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The Effect of Scrap Tires Recycled Steel Fibers on Some Hardened Properties of Green SCC

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HIGHLIGHTS

- Using recycled fibers as a substitute for commercial fibers was investigated.
- The effect of fibers volume fraction and aspect ratio on the mechanical properties of SCC were studied.
- The possibility of producing sustainable high Strength GSCC using recycled coarse aggregate and recycled fibers was investigated.

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ABSTRACT

The purpose of this study is to investigate some hardened properties of green self-compacting concrete (GSCC) with 15% volumetric replacements of crushed clay brick waste as coarse aggregate and reinforced with scrap tires recycled steel fibers (STRSF) with 0, 0.25, 0.5and 0.75%volume fraction and 40 as an aspect ratio. Also, a combination of two STRSF aspect ratios of 40 and 60 was used in GSCC as hybrid fiber reinforcement (0.25 and 0.25%, 0.5 and 0.25%, 0.25 and 0.5% of aspect ratios 40 and 65, respectively). Scrap tires recycled steel fibers had been used to improve the properties of the green self-compacting concrete containing crushed clay brick waste aggregate. Dry density, water absorption, compressive strength, splitting tensile strength, flexural strength, and Ultrasonic Pulse Velocity (UPV) were among the properties of SCC that had been investigated. To achieve the purpose of this study, seven concrete mixes were prepared.SCC density, compressive strength, splitting tensile strength, flexural strength, and UPV are all increased with the increase of recycled steel fibers content in self-compacted concrete. Including different volume fractions and aspect ratios of scrap tire recycled steel fibers increased the compressive strength between 2.54% to 23%. The splitting tensile strength was about 5.6% to 13.9%, and the flexural strength increased from 1.6% to 14.8%. All GSCC mixes reinforced with STRSF show good performance according to the classification limits of SCC with high compressive strength, so these mixes are applicable for different weather conditions and construction projects.

1. Introduction

The first study on SCC development employing viscosity-agent and super-plasticizer was published in Japan in 1988. Then, in 1992, the researchers illustrated the factors that impact self-compatibility, including the content of aggregates (fine and coarse aggregate). Furthermore, they devised new test procedures to assess self-compatibility again and determined that the water-powder ratio impacts self-compatibility [1].

Green SCC represents the SCC that contains waste materials since it is considered sustainable concrete and friendly to the environment. According to the properties of this concrete, it can be used in a different construction projects, and several concrete products such as concrete masonry units can be produced from this type of concrete.

Grdic et al. [2] investigated some properties of self-compacting concrete prepared with coarse recycled concrete aggregate. Three types of concrete mixes were created based on the percentages of recycled aggregate used as a replacement for coarse aggregate (0, 50, and 100 percent). The results show that recycled aggregate can be utilized to make SCC. However, large amounts of waste clay bricks are created during the building, demolition, and brick production processes. Because these pollutants are dumped, they generate plenty of environmental issues [3]. As a result, many researchers investigate the ability to include waste clay bricks in concrete.

Bhanbhro et al. [4] conducted an experimental study on the effect of utilizing recycled crushed brick waste in concrete as a volumetric replacement for coarse natural aggregates. The results illustrated that the density was reduced by about 16%

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compared to the reference mix. Furthermore, compared to conventional reference concrete, concrete containing recycled aggregate had a drop in compressive strength of around 23.2%, 34%, and 37% at 7, 14, and 28 days respectively.

