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# Self-compacting Concrete Strengthening Efficiency Investigation by Using Recycled Steel Waste as Fibers

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**ABSTRACT**

Steel recycling saves energy and time and is more environmentally friendly. It rids the environment from huge amounts of scrap cars and huge structures, as well as reduces mining operations that destroy the natural environment. In this investigation, the steel scrap effect on the mechanical properties of concrete was investigated, inadditiontoinvestigatethevariationofmechanicalpropertieswithincreasingtheconcrete age. Three concrete mixes were studied: one without steel waste as a control, one with 1 % steel waste by volume of concrete, and one with 1.5% steel waste by volume of concrete. The results show that adding waste steel to the concrete improved compressive strength as well as tensile strength. where, the mixing which contains 1% of steel waste, has an increase in strength that reaches up to 12% and 23% at 28 days for compressive strength and tensile strength sequentially as compared to the reference mix. Furthermore, the results show that there is a significant increase in splitting tensile strength that reaches 29% at day 28 for a mix of 1.5% steel waste as compared to the reference concrete mix. The best improvement in compressive strength over time was obtained when using 1% steel waste. Whilethebestimprovementintensilestrengthovertimewasobtainedwhenusing 1.5% steelwaste.In both cases, the amount of improvement is better than the models without steel waste, which gives us confidence in giving recommendations for conducting more in-depth studies to achieve maximum advantage.

**Keywords:** self-compacting concrete, waste steel fiber, compressive strength, recycling material, splitting tensile strength, and adding recycled material.

## INTRODUCTION

In general, many studies have been done to reuse waste material in concrete, such as carpet waste, used tires, polypropylene and nylon, wood fiber as paper products waste, steel shavings as an alternative to steel fibers (Wanget al., 2000), and iron waste (Ghannam et al., 2016) to get benefit from waste material to improve concrete properties and performance while also lowering costs by including recycle fiber to process as a substitute for manufacturer fibersto get rid of disposal waste in landfill.

Steel fibers are commonly utilized in structural facilities as well as other applications. Slope stabilization is a term used to describe the process of making a slope more stable. Artificial fibers improve the efficiency of concrete, but they are not without their drawbacks. Produced from nonrenewable and expensive materials. Steel industry generates large quantities of steel waste materials, which can be environmentally damaging if left untreated (Merli et al., 2020).

The primary waste products from steel products manufacturing, which are a severe apprehension across the world, may be reduced by using resources, for example turning machine recyclable materials as fiber into concrete. It is a safe resource to use certain wastes in concrete (Prasad et al., 2020).

Mohammadi et al. (2008) discussed steel waste fiber as an admixture material in concrete, which was an appealing indication because steel waste has high strength and durability, which could lead to an increase in concrete's strength as well as improve some of its properties such as ductility, impact resistance, dynamic load resistance, and delaying the evolution of macro cracks or rather their width.

Aghaee and Yazdi (2014) used waste steel wire from rebar and wooden molds previously used in construction projects in lightweight structural concrete. To assess the mechanical characteristics of 28-day reinforced lightweight concrete samples using waste wires, tensile, flexural, and impact tests were conducted. In the volume fraction of concrete, the percentage of wire in fiber-reinforced concrete was 0.25%, 0.5%, and 0.75%. The findings show that concrete's bending, tensile, and impact characteristics may be significantly enhanced by the use of discarded wires. The use of scrap steel wire as a suitable fine reinforcement in light weight concrete is also concluded.

In general, it is understood that fiber-reinforced concrete, which uses a variety of metallic, hybrid, and polymeric fibers, may enhance the behavior of concrete when it has cracked by bridging fractures, reducing energy consumption, and enhancing the ductility capacity of concrete elements.

Jang and Yun (2018) investigated the effect of steel fibers content and coarse aggregate size on the mechanical properties of high strength concrete. The research also showed the relationship of compressive strength and bending strength of high strength steel fiber reinforced concrete using four ratios (Vf = 0.5%, 1.0%, 1.5%, and 2.0%). Compression and bending tests were performed, and the test results were used to verify the effect of the steel fiber volume fraction and the total volume on the SFRC's compressive, flexural and bending hardness which increase significantly with increasing steel fiber ratio. Also, the equations that have been proposed to determine the compressive stiffness ratio based on the equivalent flexural strength ratio were used to predict the mechanical properties of SFRC in this study.

