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# Experimental Investigation on Mechanical Properties of Normal Concrete Reinforced with Discarded Steel Fibers

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**ABSTRACT**

This study presents an investigation of the mechanical properties of normal concrete reinforced with discarded steel fibers (DSFs) resulting from tire manufacturing. DSFs were added to concrete in two different volume fractions of (0.25 %, and 0.5 %), and these fibers have dimensions of (40 mm length×0.92 mm diameter). The results showed that the compressive strength of the concrete was enhanced by (8.8%, and 3.3%) by adding of DSFs. However, the workability of concrete decreased at all added ratios. While the density is slightly changed. Also, the results indicate that the modulus of elasticity shows slight increases by (3.06%, and 2.25%). Additionally, the incorporation of DSFs improves the splitting tensile strength and modulus of rupture significantly. For concrete mixes having volume fractions of 0.25% and 0.5%, the splitting tensile increased by (7.89%, and 23.68%), and the modulus of rupture increased by (6.67% and 25.58%), respectively. It was concluded that using this type of discarded fibers can improve the mechanical properties of concrete as an alternative type for other types of industrial fibers.

## 1. Introduction

Concrete is a brittle material with low tensile and strain capacities (Atoyebi, Odeyemi, Bello, & Ogbeifun, 2018). The incorporation of a small amount of randomly arranged fibers (steel, glass, polypropylene, and synthetic) can overcome this property, which limits the application of the materials (Vairagade & Kene, 2013; Yuan & Jia, 2021). In recent years, steel fibers are one of the most commonly employed types of fibers to improve properties of concrete (Behbahani, Nematollahi, Sam, & Lai, 2012). This may be due to it's a significant improvement in the properties of concrete such as flexural strength, toughness, post-cracking behavior, and ductility (Behbahani, 2010; Köksal, Rao, Babayev, & Kaya, 2022). (Abbass, Khan, & Mourad, 2018), founded that the addition of different content and lengths of steel fibers with increasing water-to-cement ratios caused significant change in the mechanical properties of concrete, with an increase of about 10–25% in compressive

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strength and about 31–47% in direct tensile strength. However, the use of this kind of fibers in the construction industry has a few limitations. One of these limitations is the lack of supply of industrial steel fibers (ISF) in many parts of the world, in addition to their high cost (Baričević, Lakušić, Bjegović, & Serdar, 2013). Therefore, significant researches have been carried out to find sustainable and effective replacements for these fibers.

The world uses 1.3 billion cars annually, which requires more than 5.2 billion tires, each tire contains (15-25%) steel fibers for normal and heavy cars, respectively, meaning that a significant lot of steel fibers are employed in this industry (Liew & Akbar, 2020). As a result, many researchers showed an interest in testing recycled steel fibers (RSF) from end-of-life tires instead of standard steel fibers in concrete. In this regard, Zhang and Gao (2020) conducted a study to compare the mechanical properties of concrete reinforced with RSF and that prepared with ISF. The results of this study showed that the compressive strength, splitting tensile strength, flexural strength, and flexural toughness of RSFC are lower than that of ISFC when the fibers' volume ratios are same. Also, the content of RSF should be between 1 and 2% greater than that of ISF in order to produce concrete with adequate strength or toughness. Rossli & Ibrahim (2012) evaluated the mechanical properties of concrete reinforced with RSF. The results showed that RSFs had an adverse effect on workability. However, the inclusion of RSF led to enhance the compressive, flexural, and tensile strengths. (H Younis, S Ahmed, & B Najim, 2018), investigated the mechanical performance of self-compacting concrete (SCC) reinforced with RSF recovered from the discarded tires. The fibers were added with contents of 30, 60, and 90 kg/$m^3$, and for each fiber content, four mixes with four different fibers lengths were prepared as follows: (10, 15, 25, 35 mm). The testing results indicated, the compressive strength noticeably improved for short fibers (10 and 15mm) and slightly decreased for long fibers at moderate fibers content (60 kg/$m^3$) (25 and 35mm). Increasing fibers length results in greater flexural strength for a similar fibers percentage. (Samarakoon, Ruben, Pedersen, & Evangelista, 2019), investigated the mechanical characteristics of RSFC. The percentages of RSF were (0.5%, and 1%). Results showed that the compressive was enhanced by 5-12% with the inclusion of RF. The secant modulus of elasticity is not significantly changed. Also, splitting tensile strength of RFRC increased.

