Fibre self-compacting concrete performance at high temperatures

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ABSTRACT: *This paper offers the impact of high temperature with and without fiber of the fresh and hardened properties of Self-Compacting Concrete (SCC). For this study, the experimental approach has four mixtures, and a different amount of fibers have been used: The control mixture was formed without fibres (SCC), the mixture contains 1% polypropylene fibres (SCC-$_{PF}$), the mixture contains 1% steel fibres (SCC-$_{SF}$), the mixture contains hybrid fibres, 0.5% steel and polypropylene fibres (SCC-$_{SF\ \&\ PF}$). The characteristics of the mixtures self-compacting concrete and fiber reinforced self-compacting concrete (FR-SCC) were calculated at 20, 200, 400, 600, and 800 ° C after 28 days. The specimens were heated with electric furnace at a heating rate of 5 ° C / min. The findings show that the compressive strength, tensile strength, and flexural strength enhanced with rising temperatures up to 200 ° C and lessened at temperatures above 200 ° C. A polypropylene fibers reduced and minimized the risk of spalling inside the SCC. In the concrete mixture such as steel fibers and hybrid fibres, the better mechanical characteristics and spalling resistant occur with rising temperature. Of the polypropylene and steel fiber SCC mixtures the weight losses were smaller than without polypropylene and steel fibres. The properties of fresh concretes were typically reduced by fibers.*

KEYWORDS: self-compacting concrete; fiber reinforced self-compacting concrete; high temperature; steel fiber; polypropylene fibres; hybrid fiber.

INTRODUCTION

Self-compacting concrete (SCC) is considered as a strong workable concrete which can flow by its own weight without any vibration, characterized by non-segregation which can easily achieve far corners, populate crowded shapes and reinforcements [1]. Hajime Okamura suggested in 1986 the importance of SCC [2]. The SCC system was installed in 1988 in Ozawa, Japan [3]. To achieve high mobility, SCC usually involves using super-plasticizers. A significant amount of coated material must be used to avoid segregation. The packed products are silica fume, fly ash, ground granulated blast furnace slag, quartzite filler, lime stone filler, and glass filler that can be added to improve the concrete mix slump and thus minimize the SCC prices..

High temperatures can lead to through cracks and spills. As all other cracks, these cracks inevitably create a lack of structural stability and shorten the operational life [4]. Extreme fire temperatures influence the strength and fracture of the different structural elements [5].

In this type of concrete, fibre-reinforced concrete (FRC) is indeed an instance of three-dimensional fibers spreading in the matrix coincidentally. The fibers can boost concrete strength and residual stress, replace traditional steel strengthening, minimize crack width, increase bar distance and minimize labor costs. The addition of fibers enabled the explosive spalling of specimens so that the spalling threshold was raised to higher temperature levels [6, 7]. Ding et al [8] have proposed a new kind of high-performance concrtr, self-compacting (SC-HPC) and fibre-reinforced self-compacting (FRSC-HPC).

When using steel fibers, both the compressive and flexural strength of high-resistance mortar increased and impermeated slightly through using 20 ° C polypropylene fibers [9, 10]. Steel fibers enhanced both compressive and flexural strength at high temperatures, while compressive and flexural strength decreased slightly with Polyethylene fibres. Such behavior may be due to Polyethylene fibers melting, creating several spaces in the framework. The mechanical properties, such as the melting and ignition point of the fibers, significantly influence the characteristics of concrete composites with the introduction of fibres. Mixing steel and artificial fibers is an effective alternative for ensuring the strong toughness of a concrete composite before heating and enhancing its remaining mechanical conduct and spinning resistance, and also after ductility heating. Although artificial fibers enhance concrete spreading resistance, steel fibers in a concrete mix help to improve both mechanical characteristics and heating strength [11]. The use of hybrid fibers (steel and polypropylene) has shown significant success in achieving higher compressive strength and improved longevity at high temperatures [12, 13]. The SCC that is subjected to high temperatures appears to spall comparatively higher than normal concrete. The addition of SCC fibers reduces spread and increases ductility, tensile strength and durability.

The purpose of this study is to analyse the influence of introducing various types of fibers (steel, polypropylene, and hybrid) to the mechanical properties of SCC for one hour under high temperatures of up to 800 ° C.

