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Comportamiento del hormigón con árido grueso reciclado y fibras de polipropileno para construcciones sostenibles
Performance of concrete with recycled coarse aggregate and polypropylene fibres for sustainable

Carla Pamela Albuja Zurita.

[a] Polytechnic University of Madrid, Higher Technical School of Building.

Resumen-- **Esta investigación se centra en analizar el comportamiento del uso de áridos finos reciclados RFA y áridos gruesos RCA, así como la adición de fibras de polipropileno tanto en hormigones autocompactantes como en hormigones tradicionales, y cómo influye en las propiedades en fresco y mecánicas en función de su tasa de sustitución referida a áridos naturales por áridos reciclados. La utilización de porcentajes del 0,1% de fibras de polipropileno en hormigones autocompactantes y una tasa de sustitución de entre el 25% de RFA y el 25% de RCA, así como una tasa de sustitución del 50% de RFA, obtienen mejores resultados en su fluidez y trabajabilidad, así como en su resistencia a compresión y tracción. La utilización de porcentajes comprendidos entre el 1,0% y el 1,5% de fibras de polipropileno en los hormigones tradicionales permite obtener mejores resultados en términos de resistencia a la compresión.**

Palabras clave— Hormigón reciclado; áridos de hormigón reciclado; RCD; fibra de polipropileno; resistencia a la compresión.

Abstract— **This research focuses on analysing the behavior of the use of RFA fine recycled aggregates and RCA coarse aggregates, as well as the addition of polypropylene fibres in both self-compacting concrete and traditional concrete, and how this influences the fresh and mechanical properties depending on its substitution rate referred to natural aggregates by recycled aggregates. The use of percentages of 0.1% polypropylene fibres in self-compacting concretes and a substitution rate of between 25% RFA and 25% RCA, as well as a substitution rate of 50% RFA, obtain better results in their fluidity and workability, as well as in their compressive and tensile strength. The use of percentages of between 1.0% and 1.5% of polypropylene fibres in traditional concretes allows to achieve better results in terms of compressive strength.**

Index Terms— Recycled concrete; recycled concrete aggregates; CDW; Polypropylene fibre; Compressive strength.

I. INTRODUCTION

The growth of cities around the world and their industrial development presents challenges regarding the disposal or recycling of construction and consumer waste, this encompasses a series of environmental problems where ecological pollution is an issue to be addressed. Therefore, reducing the amount of waste generated, promoting its use, recycling and recovery could be the basis for achieving environmental sustainability. (Adazabra et al., 2023)

The development of industry, technology, consumption, and the excessive increase in waste generated by the construction, industry, services and household sectors, entails a treatment of these materials and their reincorporation process through recycling and reuse either through the base material or due to treatment processes to form new materials. This involves a process of treatment, costs and consumption of energy, as well as industrialized labour.

C.P.A.Z. is PhD student at Escuela Técnica Superior de Edificación from Universidad Politécnica de Madrid.

According to the National Institute of Statistics, the Spanish economy generated 105.6 million tons of waste in 2020, in which 54.7% of the waste treated was destined for recycling. Corresponding to the generation of waste generated by the construction sector was 32.5 million tons of waste, which for that year corresponded to 30.8% of the total and the waste generated by agriculture, livestock, forestry and fishing was 6,330.7 tons corresponding to 6.0% of the total. (Ine National Institute of Statistics, 2022). Waste recycling management must be of primary attention. Based on the United Nations SDG 12 with its special emphasis on responsible consumption and production, it emphasizes decoupling economic growth from environmental degradation, increasing resource efficiency and promoting a sustainable lifestyle. According to UN data corresponding to the aforementioned SDG, 95,900 million metric tons correspond to materials extracted to meet the demand for consumption in a country, in which comparisons reveal inequality in excessive consumption, for example in North Africa and Western Asia, Europe and North America exceed national consumption of materials by 18% and 14% respectively. compared to Latin America and the Caribbean and sub-Saharan Africa, in which their material footprint was lower than the national consumption of materials by 17% and 32%, respectively. (United Nations, 2023)(United Nations, 2023b)

After the crisis that the world went through due to the COVID-19 pandemic caused changes in buildings and in the low demand for their construction worldwide, by 2021 the energy demand increased 4% since 2020, and therefore the increase in CO2 emissions around 10 $GtCO_2$, when an approximation of 3.6 $GtCO_2$ from the manufacturing operations of building materials such as concrete, aluminium, bricks and glass is included, where buildings accounted for 37% of global emissions in 2021. (An environment program, 2022).

The consumption of raw materials by 2060 will have doubled due to the increase in the world economy, the standard of living, which will aggravate the environmental overload, in the G7 countries material efficiency strategies such as the use of recycled materials could reduce more than 80% of greenhouse gas emissions from the material cycle of residential buildings by 2050. , which denotes that the efficiency of the materials provided must take into account the complete life cycle of the building and incorporate systemic thinking, in which the longevity of the infrastructure will be encouraged.(A environment program , 2022)

The reuse of waste materials could help to mitigate in part the overexploitation of natural resources, and thus reduce the use of raw materials. The proper reuse of waste materials from construction could generate significant changes in the reduction of the carbon footprint generated in recent years, as well as the reduction of the degradation of natural areas from which the raw materials of many of the products used in construction come.

One of the most representative waste materials are those from construction waste originally from concrete, several of the academics have investigated the reuse of recycled aggregates for optimal mixtures in self-compacting concretes, as well as for use in traditional concretes, these investigations cover both the physical and mechanical properties of concrete.

These properties can increase or decrease depending on the percentage of recycled aggregate that is replaced in the mixture, that is to say that the higher the percentage of recycled aggregate the mechanical resistance of the concrete tends to decrease, this may be due to the fact that recycled aggregates have a high degree of water absorption, which affects the mixture. (Aslani et al., 2019)(Gao et al., 2023), (Wang et al., 2023), (Abraham et al., 2015) (Fiol et al., 2018)(Lotfy & Al-Fayez , 2015)(Xu et al., 2021)therefore, its density is reduced, increasing porosity, while decreasing the modulus of elasticity of the concrete, compared to a conventional concrete with mixtures of natural aggregates, therefore, it can also influence its durability, workability, as well as its physical-mechanical properties (Lomas Franco, 2022)(García Beltrán, 2017)(Silva et al., 2018), (Ajmani et al., 2019)

Both the physical and mechanical properties of the concrete can also be influenced by the initial strength of the recycled concrete used for recycled aggregate in the mix, as well as the shape of the recycled aggregate, the irregular size of the particles, and its porosity are also factors to be taken into account in reference to the workability and mechanical properties mentioned above (Lotfy & Al- Fayez , 2015)(Silva et al., 2018).

Several references in the literature have shown that the addition of fibres effectively improves the mechanical properties of concrete compared to normal concrete , (Aslani et al., 2019)(Gao et al., 2023), (Wang et al., 2023) (Abraham et al., 2015). The reference fibres used are MSF steel fibres and PPF Polypropylene fibres, which for self-compacting concretes the optimal mixture is between 0.1% of volume addition of polypropylene fibre, (Kanishka & Ramesh Kumar, 2023)(Xu et al., 2021)(Mohseni et al., 2017)(Barrios, 2021)(Zhong & Zhang, 2020)(Aslani et al., 2019)(Gao et al., 2023)(Zhong & Zhang, 2020), for certain traditional concretes the use of recycled concrete aggregates with an optimal mixture of between 1% and 1.5% of addition of polypropylene fibres this allows its mechanical properties such as compressive strength to increase (Wang et al., 2023), (Abraham et al., 2015), (Serrano et al., 2016).

Several of the physical and mechanical properties of concrete are affected when the addition of volume polypropylene fibres and steel fibres in the mix is increased, an example of this is the decrease in workability. (Wang et al., 2023)(Kanishka & Ramesh Kumar, 2023)(Zhong & Zhang, 2020)

Therefore, the aim of the present work is to understand the impact of the substitution of natural aggregates by RFA fine recycled aggregates and RCA coarse aggregates, as well as the addition of polypropylene fibres in the composition of both self-compacting concrete and traditional concrete. The research focuses on analysing in detail the resulting behaviour in the physical and mechanical properties of concretes, comparing references and thus contributing to the understanding of their possible optimal percentages.

