Advanced Topics in Mechanics of Materials, Structures and Construction - AToMech1-2023 Materials Research Forum LLC
Materials Research Proceedings 31 (2023) 155-164 https://doi.org/10.21741/9781644902592-17

Performance of self-compacting concrete based on fine recycled concrete aggregate incorporating polyethylene terephtalate fibers

Bayah Meriem[1,2,a*], Debieb Farid[1,b]

[1]LME Laboratory, Faculty of Technology, UniversityYahia Fares of Medea, Algeria

[2]Civil Engineering departement, Faculty of Technology, UniversitySaad Dahleb of Blida1, Algeria

[a]meriembayah@gmail.com, [b]debieb.farid@univ-medea.dz

Keywords: Self-Compacting Concrete, Fiber-Reinforced Concrete, Recycled Concrete, Polyethylene Terephthalate Fiber, Mechanical Resistance, Fresh Properties

Abstract. This experimental research aims to investigate the effect of adding polyethylene terephthalate plastic fibers (PETF) on the behavior of recycled self-compacting concrete (RSCC) based on recycled fine concrete aggregates (RFCA). Twenty RSCC mixes were made for this study. RFCA was obtained from the laboratory demolition of a moderate concrete slab and substituted by natural fine aggregates (NFA) at various mass fractions (0%, 25%, 50%, 75%, and 100%). Furthermore, four volumetric fractions (V_f) of plastic fibers (0.3%, 0.5%, 1%, and 1.2%) were added and sorted from plastic bottle recycling. The properties of the fresh and hardened new composite (RSCC made with PETF and RFCA contents) are analyzed and compared. The results showed that the mechanical performances of RSCC in terms of flexural strength and elasticity modulus were improved, where the compressive strength decreased with an increase in the V_f content of PETF and RFCA. The incorporation of 100% RFCA combined with 1.2% of PETF can enhance both flexural strength and modulus of elasticity of concrete up to 9% and 24%. This type of concrete can be recommended for structural repair applications.

Introduction

Concrete has become the most material of construction used in the world, which is made with a high number of natural resources (aggregates). Therefore the consumption of the natural resources in concrete creates environmental and economic problems and also effect the reduction of these natural resources protection[1-2]. But currently, the using of waste in construction has become a necessary solution to countries' environmental and economic problems, particularly in third-world countries[3].In this context, reflection on the search for new concretes capable of solving the economic and technical problems encountered in the construction industry begins. These materials include self-compacting concrete (SCC), it can be flowing freely in narrow gaps between reinforcement bars and consolidate under its weight without any external vibration with superior deformability and high resistance to segregation[4-5]. Also, there are many studies show that we can use different waste (construction and/or demolition waste (CDW), glass, plastic) to replace those aggregates with the coarse and/or fine natural aggregates (NA) in concrete design[6-7].
The CDW is considered the waste most widely used in the concrete in form of aggregates. There are many studies on the effect of recycled concrete aggregates (RCA) on the properties of concrete [8]. In this among, Sasanipour et al [9]. Assessed the effect contents 25%, 50%, 75%, and 100% of fine and coarse RCA as a partial substitute of natural coarse and fine aggregates (NCA, NFA) on the mechanical properties (compressive, flexural strengths and ultrasonic pulse velocity) of SCC. They found that the partial use of RCA and RFCA as a substitute for NCA decreased the mechanical behavior of specimens by 43% and 52% respectively for those mixes by replacing 75%. Silva et al [10] also showed that the increase in the replacement of RCA led to a decrease in

the mechanical properties of concrete this can be attributed to the porosity of the mortar adhering to RCA, their high water absorption, and the formation of the interface transition zones (ITZ)[11]. The researchers were significantly investigating; they can produce the concrete with RCA by controlling the water-cement ratio, proper use of chemical and mineral admixtures as well as appropriate preparation methods before using RCA[12]. The influence of fine RCA on the fresh properties and the microstructural characteristics of mortar were studied by Carro-López [13]. The obtained results of this study showed that the porosity increased with the percentage of fine RCA. And also Nieto et al [14] determined the durability (water absorption and carbonatation) and mechanical characteristics of SCC produced by coarse RCA as a substitute for natural coarse aggregates (NCA). For this aim, NCA was replaced by coarse RCA at 0%, 20%, 40%, 60%, 80%, and 100% and water-cement ratios of 0.45, 0.50, and 0.55. They found that using up to 20% coarse RCA has little influence on the characteristics of the RSCC.

According to the literature, the using of RCA decreased the mechanical properties of concrete. Therefore, the researchers are working to improve the behavior of RCA concrete by using additional materials. A research study found that using fiber in concrete, enhanced the mechanical characteristic of concrete[15]. Aslani et al.[16].Assessed the impact of polypropylene fiber (PPF) and steel fiber (SF) on the fresh property and hardened mechanical of recycled aggregates self-compacting concrete (RASCC). A total of RCA replacement contents of NCA were considered 100% in terms of mass. In addition, PPF was added at 0%, 0.1%, 0.15%, 0.2%, and 0.25% in terms of volume, and SF at 0.25, 0.5, 0.75, and 1% in terms of volume. They found that the addition of fibers leads to enhancing the tensile strength of concrete.

