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Effect of recycled polypropylene fiber on high strength concrete and normal strength concrete properties

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Abstract. An experimental study was undertaken to evaluate the performance of recycled polypropylene fiber (RPF) in concrete. The RPF materials were recycled from woven bags and used in concrete at various volume fractions corresponding to 0.1%, 0.2%, and 0.3%. Two different classes of strength, corresponding to normal and high strength concrete, were investigated. Fiber was used as substitution of coarse aggregate in concrete. The dosage of fiber was used at relatively lower dosages to avoid altering fluidity and to limit the reduction in coarse aggregate content. On the other hand, a commercial polypropylene fiber (PPF) was used at equivalent dosages than RPF for comparisons purposes. Test results indicated that optimized RPF volumes can secure comparable mechanical performance than those obtained with commercial PPF. On the other hand, the use of both fiber types resulted in lower compressive strength (10 to 20%), higher flexural strength (up to 27%), and lower elastic modulus (by 16%). Furthermore, the use of RPF type reduced the drying shrinkage (6 to 10%) of normal and high strength concrete types and increased the permeable pore void of both concrete types.

Keywords: compressive strength; elastic modulus; flexural strength; high strength concrete; permeable pore void; recycled polypropylene fiber; shrinkage

1. Introduction

Polypropylene fibres (PPF) have been applied for the concrete reinforcement for many years (Bentur and Mindess 2019, Zheng and Feldman 1995, Merli *et al*. 2020). They have been widely used to reinforce concrete as an alternative to steel fibers. The PPF possess high chemical and biological resistance including very good resistance in concretes alkaline environment (Segre *et al*. 1998). Conventionally polypropylene fibers are used in concrete at relatively low contents, 0.1 to 0.3% by volume, as a secondary reinforcement to control and reduce the plastic shrinkage cracking of concrete. They are hydrophobic due to their chemical structure, which leads to reduce bonding with the cement, and negatively affecting its dispersion in the matrix. The bonding strength between fibers and matrix can be developed by fiber surface treatment (Donghwan *et al*. 2004).

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The PPF fibers have been successfully used in cementitious materials to control shrinkage cracking, to improve material toughness and impact resistance, and to increase significantly the energy absorption capacity of the material (Song *et al*. 2005, Nili and Afroughsabet 2010, Karahan and Atis 2011). Zeiml *et al*. (2006) and Merli *et al*. (2020) suggested that there is a great influence of the amount of polypropylene fibers on the spalling behavior of concrete under fire loading. The uniformly dispersed fibers strengthen the cement matrix and bridge over cracks, reduce the cracking sensitivity of the matrix and decrease the crack width (Aly *et al*. 2008).

Any addition of fibers into a plain concrete mixture affects its properties in both fresh mixture and hardened composite. Studies show that increase in fiber content decreases the workability of the composite due to high specific area of fibers (Zhang and Li 2013). The factor to consider here is the surface area of the fibers. In addition to the coarse aggregate the mortar must also coat the fibers. According to ACI Committee 544 (2002), it is advised to increase the mortar fraction and reduce the coarse aggregate content to accommodate the increase in surface area due to polypropylene fiber addition. The coarse to fine aggregates ratio in the mix is reduced so that individual coarse aggregate particles are fully surrounded by a layer of mortar. The exact amount of coarse aggregate to be reduced in mixes can be calculated using the methodology based on thickness of mortar layer (Voigt *et al*. 2004).

Polypropylene fibers have been extensively used as a reinforcement in Portland cement based materials because of its high toughness and durability; while there was a conflict about the correlation of the PPF content and the corresponding compressive strength of the concrete. Although it was stated by Orasutthikul *et al*. (2017) that incorporation of PPF reduces the compressive strength of concretes, some researchers (Yin *et al*. 2016, Vairagade *et al*. 2012, Ahmed *et al*. 2006) reported that PPF in small volume fraction, ranging from 0.05% to 0.5%, has no or very small effect on the compressive strength of fibre reinforced concrete. This conflict was studied by Richardson (2006) and he concluded, because of the cement bond breaking by PPF, the concrete compressive strength is reduced notably.