Experimental Program

MATERIALS AND METHODS

Ordinary Portland cement, silica fume (SF), aggregate (fine and coarse), water, super-plasticizer, and fibers (metal or polypropylene) are the mixture components. Table 1 describes the proportions of the mix, the components of the mix and their amounts. Coarse aggregate is a broken dolomite with a gross nominal size of 9.5 mm and the use of 4 mm average natural sand. A 25 per cent proportion of silica fume were added by cement weight. Silica fumes with a specific gravity of 2.1 and a specific area of 172000 cm^2 / g (production data sheets). In this study, a locally developed third generation super-plasticizer called Visco-Crete 3425 was used to help boost concrete workability without water added and to help fine particles occupy the pore space and minimize the amount of mixing water. This is a modified polycarboxylate aqueous solution, with a specific gravity of 1.08. It is ASTM C494 compliant type G and F [14].

The used fibers are steel fibers hooked to the end with a length of 25 mm, a diameter of 80 µm and a density of 7.85 g / cm^3, and polypropylene fibers with a length of 12 mm, a diameter of 18 µm and a density of 0.91 g / cm^3. In this case, tap water converted into used during mixing and curing phases for the concrete.

Four forms of mixture concrete have been designed: control mix (SCC) has been insane without adding fiber, mixture contains 1% polypropylene fibers (SCC_{PF}), mixture contains 1% steel fibers (SCC_{SF}), and mixture contains hybrid fibers, 0.5% for both steel and polypropylene fibers ($SCC_{SF\ \&\ PF}$) by concrete volume.
Generic Portland cement has been used for all mixtures, 420 kg / m^3 with 25 per cent Silica fume cement weight.

Table 1: The constituents of the mixture are per kg / m^3

Mix No.	Cement	Silica fume	Aggregate		Water	Super-Plasticizer	Fibers	
			C.A	F.A			Steel	PP.F
SCC	420	105 (0.25)	909.2	909.2	189 (0.45)	4.2 (0.01)	0	0
SCC_{PF}	420	105 (0.25)	910.8	910.8	189 (0.45)	4.2 (0.01)	0	0.91
SCC_{SF}	420	105 (0.25)	898.7	898.7	189 (0.45)	4.2 (0.01)	78.5	0
$SCC_{SF\ \&\ PF}$	420	105 (0.25)	905.4	905.4	189 (0.45)	4.2 (0.01)	40	0.45

Note: bracket values show the mixing proportions for the various SCC mixes

Mixing, moulding and healing

In dry conditions, portland cement, aggregate and silica fumes were mixed, then water and super-plasticizer were added. For fibers-SCC, the fibers were added to dry materials before water, and admixtures were added. For compressive testing, a 10x10x10 cm volume cube, a 10 cm diameter cylinder and a 20 cm height cylinder for tension test, as well as a 10x10x30 cm bending strength prism were applied. The slump-flow experiment, L-box time series T50 and stability of the GTM screen were measured to study the fresh characteristics of concrete (filling strength, passing capacity and segregation resistance).

RESULTS AND DISCUSSION

Fresh ingredients

Table 2 and figures 1 to 4 shows all mixes with the fresh assets. The samples were produced with no shaking and are stored at lab temperature for 24 hours. Then remove the molded from the specimens and put them in water bath for 28 days to heal until the test day.

Table 2: All the mixtures workable

Mix No.	Slump-flow mm	T50 cm second	L-box H2/H1	GTM (%)
SCC	780	2.3	0.96	11.1
SCC_{-PF}	690	3.6	0.83	9.0
SCC_{-SF}	710	3.3	0.90	9.1
$SCC_{-SF\ \&\ PF}$	700	4.0	0.82	8.6

