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Investigating the feasibility of using recycled fibres instead of industrial fibres in shotcrete

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Preliminary communication

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Abstract
Shotcrete is one of the standard systems used in the tunnelling industry, including cement, sand, water, and additives. Adding fibres to shotcrete is a method to enhance its mechanical properties. This study is laboratory research investigating the feasibility of using recycled steel fibres instead of industrial fibres and the effect of adding industrial and recycled fibres on the mechanical properties of shotcrete. For this research, laboratory samples were created using industrial steel fibres and recycled steel fibre types 1 and 2 sourced from worn tires. Laboratory samples include cubic and cylindrical samples with 12 mixing designs. These 12 mixing designs are plain shotcrete, shotcrete containing 1, 2, and 5 percent industrial steel fibres, shotcrete containing 0.5, 1, 1.5, and 2 percent type 1 recycled fibre, and shotcrete containing 0.5, 1, 1.5, 2 percent type 2 recycled fibres. Laboratory tests include compressive strength, tensile strength, and modulus of elasticity for durations of 3, 7, and 28 days. According to the results, adding industrial and recycled fibres to the shotcrete composition improves the resistance properties of shotcrete, and recycled fibres can replace industrial fibres.

Keywords:
shotcrete; fibres; compressive strength; tensile strength; modulus of elasticity

1. Introduction

The final concrete linings for tunnel structures and underground spaces are usually cast-in-situ or prefabricated concrete sections due to their excellent durability and economic efficiency, which provide safe and durable tunnel support. The weakness of these systems is their complex installation in the tunnel excavation phase and the need for molds or assembly systems for safe and stable excavation in tunnel openings (**Wang et al., 2021; Joshaghani et al., 2018; ACI, 2009**). Shotcrete is one of the tunnel support methods that has received attention as an alternative system (**Wang, 2015; Ning et al., 2024**). Compared to concrete, shotcrete usually contains a higher cement content (**Basireddy et al., 2021**). An essential property of shotcrete, particularly in tunnel settings, is its rapid strength gain through compaction and simultaneous hardening (**Galan et al., 2019; Polat and Ozel., 2024**). Despite its beneficial properties, the primary weaknesses of shotcrete are its low tensile strength and susceptibility to cracking under various loads on coated surfaces (**Guler et al., 2021; Liu et al., 2020**). In recent years, additives such as silicates, steel mesh, and fibrous shotcrete have been used to fix these weaknesses and improve the properties of shotcrete (**Guler et al., 2021; Wang et al., 2021; Shah ae al., 2021**).

The use of fibres has an essential role in strengthening shotcrete; it is a valuable tool for improving the mechanical parameters of shotcrete, such as the capacity of deformation, durability of concrete, increasing toughness, fatigue, impact resistance, reduction creep, reduction cracking, and also improving in the behavior after cracking (**Wang et al., 2021**). Steel fibres, natural fibres like jute and basalt, and synthetic fibres such as glass, polymer, and polypropylene are some examples of fibre types. Various studies have been conducted to investigate the effect of fibres on concrete and shotcrete, and in this section, several of these studies have been reviewed (**Wen et al., 2022**).

Khan et al. (2023) conducted laboratory studies on the mechanical properties of shotcrete containing industrial steel fibres extracted from the Golpur hydropower project in Pakistan. Laboratory tests have been performed for durations of 7 and 28 days, and with the increase in the percentage of fibres and the age of the samples, their compressive strength has increased (**Khan et al., 2023**). **Monteiro et al. (2021)** investigated shotcrete containing industrial steel fibres and propylene fibres used in the Copiapó mine (Chile) and performed labora-

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tory tests. They found that using shotcrete containing propylene fibres is suitable for hard rock areas with tension (**Monteiro et al., 2021**).

Zhao et al. (2021) investigated the mechanical properties of shotcrete containing industrial steel fibres and plastic waste fibres. Laboratory tests have been shown using fibres of varying lengths and widths to determine the ideal size of the fibres. The results show that different lengths and widths affect the mechanical properties (compressive strength, tensile strength, modulus of elasticity) of shotcrete (**Zhao et al., 2021**). **Ali Shah et al. (2021)**, using polypropylene and steel fibres, found that adding 3 kg/m^2 of polypropylene fibres, the compressive strength increases by 20% (from plain shotcrete (29.4 MPa) to polypropylene reinforced shotcrete (35.5 MPa)), and with the increase in the number of fibres, the compressive strength decreases, but the tensile strength increases. By adding 50 kg/m^3 of steel fibres, the compressive strength increases by 12%, and the tensile and bending strength increases by more than 100% (**Ali Shah et al., 2021**). **Larive et al. (2020)** examined the potential time and cost savings by utilizing shotcrete with steel fibres as an alternative to in-situ concrete lining in a tunnel in France. They found that using shotcrete containing steel fibres as a permanent cover saves money and time and reduces environmental effects (**Larive et al., 2020**).