Fiber reinforcement using different types of virgin fibers has been extensively studied, and has generally been observed that the recycled fibers could provide similar reinforcement as virgin materials. This was demonstrated in studies on recycled synthetic fibers from various sources including carpet, tires, and plastic containers in comparison with commercially available virgin synthetic fibers (Wang *et al*. 2000, Yin *et al*. 2016). The alkali resistance of RPF fiber was tested in four different alkaline solutions to study the RPF degradation. The post-cracking performance of RPF reinforced concretes was also quantified and compared with that of virgin PP fibre reinforced concretes through the CMOD (Crack Mouth Opening Displacement) test and RPDT (Round Determinate Panel Test). In this study, two volumes percentages of fibres were chosen to reinforce 40 MPa and 25 MPa concretes which are the standard grades of concrete used in precast panels and concrete footpaths, respectively. They concluded that RPF can be used to replace virgin PPF fibres in the concrete footpaths and precast panels.

The construction industry is the second largest consumer of plastics after the packaging industry (Addis 2012). Concrete is the most widely used construction material in the world with production of over 2 billion tons per year (ONS 2018). Therefore, the use of recycled plastics in concrete provides a huge scope for the re-utilization of waste plastic on an industrial scale. Using recycled polypropylene fibre (RPF) has the potential to significantly reduce environmental impacts and extend the applications of recycled plastic products. The advantages of using such RPF include generally lower cost to process than virgin PPF, and the elimination of the need for waste disposal in landfills.

The authors investigated the performance of recycled polypropylene fiber (RPF) when used in normal and high strength concrete. RPF materials were recycled from used woven bags, cut to 40 mm length like commercial fiber and used at various dosages corresponding to 0.1, 0.2, and 0.3%. On the other hand, a commercial polypropylene fiber (PPF) was used at equivalent dosages than RPF for comparisons purposes. An experimental study was carried out to investigate RPF effects on compressive strength, flexural strength, elastic modulus, permeable pore void and shrinkage when introduced in concrete formulation.

2. Experimental program

2.1 Materials

All investigated mixtures were formulated using Type I ordinary cement complying with ASTM C150 (2020) standards. The chemical properties of cement are summarized in Table 1. Crushed limestone coarse aggregate with a maximum size aggregate of 14 mm and specific gravity of 2.7 was used. Well-graded natural river sand with fineness modulus of 2.66 and specific gravity of 2.65 was used for the fine aggregate. The RPF was obtained from worn polypropylene fiber woven bags. The RPF was used in concrete without any special pre-treatment. The bags were just collected from landfills, manually unwoven, cleaned and cut to an equal length of 40 mm to be identical to the commercialized Strux 90/40 fiber (PPF); length: 40 mm and aspect ratio: 90. Fig. 1 shows the worn woven bags and the RPF recovered. The PPF has a tensile strength of 620 MPa and an elastic modulus of 9.5 GPa. On the other hand, the RPF has a tensile strength of 400 MPa and an elastic modulus of 4.3 GPa, and a specific gravity of 0.74 g/cm³, which satisfy the ACI Committee 544 (2002). Both Strux 90/40 and RPF fibers had the same length of 40 mm. The Strux fibers were stiff and have a straight shape, while the RPF was smooth and flat. The physical properties of both fiber types are summarized in Table 2.

A commercial polycarboxylate admixture Type F conforming to ASTM C494 (2005) having a density of 1.16 and solids content of 27% was used as a high-range water-reducing (HRWR) to

Table 1 Chemical and physical characteristics of cement

Chemical characteristics	SiO_2	(%)	21.0
	Al_2O_3		4.2
	Fe_2O_3		3.1
	CaO		62
	MgO		2.9
	Na_2O eq.		0.74
Physical characteristics	50 % passing diameter (D_{50}), µm		19
	Blaine surface area, m²/kg		420
	Percent passing 45 µm (%)		17
	Specific gravity		3.15
	LOI (%)		2.5

Table 2 Physical properties of both fiber types

	Fiber type	
	PPF (Strux 40/90)	RPF
Specific gravity	0.92	0.74
Modulus of elasticity (GPa)	9.5	4.3
Tensile strength (MPa)	620	400
Melting point (°C)	165	165
Length (mm)	40	40
Aspect ratio	90	66

Fig. 1 Woven bags and recycled polypropylene fiber (RPF) used

produce a workable concrete. The dosage of HRWR was varied between 1.3 and 1.5%, by mass of cement, to produce concrete mixtures with a slump of 120 ± 20 mm.