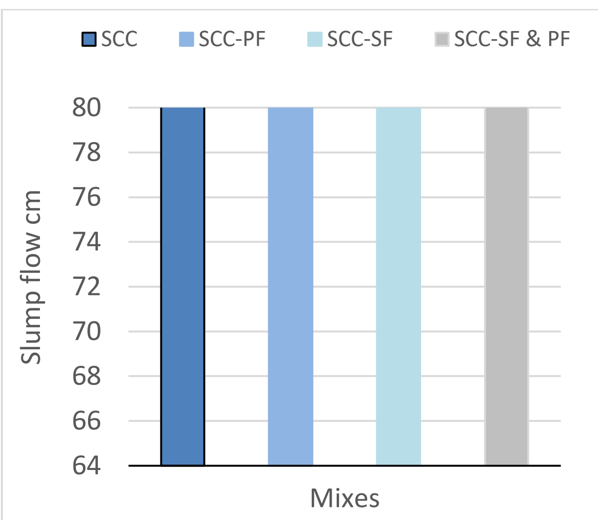


Fig. 1: Effect of fiber content on slump flow,

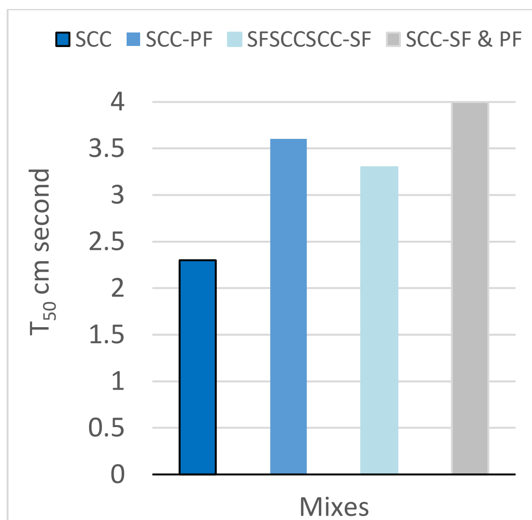
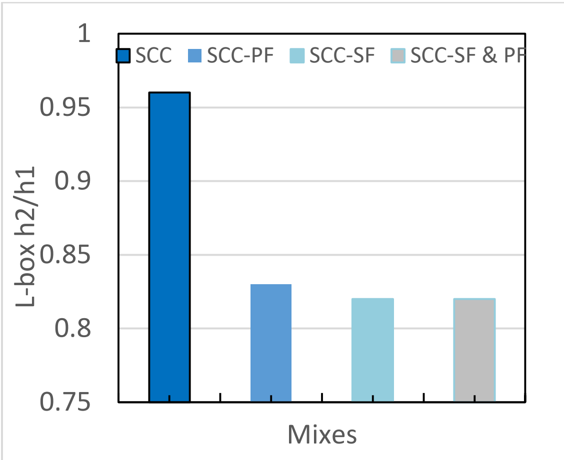


Fig. 2:Effect of fiber content on T_{50} slump flow



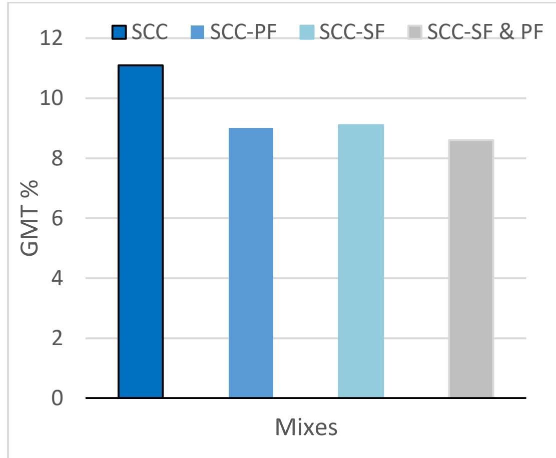


Fig. 3: Fiber content impact on blocking ratio, Fig. 4: Fiber content impact on segregation ratio

Test Procedure

Both mass and velocity of the ultra-sonic pulse were determined after the end of the sample processing time and before heating in the electrical furnace. Samples were heated at 5 ° C per minute up to 200, 400, 600 and 800 ° C using an electric oven. The Samples were kept for 1 hour at a specified temperature (figure 5). The samples were removed from the oven and then tested for ultrasonic wave frequency, mass loss, compressive, tensile and flexural strength.

