29th International Conference
ENGINEERING MECHANICS 2023
Milovy, Czech Republic, May 9 – 11, 2023

APPLICATION OF DISCARDED TIRE STEEL FOR IMPROVING THE SUSTAINABILITY OF CONCRETE STRUCTURES

Zia A.[*], Zhang P.[**], Holly I.[***], Prokop J.[****] Ondák, A.[*****]

Abstract: *The use of fibers is crucial for the sustainability enhancement of concrete structures. However, the commonly used commercial fibers are costly, and their production involves the generation of CO_2. On the other hand, the accumulation of discarded tire steel fibers (DSFs) is a big hurdle in the sustainability enhancement of modern society. Therefore, it is vital to study the effectiveness of steel fibers recovered from discarded tires (DSF) for potential applications in the construction industry. Therefore, this study aims to examine the effectiveness of DSFs in achieving sustainable concrete structures. As a preliminary study, the linear shrinkage (LS) and indirect tensile strength (TS) of the DSF-reinforced concrete (DFRC) are examined. 0.30% and 0.75% of the DSFs are incorporated into concrete by volume fraction. Plain concrete (PC) is used as a reference. All tests are carried out following the ASTM standard. An improvement of 16% is noted in the TS of DFRCs compared to PC. The LS of DFRC decreased by 34% compared to the LS of PC. Therefore, it can be concluded that the DSFs can improve the sustainability of concrete structures. Therefore, it is recommended to study the long-term durability of DSF-reinforced concrete structures for practical implementation.*

Keywords: Waste tire recycling, Recycled steel fibers, Waste tires steel fibers, Fiber-reinforced concrete, Steel-fiber reinforced concrete, Recycled steel fiber-reinforced concrete.

1. Introduction

The sustainability of concrete structures is critical in achieving the sustainability goals of the United Nations. For sustainability improvement, it is essential to increase the serviceable lifespan of concrete structures. Fibers, including industrial, artificial, and natural fibers, are commonly used to increase the serviceable life of concrete structures. Different types of fibers have been used for this purpose (Zia & Ali, 2017, 2018). However, all types of industrial fiber involve production costs and the generation of CO_2 (Liew & Akbar, 2020a).

On the other hand, the reuse of waste in construction materials has been considered in the construction industry. One of the major pollutions is the increasing burden of discarded tires. Approximately 42 million discarded tires are accumulated in the Kuwait desert (Hagagy, 2021). The waste tires have been recycled in various sectors for numerous applications, including the energy sector (ETRMA, 2021). Many steel fibers are obtained from discarded tires after use in the energy sector as fuel. However, the discarded tire steel fibers (DSFs) are solid and not easy to recycle as they are not biodegradable. Therefore, it has been

[*] MSc. Eng. Asad Zia: School of water conservancy and civil engineering, Zhengzhou University China & Department of Concrete Structures and Bridges, Slovak University of Technology, Radlinského 11; 810 05, Bratislava; SK. asadzia005@gs.zzu.edu.cn, and xzia@stuba.sk

[**] Prof. Pu Zhang, PhD.: School of water conservancy and civil engineering, Zhengzhou University China. zhpu@zzu.edu.cn

[***] Assoc. Prof., Eng. Ivan Holly, PhD.: Department of Concrete Structures and Bridges, Slovak University of Technology, Radlinského 11; 810 05, Bratislava; SK, ivan.holly@stuba.sk

[****] Eng. Jaroslav Prokop: Department of Concrete Structures and Bridges, Slovak University of Technology, Radlinského 11; 810 05, Bratislava; SK, jaroslav.prokop@stuba.sk

[*****] Eng. Adrián Ondák: Department of Concrete Structures and Bridges, Slovak University of Technology, Radlinského 11; 810 05, Bratislava; SK, adrian.ondak@stuba.sk

ISSN: 1805-8256, doi: 10.21495/em2023-271

recommended to reuse DSFs in construction materials to maximize recycling. Furthermore, due to the resemblance of the DSFs with industrial fibers, it is expected that they can replace partially or fully industrial fibers for various applications in the construction industry. Therefore, it is crucial to examine the effectiveness of DSFs in the performance improvement of concrete.