Since SCC should expand into a place under its weight and achieve consolidation without external or internal vibration, the Fiber Reinforced SCC (FRSCC) should be similar and have minimal trapping of air gaps and homogeneity loss until hardening [5]. According to ACI Committee 544.4R-2002 [6], the used volume fraction of steel fibers is from 0.5 percent to 1.5 percent by volume of concrete, and the used aspect ratio of steel fibers is from 50 to 100. Many pieces of research have been accomplished in the last two decades to improve appropriate guiding lines for FRSCC. Irki et al. [7] investigated the impact of three wavy steel fibers with lengths of 35, 40, and 50±2 mm and volume fractions (V_f) of 0.3, 0.5, 0.8, 1, 1.2, and 1.4 percent on certain characteristics of SCC, and the main conclusions were that the inclusion of steel fibers with a higher volume fraction content in SCC shows higher elasticity modulus and flexural strength. However, the compressive strength had been slightly decreased. The effect of the steel fibers recycled from waste tires on the fresh and hard properties of SCC had been studied by Singh and Simalti[8]. The recycled steel fibers used with 0.5, 1, and 1.5% volume fraction, aspect ratio of 22, and a length of 35 mm. According to the results, adding recycled steel fibers from waste tires into concrete increases its compressive strength. Thus, using recycled steel fibers from waste tires as reinforcement in SCC is advantageous. The results of the study of Saba et al. [9] showed that a reduction in workability was obtained from steel fibers while the hardened concrete characteristics, particularly the hardness, will be enhanced. The mechanical behavior of hybrid steel fiber reinforcement and fiber dispersion had been investigated by Akcayand Tasdemir [10]. The results show that the flexural strength was increased slightly with an increase in fibers aspect ratio.

2. Research Significance

Previous studies indicated that crushed brick waste material, used as aggregate in SCC to reduce its negative environment, affects and promotes sustainability by reducing the strength of concrete. So fibers can be used to improve the strength and other characteristics of concrete containing crushed brick waste aggregate. Also, using fibers recycled from waste materials to reinforce such SCC will lead to the production of more sustainable SCC.

The fresh and hardened properties of SCC that contain a combination of crushed brick waste aggregate and waste fibers had not yet been sufficiently investigated. Therefore, this study aims to generate GSCC by using crushed brick wastes as a partial volumetric replacement for natural coarse aggregate and reinforced with various quantities and aspect ratios of steel fibers obtained from recycled scrap tires, then evaluate its properties.

The reason for using these waste materials is to reduce their environmental impact in a useful way. Also, they can be used in the mixtures to enhance the properties of the SCC.

3. Experimental Work

3.1 Materials

1) The cement used was ordinary Portland cement Type I, made under the trademark (mass). It was stored in sealed plastic containers to reduce exposure to outdoor conditions. It conforms to Iraqi Standard Specification No. 5 [11].
2) Natural crushed coarse aggregate with a maximum size of 12 mm, a specific gravity of 2.65, sulfate (SO_3) content of 0.06%, and water absorption of 2% was used. Therefore, it fulfills the requirements of the Iraqi Standard No.45/ [12]. Table 1 displays the gradation of natural coarse aggregate.
3) The natural sand utilized had a specific gravity of 2.65, absorption of 2.4%, fineness modulus of 2.32, sulfate content (SO_3) of 0.5%, and maximum aggregate size of 4.75mm. Therefore, it conforms to Iraqi Standard No.45/ [12]. Table 2 shows the natural fine aggregate gradation.
4) For mixing and curing self-compacted concrete, potable water was utilized.
5) As a High Range Water Reducing Admixture (HRWRA), MasterGLENIUM54® (trademark) with a density of 1.07 kg/liter at room temperature and dosage ranging from 2.2-2.8% of the cement weight (recommended by the manufacturer), was also used (for all mixes). This admixture contains no chloride and complies with ASTM C494type F requirements [13].
6) Clay brick wastes were collected from building demolition, crushed to a maximum size of 12mm as shown in Plate 1, cleaned and dried, then prepared with the same grading of natural coarse aggregate. Its physical and chemical properties are shown in Table 3.
7) As indicated in Plate 2, steel fibers recovered from waste tires with a diameter of 1.05 mm, an aspect ratio of 40and 65, and a density of 7850 kg/m^3 were utilized.

