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Properties of Centrifugally Cast High Strength Fiber Reinforced Concrete

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Abstract: Centrifugally cast, spun concrete has been used to produce electric poles, concrete pipes and tubular precast concrete elements. Prestressing wires and/or steel bars were commonly used as reinforcement of such type of concrete elements. Researches over the years have shown that steel fibers reinforcement has sufficient strength and ductility to be used as a complete replacement to conventional steel bars in some types of structures. The saving of the traditional reinforcement results in a reduction of assembling operations, labor force and machinery, as well as in a decrease in the risks associated to manufacturing. The current study was carried out to address the improvement that may be achieved utilizing High Strength Fibers Reinforced Spun Concrete (HSFRSC) in manufacturing of tubular elements with either steel fibers (SF) or synthetic fibers (polypropylene fibers [PPF]). The purpose of embracing PPF is its stability under the aggressive exposure conditions (e.g. sanitary sewer environments); therefore, it may succeed to replace the SF in such conditions. Comprehensive experimental investigation was undertaken to evaluate the efficiency of these fibers (SF&PPF) at various volume fractions (SF: 0.75, 1.5, 3 vol. % and PPF: 0.5, 1 vol. % of concrete). The experimental program encompasses testing of statically as well as spun cast specimens. Casting of concrete specimens centrifugally was made by specially designed and manufactured laboratory-scale machine adopting similar technique used in producing full scale spun concrete pipes. Concrete microstructure was evaluated using polarization and fluorescence microscopy (PFM) to identify the effect of spun cast on interfacial transition zone, microcracks formation and porosity as well. Furthermore, water permeable porosity, compressive strength, splitting tensile strength and load-displacement characteristics under two-edge loading test were investigated.

Key words: Spun concrete · Fibers · High strength · Microstructure · Mechanical properties

INTRODUCTION

Spun concrete technology has been adopted to produce the poles of high-voltage electrical transmission lines. The spinning process generates very high uniform and passive compaction forces resulting in voids elimination, producing high-density concrete and virtually pore-free surface that is extremely resistant to aggressive environmental media. These results are based on intensive work in this technology for over 50 years [1]. The oldest concrete poles are still in use since 1957. CDF tests (freeze-thaw resistance in concrete tests with sodium chloride solution) and tests for carbonation provide additional evidence of extreme resistance to chlorine action, carbonation, weathering and mechanical impact according to EN12843 [2]. The spinning process compacts concrete at 20g and results in concrete with very low water-cement ratios, down to 0.28 [1] and thus high compressive strengths. Reinforcing cages and prestressing strands are normally used to reinforce electric poles therefore; the prestressing prevents cracks and contributes to optimized utilization of steel and concrete. A number of advantages with respect to economic, structural and architectural features are characteristic of prefabricated spun concrete building columns [3]. The structural efficiency of poles and columns using prestressed tendons or steel fibers depends on the type of load carrying structures [4, 5]. Centrifugal spinning process has been also employed for the manufacturing of either reinforced or non-reinforced concrete pipes due to the ability of handling and compacting concrete that is low in water content but high

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in cement and thus, has low workability [6]. The water/cement ratio of concrete in pipes made using this processes is always less than 0.4 and more commonly in the range 0.3 to 0.35. This combination of such low water/cement ratios and high levels of compaction commonly achieves concrete compressive strengths up to 60 MPa and above [6]. Concrete is commonly reinforced by large continuous steel bars. Placing the steel bars takes many man-hours, which contributes to a significant part of the total concrete costs. By eliminating the reinforcement, part of the construction work and cost can be reduced considerably. Fibers are incorporated in concretes to enhance the ductility, splitting tensile strength and flexural strength of the concrete. Researches over the years have shown that fibers reinforcement has sufficient strength and ductility to be used as a complete replacement to conventional steel bars in some types of structures [7]. The addition of fibers to concrete statically cast pipes has shown improvement of concrete mechanical properties as well as cost savings. The saving of the traditional reinforcement results in a reduction of assembling operations, labour force and machinery, as well as in a decrease in the risks associated to manufacturing [8]. However, there is a lake of knowledge concerning the viability and properties of fibers reinforced spun concrete.

MATERIALS AND METHODS

Materials:

- Ordinary Portland Cement CEM I 52.5 N complying ES: 4756-1 [9].
- Crushed dolomite with max size 5 mm as coarse aggregate.
- Normal siliceous sand was used as fine aggregate of concrete with 2.6 fineness modulus.
- Polycarboxylic ether based superplasticiser was used to adjust the workability of concrete.
- Silica fume (micro-silica) which is locally produced was used as mineral to.
- Polypropylene fibers (PPF) and steel fibers (SF).