The using of RCA as a partial replacement of both NCA and NFA in previous studies has indicated a negative effect on the workability and mechanical behavior of SCC. On the other hand, adding fibers in terms of volume in the concrete can improve the mechanical properties of concrete. The main objective of this study is to investigate the mechanical properties of SCC incorporated with up to 25%, 50%, 75%, and 100% of RFCA and containing different volume fractions of PETF.

Experimental program

Materials

An industrial Portland cement type CEM II/B 42.5N product by Lafarge-M'sila Company in Algeria, with a density of 3.08 kg/m^3 and a specific surface of 3900 cm^2/g, was used for all concrete mixtures. It is one of the most frequent cement for concrete structures in Algeria. **Table1** shows the chemical composition of this cement. Two types of NFA and RFCA (0/4 mm) obtained from the demolition of moderate concrete slab made in the laboratory are used. The NFA is partially replaced by various fractions (25%, 50%, 75%, and 100%) of RFCA. Two types of NCA (3/8 and 8/15 mm) are used. The chemical composition and characteristics of coarse and fine aggregate are shown in Table1, 2.

Table1.*Chemical composition of fine natural, recycled fine concrete aggregates and cementitious.*

Composition(%)	SiO_2	CaO	CO_2	Fe_2O_3	Al_2O_3	MgO	Na_2O	K_2O	SO_3
Cement	15.96	62.17	11.46	2.75	3.75	1.33	0.12	0.52	2.30
NFA	92.86	0.37	0.64	0.25	2.52	0.13	0.04	1.01	0.30
RFCA	9.58	49.40	38.76	0.91	2.43	1.54	-	0.20	2.75

***Table2**. Physical properties of used aggregates.*

Type of Aggregate	Maximum Size (mm)	Apparent density (g/ cm^3)	Bulk density (g/cm^3)	Water absorption (%)	Fineness Modulus	Los Angeles Abrasion (%)
CNA	15	1.52	2.61	0.59	-	26.5
CNA	8	1.50	2.63	0.79	-	27.5
NFA	4	1.59	2.65	0.65	2.24	-
RFCA	4	1.24	2.40	8.5	3.01	-

The used PETF in this research was produced by recycling waste plastic bottles. The physical and mechanical properties of this fiber are presented in Table 3. Therefore, we used PETF at four volumetric percentages of 0.3%, 0.5%, 1%, and 1.2%. Superplasticizer is based on Polycarboxylates which significantly improves the properties of concrete. It is made by Granitex-NP Company in Algeria.

***Table 3.** Main properties of used PET fiber.*

Length (mm)	Diameter (mm)	Elongation to break (%)	Density (20 ◦C) (g/cm^3)	Tensile strength (MPa)	Young's modulus (GPa)
30	0.44	53	0.690	383	7.17

Concrete mixes design

We created twenty concrete mixtures for this study, which are shown in Table 4. Three steps of mixing are involved in the creation of SCC mixes. The cement and aggregates were first briefly mixed for 30 seconds. Following the addition of 70% of the mixing water, the mixture was mixed for 1 minute. It was then mixed for a minute with the remaining 30% of the superplasticizer-containing water. This procedure continued for another 5 minutes before coming to an abrupt halt for 2 minutes. Before discharge, the SCC was mixed once more for 30 seconds to ensure uniformity of mixtures.

***Table 4.** Concrete mixes design (kg/m^3).*

Specimens	Cement	NFA	RFCA	NCA	PETF	SP	W/B
Control mix	483.69	922.43	-	750.04	-	4.60	0.4
25RFCA-0PETF	483.69	691.82	230.60	750.04	-	4.60	0.4
25RFCA-0.3PETF	483.69	691.82	230.60	750.04	2.07	4.69	0.4
25RFCA-0.5PETF	483.69	691.82	230.60	750.04	3.45	4.69	0.4
25RFCA-1PETF	483.69	691.82	230.60	750.04	6.9	4.84	0.4
25RFCA-1.2PETF	483.69	691.82	230.60	750.04	8.28	4.84	0.4
50RFCA-0PETF	483.69	461.21	461.21	750.04	-	4.60	0.4
50RFCA-0.3PETF	483.69	461.21	461.21	750.04	2.07	4.69	0.4
50RFCA-0.5PETF	483.69	461.21	461.21	750.04	3.45	4.69	0.4
50RFCA-1PETF	483.69	461.21	461.21	750.04	6.9	4.84	0.4
50RFCA-1.2PETF	483.69	461.21	461.21	750.04	8.28	4.84	0.4
75RFCA-0PETF	483.69	230.60	691.82	750.04	-	4.60	0.4
75RFCA-0.3PETF	483.69	230.60	691.82	750.04	2.07	4.69	0.4
75RFCA-0.5PETF	483.69	230.60	691.82	750.04	3.45	4.69	0.4
75RFCA-1PETF	483.69	230.60	691.82	750.04	6.9	4.84	0.4
75RFCA-1.2PETF	483.69	230.60	691.82	750.04	8.28	4.84	0.4