Discarded steel fibers (DSFs) are steel wires used in tires manufacturing before being used in the tire body (remaining raw materials), for reasons such as defects, failure to achieve the necessary standard specification, or redundancy. Therefore, discarded steel fibers (DSF) were utilized as a good, an economic and environmental alternative to ISF and RSF. In contrast to steel fibers from recycled tires, one of the major advantages of these fibers is that they have not been damaged in any way. Additionally, during the cutting process, the length of the fibers can be chosen. (Mezzal, Al-Azzawi, & Najim, 2021), studied the effect of DSF on the mechanical properties of high-strength self-compacting concrete (HSCC). According to the findings, Compressive strength, tensile strength, and toughness index increased about 12%, 77%, and 700% respectively compared to SCC. (Mezaal, Najim, & Noaman, 2022), evaluated the influence of adding DSF in hybrid length on the mechanical properties of HSCC. The results showed that adding these fibers increased compressive strength. Also, the inclusion of DSF significantly enhanced the splitting tensile strength. The aim of this study was to evaluate the mechanical properties of normal concrete reinforced with DSF, in terms of density, compressive strength, tensile strength, modulus of elasticity, and modulus of rupture.

## 2. Experimental program

### *2.1. Materials*

In order to produce a concrete mixture with the desired mechanical properties in this study, Ordinary Portland Cement (Type I) was used. Tables 1, and 2 lists the chemical and physical properties of this type of cement, respectively, which confirm to Iraqi specifications (No.5-2019) .Local sand, with a maximum particle size of 4.75 mm and a specific gravity of 2.64 g/$cm^3$, was used as the fine aggregate. Crushed gravel stone with a maximum particle size of 10 mm and a specific gravity of 2.65 g/$cm^3$, was used as coarse aggregate The results of the sieve analysis of fine, and coarse aggregate are shown in Table 3, and Table 4 respectively, which were found to be conformed to Iraqi Specification No. 45. SikaViscoCrete-5930 superplasticizer (SP) was used as a high-range-water-reducing agent. Discarded tire steel fibers (DSFs) were used in this study as fibers. These steel wires are discarded during the tire-fabricating process before being utilized into the tire body due to issues including defects, failure to meet the required standard, or redundancy. The percentages of DSFs were (0.25%, and 0.5%) by volume of concrete. DSF properties are listed in Table 5.The tensile strength test is carried out in in the laboratories of the production Department-College of Engineering University of Technology as shown in Fig. 1(Kareem, 2022). Fig. 2 shows DSF after cutting.

