DURABILITY PERFORMANCE AND MECHANICAL BEHAVIOR OF PET FIBER REINFORCED RECYCLED FLUID CONCRETE

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Received: 06.11.2023 / Accepted: 30.11.2023 / Revised: 19.02.2024 / Available online: 31.05.2024

DOI: 10.2478/jaes-2024-0005

KEYWORDS: self-compacting concrete, recycled fine concrete aggregates, recycled polyethylene terephthalate fibers, reinforced material, resistance.

ABSTRACT

Many environmental problems can be attributed to various sources, such as the demolition of old buildings, waste from bricks, glass waste, among others, which are generated worldwide. This waste is converted and recycled as natural aggregate. On the other hand, a significant issue with concrete incorporating Recycled Concrete Aggregate (RCA) is its inferior properties compared to natural aggregate concrete. The subpar properties of RCA concrete can be enhanced by the addition of Fibers. This research examines the effects of polyethylene terephthalate fiber (RPETF) and recycled fine concrete aggregates (RFCA) on the mechanical properties and durability of self-compacting concrete (SCC). Three concrete families were created: one using RPETF alone, one using RFCA alone, and a third utilizing both RPETF and RFCA combined. The natural fine aggregates (NFA) were replaced with RFCA in increments of 25% from 0% to 100%. The results showed that the split tensile strengths of the mix of 100% RFCA and 1.2 % RPETF have improved over time by 28% compared to the mix with 100% RFCA alone. However, the inclusion of RPETF in SCC mixtures with varying amounts of RFCA resulted in reduced durability of the composite.

1. INTRODUCTION

The world consumes more than 6 billion cube meters of concrete each year in the construction industry (Wang et al. 2015). Concrete consists of 60% to 80% aggregates by volume and serves as the primary material in its composition. This high demand for concrete indicates a significant increase in material requirements, which are primarily fulfilled by exploiting natural resources. Simultaneously, approximately 900 million tons of construction and demolition waste (CDW) are generated in urban areas worldwide (Klee 2009; Mesboua et al. 2021). Given this substantial amount of CDW, effective control and management of waste have become critical issues for large urban centers (Güneyisi et al. 2016; Kemer et al. 2021; Aissa et al. 2022). In this context, the recycling and reuse of CDW as aggregates have emerged as necessary solutions to address environmental and economic challenges faced by countries.

In recent years, numerous studies have investigated the properties of concrete made with recycled concrete aggregates (RCA) (Nili, Sasanipour, and Aslani 2019; Debieb et al. 2009). The presence of old mortar adhered to the surface of RCA significantly impact the quality of these aggregates by reducing density, increasing water absorption, and lowering abrasion resistance. Consequently, the properties of hardened concrete, including compressive and tensile strength, elastic modulus, and durability, are adversely affected by this decline in quality (Silva et al. 2016). on the other hand, the workability of concrete is also influenced by the shape and texture of aggregate (Debieb et al. 2009).

The majority of the studies indicate that RCA have lower compressive strength and durability compared to concrete made with natural aggregates due to the inherent weakness of RCA (Toghroli et al. 2020).In a study by Behera et al.(2019). The use of RFCA in SCC with 50% and 100% replacement resulted in a reduction of compressive strength by 9.5% and 27.5% respectively. Additionally, an increase in the replacement of RFCA led

to a decrease in splitting tensile strength, flexural strength, and elastic modulus. However, it was observed that the 50% replacement ratio of RFCA had a lesser influence compared to mixes with 100% RFCA.

Tang et al. (2022). Investigated the replacement of recycled fine and coarse aggregates (RFCA, RCCA) in concrete, along with the addition of recycled powder as a partial replacement of cement at three different contents (10%-20%-30%). They assessed the impact of these replacements on the mechanical properties, specifically compressive and tensile strength, as well as the uniaxial compressive stress–strain relationship in the concrete. The findings revealed that the tensile strength results for RFCA and RCCA were comparable to those of natural aggregates (NA) after 28 days.

Zong et al.(2007) evaluated the mechanical properties and durability properties of recycled aggregate concrete (RAC), specifically focusing on coarse aggregates. The study indicated that the inclusion of RCA in RAC leads to an increase in water permeability, air permeability, and chloride ion penetration. This increase can be attributed to the high porosity of recycled aggregates (RA). On the other hand, several researchers have also worked on improving the mechanical and durability properties of RCA through various methods. These methods include the addition of admixture, increasing the amount of cement, removing adhered mortar, utilizing fiber, and strengthening adhered mortar (Dimitriou, Savva, and Petrou 2018).

Fiber reinforcement is a widely employed method to enhance the mechanical behavior of concrete. Previously, Toghroli et al. (2020) investigated the improvement of mechanical strength in mixes containing RCA by incorporating steel fiber (STF) and waste plastic fiber (WPF). Their findings revealed that the addition of STF and WPF enhanced both compressive and flexural strength, although WPF reinforcement exhibited inferior performance compared to STF reinforcement.

In another study, He et al.(2020)examined the effect of incorporating hybrid steel and polypropylene fibers on the mechanical properties of RCA. They demonstrated that the use of hybrid fibers improved the splitting tensile and flexural strength of RCA. Furthermore, Chakradhara et al. (2019)investigated the influence of different types of fibers on the mechanical properties of concrete containing 50% RCA. Their experimental results indicated that the presence of fibers significantly enhanced the mechanical properties of RCA bridging cracks and improved crack resistance.

According to the available literature, numerous studies have examined the combined use of RCA as aggregates and fiber reinforcement about the rheological and mechanical properties of concrete. Furthermore, there is a growing interest in understanding the durability aspect of RCA reinforced with recycled polyethylene terephthalate fiber (RPETF). In line with this objective, our study focuses on investigating the influence of different volumes of RPETF in the RFCA mixes while evaluating their mechanical properties and durability.

2. MATERIALS

2.1. Cement

In this study, we utilized type CEM II/B 42.5N cement, which was obtained from the Lafarge-M'sila company in Algeria. This particular cement has a compressive strength of 42.5 MPa at 28 days, a specific surface of 3900 cm^2/g, and a density of 3.08 kg/m3. Furthermore, the chemical composition of cement was determined using the X-ray fluorescence (XRF) technique, and Table 1 presents the detected chemical composition of cement.