II. METHODS

To carry out the analysis of the specimens, the dosages used by the different authors for both self-compacting concrete study specimens and traditional concrete specimens are studied.

Only the trials used are analysed based on the study carried out for this work. Therefore, it allows the study of the values resulting from their physical and mechanical properties in the section of results submitted to the tests mentioned in this section.

A. Mixing Configuration

In reference to the study of the Self-compacting concrete, the impact of PP and steel fibres on the behaviour of self-compacting recycled aggregate concrete - RASCC is evaluated, references of the authors were studied Aslani et al. and Gao et al., where The respective dosages used by each author are displayed in the Table 1.

A control mixture called Mc and RMc was established, which incorporates the parameters of the base mixture for comparative purposes. In addition, an optimal mixture of self-compacting concrete of recycled aggregates - RASCC reinforced with PP fibres in volume fractions of 0.1% M1 PPF was developed, which are compared with the study of , in which its mixtures were reinforced with polypropylene fibres in volume fractions of 0.1% for specimens RC100RF00S10P10, RC00RF50S10P10 and RC25RF25S10P10, but unlike the previous author, the variations are made to replace the fine and coarse aggregate with fine and coarse aggregate recycled concrete. (Gao et al., 2023).

In the Table 1, the research of Aslani et al., in the study specimen M1 PPF the percentage of replacement of recycled aggregate from RCA concrete remains constant, while, compared to the research of Gao et al., the percentage of substitution of fine and coarse natural aggregates by recycled fine and coarse aggregates is variable in percentages of 25%, 50% and 100%.

The Mc and M1PPF specimens in comparison to the RMc specimens do not use dross, it is mentioned that the use of these slags allows to obtain a low heat of hydration in the mixture.

It is denoted that the Mc and M1PPF specimens use chemical additives such as the superplasticizer SP, as well as the modifier additive VMA (increases stability and reduces bleeding in the mixture) and the water reducing agent WRA (reduces water consumption and increases density while maintaining fluidity), which are used to change the fresh properties of the concrete and meet the study limits, while RMc specimens and their mixtures do not use chemical additives.

In reference to the study of the traditional concrete, two types of cases are studied:

TABLE I
DOSAGES USED BY AUTHORS TO ANALYSE THEM IN THIS STUDY – SELF-COMPACTING CONCRETE

Ref. Colour	Grouping	Cement (kg/m³)	Flywheel ash (kg/m³)	Dross (kg/m³)	Silica fume (kg/m³)	Arena (kg/m³)	Steel Fiber	PP fibre	Fiber Volume Ratio
[5]	Mc	160	120	90	30.5	323	-	0.00	0
[5]	M1 PPF	160	120	90	30.5	329	-	0.90	0.10%

Ref. Colour	Grouping	C (Cement)	FA (fly ash)	Dross (kg/m)	SF (Silica Fume)	Arena (kg/m)	MSF (Milled Steel Fibres)	PPF (Polypropylene Fibres)	P (PPF) %
[6]	RMc	400	111	-	44	-	0	0	0
[6]	RC100RF00S10P10	400	111	-	44	-	78	091	0.1%
[6]	RC00RF50S10P10	400	111	-	44	-	78	091	0.1%
[6]	RC25RF25S10P10	400	111	-	44	-	78	091	0.1%

Ref. Colour	Grouping	Fine aggregates (kg/m³)	Coarse aggregates (kg/m³)	Water	WRA	SP Super-plasticising	VWA Additive modif. viscosity	RCA %	RFA %
[5]	Mc	321.5	667	180	0.67	2.96	1.48	cte	100
[5]	M1 PPF	329	667	180	0.67	2.22	1.48	cte	102

Ref. Colour	Grouping	NFA Natural Fine Aggregate	RFA Recycled Fine Aggregate	Natural Coarse Aggregate NCA	RCA Recycled Coarse Aggregate	W Mixing Water	AW Additional Water	SP Super-plasticising	VWA Additive modif. viscosity	RCA %	RFA %
[6]	RMc	791	0	844	0	205	0	-	-	0	0
[6]	RC100RF00S10P10	791	0	0	792	205	28	-	-	100	0
[6]	RC00RF50S10P10	396	396	844	0	205	37	-	-	0	50
[6]	RC25RF25S10P10	594	198	623	208	205	26	-	-	25	25

TABLE II
DOSAGES % CONSTANT PPF, USED BY AUTHORS TO ANALYZE IN THIS STUDY – TRADITIONAL CONCRETE

Ref. Colour	Grouping	Agua (kg/m^3)	Cement (kg/m^3)	Arena (kg/m^3)	NATP1	NATP2	Crushed stones (kg/m^3)
[7]	FNC-0-15-50	295	590	704.48	-	-	810.53
[7]	FRRC-30-15-50	295	590	704.48	-	-	567.37
[7]	FRRC-60-15-50	295	590	704.48	-	-	324.21
[7]	FRRC-100-15-50	295	590	704.48	-	-	0.00
Ref. Colour	**Grouping**	**Water (kg/m^3)**	**Cement (kg/m3)**	**Arena (kg/m^3)**	**NATP1**	**NATP2**	**RATP1**
[8]	N-C	169	318	818	459	564	0
[8]	R1-C	169	318	818	0	563	445
[8]	R2-C	169	318	818	459	0	0
[8]	R12-C	169	318	818	0	0	445

Ref. Colour	Grouping	RCA (kg/m^3)	% RCA	Additional water (kg/ m^3)	WPF% by volume	Fiber long-diameter ratio	Superplast. (kg)
[7]	FNC-0-15-50	0.00	0.00%	0.00	1.50	47.85	-
[7]	FRRC-30-15-50	243.16	30.00%	6.98	1.50	47.85	-
[7]	FRRC-60-15-50	486.32	60.00%	13.96	1.50	47.85	-
[7]	FRRC-100-15-50	810.53	100.00%	23.26	1.50	47.85	-
Ref. Colour	**Grouping**	**RATP2**	**% RCA**	**Additional water (kg/m^3)**	**WPF% by volume**	**Fiber long-diameter ratio**	**Superplast. (kg/m^3)**
[8]	N-C	0	0.00%	-	1.50%	-	6.35
[8]	R1-C	0	25.00%	-	1.50%	-	6.67
[8]	R2-C	496	30.00%	-	1.50%	-	6.35
[8]	R12-C	496	55.00%	-	1.50%	-	7

The first case studies the behaviour of traditional concrete when the percentage of PPF or WPF polypropylene fibres is constant and the variation in the percentage of recycled aggregate RCA from the research of Wang et al., and Akça et al.

In the Table 2, the dosages of this case are visualized in which the constant percentage of addition of polypropylene fibres is 1.5%, and the variation of substitution of natural coarse aggregates by recycled coarse aggregates is variable in 0%, 30%, 60% and 100%, in the reference specimen FNC-0-15-50 and its FRRC compounds, while the group of specimens N-C and its R-C mixture compounds have a variable percentage of RCA recycled coarse aggregates of 0%, 25%, 30% and 55%.

The N-C reference specimen and its compounds R1, R2, R12-C, use chemical additives such as the polycarboxylate superplasticizer SP, while the FNC-0-15-50 specimens and their compounds in the FRRC mixtures do not use chemical additives.

The second case of the investigations of Wang et al., y Akça et al, It studies the behaviour of traditional concrete when the percentage of substitution of recycled concrete aggregate remains constant and the percentage of addition of polypropylene fibre varies.

In the Table 3, the dosages of this case in which the percentage of constant substitution of recycled coarse aggregates is 100% for the RC-100-0 specimen group are displayed and their mixture compounds FRRC, and the variable percentage of WPF polypropylene fibres is 0%, 1%, 1.5%, and 2%, while in R12-A, R12-B, R12-C specimens the percentage of constant substitution of recycled coarse aggregates is 55%, and the variable percentage of WPF polypropylene fibres is 0%, 1%, and 1.5%.

The test tube R-12A which is the reference specimen and its compounds R12-B, R12-C, use chemical additives such as polycarboxylate superplasticizer SP, while specimens RC-100-0 and its compounds in FRRC mixtures, They do not use chemical additives.