100RFCA-0PETF	483.69	-	922.43	750.04	-	4.60	0.4
100RFCA-0.3PETF	483.69	-	922.43	750.04	2.07	4.69	0.4
100RFCA-0.5PETF	483.69	-	922.43	750.04	3.45	4.69	0.4
100RFCA-1PETF	483.69	-	922.43	750.04	6.9	4.84	0.4
100RFCA-1.2PETF	483.69	-	922.43	750.04	8.28	4.84	0.4

Testing procedures

The fresh concrete state is the main property of SCC in this study, it is descript the filling ability, passing ability, and stability of self-compacting concrete is measured at different tests:

- The slump flow diameter (EN 12350-8)[17];
- The V-funnel flow time (EN 12350-9) [17];
- The L-box height ration (EN 12350-10)[18];
- The sieve stability (EN 12350-11) [19].

The compressive strength and flexural strength were measured at 28 and 90 days. For each mixture, three cubic specimens 100×100×100 mm were used to measure compressive strength, according to EN 12390-3[20], the flexural strength was tested under three-point flexural load by using three prismatic samples 70×70×280 mm according to EN 12390-5[21]. The static modulus of elasticity was determined by using cylindrical specimens of 100×200 mm at the curing age of 90 days according ASTM C469-02[22].

Results and discussion

Fresh properties

The results from the slump flow test are shown in Fig1.(a), and all mixtures indicated the best deformability in the slump flow diameter between 767.5 and 650mm and compliance with the EFNARC recommendation[23].The replacement of RFCA presents a remarkable reduction in the diameter of diffusion of SCC. The reduction in the slump flow diameter for RFCA75%, and RFCA100% compared to NFA was 8.15% and 10.09% respectively. This reduction in the workability is attributed to its specific surface and also due to its high water absorption of RFCA compared to that of natural aggregates[13]. The analysis of the results also shows the use of the PETF which presented a less decrease in the diameter of all mixtures of RSCC which contained 0.3% and 0.5% of PETF compared to those with the volume 1% and 1.2% of fibers, this was due to the difference in the dosage of SP, and also can be attributed to the reason for the large specific surface area of these fibers[24].

Fig1.(b) shows the time results of the (V-Funnel) test. We observe from these resultsV-Funnel time that all SCC mixtures values are acceptable by the EFNARC recommendations[23]. It can be concluded that the replacement of NFA by RFCA increases the flow time of RSCC compared to the reference mixture, which is in the range of 2 and 6 seconds, The mixture contained 100% RFCA shows a high plastic viscosity that could result in a loss of flow capacity property and this is due to the powder content and the increase in the specific surface area of RFCA[10]. According to Fig1.(b), we observed that the addition in PETF increases the flow time (V-Funnel) of RSCC mixes compared to the SCC reference, but still the recorded flow times that respond to the properties of the SCC by the increase in SP dosage, which showed the best filling ability without any sign of blocking. The reason for this increment is the decrease in the thickness of the surrounding aggregate layer (cement paste) and more friction between the particles and fibers which leads to an increase the viscosity of the concrete mixture[16].

The Fig1.(c) showed the ratio of H2/H1 in the L-box test can be taken as an indicator of the ability to pass SCC. According to the recommendation of the EFNARC[23],this ratio should not be less than 0.8 to ensure an adequate capacity of passage of the SCC. The substitution of NFA by RFCA resulted in a reduction of H2/H1 measured in this study. The reduction rate ranged from about 2% with 25% RFCA to 13% with 100% RFCA substitution. this reduction can due to the high values of water absorption of RFCA compared with natural aggregates. It was also noted that the present of PETF in the mixtures of RSCC, which gives a small reduction of H2/H1 between the two volume increments of fibres (about 0.1% to 0.2%), and the mix with 100%RFCA+1.2%PETF showed a severe reduction in the passing ability.

Fig1.(D) shows the influence of PETF and the replacement of RFCA on the sieve stability of SCC. These results showed that all the mixtures of SCC containing only RFCA have a segregation rate between 6-13% which indicates good stability,while these percentages decreased for the mixes incorporating RFCA and PETF together . In the end, they noticed that there was a decrease in the segregation ratio of RSCC by the PETF addition. This result could be attributed to the large amount of fins in the particulate of RFCA, and due to the higher water absorption rate of these aggregates [11] ,and we can due to the high amount of fiber in the mix.