2.2. Superplasticizer

The superplasticizer used in this study is based on Polycarboxylates, which is known to significantly improve the properties of concrete. The superplasticizer is produced by Granitex-NP Company in Algeria. It is available in liquid form and is typically dosed within the range of 0.5% to 2% by mass of powder. The specific gravity of the superplasticizer is 1.07, and it has a PH value of 6.

2.3. Aggregates

Dune sand, with a maximum size of 4 mm, was employed as NFA in this study. RFCA were utilized to replace NFA at varying levels of 0%, 25%, 50%, 75%, and 100% by weight. The RFCA was obtained by crushing slab concrete into small rocks, which were subsequently processed using a crusher machine to produce the desired aggregates. Additionally, Figures 1 and 2 illustrate a sample and the morphology of the fine aggregates used in the study. Two classes of gravel, namely G 3/8 and G 8/15, were employed as the coarse aggregate.



(a) (b)

Figure 1. Used aggregate in this study a) NFA and b) RFCA

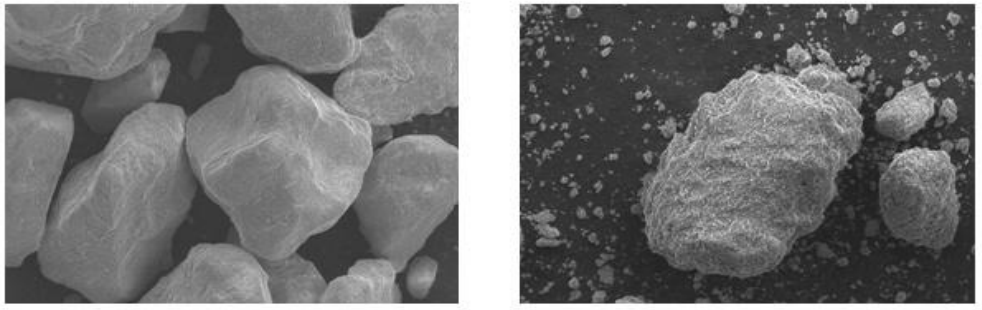


Figure 2. SEM morphology of (a) NFA (b) RFCA

The grading size distribution of the aggregates used is presented in Figure 3. Furthermore, Table 1 and Table 2 provide the physical and chemical properties of fine and coarse aggregates, respectively.

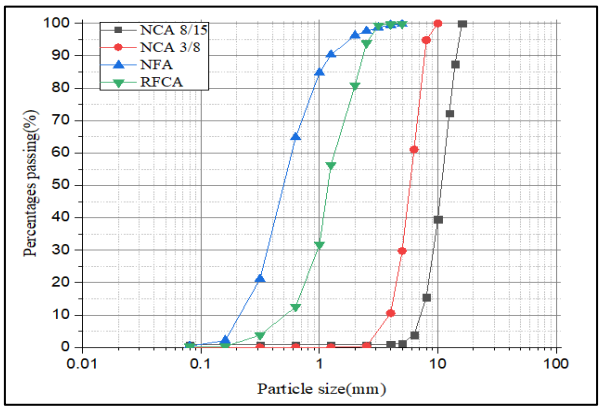


Figure 3. Particles size distribution of used aggregates

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

Table 1. Chemical composition of cement and fine 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	-

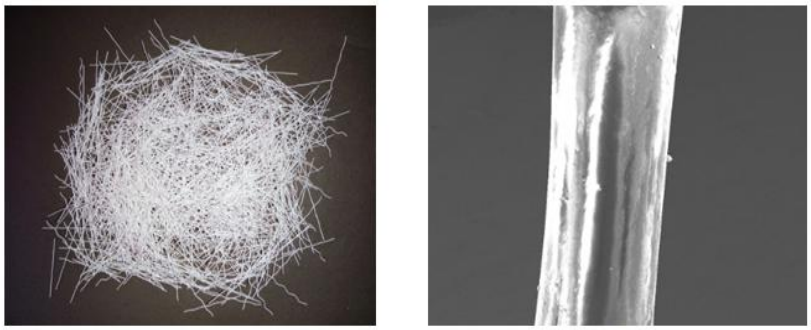
Table 2. Physical properties of used aggregates

2.4. Polyethylene terephthalate fibers

The recycled polyethylene terephthalate (RPET) fiber used in this research was produced by recycling waste plastic bottles. It was incorporated at four different volumetric percentages: 0.3%, 0.5%, 1%, and 1.2%. The physical and mechanical properties of RPETF are presented in Table 3. Furthermore, the morphology of the RPETF is depicted in Figure 4.

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

Table 3. Main properties of used RPETF



(a) (b)

Figure 4. RPET fibers: nature (a) and morphology (b)

3. CONCRETE MIXES DESIGN

In this study, a total of 25 mixtures were produced to examine the combination RPETF and RFCA on the mechanical properties and durability of self-compacting concrete (SCC). Three different concrete families were produced; the first family of mixes contained NFA with varying ratios of RPETF. In the second family of mixes, the NFA was replaced by RFCA in increments of 25% from 0% to 100% without the addition of RPETF. The third family of mixes involved a combination of RFCA inclusion and the addition of RPETF at the same ratios to the mix. The details of all SCC mix proportions can be found in Table 4. The results of the fresh properties of these mixtures are presented in Table 5.

	Specimens	Cement	NFA	RFCA	NCA	RPETF	SP	W/B
Series I	0RFCA-0RPETF	483.69	922.43	-	750.04	-	4.60	0.4
	0RFCA-0.3RPETF	483.69	922.43	-	750.04	2.07	4.69	0.4
	0RFCA-0.5RPETF	483.69	922.43	-	750.04	3.45	4.69	0.4
	0RFCA-1RPETF	483.69	922.43	-	750.04	6.9	4.84	0.4
	0RFCA-1.2RPETF	483.69	922.43	-	750.04	8.28	4.84	0.4
Series II	25RFCA-0RPETF	483.69	691.82	230.60	750.04	-	4.60	0.4
	25RFCA-0.3RPETF	483.69	691.82	230.60	750.04	2.07	4.69	0.4
	25RFCA-0.5RPETF	483.69	691.82	230.60	750.04	3.45	4.69	0.4
	25RFCA-1RPETF	483.69	691.82	230.60	750.04	6.9	4.84	0.4
	25RFCA-1.2RPETF	483.69	691.82	230.60	750.04	8.28	4.84	0.4
Series III	50RFCA-0RPETF	483.69	461.21	461.21	750.04	-	4.60	0.4
	50RFCA-0.3RPETF	483.69	461.21	461.21	750.04	2.07	4.69	0.4
	50RFCA-0.5RPETF	483.69	461.21	461.21	750.04	3.45	4.69	0.4
	50RFCA-1RPETF	483.69	461.21	461.21	750.04	6.9	4.84	0.4
	50RFCA-1.2RPETF	483.69	461.21	461.21	750.04	8.28	4.84	0.4
Series IV	75RFCA-0RPETF	483.69	230.60	691.82	750.04	-	4.60	0.4
	75RFCA-0.3RPETF	483.69	230.60	691.82	750.04	2.07	4.69	0.4
	75RFCA-0.5RPETF	483.69	230.60	691.82	750.04	3.45	4.69	0.4
	75RFCA-1RPETF	483.69	230.60	691.82	750.04	6.9	4.84	0.4
	75RFCA-1.2RPETF	483.69	230.60	691.82	750.04	8.28	4.84	0.4