Figure 5: The electric oven used for heating the specimens

Hardened Properties

Residual Compressive Strength

Table 3 and figure 6 display the residual compressive strength outcome for four concrete mixtures. The compressive strength value is the average product of three cubes (100 mm) of the study. At age 28 days the compressive strength was determined. Figure 6 shows the SCC, SCC-$_{PF}$, SCC-$_{SF}$, and SCC-$_{SF\ \&\ PF}$ compressive strength at high temperatures. It can be shown that out of the SCC-$_{PF}$ and SCC mixes the smallest compressive strength outcomes were achieved, but the SCC-$_{SF}$ gave the best results. In addition, the best compressive strengths were provided by the SCC-$_{SF}$ including steel fibres. SCC's compressive strength decreased by approximately 0.0 percent, 38 percent, 73 percent, and 87 percent, respectively, as temperature rose to 200, 400, 600, and 800 °C. SCC-$_{PF}$'s compressive strength decreased by around 14 percent, 38 percent, 68 percent, and 87 percent, respectively, with temperatures increasing to 200, 400, 600, and 800 ° C. The compressive strength of SCC-$_{SF}$ and SCC-$_{SF\ \&\ PF}$ improved by approximately 4 percent when the temperature increaed to 200 °C. The compressive strength diminished for SCC-$_{SF}$ as the temperature rose by around 23 percent to 400 ° C, 600 ° C, and 800, respectively, 54 percent, and 85 percent. For SCC-$_{SF\ \&\ PF}$ the compressive strength diminished as the temperature rose by around 43%, 65% and 85% respectively, up to 400, 600, and 800 ° C.

The key explanation for rising compressive strength with rising temperature up to 200 ° C could be related with hydration of cement. Loss of strength associated with temperature increase above 400 ° C may result from forced moisture during warming, failure in thermal expansion between aggregates and cement paste, deterioration of cement paste above 400 ° C and aggregate decay above 600 ° C. The remaining compressive strengths of the mixture containing Polyethylene fibers were significantly lower than for the concrete mixtures without Polypropylene fiber upon exposure to high temperaturesThe addition of Polypropylene fibres has a important, adverse effect on the strength of concrete. The use of Polypropylene fibers has provided a better structure of the remaining capillary pore, reducing the remaining compressive strength of SCC [15]. During the rapidly growing temperature process, Polyethylene fibers dissolve due to lower melting point (170 ° C), which allows free space in the concrete system's microchannels. Figure 7 shows the SEM photo blend at 200 and 400 ° C with SCC-$_{PF}$

Table 3: The compressive strength outcome for all mixtures

Mix No.	Compressive strength at high temperature (N/mm^2)				
	25°C	200°C	400°C	600°C	800°C
SCC	45.2 (1)	46 (1.02)	28 (0.62)	12 (0.27)	6 (0.13)
SCC-$_{PF}$	44 (1)	38 (0.86)	24 (0.55)	14 (0.32)	5.5 (0.13)
SCC-$_{SF}$	52 (1)	54 (1.04)	40 (0.77)	24 (0.46)	8 (0.15)
SCC-$_{SF\ \&\ PF}$	46 (1)	48 (1.04)	26 (0.57)	16 (0.35)	7 (0.15)

Note: Bracket results for the different SCC mixes indicate the relative compressive strength

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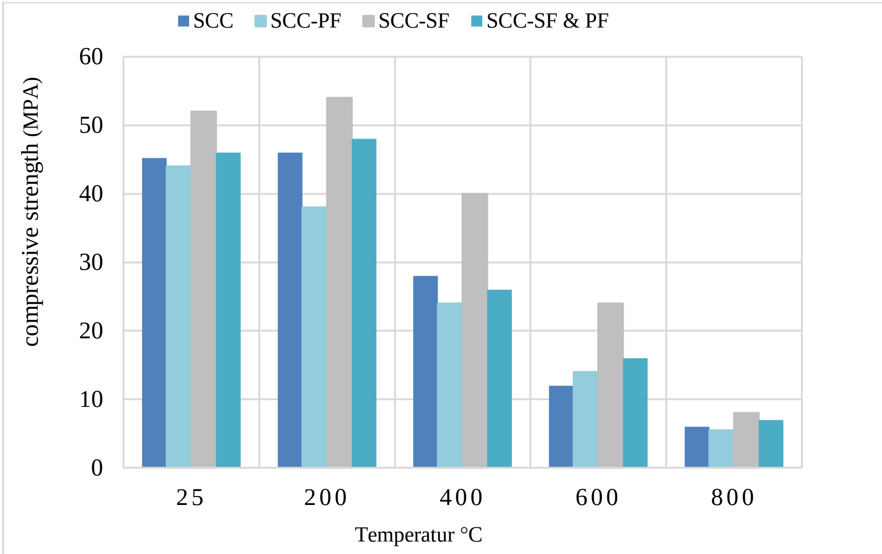

