



EFFECT OF STEEL FIBERS EXTRACTED FROM WASTE TYRES ON HIGH-EARLY-STRENGTH SELF-COMPACTING CONCRETE (HESSCC)

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ABSTRACT: Self-compacting concrete (SCC) is an innovative material widely applied in high-rise and precast structures due to its ability to flow and consolidate without vibration. However, research on high-early-strength self-compacting concrete (HESSCC) remains limited, particularly regarding the use of sustainable materials. This study investigates the effect of incorporating steel fibers derived from waste tyres (SFWT) on the fresh and hardened properties of both SCC and HESSCC. Ten mixtures with fiber contents of 0%, 0.5%, 1%, 1.5%, and 2% by volume were prepared and subjected to slump flow, V-funnel, compressive, tensile, and flexural strength tests at 1 and 28 days. The results indicate that the addition of SFWT decreases the slump flow diameter and increases V-funnel time due to higher internal resistance; however, all mixtures remained within the acceptable limits of ACI 237R-07. At an early age, HESSCC achieved a compressive strength nearly twice that of SCC, while at 28 days, their strengths converged. Tensile and flexural strengths increased significantly with SFWT, with the maximum improvement observed at 2% SFWT, yielding 50.3% higher tensile and 48.65% higher flexural strength for HESSCC at 28 days compared to the control. These results demonstrate that SFWT improves crack resistance and enhances the hardened properties of SCC and HESSCC. In conclusion, using recycled steel fibers provides an effective and sustainable approach to producing high-performance concrete with rapid early strength development.

Keywords: *Self-Compacting Concrete (SCC), High-Early-Strength Concrete, Steel Fibers from Waste Tyres, Concrete Properties, Segregation Resistance*

1. INTRODUCTION

Self-compacting concrete (SCC), first introduced in Japan, is a specialized type of concrete capable of flowing and filling every corner of formwork, even in the presence of dense reinforcement, solely under its own weight without requiring vibration or mechanical compaction [1–2]. As a highly fluid and non-segregating material, SCC effectively envelops reinforcement and completely fills formwork, thereby enhancing the overall efficiency of construction projects, as illustrated in Fig. 1.

SCC is highly suitable for structural elements where manual compaction is difficult, such as those with dense reinforcement or complex formwork geometries. Its superior resistance to segregation makes it advantageous over conventional concrete, which is prone to segregation during the construction of complex structures [3–5]. Segregation in concrete structures poses significant risks, including structural collapse during seismic events, as it compromises the concrete's quality and deviates from design specifications [6–9].

The application of SCC in construction is common in tunnels, bridge piers, high-rise buildings, and

precast concrete elements. Consequently, SCC is classified as an advanced construction material. While extensive research has been conducted on SCC, studies specifically focusing on enhancing the early strength of High-Early-Strength Self-Compacting Concrete (HESSCC) remain limited [10–11]. Given that the use of steel fibers from waste tyres (SFWT) has been shown to improve the mechanical properties of concrete [12], this study investigates the incorporation of SFWT as an additive in both SCC and HESSCC to contribute to the development and application of advanced construction materials.

This study investigates the effect of incorporating SFWT as an additive in SCC mixtures to optimize its tensile and flexural strength. Furthermore, it aims to develop HESSCC by utilizing a chemical accelerator to achieve high early-age strength development.

2. RESEARCH SIGNIFICANCE

This study aims to determine the optimal composition of SCC incorporating SFWT to achieve superior performance, particularly regarding enhanced tensile and flexural strength, as well as rapid early strength development (HESSCC) suitable

for high-rise buildings and precast applications. The research systematically examines the fresh and hardened properties of SCC and HESSCC, while also evaluating the economic feasibility of using waste-derived fibers compared to commercial steel fibers. The findings contribute to advancements in concrete technology by offering a sustainable, high-performance material that balances workability, durability, and early-age strength development.



Fig.1 Self-compacting concrete

3. MATERIALS AND MIX DESIGN

3.1 Materials

3.1.1 Cement

Ordinary Portland Cement (OPC), produced by a cement factory in Padang (PT. Semen Padang), Indonesia, was used in this study.

3.1.2 Coarse aggregate

Coarse aggregate was sourced locally, with a maximum particle size of 19 mm in accordance with ASTM C33/C33M [13]. The physical properties of the coarse aggregate are presented in Table 1.

