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EFFECT OF STRAPPING STRAPS WASTE FIBERS ON FRESH AND HARDENED PROPERTIES OF CONCRETE

Rachid DJEBIEN[1*], Rachid KEBOUT[1], Mouloud BELACHIA[2]

Abstract

Faced with the increasingly growing need for construction material resources and the strict requirements and conditions for preserving the environment, it has become necessary and relevant to study all possibilities and opportunities for the recycling and valorization of industrial waste and by-products in the construction field. Strapping straps is a product used to bundle and transport goods and construction materials. After its use, it is considered as waste. The objective of this experimental work is to study the possibility of reusing the strapping strap waste as fibers in the production of fiber-reinforced concrete. For this purpose, three families of concrete were composed using strapping strap fibers, steel fibers, and polypropylene fibers, which were introduced into a concrete composition by volumetric substitution (0.4%, 0.8% and 1.2%) of aggregates. The fresh properties were evaluated through slump, density and air content tests. Hardened properties were investigated using the compressive and flexural strengths, pulse velocity, dynamic elastic modulus, and water absorption tests. The results obtained showed that strapping strap waste fibers significantly improve the mechanical properties of fiber-reinforced concrete and have a behavior similar to that of steel fibers. The optimum rates of strapping strap fibers were 0.4% and 1.2% for compressive and flexural strengths respectively. Compared to polypropylene fibers, the strapping strap fibers were found to be more efficient and led to a gradual increase in flexural strength with an increase in the strapping strap fibers. The results obtained also showed that the increase in strapping strap fiber content gradually increased the water absorption of fiber-reinforced concrete.

Address

[1] LMGHU Laboratory, Department of Civil Engineering, University 20 August 1955, Skikda, Algeria.

[2] Dept. of Civil Engineering and Hydraulic, University 08 May 1945, Guelma, Algeria.

* ***Corresponding author:*** dj_rachid_08@yahoo.fr

Key words

- Strapping straps,
- Fibers,
- Reinforced concrete,
- Properties.

1 INTRODUCTION

Fiber-reinforced concrete (FRC) is a composite material in which fibers are incorporated. Unlike traditional reinforcements, the fibers are distributed throughout the concrete mass. FRC exhibits better flexural and tensile strength (Tiberti et al., 2014; Cuenca et al., 2015) and more ductile behavior (Alabduljabbar et al., 2019; Ghamari et al., 2020). Fibers used in concrete also permit higher impact energy absorption (Chalioris, 2013, Rahmani et al., 2014) and higher dynamic strength

(Deepa Raj et al., 2020; Abid et al., 2020). The fibers used make the concrete suitable for various applications such as offshore and military infrastructures (Abid et al., 2020), airports pavements (Aydin, 2007, Watanabe et al., 2010), bridge decks, channel lining and industrial flooring (Ding et al., 2011; Slater et al., 2012; Abid et al., 2020). The efficiency of adding fibers to a concrete composition depends on the type, geometry, content, and orientation of the fibers (Bentur and Mindess, 1990; Buratti et al., 2011). Several types of fibers are used in FRC technology. Steel and polypropylene fibers are the most commonly used in FRC compositions (Sorelli et al., 2006; Caratelli et al., 2011). FRC containing steel fibers (SF) found their first applications in the 1960s. Polymeric fibers were marketed in the 1970s, glass fibers in the 1980s, and carbon fibers in the 1990s (Abid et al., 2020).

