MIX PROPORTIONING OF RECYCLED STEEL FIBER REINFORCED SELF COMPACTING CONCRETE

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ABSTRACT. In this paper it has been investigated that how the fresh and solidified properties of Self compacting concrete (SCC) influenced by recycled steel fiber (RSF) obtained from end life of used tires. The recycled steel fiber of length 35 mm and aspect ratio of 22 was used at percentage of 0.5, 1 and 1.5% by volume. The slump flow and J ring apparatus were primely used to check the workability criteria as per EFNARC 2005 guideline because yet there is no codal provisions or guidelines made for fiber reinforced self-compacting concrete. To make a sustainable and economically viable mix, mineral admixtures i.e. Fly ash and silica fume were used which also helps in increasing workability and viscosity respectively. Grading of aggregate was also done to get desire workability. Super plasticizer was used to increase flowability of mix. And seven days compressive strength checked to get the desire proportioning of the mix.

Keywords: SCC, Recycled steel fiber, Fly ash, workability, silica fume

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INTRODUCTION

The waste management of used tires is major concern for many environmental bodies and agencies worldwide. The problem has drawn attention of planners, environmentalists, consumers and industry in the developed countries in Western Europe, USA, Japan, Australia etc. where billions of used tires are stockpiled. These stockpiles are also direct loss of energy and resources. Besides of it may prone to fire, health hazard and other environmental issues. To use waste material by material recovery from used tires is undertaken by utilizing either mechanical or thermal degradation processes. The former reduces tire to steel fibers and granulated rubber whereas the later process breaks down the tires into steel, char, liquids and gases [1]. Timely action regarding recycling of used tires is necessary in view of the problem of disposing of used tires. keeping in view the increasing cost of raw material, resource constraints and environmental problems, including fire and health hazards associated with the stockpiles of the used tires [2,3].

SCC is characterized by its ability to consolidate under its own weight without any means of compaction or vibration. SCC has the ability to spread smoothly in congested reinforced elements due to its flowability and use of small size aggregates [7-12]. SCC has been used in several projects, including residential buildings or large infrastructure for densely reinforced elements such as walls, load transfers floors, precast elements, and offshore structures and for many other [11,13-15].

Nowadays, it is well documented that the fibers added to concrete can substantially improve many of its engineering properties [7]. Introducing fibers into the concrete matrix can improve its properties, and enable the utilization of high strength concrete, while maintaining a ductile behavior. Steel or synthetic fibers help to improve various mechanical properties, fire resistance and reduce plastic shrinkage of SCC as well as to enhance the sustainability of a SCC matrix [16-21]. It has been observed that the performance of Self compacting fiber reinforced concrete (SCFRC) was much better than that of the corresponding Normal Vibrated Fiber Reinforced Concrete (NVFRC). Optimum fiber content was governed by the workability requirement of the concrete mixture. Information on the mix proportioning methods of SCC and SCFRC is also available [8,22-24]. There are numerous studies which have been done on the behaviour of Normal vibrated concrete incorporating recycled steel fiber obtained from the waste tires [25-38].

RESEARCH SIGNIFICANCE

Very little information exists in literature on the mix proportioning and fresh properties of SCC with recycled steel fiber [39-41]. So, this study mainly focuses on the proportioning of ingredient of concrete and form SCC with RSF.

EXPERIMENTAL PROGRAM

Materials

- Fibers

Recycled steel fibers of aspect ratio of 22 and diameter 1.65 was used in this study which was prepared from the steel wire obtained from the end life of scrap trucks tire. These wires are extracted through shredding process but there is little amount of tire rubber remained which was removed by peeling out it from board cutter and made bunch of cleaned surface wire so that it is easy to cut by the abrasive tool in required size of fibers. In the present study three fiber volume fractions i.e. 0.5, 1 and 1.5 % was used.

- Cement

Ordinary Portland Cement (OPC) of 43 Grade confirming IS 8112 :1989 was used.

- Filler material

Fly ash and silica fume was used as a replacement of cement to increase the workability and viscosity for stability of the mix respectively. The fly ash was provided by Ambuja Cement Plant Ropar. And silica fume was procured from Astra Chemicals, Chennai.

- Aggregates

Crushed stone aggregates of size 12.5 mm or below will be used as coarse aggregates (CA) in three size gradations i.e. 12.5-10 mm, 10-6.3 mm and 6.3-4.75 mm in percentage of 33%, 42% and 25% of amount of CA for mix and locally available coarse sand will be used as fine aggregates confirming to IS 383-2016.