Figure 6. Link between compressive strength and temperature

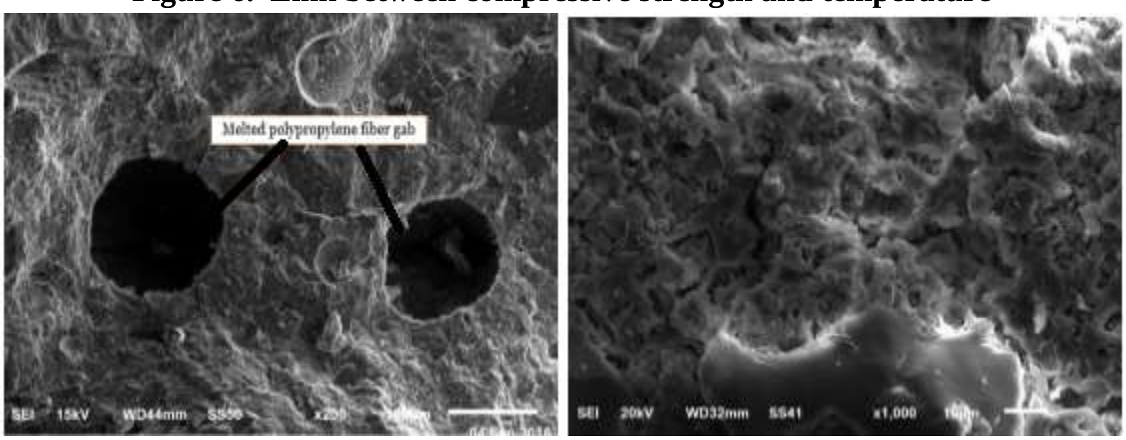

Figure 7. SEM photos blend with SCC-PF at 200 and 400 ° C

Spalling

After exposure to high temperatures, a thorough visual examination was conducted to assess the telltale symptoms of cracking and spalling on a specimen face. There was no noticeable cracking or breakage in specimens with temperatures between 200-400 ° C. Figure 8 demonstrates the surface characterization of SCC samples at various temperatures, with and without fibres. Hair-line cracks started to show up widely at around 600 ° C. Just a small amount of spalling was found around the corners and edges of certain specimens around 600 ° C. Explosive spalling occurs in SCC situations when the furnace temperature reached about 425 ° C to 475 ° C. Small permeability identified with dense concrete microstructure that inhibits water vapor dissipation due to heat and results in higher pore pressure build-up.

Figure 8. Surface behavior of SCC samples in 200, 400, 600 and 800 ° C with and without fibres

Figure 8 indicates that the harm and spalling of SCC-$_{SF}$ is much less than the SCC mixture. At temperature, silica-fume can minimize concrete expansion due to rapid temperature changes, minimize the large temperature difference attributable to higher coefficient of thermal transfer, and minimize crack growth and thermal crack bridging. The Polyethylene fibers decreased the likelihood that the SCC-PF mix might become explosive spalling. It may be because the PP fibers dissolve and vaporize during the accelerated operation, which leads to the formation of small channels throughout concrete. Stronger vapor stress in the capillary walls could therefore be mitigated and discharged, which could explain why there was no destructive spilling with Polypropylene fibers in the SCC. All the samples at 800 ° C showed clear spalling on the corners and edges. No major cracking and spilling of concrete like steel fibers.

Splitting Tensile Strength

Concrete is typically not constructed for withstand straightforward stress, that benefit of knowing the tensile strength is to estimate the pressure over which fracturing will occur. A lack of crack formation is of high significance to corrosion avoidance in several ways in the maintenance of the concrete system [16]. The tensile strength is an important feature for cracking production and thus for the estimation of concrete durability. Table 4 and figure 9 display the effects of a 28-day tensile strength check of four concrete mixes. Three test sets have been conducted to assess the splitting tensile strength at each mixture, as well as the tensile strength is really the sum of these three measurements. For all mixes, small improvement in tensile strength at 200 ° C, with temperature. The tensile strength declined by around

40%, 41%, 7%, 13% respectively for SCC, SCC-$_{PF}$, SCC-$_{SF}$, and SCC-$_{SF\ \&\ PF}$ after warming to 400 ° C. At 600 ° C, the tensile strength for SCC, SCC-$_{PF}$, SCC-$_{SF}$, and SCC-$_{SF\ \&\ PF}$ declined by about 89.5 percent, 91 percent, 68 percent, and 67 percent. This loss of strength is induced by the thermal inconsistency among cement and aggregates, the degradation of the cement matrix and the decay of aggregate.