2.2 Tests procedures

Normal strength concrete (NSC) and high-strength concrete (HSC) were investigated in this study. The mixture proportioning of NSC and HSC is summarized in Tables 3 and 4, respectively. The NSC mixtures were proportioned with a cement content of 320 kg/m^3 and a water-to-cement ratio (W/C) of 0.55. These mixtures were proportioned to secure a 28-day compressive strength of 30 MPa. On the other hand, HSC mixtures incorporated higher cement content of 400 kg/m^3 and were made with a lower W/C of 0.40 to achieve a targeted compressive strength of 50 MPa. The effect of various fiber contents ranging between 0 and 0.3%, by volume, was used to evaluate some properties of NSC and HSC. The fibers were used as replacement of coarse aggregate according to the mortar thickness concept. This concept consists in maintaining constant mortar thickness layer (tm) covering the solid particles (fiber and coarse aggregate) in the matrix (Voigt *et al*. 2004). Also, it was well known that the formulation of fiber concrete is achieved by substituting an inert material such as sand or coarse aggregates with fibers. This is realized by volume because of the difference in the densities of the materials. In this study, coarse aggregates were substituted by polypropylene fiber for rates of 0.1, 0.2 and 0.3% of concrete volume which are rates very used in practice. The HRWR dosage was adjusted to secure a slump value of 120 ± 20 mm.

Table 3 Mixture proportioning of investigated NSC concretes

	Water	Fiber	Cement	Sand	Coarse aggregate
	kg/m^3				
NSC	176	0	320	818	1070
NSC-PPF-0.10	176	0.9	320	830	1053
NSC-PPF-0.20	176	1.8	320	844	1036
NSC-PPF-0.30	176	2.7	320	858	1019
NSC-RPF-0.10	176	0.9	320	839	1044
NSC-RPF-0.20	176	1.8	320	853	1028
NSC-RPF-0.30	176	2.7	320	867	1010

Table 4 Mixture proportioning of investigated HSC concretes

	Water	Fiber	Cement	Sand	Coarse aggregate
	kg/m^3				
HSC	160	0	400	770	1078
HSC-PPF-0.10	160	0.9	400	785	1063
HSC-PPF-0.20	160	1.8	400	799	1043
HSC-PPF-0.30	160	2.7	400	813	1027
HSC-RPF-0.10	160	0.9	400	794	1051
HSC-RPF-0.20	160	1.8	400	808	1035
HSC-RPF-0.30	160	2.7	400	822	1017

Concrete mixtures were prepared in 100-L capacity open pan mixer. The mixing sequence consisted of homogenizing the coarse aggregate and sand for 1 minute before introducing the cement amount and adding another 1 minute to mixing. The fibers were then spread into the mixture, and the materials were mixed again for further 1 minute. 2/3 part of the mixing water was added and mixing continued for 2 minutes. Finally, the HRWR and the remaining mixing water were added and the mix was mixed for a period of 2 minutes. Ambient temperature during mixing and testing was maintained at 22 ± 2°C. The HRWR dosage was adjusted to secure a slump consistency value of 120 ± 20 mm. Following slump adjustment, the unit weight, temperature, and fresh air content were determined. Concrete cylinders of 100×200 mm were made for compressive strength and elastic modulus test. 100×100×400 prisms were cast to determine flexural strength and shrinkage developments. All samples were stored in moist curing according to ASTM C39 (2018) specifications until the testing age. Each value obtained represents the average of three tests whose coefficients of variation were less than 5% for the various test results. The samples intended for the shrinkage measurement were kept under laboratory conditions where the shrinkage represents the average measurement of two test specimens.

3. Test results and discussion

All the investigated mixtures achieved slump of 120 ± 20 mm and an air content of 2 ± 0.5%. As expected, the incorporation of fiber increased the HRWR demand to maintain a given fluidity. The compressive and flexural strengths as well as elastic modulus values of NSC and HSC mixtures were calculated as an average of three different measurements.

3.1 Compressive strength

As can be observed in Fig. 2, the incorporation of PPF in NSC mixtures resulted in reducing compressive strength. The use of recycled polypropylene fiber (RPF) is shown to exhibit similar behavior than the commercial PPF fiber, especially at low content. However, for higher content (0.20 and 0.30%), the use of RPF resulted in slightly higher reduction in compressive strength of NSC compared to HSC. For example, the use of 0.10% and 0.20% PPF resulted in 6% (from 34.6 to 32.4 MPa) and 12% (from 34.6 to 30.4 MPa) reduction in compressive strength, respectively. However, the use of 0.30% resulted in 20% (from 34.6 to 27.4 MPa) reduction. In the case of HSC mixtures, the incorporation of 0.20% and 0.30% PPF reduced compressive strength by 10% (from 50.4 to 45.5 MPa) and 15% (from 50.4 to 42.0 MPa), respectively. The correlations presented in Fig. 2 show a linear decrease of compressive strength according to fiber content used in the mixture. The NSC strength is reduced by 2.3 and 3.1 MPa for each 0.1% PPF or RPF used respectively. Whereas for HSC mixtures this decrease is only 2.7 and 2.9 MPa.