- Admixtures

A polycarboxylic ether-based superplasticizer Master Glenium 51 was used in suitable dosages to obtain the required SCC and SCFRC mixes with different volume fractions of steel fiber.

Methodology

The basic mix proportion for SCC was done on the basis of Nan Su method [23] and Modified Nan Su Method [24] as follows:-

1. Calculation of quantity of fine and coarse aggregate

The packing factor (PF) find out experimentally 1.10 by proportioning the gradation of coarse aggregates (density w_{ca} =1504 kg/m^3) and fine aggregates (density w_{fa} =1400 kg/m^3). The volume of FA to all in aggregate (s/a) ratio taken from the literature which may be 0.50-0.57 but in this study it was consider 0.59 due to fiber inclusion.

$$W_{fa} = PF \times w_{fa} \times (s/a)$$
$$= 1.1 \times 1400 \times 0.59 = 908.6 \text{ kg/m}^3$$

$$W_{ca} = PF \times w_{ca} \times (1\text{-}s/a)$$
$$= 1.1 \times 1504 \times (1\text{-}0.59) = 678.3 \text{ kg/m}^3$$

2. Calculation of cement content

The design strength of concrete (f_c) opted 40 MPa

$$C = 7f_c \times C.F. = 7 \times 40 \times 1.38 = 386.4 \text{ kg/m}^3$$

Where CF represent correction factor as per method proposed by [24].

3. Calculation of mixing water content required by cement

The water to cement ration was kept 0.58

$$W_{wc} = (w/c) \times C = 0.58 \times 386.4 = 224.11 = 224.11 \text{ say } 224 \text{ kg/m}^3$$

4. Calculation of fly ash (FA) and silica fume (SF) contents

Total volume of filler V_{pf} for the assumed air entrained V_a= 1.5%

V_{pf} = 1- (W_{ca}/ (1000 × G_{ca})) - (W_w/ (1000 × G_w)) - (W_{fa}/ (1000 × G_{fa})) - (C/ (1000 × G_c))- V_a

= 1- (678/(1000 × 2.65)) - (224/(1000 × 1)) - (909/(1000 × 2.64)) - (386/(1000 × 3.15)) - 0.015

= 0.0383 m^3

Now the amount of filler calculated as follows

V_{pf} = (1+ w/FA) × A% × (W_{pm}/1000 × G_{fa}) + (1+ w/SF) × B% × (W_{pm}/1000 × G_{sf})

0.0383 **= (**(1+ 0.58) × 0.6 × W_{pm}/1000 × 2.10) + ((1+0.58) × 0.4 × W_{pm}/1000 × 2)

W_{pm} = 49.93 say 50 kg/m^3

Now, content of Fly Ash = W_{pm} × A% = 50×0.6 =30 kg/m^3

content of Silica Fume = W_{pm} × B% = 50×0.4 =20 kg/m^3

5. Calculation of mixing water content for fly ash and silica fume needed in SCC

Water required for Fly Ash (W_{FA})= 30 × 0.58 = 17.4 kg/m^3

Water required for Silica Fume (W_{SF})= 20 × 0.58 = 11.6 kg/m^3

6. Calculation of SP dosage

W_{SP} = 0.60 × (386 + 30 + 20) / 100 = 2.62 kg/m^3

Amount of water in SP

Ww_{SP} = (1-0.4) × 2.62 = 1.57 kg/m^3

7. Adjustment of mixing water content needed in SCC

W = 224 + 17.4 + 11.6 – 1.57 = 251.43 kg/m^3

8. Trial mixes and tests on SCC properties

trials were made to obtain suitable SCC (table 1)

Table 1 Mix for SCC after trials

CEMENT	FLY ASH	SILICA FUME	FINE AGGREGATES	C.A.	WATER	SP
386	78	52	817	503	251	3.61

9. Adjustment of mix proportions

There were adjustments made in amount of water, superplasticizer, FA and SF for maintaining workability and viscosity in the mix respectively. Also, it helps to make mixture more flowable and stable without adding viscosity modifying agent (VMA) requirement. Haddadou 2014 [42] and [43], investigate that increased amount of binders and altering in fine aggregates provide better dispersion of fibers and compensate for the effect of randomly distribution of fibers which causes porosity [43].