Table 4: The product of tensile strength for all mixtures

Mix	Tensile strength at elevated temperature (N/mm^2)			
	25°C	200°C	400°C	600°C
SCC	4.0	4.20	2.40	0.42
SCC-$_{PF}$	4.40	4.40	2.60	0.40
SCC-$_{SF}$	5.60	6.00	5.20	1.8
SCC-$_{SF\ \&\ PF}$	4.60	4.80	4.0	1.5

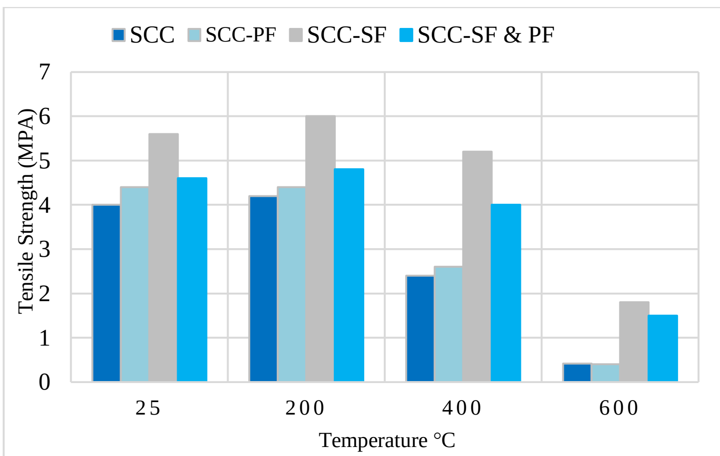

Figure 9. Link between temperature and tensile strength

Flexural strength

A simple concrete prisms underwent flexural use in this wark. The flexural stress tests were carried out on 10 x 10 x 30 cm prisms. Table 5 and Figure 10 show the difference in the rest of the flexural strength by temperature. Of the SCC mixes, the flexural strength drops to 200, 400, and 600 ° C with temperature changes of around 2.0%, 37% and 94% respectively. For SCC-$_{PF}$ mixes, the flexural strength falls with temperature rises of about 12%, 49% and 96% respectively at 200, 400, and 600 ° C. The flexural strength of the other mixtures dropped from 8 to 6 percent at 200 ° C. Figure 10 shows a decline in flexural strength of around 25% and 81% for SCC-$_{SF}$ and SCC-$_{SF\ \&\ PF}$ at 400 ° C, and around 30% and 88% for SCC-$_{SF}$ and SCC-$_{SF\ \&\ PF}$ at 600 ° C , respectively. This reduction in flexural strength was attributed to the creation in the samples of several macro - level fissures attributed to a thermal inconsistency between the past of cement and the aggregates. The flexural strength of high strength concrete improved by use of steel fibers and marginally improved by use of PP fibers at 25 ° C. But steel fibers also improved compressive and flexural strength with rising temperatures, while PP fibers reduced flexural strength during autoclave healing before high temps exposed.. This action may be due to a melting of Polypropylene fibers in the matrix that generates certain holes [17].

Table 5: Flexural strength compared to all mixtures

Mix	Relative flexural strength at elevated temperature			
	25°C	200°C	400°C	600°C
SCC	7.16	7.02	4.54	0.40
$SCC\text{-}_{PF}$	8.40	7.40	4.28	0.30
$SCC\text{-}_{SF}$	10.16	11.02	7.60	1.90
$SCC\text{-}_{SF\ \&\ PF}$	9.54	10.10	6.64	1.14