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

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

	Specimens	Slump flow(mm)	T_{500}(s)	V-final(s)	L-Box (%)	Sieve stability (%)
	0RFA-0RPETF	767.5	0.86	2.55	1	12.47
	0RFA-0.3RPETF	737.5	1.18	3.15	0.96	10.23
Series I	0RFA-0.5RPETF	725	1.29	3.76	0.92	9.15
	0RFA-1RPETF	712.5	1.37	4.24	0.9	7.22
	0RFA-1.2RPETF	692.5	1.42	5.56	0.88	6.43
	25RFA-0RPETF	757.5	1.05	2.98	0.98	10.86
	25RFA-0.3RPETF	725	1.27	3.48	0.95	9.25
Series II	25RFA-0.5RPETF	707.5	1.38	4.32	0.9	8.32
	25RFA-1RPETF	697.5	1.43	5.18	0.87	7.05
	25RFA-1.2RPETF	687.5	1.52	6.11	0.85	6.14
	50RFA-0RPETF	732.5	1.25	3.79	0.96	9.42
	50RFA-0.3RPETF	702.5	1.36	4.42	0.9	8.54
Series III	50RFA-0.5RPETF	692.5	1.45	5.26	0.87	7.66
	50RFA-1RPETF	682.5	1.53	5.76	0.85	6.08
	50RFA-1.2RPETF	675	1.67	6.86	0.83	5.48
	75RFA-0RPETF	705	1.35	4.15	0.9	8.42
	75RFA-0.3RPETF	690	1.44	5.14	0.87	7.34
Series IV	75RFA-0.5RPETF	685	1.58	5.86	0.85	6.58
	75RFA-1RPETF	679	1.62	6.27	0.83	5.62
	75RFA-1.2RPETF	662.5	1.73	7.58	0.82	4.97
	100RFA-0RPETF	690	1.49	5.32	0.87	7.26
	100RFA-0.3RPETF	680	1.55	5.96	0.84	6.55
Series V	100RFA-0.5RPETF	670	1.69	6.62	0.82	5.69
	100RFA-1RPETF	664	1.75	7.36	0.81	4.75
	100RFA-1.2RPETF	650	1.85	7.89	0.8	4.01

Table 5. Fresh properties of SCC mixes

It is worth noting that based on these results, all the mixtures exhibited excellent workability, meeting the acceptable criteria outlined by the EFNARC recommendations (EFNARC 2005). The workability values obtained for all the mixtures were within the acceptable range as per EFNARC guidelines.

The preparation of SCC mixes involved three mixing steps. Initially, the cement, fibers, and aggregates were combined and blended for 30 seconds. Subsequently, 70% of the mixing water was added, and the mixture was further blended for 1 minute. Following this, the remaining 30% of the water containing the superplasticizer was added and mixed for an additional minute. During this process, an additional 5 minutes elapsed before a 2-minute pause. To ensure the homogeneity of the SCC mixes before discharging, the SCC was mixed for an additional 30 seconds (Benabed et al. 2012).

4. TESTING METHOD

4.1. Compressive and splitting tensile strengths

The compressive strengths of the samples were measured at the ages of 28 and 90 days after the curing process. That was using 100-mm cubic samples in accordance with the EN 12390-3 (EN 1993) standard. Additionally, the splitting tensile strength tests were conducted on 100×200mm cylindrical samples at 28 and 90 days, following the ASTM C496-11 (ASTM 2008) standard.

4.2. Ultrasonic pulse velocity test

The ultrasonic pulse velocity was determined by dividing the pulse time by the length of the path, as indicated in the following equation. This test was conducted on 100-mm cube samples after 28 and 90 days of curing, following the ASTM C597-16 (ASTM 2009) standard.

$$V = \frac{l}{t} \qquad (1)$$

V: Velocity (m/sec),

L: length of path(m),

t: time (seconds).

4.3. Porosity test

The porosity accessible to water test is conducted after 90 days, following the guidelines of NF P18-459 (NF P 2010). For this test, three discs measuring 100*50mm, obtained by cutting from cylindrical specimens with a diameter of 100 mm and a height of 200 mm, are used to assess their porosity. The specimens are then placed in an

oven until two successive weighing's do not differ by more than 0.1%. This final mass is noted as the dry mass, M_{dry}. Next, the sample is immersed in a vacuum using a pump for 4 hours in a desiccator. Following this, the sample undergoes complete immersion in water for 182 hours. After removing the test pieces from the container, they were weighed in water (M_{wat}) and in air (M_{air}). The following equation expresses the porosity calculation:

$$\text{Porosité (\%)} = \frac{M_{air}-M_{dry}}{M_{air}-M_{wat}} \times 100 \quad (2)$$

4.4. Chloride Penetration test

In accordance with the ASTM C-1202-12 (ASTM 1997) standard, a test was conducted to measure the resistance to chloride ions penetration in a concrete disc measuring 200 mm in diameter and 50 mm in height. The test specimen was positioned between two cell electrodes and immersed in two different solutions: one containing a 3% sodium chloride solution (NaCl) and the other containing a 0.3% sodium hydroxide solution (NaOH). The electrical charge was then calculated after applying an electrical potential of 60 V for duration of 6 hours using the following equation (3):

$$Q = 900(I_0 + 2I_{30} + 2I_{60} + \cdots + 2I_{300} + 2I_{330} + 2I_{360}) \quad (3)$$

4.5. Gas Permeability test

The gas permeability test was conducted following the CEMBUREAU method as outlined in XP P18-463(XP P 2011). To evaluate this test, cylindrical specimens with a diameter of 150mm and a height of 50 mm were used. The specimens were laterally protected and confined to ensure a unidirectional transfer of the gas. The apparent gas permeability, Kapp, was measured using the following equation:

$$K_{app} = \frac{2.P_i.Q.L.\mu}{A(P_i^2-P_0^2)} \quad (4)$$

L: Thickness of the specimen in (m).