Table 1: Grading of Natural Coarse Aggregate

Sieve Size (mm)	Passing (%)	Limits of Iraqi Standard No. 45/1984 with (5- 12)mm[12]
14	100	90-100
12.5	100	------
10	54.23	50-85
4.75	1.9	0-10

Table 2: Grading of Natural Fine Aggregate

Sieve size (mm) According to Iraqi Standard No.23	Passing (%)	Limits of Iraqi Standard No. 45/1984 Zone (2)[12]
10	100	100
4.75	97	90-100
2.36	90.6	85-100
1.18	84	75-100
0.60	67	60-79
0.30	18	12-40
0.15	5	0-10

Table 3: Aggregate Physical and Chemical Properties of Coarse Clay Brick Waste

The Properties of Coarse Clay Brick Waste	Test Results	Limits of the Iraqi specification No.45/1984 [12]
Absorption (%)	24	-
Specific Gravity	1.57	-

(a) Clay brick waste (b) Prepared clay brick waste

Plate 1. Preparation of Clay brick Waste

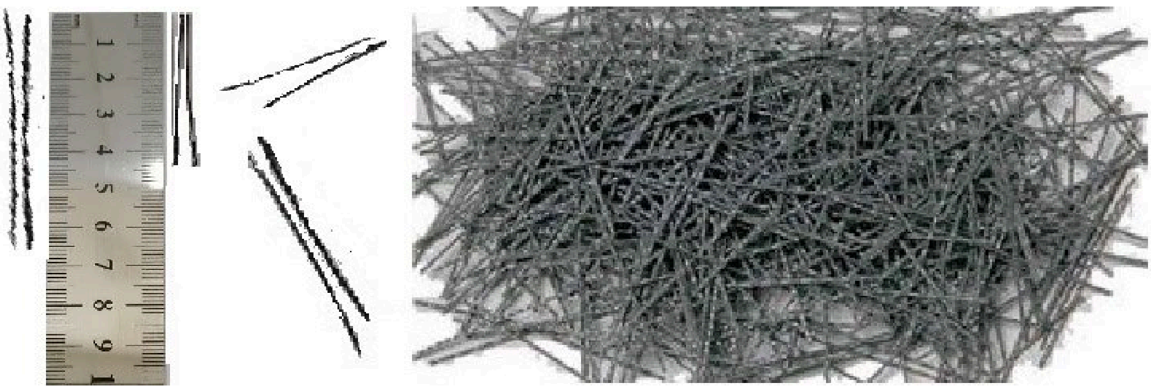

Plate 2. Scrap Tires Recycled Steel Fibers

3.2 Concrete Mixes

Seven SCC mixes were prepared for this investigation. The proportions and the quantities of the materials per 1 m^3 of SCC are listed in Table 4.

3.3 Selection of Mix Proportions

The mix proportions were 1:1.72:1.97 (cement: sand: gravel), with 450 kg/m^3 cement content and 0.36 as w/c ratio. According to EFNARC [14], this self-compacting concrete mix produced concrete with a minimum compressive strength of 50 MPa after 28 days. The optimal dose of HRWRA (high range water reducing admixture) that fulfills the standard specifications for SCC workability was determined after many trial mixes. According to the results of this investigation, the optimal HRWRA dosage for mixtures without fibers is 2.6 liters per 100 kg of cement.