In the past decades, various types of fibres have been widely used to improve concrete's mechanical properties, toughness, ductility, and durability. However, the production of synthetic fibres leads to the emission of carbon dioxide gas and pollution. For this reason and to use recycled materials to deal with the problem of disposing of solid materials (for example, waste tires), reducing the cost of fibre production, and preventing pollution, the production and use of recycled fibres were considered (**Chen et al., 2021**). Rubber disposal is a global environmental problem. Tires are durable waste that do not decompose naturally and must be recycled. One of the methods of disposing of rubber is recycling. Between 13 and 27 percent of the composition of tires consists of steel, a raw material used in their production. Utilizing steel materials effectively in recycled tires can significantly alleviate the issues associated with used tires (**Li et al., 2021; Moasas et al., 2021; Amin et al., 2020**).

Multiple studies have indicated that concrete reinforced with recycled steel fibres sourced from waste tires performs similarly to concrete reinforced with traditional steel fibres. Furthermore, recycled tire polymer fibres are another primary material derived from waste tires. **Yu et al. (2022)** investigated the extraction of different fibres from recycled waste tires. The researchers confirmed that using recycled tires as an alternative to traditional fibres can help lower construction expenses and minimize adverse environmental impacts (**Yu et al., 2022**). **Michalik et al. (2023)** explored the effect of using recycled tire fibres in concrete, revealing that these fibres enhance concrete strength, reduce costs, and align with sustainable construction practices (**Michalik et al., 2023**). **Chen et al. (2021)** investigated the properties of shotcrete containing recycled fibres from tires and recycled polymer fibres. They found that adding these fibres to the concrete composition causes positive effects, especially in the cost of production, recycling of waste tires, and increasing compressive strength and bending strength (**Chen et al., 2021**). **Simalti et al. (2021)** present an experimental study of recycled steel fibres extracted from shredded tires in self-consolidating concrete (SCC) with percentages of 0.5, 1, and 2 to investigate mechanical properties and performance. The results of the laboratory tests showed that the fibre percentage of 1.5 has the best performance in concrete (**Simalti et al., 2021**). **Ali et al. (2023)** studied and tasted two common types of recycled steel fibres (RSF), i.e. plain RSF (PRSF) and twisted RSF (TRSF) in high-strength plain concrete. Both physical and mechanical properties of fibre-reinforced concrete (FRC), including density, compressive strength-modulus of rupture tensile crack strength, and ultrasonic pulse speed, were studied. The results revealed that TRSF performed better than PRSF in overall mechanical performance (**Ali et al., 2023**). **Sharghi et al. (2021)** investigated the performance of recycled steel fibres added to concrete using laboratory tests and numerical modelling. The results showed that recycled steel fibres (RFS) can be used as an affordable reinforcement in hybrid reinforcements (rebars + fibres) to reduce the crack propagation (**Sharghi et al., 2021**).

In this study, laboratory studies have been conducted to investigate the effect of industrial and recycled steel fibres on the mechanical properties of shotcrete. All data has been collected through experiments in a controlled situation. It should be noted that all the samples are cubes (10×10×10 cm) and cylindrical (15×30 cm), that are without fibres, with industrial steel fibres with amounts 20, 40, and 100 kg/m^3 (respectively 1, 2, and 5 percent industrial steel fibres), shotcrete containing 10, 20, 30, and 40 kg/m^3 of type 1 recycled fibres and 10, 20, 30, and 40 kg/m^3 (respectively 0.5, 1, 1.5, 2 percent) are type 2 recycled fibres, repeated for durations of 3, 7, and 28 days.

2. Materials and methods

In this section, the properties of the materials used in shotcrete have been investigated. The materials include cement, sand, water, and additives. The cement used in shotcrete must be type 1 or 2 portland cement according to the ASTM C150/C150M standard (**ASTM, 2015**). The cement used in this study is Sufian type 2 cement according to the mentioned standard. Normal weight aggregate for shotcrete should follow the standard ASTM C33/C33M (**ASTM, 2011**). Composite aggregate should have one of the grades according to the ACI 506R-16 standard, as shown in **Table 1**. In **Table 1**, grade No. 1 should be used for fine-grained shotcrete, and Grade No. 2 should be used for other shotcretes (**ACI, 2016**). The aggregate used in this study, the sand around Tabriz city, has been prepared according to the grading No. 2 listed in the table. The granulation diagram of the sand used in tests is presented in **Figure 1**. The water must meet the requirements of ASTM C1602/C1602M and be clean and free of materials that may be harmful to concrete or steel. If water conforming to ASTM C1602/C1602M is not available, the water must be tested to ensure that the compressive strength of cubes made with that water is at least 90% of the compressive strength of cubes made with distilled water (**Water**, ASTM). The water used in this research is the tap water of Tabriz Sahand University of Technology.