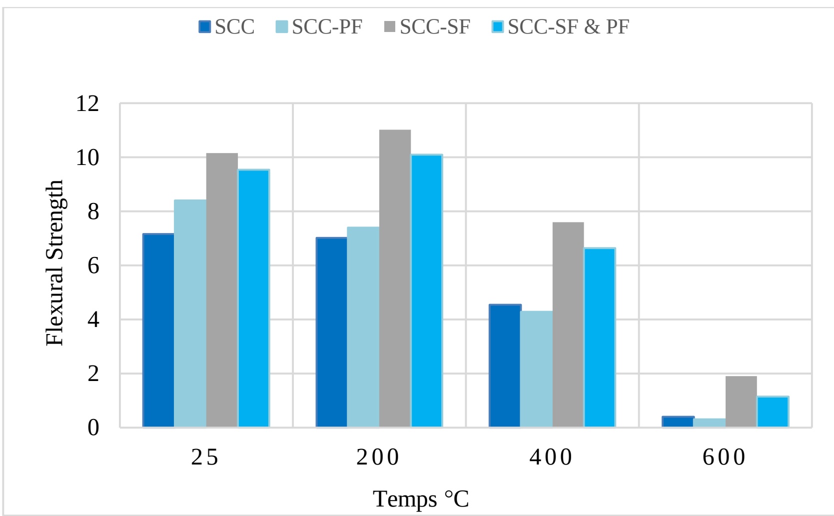

Figure 10. Link between strength and temperature of the flexion

Ratio for mass losses

The ratio for mass loss is known as the proportion of a difference in weight at ambient temperature to a weight at ambient temperature at a specific temperature. The mass was determined at ambient temperature for each sample, and at extreme after exposure. The losing weight versus temperature of the four concretes analyzed was quite close. The mass loss ratio ranged from 2.96 to 18.0 per cent, with temperatures increasing from 200 to 800 ° C. It indicates that the ratio of self-compacting concrete to mass loss was greater than that of self-compacting concrete reinforced by fibre. Figure 11 and Table 6 include the percentage mass reduction of the SCC mixes with rising temperature. Figure 11 shows that the losing weight for Scc mixes with polypropylene and steel fibers is smaller than those without them. There are several possible reasons of the concrete weight loss after exposure to fire. Fragment ejection or breaking of concrete from external surface are primary causes of losing weight [18]. Significant explosion spalling or the removal of chunks was found in this study. The loss of weight at low temperatures can be due to the removal of free water present in the capillaries. According to Rami et al [19], the losing weight correlates to the evaporation of water molecules among 150 to 300 ° C.

Table 6: Ratio of mass losses for all mixes

Mix	Mass loss ratio at elevated temperature (%)				
	25°C	200°C	400°C	600°C	800°C
SCC	0	5.16	7.58	11.24	18.00
SCC_{-PF}	0	3.60	6.82	8.82	14.72
SCC_{-SF}	0	2.96	6.52	8.50	13.54
$SCC_{-SF\ \&\ PF}$	0	4.64	7.16	9.06	15.44

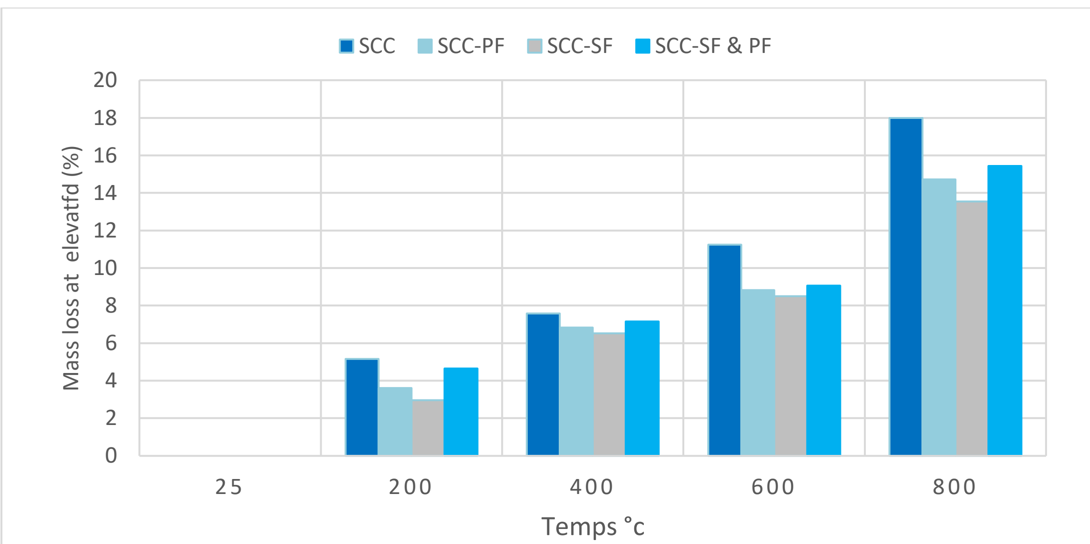

Figure 11: The relation between the ratio of mass loss and the temperature

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Velocity of ultrasonic pulses