Many studies have been conducted to evaluate the influence of various types of DSFs on the properties of concrete. Significant improvements were reported in the compressive, splitting tensile, and flexure strengths of DSF-reinforced concrete compared to plain concrete (Liew & Akbar, 2020b; Zia et al., 2022). However, the available results are insufficient to conclude the optimal dosage of DSFs for a particular application in the construction industry for practical implementation. The results related to some strength properties of DFRC, such as tensile strength and linear shrinkage reported in previous studies, are contradictory. Some authors noticed an increase in the split tensile strength (Leone et al., 2016), while some noticed a decrease in split tensile strength for incorporating DSFs (Groli et al., 2014). In addition, the durability-defining properties are also not explored as needed. Therefore, it is necessary to extend the available database of the experimental tests of the DFRC. Particularly, the linear shrinkage and water absorption need to be examined. It can help extend the uses of DSFs for achieving sustainable concrete structures.

Therefore, the current study is conducted to examine the influence of the local DSFs of Bratislava, Slovakia, on the local concrete C20/25. The indirect tensile strength (TS) and linear shrinkage are determined. In addition, 0.30% and 0.75% of DSFs are added to concrete by volume fraction. The densities and slumps are also reported. The study can help to examine the sustainability of local DSFs for possible use in improving the sustainability of local structures.

2. Casting and testing procedures

The locally available materials are used in this study. Locally available concrete, C20/25 of Cemix Bratislava Slovakia, is used. The locally discarded tire steel fibers (DSFs) of Bratislava, Slovakia, are used. The fibers are used in the raw form, containing approximately 1% of impurities such as polyester and rubber particles. The diameter of the DSFs used in the current study varies from 0.05 mm to 1.882 mm. Most DSFs used had lengths of 1.5 mm to 22.5 mm. The detailed properties of DSFs are given in another study (Zia et al., 2023). A traditional concrete mixer is used for mixing concrete. The same amount of water is used for all mixtures. Specimens for all types of tests are prepared in standard sizes as per ASTM standards. Splitting tensile strength and linear shrinkage tests are performed according to C496/C496 M-17 and ASTM C157/C157 M-08, respectively. The initial reading of linear shrinkage is taken after 12 hours of adding water. The specimens are cured for 28 days in water and then tested. An average of three readings is taken for each property.

3. Results and analysis

3.1 Workability test results

The results of the slump cone test for each batch are demonstrated in Tab. 1. The slumps of 120 mm, 76 mm, and 40 mm are noted for PC, 0.3DFRC, and 0.7DFRC, respectively. Reductions of 44 mm and 80 mm are noted in the slumps of 0.3DFRC and 0.7DFRC, respectively. The slumps of 0.3DFRC and 0.7DFRC decreased by 37% and 67% than that of PC, respectively.

Tab. 1: Slump cone test results

Mixture	Value (mm)	Percent slump (%)
PC	120	100
0.3DFRC	76	63
0.7DFRC	40	33

3.2 Linear Shrinkage

The linear shrinkage test results are demonstrated in Tab. 2. The coefficient of variation (COV) is also given for the linear shrinkage (LS). The LS of 0.016%, 0.012%, and 0.013% are noted for PC, 0.3DFRC, and 0.7DFRC, respectively. The LS of 0.3DFRC and 0.7DFRC decreased by 0.004% and 0.013% than that of PC. The percent comparison of the LS is also given in Tab. 2. A reduction of 25% and 19% is noticed in the LS of 0.3DFRC, and 0.7DFRC than that of PC, respectively. The discarded tire steel fibers (DSFs) decreased the LS significantly due to their constraining effect. It is noted that an increase in the dose of DSFs adversely affects the LS compared to the low dosage. The probable reason could be the increase in heterogeneity of the concrete due to the insertion of a high volume of DSFs. Although, the LS at 0.75% DSFs is not more than the LS of PC.