Table 1. Properties of coarse aggregate

Property	Value
Specific Gravity	2.41
Water Absorption	1.93 %
Fine Modulus (FM)	3.4
Water Content	1.99 %

3.1.3 Fine aggregate

Locally sourced fine aggregate with a maximum particle size of 4.75 mm was used in this study. The physical properties of the fine aggregate are presented in Table 2 [14].

Table 2. Properties of fine aggregate

Property	Value
Specific Gravity	2.54
Water Absorption	2 %
Fine Modulus (FM)	2.85
Water Content	1.83 %

3.1.4 Water

Potable water, free from harmful acids or organic substances, was used for both concrete mixing and curing in this study.

3.1.5 Admixture

SCC is characterized by its high flowability; therefore, it requires a superplasticizer, specifically a high-range water-reducing admixture (HRWRA). In this study, ViscoCrete-3115N (Fig. 2), a third-generation superplasticizer produced by Sika, was used. This admixture was specifically developed to produce high-flow concrete with exceptional flow-retention properties.



Fig.2 Sika ViscoCrete-3115N

3.1.6 Accelerator

Sika Rapid-505 (Fig. 3), a liquid admixture designed to promote early setting and strength development without compromising the long-term compressive strength of the concrete, was used in this study.



Fig.3 Sika Rapid-505

3.1.7 Steel Fibers from Waste Tyres (SFWT)

The steel fiber used in this study was obtained by cutting recycled tyre steel wire. This recycled wire is a byproduct of the tyre recycling process, as shown in Fig. 4. The steel rope is removed from the tyre and cut into small fibers (approximately 4 cm long), as shown in Fig. 5.



Fig.4 Steel fibers extracted from the waste tyres recycling process



Fig.5 Steel fiber from waste tyres (4 cm in length)

In this study, four different fiber volume fractions were added to the SCC mixtures: 0.5%, 1.0%, 1.5%, and 2.0% by volume of concrete. The amount of scrap tyre fibers in concrete is generally limited to approximately 2% by volume, as higher dosages reduce workability and make it difficult to ensure uniform dispersion [15]. The properties of the steel fibers from waste tyres are shown in Table 3.

Table 3. Properties of steel fibers from waste tyres

Characteristic	Description
Form	Irregular, Sharp-edged
Size	Dia. 0.5 mm and Length 40 mm
Aspect ratio	80
Density	7850 kg/m ³
Tensile Strength	500-2000 N/mm ²

3.2 Mix Design Proportions

The mix designs for the Self-Compacting Concrete (SCC) and High Early Strength Self-Compacting Concrete (HESCC) with a target compressive strength of 55 MPa (8000 psi) were calculated based on ACI 237R-07 [16]. The water-to-cement ratio was maintained at a constant value of 0.291 for all mixtures. The different volume fractions of steel fibers from waste tyres (SFWT) used were 0.5%, 1.0%, 1.5%, and 2.0% of the specimen volume, with the control mix set at 0% SFWT. Details of the concrete mix proportions are listed in Tables 4 and 5.

3.3 Test Specimens

A total of 120 cylindrical specimens and 20 block specimens were prepared: 60 cylinders for compressive strength testing, 60 for tensile strength testing, and 20 blocks for flexural strength testing (Fig. 6).

The testing is divided into fresh and hardened concrete properties. Fresh concrete properties were evaluated based on the slump flow diameter using a V-funnel, in accordance with ACI 237R-07 [16]. The target slump flow diameter is 450–760 mm, which ensures the concrete can flow through dense reinforcement. Hardened SCC properties were tested on cylindrical specimens at 1 and 28 days (Figs. 7–9) to determine compressive [17], tensile [18], and flexural strength [19].

Table 4. Mix proportions of SCC-SFWT

Material	SFWT proportion				
	0%	0.5%	1.0%	1.5%	2.0%
Cement (kg/m ³)	650.5	650.5	650.5	650.5	650.5
Fine Aggregate (kg/m ³)	793.9	781.0	768.1	755.1	742.2
Coarse Aggregate (kg/m ³)	679.9	679.9	679.9	679.9	679.9
Water (kg/m ³)	189.9	189.9	189.9	189.9	189.9
SFWT (kg/m ³)	0.0	39.3	78.5	117.8	157.0
Viscocrete-3115 (L/m ³)	12.4	12.4	12.4	12.4	12.4