In the Table 4, the optimal dosages that could be studied in the future of self-compacting concrete with different variations are visualized, these are chosen due to the study in the results section. Each of these dosage data of the Table 1, 2 and 3 mentioned above, allow us to carry out an exhaustive analysis detailed in the Results section.

B. Trials and tests

This section specifies the trials and tests carried out by the different reference authors Aslani et al., Gao et al., Wang et al., and Akça et al., which allow us to understand the procedure of the preparation of the study specimens and the different tests carried out to obtain the results that are analysed in this work.

1) Evidence

In the first article by Aslani et al. (Aslani et al., 2019), to carry out the tests, the recycled aggregates are prepared which obtains the recycled aggregates from demolished buildings, they are subjected to a saturation treatment by placing it in a bucket and filling it with water for 24 hours, then it is drained for 1 hour to obtain a dry surface condition before adding it to the mixture.

12 cylindrical specimens of 100x200 mm were made, which were demoulded after 24 hours, to later take them to a curing

TABLE III
CONSTANT % RCA DOSAGES, USED BY AUTHORS TO ANALYZE THEM IN THIS STUDY – TRADITIONAL CONCRETE

Ref. Colour	Grouping	Agua (kg/m^3)	Cement (kg/m^3)	Arena (kg/m^3)	NATP1	NATP2	Crushed stones (kg/m^3)
[7]	FNC-0-15-50	295	590	704.48	-	-	810.53
[7]	FRRC-30-15-50	295	590	704.48	-	-	567.37
[7]	FRRC-60-15-50	295	590	704.48	-	-	324.21
[7]	FRRC-100-15-50	295	590	704.48	-	-	0.00
Ref. Colour	**Grouping**	**Water (kg/m^3)**	**Cement (kg/m3)**	**Arena (kg/m^3)**	**NATP1**	**NATP2**	**RATP1**
[8]	N-C	169	318	818	459	564	0
[8]	R1-C	169	318	818	0	563	445
[8]	R2-C	169	318	818	459	0	0
[8]	R12-C	169	318	818	0	0	445

Ref. Colour	Grouping	RCA (kg/m^3)	% RCA	Additional water (kg/ m^3)	WPF% by volume	Fiber long-diameter ratio	Superplast. (kg)
[7]	FNC-0-15-50	0.00	0.00%	0.00	1.50	47.85	-
[7]	FRRC-30-15-50	243.16	30.00%	6.98	1.50	47.85	-
[7]	FRRC-60-15-50	486.32	60.00%	13.96	1.50	47.85	-
[7]	FRRC-100-15-50	810.53	100.00%	23.26	1.50	47.85	-
Ref. Colour	**Grouping**	**RATP2**	**% RCA**	**Additional water (kg/m^3)**	**WPF% by volume**	**Fiber long-diameter ratio**	**Superplast. (kg/m^3)**
[8]	N-C	0	0.00%	-	1.50%	-	6.35
[8]	R1-C	0	25.00%	-	1.50%	-	6.67
[8]	R2-C	496	30.00%	-	1.50%	-	6.35
[8]	R12-C	496	55.00%	-	1.50%	-	7

humidifier room at a temperature of 20 °C until the mechanical tests of 7 and 28 days were carried out.

The second article Gao et al., , uses recycled RCA and RFA aggregates from laboratory-tested concrete specimens which had a compressive strength of 50 MPa.(Gao et al., 2023)

Make 10 proportions of mixtures in which their proportions are in the Table 1, in which the RFA fine recycled aggregates and RCA coarse aggregates were air-dried due to the high amount of absorption they present, the additional amount of water is calculated by the actual moisture content and its absorption capacity that RCA and RFA present. The mixture of binding materials is carried out, it is included in cement, FA fly ash, SF silica fume for 1 min, then 50% of water is added and SP is mixed for 1 min more, RFA and RAC are added mixing them for 1 min., the rest of the natural aggregates are added mixing them again for 1 min, then the milled steel fibres MSF are placed mixing them for 30 s. then the polypropylene fibres are dispersed by mixing them for 30 minutes. 30 s. until the mixture does not have lumps, finally add the remaining water to the SP for 2 min to obtain a homogeneous mixture.

Aslani et al. perform settling tests which allow measuring the consistency of the concrete and the fluidity of the mixture in the fresh state, the cone is filled with the fresh mixture, it is gradually raised upwards so that the concrete falls freely and the average diameter obtained and the T500 time in its settling are measured (Aslani et al., 2019).

Gao et al., performs workability tests of self-compacting concrete in its fresh state, in which it was measured by means of the settling flow diameter to measure the fluidity property of these mixtures based on the different dosages used in each specimen, settling flow time T500 time to study the viscosity of the concrete, Japanese ring (J ring) to evaluate the passing capacity of self-compacting concrete in the J ring, which are chosen for this study(Gao et al., 2023).

In which the settlement test evaluates the deformity and fluidity of the self-compacting concrete, this test was performed

TABLE IV
POTENTIAL DOSAGES FOR STUDY – SELF-COMPACTING CONCRETE

Ref. Colour	Grouping	Cement (kg/m^3)	FA (fly ash) (kg/m^3)	Dross (kg/m^3)	SF (silica fume) (kg/m^3)	PPF (PP Fibres)	MSF (Milled Steel Fibres)	P (PPF) %	Sand kg/m^3	NFA (Natural Fine Aggregate)
[6]	RC00RF50S10P10	400	111	-	44	091	78	0.1%	-	396
[6]	RC25RF25S10P10	400	111	-	44	091	78	0.1%	-	594
Ref. Colour	**Grouping**	**RFA Recycled Fine Aggregate**	**Natural Coarse Aggregate NCA**	**RCA Recycled Coarse Aggregate**	**W Mixing Water**	**AW Addition al Water**	**SP Super-plasticising**	**VWA Viscosity Modifier Additive**	**RCA %**	**RFA %**
[6]	RC00RF50S10P10	396	844	0	205	37	-	-	0	50
[6]	RC25RF25S10P10	198	623	208	205	26	-	-	25	25

in two series, the first was performed after mixing, the second after 30 minutes of mixing, thus evaluating the loss of settlement of the self-compacting concrete.

The Japanese ring test was conducted to examine the ability of self-compacting concrete with recycled aggregates reinforced with polypropylene fibres HFRA-SCC to pass through rebar.

The third referent , Wang et al., uses RCA coarse aggregates from the abandoned test wall of the structural laboratory which had a rebound strength of 27.6 MPa, they are crushed, sieved and cleaned and the possible sizes of recycled aggregates are selected. The polypropylene fibre is obtained from the waste of the hot melting machine, this is cut manually, its average width varies from 0.45 to 0.55 mm, with variable lengths from 30.02 mm to 58.97 mm (Wang et al., 2023).

Wang et al., uses high water consumption per unit volume, and sand thus reducing the amount of aggregate, where the fibre is evenly distributed, this high consumption is attributed to the fact that the recycled aggregate used has cracks which absorb greater amounts of water.

11 groups of mixtures are made in which several of their studied proportions are found in the Table 2 and Table 3 each group presented 6 and 3 study specimens for compression and modulus of elasticity.

The specimens with a dimension of 150x150x300 mm are made to perform the tests of resistance to axial compression, these specimens are stored in a curing chamber at a temperature of 20 °C where the relative humidity is greater than 95% for 28 days of curing.

The fourth referent Akça et al., makes 12 mixtures for study, the obtaining of the recycled aggregates was acquired from the urban transformation project in Istanbul, this recycled concrete aggregate has a compressive strength of 8 and 10 MPa. The specimens are demoulded after 24 h. curing them in water saturated with lime at 20 °C until the day of the 28-day experiment. Specimens that are 28 days old are exposed to a column of water for 72 hours to measure the depth of the water(Akça et al., 2015).

C. Tests

The authors for the study of the mechanical properties of self-compacting concrete carried out tests of compressive and tensile strengths.

Aslani et al., to perform the compression tests, the hydraulic load machine was used, which presented a ratio of 0.2 kN/s until failure, according to the standard used of AS1012.14

The tests carried out allowed the mechanical properties of self-compacting concrete to be studied. Gao et al., for the compression tests, three cubic specimens of 150x150x150 mm were used , in which resistance tests were carried out at 3, 7 and 28 days of curing of the concrete, for this study the resistances obtained in 7 and 28 days of curing were analysed, testing them at a speed of 0.5 kN/s until failure.