Table 4: Concrete Proportions of Green Self-Compacted Concrete Mixes

Mix Proportions	Mix symbol	Cement (kg/m^3)	Natural Fine Aggregate (kg/m^3)	Natural Coarse Aggregate (kg/m^3)	Dosage of HRWRA (liter /100kg of Cement)	w/c ratio	Waste Clay Bick as a Replacement to NaturalCoarse Aggregate (%)	Waste Clay brick as a Replacement toNatural Coarse Aggregate (kg/m^3)	Volume Faction of STRSF with 40 aspect ratio (%)	Scrap tires recycled steel fibers with 40 as aspect ratio (kg/m^3)	The volume fraction of STRSF with a 65 aspect ratio (%)	Scrap tires recycled steel fibers with 65 as aspect ratio (kg/m^3)
Cement:Sand:Gravel (1:1.72:1.9)	B15	450	774	808.6	2.6	0.36	15%	77.9	-	-	-	-
	0.25B15	450	774	808.6	2.6	0.36	15%	77.9	0.25%	1.138	-	-
	0.5B15	450	774	808.6	2.6	0.36	15%	77.9	0.50%	2.276	-	-
	0.75B15	450	774	808.6	2.6	0.36	15%	77.9	0.75%	3.414	-	-
	0.5HB15	450	774	808.6	2.6	0.36	15%	77.9	0.25%	1.138	0.25%	1.138
	0.75H1B15	450	774	808.6	2.6	0.36	15%	77.9	0.50%	1.138	0. 25%	2.276
	0.75H2B15	450	774	808.6	2.6	0.36	15%	77.9	0.25%	2.276	0.50%	1.138

3.4 Concrete Mixing Procedure

In a $0.1m^3$ rotary mixer, SCC was mixed. The procedure for mixing was as follows:

1) The natural coarse and fine aggregate, cement, and crushed clay brick aggregate were mixed for at least 3 minutes. All aggregates were washed with water and then exposed to air for 24 – 48 hours in a saturated surface dry condition.
2) All amount of the mixing water was combined with the admixture before being fed to the mixer. The mixing time was divided into the following sections:
   - Mixing for 3 minutes.
   - Rest for 1 minute (to give the admixture the needed time to react)
   - Additional mixing time of 2 minutes ensures that the SCC mixture is completely homogenous.
3) The fibers (for fiber-reinforced mixtures) were introduced to the mixture by dispersed and fragmented distribution during the first 3 minutes of mixing to guarantee that no fiber balling would occur.

3.5 Preparation of Concrete Specimens

Standard steel molds were cleaned and lubricated to prevent concrete adherence after hardening. Since SCC mixes did not require compacting, they were cast into steel molds (cubes, cylinders, and prisms) until they were filled. The molds were covered with a polyethylene sheet for about 24 hours. It will then be immersed in water to cure properly for 28 days. All the work had been accomplished in the laboratories of the University of Technology, Baghdad.

3.6 Experimental Tests

The following experiment tests were performed on three hardened specimens of SCC for each test:

1) **Oven Dry Density and Absorption Water Tests -** According to ASTM C 642 – 13[15], these tests were determined at 28 days.
2) **Compressive Strength Test -** According to BS 1881: part116[16], this test was performed on concrete cube specimens of 100 mm.
3) **Splitting Tensile Strength Test -** According to ASTM C496-17 [17], this test was performed on 100 x 200 mm cylindrical specimens.
4) **Modulus of Rupture Test (Flexural Strength) -** According to ASTM C78-02 [18], this test was performed on concrete prismatic specimens (100 x 100 x 400 mm) to evaluate the modulus of rupture under two-point loads.
5) **Ultrasonic Pulse Velocity Test -** According to ASTM C597 [19], this test was determined at 28 days.

All the experimental work had been accomplished in the laboratories of the University of Technology, Baghdad.

4. Results and Discussion

Compared to the reference mix, HRWRA results in a considerable increase in compressive strength and a drop in the water-cement ratio. This is due to the superplasticizer's action mode, in which the polar chain is adsorbed on the surface of cement particles when added to the cement water system. This creates a high negative charge surrounding the grains, decreasing inter-particle attraction by an electrostatic process and lowering the quantity of water needed to achieve equivalent workability [20]. The workability of all SCC mixes prepared in this investigation satisfied the EFNARC limitations [14].