Table 7 and Figure 12 display the effects of the ultrasonic testing analyses with all self-compacting concrete samples that are subject to specific extreme temps. Every data point is the average number measures. As illustrated in Figure 12, the ultra - sonic speed of warm self-compacting concrete specimens decreased as the temperature rose, and a important decrease in ultra-sonic speed soon after exposure of the samples to high temperatures above 400 ° C. The transfer of pulse waves thru a concrete structure is obviously hugely affected by the concrete 's micro crack propagation. Thus, the decrease in pulse velocity with increasing temperature is a sensitive measure of the progress of cracking in the material [20]. Because of the elevated temperature , thermal growth and dryness of the concrete could result in cracks forming in the concrete. The cracks or micropaths prolong the pulse speed of the concrete with further cracks [18]. Micro-cracks therefore minimize the pulse speed and lead to low ultrasonic velocities. The introduction of polypropelene fibers can be assumed to have a detrimental effect upon this ultrasonic wave velocity of self-compacting concrete mixes subjected to high temperatures. The fibers generated extra randomly dispersed paths or voids in self-compacting concrete once the heat was above melting point of the polypropylene fiber (170 ° C). The cracks or micropaths prolong the pulse speed of the concrete with further fissures [18].

Table 7: Result of ultrasonic pulse velocity for all mixes

Mix	ultrasonic pulse velocity at elevated temperature (km/sec)				
	25°C	200°C	400°C	600°C	800°C
SCC	4.46	3.6	2.34	1.12	0.84
SCC_{-PF}	4.40	3.42	2.24	1.10	0.50
SCC_{-SF}	4.42	4.06	2.62	1.56	0.84
$SCC_{-SF\ \&\ PF}$	4.34	3.52	2.42	1.06	0.44

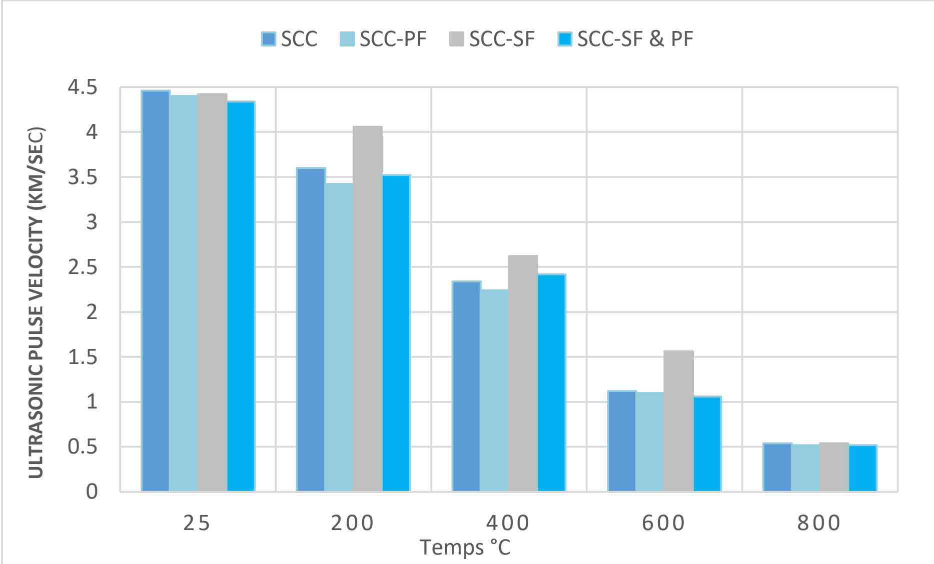

Figure 12. Relation of the ratio of mass loss to temperature

CONCLUSIONS

Throughout this study, a series of experiments were performed to evaluate changes throughout mechanical characteristics on self-compacting concrete exposed to significant temperatures between 25 and 800 ° C and to analyze the impact of incorporating steel fibres, polypropylene fibers and synthetic fibers on mechanical properties. The following findings are reported obtained from experimental findings presented in this study:

- The mechanical properties of SCC steel fiber increased to 200 ° C and the loses over 400 ° C. Whilst the mechanical properties for PP fiber declined to 200 ° C.
- The better mechanical characteristics were provided by concrete mixtures which include steel fibers as well as hybrid fibres.
- The inclusion of steel fibers and Polyethylene fibers minimized the possibility of explosion spilling in the self-compacting concrete.
- Spalling happens when the furnace temperature is around 425 ° C to 475 ° C in cases of SCC.
- With the temperature rise the mass loss ratio increased.
- Using steel fibers and Polyethylene fibres lowered the mass-loss ratio.

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Conflict of Interest

The authors claim they are not fighting for interest.

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