Table 1: Grading for fine-grained shotcrete and other shotcretes

Grade No. 2	Grade No. 1	Mesh No.
-	-	3.4 in (19 mm)
100	-	1.2 in (12 mm)
90-100	100	3.8 in (10 mm)
70-85	95-100	4 mesh (4.75 mm)
50-70	80-98	8 mesh (1.2 mm)
35-55	50-85	16 mesh (1.2 mm)
20-35	25-60	30 mesh (600 µm)
8-20	10-30	50 mesh (300 µm)
2-10	2-10	100 mesh (150 µm)

2.1. Additives

Additional materials used to construct shotcrete to increase properties and special applications of shotcrete. Additives should conform to the ASTM C1141/C1141M requirements for shotcrete (Hanskat, 2013). The additive used in this study is SA-161 (brand name). Its properties are presented in **Table 2**.

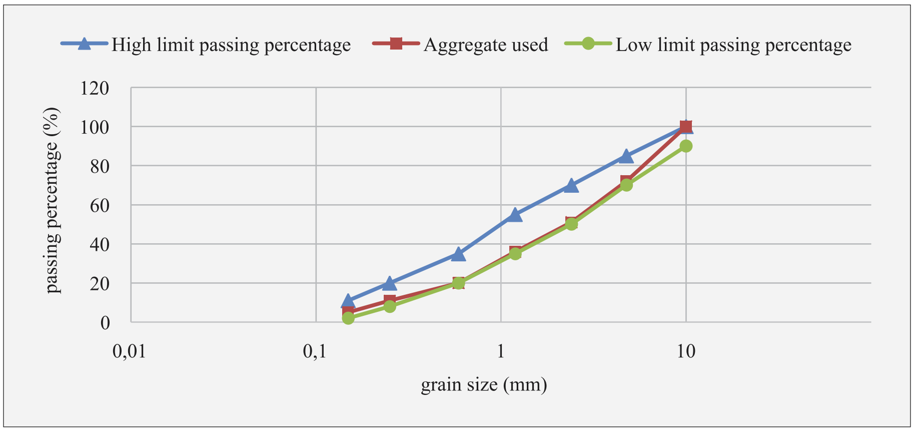

Figure 1: Granulation diagram of the used sand

Table 2: Additive properties used in the study

Title	Mode	Density (kg/m^3)	Amount used (kg/m^3)
sodium silicate	liquid	1500	10

Various materials, such as steel, glass, synthetic polymers, and natural substances, can create fibres for shotcrete applications. When the tension reaches the maximum, many hairline cracks are created in the shotcrete. The length and thickness of these cracks are formed by

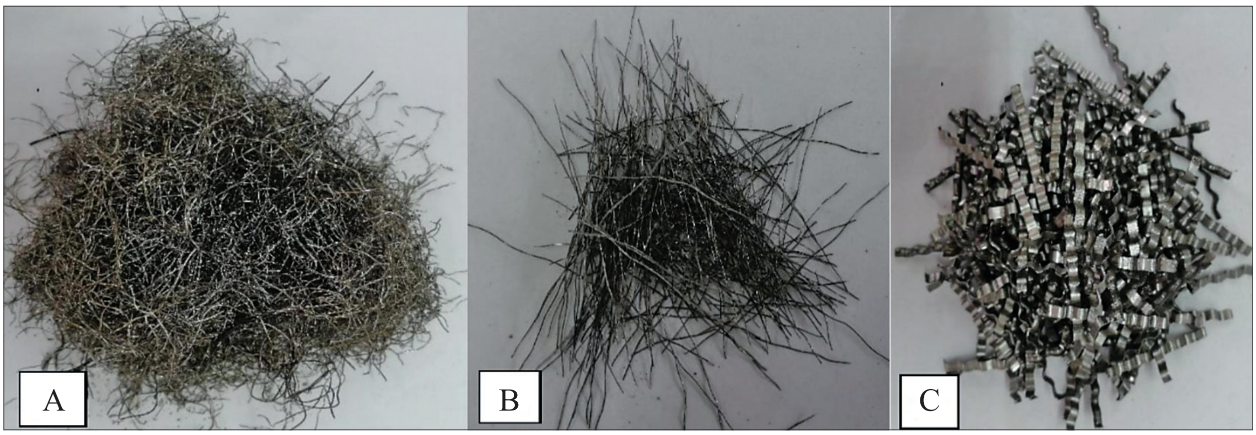

Figure 2: The steel fibres used are (A)- mixed recycled fibres (type 2), (B)- coarse recycled fibres (type 1), and (C)- corrugated industrial fibres.

increasing the force and connecting the cracks, and the accumulation of these cracks in one area causes the failure of shotcrete. Therefore, the role of steel fibres is to prevent the lengthening and formation of these cracks. Steel fibres should meet the requirements of the ASTM A820/A820M standard (**ASTM, 2016**). In this study, two types of fibres were used. The first fibres are industrial steel fibres (ISF), and the second fibres are recycled steel fibres (RSF), which are types 1 and 2, respectively. The images of the used fibres are shown in **Figure 2**, and their mechanical properties are presented in **Table 3**.

