

Influence of Steel Fiber Volume and Volcanic Pumice Powder on Self-Consolidating Concrete Properties

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Abstract. This study investigated the effect hook-end steel fiber (HSF) and volcanic pumice powder (VP) on the behavior of self-consolidating concrete (SCC). VP is considered a partial replacement material of cement because its mass has a high content of pozzolanic properties (up to 76.4%). The VP replacement rate of cement mass was 30%. In addition, SCC was reinforced with HSFs with a length of 60 mm and concrete volume fraction of 0%, 0.25%, 0.50%, 0.75%, and 1%. The rheology, workability, flowability passability, fillability, and consistency of fresh SCC were assessed using bleeding and segregation resistance, slump, L-box, and V-funnel tests. The properties of hardened SCC were examined through compressive, indirect tensile, and flexural strength tests. Results showed that the use of VP improved the fresh properties of SCC. However, the addition of HSF led to a negative effect on the fresh properties of SCC. The results of indirect tensile and flexural strength tests demonstrated that the addition of HSF enhanced the properties of hardened SCC.

Keywords: Fresh concrete, Hardened concrete, Hook-end steel fibers, Natural pozzolana, Self-consolidating concrete.

1. Introduction

The increase in global demand for cement has contributed considerably to the increased consumption of nonrenewable natural resources and serious environmental degradation. Environmental damage is caused by the emission of carbon dioxide, destruction of nature, and the consumption of large amounts of fuel and energy [1]. Therefore, studies have focused on finding alternatives to minimize the consumption of Portland cement, contribute to the protection of the environment, and achieve sustainable development [2,3]. Apart from saving energy and protecting the environment, a basic function that scientists consider is the

possibility of enhancing the characteristics of concrete and reinforcing concrete structures in the aggressive environment by using alternative materials. Scientists have previously explored the possibility of utilizing natural pozzolans, such as volcanic ash, pumice powder (VP), and rock powder, which are available either locally or regionally to produce modified cement and environmentally friendly green concrete. Many volcanic areas are located in the Arabian Peninsula, especially in Saudi Arabia; these areas can be utilized to meet the requirements of green concrete [4,5]. Therefore, this study aims to promote the production of self-consolidating concrete (SCC) and use cement alternatives by integrating locally available

volcanic residues instead of imported cement alternatives, such as ground-granulated blast-furnace slag, fly ash–metakaolin, silica fume, and others. Incorporating VP as a cement alternative in the manufacture of SCC can achieve sufficient consistency, workability, and rheology; suitable viscosity; and decreased rates of segregation, bleeding, and plastic shrinkage. Cement alternatives are also utilized in concrete mixes to improve the characteristics of hardened concrete, including impermeability, strength, and durability. The use of cement alternatives as pozzolanic materials generally helps reduce the required dosage of superplasticizers (SPs) to obtain the suitable workability [6-9]. Previous studies have reported that increasing the replacement rate of pozzolanic materials by up to 30% of cement mass significantly improves the results of fresh concrete but reduces the hardened test results [10-12]. Hook-end steel fibers (HSFs) are typically utilized to enhance the flexural, tensile, and toughness properties of concrete. Therefore, the use of fiber promotes tensile and flexural strength and increases the toughness of concrete. Many studies have reported that the addition of steel fibers by a volume fraction of 0.1%–1.5% is the optimal amount for improving the flexural and tensile strength, toughness, and some engineering properties of concrete [13-15]. However, the addition of HSFs results in decreased workability of SCC. Many physical parameters of steel fiber, such as fiber type, aspect ratio, length, shape, shape, and texture, affect the properties of fresh concrete [16-18]. This investigation aimed to promote for the use of VP as a cement alternative by further understanding the behavior of fresh and hardened properties of SCC with or without HSF. VP was used as a cement alternative in 30% of cement mass. In addition, HSFs with a length of 60 mm were used in the cement mixes at the volumetric fractions of 0%, 0.25%, 0.5%, 0.75%, and 1% to produce SCFRC_x.

Slump flow, slump flow T₅₀, L-box, and V-funnel, V-funnel T₅, and segregation and bleeding tests were carried out in the fresh concrete state. The compressive, flexural, and indirect tensile strengths at ages 7, 14, 28, and 90 days were also investigated in the hardened concrete state.

2. Materials and Methods

2.1 Cement

Tests on the properties of ordinary Portland cement (OPC) were carried out in accordance with ASTM C150. Table 1 lists the physical characteristics and chemical composition of OPC.

2.2 VP

VP is a natural pozzolana of industry residual of lightweight aggregate and abundantly available in volcanic areas. VP used in this study was collected from a quarry in Jazan, which is a city located in southwestern Saudi Arabia. Then, a ball mill was used in the laboratory to increase the VP fineness. The milling process lasted around 3 hours to obtain the fineness modulus and specific gravity of 4020 cm²/gr and 2.69, respectively. In addition, VP met the requirements of ASTM C618 [19]. Figures 1 and 2 show the volcanic pumice quarry and ball mill for refinement, respectively. Table 2 lists the chemical composition of VP.