Oroujia et al. (2021) added different quantities of glass fiber and polypropylene fiber to investigate its effect on compression and flexural strength of lightweight concrete. The percentages of used glass are 20, 25, and 30%, and the percentages of used polypropylene fibers are 0.5, 0.75, 1, 1.5, and 2%. the increase in the compressive strength, flexural strength, and ductility of tested specimens reached to about 1.6, 4, and 13.2 times, respectively.

Erfan Najaf etal. (2022) studied the effect of using waste glass powder, polypropylene fibers and microsilica to manufacture lightweight and sustainable concrete with high compressive and bending strength, ductility and impact resistance.

The objective of this research is to investigate the efficiency of recycled steel scrap as a fiber on the mechanical characteristics of self-compacting concrete. The more highlighted goal is evaluating the optimal amount and percentage of steel scrap. Also, investigate the variation in the mechanical properties of concrete with time. As a result, more research is needed on the strength of concrete as well as estimating the best dosage for adding recycled steel waste.

This study's goal is to examine how effectively self-compacting concrete's mechanical properties perform when recycled steel is used as a fibrous reinforcing material.

## EXPERIMENTAL PROGRAM

The implications of steel waste addition on the mechanical characteristics of self-compacting concrete were studied. Waste Steel scrap was used as fibers to strengthen concrete. Compressive and splitting tensile strengths are the properties studied. As well as, its effect on strength development with time was investigated. Slump test concrete workability diminishes according to the fraction of recycled steel scrap that is added (Sharma and Ahuja, 2015).

### Materials specifications

Tables 1 and 2 illustrate the cement properties that used to manufacture the concrete. Ordinary Portland Cement was adopted. The physical characteristics of the cement were tested using the standards established by the American Society for Testing and Materials ASTM C184 (2020), ASTM C187 (2020), ASTM C 188 (2020), and ASTM C19 (2020). A fine aggregate which is natural sand, has a fineness modulus of (2.65). the particles of sand bigger than 4.75 mm were eliminated utilizing sieve analysis (Table 3). Crushed coarse aggregate with a maximum size of 19 mm and a fineness modulus of (2.7), the gradation of coarse aggregate's proportionate particle sizes was assessed utilizing sieve analysis as shown in Table 4.

To avoid that negative effect, a superplasticizer was added to the concrete mix. Table below

**Table 1.** The chemical analysis of cement

| Specifications limit | Test results | Chemical element |
|---|---|---|
| - | 22.4 | $SiO_2$ |
| - | 5.78 | $Al_2O_3$ |
| - | 3.24 | $Fe_2O_3$ |
| - | 66.55 | CaO |
| Not more than 5% | 3.98% | MgO |
| Not more than 2.5% | 2.23% | $SO_3$ |
| Not more than 4% | 3.11% | I.O.I |
| 0.66–1.02% | 0.98% | I.R |
| Not more than 3.5% | 2.89% | C3A |

**Table 2.** The physical test results of cement

| Specifications limit | Test results | Test item |
|---|---|---|
| Not less than 45 min | 112 min | Initial setting |
| Not more than 10 hr | 334 min | Final setting |
| Not more than 10 mm | 1.4 mm | Soundness expansion lechatelier |
| Not less than 15 MPa | 15.39MPa | Compressive strength (3 days) |
| Not less than 23 MPa | 24.1 MPa | Compressive strength (7 days) |

**Table 3.** The test results of sand

| Specifications | | | | Passing **(%)** | Opening size (mm) |
|---|---|---|---|---|---|
| (D) | (C) | (B) | (A) | | |
| **100** | **100** | **100** | 100 | **100** | **9.5** |
| 95 - 100 | 85 - 100 | 90 - 100 | 90 - 100 | **98.99** | **4.75** |
| 95 - 100 | 85 - 100 | 75 - 100 | 60 - 95 | **89.22** | **2.36** |
| 90 - 100 | 75 - 100 | 55 -90 | 30 -70 | **75.68** | **1.18** |
| 80 - 100 | 60 -79 | 35 - 59 | **15-34** | **53.88** | **0.6** |
| 15 -50 | 12 - 40 | 8 - 30 | **5 - 20** | **17.79** | **0.3** |
| 0 - 10 | 0 - 10 | 0 - 10 | 0 - 10 | **3.01** | **0.15** |
| Specifications | | | | Test result | ($So_3$) |
| **<0.5%** | | | | **%0.41** | |