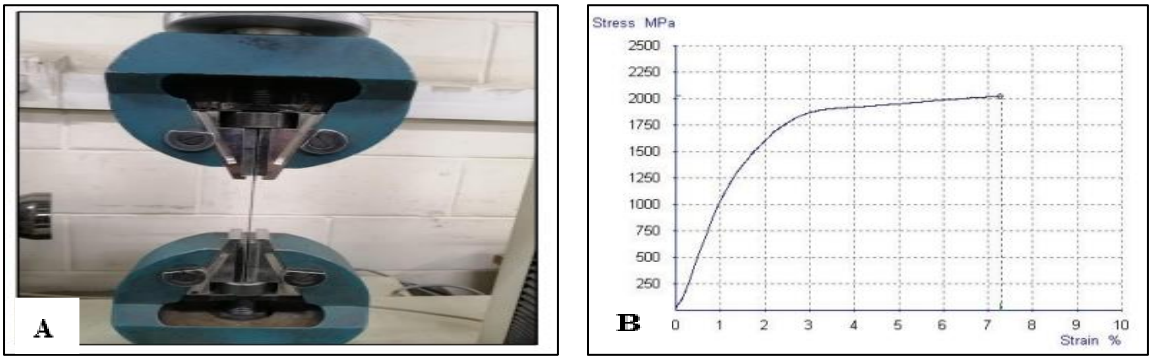


**Fig.1 (A) Tensile strength test of DSF, and (B) Stress-strain curve of DSF (Kareem, 2022).**

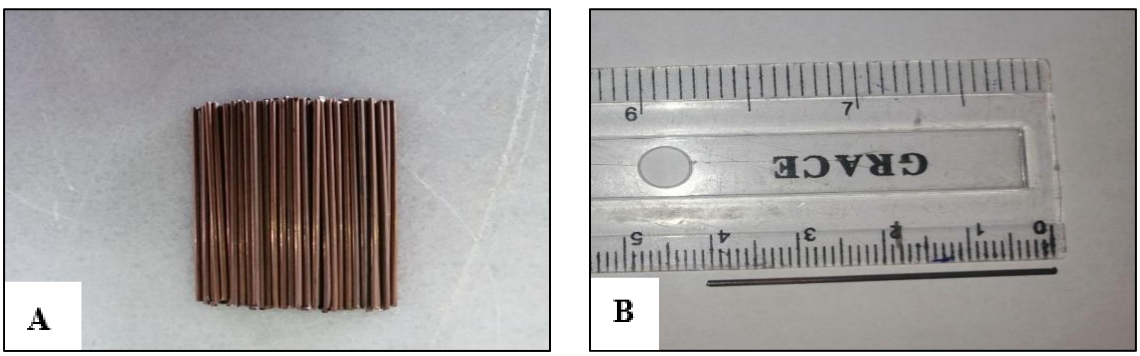


**Fig.2 Discarded steel fibres: (A) DSF after cutting, and (B) length of DSFs.**

**Table 1- Chemical Composition of the Cement.**

| Compound | Percentage by weight | Iraqi standard No. 5/2019 Limits |
|---|---|---|
| CaO | 64.1 | - |
| $Fe_2O_3$ | 3.4 | - |
| $SiO_2$ | 21.1 | - |
| $Al_2O_3$ | 3.81 | ⩽ 3.5 |
| MgO | 2.2 | A maximum of 5% |
| **Main compounds** | **Oxide % by Weight** | **Iraqi standard No. 5/2019 Limits** |
| $C_3$A | 5.4 | ≤ 3.5% |
| C4AF | 14.62 | - |
| C3S | 19.42 | - |
| C2S | 49.45 | - |

**Table 2- Physical characteristics of cement.**

| Test type | Results | limit of Iraqi specification IQS 5/2019 |
|---|---|---|
| Initial setting time (min) | 160 | ≥ 45 min |
| Final setting time (min) | 245 | Not more than 600 min |
| Fineness by Blaine method ($cm^2$/g) | 2530 | ≥ 2500 |
| Compressive strength at 2 days (MPa) | 12.5 | ≥ 10 MPa |
| Compressive strength at 28 days (MPa) | 42.5 | ≥ 32.5 MPa |

**Table 3- Sieve analysis for fine aggregates**

| Sieve Size (mm) | Cumulative Passing % | Iraqi specification limits (NO. 45 /1984) |
|---|---|---|
| 10 | 100 | 100 |
| 4.75 | 98 | 90-100 |
| 2.36 | 84 | 75-100 |
| 1.18 | 71 | 55-90 |
| 0.6 | 54 | 35-59 |
| 0.3 | 16 | 8-30 |
| 0.15 | 3 | 0-10 |

**Table 4- Sieve analysis for coarse aggregates**

| Sieve Size (mm) | Cumulative passing % | Iraqi specification limits (NO. 45 /1984) |
|---|---|---|
| 20 | 100 | 100 |
| 14 | 100 | 90-100 |
| 10 | 80.7 | 50-85 |
| 5 | 9 | 0-10 |

**Table 5- DSF properties**

| Property | Description |
|---|---|
| Length (mm) | 40 |
| Cross Section | Circular |
| Diameter (mm) | 0.92 |
| Tensile Strength (MPa) | 2000 |
| Geometry | Straight |

## *2.2. Mixing Proportions*

The American Concrete Institute ACI 211 method was adopted this study to obtain the required workability and compressive strength. The design compressive strength was (45 MPa) with a water-cement ratio (w/c) of 0.45. Three concrete mixtures were prepared based on the amount of discarded steel fibers they contained. Table 6 contains a list of the ingredients in these three mixtures.