2.3 Coarse and Fine Aggregates

In this investigation, coarse aggregate (CA) of crushed limestone rock with a maximum size of 12.7 mm was used. Moreover, natural sand filtered with a 4.75 mm sieve was used as fine aggregate (FA). CA and FA had specific gravities of 2.63 and 2.71 and water absorption of 0.6% and 0.9% of aggregate mass, respectively. Aggregate grading of CA and FA conformed to ASTM C33 [20].

2.4 Steel Fibers

The steel fibers used in the production of SCFRC_x samples had a length of 60 mm and a hooked end. HSFs used in this study conformed to the requirements of the ASTM 820 standard. Many researchers have reported that the optimum volume fraction of HSF ranges between 0.1% and 1.5% of concrete volume fraction to avoid the decline in workability and compressive strength of concrete [14, 15]. Table 3 presents the physical properties of HSF, and Fig. 3 shows the HSFs.

2.5 SP

A new-generation copolymer-based SP designed for SCC production (Sicka 1050) was used in this investigation. Table 4 lists the properties of SP.

2.6 Mix proportion

In this study, five SCC mixes were designed in addition to the reference mixture (RC). The design method of SCC mixtures considering the estimated batch weights involved many adequate stages in the proportioning procedure. In this stage, the experimental mixtures were used in conjunction with SP to provide fresh mixtures that met the requirements of SCC. All the mixtures had a constant water-to-binder ratio (w/b) of 0.40% and a constant binder material content of 500 kg/m³. Moreover, HSFs were incorporated at the various concrete volume fraction levels of 0%, 0.25%, 0.50%, 0.75%, and 1%. The concrete mix proportions of RC, SCC, and SCFRC_x are listed in Table 5.

2.7 Mixture Proportions

The mixing steps in the preparation of test samples were as follows. First, FA, CA, and cementitious materials were combined using a mixer in dry condition for 2 min. Second, 70% of the water was gradually added and mixing continued for 2 min. Third, 30% of the water was added to the mixture. Fourth,

blending continued for 3 min until the mixture became homogeneous. Fifth, steel fibers were manually added to the concrete mixture to ensure that the fibers were gradually and evenly distributed in the mixture. Sixth, the mixture was further blended for another 3 min prior to testing the fresh concrete. Seventh, immediately after the tests, the fresh concrete mixture was placed in molds without using a vibration machine. Eighth, suitable mold cubes, cylinders, and prisms were used in the hardened concrete measurements. Ninth, after casting the concrete, the specimen's molds were covered with water-saturated burlap and the hardened concrete specimens were removed from the molds after 24 hours. Tenth, the specimens were immersed in a water tank under laboratory conditions in accordance with ASTM.

2.8 Fresh Concrete

Slump flow, slump flow T₅₀, V-funnel, V-funnel T₅, L-box, and segregation and bleeding tests were carried out to measure the fresh concrete properties. The measurement period of fresh concrete properties was within 20 min after the addition of water to avoid the mixing time effect on the test results of fresh concrete samples. Fresh concrete tests were performed in accordance with the European guidelines and standards [21], whereas segregation and bleeding tests were conducted on the basis of the ASTM C232 and ASTM 1610 standards [22,23]. Figure 4 shows the tests applied to fresh concrete.

The rate of bleeding water per unit area of surface (V) and segregation (%) were measured as follows:

Equations 1 and 2 show the calculation method for bleeding and segregation, respectively.

$$V = \frac{V_b}{A}, \quad (1)$$

$$S = \frac{T}{B} \times 100, \quad (2)$$

Where:

V= bleeding rate

S= segregation percentage;

T = mass of CA from the top sections;
 B = mass of CA from the bottom sections;
 A = area of exposed concrete, cm²;
 V_b = volume of bleeding, mL.

Table 1. Characteristics of OPC.

Chemical composition analysis									
Al ₂ O ₃	SiO ₂	Fe ₂ O ₃	CaO	Na ₂ O	MgO	TiO ₂	K ₂ O	P ₂ O ₅	SO ₃
4.68	19.01	3.20	66.89	0.09	0.81	0.22	1.17	0.08	3.66
Physical characteristics									
Specific surface area (cm ² /gm)					Specific gravity			LOI	
3220					3.15			2.48	



Fig. 1. Volcanic area.



Fig. 2. Ball mill.

Table 2. Characteristics of VP.

Chemical composition										
Composition	Al ₂ O ₃	SiO ₂	Fe ₂ O ₃	CaO	Na ₂ O	MgO	TiO ₂	P ₂ O ₅	K ₂ O	SO ₃
(%)	18.57	47.40	10.44	7.90	2.58	6.04	1.62	0.64	1.07	0.34
SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃ = 76.4%										
Physical characteristics										
Specific surface area (cm ² /gm)					Specific gravity			LOI		
4020					2.69			1.61		

Table 3. Physical properties of HSFs.