Table 5. Mix proportions of HESSCC-SFWT

Material	SFWT proportion				
	0%	0.5%	1.0%	1.5%	2.0%
Cement (kg/m ³)	650.5	650.5	650.5	650.5	650.5
Fine Aggregate (kg/m ³)	793.9	781.0	768.1	755.1	742.2
Coarse Agg (kg/m ³)	679.9	679.9	679.9	679.9	679.9
Water (kg/m ³)	189.9	189.9	189.9	189.9	189.9
SFWT (kg/m ³)	0.0	39.3	78.5	117.8	157.0
Viscocrete-3115 (L/m ³)	12.4	12.4	12.4	12.4	12.4
SikaRapid-505 (L/m ³)	7.5	7.5	7.5	7.5	7.5



Fig.6 Test specimens



Fig.8 Tensile test on cylindrical specimens



Fig.7 Compression test on cylindrical specimens



Fig.9 Flexural test on beam specimens

4. RESULTS AND DISCUSSION

4.1 Fresh Concrete Properties

The results of the slump flow and V-funnel tests indicate that the addition of steel fibers from waste tyres (SFWT) reduces the flow and passing ability of both SCC and HESSCC. This is due to the larger surface area of the fibers, which increases flow resistance. In general, the workability of HESSCC is greater than that of SCC. Fig. 10 shows that the addition of 2% SFWT significantly reduces the slump flow, causing it to fall outside the acceptable range for SCC.

The time required for the concrete to expand to a diameter of 500 mm (T_{500}) during a slump flow test reflects its viscosity and stability. The T_{500} times for the mixtures were in the range of 3.5–4.8 seconds, with slump flow diameters of 500–700 mm. Consequently, all concrete mixes fall within the specified limits for SCC, as predicted. Adding fibers decreases the slump flow, increasing the probability of obstruction, as shown in Fig. 11. The results of the V-funnel test for all SFWT percentage variations indicate that both SCC and HESSCC mixtures met the required flow time, as shown in Fig. 12.

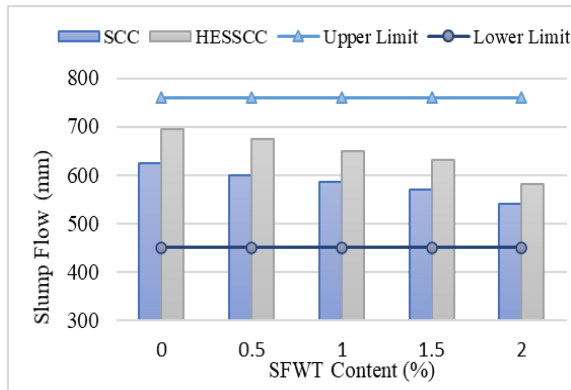


Fig.10 Slump flow test results

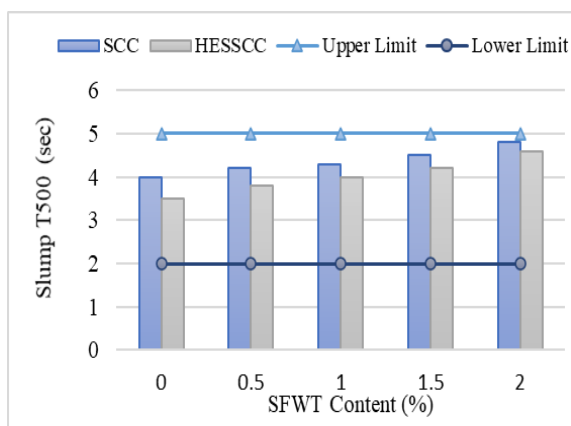
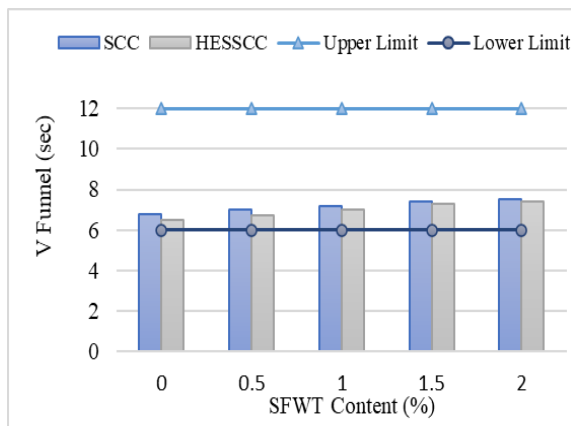