Now the obtained mix proportion from the above method as follows (table 2): -

Table 2- Mix after adjustment

CEMENT (kg/m^3)	FLYASH (kg/m^3)	S.F. (kg/m^3)	F.A. (kg/m^3)	C.A. (kg/m^3)	WATER (kg/m^3)	SP (%)
389.16	376.65	92.94	812.50	500.11	229.78	0.7%

10. Inclusion of fibers in SCC

As Grunewald and Wal raven 2001 [43] investigate that fibers have a long shape and compare with the aggregate of the same volume, a higher specific surface. Zhao and Du 2008[44] replace the equal amount of coarse aggregate with equal amount of steel fiber. And the quantity of steel fiber is consider in the sand ratio but this technique was used for normal vibrated concrete. In this study the paste and fine aggregate amount is more aggregate content. So here the coarse aggregate was directly replaced by equal amount of weight of the fiber content. Proceeding this approach, the mixes were formed and amount of SP also adjusted as per requirement of mix based on trials as tabulated in table 3-

Table.3 final mix proportion with and without fibers

Mix ID	C (kg/m^3)	FyA (kg/m^3)	S.F. (kg/m^3)	F.A. (kg/m^3)	C.A. (kg/m^3)	Water (kg/m^3)	SP (%of TOTAL BINDER CONTENT)	FIBER CONTENT (kg/m^3)
M0	389.16	376.65	92.94	812.50	500.11	229.78	0.7%	-
M1	389.16	376.65	92.94	812.50	460.86	229.78	0.8%	39.25
M2	389.16	376.65	92.94	812.50	421.61	229.78	0.8%	78.50
M3	389.16	376.65	92.94	812.50	382.36	229.78	0.8%	117.75

Mixing procedure

For mixing a drum mixture was used. Firstly, fine and coarse aggregate were dry mixed for 3 min. In this amount of water was also added as per water absorption of aggregate to made them surface saturated condition. Then Fly ash, silica fume and cement were added and mixed the whole quantity for 5 min. Now, the water with required amount of superplasticizer added up to 90% of total amount of water and SP, and mixed for 5 mins. Add fiber by sprinkling by hand and remaining 10 % water added and mix it for 3 to 5 min till the sign of forming SCC.

RESULT AND DISCUSSION

Fresh Properties and compressive strength

There is no codal criteria to check properties of steel fiber reinforced self- compacting concrete (SFRSCC) yet, so to check the fresh properties of SCC with fiber EFNARC 2005 for SCC was used. For the preliminary examination for SFRSCC here only two criteria of flowability was checked one slump flow test and another one J ring test. The result obtained is given in table 4 from the result it was observed that the flowability is reduced as the fiber volume was increased as shown in **Fig. 1 (a)** and **(b)**, the same result was shown by Matsali et. Al (2017,2016) [39,41]. There is increase in compressive strength as the fiber content increased as show in table 4. the same pattern was show in the study by Matsali et. Al (2017) [41].

Table .4 Result of Slump flow, J Ring test and 7 day compressive strength of mixes

MIX ID	SLUMP FLOW (MM)	J RING TEST (MM)	COMPRESSIVE STRENGTH (7 DAYS IN MPA)
M0	760 mm	730	26.05
M1	720 mm	700	28.45
M2	710 mm	685	29.80
M3	705 mm	670	31.70

Figure1 (a) J ring for SCC with No fiber content (M0) and (b) J ring for SCC with 1.5 % fiber content (M3)

CONCLUSION

On the basis of experimental work, the following finding was observed-

- On the basis of J ring Test and slump flow test it can be stated that the workability was affected by the inclusion of RSF in concrete and the superplasticizer demand increases.
- The compressive strength was increased with increasing the RSF in the mix.

The RSF increase its strength by incorporating in concrete. So, it is beneficial to use RSF as reinforcement in SCC.

REFERENCES

1. http://tifac.org.in/index.php?option=com_content&id=676&Itemid=205

2. SUDHA RANI, RAJESH AGNIHOTRI, “Recycling of scrap tyres”, International Journal of Materials Science and Applications, 3(5), 2014, pp 164-167.

3. https://www.nbmcw.com/concrete/20090-sustainable-concrete-with-scrap-tyre-aggregate.html

4. M. LEONE et.al. “Fiber-reinforced concrete with low content of recycled steel fiber: Shear behavior”, Construction and Building Materials 161, 2018, pp141–155.

5. HANG HU et.al, “Mechanical properties of SFRC using blended manufactured and recycled tyre steel fibres”, Construction and Building Materials 163, 2018, pp 376–389.