A: Cross-sectional area of the specimen in (m^2).

Q: Gas flow in (m^3s^{-1}).

l: Dynamic viscosity coefficient of nitrogen gas (17.5 $\times 10^{-6}$ Pa s).

P_i : Inlet pressure (Pa).

P_0 : Atmospheric pressure (Pa).

4.6. Water Permeability test

Water permeability tests were conducted on cubic specimens measuring (150×150×150) mm to measure the depth of water penetration for each composition. In this test, the specimens were subjected to a water pressure of 5 bars for a duration of 72 hours, following standard DIN 1048-5("DIN1048 2000). After the test, each specimen was divided into two parts to determine the water penetration depth. Five equidistant spots were then taken along each face of the split specimen for measurement.

5. RESULTS AND DISCUSSION

5.1. Compressive strength

Figure 5 illustrates the impact of RPETF and RFCA on the compressive strength of the SCC mixture after 28 and 90 days of curing. The figure demonstrates that the compressive strength of SCC increases with the curing duration. However, the use of RFCA resulted in a reduction in compressive strength at all stages of hardening. At 28 days, the compressive strength of the control SCC mixture without RFCA and RPETF was 48.11 MPa. Upon replacing NFA with RFCA, the compressive strength decreased by approximately 1.59%, 3.93%, 6.80%, and 9.33% for the mixtures containing 25%, 50%, 75%, and 100% of RFCA, respectively. Similar decreases in strength were observed at 90 days for mixtures containing 25%, 50%, 75%, and 100% RFCA, resulting in strengths of 52 MPa, 51 MPa, 49 MPa, and 47 MPa, respectively, compared to the control SCC strength of 53 MPa. This reduction in compressive strength can be attributed to the intrinsic properties of RCA and the higher absorption capacity of the adhered mortar in the RCA (Liu et al. 2023). The presence of RCA leads to poorer adhesion between the cement paste and the RCA as compared to NFA (Silva et al. 2016). Sasanipour et al. (2020) Conducted a study on the influence of RFCA and RCCA on concrete properties. Their research also indicated a reduction in compressive strength with the replacement of RFCA. This decrease in strength can be attributed to the high porosity of the recycled aggregates and the poor-quality mortar matrix attached to the RCA. Additionally, as shown in Figure 5, an increase in the percentage of PETF resulted in a decrease in compressive strength. At 28 days, RPETF contents of 0.3%, 0.5%, 1%, and 1.2% reduce the strength of SCC by approximately 3%, 6%, 4%, and 5%, respectively.

Among the analyzed fiber concretes, the RPETF concrete with a content of 1.0% exhibited the most favorable fiber distribution. The observed reduction in compressive strength can be attributed to fiber entanglement during the mixing and casting processes, which increase the likelihood of fiber surfaces coming into contact with each other (Shahidan et al. 2018). The addition of RPETF to RSCC resulted in a decrease in compressive strength. The 90-day compressive strength of recycled self-compacting concretes (RSCC) containing RPETF exhibited a reduction rate of 2%, 4%, and 3% for mixtures of 0.3% RPETF+100 %RFCA, 0.5% RPETF+100 %RFCA, 1% RPETF+100 %RFCA, and 1.2% RPETF+100 %RFCA, respectively. Some research studies have reported improvements in compressive strength when using RPETF in SCC mixtures (Allawi, Al-hadithi, and Mohmoud 2021). However, previous investigations have emphasized that the influence of fiber on compressive strength is relatively minor compared to aggregate strength, cement paste strength, and the interfacial transition zone (Shahidan et al. 2018).