**Table 4.** The test results of gravel

| Specifications | | | Passing **(%)** | Opening size (mm) |
|---|---|---|---|---|
| 5-14 mm | 5-20 mm | 5-40 mm | | |
| **---** | **100** | **95-100** | **100** | **37.5** |
| **100** | **95-100** | **35-70** | **98.1** | **19** |
| **50-80** | **30-60** | **10-40** | **42.3** | **9.5** |
| **0-10** | **0-10** | **0-5** | **8.6** | **4.75** |
| Specifications | | | Test result | ($SO_3$) |
| **<0.1%** | | | **%0.41** | |

illustrate the properties of superplasticizer that used in this investigation. The superplasticizer SEKA 5390 conforms to ASTM C494 (2012).

Steel fibers have a detrimental impact on workability; in spite, they improve the mechanical characteristics of concrete (Ulas et al. 2017). As illustrated in Figure 1, discarded steel waste was selected for mixing purposes. Since waste steel scrap performs as steel fiber in concrete, the aspect ratio (length to diameter) was set at 50-60 according to the ACI 544.3R-93 (1993) standard related to steel fibers. The material qualities of the primary

**Figure 1.** Technique for processing recycled steel fiber

structural steel are passed down to the waste steel, to meet this requirement, the steel wastes were cut to the size that did not exceed 3/8 inch, as shown in Figure 1. The Poisson's ratio was 0.3, the modulus of elasticity was set to 200,000 MPa, and the relative density was set at 7850 kg/m$^3$.

## Mix Design

The mix design was carried out in accordance with ACI 544.3R-93 (1993). All material quantities are described in Table 5.

## Specimens preparation

The experimental work addressed three concrete groups labeled as follows: ws0, ws1, and ws1.5, which were ws0 without steel waste fiber addition, ws1 with 1% steel waste fiber addition, and ws1.5 with 1.5% steel waste fiber addition. Concrete samples were stored for 28 days in a water pool for curing mix. samples during preparing shown in Figure 2.

# EXPERIMENTAL TESTS

## Compressive strength test

To investigate the compressive strength of the concrete, using standard cube specimens with dimensions of (15×15×15 cm) in accordance with ACI 544.2R-89 (1989). A uniaxial compression test has been constructed. Concrete grade C-30's

**Table 5.** The quantity of material for the designed concrete mix of concrete samples groups

| Concrete samples groups | Cement (kg/m$^3$) | Sand (kg/m$^3$) | Crushed gravel (kg/m$^3$) | w/c | Plasticizer SEKA concrete-5930 percentage | Steel waste fiber |
|---|---|---|---|---|---|---|
| Ws o | 380 | 750 | 1024 | 0.38 | 0.8% | 0% |
| Ws1 | 380 | 750 | 1024 | 0.38 | 0.8% | 1% |
| Ws 1.5 | 380 | 750 | 1024 | 0.38 | 0.8% | 1.5% |