For the tensile burst tests, three cubic specimens of 150x150x150 mm were used, the test was carried out under conditions of controlled displacement with a speed of 0.1 mm/min. The strengths obtained in 7 and 28 days of concrete curing are analysed, the DIC digital image correlation technique was used, which allows monitoring the deformation and propagation of cracks in the specimens.

The authors for the study of the mechanical properties of self-compacting concrete carried out tests of compressive and tensile strengths.

Wang et al, employed a 2000 kN press, using the 150x150x300 mm test specimens, in which the failure load is 0.1 MPa. In addition to this, a tension gauge is used to measure the modulus of elasticity, MOE, the compressive toughness of the polypropylene fibre.

Akça et al. Analyse compressive strength tests, modulus of elasticity to analyse the mechanical performance of concrete, compressive strength is performed with cubic specimens of 150x150x150 mm and to determine the modulus of elasticity cylindrical specimens of 150x300 mm are used.

III. Results

A. Discussion of the results: Self-compacting concrete

1) Properties

Based on the results compared in the ***Table 5*** we can study that in the first MC reference matrix the dosage has 100% recycled fine aggregates RFA and 100% recycled coarse aggregates RCA in which the latter remains constant through the tests. While the second RMc control matrix and its pertinent specimens are The study is carried out in which natural coarse and fine aggregates are replaced in varying volume ratios of 0%, 25%, and 100% coarse aggregate while the ratio of natural fine aggregate to RFA replacement is 0%, 25%, and 50%.

Likewise, the Mc and M1PPF specimens do not use steel fibre in addition together with the polypropylene fibres, but their study is based on the behaviour of self-compacting concrete with polypropylene fibres in the specimens.

In the relevant RMc and CR specimens in the study, the proportion of MSF steel fibres is added, together with the addition of polypropylene fibres of the PPF monofilament type.

Fig. 1 shows that the base matrix is the reference for the studies which when compared depending on the proportion of addition of polypropylene fibre and in the case of the article (Gao et al., 2023)the addition of steel fibres together with the PPF study fibres denotes the following:

The travel diameter of the self-compacting concrete in the settling test is larger and its travel time is shorter in the M1PPF sample with the incorporation of PPF in an addition of 0.1% compared to its base matrix Mc.

While the study of the RC group specimens (RC100RF00S10P10,RC00RF50S10P10, RC25RF25S10P10), the travel diameter is smaller when 0.1% of PPF is added to the mixture in reference to its RMc base matrix, this can be attributed to the weight added by RCAs greater than the first study and by the incorporation of steel fibres in the mixture.

When you make the comparison that is displayed in the Fig. 1 results can be defined based on the addition of PPF and other results with recycled aggregates. The higher the percentage of incorporation of polypropylene fibres and the higher percentage of recycled aggregates, the diameter in the settling test

TABLE V
POTENTIAL DOSAGES FOR STUDY – SELF-COMPACTING CONCRETE

Ref. Colour	Grouping	Cement (kg/m^3)	FA (fly ash) (kg/m^3)	Dross (kg/m^3)	SF (silica fume) (kg/m^3)	PPF (PP Fibres)	MSF (Milled Steel Fibres)	P (PPF) %	Sand kg/m^3	NFA (Natural Fine Aggregate)
[6]	RC00RF50S10P10	400	111	-	44	091	78	0.1%	-	396
[6]	RC25RF25S10P10	400	111	-	44	091	78	0.1%	-	594
Ref. Colour	**Grouping**	**RFA Recycled Fine Aggregate**	**Natural Coarse Aggregate NCA**	**RCA Recycled Coarse Aggregate**	**W Mixing Water**	**AW Additional Water**	**SP Super-plasticising**	**VWA Viscosity Modifier Additive**	**RCA %**	**RFA %**
[6]	RC00RF50S10P10	396	844	0	205	37	-	-	0	50
[6]	RC25RF25S10P10	198	623	208	205	26	-	-	25	25

decreases, where its travel time is much longer, which for a self-compacting concrete can influence its ability to pass through the surface and the metal structure and affect the setting.

Therefore, the incorporation of polypropylene fibres reduces fluidity and the ability to pass through in its fresh state.

In terms of substituting natural coarse and fine aggregate for recycled aggregates, it can be concluded that by incorporating a higher percentage of recycled aggregates, the T500 time in the mixtures increases, in a proportion by weight of 25% of RFA and 25% RCA is 43.75% (RC25RF25S10P10) compared to the base matrix RMc, while when substituting 50% of RFA it is 31.25% (RC00RF50S10P10) compared to RMc and when substituting 100% of natural coarse aggregate by RCA a time increase of 156.25% is obtained. (RC100RF00S10P10), so that its fluidity of passage decreases over a longer time.

In the Japanese Ring Studio Fig. 2. it is visualized when substituting natural aggregates for coarse recycled aggregates at 102% M1 PPF compared to the reference matrix and the addition of 0.1% polypropylene fibre in the mixture, its settling diameter is larger and the T500 passage time is shorter, which concludes that this dosage is optimal for the M1 PPF study in this case.

Continuing with the study, it is visualized that the greater the substitution of coarse recycled aggregates in the RC100RF00S10P10 mixture compared to the rest of the studies, it can be stated that the value of PJ has a lower capacity to pass through the Japanese ring, leading to difficulties in the fluidity of the concrete, while when comparing M1 PPF, it is clearly visualized that its travel diameter is larger, and its travel time in the study is lower, which implies that the passage capacity through the J ring allows the concrete to have better fluidity and therefore its passage capacity in a shorter time, than compared to the RC100RF00S10P10 specimen, in which the T500 percentage spreading value/time is 159.11% higher than the M1 PPF specimen.

When reducing the recycled aggregate RFA to 50% we can notice that the fluidity within the J ring is better, but it is still not optimal as its reference matrix, the same result is shown with the substitution of 25% of RFA and 25% of RCA, the difference is that the travel time in the last result is greater, This must be due to the use of steel fibres.

B. *Mechanical Properties*

1) *Compressive strength*

Based on the study of the Table 6 and Fig. 3 of the specimens of the Mc group (M1 PPF), the addition of the polypropylene fibres after 7 days of curing of the concrete causes a decrease in the compressive strength, while in comparison with the study of the specimens of the RMc group (RC100RF00S10P10) it shows that the higher the proportion by weight of coarse recycled aggregate RCA, the lower the compressive strength, but the lower the proportion of recycled coarse or fine aggregate (RC00RF50S10P10, RC25RF25S10P10), the addition of hybrid fibres in the case of the addition of 1% steel fibres and 0.1% polypropylene fibres, allows the mixture to be more resistant to compression tests, so that the high elastic MOE

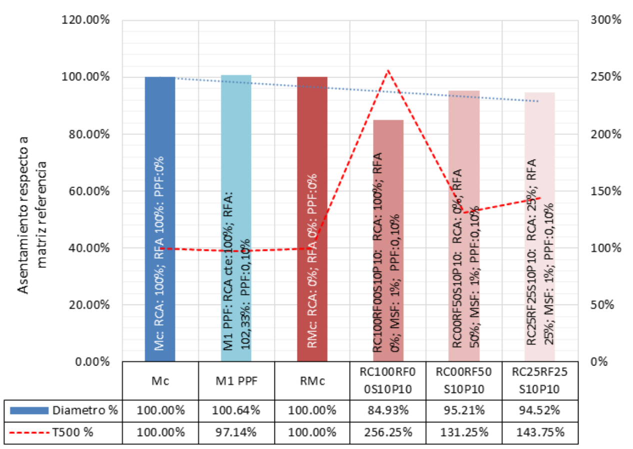


Fig. 1. Comparison of Step Skill- Settlement Test and T500 in HFRA SCC. (Source: Own elaboration)