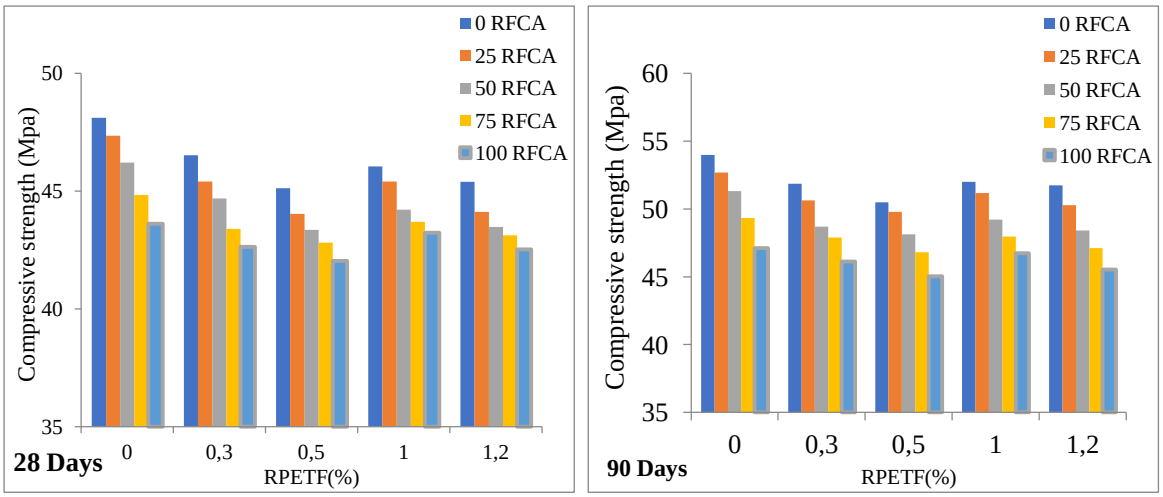


Figure 5. Influence of RFCA and RPETF on the compressive strength

5.2. Splitting tensile strength

Figure 6 illustrates the variation in splitting tensile strength of the different SCC mixtures containing RFCA and RPETF after 28 and 90 days of curing. The splitting tensile strength decreased with increasing RFCA content, similar to the trend observed in compressive strength. At 28 days, the splitting tensile strength decreased by approximately 1.84%, 10.42%, 24.23%, and 29.14% when 25%, 50%, 75%, and 100% RFCA were used instead of NFA, respectively. The negative impact of RFCA on the splitting tensile strength of concrete could be due to the lower quality, strength, and density of RFCA compared to natural aggregates(Güneyisi et al. 2016). The influence of RFCA on the splitting tensile strength of concrete has previously been studied. Dimitriou et al. (2018)Reported a 25% decrease in splitting tensile strength when 100% NCA were replaced with RCA. They attributed this decrease to the presence of porous adhered mortar on the surface of the RFCA and noted that the strength of concrete is influenced by the form and texture of aggregates. In contrast, the addition of RPETF resulted in an improvement in splitting tensile strength, with the degree of improvement increasing with higher RPETF content. Therefore, at 28 days, RPETF contents of 0.3%, 0.5%, 1%, and 1.2% improved the splitting tensile strength of SCC by approximately 2.45%, 5.52%, 9.50%, and 14.11%, respectively. The addition of RPETF to concrete leads to an improvement in the splitting tensile strength as the fibers act as bridges across fissures, providing increased ductility and delaying the breakdown of the concrete compared to normal specimens(He et al. 2020). Vijaya et al.(2018). Investigated the influence of waste plastic fiber on the mechanical properties of SCC and found that the increase in fiber content enhanced the binding strength by improving the adhesion between the fibers and the paste, resulting in increased splitting tensile strength. Furthermore, it was observed that the splitting tensile strength of RSCC increased with higher RPETF content. The inclusion of RPETF at 0.3%, 0.5%, 1%, and 1.2% improved the strength of 100% RFCA by approximately 7.35%, 13.85%, 20.34%, and 28.57%, respectively.

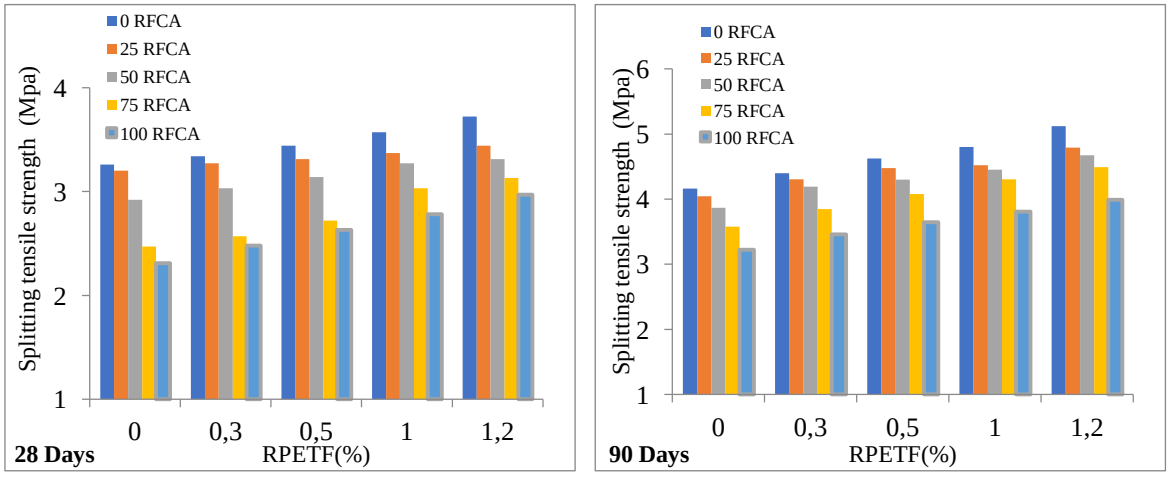


Figure 6. Influence of RFA and RPETF on the splitting tensile strength

5.3. Ultrasonic pulse velocity (UPV)

Figure 7 illustrates the influence of RFCA and RPETF on the UPV test after 28 and 90 days of curing, respectively. The UPV values decrease as the percentage of RFCA content increases and this reduction is further amplified with higher RPETF content. For instance, when only 0.3%, 0.5%, 1%, and 1.2% RPETF are used without RFCA, the UPV values decrease by approximately 4376 m/s, 4338 m/s, 4385 m/s, and 4366 m/s, respectively. The decrease in UPV values with the addition of RPETF can be attributed to the density of the material and the increase in the number of spaces and pores within the mixtures due to the presence of fibers (El Ouni et al. 2022). When 100% RFCA is used in combination with 0.3%, 0.5%, 1%, and 1.2% RPETF, the UPV value decreases by approximately 1%, 3%, 1%, and 2%, respectively. This reduction in UPV values due to the influence of fibers has also been confirmed by Al Hadithi et al. (2017), who demonstrated that the incorporation of RPETF leads to a decrease in UPV compared to reference mixtures.

