blaisi, "Development, testing, and environmental impact assessment of glow-in-the-dark concrete," *Struct. Concr.*, vol. 20, Jul. 2019, doi: 10.1002/suco.201800221.

[18] M. Zubair *et al.*, "Cellulose Nanocrystals from Office Paper Waste for Green Mortar: Process Optimization Modeling, Characterization, and Mechanical Properties," *Arab. J. Sci. Eng.*, Feb. 2022, doi: 10.1007/s13369-022-06609-8.

[19] "ASTM International - ASTM C494/C494M-17 - Standard Specification for Chemical Admixtures for Concrete | Engineering360." https://standards.globalspec.com/std/3865048/astm-c494-c494m-17 (accessed Jan. 20, 2022).

[20] "ASTM C39.C39M - 16 _ Compressive Strength of Cylindrical Concrete Specimens," *pdfcoffee.com*. https://pdfcoffee.com/astm-c39c39m-16-compressive-strength-of-cylindrical-concrete-specimens-4-pdf-free.html (accessed Jan. 20, 2022).

[21] F. Majdzadeh, S. M. Soleimani, and N. Banthia, "Shear strength of reinforced concrete beams with a fiber concrete matrix," *Can. J. Civ. Eng.*, vol. 33, pp. 726–734, Feb. 2011, doi: 10.1139/l05-118.

[22] R. S. Olivito and F. A. Zuccarello, "An experimental study on the tensile strength of steel fiber reinforced concrete," *Compos. Part B Eng.*, vol. 41, no. 3, pp. 246–255, Apr. 2010, doi: 10.1016/j.compositesb.2009.12.003.

[23] C. Wang, "Experimental investigation on behavior of steel fiber reinforced concrete (SFRC)," 2006, doi: 10.26021/3503.