**Table 6- Mixing proportions**

| Mix Type | Cement (kg/$m^3$) | Fine Agg (kg/$m^3$) | Coars Agg (kg/$m^3$) | Water (kg/$m^3$) | SP (kg/$m^3$) | (%) DSFs | w/c |
|---|---|---|---|---|---|---|---|
| Mix1 | 380 | 880 | 1000 | 171 | 1.14 | 0 | 0.45 |
| Mix2 | 380 | 880 | 1000 | 171 | 1.14 | 0.25 | 0.45 |
| Mix3 | 380 | 880 | 1000 | 171 | 1.14 | 0.5 | 0.45 |

## *2.3. Mixing method*

A laboratory rotary mixer having a capacity of 0.01 $m^3$ was used to prepare all concrete mixtures. Before adding materials, the mixer was cleaned and damped with water. For all stages of this study, the same mixing process was used. Firstly, dry sand and coarse aggregate were mixed for three minutes. After that, cement was added, and the mixing process continued for one minutes. During mixing, two-thirds mixing water was added and mixed. After that, DSFs were added and the mixing continued for 2 minutes. DSFs were added gradually by spreading them by hand to prevent the balling configuration. Finally, SP was mixed with the remaining water, which was added and the mixing continued for an additional three minutes.

## *2.4. Specimens*

For each mixture, three cubes (100 mm x 100 mm x100 mm), three cylinders (100 mm x 200 mm), three cylinders (150 mm x 300 mm), one cylinder (150 mm x 300 mm), and three prisms (100 mm x 100 mm x 400 mm) were prepared to evaluate density, compressive strength, tensile strength, static modulus of elasticity, and modulus of rupture, respectively.

# 3. Results and Discussions

## *3.1. Fresh and mechanical properties*

### *3.1.1 Slump*

Slump is used to evaluate the effect of DSFs on the fresh workability of concrete. It can be classified as one of the characteristics of freshly mixed concrete. As indicated in Table 7, the inclusion of steel fibres leads to decreased slump, and workability decreased as the content of DSFs increased. This decrease can be attributed to the fact that an increase in the amount of fibres in the concrete mixture leads to an increase in the internal friction between the fibres and the coarse aggregate, as well as an increase in the resistance to compaction (Mezaal, Najim, & Noaman, 2022).

**Table 7- Results of slump test.**

| Mix Type | DSFs Content by volume % | Slump(mm) |
|---|---|---|
| Mix1 | 0% | 100 |
| Mix2 | 0.25% | 85 |
| Mix3 | 0.5% | 75 |

### *3.1.2 Density*

Results of the density test are presented in Table 8, which indicates the average density of three samples for each mix type. A slight increase in the density could be observed by adding DSF to the concrete mixture. This increase is due to the high density of DSFs in comparison with other ingredients.

**Table 8- Density test results.**

| Mix Type | DSFs Content by volume % | Density ($kg/m^3$) | Increase (%) |
|---|---|---|---|
| Mix1 | 0 | 2398 | - |
| Mix2 | 0.25 | 2410 | 0.5% |
| Mix3 | 0.5 | 2423 | 1.04% |

### *3.1.3 Compressive strength*

The compressive strength results for each mix are given as an average of three specimens in Table 9. The compressive strength of the concrete reinforced with DSFs increased by 8.8%, and 3.3% for fibers content 0.25% and 0.5%, respectively, as compared to the reference mix. This increase is attributed to the influence of DSF, which effectively prevents cracks spreading due to the presence of a good bonding between the concrete matrix and these fibers (Mezzal, Al-Azzawi, & Najim, 2021). The reduction in the compressive strength in the mix3 (0.5% ) might be ascribed to the increment in the amount of DSFs, where the increase in fibers content can contribute to the presence of voids between the components of the concrete mix, which leads to a decrease in the compressive strength (H Younis, S Ahmed, & B Najim, 2018). Fig. 3 shows the failure modes of cylinders under compressive force.

**Table 9- Results of compressive Strength.**

| Mix Type | DSFs Content by volume % | Compressive Strength (MPa) | Increase (%) |
|---|---|---|---|
| Mix1 | 0 | 45 | - |
| Mix2 | 0.25 | 49 | 8.8 |
| Mix3 | 0.5 | 46.5 | 3.3 |


**Fig.3 Failure mode of cylinders specimens.**

### *3.1.4 Splitting tensile strength*

One of the main disadvantages of concrete is that it has a poor resistance to tensile forces, which is commonly known as the brittle behavior of concrete. Tensile strength is typically not taken into consideration when designing, however, its value is still very necessary as the cracking of concrete is reflected by the tensile behavior. The results of splitting tensile strength are illustrated in Fig. 4. In contrast to compressive strength, it was found that the increase in the percentage of DSFs leads to a significant improvement in the splitting tensile strength, which increased by 7.89% for concrete with a volume fraction of 0.25%, and 23.68% for concrete with a volume fraction of 0.5% when compared to the reference mix. This improvement can be explained by the effect of the fibers in increasing the load-carrying capacity against the tensile stress, which prevents the rapid splitting of the cylinders. Fig. 5 compares the failure of plain, and fiber-reinforced concrete specimens. As seen, the plain specimen split into two pieces, where the fibers-reinforced specimens held together and indicated a strong resistance to splitting.