Table 1 summarizes the information of different concrete materials that have been used in the experimental program.

Concrete Mix Constituents: Mix design has been carried out to determine materials proportions that yield concrete with normal and high strength concrete incorporating SF or PPF. Concrete strength level was classified by Eurocode 2 [10]. The code has specified high strength concrete as the concrete having strength classes greater than or equal to C55 based on cylinders 150 x 300mm. In the same time, spun cast necessitates concrete with relatively high workability particularly in the presence of fibers. Some researchers, Abbas [7], Yu *et al.* [11] and Rana [12] showed that high performance fibers reinforced systems, which is suitable for spun cast, have extremely dense matrixes with relatively large cement content and very low w/c. Consequently, cement content selected in the current study was 450kg/m^3 and 650kg/m^3 for normal and high strength concrete, respectively. Additionally, several trial concrete mixes with/without fibers were examined to find out the appropriate workability. The inquired slump of about 130mm was achieved by adopting maximum doze of superplasticizer and the amount of water needed to attain slump of 130±5mm. Steel fibers contents for both normal and high strength concrete were 0.75%, 1.5% and 3% by volume of concrete. Polypropylene fibers contents for high strength concrete were 0.5% and 1% by volume of concrete, while PPF content for normal strength concrete was only 0.5% by volume of concrete since higher PPF content required high cement content to provide more paste volume different mixes constituents are listed in Table 2. It should be kept in mind that w/(c+sf) cannot be maintained at the same level for all mixes due to the nature of spun cast technique that requires a particulate slump, which makes concrete spread easily in the mold under spinning effect. Table 1 shows that w/(c+sf) increased significantly for normal strength concrete incorporating either PPF or SF. On the other hand, w/(c+sf) slightly varied for high strength concrete due to the addition of fibers. This may be attributed to the high paste volume provided by high cement content.

Specimens Preparation: After mixing, cylinders 150 x 300 mm were cast (statically) as specified by to ASTM C192 [13]. In addition, cylinders 150 x 300 mm were cast centrifugally (spun cast) using specially designed and manufactured laboratory-scale machine adopting similar technique used in producing full scale spun concrete pipes. Special molds have been manufactured to prepare spun cast specimens. The used machine and mold are illustrated in Fig. 1. Concrete was poured into the cylinder up to the top then the mold is assembled, mounted firmly in the machine and spun at 1000rpm for 60 seconds. Spun caused flinging concrete against the wall of the mold through centrifugal force. It should be pointed out here that cylinders cast centrifugally contained a hollow core

Table 1: Information of the used materials

Materials	Type	Specific gravity
Cement	CEM I 52.5 N	3.15
Coarse aggregate	Dolomite	2.63
Fine aggregate	Sand	2.72
Superplasticizer	Polycarboxylic ether	1.05
Mineral admixture	Silica fume (micro-silica)	2.20
Fibers materials	Steel fibers (Dramix 65/60)	7.80
	Polypropylene	0.90

Table 2: Recipes of normal and high strength concrete with/without fibers

	Mix identification										
Items	Normal strength concrete mixes					High strength concrete mixes					
Constituents	NSC1	NSC2	NSC3	NSC4	NSC5	HSC1	HSC2	HSC3	HSC4	HSC5	HSC6
w/(c+sf)	0.38	0.46	0.53	0.51	0.53	0.25	0.26	0.29	0.27	0.27	0.28
SF, vol.%	0.0	0.0	0.75	1.5	3.0	0.0	0.0	0.0	0.75	1.5	3.0
PPF, vol.%	0.0	0.5	0.0	0.0	0.0	0.0	0.5	1	0.0	0.0	0.0
Cement (c), kg/m^3			450					650			
Dolomite, kg/m^3			1000					820			
Sand, kg/m^3			721					570			
Superplasticizer, %			2.2					2.2			
Silica fume (sf), kg/m^3			45					65			

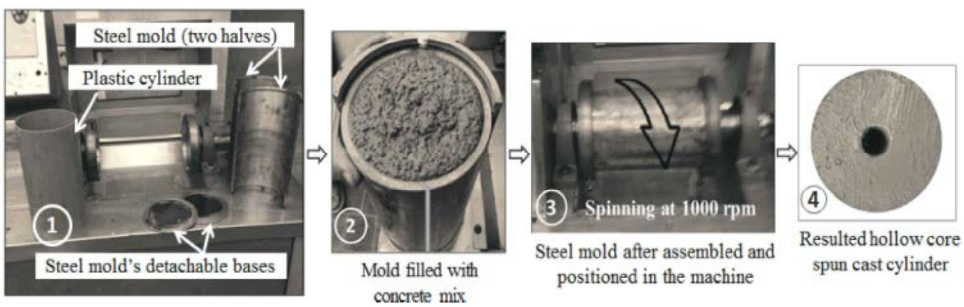

Fig. 1: Sequence of spun cast concrete cylinders (1: Spinning machine and the cylindrical mold, 2: Plastic cylinder filled with concrete, 3: The mold is mounted in the spinning machine, 4: Concrete cylinder with hollow)