Items	Form	Density	Fiber length	Fiber diameter	Length/diameter ratio	Tensile strength
HSFs	Hooked end steel fiber	7850 kg/m ³	60 mm	0.90 mm	65	1160 MPa



Fig. 3. HSFs.

Table 4. Properties of the copolymer-based SP.

Items	Chemical base	Color	Density	Chloride ion	Alkaligehalte
Information	Modified polycarboxylate	Light yellow	1070 kg/m ³ 20 °C	< 0.1 %	< 0.5 % w/w

Table 5. Mixture proportions of concrete (kg/m³).

Mix	OPC	VP	C _A	F _A	HSF	Water	SP
RC	500	0	854	837	0	200	8
SCC	400	100	854	823	0	200	8
SCFRC1	400	100	854	817	19.62	200	8
SCFRC2	400	100	854	811	39.25	200	8
SCFRC3	400	100	854	805	58.87	200	8
SCFRC4	400	100	854	796	78.50	200	8



(a) Slump flow and slum flow T₅₀ tests



(b) L-box test



(c) V-funnel and V-funnel T₅ tests



(d) Segregation and bleeding test

Fig. 4. Fresh concrete tests.

2.9 Hardened Concrete

Compressive, indirect tensile, and flexural strength, and toughness tests were performed in accordance with ASTM standards. Cubes, cylinders, and beams with dimensions of 100 mm × 100 mm × 100 mm, 100 mm (diameter) × 200 mm (height), and 100 mm × 100 mm × 400 mm were used in the compressive, indirect, and flexural strength tests, respectively. Three samples were examined at the curing ages 7, 14, 28, and 90 days in the compressive, indirect tensile, and flexural strength tests^[24-26].

3. Test Results and Discussion

3.1 Fresh Concrete Results

The slump flow and slump flow T_{50} tests were used to evaluate the flowability and viscosity of SCC without obstructions. Figure 5 shows the slump flow diameters of concrete under the self-weight effect^[27, 28]. SCC slump flow with a diameter of more than 75 cm indicated the low viscosity that may lead to the occurrence of segregation and bleeding. However, concrete with a slump flow diameter of less than 50 cm was unsuitable for SCC applications.

Figure 5 clearly shows that the design proportions of concrete mixes without VP fulfill the acceptance mixture requirements of SCC. However, this type of concrete mixture shows excessive bleeding compared with that containing VP. Moreover, replacing 30% of the cement mass with VP contributed significantly to the reduction of bleeding and segregation rates while meeting the requirements of SCC. Table 7 lists the results of the bleeding and segregation test. Hence, the incorporation of VP significantly improved the fresh concrete properties. By contrast, the addition of HSF had a negative impact on the fresh concrete properties, wherein the slump flow diameter clearly decreased. The high addition of HSF volume fraction accelerated

the decrease in the value of flow diameter. Moreover, the high rates of HSF addition of up to 0.75% - 1% of the concrete volume fraction demonstrated very clear negative effects on the fresh concrete properties, such that concrete movement was suspended, and the flow stopped. The results showed that replacing 30% of the cement content with VP resulted in the improvement of slump flow characteristics, such that the spreading diameter increased by 3% compared with that of RC. Additionally, the HSF addition of 0.25% and 0.50% of the volume fraction of the SCC mixture reduced the spreading diameter by 7% and 20% compared with SCC, respectively. Moreover, the addition of high HSF content (up to 0.75% - 1%) of the volume fraction stopped the spreading of the mixture. Thus, the mixture did not reach the diameter of 50 cm. Notably, the addition of HSFs at the rates of 0.5%, 0.75%, and 1% of the volume fraction did not correspond to the SCC requirements likely due to the effect of HSF physical properties, such as length, hook-end shape, and volume, and led to the entangling and overlapping of HSFs that reduced or stopped the movement of the mixture^[17]. Accordingly, the use of VP as a partial substitute for cement at the rate of 30% contributed to reducing the negative impact of fiber addition in SCC.

Figure 6 shows the results of the time it takes for the slump flow to reach the diameter of 50 cm. ASTM suggested a slump flow diameter of at least 50 cm for concrete to be classified as SCC. The behavior of concrete in this test was similar to the flow results shown in Fig. 5. In this test, the effect of concrete viscosity had a very important role in determining the arrival time to the diameter of 50 cm. Therefore, the slump flow times were set to 3, 2.5, 4.5, and 7 sec for the RC, SCC, SCFRC1, and SCFRC2 mixes, respectively. In addition, the slump flow T_5 tests failed in the cases of SCFRC3 and SCFRC4 due to the

high-volume fraction of HSFs in the concrete mixture. The fibers impeded the movement and flow of fresh concrete, which in turn, negatively affected the SCC properties. Accordingly, the use of VP as a partial substitute for cement at the rate of 30% contributed to reducing the negative impact of fiber addition in SCC [29,30].