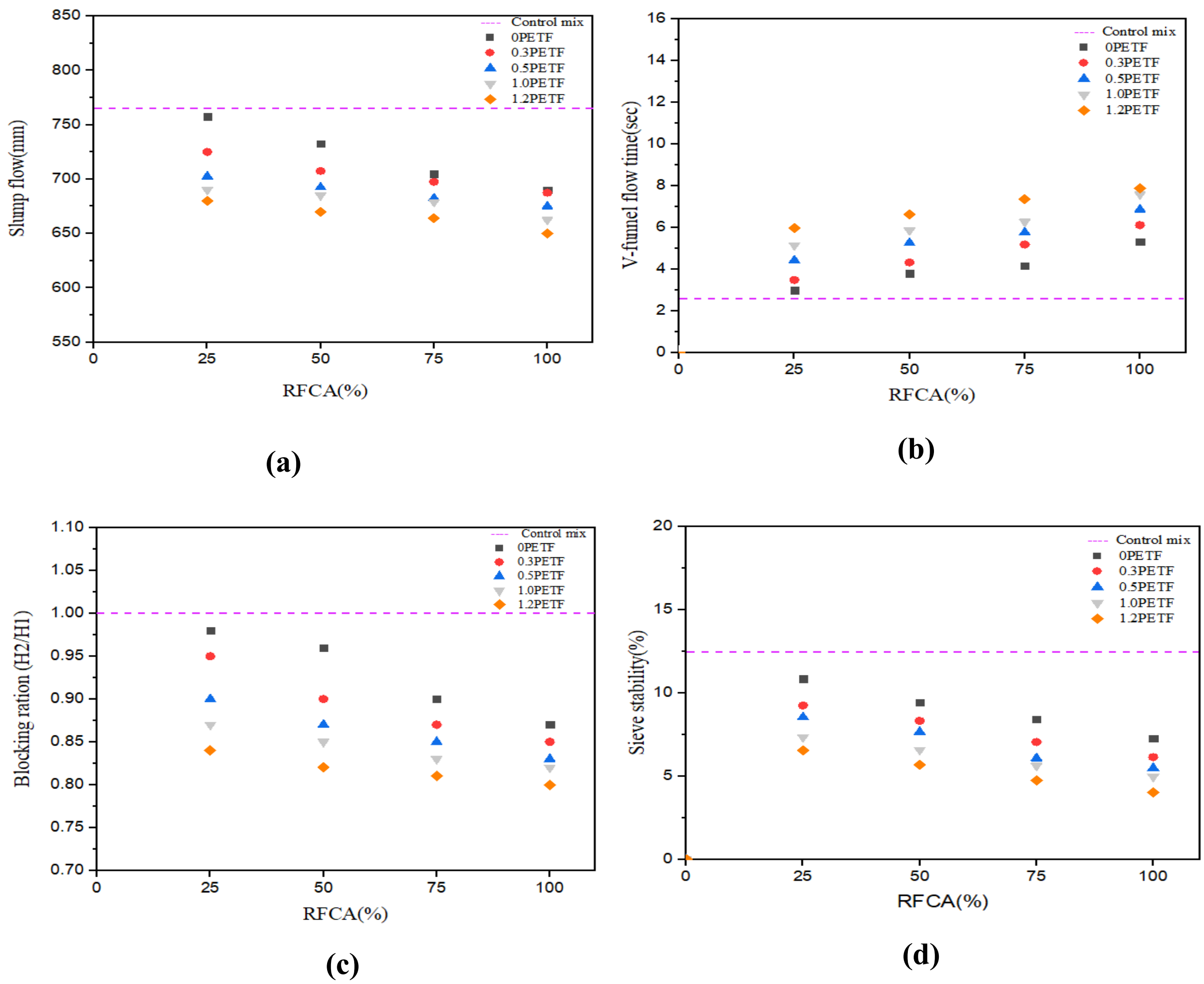

Fig. 1. *Influence of RFCA and PETF on: (a) slump flow;(b) V-funnel flow time; (c) L-box ratio;(D) sieve stability.*

Materials Research Proceedings 31 (2023) 155-164 https://doi.org/10.21741/9781644902592-17

Mechanical properties

Compressive strength

Fig.2 shows the effect of PETF and RFCA in the SCC mixture on the compressive strength at 28, and 90 days after curing. As shown in this figure, the compressive strength results of SCC increase with the age of curring and also showed there was a reduction in the compressive strength with the use of RFCA at all ages of hardening. At 28 days, the compressive strength of the control mix is 48.11 Mpa. On the replacement of NFA with the RFCA, the compressive strength decreased about 1.59%, 3.93 %,6.80%,and 9.33% for the mixtures made with 25%,50%,75%, and 100% of RFCA respectively. This reduction in the compressive strength with the presence of RFCA on the SCC is due to the intrinsic properties of RFCA and attributed to the higher absorption capacity of the adhered mortar in the RFCA, which provides worse adhesión between the cement paste and the RFCA compared with NFA[1]. The addition of PETF in RSCC decreases compressive strength. The 90days compressive strength of RSCC containing PETF had a rate decreasing from 2%, 4%1% ,and 3% for mixtures 0.3 PETF+ 100 RFCA, 0.5 PETF+ 100 RFCA, 1 PETF+ 100 RFCA, and 1.2 PETF+ 100 RFCA. This reduction is explained by the bundling of fibers during mixing and casting. This assembly of fiber leads to grow a weak point in concrete between the area and the fiber surface and this area make microcracks and macrocracks caused by compression loading [25].