Over the decades, various studies have demonstrated the use of fibers in concrete technology. Aydin (2007) used up 2% of SF in self-compacting concrete (SCC) compositions. He found that SF decreased the workability and increased the compressive and tensile strengths of SCC. Similar results were obtained by Alabduljabbar et al. (2019), who added that SF improved the segregation resistance and mechanical properties of SCC with an optimum rate equal to 2%. With 2% of SF, the compressive strength and splitting strength increased by 13.38% and 91.44% respectively at 90 days. Akcay and Tasdemir (2012) reported that the main factor concerning the ability to flow of SCC containing SF was the geometry of the fibers. Khaloo et al. (2014) found that both the workability and the compressive strength of SCC containing SF decreased, but the splitting tensile and flexural strengths tended to increase. The addition of 2% SF decreased the compressive strength by 18.60% and increased the tensile strength by 28.50%. Iqbal et al. (2015) reported that the flexural and tensile strength of SCC containing SF were significantly improved. They also reported that there was no significant impact of SF on the compressive strength and elastic modulus. Nagarkar et al. (1987) observed that the compressive and flexural strengths of steel fiber-reinforced concrete (SFRC) increased by 13 and 40% when 0.5% of SF were used. Olivito and Zuccarello (2010) reported that the failure mode of FRC considerably changed from fragile to ductile when SF were used. They also reported that the ductility and tenacity of FRC increased when the fiber length and content increased. A similar trend was observed by Tadepalli et al. (2013). Bentur and Mindess (1990) reported that the effect of fibers on the mechanical properties of FRC depended on the load transfer process from the matrix to the fibers and the bridging effect across the cracks. Banthia et al. (1996) reported that concrete containing 0.5% of SF exhibited an increase in fracture energy by 2.4 times. Shah and Naaman (1976) added that the flexural and tensile strengths of FRC containing SF increased by two to three times. De Figueiredo and Ceccato (2015) found that the use of fibers in FRC composition decreased its workability. This decrease was more pronounced when SF were used (Hughes and Fattuhi, 1976; Bayasi and Soroushian, 1992; Guerini et al., 2018). Song and Hwang (2004) reported that the compressive strength of FRC increased by up to 1.5% of SF content. With further additions, the compressive strength tended to decrease. Ma et al. (2013) showed an improvement in compressive strength, splitting tensile strength, and flexural toughness when 2% SF was used. Additionally, they found that the improvement in splitting tensile strength was more pronounced.

On the other hand, Alhozaimy et al. (1996) reported that polypropylene fibers (PPF) had no significant effects on the compressive and flexural strengths of FRC. They also found that PPF significantly affected the flexural toughness. With 0.3% PPF, the flexural toughness and failure impact resistance increased by 387% and 90% respectively. Similar results were found by Song et al. (2005). However, Kakooei et al. (2012) reported that the presence of PPF in a concrete composition improved the compressive strength and electrical resistivity and reduced the permeability and volume variations of FRC with an optimum rate equal to 1.50 kg/m^3. Han et al. (2005) reported that the PPF did not significantly affect the bulk density and air content of FRC. They also reported that PPF slightly increased the compressive strength and significantly improved the spalling strength. Mazaheripour et al. (2011) observed that PPF decreased the workability of SCC, increased the flexural and splitting tensile strengths, and did not affect the compressive strength and elastic modulus. A similar trend was also observed by Yap et al. (2013). Mindess and Vondran (1988) reported that the use of 0.5% PPF led to increasing the bending load by 40% and double the fracture energy. Afroughsabet and Ozbakkaloglu (2015) reported that the improvement in mechanical strength was more pronounced when the SF were used compared to the PPF. They also observed that both the SF and PPF reduced the electrical resistivity of FRC. Similar results were found by Mastali and Dalvand (2017). Guerini et al. (2018) found that the use of fibers in a concrete composition slightly increased the air content. They also showed that PPF adversely affected the air content more than SF.

2 SIGNIFICANCE OF RESEARCH

Ordinary concrete exhibits low tensile strength and poor ductility. To resolve these handicaps, previous studies have broached the effect of fibers such as SF and PPF on the properties of concrete. However, much less is known about the properties and behavior of concrete containing strapping straps waste fiber (SSF). The strapping strap are made of polyethylene terephthalate (PET) and used for both manual and automatic applications to strengthen packaging. After its use, the strapping strap is discarded as waste, thereby causing environmental problems (disposal and aesthetic problems, clogging the waterways). The objective of this study is to investigate the effect of SSF considered as waste on fresh and hardened properties of FRC and compare it with commonly available fibers used in reinforcing concrete. For this purpose, SF, PPF and SSF were used to carry out this experimental investigation. The valorization of SSF in the composition of concrete not only aims to improve some properties of concrete, but also to produce a ‘green’ concrete. On the other hand, concrete is one of the most used materials in the world because of its high strength, low cost and durability (Afroughsabet and Ozbakkaloglu, 2015; Mazloom and Mirzamohammadi, 2019; Alwesabi et al., 2020). When waste can be used in the composition of concrete, then a large quantity of this waste can be eliminated from the environment.