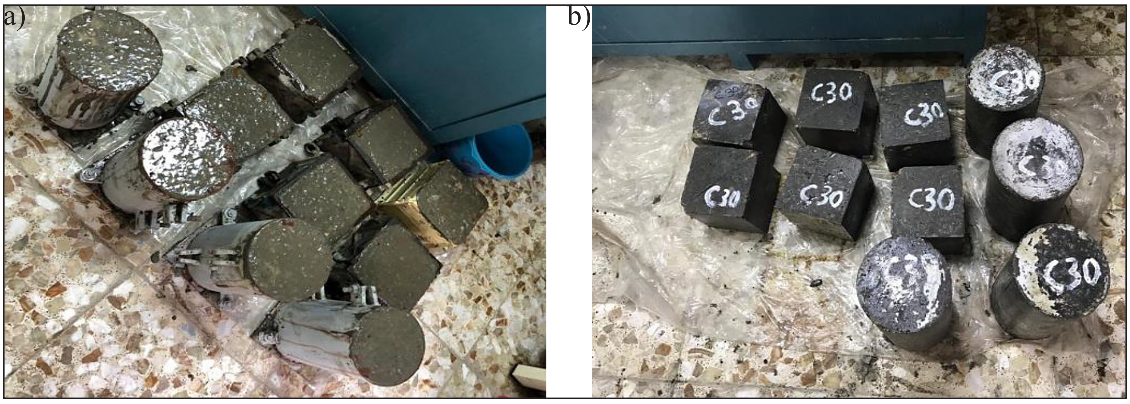

**Figure 2.** Preparing samples groups for testing:(a) concrete samples in molds, (b) concrete samples after 28 days

**Figure 3.** Compressive strength test

compressive strength was the intended result. Concrete with steel waste fibers volumetric ratio was the variable. Three steel waste volumetric ratios of 0%, 1%, and 1.5% were evaluated.

The compressive strength of the cube sample is calculated by the proof of:

$$f_{comp.} = \frac{P_C}{A} \tag{1}$$

where: $P_C$ – compression Failure load;
$A$ – loaded area of cube.

Compressive tests as shown in Figure 3, were conducted at 7,14, and 28 days of dipping in water for curing.

### Tensile strength test

For tensile strength, cylinders with a diameter of 15 cm and 30 cm‘s length all samples were tested by splitting tests with an aimed load of 1.2 MPa/s. Set up for the splitting test is shown in Figure 4. The test was conceded out in accordance with ASTM C 496-86. (1986)

$$f_{split.} = \frac{2\,P}{\pi DL} \tag{2}$$

where: $P$ – compressive load (kN);
$D$ –diameter of cylinder sample;
$L$ – length of cylinder sample.

## RESULTS

### Compression strength

Compressive strength of samples testsis pointed out in Table 6 for age 7th, and 14th days as well for age 28th days for groups WS0, WS1, and WS1.5. A value of average compressive strength is represented in Figure 5a at the age of the 14th day. Figure 5b represented the compressive strength average at the age of 28th day.The uniaxial compression test shows that 1% steel waste increases compressive strength on the 28th day by 12% as a result of bridging effect of steel waste made the crack have a difficulty to extend. But 1.5% steel waste increases compressive strength by only 0.35% in comparison with specimen without fiber at 28 day. The reason for the low difference in the compressive strength, is that the low strength of concrete, correspond by high strength of steel fibers, causes severe spalling of the concrete around the splitting hole of the fibers. The experiment’s results are compiled in Table 5.

### Tensile strength

Results of tensile strength are pointed in Table 6 for age 7th, and 14th days, as well as a Table 7