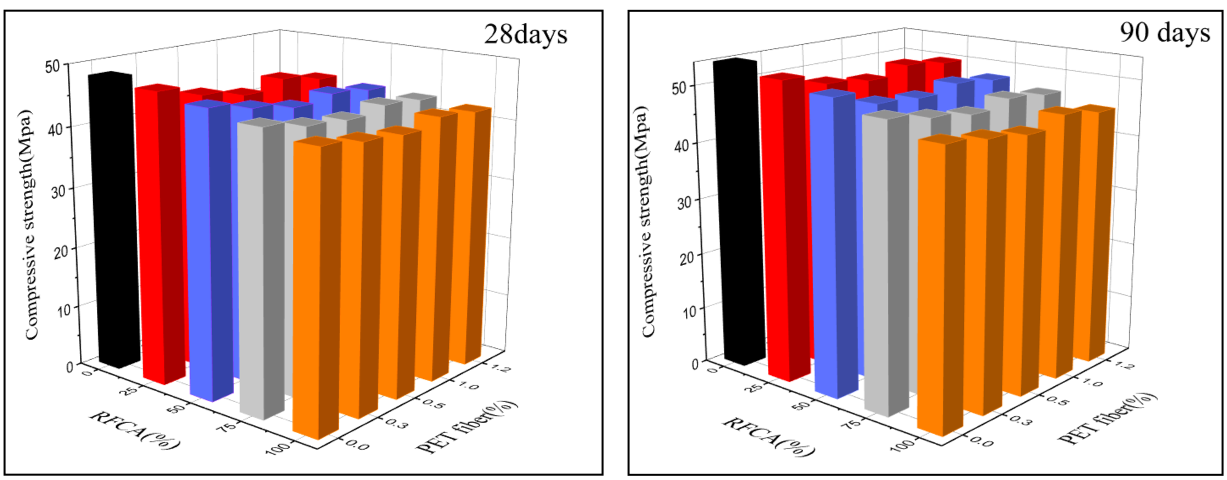

Fig.2. *Influence of RFCA and PETF on the compressive strength.*

Flexural strength
The flexural strength results of RFCA and PETF contents at 28 and 90 days after curing are illustrated in Fig.3. Similarly to compressive strengths, the flexural resistance was significantly decreased with using RFCA. Therefore, the flexural strength was decreased by 4%, 11%, 16% , and 20% when 25%, 50%, 75% and100% RFCA was used as a replacement for NFA, The same results we observed with Mahakavi et al.Previous studies showed that reduction can be due to the low strength of the mortar adhered to RCA [8] . However, Fig.3 showed also that adding PETF in the RSCC increase the flexural strength, the addition of 0.3, 0.5,1 and1.2% PETF with 100% RFCA improved this property respectively by 2%, 5%, 8% ,and 9% because the presence of fiber in the concrete enhances to fill the cracks during the occurrence of tensile stresses.