3 MATERIALS USED

3.1 Cement

Ordinary Portland cement (OPC) Type CEMI 42.5 with a specific gravity of 3.15 g/cm^3 and specific surface of 3600 cm^2/g produced by the Hadjar Elsoud Cement Plant (Eastern Algeria) was used in this experimental work. The chemical properties of OPC are illustrated in Table 1.

Tab. 1 *Chemical properties of OPC*

Chemical properties (%)	OPC
CaO	61.38
Al_2O_3	5.18
Fe_2O_3	3.34
SiO_2	19.97
MgO	0.99
Na2O	0.20
K2O	0.44
Cl-	0.19
SO_3	2.90
Loss in ignition	3.71
C_4AF	10.25
C_3A	8.08
C_3S	58.45
C_2S	13.24

3.2 Aggregates

Coarse aggregate (CA) from natural crushed limestone aggregate was used for all the mixtures. Two types of gravel (G1 and G2) were used with maximal nominal sizes of 16 mm and 25 mm respectively. The specific density of these gravels is 2.65 g/cm^3. Moreover, fine aggregate (FA) from natural crushed limestone sand (CS) with a specific density of 2.61 g/cm^3 and a water absorption of 0.80 % was used. The CS had a maximum particle size of 4.00 mm. The fineness modulus, which was obtained from the sieve analysis, was equal to 2.91. The aggregate properties are illustrated in Table 2.

Tab. 2 *Properties of aggregates*

Properties	FA	CA
Specific density (g/cm^3)	2.61	2.65
Sand equivalent (%)	70	-
Fineness modulus	2.91	-
Methylene blue value	0.50	-
Micro-deval test (%)	-	14.40
Los Angeles test (%)	-	20.10

The particle distributions of FA and CA are presented in Fig 1.

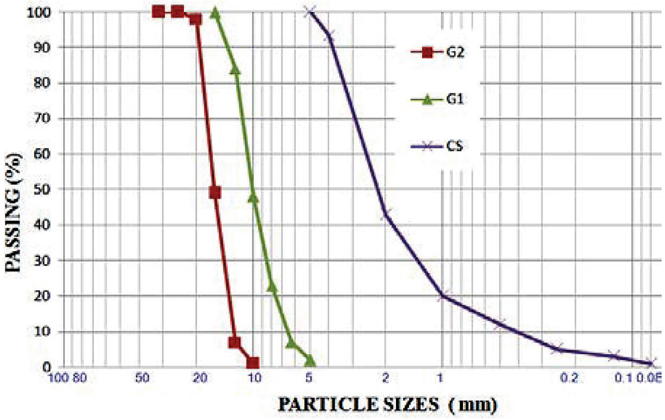

Fig. 1 *Particle size distribution of aggregates used*

3.3 Fibers

SF with a 50 mm length and a diameter of 0.95 mm, PPF with a 12 mm length, and SSF with a 50 mm were used in this study. The SSF were derived from shredding strapping strap waste. The properties of the fibers are provided in Table 3.

Tab. 3 *Properties of fibers*

Properties	SF	PPF	SSF
Length (mm)	50	12	50
Color	Grey	White	Green
Diameter (µm)	95	25	95
Density (g/cm^3)	7.85	0.91	1.27

Fig 2 shows the SSF used for the composition of the FRC mixtures.

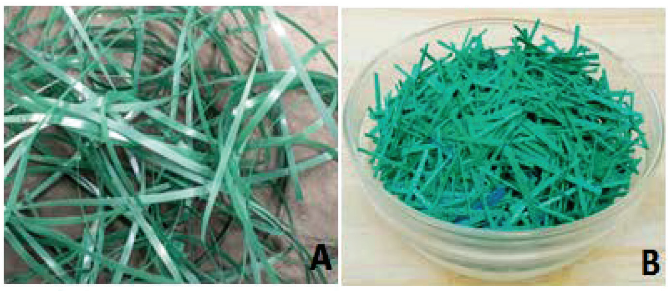

Fig. 2 *SSF used in FRC composition: A) Strapping strap waste before shredding; B) SSF after shredding*

3.4 Admixture

To obtain the desired workability for the control concrete mixture, the superplasticizer (SP) used was Polyflow SR 5400, which is based on polycarboxylate with a brown color, a density of 1.07, and a PH of 5.