Tab. 2: Linear shrinkage test results

Mixture	LS (%)	COV (%)	Percent LS (%)
PC	0.016	0	100
0.3DFRC	0.012	2	75
0.7DFRC	0.013	5	81

3.3 Indirect tensile strength

The splitting tensile strength test determines the indirect tensile strength of specimens. Indirect tensile strength properties of specimens are given in Tab. 3.

Tab. 3: Indirect tensile test results

Mixture	TS (MPa)	TS-COV (%)	Percent TS (%)	TSE (kN.s)	Percent TSE (%)
PC	1.60	3.9	100	4039	100
0.3DFRC	1.80	3.0	13	6740	67
0.7DFRC	1.70	0.1	6	5392	33

The coefficients of variation (COVs) are also given for the indirect tensile strengths (TS). The TS of 1.60 MPa, 1.80 MPa, and 1.70 MPa are noted for PC, 0.3DFRC, and 0.7DFRC, respectively. The TS of 0.3DFRC and 0.7DFRC increased by 0.20 MPa and 0.10 MPa than that of PC, respectively. The total energy absorption is also computed for TS. The total energy absorption for TS (TSE) is the total area under the load-time curve of splitting tensile strength. The TSEs of 4039 kN.s, 6740 kN.s, and 5392 kN.s are noted for PC, 0.3DFRC, and 0.7DFRC, respectively. The TSEs of 0.3DFRC and 0.7DFRC increased by 2701 kN.s and 1353 kN.s than the TSE of PC, respectively.

Percent comparison of indirect tensile strength test results is also demonstrated in Tab. 3. Increases of 13% and 6% are noticed in the TS of 0.3DFRC and 0.7DFRC than TS of PC, respectively. The DSFs increased the tensile strength of concrete significantly than that of PC. An increase in TS shows the potential of DSFs to improve the resistance of concrete against tensile stresses and tensile cracking. The TSEs of 0.3DFRC and 0.7DFRC improved by 67% and 33%, respectively. DSFs improved the tensile strength and energy absorption of concrete considerably. By using DSFs, the post-crack, and pre-crack properties are likely to be improved. It can be concluded that the DSFs are likely to control the tensile cracking in concrete due to alternate wetting and drying and due to extreme weather conditions.

4. Discussion

The construction industry is striving to increase the sustainability of civil engineering structures. One of the major flaws is the brittleness and lower tensile strength of concrete. Due to non-ductile behavior, the micro-cracks in concrete convert to macro cracks rapidly with zero post-crack energy absorption. On the other hand, due to negligible tensile strength, plain concrete does not perform well when subjected to alternate wetting and drying and other environmental drivers causing tensile stresses in concrete structures. Marine structures, side walls of water channels, and concrete waterways are commonly subjected to tensile stresses and length changes. Thus, their serviceable life and sustainability are significantly decreased. The inclusion of fibers can improve the tensile properties and ductility of concrete. But commonly used fibers, including natural and industrial fibers, carry a cost and significantly increase the project cost. Therefore, it is necessary to find alternative materials to improve the properties and sustainability of concrete structures. In this respect, discarded tire fibers (DSFs), which resemble industrial steel fibers, are expected to replace industrial fibers partially or wholly.

Therefore, in this preliminary study, the effectiveness of discarded tire steel fiber for the properties improvement of concrete is evaluated. The linear shrinkage, indirect tensile strength, and indirect tensile energy absorption capacity are determined. Furthermore, significant improvements are noticed in the considered properties of DSF-reinforced concrete than that of plain concrete. It showed that DSFs are likely to improve the cracking behavior of concrete by improving its linear shrinkage, strength properties, and energy absorption. Using the DSFs, the fracture properties can be enhanced, and the structures can sustain loads even after the first crack. Most importantly, the cracked sections of concrete structures like canal linings can be repaired at a low cost without needing to replace them with new ones. Thus, the sustainability of concrete structures can be increased further at the minimum cost compared to the costly industrial fiber-reinforced concrete.