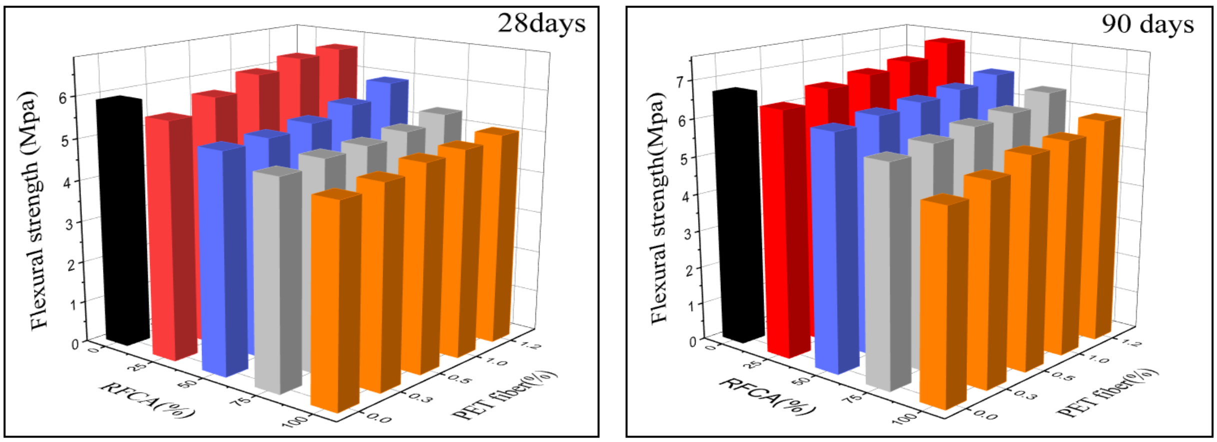

***Fig.3.** Influence of RFCA and PETF on the flexural strength.*

Modulusof elasticity
Fig.4 presents the effect of RFCA and PETF on the elastic modulus of all the SCC mixtures. Regarding this figure, the elastic modulus was decreased with an increase in RFCA contents. Therefore, in specimens without PET fiber, the elastic modulus was decreased by 5.01%, 7.41%, 14.10% ,and 19.30% when 25%, 50%, 75% ,and 100% RFCA were used as a substitute for NFA, respectively. The same reduction in the elastic modulus of concrete was shown by previous investigations[26].Conversely, this test was improved with the addition of PETF and the elastic modulus was further enhanced with an increase in PETF content. Additionally, the highest modulus elastic was obtained for all specimens with 1.2% PETF contents. Therefore, the addition of 0.3%, 0.5%, 1% ,and 1.2% PETF with 100% RFCA enhanced the modulus elasticity respectively by 11.40%, 13.29%, 17.21%, and 24.87%, in comparison with the control sample with 100% RFCA.

Microstructure analysis
Fig.5 (a), (b), (c), (d) presents the list of scanning electron microscopy (SEM) images for the different fractured surfaces of SCC with RFCA and PETF. The SEM images in fig.10(c) showed that the surface of 100% RFCA has a large number of pores areas and cracks in the interfacial transition zone (ITZ), which analyzes of porosity higher in this mixture. These areas (ITZ) consider the most easily damaged in the matrix due to the subjected internal stress, which is the main reason for the low strength of the sample (100% RFCA). Fig.5 (b) shows that the through cracks and the number of connected pores are not present in the 1.2 PETF matrix significantly. This may explain why the sample had a uniform and denser structure between the paste and fiber, which make a small decrease in the compressive strength. On the other hand, Fig 5. (d) presents weak points PETF in the sample with 100% of RFCA, so we observed some pores In the area between fiber and cement paste, this explains the weak adherent of fiber to cement paste in

concrete. It can be engendered by the rippling surface of PETF. Presence of the fibers in these samples trigger an increase in the strength of RFCA so that it doesn't break easily into two pieces when it is subjected to flexural or splitting tensile strength. It can be from the friction strength between the surfaces of fiber and cement paste around the fibers.

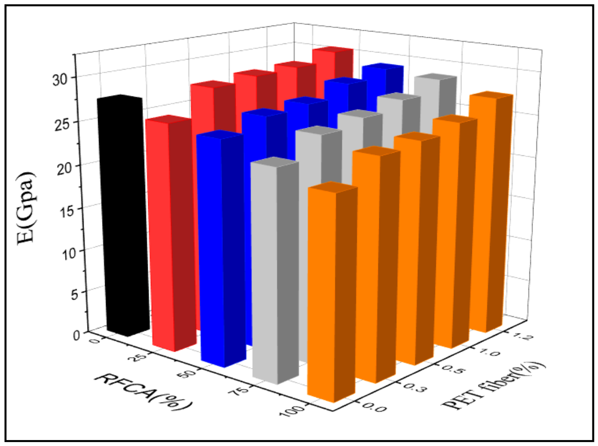

Fig.4. *Influence of RFCA and PETF on the modulus elastic.*

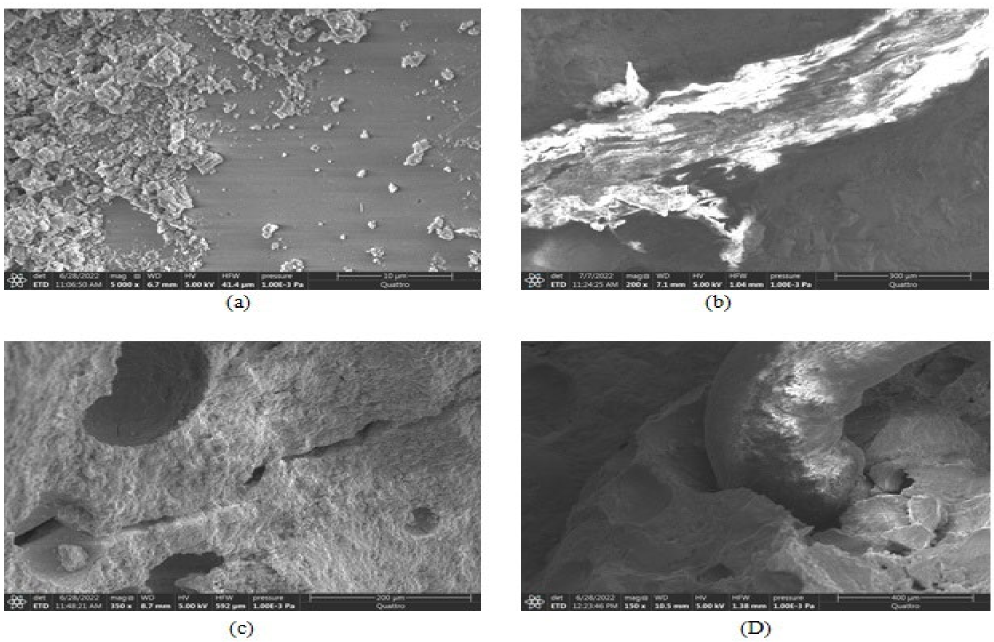

Fig. 5. *SEM images of typical specimens a) 0RFCA-0PETF, b) 0RFCA-1.2PETF, c) 100RFCA-0PETF and D) 100RFCA-1.2PETF.*