Fig.11 T₅₀₀ slump test results


Fig.12 V-funnel test results

4.2 Hardened Concrete Properties

4.2.1 Compressive strength test

The compressive strength of all mixtures was tested after 1 and 28 days of curing [9]. The results for SCC and HESSCC mixtures with varying SFWT percentages are shown in Fig. 13. As presented in Table 6, the 1-day compressive strength of HESSCC is approximately twice that of the SCC control mix. At

1 day, the compressive strength of the control mixtures (0% SFWT) for SCC and HESSCC are 9.2 MPa and 23 MPa, respectively. The compressive strength results for SCC with 0.5%, 1%, 1.5%, and 2% SFWT replacement are 8.7 MPa, 8.5 MPa, 9.0 MPa, and 10.2 MPa, respectively.

Meanwhile, for HESSCC with 0.5%, 1.0%, 1.5%, and 2.0% SFWT replacement, the compressive strength results were 22.6 MPa, 23.6 MPa, 24.5 MPa, and 25.6 MPa, respectively. When the compressive strength of all mixtures was tested after 28 days of curing, both types of concrete (HESSCC and SCC) exhibited similar compressive strengths, as shown in Table 6 and Fig. 13. The maximum percentage increase in compressive strength for SCC and HESSCC at 28 days was 25.25% and 21.77%, respectively (Table 6).

Table 6. Percentage increase in compressive strength

No	SFWT (%)	Day-1		Day-28	
		Increase in strength (%)		Increase in strength (%)	
		SCC	HESSCC	SCC	HESSCC
1	0	-	-	-	-
2	0.5	-5.43	-1.74	2.65	3.88
3	1	-7.61	2.61	10.55	11.43
4	1.5	-2.17	6.52	20.91	17.15
5	2	10.87	11.30	25.25	21.77

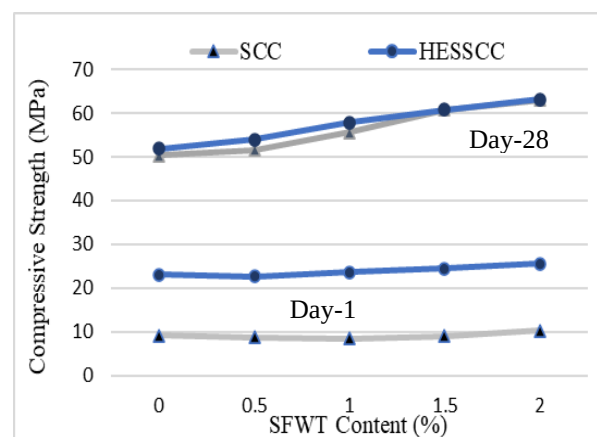


Fig.13 Compressive test results

4.2.2 Tensile strength test

Tensile strength tests were conducted on self-compacting concrete (SCC) and high early-strength concrete (HESSCC) containing SFWT at 1 and 28 days. Overall, the tensile strength of HESSCC was higher than that of SCC, attributed to the inclusion of the accelerator in the HESSCC mix.

Table 7 and Fig. 14 illustrate the increase in strength corresponding to each additional percentage of SFWT content. This improvement is attributed to the ability of SFWT to inhibit the development of cracks, particularly internal microcracks.

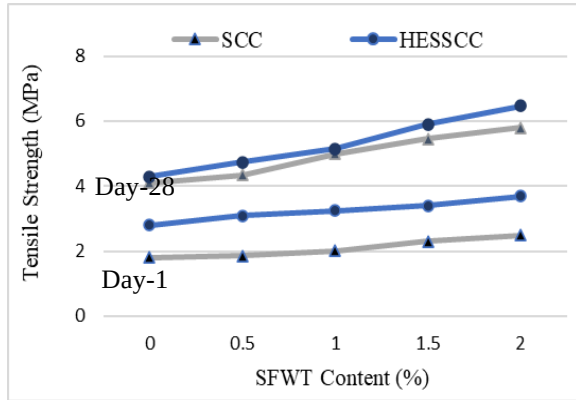


Fig.14 Tensile strength test results

Table 7. Percentage increase in tensile strength

No	SFWT (%)	Day-1		Day-28	
		Increase in strength (%)		Increase in strength (%)	
		SCC	HESSCC	SCC	HESSCC
1	0	-	-	-	-
2	0.5	2.78	10.71	5.78	10.18
3	1	11.67	16.07	21.97	19.76
4	1.5	27.78	21.43	32.95	37.13
5	2	38.89	32.14	41.62	50.30