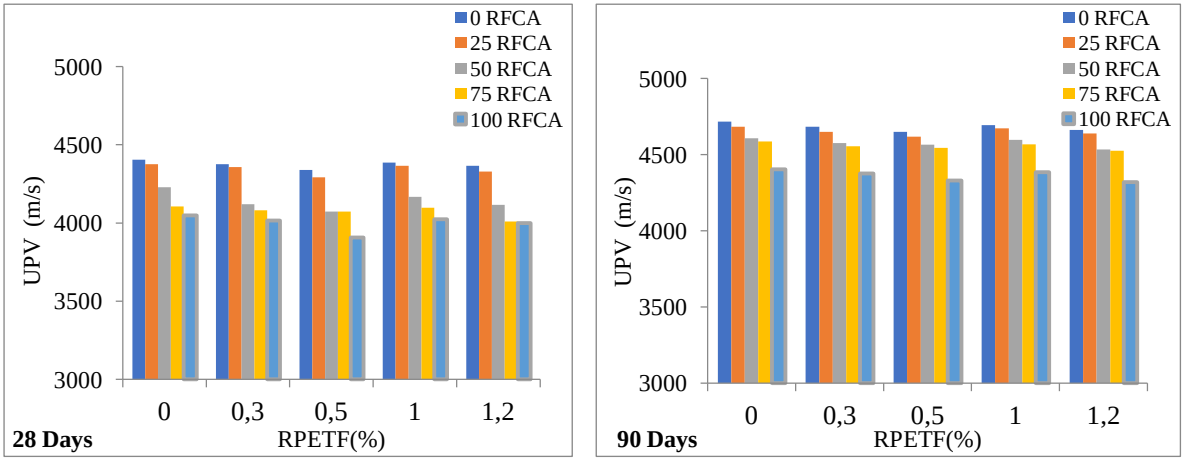


Figure 7. Influence of RFCA and RPETF on the UPV test

5.4. Porosity

In this section, the porosity results illustrated in Figure 8 are considered, considering the influence of RFCA and RPETF. An increase in RFCA content leads to an increase in porosity, which is significantly higher compared to the reference concrete. For samples without RPETF, the porosity increases by approximately 11%, 22%, 42%, and 68% when 25%, 50%, 75%, and 100% RFCA are used as a substitute for NFA. This increase in porosity can be attributed to the presence of pores and microcracks in the RCA that are formed during production, resulting in a weak interface between the RCA and cement paste, which increases air voids (Gesoglu et al. 2015; El-Hassan, Kianmehr, and Zouaoui 2019). Figure 8 also shows a slight increase in porosity with the addition of RPETF. For the control SCC, the porosity is 9.14%, which increases to 9.74%, 9.96%, 9.66%, and 9.70% for SCC mixtures prepared with RPETF contents of 0.3%, 0.5%, 1%, and 1.2%, respectively.

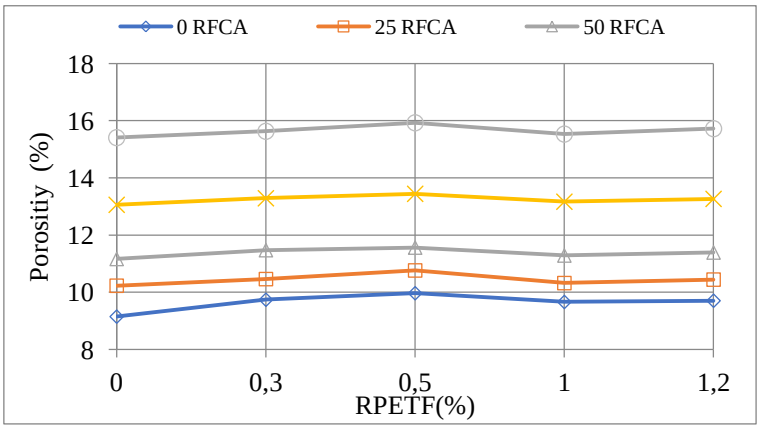


Figure 8. Influence of RFCA and RPETF on the Porosity test

The maximum porosity was recorded for the mixture containing 100% RFCA reinforced with 0.5% RPETF, which was approximately 74.08% higher than that of the control mixture. This increase in porosity can be attributed to the non-homogeneous fibers' surface, which creates voids

between the pulp and the fiber itself (Mastali and Dalvand 2016). Consequently, the higher number of fibers in the mixture increases the occurrence of microcracks, resulting in a large interface between the fibers and cement paste (Toghroli et al. 2020). Figure 9 illustrates the relationship between compressive strengths, UPV, and porosity of specimens with various RFCA and RPETF contents. In general, there is a decreasing trend in compressive strength and UPV with increasing porosity. The coefficient between compressive strengths, UPV, and porosity is R^2 >0.8, indicating a strong correlation among these factors.

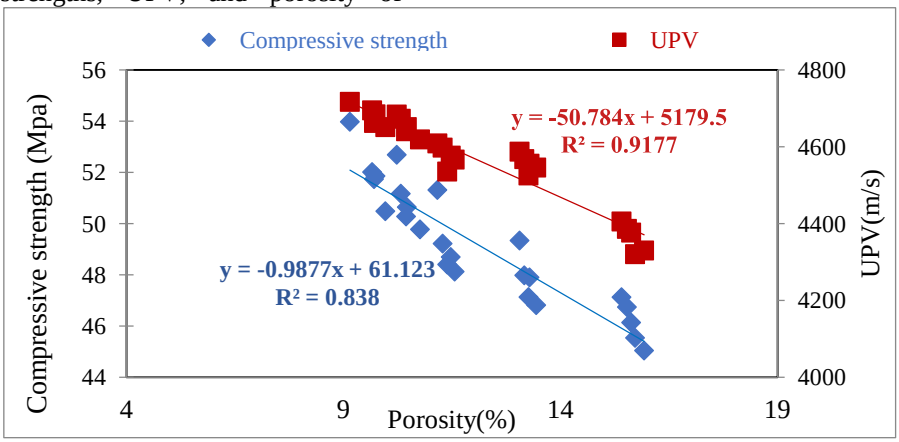


Figure 9. Correlation between compressive strengths, UPV and porosity.

5.5. Chloride Penetration

The chloride-ion penetration resistance of the SCC mixture, made with RFCA and RPETF, was tested according to ASTM C1202 (1997) at 90 days, and the results are presented in Figure 10. The substitution of NFA with RFCA resulted in an increase in the electric charge (in Coulombs) passed through the cylindrical specimens, indicating higher chloride-ion penetration. Specifically, the replacement of 25, 50%, 75%, and 100% of RFCA increased the chloride-ion penetration by 1.33%, 3.50%, 4.16%, and 31.09%, respectively, compared to the reference concrete. Notably, the mixture containing 100% RFCA exhibited a significant effect on chloride penetration. This increase in chloride penetration can be attributed to the higher porosity of the RFCA compared to the NFA (Dimitriou, Savva, and Petrou 2018), primarily due to the presence of adherent mortar on the surface of the RFCA.

However, Tiago Barroqueiro et al. (2020) reported an increase in chloride ion penetration with an increase in RA compared to the reference mix. Their study indicated that the partial replacement of 100% NFA with RFCA resulted in a significant increase of approximately 58%. In Figure 10, a slight increase in chloride-ion penetration is observed due to the addition of fibers. The mixtures prepared with 0.3%, 0.5%, 1%, and 1.2% of RPETF showed an increase of 0.49%, 1.02%, 3.06%, and 4.29%, respectively, compared to the reference mix.

Furthermore, the mixtures containing 0.3 to 1.2% of RPETF and 100% RFCA exhibited a higher increase in chloride penetration (5000 C), which can be attributed to the high porosity of the concrete. Similar results were reported by Bui et al. (2018), who stated that the resistance to chloride ion penetration of RAC was lower than that of NAC. They also found that the addition of a small amount of plastic fiber (0.25% fiber) to RAC slightly increased the resistance to chloride ion penetration, likely due to the high electrical resistance of the plastic fiber. However, the resistance to chloride infiltration decreased with increasing fiber in RAC.