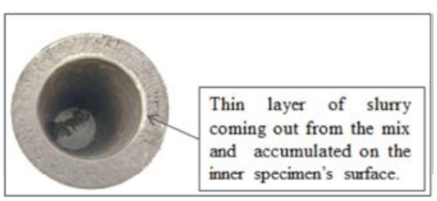

Fig. 2: Freshly spun cast tubular specimen

(Fig. 1) resulted from voids that accumulated towards the center due to spun effect although the mold was filled completely with concrete. Both statically and spun cast specimens were employed to determine compressive strength and evaluation of concrete microstructure, while only statically cast cylinders were tested to determine splitting tensile strength of concrete since it was not possible to cast solid cylinders centrifugally as explained earlier. Spun cast tubular specimens 150 x 300 mm with 30mm thickness have been prepared to investigate load-displacement characteristics of tubular specimens under two-edge loading.

Spun cast concrete tubes were prepared with the same method implemented to prepare spun cast cylinders. To get tubular specimens, only third of the mold was filled with concrete to give a wall thickness of about 30 mm. The tubular specimen after spun cast is shown in Fig. 2. The Figure shows the effect of spinning on concrete high compaction which results in extraction of some slurry from the concrete mix.

RESULTS AND DISCUSSION

Microstructure Evaluation: Microstructure of statically and spun cast concrete was evaluated by polarization and fluorescence microscopy (PFM). Concrete specimens

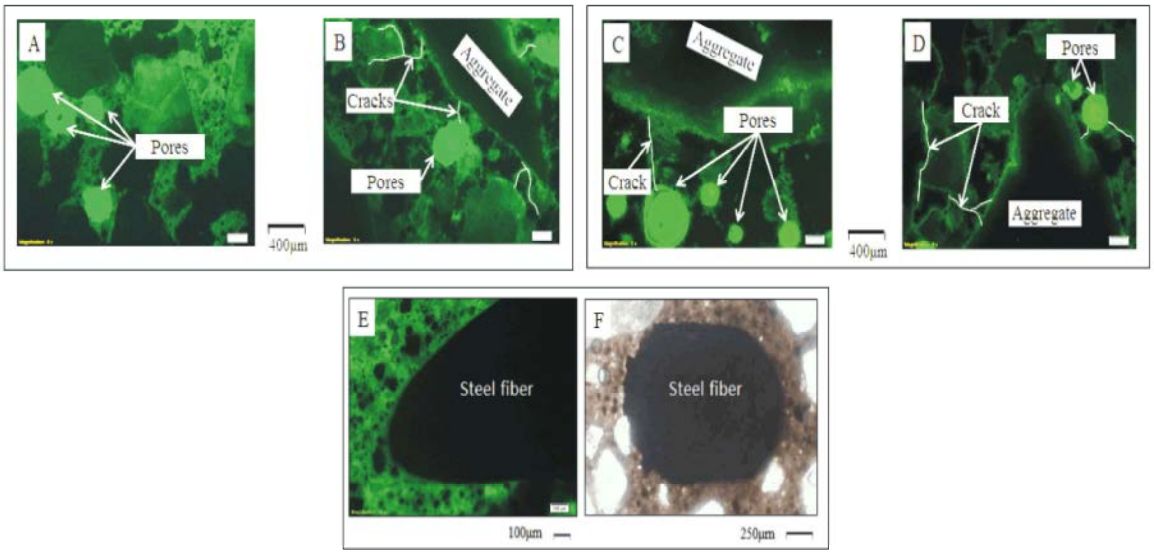

Fig. 3: PFM micrographs of (A: Statically cast normal strength concrete [NSC], B: Spun cast normal strength concrete, C: Statically cast high strength concrete [HSC], D: Spun cast high strength concrete and E: High strength steel fibers (0.75%) reinforced spun concrete [HSFRSC]) and photomicrograph (F) of concrete thin section of HSFRSC