Table 3: The properties of the fibres used in the study

Type of fibre	Diameter (mm) (d)	Length (mm) (l)	Length /Diameter (l/d)
Industrial steel fibres (ISF)	1.5	37.5	25
Coarse recycled steel fibres (RSF) (type 1)	0.2	52	260
Mixed recycled steel fibres (RSF) (type 2)	0.2	3-45	15-225

2.2. Preparation of the samples

This study presents the mixing designs examined for normal shotcrete, shotcrete with industrial steel fibres, and shotcrete with recycled fibres type 1 and type 2 in **Table 4**. As shown in **Table 4**, the amount of cement, sand, gravel, additives, and water remains consistent across all designs, with variations in the fibre content. The normal shotcrete mixing design was selected according to the mixing design used for excavating the Tabriz metro line 2 tunnel and the ACI 544.3R standard (**ACI, 2008**).

Regarding other mixing designs, different amounts of fibres (20, 40, and 100 kg/m^3 for industrial fibres, 10, 20,

Table 4: Properties of materials and mixing designs used in all types of shotcretes

Design \ Materials	Cement kg/m^3	Additive kg/m^3	Sand kg/m^3	Gravel kg/^{m}3	Water l/m^3	Fibres kg/m^3
Shotcrete (without fibres)	460	10	205	1255	280	-
Shotcrete (ISF-20)	460	10	205	1255	280	20
Shotcrete (ISF-40)	460	10	205	1255	280	40
Shotcrete (ISF-100)	460	10	205	1255	280	100
Shotcrete (RSF-10) (Type 1)	460	10	205	1255	280	10
Shotcrete (RSF-20) (Type 1)	460	10	205	1255	280	20
Shotcrete (RSF-30) (Type 1)	460	10	205	1255	280	30
Shotcrete (RSF-40) (Type 1)	460	10	205	1255	280	40
Shotcrete (RSF-10) (Type 2)	460	10	205	1255	280	10
Shotcrete (RSF-20) (Type 2)	460	10	205	1255	280	20
Shotcrete (RSF-30) (Type 2)	460	10	205	1255	280	30
Shotcrete (RSF-40) (Type 2)	460	10	205	1255	280	40

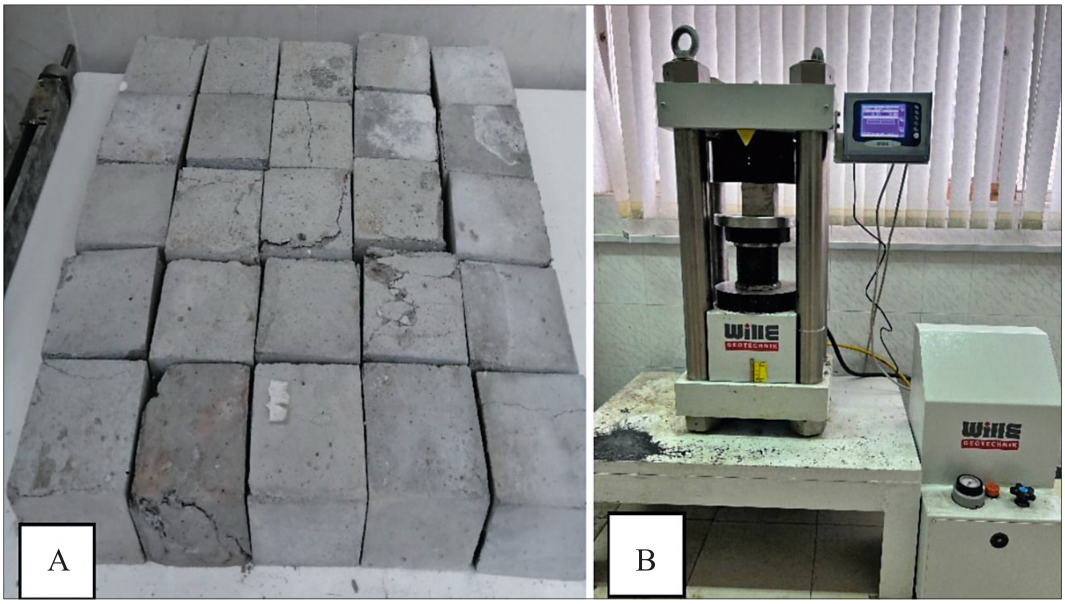

Figure 3: (A)- Cubic samples, (B)- Uniaxial compressive strength (UCS) test device

30, and 40 kg/m³ for type 1 recycled fibres, and 10, 20, 30, and 40 kg/m³ for recycled fibres Type 2) have been used.

The materials required to prepare the concrete samples are mixed into the laboratory mixer according to the desired mixing design. Then, immediately after mixing, they are poured into cubic and cylindrical molds. To prevent air inside the samples and spreading evenly, all the samples are placed on the vibrating table. After 24 hours, the samples were removed from the molds and put in a pond with a temperature of 23-25°C to perform laboratory tests for durations of 3, 7, and 28 days.