4.1 Oven Dry Density and Water Absorption

Table 5 reveals that the increased amount of recycled steel fibers will slightly increase the dry density. The percentage of increase varied from 2.1 to 5.5%. This is because of the small amounts of the fibers added to the SCC specimens, which have a high density (7850 kg/m^3), as revealed in Figure 1. The Water absorption decreases due to the increased amount of recycled steel fibers. The decrease percentage varied from 9.71% to 28.9%as revealed in Fig.1. The results of water absorption are in agreement with previous research [21]. The reduction in water absorption for fiber-reinforced GSCC may be because fibers will restrict cracks and cut off the continuity of paths and pores within the concrete, which leads to a decrease in water absorption.

Table 5: Test Results for Different GSCC Mixes

Mix symbol	B15	0.25B15	0.5B15	0.75B15	0.5HB15	0.75H1B15	0.75H2B15
Oven Dry Density, kg/m^3	2271.7	2319.3	2358.8	2375.1	2373.8	2396.0	2396.8
Water Absorption, %	3.81	3.44	3.17	2.98	2.78	2.48	2.41
Compressive Strength, MPa	55.3	56.7	58.87	62	61.2	66.4	68
Splitting Tensile Strength, MPa	3.6	3.8	3.9	4.1	4.2	4.5	5.0
Flexural Strength, MPa	5.95	6.37	6.47	6.57	6.65	6.93	7.2
Ultrasonic Pulse Velocity, m/sec	4.55	4.65	4.78	4.89	4.84	4.98	5.04

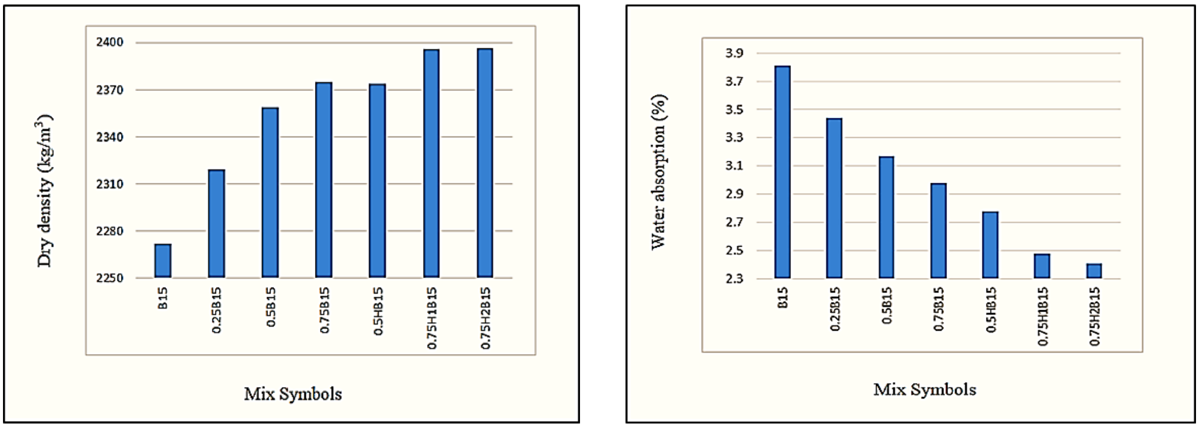

Figure 1: Effect of the STRSF on Oven Dry Density and Water Absorption of GSCC

4.2 Compressive, Splitting Tensile, Flexural Strengths and Upv

Table 5 shows the influence of reinforcing GSCC containing 15% crushed clay bricks aggregate with steel fiber recycled from scrap tires on compression strength, splitting tensile strength, flexural strength, and ultrasonic pulse velocity (UPV) at the age of28 days. GSCC specimens with various percentages of recycled steel fibers had higher compressive strength, splitting tensile, and flexural strengths than GSCC reference specimens (B15 - contain 15%of clay brick wastes aggregate as a partial volumetric replacement) without fibers).