The reduction in compressive strength in NSC may be attributed to the relatively higher void volume and the relatively lower volume of coarse aggregate resulting in lower interlock effect in fiber reinforced concrete. The addition of fiber creates more Interfacial Transition Zone (ITZ) which may affect the compressive strength. On the other hand, the lower compressive strength obtained with RPF compared to PPF fiber can be due to its smooth surface and flat shape. It is well established that fibers can contribute in increasing concrete strength if they have a modulus of elasticity greater than that of the matrix. Given the modulus of elasticity of concrete of about 15 to 30 GPa, this condition seems to be difficult to meet with most synthetic fibers (Zheng and

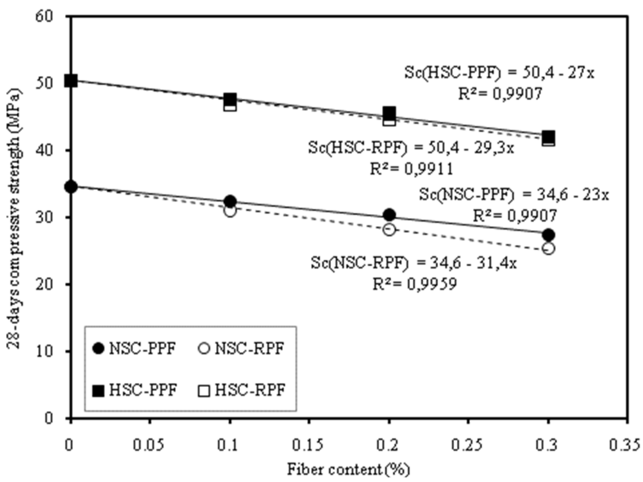

Fig. 2 Variation of compressive strength for NSC and HSC according to fiber content type

Feldman 1995). This result is in conformity with that found by Marthong (2019) in which concrete with polypropylene fibers exhibit 3% to 21% lower compressive strength compared to the control concrete. On the other hand, some researchers (Chandra *et al*. 2018, Geok *et al*. 2020) showed that PPF fibers have minimal effects on compressive strength and just a slight effect is observed for low fiber content as compared to the control concrete.

3.2 Flexural strength

According to the flexural strength results shown in Fig. 3, the use of up to 0.30% PPF resulted in approximately 10% increase in flexural strength, regardless of the concrete type. In the case of RPF, the reduction is about 10% and 25% for NSC and HSC, respectively. The use of RPF resulted in relatively higher flexural strength than PPF and this reduction is more pronounced in the case of HSC. This result can be due to the relatively lower tensile strength and elastic modulus characteristics of RPF compared to that of PPF.

These results match with previous results (Marthong 2019, Setti *et al*. 2020) where the relative increases in flexural strength of fibers concrete specimens are higher about 5-40%. Also, Mazloom and Mirzamohammadi (2019) reported that the flexural strength of cement composite having polypropylene fibers increased from 6 MPa to 7.82 MPa resulted by bond strength between the fibers and the cement matrix. Similar trend was reported by Niranjana *et al*. (2015) for short polypropylene fibers where the increase in strength is caused by the better fibers dispersion which deflects the cracks path and lead to greater energy consumption. Statistical models established using a central composite design indicate that the fiber content is shown to have the greatest effect on flexural strength (Hadjoudja *et al*. 2014).

The improvement provided by the addition of polypropylene fibers is due to the participation of these fibers in resisting to cracks propagation. Any fiber that crosses a crack creates a bridge between the two edges. This bridge will allow part of the stress to be transferred from one edge to the other. Thus, the fibers oppose the crack widening and play the role of a joint which increases the strength of the concrete after cracking. The RPF and PPF fibers help to sew up the micro-cracks and delay their propagation, which prevents the appearance of macro-cracks. From this,