Table 5: Compressive strength of shotcrete

Sample \ Age (day)	3 σ_c (MPa)	7 σ_c (MPa)	28 σ_c (MPa)
Shotcrete (without fibres)	8.9	20.7	28.42
Shotcrete (ISF-20)	10.7	21.36	30.7
Shotcrete (ISF-40)	11.4	21.72	32.1
Shotcrete (ISF-100)	12.3	23.9	37.8
Shotcrete (RSF-10) (Type 1)	8.7	-	23.6
Shotcrete (RSF-20) (Type 1)	10.4	-	29.1
Shotcrete (RSF-30) (Type 1)	12.53	21.85	36.9
Shotcrete (RSF-40) (Type 1)	14.3	-	39.1
Shotcrete (RSF-10) (Type 2)	9.1	-	-
Shotcrete (RSF-20) (Type 2)	13.6	-	-
Shotcrete (RSF-30) (Type 2)	15.8	-	-
Shotcrete (RSF-40) (Type 2)	18.1	-	-

3. Results and discussion

Shotcrete is one of the main materials used in tunnelling projects. After tunnel excavation, shotcrete is sprayed on the tunnel walls and roof surfaces as tunnel support. Therefore, shotcrete's mechanical properties are very important for withstanding the various loads applied to the tunnel surfaces. To determine the mechanical properties, cubic (10×10×10 cm) and cylindrical (15×30 cm) samples were subjected to compressive strength, indirect tensile strength (Brazilian), and the modulus of elasticity tests.

3.1. Compressive strength test

Cube samples (10×10×10 cm) aged 3, 7, and 28 days with industrial steel fibres, recycled fibres, and without fibres have been tested according to BS EN 12390 standards (Testing Hardened Concrete, **2009**). **Figure 3** shows some of the tested samples. The results of the uniaxial compressive strength tests for the 3, 7, and 28-day samples are presented in **Table 5.**

The results indicate that compressive strength improves as the percentage of fibres increases. For samples with 20, 40, and 100 kg/m³ of industrial steel fibres, the compressive strength increased by 20%, 28%, and 38% at 3 days; by 3%, 4.9%, and 15% at 7 days; and by 8%, 12%, and 33% at 28 days. These findings suggest that fibres have a significant impact at an early stage, with the strength increase in 3-day samples being much higher than in the 7-day and 28-day samples. Using 10 kg/m³ of the first type of recycled fibres resulted in a decrease in compressive strength at 3 and 28 days compared to samples without fibres. However, with 20, 30, and 40 kg/m³ of fibres, there was an increase in strength by 16%, 40%, and 60% at 3 days, and by 2%, 29%, and 37% at 28 days. As shown in **Figure 4**, the compressive strength of samples with the second type of recycled fibres at 10, 20, 30, and 40 kg/m³ increased by 2.24%,

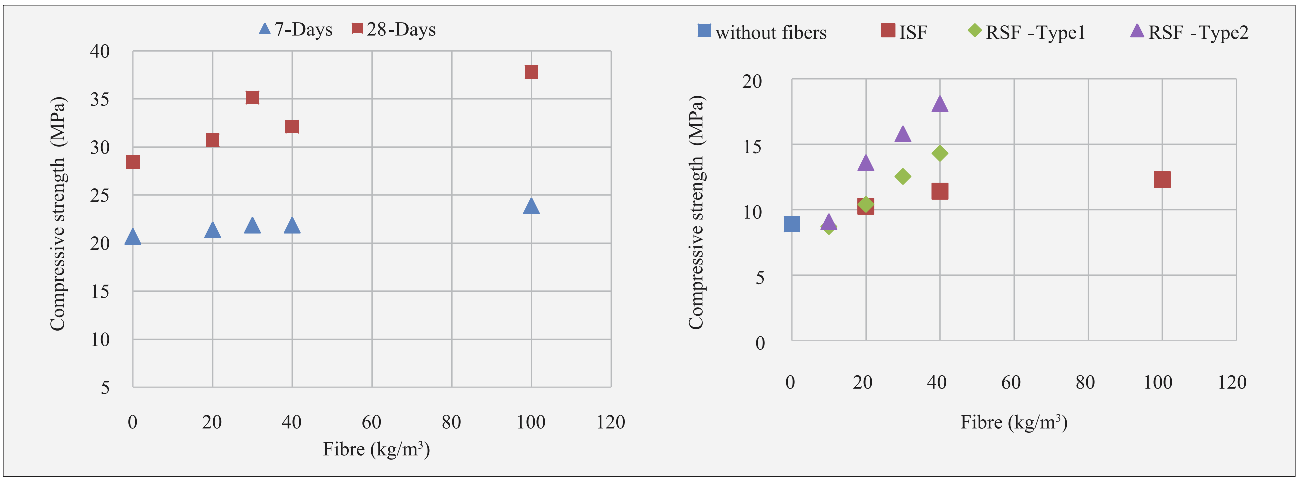

Figure 4: Graph of compressive strength regarding fibre volume changes for industrial and recycled steel fibres. Left- 7 and 28-day samples. Right- 3-day samples.