The compressive strength of SCC specimens with 15% clay brick waste aggregate had an increasing percentage varies from 2.54% to 12.12% with the increase of fiber content (for the 40 as aspect ratio) compared to the GSCC reference specimens that contain no fiber as revealed in Figure 2. Short fibers can help to prevent crack growth by providing a better bridging effect [22,23]. Steel fibers are uniformly distributed to prevent cracks in concrete and provide high mechanical strength to the concrete due to their incorporation [24]. It was observed that there is a 6.5% increase in compressive strength for GSCC reinforced with a 0.5% volume fraction of STRSF with 40 as the aspect ratio. In comparison, the compressive strength for 0.5% as volume fraction with a hybrid fibers aspect ratio of(40 and 65)was increased by about 10.8% compared to reference GSCC. Including 0.75% as a volume fraction with an aspect ratio of 40 enhances the compressive strength by about 12.1%. In comparison, the compressive strength for the same volume fraction with a hybrid fibers aspect ratio of(40 and 65) was increased by about 20.1% and 23% for mixes (0.75H1B15) and (0.75H2B15), respectively, compared to the reference GSCC. This is because a high fiber volume fraction causes more impediments to the diffusion of fresh concrete. Short fibers can help to prevent crack growth by providing a better bridging effect [22,23]. Steel fibers are uniformly distributed to prevent cracks in concrete and provide high mechanical strength to the concrete due to their incorporation [24]. This may have happened due to the good micro-crack arresting property of short steel fiber and better matrix and fiber bonding behavior of RSF due to its entangle shape [25, 26].

With the increase of fibers content (for 40 as aspect ratio), the splitting tensile strength of the GSCC specimens had an increasing percentage varies from 5.6% to 13.9% compared to reference GSCC specimens not reinforced with fibers as illustrated in Figure 3. Short fibers provide a higher bridging effect, inhibiting crack formation [22,23]. When concrete is hardened, steel fibers are evenly dispersed to prevent fissures. As a result of their integration, steel fibers provide the concrete with a high mechanical strength [24]. The splitting tensile strength for the fibers volume fraction of 0.5% with a hybrid fiber aspect ratio (40 and 65) increases by about 16.6%. In comparison, the increase was about8.3% for 0.5% fibers volume fraction with an aspect ratio of 40compared to the reference GSCC. For GSCC with 0.75% fiber volume fraction and aspect ratio of 40, the enhancement in splitting tensile strength was 13.9%, while the splitting tensile strength for the same volume fraction with hybrid fibers aspect ratio(40 and 65) was increased by25% and 38.9% for mixes (0.75H1B15) and (0.75H2B15) respectively compared to the reference GSCC (B15). This enhancement in the splitting tensile strength of GSCC with hybrid STRSF is due to the synergy performance of hybrid fibers. Short fibers can bridge micro-cracks, while the long fibers can bridge the macro cracks [27].

Compared to the GSCC reference specimens not reinforced with fibers, Figure 4 illustrates that with the increase of fiber content (for 40 fibers aspect ratio), the flexural strength of SCC specimens (with 15% clay bricks waste aggregate) had an increasing percentage varies from 1.6% to 4.8%. Short fibers have a stronger bridging effect, which helps to prevent fracture development [22,23]. Steel fibers are uniformly disseminated in concrete when it hardens to prevent fractures. In addition, steel fibers provide concrete with high mechanical strength due to their incorporation [24].

The enhancement in flexure strength was3.2% for 0.5% fibers volume fraction with an aspect ratio of 40, while the flexural strength for the 0.5% as fibers volume fraction with a hybrid aspect ratio (40 and 65) was increased by about6.1% compared to reference GSCC. About a 5% increase in flexural strength was recorded for 0.75% fibers volume fraction with an aspect ratio of 40. In comparison, the flexural strength for the same volume fraction with hybrid fibers aspect ratio (40 and 65) was increased by about 10.5% and 14.8% for concrete mixes (0.75H1B15) and (0.75H2B15), respectively, relative to the reference GSCC. This is due to the synergy performance of hybrid fibers. Short fibers can bridge micro-cracks, while the long fibers can bridge the macro cracks [27].