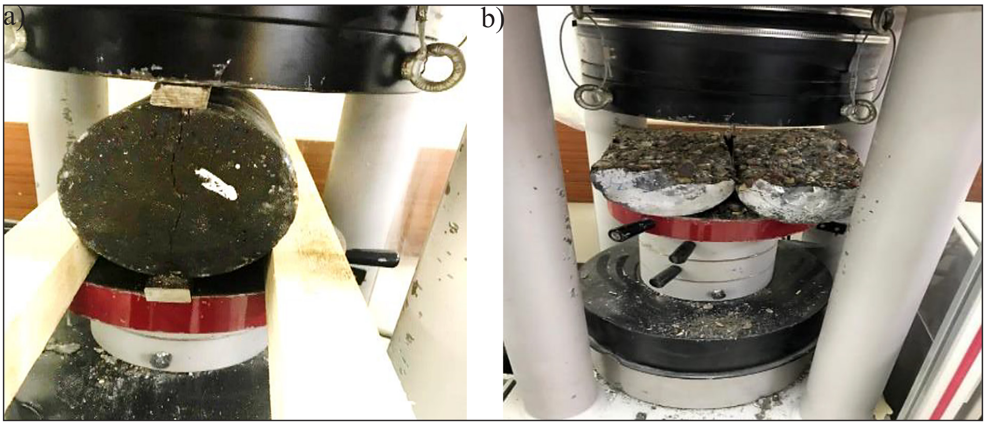

**Figure 4.** Splitting tensile test:(a) during test, (b) after failure

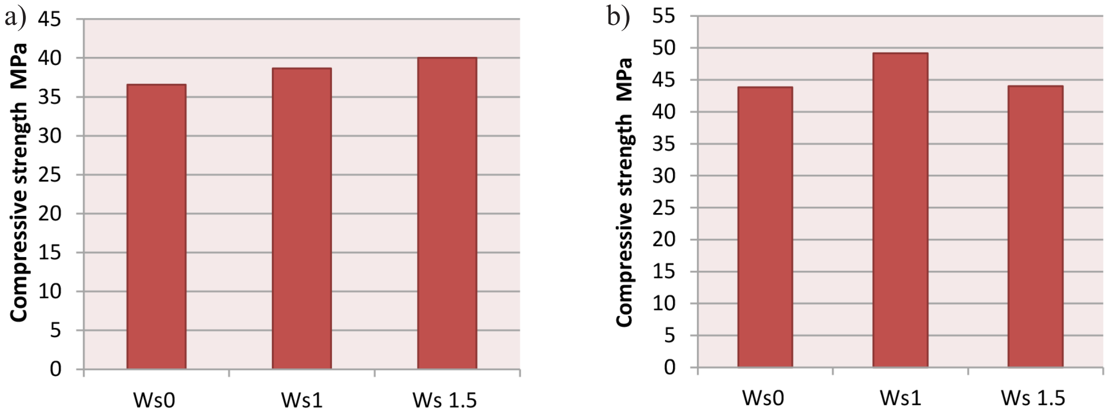

**Figure 5.** Average of compressive strength for samples groups WS0, WSI, WS1.5 at: 14th days curing (a), and at 28th days curing (b)

**Table 6.** Compressive strength with average at age 7 th,14th, and 28th day for WS0, WS1, W S1.5 samples groups

| Groups | Density (kg/m³) | Water content (%) | Average compressive strength for samples at 7 day | Average compressive strength for samples at 14 days | Average compressive strength for samples at 28 days |
|---|---|---|---|---|---|
| Ws0 | 2350 | 144.4 | 30.681 | 36.56 | 43.83 |
| Ws1 | 2691 | 144.4 | 35 | 38.66 | 49.15 |
| Ws 1.5 | 2788 | 144.4 | 30.8 | 40 | 44 |

for ages 28th days for groups WS0, WS1 WS1.5, Values of average tensile strength, are represented in Figure6a for ages 14th day, the average of WS was 2.92 as well as it was 3.5, 3.63 for WS1 and WS1.5 respectively. The reason for this is due to the increased interlocking between the components of the concrete mixture by increasing the percentage of fibers in the concrete mixture, which in turn delays the appearance of cracks and reduces their width. Also, fibers have a major role in forming connecting bridges in the crack area that helps to increase endurance and create additional tensile resistance.While Figure 6b represented that the tensile strength average at age 28th day, was 3.18, 3.91, and 4.1for WS0, WS1, and WS1.5 respectively.

**Table 7**. Tensile strength with average at age 7 th,14th day, and Age 28th day for WS0, WS1, W S1.5 samples groups

| Groups | Average tensile strength MPa for samples at 7 day | Average tensile strength MPa for samples at 14 day | Average tensile strength MPa at 28 day |
|---|---|---|---|
| Ws 0 | 2.226 | 2.92 | 3.18 |
| Ws 1 | 2.737 | 3.498 | 3.91 |
| Ws 1.5 | 2.87 | 3.63 | 4.1 |