examined by PFM were prepared by sawing a concrete 50mm cube from the statically and spun cast cylinder after 28 days using a special eclectic devise. Examination by polarization and fluorescence microscopy was performed according to Roy *et al.* [14]. PFM micrographs of normal and high strength concrete are displayed in Fig. 3. It was observed that statically cast NSC and HSC contained much more voids than spun cast either NSC or HSC. This may be attributed to the spinning process which generated high passive compaction forces resulting in voids reduction. It can be noticed also that spun cast either NSC or HSC specimens exhibited microcracks. The formation of such microcracks may be caused by the effect of spinning, which pressed concrete mix and resulted in reduction in w/(c+sf) due to the extraction of some mixing water in the form of slurry as shown previously in Fig. 2. It is known that the hydration products formed by Portland cement hydration occupy less space than the reacting water causing chemical shrinkage. At low w/(c+sf), this phenomenon causes a successive emptying of the pore structure and leads to tensile stresses in the pore water through the formation of menisci [15]. Menisci formation leads to relative humidity to drop and self-desiccation occurs in the cement paste. The build-up of tensile stresses in the pore, furthermore, results in bulk shrinkage of the hardening concrete, so-called self-desiccation shrinkage, which results in cracking [15]. Microcracks formed in spun cast specimens occurred at aggregate surfaces (the non-shrinkage constituent of concrete matrix). Some other microcracks were noticed to connect between aggregate surface and pore. Much fewer microcracks were also observed in case of statically cast HSC due to the shrinkage caused by high cement content (650kg/m^3), same result was also indicated by Tazawa and Miyazawa [16].

The effect of steel fibers addition on concrete microstructure is illustrated in Fig. 3-E and 3-F. It can be observed clearly that steel fibers prohibited the formation of microcracks. Dense ITZ between steel fibers and surrounding concrete was also noticed. It should be mentioned here that although steel fibers banned microcracks of high strength concrete, pores were still observed.

Water Permeable Porosity: The porosity of each mix was measured applying the saturation technique given by ASTM C642-06 [17]. Saturation is carried out on three 50 mm cubes sawed from statically and spun cast cylinders of each concrete mix. The saturation technique involves soaking the specimens in water at room temperature for 48 hours to ensure that the water enters the specimen pores until two successive mass values of the surface-dried sample at 24 hours interval show an increase in mass of less than 0.5% of the previous value. The water permeable porosity is calculated from the following equation given by Yu *et al.* [11]:

$$W_{pp} = [(m_s - m_d)/ (m_s - m_w)] \text{ x}100 \quad (1)$$

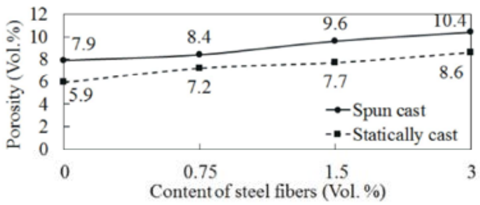

Fig. 4: Water permeable porosity of NSC specimens

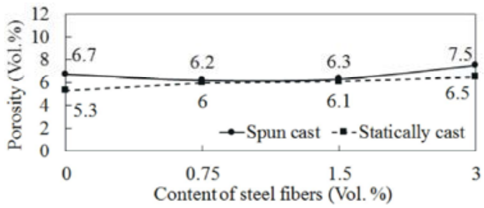

Fig. 5: Water permeable porosity of HSC specimens

where:

W_{pp} : Water permeable porosity (%);

m_s : Mass of the saturated sample in surface-dry condition measured in air (g);

m_w : Mass of water-saturated sample in water (g);

m_d : Mass of oven-dried sample (g).

Water permeable porosity versus the volumetric steel fibers content is plotted in Fig. 4 and Fig. 5 for normal strength concrete (NSC) and high strength concrete (HSC) respectively.

In Fig. 4, it can be noticed that all spun normal strength concrete specimens exhibited higher water permeable porosity than statically cast concrete regardless content of steel fibers. This observation can be explained based on the results of microstructure evaluation, which showed that reduction of pores of spun cast concrete accompanied by formation of microcracks resulted from the chemical shrinkage. These microcracks caused water permeable porosity increment. The influence of steel fibers addition on concrete porosity can be explained by the effect of fibers on the particle packing of concrete ingredients. As cited by Grünewald [18], due to the internal force between the fibers and aggregate (and/or fibers themselves), the packing density of concrete will significantly decrease with the addition of steel fibers. Hence, in the current study, with the increase of fibers content, porosity increase was noticed. Spun concrete porosity increased by about 6%, 21% and 31% when steel fibers content increased by 0.75%, 1.5% and 3%, respectively, while statically cast concrete porosity increased by 22%, 30% and 45% when steel fibers content increased by 0.75%, 1.5% and 3%, respectively. These results indicated that spun cast could relatively reduce the effect of steel fibers on porosity increase due to packing effect [18]. As can be seen in Fig. 5, it is apparent that with increase of steel fibers content, the porosity of statically cast high strength concrete remained relatively constant, since porosity increased by about 5% at 3% steel fibers content. This can be attributed to the effect of steel fibers in dimensioning of microcracks as observed from the examination of polarization and fluorescence microscopy shown in Fig. 3-E and 3-F. It can be also seen that porosity of high strength spun concrete is generally less than that of normal strength concrete due to denser concrete matrix.