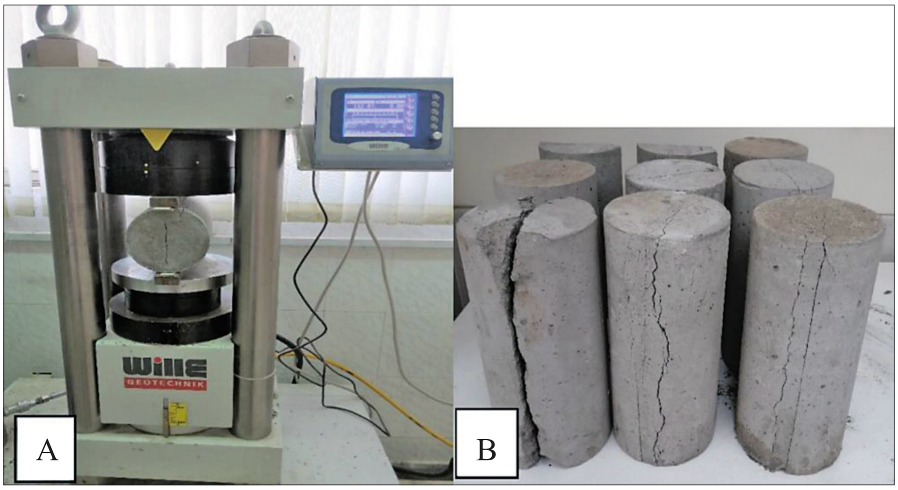

Figure 5: (A) The set-up used to perform the tensile strength of the cylindrical sample. (B) Tested cylindrical samples.

Table 6: Tensile strength of shotcrete

Sample \ Age (day)	3 τ (MPa)	7 τ (MPa)	28 τ (MPa)
Shotcrete (without fibres)	1.1	1.5	2.4
Shotcrete (ISF-20)	-	1.76	2.53
Shotcrete (ISF-40)	-	1.92	2.69
Shotcrete (ISF-100)	-	2.15	2.81
Shotcrete (RSF-10) (Type 1)	1.9	-	-
Shotcrete (RSF-20) (Type 1)	2.03	-	-
Shotcrete (RSF-30) (Type 1)	2.05	1.9	2.56
Shotcrete (RSF-40) (Type 1)	2.1	-	-
Shotcrete (RSF-10) (Type 2)	1.656	-	-
Shotcrete (RSF-20) (Type 2)	1.755	-	-
Shotcrete (RSF-30) (Type 2)	1.684	-	-
Shotcrete (RSF-40) (Type 2)	1.578	-	-

52.8%, 77.5%, and 103.3% at 3 days compared to samples without fibres. Additionally, 1.5% of type 1 recycled fibres in samples resulted in strength increases of 29%, 5%, and 23% at 3, 7, and 28 days, respectively. **Figure 4** indicates these results.

3.2. Tensile strength test

Direct tensile testing for concrete is not common; therefore, an indirect tensile test (Brazilian) was performed on cylindrical samples (15×30 cm) aged 3, 7, and 28 days, according to the ASTM C469/ C496M-17 standard (**ASTM 2017**). In this test, according to **Figure 5**, loads were applied along the diameter of the cylindrical sample to divide the sample into two parts.

Table 6 and **Figure 6** present the results of the tensile strength test for cylindrical samples with industrial and recycled fibres.

As shown in **Figure 6**, with the increase in the percentage of fibres (20, 40, and 100 kg/m^3), at the age of 7 days, tensile strength increases by 17, 28, and 43 percent, respectively. With the increase in the percentage of fibres, 20, 40, and 100 kg/m^3, at the age of 28 days, tensile strength increased by 5, 12, and 17 percent, respectively. Increasing the percentage of fibres from 2 to 5 percent had a lower effect on the 28-day tensile strength. For shotcrete samples containing type 1 recycled fibres with an amount of 30 kg/m^3, for 3, 7, and 28-day samples, 84%, 26.6%, and 6.6% increase, and for fibre amounts of 10, 20, and 40 kg/m^3 of type 1 fibre in the 3-day tests showed an increase of 72%, 84%, and 86%, respectively, compared to the sample without fibres. For samples containing type 2 recycled fibres with values of 10, 20, 30, and 40 kg/m^3, respectively, 10.4%, 17%, 12%, and 5.2% increase in tensile strength have been observed.

The tensile strength test results on cylindrical samples with recycled fibres show that using recycled fibres increases the tensile strength. For example, the tensile strength in the state of 1.5% recycled fibres is equivalent to that in the state of 2% industrial fibres.