With the increase of fibers content (for an aspect ratio of 40), the UPV increasing percentage varies from 2.2% to 7.5% compared to the GSCC reference specimens not reinforced with fibers, as illustrated in Figure5. The UPV for the 0.5% fibers volume fraction with a hybrid aspect ratio (40 and 65) was increased by about 6.4%. In comparison, the increase was 5.1%compared to the GSCC reference specimens for 0.5% fibers volume fraction with an aspect ratio of 40. Including 0.75% fibers volume fraction with 40 as fibers aspect ratio enhances the UPV by about 7.5%. In contrast, the UPV for the same volume fraction with a hybrid aspect ratio (40 and 65) was increased by9.45%and 10.77%for GSCC mixes (0.75H1B15) and (0.75H2B15), respectively, compared to the reference GSCC mix. The results of the UPV test are in agreement with compressive strength results. The UPV values for GSCC reinforced with STRSF are in the range of 4.65 to 5.04 km/sec., which are classified as excellent quality concrete according to other researchers [28,31].

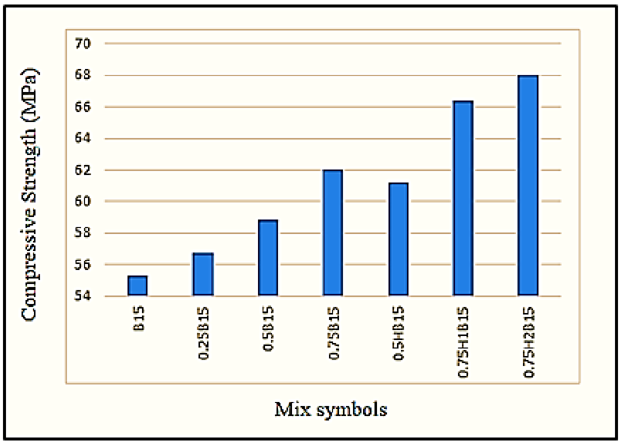

Figure 2: Effect of STRSF on the Compressive Strength of GSCC

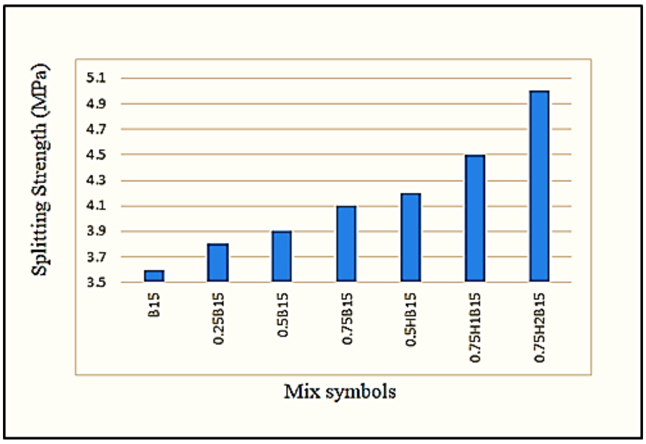

Figure 3: Effect of STRSF on the Splitting Strength of GSCC

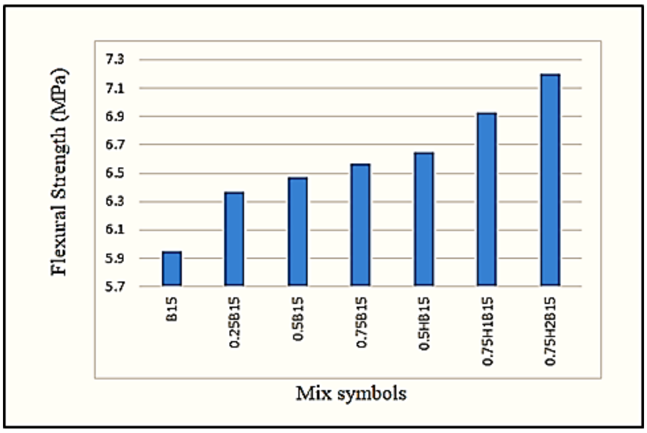

Figure 4: Effect of STRSF on the Flexural Strength of GSCC

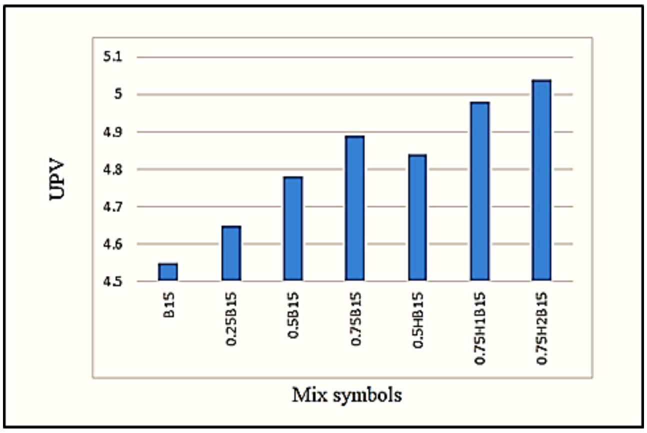

Figure 5: Effect of STRSF on UPV of GSCC

4.3 Failure Modes of SCC Specimens under Flexure Load

GSCC specimens containing coarse clay brick waste aggregate but not reinforced with fiber demonstrated brittle failure with quick breakup followed by sound, and the specimens were broken into two pieces. Whereas GSCC specimens containing STRSF failed in a ductile way, they withstand the stresses for a few minutes after the failure. The failure for GSCC specimens with different contents and aspect ratios of STRSF occurred by debonding fibers. Plate 3 shows the failure modes for some GSCC specimens prepared in this investigation.