Detailed porosity results of statically and spun cast concrete with/without steel and polypropylene fibers are summarized in Table 3. As can be noticed, the addition of 0.5% polypropylene (NSC2 and HSC2) did not affect significantly concrete porosity. Nevertheless, 1% polypropylene (HSC3) resulted in about 28% and 25% porosity increment of statically cast and spun cast concrete respectively. Table 3 shows also that the increase in cement content from 450 to 650 kg/m^3 (NSC1 and HSC1) resulted in porosity reduction by about 10% and 15% of statically cast and spun cast concrete, respectively.

Mechanical Properties: Results of compressive strength, splitting tensile strength and load carrying capacity of all concrete mixes are presented in the following subsections.

Compressive Strength: The effect of spun cast and steel fibers addition on compressive strength of both high and normal strength concrete is plotted in Fig. 6. It is important to notice that spun cast resulted in compressive strength enhancement for all mixes regardless either content of steel fibers or binder (c+sf) content. Additionally, increasing binder content from 495kg/m^3 to 715kg/m^3 (by 44.4%) resulted in compressive strength increment of statically cast mixes from 58.2MPa to 74.2MPa (27.5% increment), while it increased from 77.7MPa to 92.0MPa (by 19.2%) of spun cast mixes. With addition of steel fibers, compressive strength of both statically and spun cast NSC mixes decreased. Taking NSC5 as an example, with addition of 3% steel fibers, the compressive strength decreased from 58.2MPa to 52.0MPa and from 77.7MPa to 59.1MPa for statically and spun cast concrete respectively. Additionally, the effect of spun cast on strength enhancement of NSC mixes was more pronounced at low steel fibers content. In contrast, the effect of spun cast was more remarkable for mixes with

Table 3: Water permeable porosity of concrete specimens

	Water permeable porosity (Vol. %)										
Cast method	NSC1	NSC2	NSC3	NSC4	NSC5	HSC1	HSC2	HSC3	HSC4	HSC5	HSC6
Statically cast	5.9	6.1	7.2	7.7	8.6	5.3	5.4	6.8	6.0	6.1	6.5
Spun cast	7.9	8.0	8.4	9.6	10.4	6.7	6.8	8.4	6.2	6.3	7.5

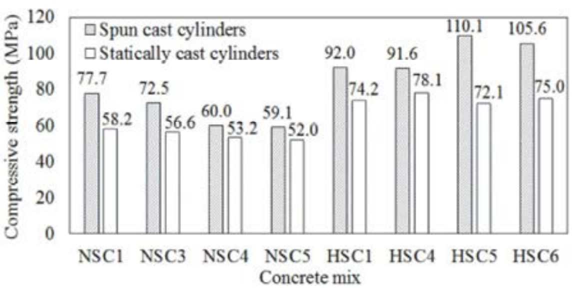

Fig. 6: Compressive strength of statically and spun cast NSC and HSC with steel fibers

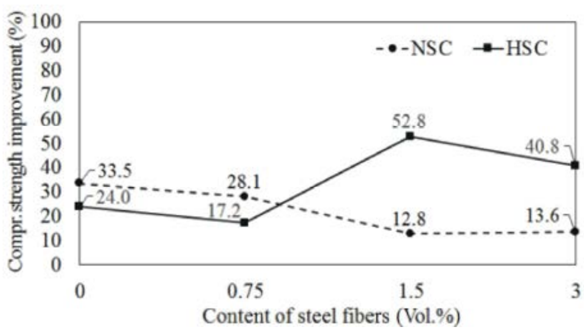

Fig. 7: Effect of spun cast on improvement of compressive strength as function of steel fibers content