6. INGEMAR LÖFGREN, Fiber-reinforced Concrete for Industrial Construction - a fracture mechanics approach to material testing and structural analysis” PhD thesis, 2005, Chalmers University of Technology, Goteborg, Sweden.

7. RAHMAT MADANDOUST et.al,” Assessment of factors influencing mechanical properties of steel fiber reinforced self-compacting concrete”, Materials & Design 83, 2015, pp 284–294.

8. SANJAY GOEL, “flexural fatigue strength of self compacting fiber reinforced concrete”, Doctoral Thesis, 2012, Dr. B R Ambedkar NIT Jalandhar-144011, Punjab, India.

9. ACI COMMITTEE 237, Self Consolidating Concrete, ACI Emerging Technology series 237R-07,2007, pp. 1-30.

10. EFNARC, “The European Guidelines for Self-Compacting Concrete, Specification, Production and Use.”, May 2005, pp 68.

11. O. GENCEL, et.al, “Workability and mechanical performance of steel fiber-reinforced self-compacting concrete with fly ash”, Compos. Interfaces 18 (2), 2011, pp 169–184.

12. K.M.A. HOSSAIN, M. LACHEMI, “Fresh, mechanical, and durability characteristics of self-consolidating concrete incorporating volcanic ash”, ASCE J. Mater. Civil Eng. 22 (7), 2010, pp 651–657.

13. H. MAZAHERIPOU, et.al, “The effect of polypropylene fibers on the properties of fresh and hardened lightweight self-compacting concrete”, Constr. Build. Mater. 251 (1), 2011, pp 351–358.

14. S.D. HWANG, K. KHAYAT, “Durability characteristics of self-consolidating concrete designated for repair applications”, Mater. Struct. 42 (1), 2009, pp 1–14.

15. A.L. ARDESHANA, A.K. DESAI, “Durability of fiber reinforced concrete of marine structures”, Int. J. Eng. Res. Appl. 4 (2), 2012, pp 215–219.

16. S. CATTANEO, F. GIUSSANI, F. MOLA, Flexural behavior of reinforced, prestressed and composite self-consolidating concrete beams, Constr. Build. Mater. 36 (11), 2012, pp 826–837.

17. BROUWERS, H. J. H. AND RADIX, H. J., “Self-Compacting Concrete: Theoretical and Experimental Study”, Cement and Concrete Research, Vol. 35, 2005, pp. 2116-2136.

18. L. FERRARA, Y.D. PARK, S.P. SHAH, “A method for mix-design of fiber-reinforced self-compacting concrete”, Cement and Concrete Res. 37 (6), 2007, pp 957–971.

19. V. CORINALDESI, G. MORICONI, “Characterization of self-compacting concretes prepared with different fibers and mineral additions”, Cement Concr. Compos. 33 (5), 2011, pp 596–601.

20. SHERIF YEHIA et.al,” Mechanical and durability evaluation of fiber-reinforced self-compacting concrete”, Construction and Building Materials 121, 2016, pp 120–133.

21. SUMIT ARORA, “Flexural fatigue performance of concrete made with recycled concrete aggregates” Doctoral Thesis,2017, Dr. B R Ambedkar NIT Jalandhar-144011, Punjab, India

22. GROTH, P. AND NEMEGEER, D., “The Use of Steel Fibers in Self-Compacting Concrete,” Proceedings of First International RILEM Symposium on Self-Compacting Concrete, 1999, pp. 497-507.

23. SU, N., HSU, K. C. AND CHAI, H. W., “A Simple Mix Design Method for Self Compacting Concrete”, Cement and Concrete Research, Vol. 31, 2001, pp. 1799-1807.

24. VILAS V. KARJINNI AND SHRISHAIL. B. ANADINNI,” Mixture proportion procedure for SCC”, Indian Concrete Journal, June, 2009.

25. DOMSKI, J., J. KATZER, M. ZAKRZEWSKI, AND T. PONIKIEWSKI. “Comparison of the mechanical characteristics of engineered and waste steel fiber used as reinforcement for concrete”. Journal of Cleaner Production 158, 2017, pp 18-28.

26. AHMADI, M., S. FARZIN, A. HASSANI, AND M. MOTAMEDI., Mechanical properties of the concrete containing recycled fibers and aggregates, Construction and Building Materials 144, 2017, pp 392-398.