The results of V-funnel and V-funnel T₅ tests are illustrated in Fig. 7 and 8, respectively. Notably, the use of VP as a partial substitute significantly contributed to improving the results of V-funnel and V-funnel T₅ of the SCC mixture compared with those of the RC mixture. Thus, both mixtures met the requirements of SCC. The use of ash as a partial cement substitute at the rate of 30% of cement mass improved the passability by reducing the time it takes for the mixture to pass through the outlet from 10 sec to 7 sec for RC and SCC. On the one hand, the addition of HSFs led to the increased passage time of the mixture through the V-funnel outlet to 7, 9, and 15 sec for SCC, SCFRC1, and SCFRC2, respectively. On the other hand, the increase in volume fraction of fibers to 0.5% and 1% of SCFRC3 and SCFRC4, respectively, stopped the movement of the mixture in the V-funnel outlet. Accordingly, failure of the mixture to pass through the outlet may be attributed to the large volume fraction of HSFs in the mixture.

The results showed that the substitution of cement with VP in the concrete contributed to the improvement of V-funnel T₅ results, and the passage time of fresh concrete (RC and SCC) through the outlet reduced from 14 sec to 11 sec. This improvement may be attributed to the decrease in cement content while the water and SP content remained constant. Increasing the fiber content clearly disrupted the movement of fresh concrete and prevented it from passing through the outlet of the device. Consequently, the passage time of fresh concrete (V-funnel and V-funnel T₅) was

not recorded. The results of the V-funnel and V-funnel T₅ tests shown in Fig. 7 and 8 were identical [30,31].

The passability and fillability results can be evaluated by applying the L-box test. The L-box test results are illustrated in Fig. 9. Notably, adding VP to RC helped improve the properties of passability and fillability. The fillability increased by 5% when 30% of the cement mass was replaced with VP. However, the addition of HSF contributed to reducing the rate of fillability of SCC. When the volume fraction of HSF increased to 0.25% and 0.50%, the fillability of SCFRC2 and SCFRC1 reduced by 8% and 20% of the concrete volume, respectively. In addition, increasing the volume fraction of HSF up to 0.75% and 1% of the concrete volume caused obstruction and restriction in the movement of the concrete mixture and failure to pass through the exit. Thus, the L-box test failed at the high-volume fraction of HSF. Based on the previous results, the addition of VP had a positive effect in reducing the loss of fresh concrete properties caused by the addition of HSF. These results contributed to a better understanding of the behavior of self-consolidating concrete containing VP and HSFs, and confirming the findings of previous studies [30,31].

The results of segregation and bleeding resistance tests are presented in Table 7. Replacing 30% of the cement mass with ash increased the segregation and bleeding resistance by 56% and 50%, respectively. Moreover, the addition of fibers by 0.25% and 0.50% of the concrete volume fraction contributed to the decrease in the segregation rate and the amount of bleeding compared with those of the SCC mix. The bleeding and segregation rates slightly increased when the fiber content increased to 0.5% and 1% of the volume fraction of concrete. This increase may be due to the high rates of HSF in fresh

concrete that impeded the movement of fresh concrete and thus increased the interstitial pores that led to a slight increase in the phenomenon of separation bleeding. Table 7 demonstrates that the incorporation of VP as partial replacement in SCC generally increased the viscosity of concrete mixture and showed less bleeding and segregation compared with RC. The addition of HSF to SCC resulted in a slight decrease in viscosity of the concrete mixtures that caused a slight increase in bleeding and segregation. These findings further explained the results of previous studies in the same field [15].

3.2 Hardened Concrete Properties

The compression strength results of the RC, SCC, and SCFRC_x concrete mixtures at the test ages of 7, 14, 28, and 90 days are shown in Fig. 10. The results showed that replacing 30% of cement mass with VP caused a clear reduction in the compressive strength of all mixtures compared with that of RC. Compared with RC, the compressive strength clearly decreased by 19%, 13%, 12%, and 11% when 30% of the cement mass was replaced in SCC at the test ages of 7, 14, 28, and 90 days, respectively. Additionally, the compression strength of SCFRC_x reduced when HSF was added to SCC. The increase in volume fraction of HSF reduced the compressive strength at the test age of 90 days. Compared with SCC, the compressive strength of SCFRC1, SCFRC2, SCFRC3, and SCFRC4 decreased at the test age of 90 days by 5%, 7.8%, 9%, and 11.5%, respectively. This decrease in compressive strength could be attributed to the effect of HSF addition on the fresh concrete properties. The results of fresh concrete tests showed that adding HSF caused damage in the fresh concrete properties. Therefore, the incompleteness of concrete compaction caused clear damage to the hardened properties of concrete. Incomplete compaction of concrete caused air bubbles to

be trapped in hardened concrete and subsequently reduced the compressive strength. The compressive strength in SCFRC_x mixtures was low because this type of concrete did not apply any mechanical or manual compaction on its molds and was only dependent on the self-consolidating properties from its own weight. In this regard, the findings of this study were consistent with those of previous studies; therefore, care should be taken regarding the application of SCFRC_x in structural sections [15, 32].

