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EFFECT OF RECYCLED STEEL FIBERS ON THE FRACTURE AND MECHANICAL PROPERTIES OF CONCRETE

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Abstract: *A considerable increase in pollution has been observed due to waste tire accumulation, causing environmental and health issues. Therefore, recycling the waste tire and its ingredients is crucial. Recycled steel fibers from waste tires (RSFs) are one of the primary ingredients of waste tires. It has been reported that incorporating RSFs in concrete can significantly improve concrete's strengths and energy absorption. This experimental research aims to investigate the compressive and flexural properties of RSF-reinforced concrete (RSFRC) with various doses of RSF. In total, 30 specimens were tested. An average of three readings is taken for each property. The compressive strength (CS) test was carried out according to STN EN 12 390-3. Flexural strength (FS) was determined on the beamlets with a notch according to JCI-S-001-2003 and JCI-S-002-2003. Plain concrete is used as a baseline. It has been observed that the inclusion of 1,9% RSF increased the CS. The bending test result is an increasing trend of fracture energy with an increasing dose of RSF. It is found that the RSFs have the potential to enhance the compressive and flexure properties of the concrete. It is recommended to evaluate the influence of RSFs on the long-term durability improvement of concrete.*

Keywords: Waste tires, Recycled steel fibers, Recycled steel fiber reinforced concrete, Compressive strength, Bending strength.

1. Introduction

As a consequence of the improper approach of waste tires, they accumulate in landfills around the world. Hu et al. (2018) stated that 1.5 billion units of billions of new tires are produced yearly, and one billion waste tires are added. Thomas et al. (2016) predicted that 1.2 billion tires will be added yearly in the 2030s. There are now strong incentives to reverse this trend. According to the "Council Directive 1999/31/EC" of the European Commission on landfills, since 2003, it is not possible to store waste tires for consumers, and since 2006 these regulations are applied on the handling of tires (Martinelli et al., 2015). The way to reduce the enormous amount of waste tires is to recycle them. It was reported that recycling of waste tires is sustainable, ecological, and health-friendly (Liew et al., 2020).

It was reported that over the past 20 years, new technologies are introduced that can recover components obtained from waste tires (Leone et al., 2018). Every year, 500 thousand tons of recycled steel fibers (RSF) are obtained from waste tires (Samarakoon et al., 2019).

There are studies focused on the experimental testing of recycled steel fiber reinforced concrete (RSFRC). Tt was found that the compressive strength of RSFRC increased with the dosage of RSF (Centonze et al., 2012), (Aiello et al., 2009). On the other hand, a decrease was observed in the compressive strength of

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RSFRC (Martinelli et al., 2015), and (Leone et al., 2018). The different conclusions of the authors above are probably due to the different geometrical and strength characteristics of RSF.

It was reported that the toughness of concrete was demonstrably increased (Martinelli et al., 2015), (Zia et al. 2023). Liew et al. (2020) and Centonze et al. (2012) confirmed that RSFs could provide comparable results to industrially produced fibers.

From the abovementioned conclusions from the research works, it is impossible to predict with certainty the behavior of RSFRC in compression and in bending. Different conclusions probably relate to different geometric and mechanical parameters of RSF. For this reason, it was necessary to develop a statistical analysis of the geometric and mechanical parameters of the RSF in this contribution and to conduct an experimental investigation of the samples under compression and bending loading.

2. Materials and methods

2.1. Recycled steel fibers

2.1.1 Geometrical parameters

Origin RFS comes from a local waste tire processing plant in the Slovak Republic Therefore, each RSF has different geometric and mechanical properties due to the origin and technology of the separation process

The average length of RSF was 12.38 mm with CoV. 41.0% minimum, respectively, and the maximum length of RSF was 1.55 mm, respectively 59.13 mm.

The mean RSF diameter was 0.241 mm with CoV. 83.7%.

2.2. Concrete type and fibers

The concrete used in the experiment was made from a dry concrete mix packed in paper bags. The concreteC20/25 is sued in the current study. The maximum aggregate size in dry mix concrete was 4 mm. Volume of water added to the dry mix of concrete was 0.134 l/kg.

Concrete mixtures were prepared with a dose of RSF of 0%, 0.4%, 0.9%, 1.4%, 1.9% by volume. The density of RSF ρ_{RSF} was determined by measurements to be 6950 kg/m3. This knowledge made it possible to calculate the exact weight of RSF that needed to be added to the concrete mix.

2.3. Methods

The concrete mixture was mixed in a gravity mixer. The concrete mixture was compacted in the molds using a vibrator. After 24 hours, the samples were placed in treatment tanks with water for 7 days. The samples were further kept in the air until they reached the age of 28 days.

The plastic molds in which the cubes were demolded for testing the compressive strength of RSFRC had an edge length of 150mm. The steel molds in which the beams were deformed for testing the bending response had dimensions of 100 x 100 x 400mm. The test for determining the compressive strength of concrete was carried out according to [STN EN 12 390-3].

3. Test results and discussion

3.1. Test results of fresh and hardened RSFRC

The results from the slump test and compression strength test are shown in Tab. 2. In the obtained results, it can be observed that the average compressive strength of concrete with a 0% dose of RSF is 18.9 MPa. In samples with a fiber dose of 0.4%, 0.9%; 1.4%, decrease in RSFRC compressive strength was recorded. This phenomenon can be explained by the fact that RSF in such low doses significantly deteriorated the workability of fresh concrete, but do not bridge the microcracks that increase when uniaxial pressure is applied to the sample. In the sample with a dosage of 1.9%, despite the deteriorated workability, the effect of the fibers on bridging expanding microcracks from the action of uniaxial pressure was manifested.