5. Conclusions and recommendations

The effectiveness of discarded tire steel fibers (DSFs) for sustainability enhancement of concrete structures in terms of tensile properties and linear shrinkage is presented in this study. Locally available DSFs and concrete from Bratislava, Slovakia, are used. The following conclusions are drawn from this study.

- The slumps of 0.3DFRC and 0.7DFRC decreased by 37% and 67% than that of PC, respectively.
- Reductions of 25% and 19% are noticed in the LS of 0.3DFRC and 0.7DFRC than that of PC.
- Increases of 13% and 6% are noticed in the TS of 0.3DFRC and 0.7DFRC than the TS of PC.
- The TSEs of 0.3DFRC and 0.7DFRC improved by 67% and 33% compared to that of PC.

The substantial improvements in tensile strength and tensile total energy absorption of DFRC showed that the DSFs could increase the resistance of concrete against tensile fracture and change its brittle behavior to ductile. The reduction in linear shrinkage also shows the effectiveness of DSFs in avoiding cracking due to changes in length in concrete. Therefore, evaluating the long-term performance and durability of DSR-reinforced concrete structures for sustainable construction is highly recommended.

Acknowledgment

The authors acknowledge the financial support from the Scientific Grant Agency VEGA under contract No. VEGA 1/0358/23.

References

ETRMA. (2021). *European Tyre and Rubber Industry Statistics 2021*. https://www.etrma.org/wp-content/uploads/2021/12/20211215-Statistics-booklet-2021VF.pdf

Groli, G., Pérez Caldentey, A., & Soto, A. G. (2014). Cracking performance of SCC reinforced with recycled fibres - An experimental study. *Structural Concrete*, *15*(2). https://doi.org/10.1002/suco.201300008

Hagagy, A. (2021, September 20). Tackling Kuwait's "tire graveyard" problem by tire recycling. *Sustainable Development Impact Summit*. https://www.weforum.org/agenda/2021/09/this-company-is-tackling-kuwaiit-s-tyre-graveyard-problem/

Leone, M., Centonze, G., Colonna, D., Micelli, F., & Aiello, M. A. (2016). Experimental Study on Bond Behavior in Fiber-Reinforced Concrete with Low Content of Recycled Steel Fiber. *Journal of Materials in Civil Engineering*, *28*(9), 04016068. https://doi.org/10.1061/(asce)mt.1943-5533.0001534

Liew, K. M., & Akbar, A. (2020a). The recent progress of recycled steel fiber reinforced concrete. *Construction and Building Materials*, *232*. https://doi.org/10.1016/j.conbuildmat.2019.117232

Liew, K. M., & Akbar, A. (2020b). The recent progress of recycled steel fiber reinforced concrete. *Construction and Building Materials*, *232*, 117232. https://doi.org/10.1016/j.conbuildmat.2019.117232

Zia, A., & Ali, M. (2017). Behavior of fiber reinforced concrete for controlling the rate of cracking in canal-lining. *Construction and Building Materials*, *155*. https://doi.org/10.1016/j.conbuildmat.2017.08.078

Zia, A., & Ali, M. (2018). Effectiveness of polypropylene fiber reinforced concrete in enhancement of long-term durability of hydraulic structures. *Materials Science Forum*, *923 MSF*. https://doi.org/10.4028/www.scientific.net/MSF.923.125

Zia, A., Pu, Z., Holly, I., Umar, T., Tariq, M. A. U. R., & Sufian, M. (2022). A Comprehensive Review of Incorporating Steel Fibers of Waste Tires in Cement Composites and Its Applications. *Materials*, *15*(21), 7420. https://doi.org/https://doi.org/10.3390/ma15217420

Zia, A., Zhang, P., & Holly, I. (2023). Experimental investigation of raw steel fibers derived from waste tires for sustainable concrete. *Construction and Building Materials*, *368*, 130410. https://doi.org/10.1016/j.conbuildmat.2023.130410