Figure 11 shows the results of indirect tensile strength of RC, SCC, and SCFRC mixtures at the test ages of 7, 14, 28, and 90 days. The results showed a decrease in strength when 30% of the cement mass was replaced with VP. Compared with RC, the strength decreased by 17%, 15%, 6%, and 4% at the test ages of 7, 14, 28, and 90 days, respectively. However, the results showed a noticeable improvement when HSF was added to produce SCFRC mixtures compared with those of the RC and SCC mixtures. Accordingly, the indirect tensile strength of SCFRC_x increased by 88%, 116%, 129%, and 152% at the test age of 7 days when the HSF volume fraction increased by 0.25%, 0.5%, 0.75%, and 1%, respectively, compared with that of SCC. Additionally, the indirect tensile strength increased by 55%, 71%, 88%, and 106% at the test age of 90 days when the HSF concrete volume fraction was 0.25%, 0.5%, 0.75%, and 1%, respectively, compared with that of SCC. This increase is attributed to the positive effect of HSF addition in the production of SCFRCs. The increase in HSF volume fraction generally leads to the increase in indirect tensile strength. HSF addition is the primary factor that improves the tensile strength property of concrete. However, HSF addition also has a negative influence on fresh properties; thus, the findings of this study confirm those of previous studies [15, 32].

Figure 12 illustrates the flexural strength results of the RC, SCC, and SCFRC_x mixtures at the test ages of 7, 14, 28, and 90 days. The results showed a decrease in strength when 30% of the cement mass was replaced with VP. Compared with RC, the decrease in strength of SCFRC_x was 10%, 8%, 9%, and 8% at the test ages of 7, 14, 28, and 90 days, respectively. By contrast, the results showed a noticeable improvement when HSF was added to produce SCFRC_x mixtures compared with the RC and SCC mixtures. Compared with SCC, the indirect tensile strength of SCFRC_x increased by 73%, 97%, 110%, and 111% at the test age of 7 days when the HSF volume fraction increased by 0.25%, 0.5%, 0.75%, and

1%, respectively. Additionally, the flexural strength of SCFRC_x was 62%, 71%, 77%, and 85% at the test age of 90 days when the concrete volume fraction of HSF was 0.25%, 0.5%, 0.75%, and 1%, respectively, compared with that of SCC. This increase in flexural strength is attributed to the positive effect of HSF addition in the production of SCFRCs. The increase in HSF volume fraction generally led to the increase in flexural strength. HSF addition is the main factor that improved the flexural strength property of concrete. However, HSF addition also has a negative impact on fresh properties; thus, the findings of this study confirm those of previous studies [15, 33].

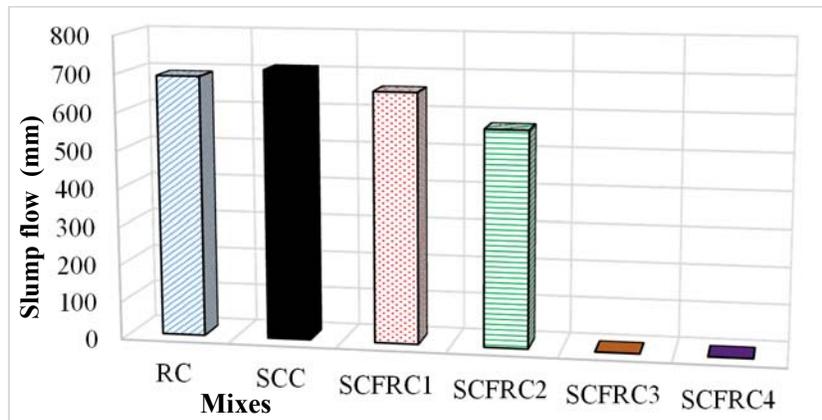


Fig. 5. Results of the slump flow test.

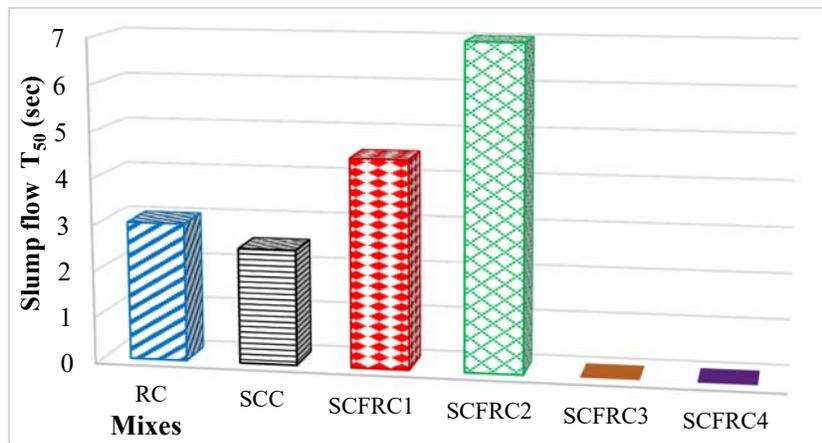


Fig. 6. Results of the slump flow T_{50} test.