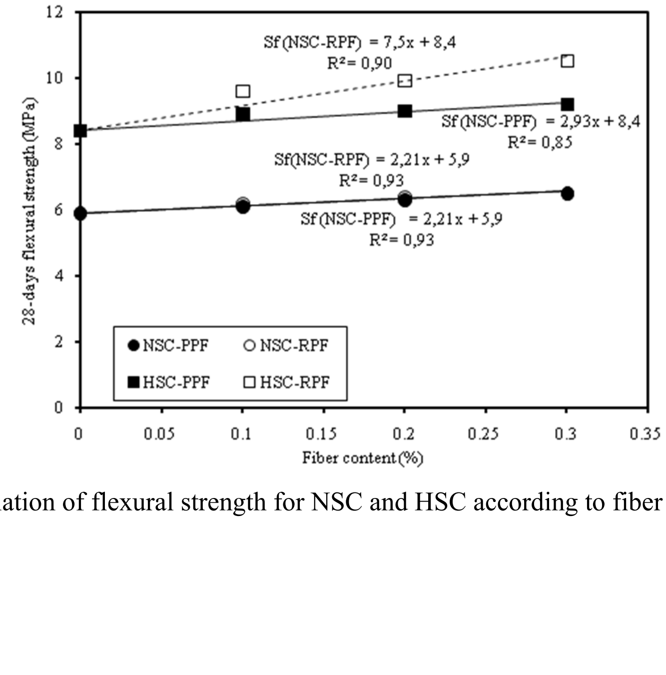

Fig. 3 Variation of flexural strength for NSC and HSC according to fiber content type

Table 5 Comparison of concrete mechanical properties results with PPF and RPF fibers

Reference	Recycling source	Compressive strength results	Flexural strength results
Meddah and Bencheikh (2009)	Waste PPF from storage bags	S_c = 30 MPa (0%) S_c = 29 MPa (0.5%)	S_f = 8.1 MPa (0%) S_f = 8.1 MPa (0.5%)
Yin *et al*. (2016)	RPF from industrial waste	S_c = 55.8 MPa (0%) S_c = 52.5 MPa (0.45%)	S_f = 6.2 MPa (0%) S_f = 5.4 MPa (0.45%)
Yin *et al*. (2016)	Recycled plastic fibres by construction industries	S_c = 45.9 MPa (0%) S_c = 47.7 MPa (0.67%)	S_f = 4.5 MPa (0%) S_f = 4.3 MPa (0.45%)
Thorneycroft *et al*. (2018)	recycled plastic waste	S_c = 53.8 MPa (0%) S_c = 54.4 MPa (1%)	S_f = 3.26 MPa (0%) S_f = 4.07 MPa (0.45%)

fiber reinforced HSC concrete exhibits better mechanical characteristics after cracking due to the high adhesion between fibers and concrete compared to NSC concrete (Setti *et al*. 2020, Yin *et al*. 2015).

In order to better quantify the flexural strength S_f as a function of the compressive strength S_c, several attempts were tested. Using least squares method for the experimental results, two relationships were found for which the correlation coefficients reached values close to unity. These relationships can be written for concrete mixture with PPT and RPT as follows

$$S_f = 0.3\, S_c^{\,0.85+0.7\,PPF^2}; \qquad R^2 = 0.965 \tag{1}$$

$$S_f = 0.3\, S_c^{\,0.85+1.1\,RPF^2}; \qquad R^2 = 0.921 \tag{2}$$

The strengths are expressed in MPa and the fiber content of PPF and RPF is expressed in percentage. The dispersion between the experimental results and predicted by Eqs. (1)-(2) describes perfectly linear variation with an average difference of 0.25 MPa and 0.48 MPa for concrete with PPF and RPF fibers respectively.

A significant number of researches are being carried out on the recovery of wastes and their use as fibers in concrete. This saves the heavy use of virgin fibers and helps to protect the environment. Table 5 recapitulates some results on the mechanical properties of concrete with PPF and RPF. It is clear that the recycled fibers are beneficial and lead to close and even high strengths compared to those of virgin fibers.

3.3 Elastic modulus

The elastic modulus of concrete is a key factor for estimating the deformation of structural elements. It is frequently expressed as function of compressive strength of concrete (Goncalves *et al*. 2007, Herve *et al*. 2010). As can be observed in Fig. 4, the incorporation of 0.10% RPF in NSC and HSC mixtures did not have a significant effect on the elastic modulus. However, the use of 0.20 and 0.30% reduced the elastic modulus of NSC by 15.8% and 20%, respectively. In the case of HSC mixtures, this reduction is about 10%. The use of RPF in NSC resulted in slightly higher reduction in elastic modulus compared to HSC. This may be attributed to the greater porosity in NSC compared to that in HSC. On the other hand, the reduction observed with both concrete types