3.3. Determination of modulus of elasticity

According to the ASTM C469 standard, the modulus of elasticity was carried out on the samples at the age of 28 days. The samples were subjected to axial load and the strain rate was recorded in different stresses. **Table 7** shows the modulus of elasticity of concrete for 28-day

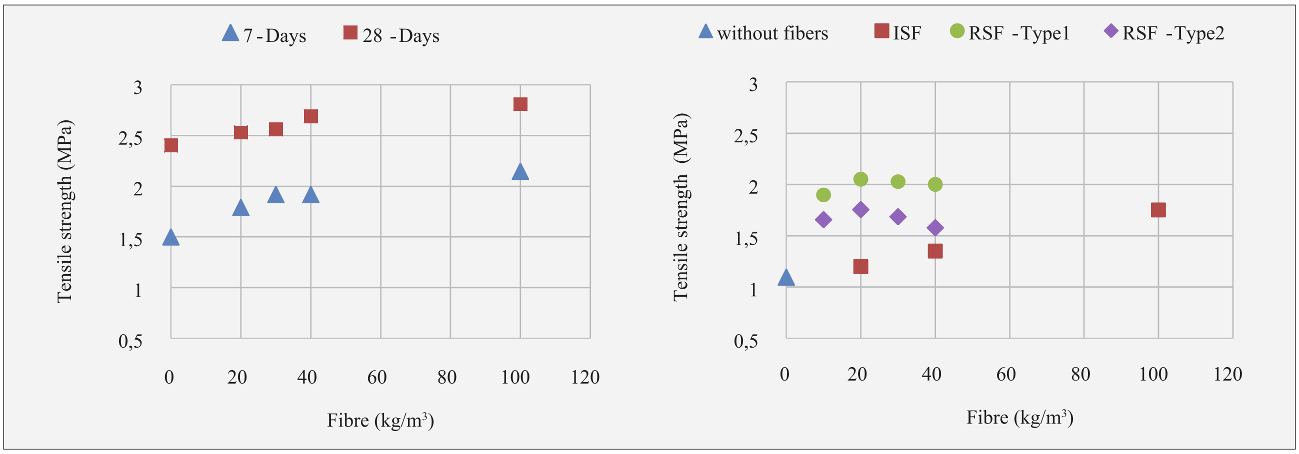

Figure 6: Tensile strength diagram according to fibre volume changes. Left- Type 1 industrial and recycled steel fibres. Right- Type 1 and 2 recycled fibres.

Table 7: Modulus of elasticity of shotcrete

Age (day) / Sample	28 E_c (GPa)
Shotcrete (without fibres)	22.96
Shotcrete (ISF-20)	24.37
Shotcrete (ISF-40)	25.5
Shotcrete (ISF-100)	29.46

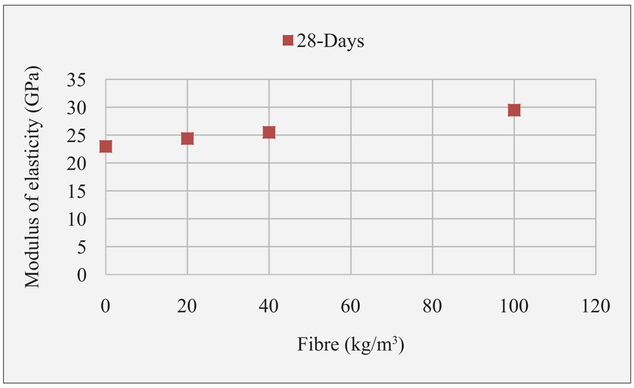

Figure 7: Diagram of modulus of elasticity according to volume changes of industrial steel fibres

samples of industrial fibre shotcrete. **Figure 7** shows a diagram of changes in modulus of elasticity according to different amounts of industrial fibres.

The results of the tests on the prepared samples show that with the increase of industrial steel fibres from 20, 40, and 100 kg/m³, the value of the modulus of elasticity is 6.1%, 11%, and 28%, respectively, increased. Laboratory tests have revealed that adding industrial and recycled fibres to shotcrete composition improves its resistance properties. Meanwhile, recycled fibres with a lower percentage (1.5%) can replace industrial fibres with a higher percentage (2%). This procedure shows the advantage of using recycled fibres as a suitable substitute for industrial fibres in terms of resistance.

4. Conclusions

Shotcrete containing steel fibres is one of the methods used for tunnel supports, which increases the resistance and stability of the tunnel against external and internal pressures.