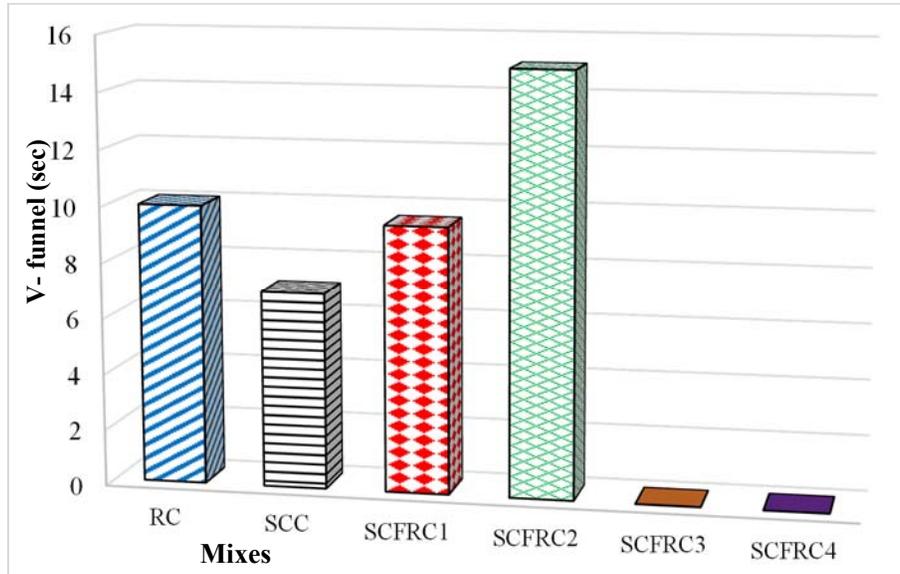


Fig. 7. Results of the V-funnel test.

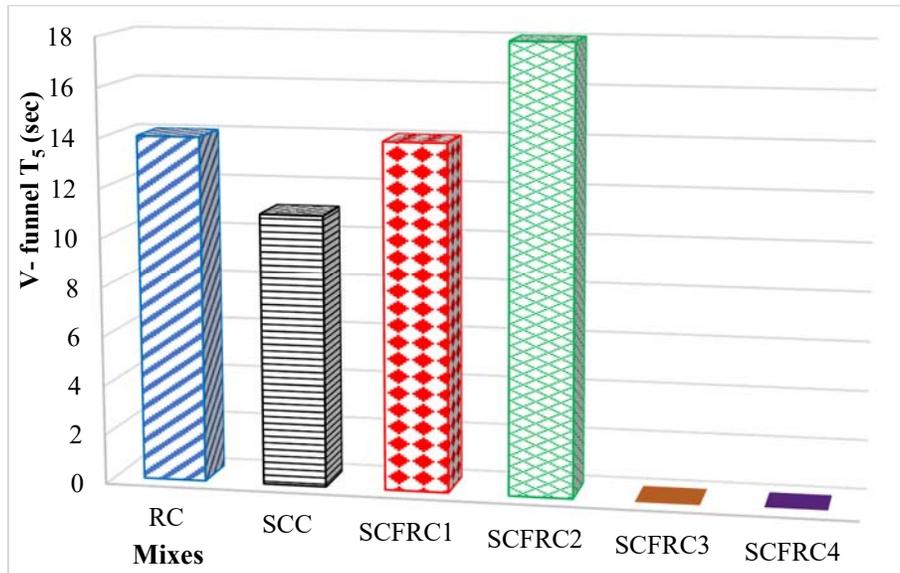


Fig. 8. Results of the V-funnel T_5 test.

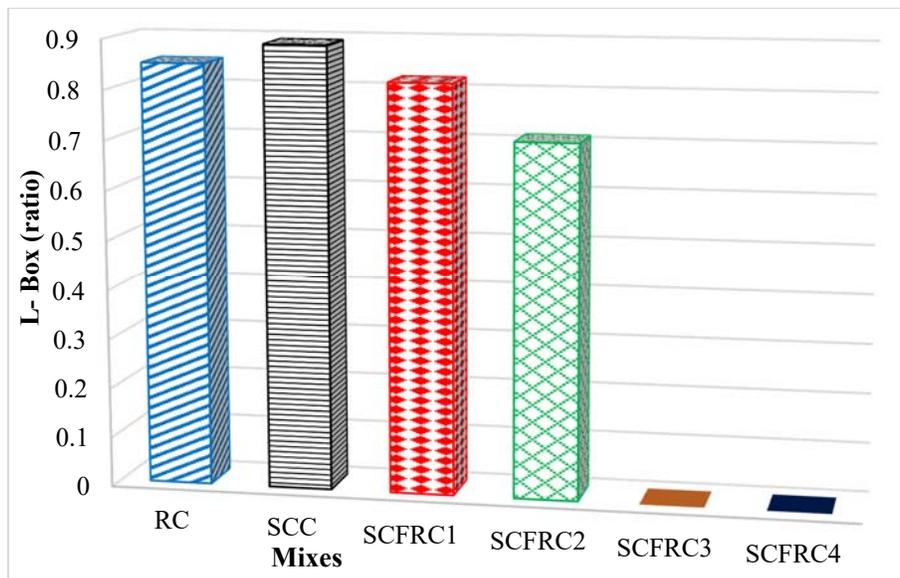


Fig. 9. Results of the L-box test.