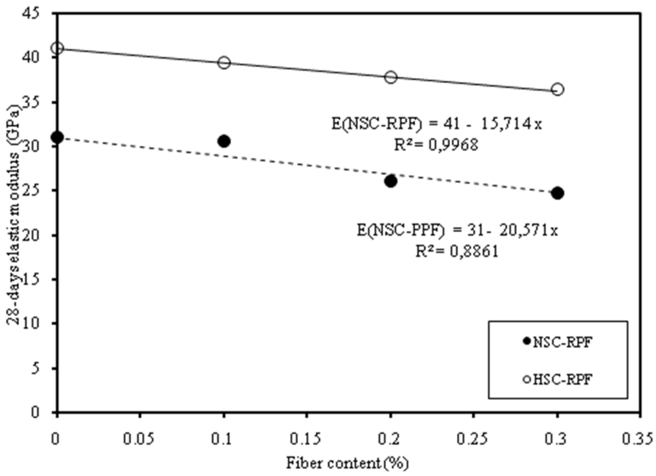

Fig. 4 Variation of elastic modulus for NSC and HSC according to fiber content type

may be due to lower aggregate content, because fibers were used as a replacement of coarse aggregates. Also, it was found that the elastic modulus slightly affected by the addition of polypropylene fiber (Altalabani *et al*. 2020, Faraj *et al*. 2019). Also, for concrete containing 1% of polypropylene fibers this modulus decreased by 28.3% compared with that of control concrete (Alwesabi *et al*. 2020); this decrease was attributed to the changes in concrete density.

By using the obtained results, it is easy to express the values of the modulus of elasticity as a function of the compressive strength S_c and the incorporated fiber ratio RPF. This relationship can be written as follows

$$E_c = 11\ 000 \left(\frac{S_c}{10}\right)^{0.82+0.016\ RPF^2} \quad ; \qquad R^2 = 0.975 \tag{3}$$

3.4 Permeable pore void

In addition to mechanical properties, the effect of fiber addition on permeable pore void of NSC and HSC was evaluated according to the ASTM C642 (2013) specifications. Test results obtained with RPF mixtures are presented in Fig. 5. The incorporation of RPF in concrete resulted in a slight increase of the permeable pore void, regardless the class of concrete (NSC and HSC). A linear increase in permeable pore void is clear on the results of Fig. 5. Each 0.1% RPF fiber used in the mixture leads to an increase of 2.9% and 5.2% permeable pore void in the NSC and HSC mixture respectively. The incorporation of 0.10%, 0.20%, and 0.30% of RPF resulted in approximately 2.3%, 4.5%, and 6.2% higher permeable pore void of NSC, respectively. In the case of HSC mixtures, higher permeable porosity of 4.5%, 9.8%, and 13% was observed. These results are in agreement with available literature (Meddah and Bencheikh 2009). The incorporation of synthetic fibers in cement-based matrix may disturb the granular skeleton and creates more void space in the composite material. In the same way, some results (Zeyad *et al*. 2020, Faraj *et al*. 2019) found that polypropylene fibers led to increased porosity at all test ages. This result may be attributed to polypropylene fibers effect on workability; which led to additional pores on the concrete mix as compared with the control concrete.

The permeability is one of the intrinsic concrete properties which controls its durability and it is

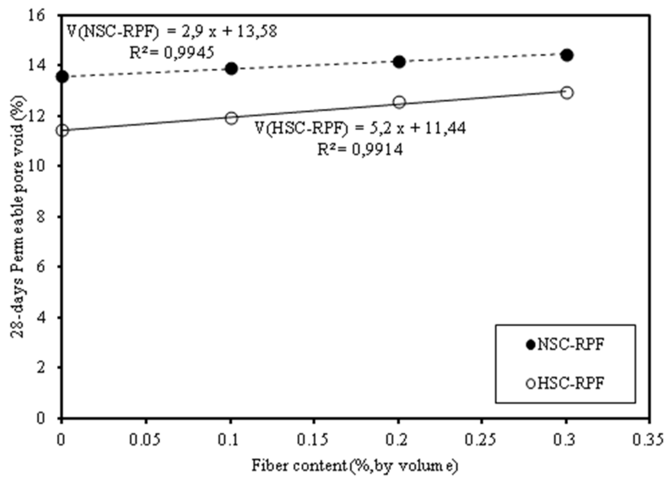

Fig. 5 Variation of permeable pore void for NSC and HSC according to RPF fiber content