4 MIXING PROCEDURE AND TESTING METHODS

The FRC mix proportions are provided in Table 4. The Dreux-Gorisse method was used for the composition of the concrete mixtures. In the table, the SP content is presented in volume and is taken as equal to 0.8% of the total weight of OPC. The dosages of OPC, water and SP are kept constant. SSF, SF and PPF have been introduced into the concrete composition by volumetric substitution (0.4%, 0.8% and 1.2%) of the aggregates.

To ensure a good degree of homogeneity for all the mixtures, the solid constituents were mixed for three minutes. The water and SP were then mixed with the other constituents for three more minutes. The mixture was then introduced and vibrated into standard steel molds according to NF P18-405. Cube samples (150×150×150 mm) were used for the compressive strength, pulse velocity, and water absorption by immersion tests. Prismatic samples (70×70×280 mm) were used for the flexural strength (Fig 3).

Fig. 3 *Flexural strength test*

After 24 hours of molding, the samples were demolded and conserved in water for curing (at 23 °C and 100% relative humidity) until their testing ages. The fresh and hardened properties tests were performed according to the standards mentioned in Table 5. For each test, the results obtained represent the average of three readings.

Tab. 5 *Tests carried out*

Tests	Standards
Workability (Slump test)	NF EN 12350-2
Bulk density	NF EN 12350-6
Air content	NF EN12350-7
Compressive strength	NF EN 12390-3
Flexural strength	NF EN 12390-5
Pulse velocity	NF EN 12504-4
Water absorption	NBN B15-215

5 DISCUSSION OF RESULTS

5.1 Workability

The results of the workability test are shown in Fig 4 for specimens containing different fiber types and volume fractions. As can be seen, the workability of FRC decreases with the increasing fiber content regardless of the type of fibers. It can also be seen that the PPF significantly affects the work-ability values of FRC compared to SF and SSF. SF and SSF. The workability decreases from 210 to 80 mm when the PPF content increases from 0 to 1.2%. While the workability decreases by 10 and 35 mm only when 1.2% of SF and SSF are used respectively. It can also be seen that with 0.4% of SF and SSF, the decrease in workability remains insignificant. The decrease in the workability of FRC was also observed

Tab. 4 *Composition of FRC mixtures for 1 m^3*

	G2 (kg/m^3)	G1 (kg/m^3)	FA (kg/m^3)	OPC (kg/m^3)	SP (L/m^3)	Water (L/m^3)	SF (kg/m^3)	PPF (kg/m^3)	SSF (kg/m^3)
C0	306	612	695.08	350	3	147	0	0	0
SFRC0.4	303.10	606.30	688.14	350	3	147	24	0	0
SFRC0.8	299.99	599.91	681.17	350	3	147	48	0	0
SFRC1.2	296.89	593.79	674.23	350	3	147	72	0	0
PFRC0.4	303.10	606.30	688.14	350	3	147	0	7.28	0
PFRC0.8	299.99	599.91	681.17	350	3	147	0	14.56	0
PFRC1.2	296.89	593.79	674.23	350	3	147	0	21.84	0
SSFRC0.4	303.10	606.30	688.14	350	3	147	0	0	5.08
SSFRC0.8	299.99	599.91	681.17	350	3	147	0	0	10.18
SSFRC1.2	296.89	593.79	674.23	350	3	147	0	0	15.26

by (Abhishek et al., 2015; Anandaraj et al., 2019; Awoyera et al., 2021), and was attributed to the fact that the fibers have a low water-wetting ability and therefore increase the friction between the concrete constituents and make the concrete flow more difficult. Ali et al. (2020) recommended the use of plasticizers to compensate for the negative effect of the fibers on FRC workability. De Figueiredo and Ceccato (2015) also recommended the reduction of the maximum size of the aggregate used and increasing the amount of mortar in the concrete composition.