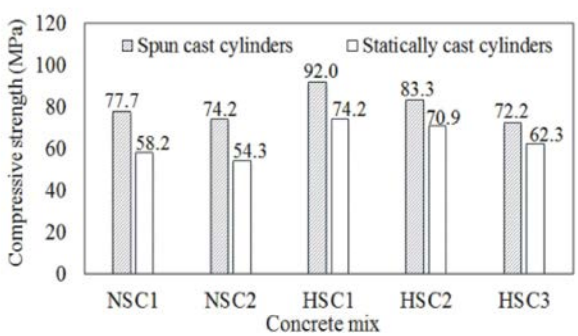

Fig. 8: Compressive strength of statically and spun cast NSC and HSC with polypropylene fibers

high addition of steel fibers. The compressive strength increased from 56.6MPa to 72.5MPa for NSC3, while it increased from 53.2MPa to 60.0MPa and from 52.0MPa to 59.1MPa for NSC4 and NSC5, respectively. Compressive strength increased from 72.1MPa to 110.1MPa and from 75.0MPa to 105.0MPa for HSC5 and HSC6, respectively, while it increased from 78.1MPa to 91.6MPa for HSC2 respectively. Compressive strength improvement ratio as a result of spun cast NSC and HSC mixes versus the volumetric steel fibers content is illustrated in Fig. 7. It can be observed that the addition of steel fibers results in less compressive strength improvement of NSC mixes. The minimum compressive strength improvement of 12.8% was noticed with steel fibers addition of 1.5%, while the maximum compressive strength improvement of 33.5% was achieved by NSC1 mix (without steel fibers addition). In case of HSC mixes with high binder content (650kg/m^3), steel fibers can efficiently bridge cracks and retard their propagation, which directly caused strength enhancement significantly [19]. HSC mixes with steel fibers addition exceeding 0.75% showed significant strength enhancement. For instance, increasing the content of steel fibers to 1.5% and 3% resulted in HSC compressive strength improvement of 52.8% and 40.8%, respectively. The effect of polypropylene fibers (PPF) addition to concrete mixes is plotted on Fig. 8. As it can be seen, PPF caused insignificant reduction in compressive strength of all concrete mixes. Compressive strength of mix NSC2 decreased from 58.2MPa to 54.3MPa (less than 7%) and from 77.7MPa to 74.2MPa (lesser than 5%) for statically and spun cast mixes, respectively. For mix with higher binder content (HSC3), remarkable reduction in compressive strength was noticed, since it decreased from 74.2MPa to 62.3MPa (by 16%) and from 92.0 MPa to 72.2 MPa (by 21.5%) for statically and spun cast mixes, respectively.

Splitting Tensile Strength: The splitting tensile test, also known as the Brazilian test, was performed on 150 mm diameter, 300 mm long specimens. It should be borne in mind that the splitting tensile strength has been carried out only on concrete cylinders that cast statically because it was not possible to centrifugally cast solid cylinders as explained in section 2.3. The ultimate splitting tensile strength of NSC and HSC mixtures incorporating steel fibers are illustrated in Fig. 9. It can be shown that increasing binder content by more than 44% did not affect significantly the splitting tensile strength of concrete since it increased from 5.0MPa to 5.5MPa (only by 10%).

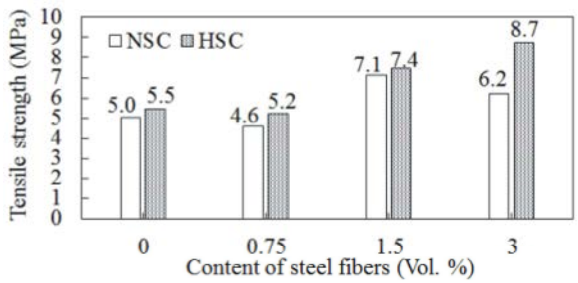

Fig. 9: Splitting tensile strength of statically cast NSC and HSC with steel fibers

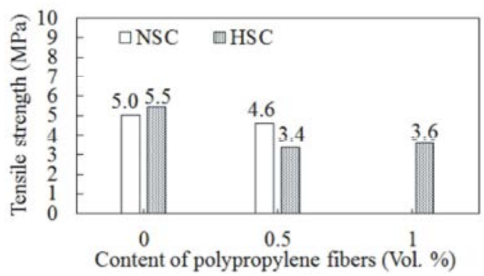

Fig. 10: Splitting tensile strength of statically cast NSC and HSC with polypropylene fibers

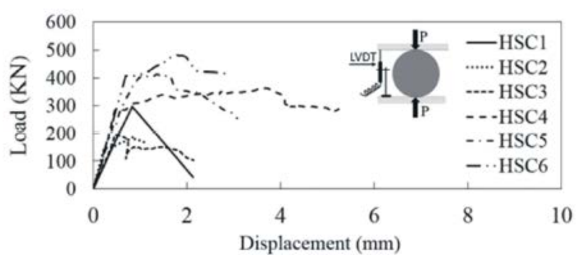

Fig. 11: Load- displacement relationship of statically cast HSC cylinders incorporating steel and polypropylene fibers