Table 7. Results of the bleeding and segregation tests.

Mixture	Segregation of aggregate and fibers (%)	Segregation of aggregate only (%)	Total bleeding water (mL/cm ²)
RC	-	23	0.36
SCC	-	10.1	0.18
SCFRC1	9.1	8.8	0.15
SCFRC2	8.9	8.3	0.17
SCFRC3	9.9	8.9	0.19
SCFRC4	10.4	9.2	0.21

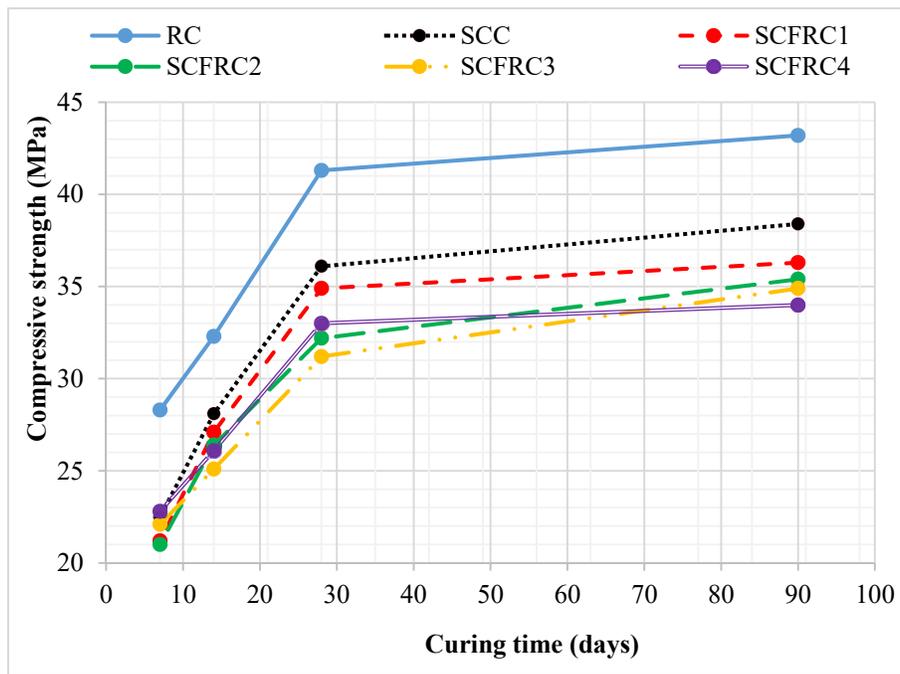


Fig. 10. Compressive strength test.

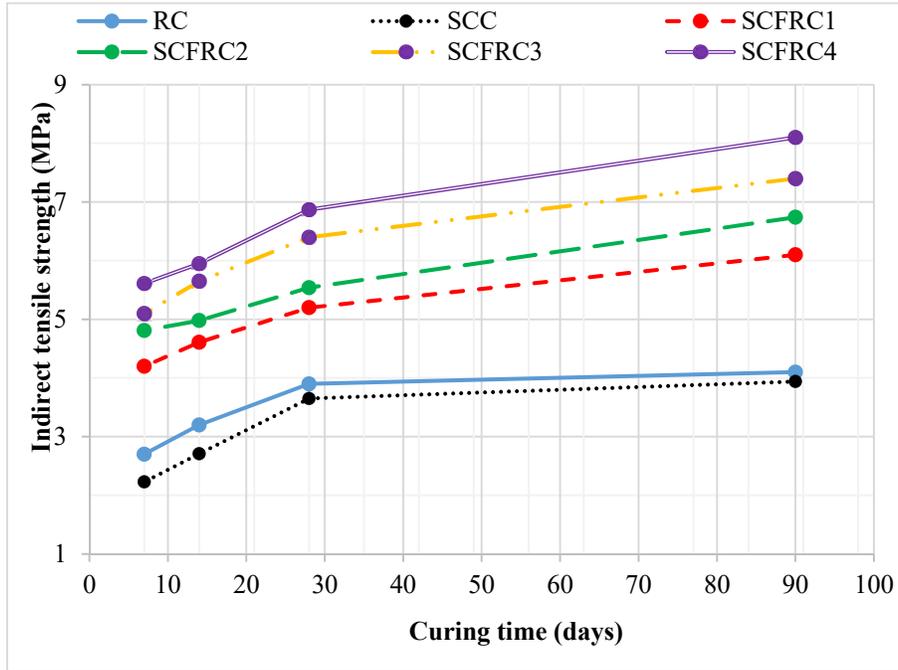


Fig. 11. Indirect tensile strength test.