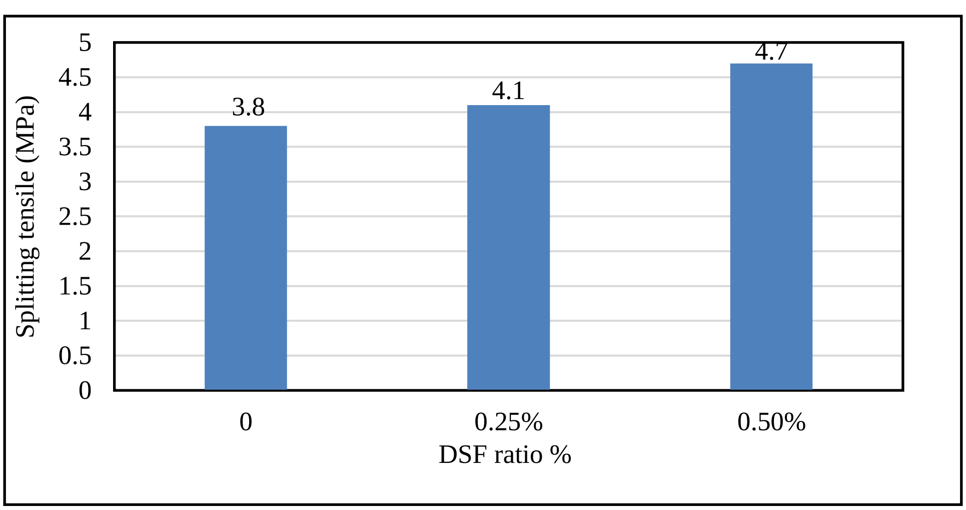


**Fig.4 Splitting tensile strength results.**

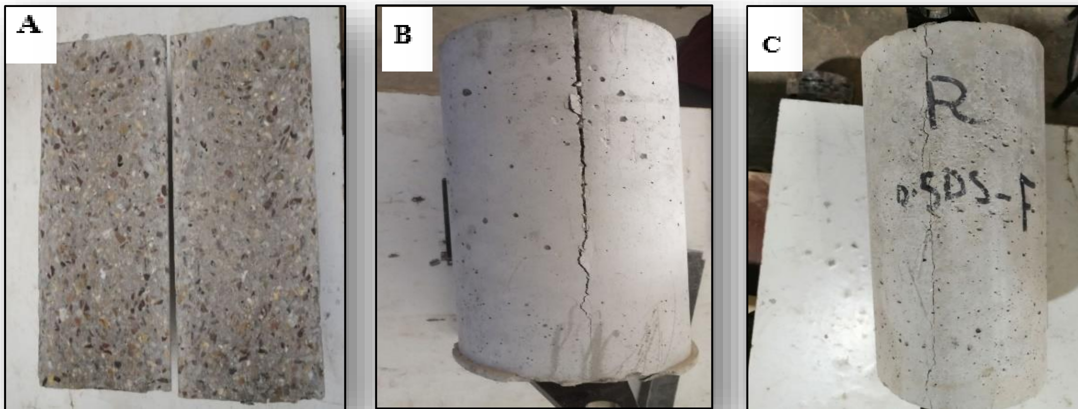


**Fig.5 Specimens after splitting tensile test (A) Plain concrete, (b) 0.25% DSF, and (c) 0.5% DSF.**

### *3.1.5 Modulus of elasticity*

The modulus of elasticity results are illustrated in Fig. 6. The values of the modulus of elasticity that were obtained for the specimens reinforced with 0.25%, and 0.5% of DSFs showed a slight increase of 3.06%, and 2.25% respectively as compared to the reference mix. This slight increase in modulus of elasticity could be justified by the same reasons related to compressive strength as mentioned above. Furthermore, the high modulus of elasticity of DSF contributes to an increase in the modulus of elasticity of concrete.