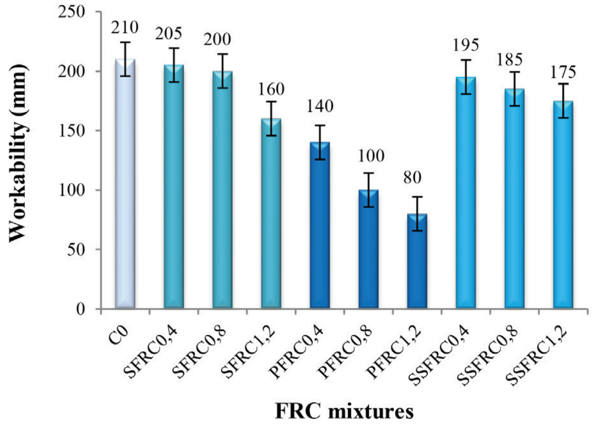

Fig. 4 *Workability of FRC mixtures*

5.2 Bulk density

Fig 5 shows the bulk density values of the FRC mixtures. Unlike SF, the increase in PPF and SSF contents gradually decreased the density of FRC. This decrease is more pronounced when PPF are used. The bulk density decreased by 4.14% and 8.29% when 1.2% of SSF and PPF are used respectively, while with the same content of SF, the bulk density of FRC increased by 1.02%. The bulk density of concrete mainly depends on the density of its components (Han et al., 2005). PPF and SSF have lower densities than the other components, and the addition of these fibers leads to decreasing the bulk density of the concrete. On the other hand, SF have higher density than those of the other constituents; therefore, FRC containing SF have higher bulk densities.

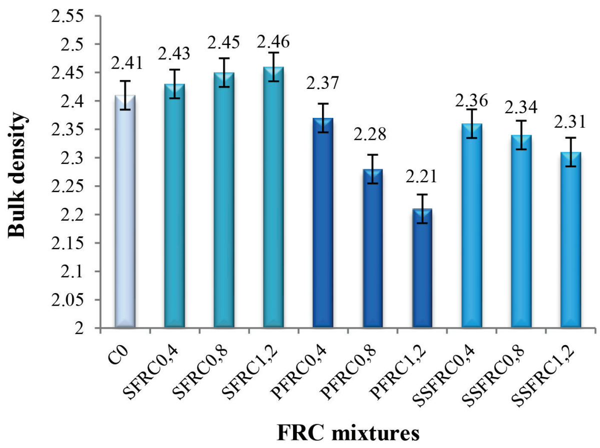

Fig. 5 *Bulk density of FRC mixtures*

5.3 Air content

The air content values are illustrated in Fig 6. As shown, increasing the fiber content in FRC composition leads to an increase in the air content values. It can also be seen that SF significantly increases the air content values compared to PPF and SSF. The air content increases by 69.69% when 1.2% of SF is used, while the air content increases by 27.27% and 15.15% only when the same content of PPF and SSF is used. A similar trend was observed by (Hughes and Fattuhi, 1976; Guerini et al., 2018), who explained this increase by the reduction in the workability of FRC, which promotes the trapping of air bubbles inside the concrete. It should be noted that with 0.4% of fibers, the increase in air content does not exceed 10.60%.