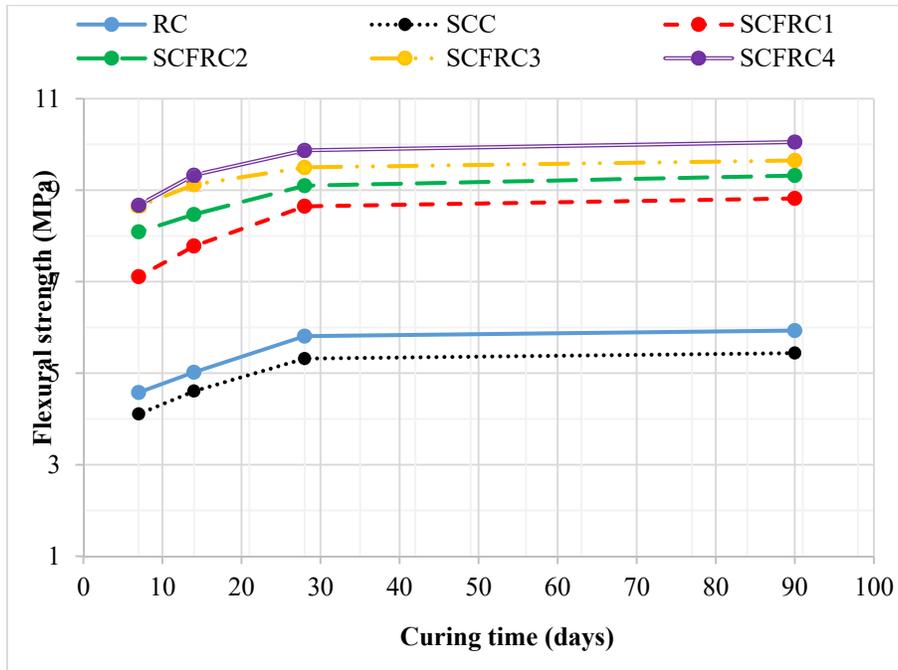


Fig. 12. Flexural strength test.

4. Conclusions

This study investigated the rheological, workability, and strength behaviors of three classes of HSF-reinforced SCC with and without VP. The following conclusions could be drawn in this study:

1- The use of VP as a partial substitute for cement mass at the rate of 30% improved the properties of fresh concrete. The workability and rheological properties of concrete were evaluated through the fillability, flowability, and passability tests.

2- The incorporation of ash as a partial substitute for cement mass of the reference concrete at the rate of 30% reduced the segregation and bleeding rates in SCC by 56% and 50%, respectively.

3- The required limit in the production of SCC specified in EFNARC could be obtained for the RC, SCC, SCFRC1, and SCFRC2 mixtures. The EFNARC requirements could no longer be fulfilled when the HSF content increased to more than 0.25% of the concrete volume fraction.

4- The decreased passability, fillability, and flowability of the SCFRC_x mixtures demonstrated the clear negative effect of the HSF addition. The high percentage of fibers in the mixture impeded its movement because of the intertwining and overlapping of HSFs with one another.

5- The HSF addition reduced the compressive strength of the mixtures due to the low workability of SCC. Thus, concrete with high HSF content was weaker than RC.

6- Compared with the RC and SCC samples, the presence of HSF in SCC significantly increased the indirect tensile strength.

7- Compared with the RC and SCC samples, the HSF addition in SCC improved

the maximum carrying capacity of SCFRC_x beams and increased the flexural strength.

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تأثير حجم ألياف الفولاذ ومسحوق الخفاف البركاني على خصائص الخرسانة ذاتية الرص

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المستخلص. في هذه الدراسة تم بحث تأثير الألياف الفولاذية ذات النهاية الخطافية (HSF) ومسحوق الخفاف البركاني (VP) على سلوك الخرسانة ذاتية الرص (SCC). يعتبر الـ VP كبديل جزئي للأسمنت، لأن كتلته تحتوي على نسبة عالية من خصائص البوزولانيك (تصل إلى 76,4%). كان معدل استبدال VP من كتلة الإسمنت بمعدل 30%. بالإضافة إلى ذلك، تم تعزيز SCC باستخدام HSFs بطول 60 ملم من حجم الخرسانة بـ 0% و 0,25% و 0,50% و 0,75% و 1%. تم تقييم الريولوجيا، وقابلية التشغيل، وقابلية التدفق، وقابلية الملء، واتساق SCC الطازجة باستخدام اختبارات النزيف والفصل، والركود، و L-box، و V-funnel. تم فحص خصائص SCC المتصلبة من خلال اختبارات قوة الضغط، وقوة الشد غير المباشر، وقوة الانثناء. أظهرت النتائج أن استخدام VP أدى إلى تحسين خصائص الخرسانة SCC الطازجة. ومع ذلك، أدت إضافة HSF إلى تأثير سلبي على الخصائص الطازجة لـ SCC. أظهرت نتائج اختبارات قوة الشد غير المباشرة وقوة الانثناء أن إضافة HSF عززت خصائص SCC المتصلب.

كلمات مفتاحية: خرسانة طازجة، خرسانة متصلبة، ألياف فولاذية نهاية خطافية، بوزولانا طبيعية، خرسانة ذاتية الرص.