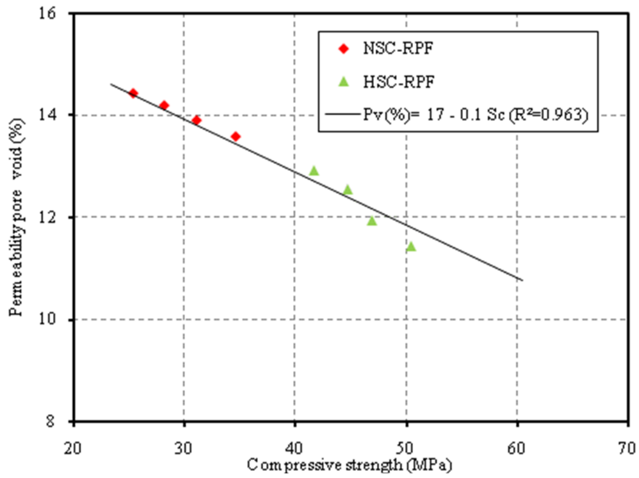

Fig. 6 Relationship between compressive strength and permeability pore void for concrete with RPF fibers

linked to its compressive strength. By correlating these two experimental results, a linear relationship has been found which indicates that high strength concrete is the least porous and has high durablily. By testing several relationships, we obtained the expression of Eq. (4), where each 10 MPa compressive strength decreases the permeabile pore void by 1%. Fig. 6 illustrates this variation where the correlation seems perfect.

$$p\ (\%) = 17 - 0.1S_c; \qquad R^2 = 0.963 \tag{4}$$

3.5 Drying shrinkage

Drying shrinkage of concrete depends on relative humidity, temperature, type and quantity of binder, air content, w/c, ratio of fine to coarse aggregate, type and volume of aggregate, curing

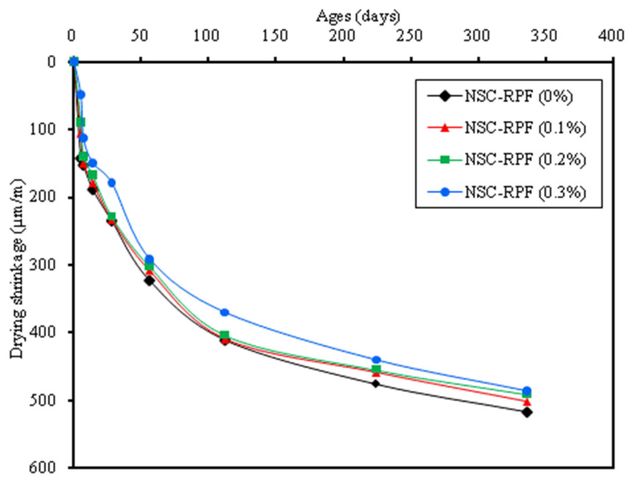

Fig. 7 Variation of drying shrinkage for NSC mixture according to RPF fiber content

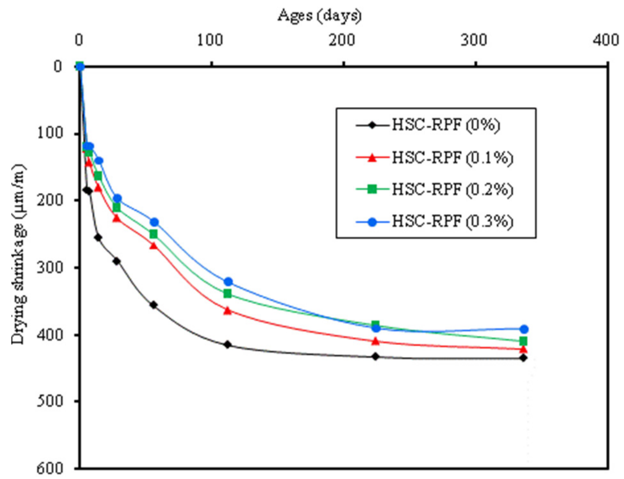

Fig. 8 Variation of drying shrinkage for HSC mixture according to RPF fiber content

method and duration, etc. (ACI-209 2009, Kovler and Zhutovsky 2006). Synthetic fibers are introduced in concrete to improve plastic shrinkage and reduce the cracking potential of concrete. Optimum dosages of fiber that allow a trade-off between mechanical properties, and plastic shrinkage should be incorporated to avoid strength reduction while improving shrinkage resistance. Drying shrinkage of NSC and HSC mixture incorporating 0.10%, 0.20% and 0.30%, RPF, by volume, was measured up to 336 days of drying in accordance with ASTM C157 (2017). For each mixture type and fiber content, three prisms have been prepared and used to follow the evolution of shrinkage. The drying shrinkage measurements for NSC and HSC are illustrated in Figs. 7 and 8, respectively.