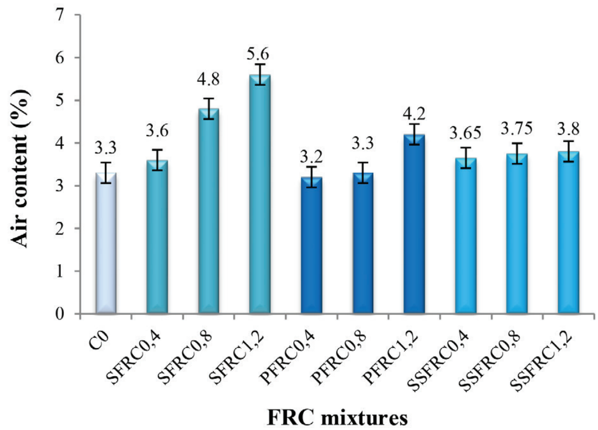

Fig. 6 *Air content of FRC mixtures*

5.4 Compressive strength

The variations in the compressive strength of FRC containing different types and volumes of fibers at 7, 28 and 56 days are illustrated in Fig 7. Except for the concrete containing the PPF, all the concrete mixtures show an improvement in compressive strength with an optimal rate of 0.4%. With further additions, the compressive strength tends to decrease. The FRC containing 0.4% of SSF exhibits an improvement in compressive strength by 16.02, 5.23, and 4.07% at 7, 28, and 56 days respectively, while the FRC containing 0.4% of SF shows the maximum increase in compressive strength at 56 days by 7.56%. The improvement in the compressive strength of FRC was shown in several studies (Yan et al., 1999; Afroughsabet and Ozbakkaloglu, 2015; Sabri and Walid, 2020), which explained it by the fact that the fibers have an ability to slow the expansion of cracks, change their direction and delay the rate growth in cracks. The increase in the compressive strength of FRC containing SF is also attributed to the higher mechanical properties of SF compared to those of SSF and PPF (Afroughsabet and Ozbakkaloglu, 2015). However, all FRC containing PPF exhibits a gradual reduction in compressive strength. This reduction is more pronounced when the PPF rate exceeds 0.8%. With 1.2% of PPF, the compressive strength drops by 22.51, 34.93, and 44.71% at 7, 28, and 56 days. The reduction in the compressive strength of FRC containing SF and PPF was shown by (Alhozaimy et al.,1996;

Iqbal et al., 2015; Khaloo et al., 2014; Marthong, 2019), who attributed this reduction to the decrease in workability and the increase in air content with increasing the fiber content in FRC composition. Additionally, when the fiber content exceeds the optimal rate, more initial voids and a lack of adhesion between the cement paste and fibers will be created and lead to a decrease in the compressive strength.

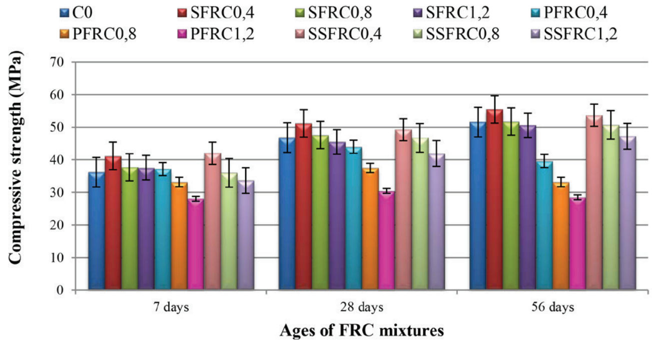

Fig. 7 *Compressive strength of FRC mixtures*

5.5 Ultrasonic pulse velocity

Fig 8 displays the ultrasonic pulse velocity of the FRC mixtures at 28 days. The control mixtures had an ultrasonic pulse velocity of 4.84 km/s, whereas the FRC containing 0.4% of SSF and SF had 4.93 and 4.88 km/s with an increase of 1.86 and 0.83% respectively. With a further addition of SSF and SF above 0.4%, the ultrasonic pulse velocity tends to gradually decrease. It can also be seen that the incorporation of PPF negatively affects the ultrasonic pulse velocity values. The FRC containing 0.4 and 0.8% of PPF showed a decrease in ultrasonic pulse velocity by 3.72 and 7.85% respectively. The decrease in the ultrasonic pulse velocity values is explained by the increase in the internal porosity of the FRC containing a higher fiber content. It should be noted that according to ASTM C597, which considers concrete to be of a very good quality when the ultrasonic pulse velocity is higher than 4.50 km/s, all the FRC mixtures are classified to have a very good quality.