As it can be seen from Fig. 9, for NSC mixes, low addition of steel fibers resulted in splitting tensile strength reduction. It decreased from 5.0MPa to 4.6MPa with the addition of 0.75% (by volume of concrete) steel fibers. At higher addition of steel fibers, the splitting tensile strength was enhanced. It increased from 5.0MPa to 7.1MPa and from 5.0MPa to 6.2MPa with the addition of 1.5% and 3% steel fibers, respectively. Similar behavior was observed for HSC mixtures, the splitting tensile strength decreased from 5.5MPa to 5.2MPa with 0.75% steel content. Higher steel fibers content resulted in remarkable splitting tensile strength enhancement. It increased from 5.5MPa to 7.4MPa and from 5.5MPa to 8.7MPa with 1.5% and 3% steel fiber content respectively. Fig. 10 represents the ultimate splitting tensile strength of NSC and HSC mixtures containing polypropylene fibers. It can be clearly noticed that addition of PPF caused splitting tensile strength reduction. The splitting strength decreased from 5.0MPa to 4.6MPa and from 5.5MPa to 3.4MPa with addition of 0.5% PPF for NSC and HSC mixes respectively. It is important to mention here that, it was impossible to produce normal strength concrete centrifugally with addition of 1% PPF due to insufficient volume of paste necessary for proper workability. As it can be seen from Fig. 10, the splitting tensile strength of HSC mix ecreased by about 35% due to addition of 1% PPF. This could be attributed to the damaging effect of such high fiber volume fraction on fiber dispersion [20].

Fig. 11 shows load- displacement relationship of statically cast HSC cylinders with different addition of steel and polypropylene fibers. It indicates clearly that addition of steel fibers enhance concrete ductility under splitting loading. Maximum ductility enhancement was achieved by HSC4 that containing 0.75% addition of steel fibers with slightly lower splitting load than control specimen HSC1. It can be noticed also that increasing steel fiber volume fraction over 0.75%, the ultimate splitting load is significantly increased. With the addition of polypropylene fibers, ductility was decreased remarkably compared with steel fiber concrete specimens. Moreover, ultimate splitting loads were decreased considerably.

Load Carrying Capacity of Tubular Specimens in Two-Edge Bearing Test: Fig. 12 and 13 illustrate the load displacement relationships in two-edge bearing test carried out on NSC and HSC spun cast tubular specimens respectively. It can be seen that adding steel fibers could improve both ductility and load carrying capacity of NSC as well as HSC specimens significantly. As it can be observed, Fig. 12, there is a well-defined softening behavior pattern in the case of specimen with low amounts of fibers (NSC3); in other words, the specimen experienced a loss of resistance capacity with the increase of displacement once ultimate load was reached. Specimens with higher volume fraction of steel fibers respond differently, showing hardening when the yielding point was reached (points Y_1 and Y_2). It was observed also that cracking began just before reaching the maximum capacity of specimen NSC3. On the other hand, for specimens NSC4 and NSC5, the appearance of first crack coincided with the change in the slope of load-displacement curve.

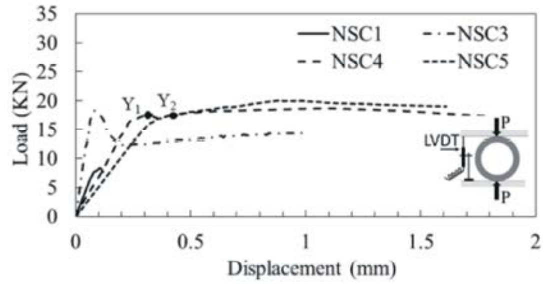

Fig. 12: Load-displacement curves in two-edge bearing test on spun cast NSC tubular specimens with steel fibers

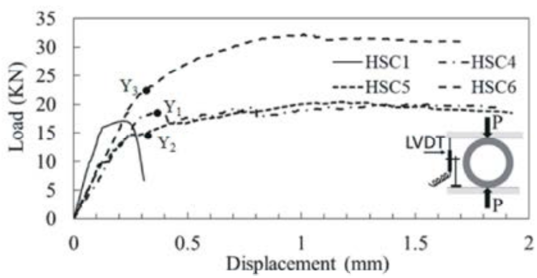

Fig. 13: Load-displacement curves in two-edge bearing test on spun cast HSC tubular specimens with steel fibers

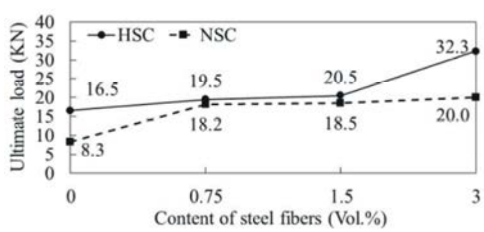

Fig. 14: Variations in ultimate load capacity of tubular specimens as function of steel fibers content