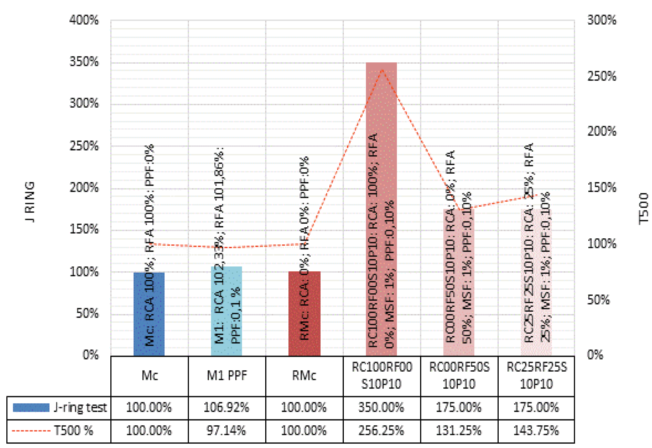


Fig. 2. Comparison of the behaviour of HFRA SCC in the J-ring and T500 test. (Source: Own elaboration)

TABLE VI
POTENTIAL DOSAGES FOR STUDY – SELF-COMPACTING CONCRETE

Ref. Colour	Grouping	% RFA	% RCA	S (MSF) %	WPF% by volume	% Compression 7 days	% Compression 28 days	Observation
[5]	Mc	100%	100.00%	0.00%	0%	100.00%	143.07%	Control Matrix
[5]	M1 PPF	102.33%	100.00%	0.00%	0.10%	51.73%	69.65%	
[6]	RMc	0.00%	0%	0.00%	0%	100.00%	138.23%	Control Matrix
[6]	RC100RF00S10P10	0.00%	100%	1.00%	0.10%	86.85%	129.68%	
[6]	RC00RF50S10P10	50.00%	0%	1.00%	0.10%	119.40%	153.51%	
[6]	RC25RF25S10P10	25.00%	25%	1.00%	0.10%	116.16%	149.68%	

modulus and the elongation properties of the fibres would limit the propagation of cracks.

In the Fig. 3 it can be observed that the greater the amount of recycled aggregates, the lower the compressive strength even when the incorporation of hybrid fibres is 1% MSF and PPF 0.1%, the compressive strength varies and exceeds the resistance of the base matrix when the incorporation of 50% of RFA recycled fine aggregates is made by 19.40% compared to the RMc reference matrix, while it decreases with the incorporation of 25% of RCA and 25% RFA by 3.25% (RC25RF25S10P10) in reference to the RC00RF50S10P10 specimen, but based on the reference matrix its compressive strength is greater by 16.16%.

The compressive strength at 28 days of curing concrete has a lower M1 PPF resistance than its reference matrix Mc when polypropylene fibre is added with a replacement of RCA of 100% and RFA of 102.33%.

But if we analyse Fig. 3 and Fig. 4 in the specimens of the RMc group, the compressive strength in the curing period of 7 days and 28 days we can denote that the resistance at 28 days increased by an average of 37.17% its compressive strength compared to the specimens with a curing of 7 days, based on the fact that the resistance of 7 days is 100% in the reference matrix specimen RMc (at 7 days)

The compressive strength decreases as RCA is incorporated, it is attributed due to RFA could have been similar to the composition of mortar (sand, concrete paste) contributing to a greater amount of dehydrated cement in RFA than in RCA.

But as the substitution of RFA and RCA is balanced and decreased, and polypropylene fibres are incorporated by 0.1%, its compressive strength increases at both 7 days and 28 days of curing.

2) Tensile strength

In the Table 7 and Fig. 5 it is visualized that the tensile strength due to rupture at 7 days decreases when 100% of RCA and RFA coarse and fine recycled aggregates are replaced as visualized in the M1 PFF specimen, but its tensile strength increases when 50% of natural fine aggregates are replaced by recycled fine aggregates in the specimen RC00RF50S10P10 by 40.07% compared to its RMc reference matrix.

By replacing 25% of natural fine and 25% coarse aggregates with recycled fine and coarse aggregates as shown in the RC25RF25S10P10 specimen, and the addition of 0.1% of 1% steel fibres and 0.1% polypropylene fibres, a higher strength than its RMc reference matrix of 29.21% is obtained. But it is denoted that this last substitution of 25% of both RFA and RCA presents a decrease in their tensile strength of 10.86% compared to when only 50% of fine recycled aggregates are replaced.

Analysing the Fig. 6 in the specimens of the RMc group, the tensile strength in the curing period of 7 days and 28 days we can denote that the resistance at 28 days increased by an average of 23.22% its tensile strength compared to the specimens with a curing of 7 days, based on the fact that the resistance at 7 days is 100% in the reference matrix specimen RMc (at 7 days).

When comparing the strengths obtained at 28 days of curing of self-compacting concrete, the RMc reference matrix specimen and the RC00RF50S10P10 specimen which presents a substitution of 50% of natural fine aggregates by recycled fine aggregates, with an addition of 0.1% of PPF and 1% of MSF, an increase in tensile strength of 22.47% is evidenced. And when a substitution of 25% of fine and coarse natural aggregates is made for 25% RFA and 25% RCA

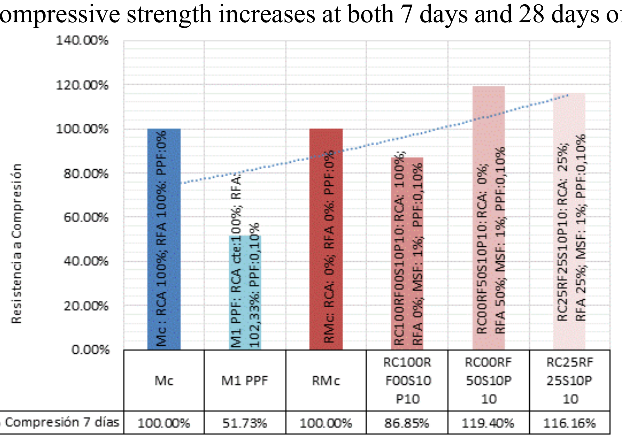


Fig. 3. Comparison of cured compressive strength 7 days HFRA SCC. (Source: Own elaboration)

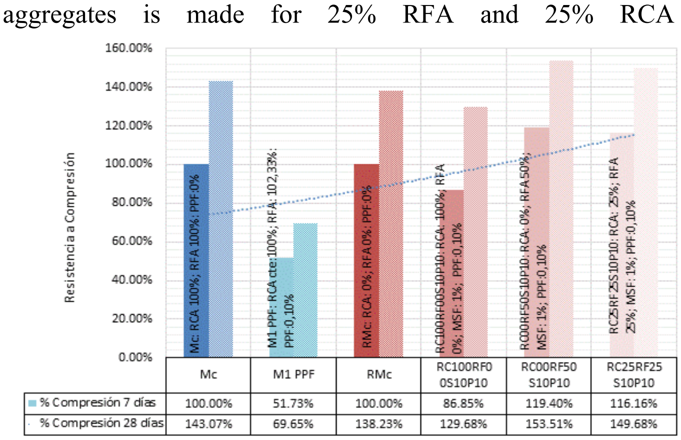


Fig. 4. Comparison of 7 and 28 day HFRA SCC cured compressive strength. (Source: Own elaboration)

TABLE VII
POTENTIAL DOSAGES FOR STUDY – SELF-COMPACTING CONCRETE

Ref. Colour	Grouping	% RFA	% RCA	S (MSF) %	WPF% by volume	% Tensile 7 days	% Tensile 28 days	Observation
[5]	Mc	100%	100.00%	0.00%	0.00%	100.00%	115.99%	Control Matrix
[5]	M1 PPF	102.33%	100.00%	0.00%	0.10%	65.83%	79.00%	
[6]	RMc	0.00%	0.00%	0.00%	0.00%	100.00%	135.96%	Control Matrix
[6]	RC100RF00S10P10	0.00%	100.00%	1.00%	0.10%	100.75%	116.85%	
[6]	RC00RF50S10P10	50.00%	0.00%	1.00%	0.10%	140.07%	158.43%	
[6]	RC25RF25S10P10	25.00%	25.00%	1.00%	0.10%	129.21%	151.69%	

(RC25RF25S10P10) compared to the RMc base matrix, an increase of 15.73% in its resistance is obtained, but it is lower than the resistance obtained with a substitution of 50% RFA (RC00RF50S10P10) which is 6.74% but even so it is much higher with the resistance of the reference matrix.