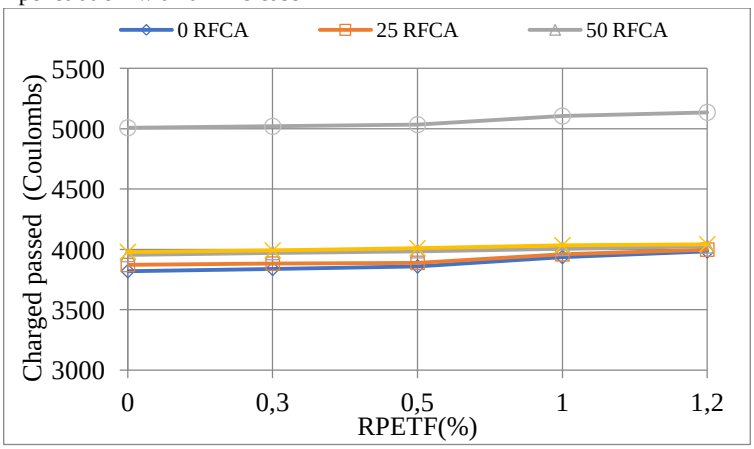


Figure10. Influence of RFCA and RPETF on the Charge Passed test

5.6. Gas Permeability

Figure 11 presents the influence of RFCA and RPETF on the gas permeability of SCC at 90 days. The test results indicate that the mixes containing RFCA exhibit higher gas permeability compared to the reference concrete. The coefficient of permeability varies for different RFCA percentages, with specimens containing 25% RFCA showing different behavior compared to those with a higher RFCA content (100%). The gas permeability coefficient values for all mixtures range from 4.98 $\times 10^{-17}$ m^2 to 8.91 $\times 10^{-17}$ m^2. These results can be attributed to the porosity characteristics of the concrete.

The coefficient of gas permeability increases with the increase in RFCA percentage, reaching a maximum value of 7.43× 10^{-17} m^2 with 100% partial substitution of RFCA. This increase in gas permeability can be attributed to the increase in pore structure within the concrete. Additionally, as mentioned earlier, the presence of residual hydrated cement adhered to the surface of the aggregate particles (new and/or old ITZ) in RA contributes to the formation of a more porous and cellular material (Plagué, Desmettre, and Charron 2017; Li et al. 2019).

This result is consistent with the findings of Lan Zong(Zong, Fei, and Zhang, n.d.), who also observed an increase in the gas permeability coefficient when replacing NFA with RFCA. In their study, the gas permeability coefficient was approximately three times higher than that of the reference mix. However, it was noted that the mixture containing 30% RA exhibited a smaller increase in gas permeability compared to the other mixtures.

Figure 11 illustrates the results of the incorporation of RPETF in SCC. The gas permeability coefficient of the reference concrete without RFCA and RPETF was measured at 4.98× $10^{-17}m^2$. The addition of 0.3%, 0.5%, 1%, and 1.2% of RPETF resulted in a gas permeability coefficient of 5.64× 10^{-17} m^2 to 5.55× 10 17 m2, 5.81 $\times 10^{-17}$ m^2, 6.87 $\times 10^{-17}$ m^2, and 6.09× 10^{-17} m^2, respectively. When 0.5%, 1%, and 1.2% RPETF were added to the mixture containing 75% RFCA, the gas permeability coefficient significantly increased by 20%, 33%, and 39% compared to the mixture with 75% RFCA alone. This increase can be attributed to the uncontrolled distribution of fibers in the mixture due to varying fiber amounts. It has been observed in previous experiments that different types of fibers have varying impacts on the air permeability of concrete (Plagué, Desmettre, and Charron 2017). The gas permeability coefficient can be influenced by factors such as fiber length, fiber size, and fiber diameter (Li et al. 2019). According to the reference (Baroghel-Bouny, 2007), samples with a permeability coefficient ranging from 10^{-17} to 10^{-16} m^2 exhibit better permeability resistance.

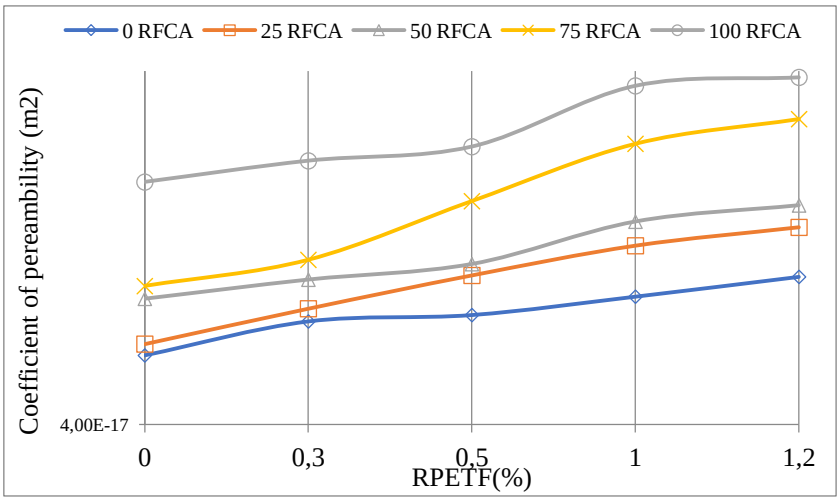


Figure 11. Influence of RFCA and RPETF on the Gaz Permeability test

In this section, the correlation between charge passed, coefficient permeability, and porosity of specimens produced with different RFCA and RPETF contents was investigated (Figure 12). The results indicate that both the charge passed and the coefficient of permeability increase with an increase in porosity. The experimental data obtained from concrete specimens with varying RFCA and RPETF contents demonstrate a strong correlation ($R^2 \geq 0.6$) between these parameters.