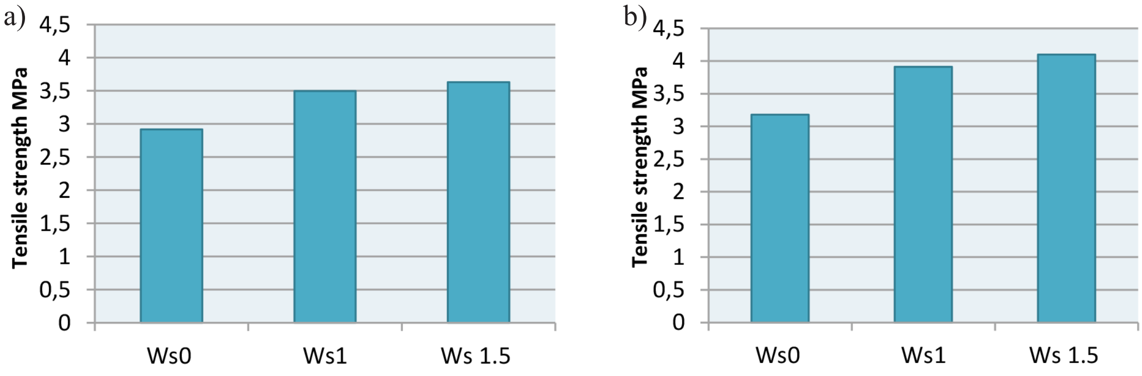

**Figure 6.** Average of tensile strength for samples groups WS0, WSI, WS1.5 at 14th day curing (a), and at 28th days curing (b)

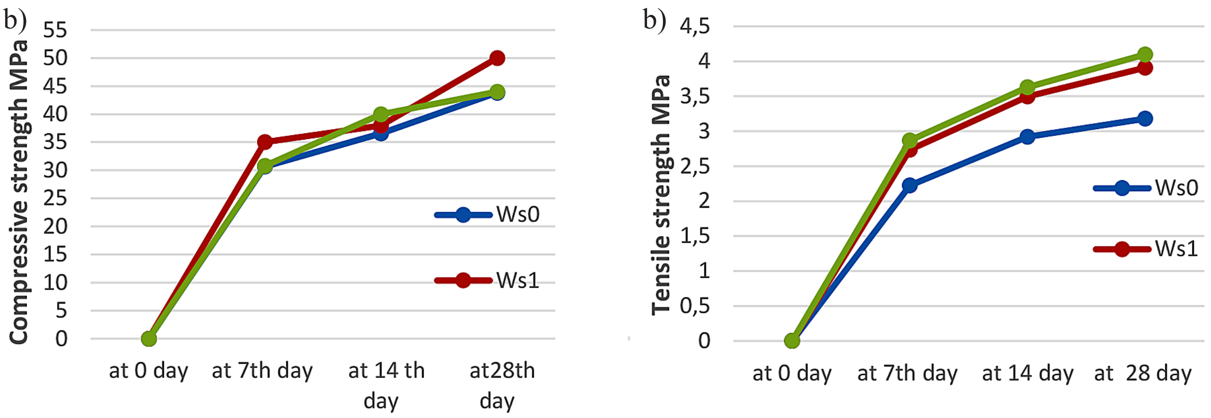

**Figure 7.** Development of compressive strength (a), and tensile strength (b), with ages 0,7, 14, and 28 for WS0, WS1, and WS1.5

## Development of strength with age

Figure 7a illustrates the relationship between compressive strength development of the strength with ages of 0 days, 7 days,14 days, and 28 days and it is indicated that in 14 days the average strength of group WS1 and WS1.5 was more than WS0 that group without waste steel fiber farther more its indicate that in 28 days WS1 was the highest value while WS1.5 close to WS0. Figure 7b showed the relationship between tensile strength development of the strength with ages of 0 days, 7 days,14 days, and 28 days and it is indicated that in 14 days the average strength of group WS1.5 was the highest value asWS1 and it was more than WS0 group as well as it is shown that in 28 days WS1.5 was the highest value.

## CONCLUSIONS

From the experimental results obtained for concrete samples containing fibers in different volumetric ratios, the following points have been appointed:

1. Addition of waste steel fibers has an effect on the compressive strength of concrete, but its effect was more pronounced on the tensile strength.
2. By increasing the percentage of fibers, the tensile strength improved until the 29% when adding 1.5% of steel fibers to concrete.
3. The addition of fibers to concrete contributed to reducing the occurrence of cracks and their widening by creating bridges that connect the components of concrete.Along with, The adding of fibers led to a change in the collapse pattern from a brittleto a ductile failure.
4. The rate of obtaining the compressive strength over the time in the case of 1% waste fibers is higher if compared with the specimens without fibers or the specimens containing the fibers ratio of 1.5%.
5. It was detected that the development in tensile strength was more when using the percentage of fibers 1.5%, compared to the specimens without fibers and the specimens containing 1% of fibers.

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