But if we analyse Fig. 6 in the specimens of the RMc group, the tensile strength in the curing period of 7 days and 28 days we can denote that the resistance at 28 days increased by an average of 23.22% its tensile strength compared to specimens with a curing of 7 days, based on the fact that the resistance of 7 days is 100% in the reference test specimen RMc (at 7 days).

In the Fig. 6 It is visualized that the tensile strength due to breakage is greater after 28 days of curing, it is denoted that the recycled coarse and fine aggregates influence the reduction of the tensile strength, but with the addition of hybrid fibres they could improve the resistance.

Taking into account that the best dosage would be found in the substitution of fine natural aggregates in 50% to RFA as well as 25% substitution of fine natural aggregates and 25% of coarse natural aggregates for 25% of RFA and 25% RCA with the addition of 0.1% of polypropylene fibres and 1% of steel fibres.

C. Traditional concrete

1) Constant percentage of polypropylene fibre

Results obtained from each of the specimens are shown in reference to the axial compressive strength as well as their modulus of elasticity, taking into account that the specimens of FNC-0-15-50 and N-C, are the control specimens, and their constant factor is the percentage of volume of polypropylene fibre (WPF), therefore it is studied how the percentage of increase of recycled aggregate influences the mixture for the analysis of compressive strength as well as in its modulus of elasticity.

Fig. 7 shows a comparison between the different proportions of substitution of natural aggregates by recycled aggregates of 0%, 30%, 60%, 100% and 0%, 25%, 30% and 55% with their constant percentage of polypropylene fibre of 1.5% with their control specimens FNC-0-15-50 and N-C respectively.

It is detailed that in the specimens with FNC and FRRC designation, a higher proportion of water was used to avoid the formation of fibre conglomerate in the mortar, during the mixing process, as well as a high rate of sand. While the specimens with the (Wang et al., 2023)N-C and R-C designation plasticizers were used to obtain better workability (Abraham et al., 2015)

The compressive strength of concrete is reduced by 5.46% when its RAC addition percentage is 30%, but the strength decreases significantly after the incorporation of higher percentages of recycled aggregates of between 5.43% and 17.34%.

It is observed in the Fig. 8, taking the premise that the

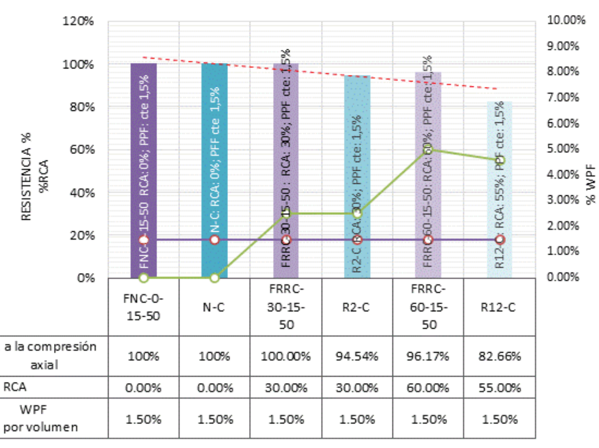


Fig. 8. Comparison of compressive strength of Concrete with recycled aggregates of 0%, 30%, 50% and 60% and PPF 1.5%. (Source: Own elaboration)

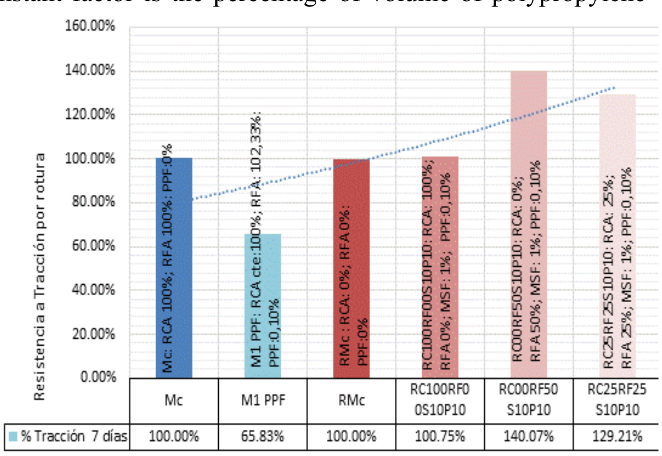


Fig. 5. Comparison of tensile strength due to 7-day curing of HFRA SCC curing. (Source: Own elaboration)

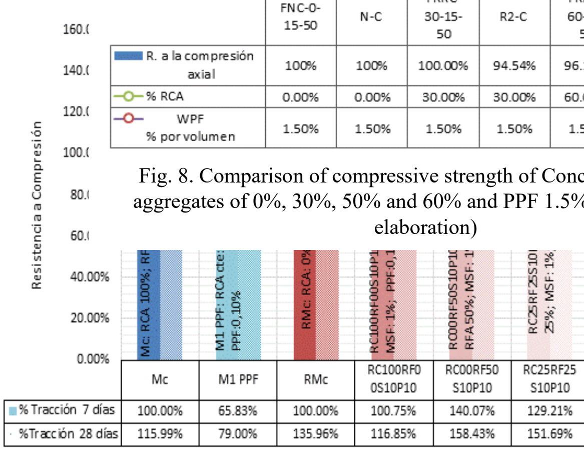
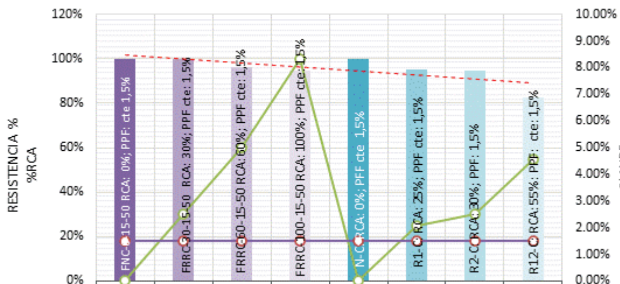


Fig. 6. Comparison of 7 and 28 day HFRA SCC curing tensile strength. (Source: Own elaboration)



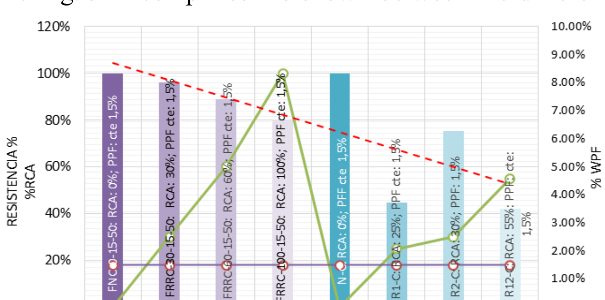
	FNC-0-15-50	FRRC-30-15-50	FRRC-60-15-50	FRRC-100-15-50	N-C	R1-C	R2-C	R12-C
R. compresión axial	100%	100.00%	96.17%	94.57%	100%	95.01%	94.54%	82.66%
% RCA	0.00%	30.00%	60.00%	100.00%	0%	25.00%	30.00%	55.00%
WPF % por volumen	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%

Fig. 7. Comparison of compressive strength of Concrete with the substitution of recycled aggregates of 0%, 30%, 60%, 100%, 25% and 55% and PPF. 1.5%. (Source: Own elaboration)

analysis is carried out with a constant percentage of polypropylene fibre volume of 1.5%, and the natural aggregates are replaced by a higher percentage of volume of recycled aggregates, the compressive strength of the concrete decreases compared to the control specimen, that is to say that when replacing the natural aggregates with 30% of recycled aggregates, a lower compressive strength of between 0 and 0 and 5.46%, while substituting between 55% and 60% of natural aggregates for recycled RAC aggregates results in a decrease of 10.58% in the compressive strength of the concrete, which can be attributed based on the references that due to the greater increase of recycled aggregates in the mixture they tend to absorb a greater amount of water, thus raising the water/cement ratio in the final mix.

Results obtained from each of the specimens are shown in reference to the modulus of elasticity, taking into account that the specimens of FNC-0-15-50 and N-C, are the control specimens, and their constant factor is the percentage of volume of polypropylene fibre (WPF), in which it is studied how the increase of recycled aggregate influences the modulus of elasticity of the concrete.