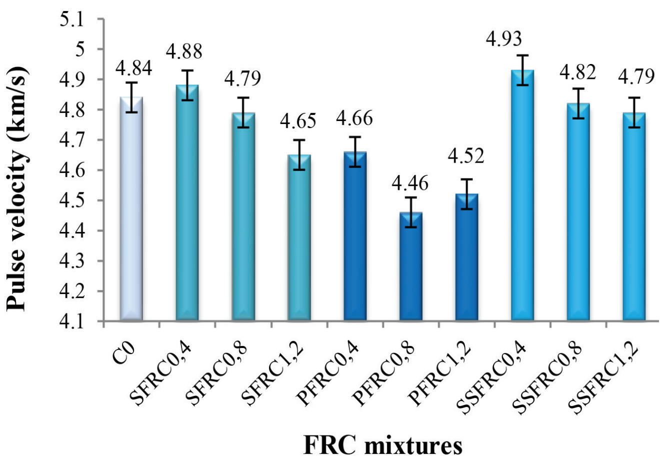

Fig. 8 *Ultrasonic pulse velocity of FRC mixtures*

5.6 Flexural strength

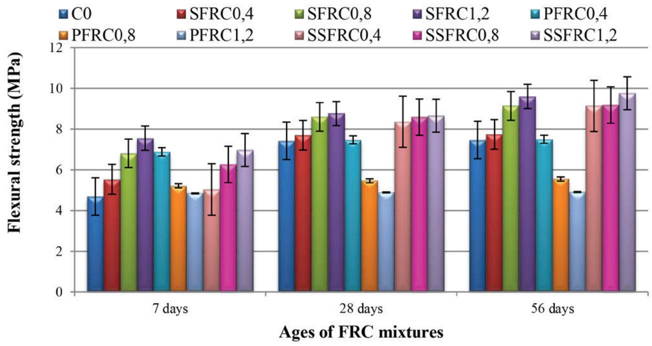

Fig. 9 *Flexural strength of FRC mixtures*

The results of the flexural strength test are illustrated in Fig 9. The addition of SF and SSF in the FRC composition has a beneficial effect on the flexural strength. The flexural strength of the FRC gradually increases with an increase in the SF and SSF fiber content. At 56 days, the flexural strength increased from 7.46 to 9.60 and 9.76 MPa when 1.2% of SF and SSF were used respectively, i.e., an increase of 28.68 and 30.83% respectively. For FRC containing PPF, the improvement in the flexural strength is more pronounced at an early age and is shown when the PPF rate does not exceed 0.4%. With 0.4% of PPF, the flexural strength increases by 46.69, 0.54, and 0.4% at 7, 28, and 56 days respectively. The enhancement of concrete's flexural strength was attributed to the arresting and bridging effects played by the fibers on the crack (Khaloo et al., 2014; Li et al., 2018; Marthong, 2019; Sabri and Walid, 2020). When the fiber content exceeds the optimal rate, the workability decreases and more initial voids and weak interfaces are produced, thereby causing flexural strength reductions (Song et al., 2005; Huang et al., 2016). Afroughsabet and Ozbakkaloglu (2015) also reported that the improvement in the flexural strength of FRC containing SF is attributed to the higher tensile strength and elastic modulus of SF.

5.8 Water absorption

The water absorption represents the permeable pore volumes and their connectivity inside the concrete. It constitutes a major factor that affects the durability (Nagarkar et al., 1987). The water absorption values of FRC mixtures are presented in Fig 10. As shown, all the FRC mixtures have water absorption values higher than that of the control concrete. The water absorption gradually increases with increasing the fiber content regardless of the type of fibers. The water absorption of the control concrete was 2.60%, while the maximum water absorption of the FRC was 3.80, 4.46, and 3.80% for the FRC containing SF, PPF, and SSF respectively. It can also be shown that the FRC containing 1.2% of PPF exhibits the maximum increase in the water absorption value by 71.53% compared to that of the control concrete. The increase in the water absorption values is attributed to a) the increase in the air content of FRC in the fresh state, which increases the air content in the hardened state b) the reduction of the workability of FRC, in particular, FRC containing PPF, which promotes the creation of voids inside the FRC and facilitates the water penetration into FRC (Hughes and Fattuhi, 1976; Guerini et al., 2018). According to (CEB-FIP, 1989), concrete having a water absorption of less than 3%, between 3 to 5%, and higher than 5% can be classified as good, average, and poor quality. According to this classification, the FRC containing 0.4% of SSF exhibits its good quality, whereas all the other FRC mixtures have an average quality.

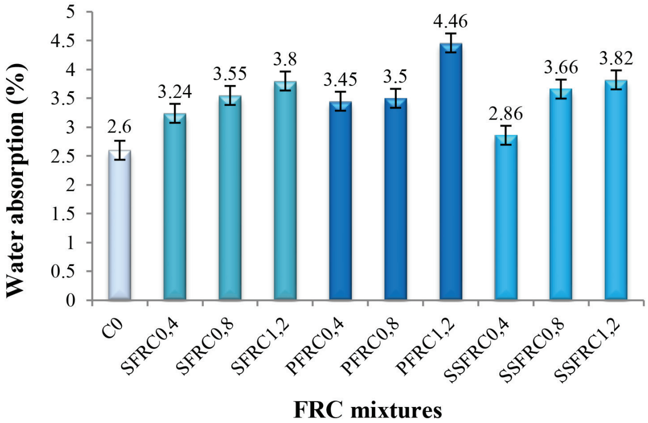

Fig. 10 *Water absorption of FRC mixtures*

5.9 Dynamic elastic modulus

The dynamic elastic modulus of the concrete mixtures was evaluated using the following equation (Uysal and Yilmaz, 2011):