Tab. 2: Results of slump and compressive strength of RSFRC

Dosage of RSF [%]	Slump test [mm]	$f_{cm.cube}$ [MPa]	St. dev. [MPa]
0	37	18.9	2.57
0.4	22	16.9	1.05
0.9	22	17.8	0.52
1.4	24	16.0	0.73
1.9	25	18.9	0.33

3.2. Flexural test results

Fig. 3 shows the curves with F-CMOD test. From the averaged curves, it can be observed that the samples with 0% RSF broke immediately after the first crack appeared. In the case of samples with 0.4%, 0.9%, and 1.4% RSF, a sharp drop in load is observed after the appearance of the first crack. This phenomenon can be explained by the fact that RSFs are activated with a certain delay in the concrete matrix. The maximum value of CMOD at these reinforcement doses is related to the failure of the specimen at a given CMOD. In the case of samples with 1.9% RSF, it is possible to observe a negligible decrease in strength after the appearance of the first crack. The final CMOD value of approximately 4600 μm is conditioned by the range of the CMOD clip gauge, which after exceeding the value shown in Fig. 3 separated from the glued steel blades.

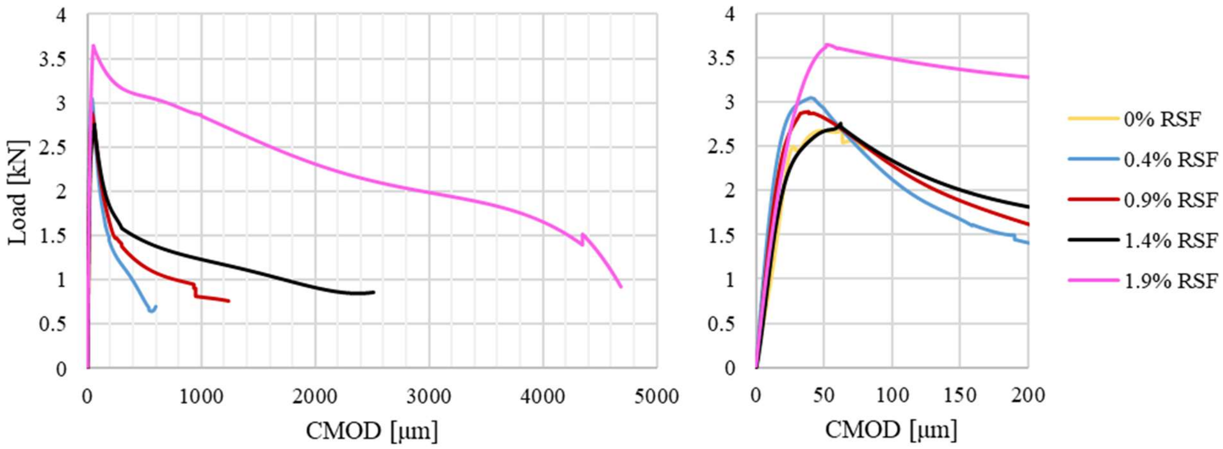

Fig. 1: Load deflection curves of CMOD test

Tab. 3 shows the maximum load values from the bending test of the RSFRC beam with a notch. In Tab. 3, the values of fracture energies calculated from the above curves, sample parameters and parameters of the test equipment are presented according to (JCI-S-001-2003) and (JCI-S-002-2003). The results show an increasing trend of fracture energies. It follows that RSF has tremendous potential in applications with a requirement for increased energy absorption.

Tab. 3: Flexural test results

Dosage of RSF	$F_{max,mean}$ [N]	$F_{max,st.dev}$ [N]	$G_{F,mean}$ [N/mm]	$G_{F,st.dev}$ [N/mm]
0	2737.5	180.3	0.016	0.002
0.4	3132.0	162.7	0.074	0.030
0.9	2950.2	175.6	0.163	0.006
1.4	2557.8	270.6	0.386	0
1.9	3160.0	26.4	1.181	0.136

4. Conclusion

In this paper, a description of the investigated materials and an analysis of the results from the experimental investigation of RSF-reinforced concrete were presented. Locally available fibers and concrete are used. Flexure and compressive strength properties are demonstrated. By analyzing the results, the following conclusions can be drawn:

-The slump of RSFRC was reduced compared with PC in case of 0.4% RSF about 15 mm, 0.9% RSF about 15 mm, 1.4% RSF about 13 mm and 1.9% RSF about 12 mm.

-The compressive strength of RSFRC decreased compared to PC. Compared to PC decrease in compressive strength in case of dose 0.4% RSF -2.0 MPa, 0.9% RSF -1.1 MPa, 1.4% RSF 16.0 MPa and 1.9% RSF 0.0 MPa.

- With an increasing dose of RSF, the fracture energy increases against PC in the case of dose 0.4% RSF +0.058 N/mm, 0.9% RSF +0.147 N/mm, 1.4% RSF +0.370 N/mm and 1.9% RSF +1,165 N/mm.

- The addition of RSFs into concrete significantly improved its bending cracking after the first crack.

Despite the abovementioned conclusions, more extensive experimental and theoretical research by RSFRC is necessary, to which it will be possible to use this material in practical applications.

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