In the Fig. 9 A comparison is shown between the different



	FNC-0-15-50	FRRC-30-15-50	FRRC-60-15-50	FRRC-100-15-50	N-C	R1-C	R2-C	R12-C
Modulo de elasticidad	100%	96.05%	89.08%	80.34%	100%	44.60%	75.33%	42.01%
% RCA	0.00%	30.00%	60.00%	100.00%	0%	25.00%	30.00%	55.00%
WPF % por volumen	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%

Fig. 9. Comparison of the modulus of elasticity of Concrete with recycled aggregates of 0%, 30%, 60%, 100%, 25% and 55% and PPF. 1.5%. (Source: Own elaboration)

proportions of substitution of natural aggregates by recycled aggregates of 0%, 30%, 60%, 100% and 0%, 25%, 30% and 55% with their constant percentage of polypropylene fibre of 1.5% with their control concretes FNC-0-15-50 N-C respectively.

The modulus of elasticity of each concrete mix is reduced between 3.95% and 24.67% when its percentage of RAC addition is 30%, but the modulus of elasticity decreases significantly after the incorporation of higher percentages of recycled aggregates of between 19.66% and 42.01 with an incorporation volume of 100%.

Fig. 10. takes the premise that the analysis is carried out with a constant percentage of polypropylene fibre volume of 1.5%, and the natural aggregates are replaced by a higher percentage of volume of recycled aggregates, the modulus of elasticity of the concrete decreases the more volume of recycled aggregate is incorporated into the mixture, with a 30% RAC substitution a decrease of 3.95% is obtained in the FRRC-30-15-50 specimen, while in the R2-C specimen a decrease of 24.67%, while by replacing between 55% and 60% of natural aggregates with RAC, a decrease of 34.45% in the modulus of elasticity of the concrete is obtained.

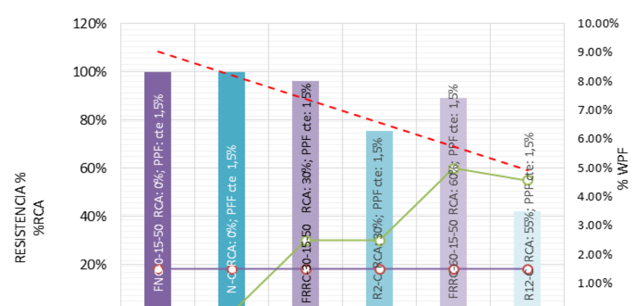
This elastic modulus has a direct influence on the static modulus, as the RAC substitution rate increases, the elastic modulus of the aggregates decreases, thus also causing a decrease in the static modulus of PPF residues.

2) Constant percentage of recycled aggregates

In the Fig. 11 , a comparison is shown between the different additions of polypropylene fibre of 0%, 1%, 1.5% and 2%, with proportions of substitution of natural aggregates by constant recycled aggregates of 100% and 55%, with their control specimens RC-100-0 and R12-A respectively.

It is detailed that in the specimens with the designation FRRC-100-20-50 and R12-C , a higher proportion of polypropylene fibre was used.

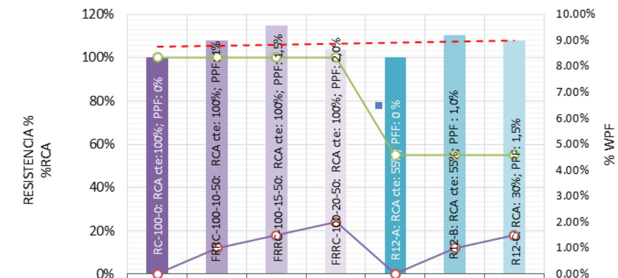
The compressive strength of concrete increases between 7% and 10.22% when its percentage of addition of polypropylene fibre is 1%, when its percentage of polypropylene fibre is 1.5% its compressive strength increases between 10.22% and



	FNC-0-15-50	N-C	FRRC-30-15-50	R2-C	FRRC-60-15-50	R12-C
Módulo de elasticidad	100%	100%	96.05%	75.33%	89.08%	42.01%
% RCA	0.00%	0.00%	30.00%	30.00%	60.00%	55.00%
WPF % por volumen	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%

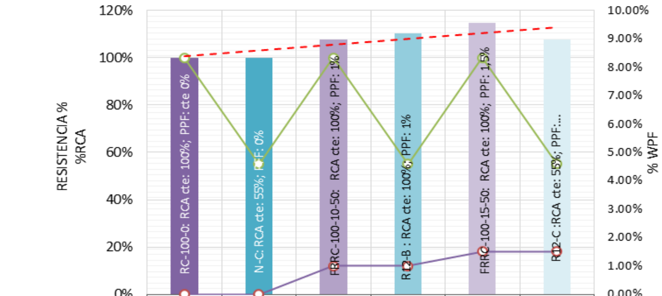
Fig. 10. Comparison of the modulus of elasticity of Concrete with recycled aggregates of 0%, 30%, 55%, 60% and PPF. 1.5% (Source: Own elaboration)

14.73%, but the strength decreases significantly after the



	RC-100-0	FRRC-100-10-50	FRRC-100-15-50	FRRC-100-20-50	R12-A	R12-B	R12-C
R. compresión axial	100.00%	107.75%	114.73%	103.88%	100.00%	110.22%	107.74%
% RCA	100.00%	100.00%	100.00%	100.00%	55%	55%	55%
WPF % por volumen	0%	1%	1.50%	2.00%	0%	1%	1.50%

Fig. 11. Comparison of compressive strength of Concrete with the substitution of recycled aggregates of 0%, 30%, 60%, 100%, 25% and 55% and PPF. 1.5%. (Source: Own elaboration)



	RC-100-0	R12-A	FRRC-100-10-50	R12-B	FRRC-100-15-50	R12-C
R. compresión axial	100.00%	100.00%	107.75%	110.22%	114.73%	107.74%
% RCA	100.00%	55%	100.00%	55%	100.00%	55%
WPF % por volumen	0%	0%	1%	1%	1.50%	1.50%

Fig. 12. Comparison of compressive strength of Concrete with recycled aggregates of 0%, 30%, 50% and 60% and PPF 1.5%. (Source: Own elaboration)

incorporation of a percentage greater than 2% with a decrease of 10.85% FRRC-100-20-50 in reference to the FRRC-100-15-50 specimen with an addition percentage of 1.5% PPF, but it should be noted that the compressive strength of this specimen is greater than the resistance obtained in the control specimen.

It is observed in Fig. 12, taking the premise of a constant percentage of volume of recycled aggregates of 100% and 55%, and varying the percentage of volume of polypropylene fibre from 0%, 1%, 1.5%, in it is visualized that, the greater the volume of addition of polypropylene fibre, the greater the axial compressive strength compared to the control specimen, which in turn influences the hardening stage of the concrete, since at certain proportions not exceeding between 1 and 1.5% of PPF, when spreading within the mixture and arriving at the concrete hardening stage, these limit the creation of microcracks, and therefore the pores of the concrete are reduced.

But if it exceeds the addition ratios of 1.5% compressive strength tends to decrease this may be due to the accumulation of fibres as well as uneven dispersion in the concrete resulting in weak cross-sections, (Wang et al., 2023)

As visualized, when an addition of 1% polypropylene fibres is made in a mixture of concrete with recycled aggregates, an increase in compressive strength of between 7.75% and 10.22% is obtained compared to the reference specimen, when the increase in fibre is 1.5%, there is a compressive strength of 6.98% compared to the specimen with an addition volume of 1% PPF, this in the case of the FRRC-100-15-50 specimen, but it is the case in which increasing 1.5% of PPF in a substitution mixture of 55% of recycled aggregates results in a decrease in compressive strength of 2.48% compared to the percentage of 1% of PFF.

The factors that can influence the compressive strength of a concrete is mainly the type of aggregate, the percentage of substitution that is incorporated into the mixture, since several of these recycled aggregates have a porous structure, which he attributes to an increase in water absorption.

The incorporation of polypropylene fibres, the length-diameter relationship influences the physical properties, since they would help the correct adhesion between the concrete and the aggregates in this mixture.

Fig. 13 shows a comparison between the different proportions of addition of polypropylene fibres of 0%, 1%, 1.5% and 2% and the substitution of recycled aggregates of 100% and 55% as a constant percentage with their control concretes RC-100-0 and R12-A respectively.