$$E = 10^5 \times V^2 \times \left(\frac{\Delta}{g}\right) \quad (1)$$

E is the dynamic elastic modulus (GPa); V is the ultrasonic pulse velocity (m/s); Δ is the bulk density of the concrete (kg/m^3); and g is the gravity acceleration (m/s^2).

As with the compressive strength, the dynamic elastic modulus increases with 0.4% of SF and SSF. With further additions, the dynamic elastic modulus tends to decrease (Fig 11). With 0.4% of fibers, the dynamic elastic modulus increases by 2.50 and 1.61% for SF and SSF respectively. This improvement is mainly due to the increase in the compressive strength values of FRC containing 0.4% SF and SSF and also to the higher mechanical properties of SF (Afroughsabet and Ozbakkaloglu , 2015) . However, all the FRC mixtures containing PPF exhibit a gradual decrease in the dynamic elastic modulus. A maximum decrease of 20.02% was shown with 1.2% of PPF. The reduction in the dynamic elastic modulus values is explained by the increase in the FRC porosity and the drop in the compressive strength with the increase in the fiber content.

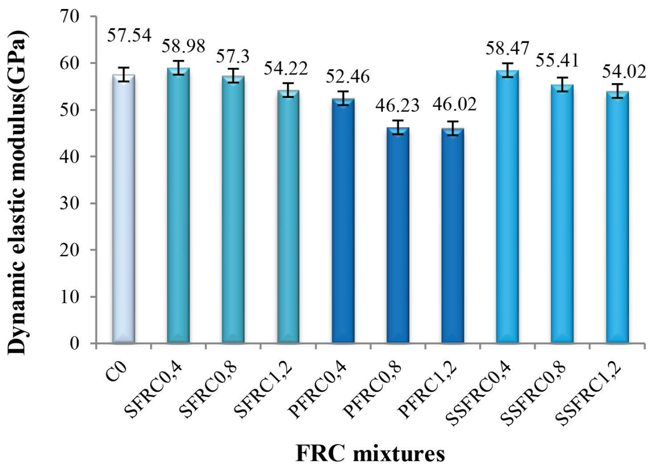

Fig. 11 *Dynamic elastic modulus of FRC mixtures*

6 CONCLUSIONS

In this study, the fresh and hardened properties of FRC containing SSF were investigated and compared with those of FRC containing SF and PF. Through this experimental work, the following conclusions can be drawn:

- As for all types of fibers, the incorporation of SSF in an FRC composition decreases the workability values. This decrease does not significantly alter the ability of the concrete to flow as long as the SSF content does not exceed 1.2%. The workability of FRC was found to be reduced by 16.66% when the SSF content reached 1.2%.
- Due to the lower density of SSF, the inclusion of SSF in an FRC composition reduces the bulk density values and makes FRC less dense than ordinary vibrated concrete and FRC containing SF. The introduction of SSF led to a gradual decrease in the bulk density, which reached 2.31 with 1.2% of SSF.
- The addition of SSF in the FRC composition increases the porosity and causes a gradual increase in water absorption in the hardened state and the air content in the fresh state.
- The FRC containing SSF has a behavior similar to that of the FRC containing SF. In fact, the addition of SSF in the FRC composition improves the mechanical properties of FRC with an optimal rate of 0.4% for the compressive strength and dynamic elastic modulus and 1.2% for flexural strength. This improvement is due to the arresting and bridging effects that the SSF plays on cracks.

In addition to the ecological interest coming from the valorization of SSF waste, this study showed promise as to the technical interest in of the introduction of this waste in the composition of FRC. From the results obtained, SSF can be considered as fibers having a mechanical behavior similar to SF. Future research should be established to study the durability and behavior of FRC containing SSF towards different chemical attacks. Also, it could be very interesting to study the ductility and energy absorption capacity for beams made of FRC containing SSF.

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