As can be observed, NSC mixtures developed relatively higher shrinkage that HSC mixtures. This is may be mainly due to the relatively higher porosity of NSC mixture compared to that of HSC. The incorporation of RPF resulted in lower drying shrinkage by 6% to 10% depending on

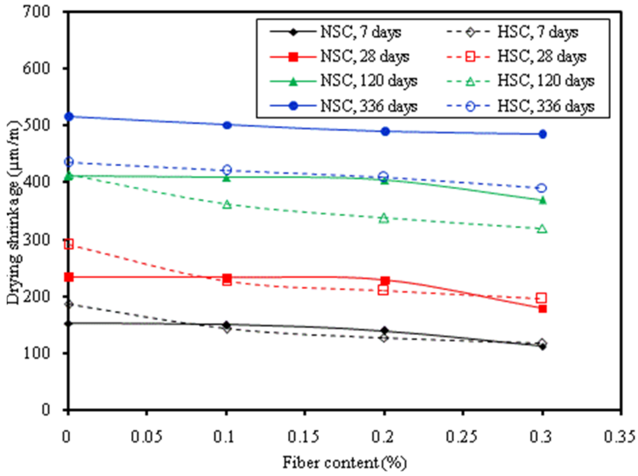

Fig. 9 Variation of drying shrinkage for HSC and NSC mixtures according to fiber content

the strength of concrete. For example, the use of a lower fiber volume of 0.10% reduced drying shrinkage by approximately 3% for both concrete types. The use of 0.30% RPF resulted in reducing drying shrinkage of NSC by approximately 6%. In the case of HSC, higher reduction of 10% wasobserved. It is expected that this reduction may probably lower the total crack area, maximum crack width and the number of cracks. Also, reduction in drying shrinkage results in eliminating the need for joints in a concrete slab. This can reduce the overall maintenance cost and improve structural performance. Further studies will be carried to investigate these issues and evaluate the effectiveness of using higher dosages and their impact on mechanical properties and shrinkage of concrete.

Comparison of the drying shrinkage results between ordinary concrete and high performance concrete illustrated in Fig. 9, shows that at early age the type of concrete has no effect on shrinkage produced whatever the RPF fiber content. After 28 days, HSC has a markedly reduced shrinkage compared to NSC. This reduction reaches 20% at later age. This is due to the flexural strength development and to the adhesion generated between the paste and RPF fibers surfaces which creates strain strength and prevents shrinkage development. In the same way, Bertelsen *et al.* (2019) show that the RPF fibers were also effective in controlling surface cracking and reducing shrinkage deformation as long as their dosage is high. 2% of RPF fibers leads to similar shrinkage deformation as 0.2% of PPF fibers. The effectiveness of PPF in reducing drying shrinkage can be associated with the fiber orientation and poor compaction of the mixture. The more the fibers are aligned in the direction of shrinkage the lower the shrinkage (Zhong and Zhang 2020, Geok *et al.* 2020).

4. Conclusions

The effect of a recycled polypropylene fiber (RPF) on mechanical properties and drying shrinkage of normal and high-strength concrete types is evaluated. Test results demonstrate the usefulness of using RPF in concrete to contribute in reducing the environmental impact of woven bags and develop cost-effective and sustainable construction materials. Based on the test results presented in this paper, the following conclusions can be pointed out:

(1) The incorporation of recycled polypropylene fiber (RPF) is shown to exhibit similar behavior than the commercial polypropylene fiber. Both types of fiber resulted in a 10% to 20% reduction in compressive and flexural strength properties.
(2) The use of 0.30% of RPF resulted in 25% increase of flexural strength for HSC compared to 9.5% obtained with PPF. For NSC 10% increase was observed for both fiber types.
(3) The use of RPF at volume content of 0.20% and 0.30% reduced the elastic moduli of NSC by 16% and 20%, respectively. In the case of HSC mixtures, this reduction is about 10%. This is due to lower elastic properties of RPF and smooth surface compared to PPF type.
(4) The addition of RPF at 0.30% reduced the drying shrinkage by 6% and 10% of normal and high-strength concrete types, respectively.
(5) Normal and high strength concrete types incorporating RPF showed relatively higher permeable pore void. In the case of 0.30% RPF, the increase is about 6.2 and 13% for NSC and HSC types, respectively.
(6) Results of this study can help to promote the use of RPF to reduce the environmental impact of woven bags, and develop less expensive and sustainable construction materials.

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