In this study, shotcrete contains industrial steel fibres with amounts of 1%, 2%, and 5% (20, 40, and 100 kg/m³, respectively) and type 1 recycled fibres with amounts of 0.5%, 1%, 1.5%, and 2% (respectively 10, 20, 30 and 40 kg/m³) and type 2 steel fibres with values of 0.5%, 1%, 1.5% and 2% (10, 20, 30 and 40 kg/m³ respectively) have been investigated. 3, 7, and 28-day compression tests, 7 and 28-day tensile tests, and 28-day tests were performed on all the samples to obtain the elasticity modulus of the samples. The results are as follows:

- The use of 1, 2 and 5% industrial steel fibres in shotcrete mixtures at the ages of 3, 7, and 28 days, respectively, in the compressive strength test on cubic samples (10×10×10 cm) has a direct relationship, as the fibre increases, the compressive strength also increases. It shows the proper dispersion of fibres in the samples and the positive effect of fibres.
- To determine the indirect tensile test on cylindrical samples (15×30 cm) containing 1%, 2%, and 5% industrial steel fibres at the ages of 7 and 28 days, respectively, the indirect tensile test has been carried out, and the results showed that tensile strength of the samples has increased by increasing the volume ratio of industrial steel fibres.
- The test to determine the modulus of elasticity has been carried out on cylindrical samples (15×30 cm) containing 1%, 2%, and 5% industrial steel fibres at the age of 28 days, which, like other tests, has increased with an increase in the volume ratio of the fibres.

Adding fibres has increased the compressive strength of samples containing type 1 recycled fibres. For type 2 recycled fibres, compressive strength significantly increases with an increasing percentage of fibres.

The results show that recycled fibres with a lower percentage (1.5%) can replace industrial fibres with a higher percentage (2%). This procedure shows the advantage of using recycled fibres as a suitable substitute for industrial fibres in terms of resistance.

- For the samples containing 20 and 40 kg/m³ fibres, the compressive strength ratio of the samples with type 1 recycled fibres compared to the industrial fibres in 3-day samples decreased by 2% and increased by 25%, respectively, and for the 28-day samples, it decreased by 5% and increased by 22%.
- For samples containing fibres of 20 and 40 kg/m³, the compressive strength ratio of samples with type 2 recycled fibres is 27% and 58% higher than that of industrial fibres.
- The increase in the compressive strength of recycled fibres type 2 to type 1 with fibre amounts of 10, 20, 30, and 40 kg/m³ was 4%, 30%, 26%, and 36% respectively, in the samples.

Adding 0.5%, 1%, 1.5%, and 2% type 1 recycled fibres has increased the tensile strength of the samples compared to the sample without fibres. Adding 0.5% and 1% of type 2 recycled fibres to the cylindrical samples also increases the tensile strength. Still, adding more fibres with higher percentages of 1.5% and 2% decreases the sample's tensile strength.

Laboratory tests have revealed that adding industrial and recycled fibres to shotcrete composition improves its resistance properties. Meanwhile, recycled fibres with a lower percentage (1.5%) can replace industrial fibres with a higher percentage (2%). This procedure shows the advantage of using recycled fibres as a suitable substitute for industrial fibres in terms of resistance.

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SAŽETAK

Istraživanje mogućnosti korištenja recikliranih vlakana umjesto industrijskih vlakana u mlaznome betonu

Mlazni beton jedan je od standardnih materijala koji se koriste u tunelogradnji. Sadržava cement, pijesak, vodu i aditive. Metodologija dodavanja vlakana mlaznom betonu poboljšava njegova mehanička svojstva. Ova studija prikazuje laboratorijsko istraživanje koje ispituje mogućnost upotrebe recikliranih čeličnih vlakana umjesto industrijskih vlakana i učinak dodavanja industrijskih i recikliranih vlakana na mehanička svojstva mlaznoga betona. Za ovo istraživanje napravljeni su laboratorijski uzorci korištenjem industrijskih čeličnih vlakana i recikliranih čeličnih vlakana tipa 1 i 2 dobivenih iz istrošenih guma. Ispitivanja su provedena na uzorcima u obliku kocke i valjka koji su napravljeni od 12 različitih sastava betona: obični mlazni beton, mlazni beton koji sadržava 1 %, 2 % i 5 % industrijskih čeličnih vlakana, zatim mlazni beton koji sadržava 0,5 %, 1 %, 1,5 % i 2 % recikliranih vlakana tipa 1 te mlazni beton koji sadržava 0,5 %, 1 %, 1,5 % i 2 % recikliranih vlakana tipa 2. Na uzorcima su laboratorijski određene tlačne čvrstoće, vlačne čvrstoće i moduli elastičnosti u vremenu od 3, 7 i 28 dana. Rezultati pokazuju da se dodavanjem industrijskih i recikliranih vlakana u mlazni beton poboljšavaju svojstva otpornosti mlaznoga betona te da reciklirana vlakna mogu zamijeniti industrijska vlakna.

Ključne riječi:
mlazni beton, vlakna, tlačna čvrstoća, vlačna čvrstoća, modul elastičnosti

Author’s contribution

Shahla Miri Darmarani (1) (MSc graduate of Mining Engineering) provided the paper and presentation of the results. **Erfan Khoshzaher (2)** (PhD candidate of Mining Engineering) provided and wrote the paper. **Hamid Chakeri (3)** (PhD, Associate Professor) proposed the idea and guided the research. **Rahman Mirzaei (4)** (PhD, Assistant Professor of Civil Engineering) proposed the idea and guided the research.