Conclusions

In this study, were investigated the effect of PETF and RFCA on the fresh property and mechanical properties in self-Compacting Concrete (SCC). This part of the study examined the use of RFCA as a replacement for NFA: 25%, 50%, 75%, and 100% in terms of mass, and were also the PETF added in the SCC at four volumetric percentages: 0.3%, 0.5%, 1% , and 1.2%. Additionally, were proposed to study the mechanical characteristics of RFCA concrete containing various PETF contents. According to the experimental results, the following conclusion can be drawn:

- The replacement of RFCA by the NFA and the adding PETF decrease the flowability of SCC, but this decreasing could be improved by using of low dosage of SP. The high-water absorption of RFCA and the specific surface of PETF are the main reason for this decrease in the flowability. Eventually, the RFCA and PETF have a negative effect on the fresh properties of SCC;

- The compressive strength of concrete was decreased with the use of RFCA as different partial replacement contents for NFA, and also the use of PETF decreased these test results of concrete, that the replacement of 25% and 50% of RFCA with NFA present a slight decrease. Adding 0.3%, 0.5%, 1%, and 1.2% PETF with the substituting 100% RFCA by NFA in the mixtures made a little drop in the compressive strength of the concrete. Therefore, these mixtures decreased by 2%, 3%,1% and 2% respectively;
- The flexural strengths and modulus elasticity of concrete containing different RFCA can be significantly enhanced with the use of PETF. Therefore, the replacement of RFCA by the NFA without PETF decreased the flexural strength by about 3.39%, 11.03%, 16.46%, and 20.54% for the mixtures 25%, 50%, 75%, and 100%, respectively. In addition, the simultaneous use of 100% RFCA with 0.3%, 0.5%, 1% and 1.2% PETF increased the flexural strength by 2.35%, 5.76%, 6.88%, and 8.76%, correspondingly.

References

[1] A. Karimipour and M. Edalati, “Influence of untreated coal and recycled aggregates on the mechanical properties of green concrete,” J. Clean. Prod., vol. 276, p. 124291, 2020, https://doi.org/10.1016/j.jclepro.2020.124291

[2] M. Ghalehnovi, A. Karimipour, A. Anvari, and J. de Brito, “Flexural strength enhancement of recycled aggregate concrete beams with steel fibre-reinforced concrete jacket,” Eng. Struct., vol. 240, no. February, p. 112325, 2021, https://doi.org/10.1016/j.engstruct.2021.112325

[3] A. Karimipour, M. Edalati, and J. de Brito, “Influence of magnetized water and water/cement ratio on the properties of untreated coal fine aggregates concrete,” Cem. Concr. Compos., vol. 122, no. February, p. 104121, 2021, https://doi.org/10.1016/j.cemconcomp.2021.104121

[4] S. Mahesh, “Self compacting concrete and its properties,” Int. J. Eng. Res. Appl., vol. 4, no. 8, pp. 72–80, 2014.

[5] M. Okamura, H; Ouchi, “Self Compacting Concrete - research paper,” Journal of Advanced Concrete Technology, vol. 1, no. 1. pp. 5–15, 2003.

[6] V. Revilla-cuesta, V. Ortega-lópez, M. Skaf, and J. Manuel, “Effect of fine recycled concrete aggregate on the mechanical behavior of self-compacting concrete,” vol. 263, 2020, https://doi.org/10.1016/j.conbuildmat.2020.120671

[7] A. A. Mohammed, I. I. Mohammed, and S. A. Mohammed, “Some properties of concrete with plastic aggregate derived from shredded PVC sheets,” Constr. Build. Mater., vol. 201, no. July, pp. 232–245, 2019, https://doi.org/10.1016/j.conbuildmat.2018.12.145

[8] F. Debieb, L. Courard, S. Kenai, and R. Degeimbre, “Mechanical and durability properties of concrete using contaminated recycled aggregates,” Cem. Concr. Compos., vol. 32, no. 6, pp. 421–426, 2010, https://doi.org/10.1016/j.cemconcomp.2010.03.004

[9] H. Sasanipour and F. Aslani, “Durability properties evaluation of self-compacting concrete prepared with waste fine and coarse recycled concrete aggregates,” Constr. Build. Mater., vol. 236, p. 117540, 2020, https://doi.org/10.1016/j.conbuildmat.2019.117540