As shown in Fig. 14, the tensile strength of HESSCC at 1 day increased by approximately 1.5 times compared to that of the control SCC. The maximum percentage increase in tensile strength at 1 day was 38.89% for SCC and 32.14% for HESSCC (Table 7). At 28 days, with SFWT additions of 0.5%, 1.0%, 1.5%, and 2.0%, the tensile strength of SCC increased by 5.78%, 21.97%, 32.95%, and 41.62%, respectively. For HESSCC at the same age, the corresponding increases were 10.18%, 19.76%, 37.13%, and 50.30%.

4.2.3 Flexural strength test

Table 8 and Fig. 15 illustrate that the flexural strength of both SCC and HESSCC improved with the addition of SFWT at 1 and 28 days. As shown in Table 8, the flexural strength increased with SFWT contents of 0.5%, 1.0%, 1.5%, and 2.0%. At 1 day, the increases for SCC were 3.12%, 11.25%, 18.75%, and

31.25%, while for HESSCC, they were 7.52%, 10.05%, 15.20%, and 22.53%. At 28 days, the corresponding increases for SCC were 4.88%, 12.20%, 26.83%, and 43.90%, and for HESSCC, they were 5.41%, 16.22%, 32.43%, and 48.65%.

The highest percentage increase in flexural strength was observed at a 2% SFWT content, reaching 43.90% for SCC and 48.65% for HESSCC at 28 days of age. The improved flexural strength in the presence of SFWT may be attributed to enhanced bonding between the concrete matrix and the SFWT additive.

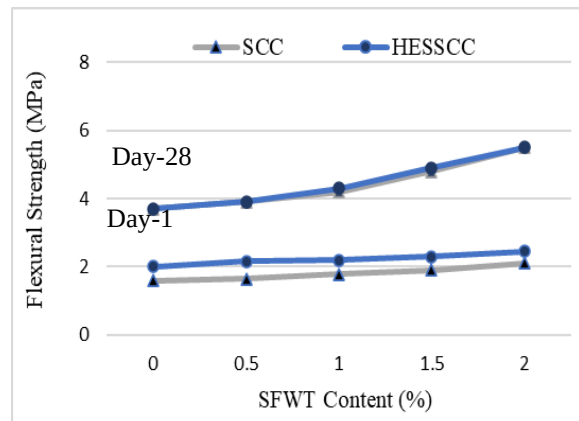


Fig.15 Flexural strength test results

Table 8. Percentage increase in flexural strength

No	SFWT (%)	Day-1		Day-28	
		Increase in strength (%)		Increase in strength (%)	
		SCC	HESSCC	SCC	HESSCC
1	0	-	-	-	-
2	0.5	3.12	7.5	4.88	5.41
3	1	11.25	10	12.20	16.22
4	1.5	18.75	15	26.83	32.43
5	2	31.25	22.5	43.90	48.65

5. CONCLUSION

Based on the experimental findings regarding the properties of SCC and HESSCC with the addition of SFWT, the following conclusions are drawn:

1. SFWT reduces the flow and passing ability of both SCC and HESSCC due to its larger surface area and increased flow resistance. However, with appropriate adjustments to the water-cement ratio and superplasticizer dosage, the concrete can achieve adequate passing and filling ability.

2. Compressive strength results at 1 day indicate that HESSCC exhibits twice the compressive strength of SCC. However, at 28 days, the compressive strengths of both mixtures converge to nearly identical values.
3. Tensile strength improved considerably with the addition of SFWT. At 1 day, the tensile strength of HESSCC was approximately 1.5 times higher than that of SCC, largely attributed to the inclusion of an accelerating additive. At 28 days, the tensile strengths of both SCC and HESSCC reached comparable values.
4. Flexural strength also improved with SFWT addition. At 1 day, HESSCC exhibited a 1.25-fold increase in flexural strength compared to SCC. The maximum flexural strength increases of 43.90% for SCC and 48.65% for HESSCC were observed at a 2% SFWT content at 28 days. This improvement is likely attributable to enhanced bonding within the concrete matrix provided by the addition of SFWT.

6. ACKNOWLEDGEMENTS

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