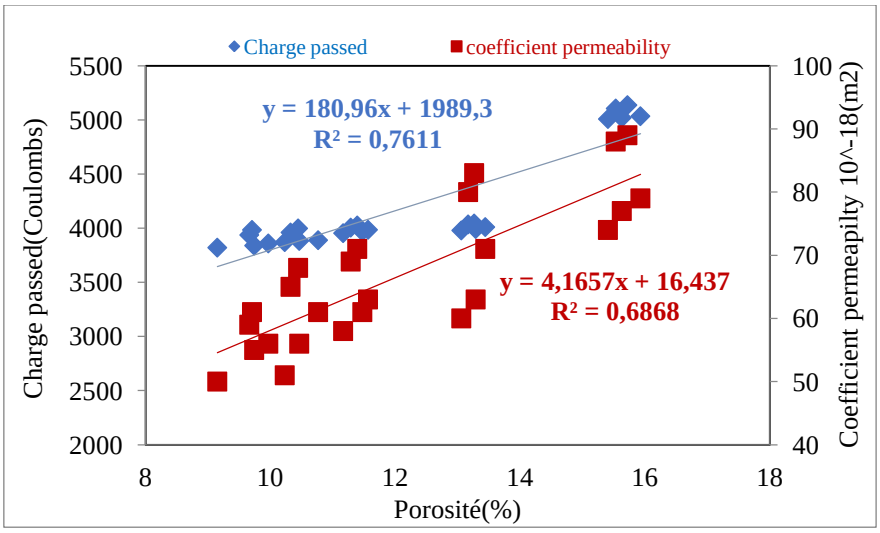


Figure12. Correlation between charge passed, coefficient permeability and porosity

5.7. Water Permeability

The variations of water permeability depth under pressure for all mixes of SCC at 90 days are shown in Figure 13. The test results demonstrate that the water penetration is more extensive in the samples containing RFCA compared to the reference concrete without any RFCA substitution. The mix of 100% RFCA exhibits the highest penetration depth, measuring 54mm. This can be attributed to the porous nature of the RFCA, which facilitates easy water penetration into and through the aggregates. Additionally, the presence of old mortar on the RCA particles and a weak interfacial transition zone (ITZ) around the aggregates contribute to the formation of more capillaries, allowing for greater water penetration(Nili, Sasanipour, and Aslani 2019). These findings align with the results obtained by Gesoglu et al. (2015), who observed a significant increase in water penetration (4,5 to 7.6 times) when coarse and fine recycled aggregates were incorporated compared to control mixtures using natural aggregates (NA). However, the addition of fibers to the SCC results in an increase in water penetration depth. Particularly, the mix with 1.2% RPETF exhibits a higher water penetration depth compared to the reference concrete. These findings are consistent with the results reported by Jain et al.(Jain et al. 2019) Other researchers, such as Islam et al.(2016), also noted that adding more than 0.25% fiber to concrete leads to an increase in the depth of water penetration. These observations suggest that the presence of fibers contributes to a greater number of voids and a weaker interfacial transition zone (ITZ) within the concrete structure, primarily due to the irregular shape of the fibers and their weaker adhesion with the cement matrix.

Furthermore, the results presented in Figure 13 demonstrate that, in addition to RFCA and RPETF, RSCC containing RPETF also exhibit an effect. For instance, the 100% RFCA replacement results in a water penetration depth of 55, 56, 57, and 58mm when 0.3%, 0.5%, 1%, and 1.2% of RPETF are added, respectively.

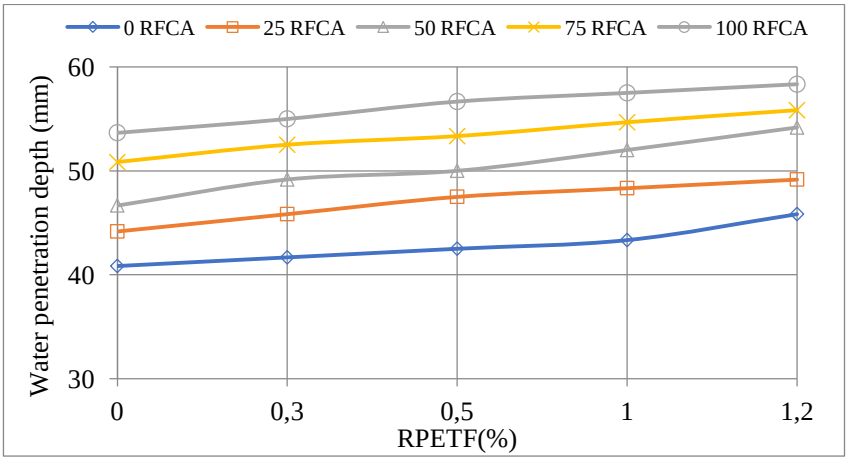


Figure13. Influence of RFCA and RPETF on the Water Penetration Depth test

6. CONCLUSIONS

This research assessed the effects of RPETF fibers on the on the durability and mechanical properties of SCC produced using RFCA. The following principal conclusions can be drawn from the current experimental study:

- RPETF can be used in SCC as addition to improve the RSCC composite
- The inclusion of RPETF increased the splitting tensile strength of RSCC containing RFCA while decreasing the compressive strength.
- The addition of RPETF to RSCC resulted in a decrease in both compressive strength and UPV as the RPETF increased. The decrease in compressive strength ranged from approximately 1% to 7%, while the decrease in UPV ranged from approximately 0.5% to 2%.
- Despite fiber reinforcement, the presence of old mortar affects the overall strength and performance of the concrete mixture.
- RPETF contributed to an enhancement in the splitting tensile strength of RSCC. The incorporation of RPETF resulted in an increase in the splitting tensile strength of RSCC by approximately 2% to 29% compared to RSCC without fiber.
- The presence of fibers bridging through the fissures and enhancing the ductility of the concrete contributed to the increased splitting tensile strength.
- The addition of RPETF to RSCC led to an increase in porosity. The porosity values exhibit a strong correlation between compressive strength and UPV measurements.
- The incorporation of RPETF in RSCC led to an increase in chloride-ion permeability cause by the high porosity of the concrete.
- The addition of RPETF to the RSCC mixes increased the permeability coefficient.

The study's findings reveal a significant advancement in the utilization of Recycled Polyethylene Terephthalate Fiber (RPETF) as an additive in Self-Compacting Concrete (SCC) to enhance the composite of Recycled Self-Compacting Concrete (RSCC). This newly acquired knowledge demonstrates the potential of RPETF to contribute positively to the overall properties of recycled concrete, providing a sustainable solution for improving the performance and durability of RSCC. The incorporation of RPETF introduces a promising avenue for optimizing the use of recycled materials in concrete construction, addressing key challenges and advancing the development of environmentally friendly and resilient concrete structures.

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