[10] Y. F. Silva, R. A. Robayo, P. E. Mattey, and S. Delvasto, “Properties of self-compacting concrete on fresh and hardened with residue of masonry and recycled concrete,” Constr. Build. Mater., vol. 124, pp. 639–644, 2016, https://doi.org/10.1016/j.conbuildmat.2016.07.057

[11] O. K. Djelloul, B. Menadi, G. Wardeh, and S. Kenai, “Performance of self-compacting concrete made with coarse and fine recycled concrete aggregates and ground granulated blast-furnace slag,” Adv. Concr. Constr., vol. 6, no. 2, pp. 103–121, 2018,

https://doi.org/10.12989/acc.2018.6.2.103
[12] I. González-Taboada, B. González-Fonteboa, F. Martínez-Abella, and S. Seara-Paz, “Analysis of rheological behaviour of self-compacting concrete made with recycled aggregates,” Constr. Build. Mater., vol. 157, pp. 18–25, 2017, https://doi.org/10.1016/j.conbuildmat.2017.09.076
[13] D. Carro-López, B. González-Fonteboa, J. De Brito, F. Martínez-Abella, I. González-Taboada, and P. Silva, “Study of the rheology of self-compacting concrete with fine recycled concrete aggregates,” Constr. Build. Mater., vol. 96, pp. 491–501, 2015, https://doi.org/10.1016/j.conbuildmat.2015.08.091
[14] D. Nieto, E. Dapena, P. Alaejos, J. Olmedo, and D. Pérez, “Properties of Self-Compacting Concrete Prepared with Coarse Recycled Concrete Aggregates and Different Water:Cement Ratios,” J. Mater. Civ. Eng., vol. 31, no. 2, p. 04018376, 2019, https://doi.org/10.1061/(asce)mt.1943-5533.0002566
[15] I. Irki, F. Debieb, E. H. Kadri, O. Boukendakdji, M. Bentchikou, and H. Soualhi, “Effect of the length and the volume fraction of wavy steel fibers on the behavior of self-compacting concrete,” J. Adhes. Sci. Technol., vol. 31, no. 7, pp. 735–748, 2017, https://doi.org/10.1080/01694243.2016.1231394
[16] F. Aslani, L. Hou, S. Nejadi, J. Sun, and S. Abbasi, “Experimental analysis of fiber-reinforced recycled aggregate self-compacting concrete using waste recycled concrete aggregates, polypropylene, and steel fibers,” Struct. Concr., vol. 20, no. 5, pp. 1670–1683, 2019, https://doi.org/10.1002/suco.201800336
[17] BS EN 12350-8:2010, “BSI Standards Publication Testing fresh concrete,” Br. Stand., no. April, p. 18, 2010.
[18] N. F. EN, “12350–10, Novembre 2010,” Partie Bét. autoplaçant–essai à la boite en L.
[19] 2010 BS EN12350-11:, “BSI Standards Publication Testing fresh concrete Part 11: Self-compacting concrete -- sieve Segregation test,” BSI Stand. Publ., 2010.
[20] B. S. I. BSI, “12390-3 Testing hardened concrete Compressive strength of test specimens,” Aberdeen’s Concr. Constr., vol. 38, no. 10, 1993.
[21] British Standards Institute, “BS EN 12390-5:2009 Testing hardened concrete — Part 5: Flexural strength of test specimens,” BSI Stand. Publ., no. August, pp. 1–22, 2009.
[22] ASTM C469/C469M, “Standard Test Method for Static Modulus of Elasticity and Poisson’s Ratio of Concrete in Compression,” ASTM Stand. B., pp. 1–5, 2014, https://doi.org/10.1520/C0469
[23] P. and U. EFNARC The European Guidelines for Self-Compacting Concrete: Specification, “The European Guidelines for Self-Compacting Concrete: Specification, Production and Use,” Eur. Guidel. Self Compact. Concr., no. May, p. 68, 2005.
[24] S. Benimam, M. Bentchikou, F. Debieb, S. Kenai, and M. Guendouz, “Physical and mechanical properties of cement mortar with LLDPE powder and PET fiber wastes,” Adv. Concr. Constr., vol. 12, no. 6, pp. 461–467, 2021, https://doi.org/10.12989/acc.2021.12.6.461
[25] M. A. Samsudin et al., “Investigation on Polyethylene Terephthalate (PET) Waste Fiber Performances in Concrete Material,” vol. 2, no. 1, pp. 682–690, 2021.
[26] Y. Wang, H. Zhang, Y. Geng, Q. Wang, and S. Zhang, “Prediction of the elastic modulus and the splitting tensile strength of concrete incorporating both fine and coarse recycled aggregate,” Constr. Build. Mater., vol. 215, pp. 332–346, 2019, https://doi.org/10.1016/j.conbuildmat.2019.04.212