The modulus of elasticity of each concrete mix is reduced between 4.01% and 29.24% when its percentage of addition of polypropylene fibres is 1.5%, the modulus of elasticity continues to decrease when the fibre is still incorporated.

It is observed in the Fig. 14, taking the premise of a constant percentage of volume of recycled aggregates of 100% and 55%, and varying the percentage of volume of polypropylene fibre from 0%, 1%, 1.5%, the modulus of elasticity of the concrete decreases the more volume of polypropylene fibre is incorporated into the mix, with 1% of PPF a decrease of modulus of elasticity of 2.56% is generated in the specimen FRRC-100-10-50, while in the R12-B specimen a decrease of 15.35%, while by substituting between 100% and 55% of natural aggregates for RAC, with the aggregate constant of polypropylene fibres of 1.5%, a decrease of 4.01% and 29.24% respectively in the modulus of elasticity of the concrete is obtained.

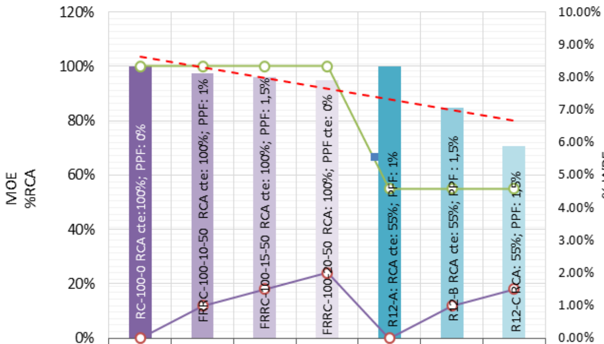
This elastic modulus has a direct influence on the static modulus, as the RAC substitution rate increases, the elastic modulus of the aggregates decreases, thus also causing a decrease in the static modulus of PPF residues.

IV. Conclusions

The necessary independent sections can be included in each work.

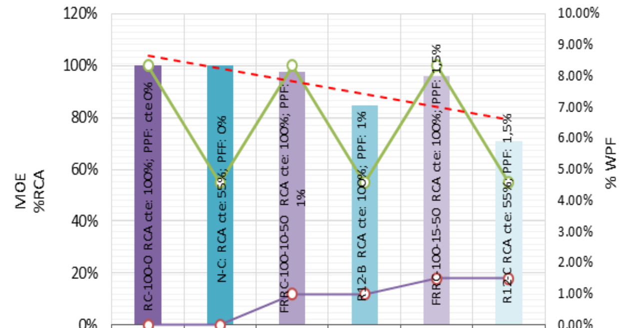
Three examples have been included in this model: "Experimental Device", "Results" and "Conclusions". An attempt should be made to preserve the original format throughout the work presented.

- The higher the percentage of incorporation of polypropylene fibres and the higher percentage of recycled aggregates, the diameter in the settling test decreases, where its travel time is much longer, which for a self-compacting concrete can influence its ability to pass through the surface and the metal structure and affect the setting.



	RC-100-0	FRRC-100-10-50	FRRC-100-15-50	FRRC-100-20-50	R12-A	R12-B	R12-C
Modulo de elasticidad	100.00%	97.44%	95.99%	94.81%	100.00%	84.65%	70.76%
% RCA	100.00%	100.00%	100.00%	100.00%	55%	55%	55%
WPF % por volumen	0%	1%	1.50%	2.00%	0%	1%	1.50%

Fig. 13. Comparison of the modulus of elasticity of Concrete with recycled aggregates of 0%, 30%, 60%, 100%, 25% and 55% and PPF. 1.5%. (Source: Own elaboration)



	RC-100-0	R12-A	FRRC-100-10-50	R12-B	FRRC-100-15-50	R12-C
Modulo de elasticidad	100.00%	100.00%	97.44%	84.65%	95.99%	70.76%
% RCA	100.00%	55%	100.00%	55%	100.00%	55%
WPF % por volumen	0%	0%	1%	1%	1.50%	1.50%

Fig. 14. Comparison of the modulus of elasticity of Concrete with recycled aggregates of 0%, 30%, 55%, 60% and PPF. 1.5% (Source: Own elaboration)

- By substituting a higher percentage of fine and coarse recycled aggregates RFA and RCA, their passing ability decreases over a longer time, which is not optimal for mixing.
- In the study of the Japanese ring, it is concluded that when replacing 50% of RFA fine recycled aggregates, the fluidity of the J ring is better, it is not optimal like a normal self-compacting concrete with natural aggregates, and its travel time in the test is longer, but it is an adequate dosage for study, the same happens when it is replaced by 25% RFA and 25% RCA the fluidity in the ring decreases and Its travel time is longer. But it is denoted that when substituting percentages greater than 100% of RFA and RCA in the mixture with the addition of 0.1% polypropylene fibres, a longer concrete path is obtained with a shorter T500 time, concluding that in the study of fresh properties the latter is better for study.
- Compressive strength decreases when 100% natural fine and coarse aggregates are replaced by RFA fine aggregates and RCA recycled coarse aggregates.
- The addition of polypropylene fibres in the mixture does not greatly influence the compressive strength when 100% natural aggregates are replaced by recycled aggregates.
- The compressive strength of self-compacting concrete increases when there is a substitution of between 25% RFA and 25% RCA, resulting in a higher strength of 3.35% compared to its reference matrix, and when it is replaced by 50% RFA, a higher strength of 19.40% is obtained. compared to its reference matrix, these values referring to 7 days of curing.
- Compressive strength increases when its curing time is 28 days by an average of 37.17% in reference to RMc, and by a total average of 34.95% compressive strength compared to its strengths at 7 days.
- By replacing 50% of natural fine aggregates with recycled fine aggregates from concrete with a polypropylene fibre ratio of 0.1%, the tensile strength is higher than a normal self-compacting concrete.
- It is denoted that by substituting 25% of the volume of fine recycled aggregates and 25% natural coarse aggregates with 25% of fine aggregates and 25% coarse recycled concrete with an addition of polypropylene fibre of 0.1% and 1% of steel fibres , its tensile strength decreases, but still exceeds the strength of a normal self-compacting concrete.
- The tensile strength increases when its curing time is 28 days by an average of 23.22% in reference to RMc, and by a total average of 20.34% tensile strength compared to its strengths at 7 days.
- The compressive strength in traditional concrete is reduced by 5.46% when a percentage of 30% RCA is replaced with a constant percentage of 1.5% polypropylene fibres, this strength decreases significantly when the percentage of replacement of recycled aggregates RAC is higher, giving a decrease in its strength in 5.43 and 17.34%, this can be attributed to the fact that due to the increase in recycled aggregates in the mixture, they tend to absorb a greater amount of water, thus raising the water/cement ratio in the final mixture, which affects the final strength of the concrete.
- When the percentage of recycled aggregate RAC is constant and the percentage of volume of WPF polypropylene fibre is variable , favourable results are obtained.
- The compressive strength increases between 7% and 10.22% when the percentage of polypropylene fibre is 1%, when the percentage of polypropylene fibre is 1.5% the compressive strength increases between 10.22 and 14.73%.
- Compressive strength decreases when the percentage of polypropylene fibre is greater than 2% compared to the strength obtained with a percentage of 1.5% PPF.

- The modulus of elasticity of the concrete decreases the higher the percentage of volume of recycled aggregate is incorporated into the mixture, with a 30% RAC substitution a decrease of 3.95% is obtained in the FRRC-30-15-50 specimen, while in the R2-C specimen a decrease of 24.67%, while when substituting greater quantities between 55% and 60% of natural aggregates by RAC, a decrease of 34.45% in the modulus of elasticity of concrete is obtained.
- This elastic modulus has a direct influence on the static modulus, as the RAC substitution rate increases, the elastic modulus of the aggregates decreases, thus also causing a decrease in the static modulus of PPF residues.
- When the percentage of recycled aggregate RAC is constant and the percentage of volume of polypropylene WPF fibre is variable , lower results are obtained.

The modulus of elasticity of concrete is reduced between 4.01% and 29.24% when its percentage of polypropylene fibres is 1.5%, and the higher the percentage of polypropylene fibre, the modulus of elasticity decreases.

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