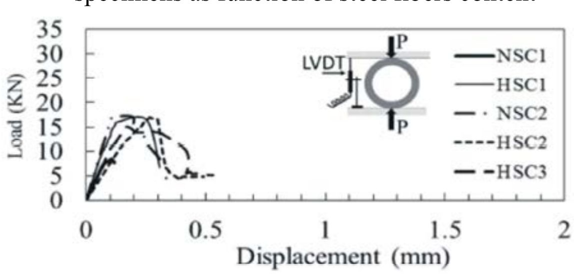

Fig. 15: Load-displacement curves in two-edge bearing test on spun tubular concrete specimens with polypropylene fibers

It can be seen from Fig. 13 that HSC with steel fibers exhibited improved ductility when compared with the control specimen HSC1, although load capacity for specimens HSC4 and HSC5 was not remarkably enhanced.

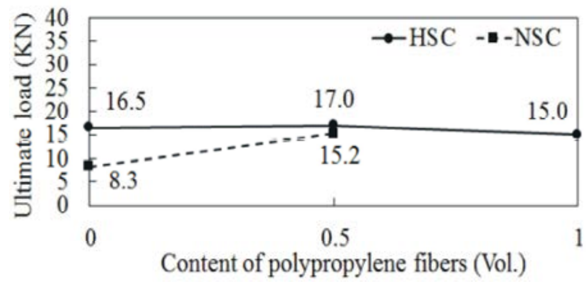

Fig. 16: Variations in ultimate load capacity of tubular specimens as function of polypropylene fibers content

Specimen HSC6 with addition of 3% steel fibers exhibited the most improvement of ductility. Similar to NSC, cracking load corresponding to points Y_1, Y_2 and Y_3 of HSC4, HSC5 and HSC6, respectively concurred with the change in the slope of the load-displacement curves. Fig. 14 demonstrates the effect of steel fibers addition on load carrying capacity of NSC and HSC tubular specimens. As it can be observed, steel fiber of 0.75% resulted in significant improvement of load capacity of spun NSC tubular specimens, while the maximum load carrying capacity of spun HSC tubular specimens was achieved with addition of 3% by volume of concrete. Load carrying capacity 16.5KN of specimen HSC1 is about twice of control specimen NSC1 (8.3KN).

Load versus displacement relationship of spun tubular specimens reinforced with polypropylene fibers (PPF) are presented in Fig.15. Normal strength concrete reinforced with 0.5% PPF produced tubular specimens (NSC2) with load carrying capacity which compared well with control specimen NSC1 (with no fibers).

Fig. 16 presents the effect of PPF addition on load carrying capacity of tubular high and normal strength concrete specimens. As it can be shown from Fig.16, load carrying capacity of NSC specimens increased from 8.3KN to 15.2KN due to addition of 0.5% PPF. Conversely, HSC specimens showed negligible increase in load carrying capacity due to addition of 0.5% PPF. With addition of 1% PPF, HSC specimens showed marginal decreased in load carrying capacity from 16.5KN to 15.0KN. This can be attributed to damaging effect of such high fiber volume fraction on fiber dispersion [20]. Since the ductility of fiber reinforced concrete depends on the ability of fibers to bridge cracks at high levels of strain, addition of PPF improved the post crack ductility of both NSC and HSC although it is not comparable with the high ductility offered by steel fibers [21].

CONCLUSIONS

- Microstructure evaluation by polarization and fluorescence microscopy (PFM) showed that statically cast NSC and HSC contains much more voids than spun cast concrete.
- Spun cast NSC and HSC specimens exhibited microcracks due to the effect of spinning that is pressing concrete mix causing reduction in w/(c+ sf) and leads to self-desiccation.
- Steel fibers prohibited the formation of microcracks of spun cast NSC and HSC specimens.
- Spun cast resulted in compressive strength enhancement for all tested mixes. Maximum compressive strength of 110.1MPa was achieved by HSFRSC with addition of 1.5% steel fibers.
- For NSC mixes, low addition of steel fibers (0.75% by volume) resulted in splitting tensile strength reduction. At higher addition, the splitting tensile strength was enhanced. Same trend was also observed for HSC mixes.
- Addition of PPF caused splitting tensile strength reduction of both NSC and HSC mixtures.
- Steel fibers addition could improve significantly cracking load, load carrying capacity and ductility of NSC as well as HSC spun cast tubular specimens.

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