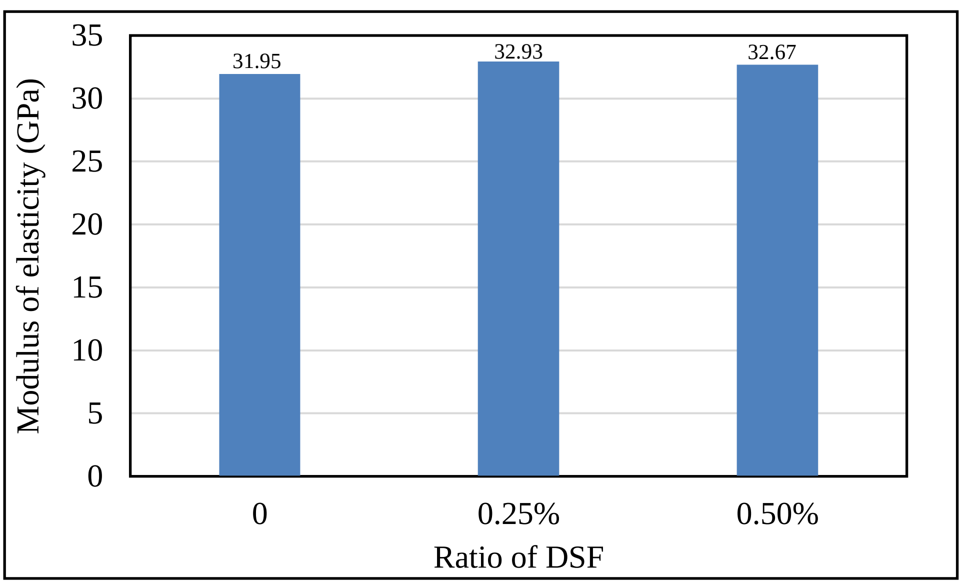


**Fig.6 Results of Modulus of elasticity.**

### *3.1.6. Modulus of rupture*

All Specimens were tested under three-point load test. According to the results of the modulus of rupture test, which are shown in Table 10, adding DSFs to concrete as reinforcement led to an increase in modulus of rupture. Also, the results indicated that the modulus of rupture changed in the same way as the tensile strength, it was found that the increase in the percentage of fibers leads to a significant improvement in the modulus of rupture, which increased by 6.97%, and 25.58% when compared with the reference mixture. This increase is mainly due to the ability of DSF to control the growth and expansion of cracks, depending on the properties of the fibers that come in the first place, which is the bridging of the micro/macro cracks and limiting their propagation during the cracking stage, and the random distribution of the fibers through the matrix, which leads to the increase in load-carrying capacity until failure. As illustrated in Fig. 7, the addition of DSF significantly changed the failure mechanism so that the specimen did not exhibits sudden failure after the occurrence of initial cracking.

**Table 10- Modulus of rupture results.**

| Mix Type | DSFs Content by volume % | Flexural Strength (MPa) | Increase (%) |
|---|---|---|---|
| x1 | 0 | 4.3 | - |
| Mix2 | 0.25 | 4.6 | 6.97 |
| Mix3 | 0.5 | 5.4 | 25.58 |


**Fig.7 Failure mode of samples under flexural loads (A) plain concrete, (B) 0.25% DSF, and (C) 0.5% DSF.**

## 4. Conclusions

Based on the experimental results presented in the previous section, the following conclusions can be summarized below:

1. The workability of the concrete mixture was decreased by the addition of DSF, and this decrease grew as the amount of DSF increased.
2. Addition DSF increased compressive strength of concrete mixture by abuot 8.8%, and 3.3% for fibers content 0.25% and 0.5% respectively, as compared to the reference mix.
3. An increase in DSF content to 0.5 %leads to a decrease in compressive strength, compared to 0.25%.

4. A slight increase in the density and modulus of elasticity could be observed by adding DSF to the concrete mixture.
5. The increase in the percentage of DSFs leads to a significant improvement in the splitting tensile strength and modulus of rupture.
6. The low tensile strength of concrete can be improved by using DSF as a steel fiber.

For future work, this study suggests using increased content of discarded steel fibers such as (0.75%, and 1%) ratios, more over, further investigations on various properties of concrete would be helpful to present an adequate evaluation on performance of this type of fibers in concrete.

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