a- Specimens B15

b- specimens 0.25B15

c- Specimen 0.5B15

d- Specimens 0.75B15

e- Specimen 0.5HB15

f- Specimen 0.75H1B15

g- Specimen 0.75H2B15

Plate 3. Some GSCC specimens were reinforced with STRSF after failure under flexural stress

5. Conclusions

The main conclusions that can be drawn from the results of this investigation can be summarized:

1) The compressive strength of GSCC containing 15% clay bricks waste aggregate as a volumetric replacement to natural coarse aggregate was increased between 2.54% to 23% with the inclusion of different volume fractions and aspect ratios of scrap tires recycled steel fibers.
2) The splitting tensile strength of GSCC not reinforced with fibers was enhanced by about 5.6% to 13.9% with the increase of STRSF volume fraction with an aspect ratio of 40. Furthermore, the inclusion of a hybrid STRSF aspect ratio (combination of 40 and 60 aspect ratios) in GSCC mixtures enhances the splitting tensile strength compared with the corresponding GSCC reinforced with an STRSF aspect ratio of 40 only.
3) While the GSCC reference mixes have a flexural strength of 6.27 MPa, the flexural strength increases due to the inclusion of scrap tires and recycled steel fibers in the GSCC mix, with values ranging from 6.37-7.2 MPa.
4) The range of UPV values for GSCC reinforced with STRSF is 4.65 to 5.04 km/sec, which is classified as excellent concrete.
5) For the same volume fraction, using hybrid aspect ratio steel fibers (a combination of 40 and 60 aspect ratios) provides better performance in the hardened phase than those with an aspect ratio of 40 only.
6) High-strength GSCC has been obtained and can be used in many construction projects. Moreover, this concrete is environmentally friendly since it reduces the environmental impact of the clay brick wastes and scraps of tires steel wires by recycling them as coarse aggregate and steel fibers, respectively.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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