27. MARTINA DRDLOVA, OLDŘICH SVITAK AND VLADAN PRACHAR, "Slurry Infiltrated Fiber Concrete with Waste Steel Fibres from Tires - The Behavior under Static and Dynamic Load", Materials Science Forum, Vol. 908, 2017, pp. 76-82.

28. AL-KAMYANI, Z., K. PILAKOUTAS, M. GUADAGNINI, AND P. PAPASTERGIOU, Free and restrained shrinkage of hybrid steel fibres reinforced concrete. High Tech Concrete: Where Technology and Engineering Meet - Proceedings of the 2017 fib Symposium, 2017 pp. 339-346.

29. BARICEVIC, A., D. BJEGOVIC, AND M. SKAZLIC, Hybrid fiber-reinforced concrete with unsorted recycled-tire steel fibers. Journal of Materials in Civil Engineering 29, 2017, no. 6.

30. CAGGIANO, A., P. FOLINO, C. LIMA, E. MARTINELLI, AND M. PEPE, On the mechanical response of hybrid fiber reinforced concrete with recycled and industrial steel fibers. Construction and Building Materials 147, 2017, pp 286-295.

31. GROLI, G. AND A. P. CALDENTEY, Improving cracking behavior with recycled steel fibres targeting specific applications – analysis according to fib model code 2010. Structural Concrete 18, no. 1, 2017, pp 29-39.

32. MEDINA, N. F., D. F. MEDINA, F. HERNÁNDEZ-OLIVARES, AND M. A. NAVACERRADA, Mechanical and thermal properties of concrete incorporating rubber and fibres from tyre recycling. Construction and Building Materials 144, 2017, pp 563-573.

33. NEHDI, M. L., M. F. NAJJAR, A. M. SOLIMAN, AND T. M. AZABI, Novel eco-efficient two-stage concrete incorporating high volume recycled content for sustainable pavement construction. Construction and Building Materials 146, 2017, pp 9-14.

34. ONUAGULUCHI, O., P. H. R. BORGES, A. BHUTTA, AND N. BANTHIA, Performance of scrap tire steel fibers in OPC and alkali-activated mortars. Materials and Structures/Materiaux Et Constructions 50, 2017, no. 2.

35. PAPAKONSTANTINOU, C.G., TOBOLSKI, M.J, Use of waste tire steel beads in Portland cement concrete Cement and Concrete Research, 36 (9), 2006, pp. 1686-1691.

36. NEOCLEOUS, K., H. TLEMAT, AND K. PILAKOUTAS, Design issues for concrete reinforced with steel fibers, including fibers recovered from used tires. Journal of Materials in Civil Engineering 18, no. 5, 2006, pp 677-685.

37. TLEMAT, H., K. PILAKOUTAS, AND K. NEOCLEOUS, Stress-strain characteristic of SFRC using recycled fibres. Materials and Structures/Materiaux Et Constructions 39, no. 287, 2006, pp 365-377.

38. PILAKOUTAS, K., K. NEOCLEOUS, AND H. TLEMAT, Reuse of tyre steel fibres as concrete reinforcement. Proceedings of the Institution of Civil Engineers: Engineering Sustainability 157, no. 3, 2004, pp 131-138.

39. MASTALI, M. AND A. DALVAND, Fresh and hardened properties of self-compacting concrete reinforced with hybrid recycled steel-polypropylene fiber. Journal of Materials in Civil Engineering 29, 2017, no. 6.

40. GROLI, G., A. PÉREZ CALDENTEY, AND A. G. SOTO, Cracking performance of SCC reinforced with recycled fibres - an experimental study, Structural Concrete 15, 2014, pp 136-153.

41. M. MASTALI, A. DALVAND, “Use of silica fume and recycled steel fibers in self-compacting concrete”, Construction and Building Materials, 125, 2016, pp 196-209.

42. NAIMA HADDADOU, RABAH CHAID & YOUCEF GHERNOUTI Experimental study on steel fibre reinforced self-compacting concrete incorporating high volume of

marble powder, European Journal of Environmental and Civil Engineering, Volume 19, 2015, Issue 1

43. GRUNEWALD, S., WALRAVEN, J.C., "Self-compacting fiber-reinforced concrete" HERON, vol. 46 (3), 2001. ISSN 0046-7316.

44. MINGLEI ZHAO, Study on effect of flowability on steel fiber distribution patterns and mechanical properties of SFRC, master of engineering thesis, 2018, RMIT University, Australia.