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Comparison of the Mechanical Behavior of Concrete Containing Recycled CFRP Fibers and Polypropylene Fibers

María Isabel Prieto [1,*], María de las Nieves González [1], Alfonso Cobo [1] and David Alonso [2]

[1] Escuela Técnica Superior de Edificación, Universidad Politécnica de Madrid, Avda. Ramiro de Maeztu, 7, 28040 Madrid, Spain; mariadelasnieves.gonzalez@upm.es (M.d.l.N.G.); alfonso.cobo@upm.es (A.C.)
[2] Ekora Rehabilitación, S.L., C/Kandelazubieta N°1, 48940 Leioa, Spain; david.alonso.redondo@gmail.com
* Correspondence: mariaisabel.prieto@upm.es; Tel.: +34-910-675-434

Abstract: The incorporation of natural or recycled fibers in concrete represents a field for improvement in this structural material and a step towards sustainability. The objective of this research is to determine whether the addition of recycled carbon fibers (CFRP), which have been hardened using epoxy resin, improves the behavior of concrete and whether its performance is comparable to that achieved by adding polypropylene fibers, which would result in a viable recycling alternative for this type of fiber. In order to explore this objective, 120 specimens were produced, on which compression, flexural, and impact tests were performed, and into which recycled CFRP fibers or polypropylene fibers were incorporated. By comparing the results obtained, it may be concluded that the addition of fibers substantially improves the ductility of the concrete and reduces the spalling effect when compared to concretes without added fibers. The concretes containing recycled CFRP fibers in quantities of 3 kg/m^3 and 6 kg/m^3 obtain better flexural and impact behaviors than concretes featuring the same amounts of polypropylene fibers, making this recycling alternative viable for CFRP fibers as well as reducing the amount of energy and raw materials that would be used to manufacture the fibers.

Keywords: recycled CFRP fibers; polypropylene fibers; concrete; compression; flexural; impact

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1. Introduction

Concrete is currently the most commonly used material in the construction industry, be it in civil works or building projects, due to its good mechanical properties and versatility, but it represents a broad field for improvement based on the addition of different types of fibers, including steel, natural, glass, etc., with these being either new or recycled [1–9].

The addition of steel fibers, the most commonly used fibers, produces a better mechanical behavior of concrete compared to concrete without fibers or with the addition of polypropylene fibers, but they have other disadvantages, which makes the addition of polypropylene fibers rise in importance [10,11].

Polypropylene is a thermoplastic obtained by the polymerization of propylene, a gaseous by-product of petroleum refining, which is transformed by extrusion into continuous and discontinuous polypropylene fibers assembled in a plastic matrix. Its incorporation into concrete leads to improvements in the non-linear behavior of concrete, increasing its resistance to crack propagation and preventing the formation of new cracks. This is because the incorporation of discontinuous fibers in a brittle material such as mass concrete ensures that they adhere internally to the composite, allowing it to resist higher stresses and increasing its ductility. The greater amount of polypropylene fibers per kg compared to steel fibers causes a better stress redistribution to be generated, increasing the total contact surface and reducing the proximity between them, which is why the polypropylene fibers offer concrete greater ductility and energy absorption capacity than steel fiber [5,12–14].

The addition of these fibers also improves the impact resistance and tensile strength of concrete [7,15–17]. With this type of addition, the quantity, type, and size of the fibers play an important role, wherein the higher percentage of the addition does not lead to better results [5]. The addition of polypropylene fibers also improves the fire resistance of the concrete as, beyond its melting point of approximately 170 °C, internal channels are created that allow the water vapor to escape, reducing the pressure within the mixture. This reduces the "spalling" effect, an effect that does not occur when steel fibers are incorporated [18–20]. In addition, it improves the mechanical properties of concretes that do not contain fibers at a cheaper price than if steel fibers were incorporated [21]. Another important aspect is that the results of the bending and impact tests depend to a great extent on the amount of fibers located in the rupture region of the specimens, hence the importance of distributing the fibers throughout the mixture [22]. It was also observed that the incorporation of polypropylene fibers produced a reduction in the diffusivity of chlorides, the opposite effect to that produced with the incorporation of steel fibers [23]. Another important aspect is that polypropylene fibers are chemically inert, which avoids the problem that could cause the corrosion of steel fibers.

Within the types of polypropylene fibers, the use of macrofibers is increasingly common, since it has been observed that their addition increases ductility and produces better energy dissipation, serving as a seam between the cracks and increasing the stress resisted by polypropylene macrofibers with increasing fissure opening. Furthermore, it is observed that once the cracks are stabilized, these fibers resist an increase in the residual load, even in large crack openings [24–27].

The use of carbon fiber reinforced polymers (CFRC) has increased significantly when used in numerous fields, such as industry, construction, transportation, etc., with the US and Mexico, with 36% of production, followed by Japan with 20%, as the largest producers of this type of material [28]. Projected estimates of CF demand reach an annual growth rate of 11%, with a total global CF demand of up to 117,000 tonnes estimated for 2022 [29,30]. This high demand due to its excellent mechanical properties, durability, and light weight will significantly increase the amount of CFRP waste in the coming years, produced both in the manufacturing process and at the end of its useful life, estimated globally as reaching an annual quantity of 20,000 tons by 2025 [31–35]; as a result, good management of these products is necessary, which would make it possible to recover carbon fibers from waste and ensure their reintroduction as secondary raw materials instead of being disposed of in landfills or burning them in incineration plants, notably the two most widely used methods currently [36]. However, the relative environmental benefits of advanced recycling processes (i.e., pyrolysis, fluidized bed, and the chemical recycling process) provide superior environmental performance compared to conventional composite waste treatment technologies [37].

Mechanical recycling will be profitable if fiber recovery rates close to 100% are achieved and degradation of fiber mechanical properties is minimized, thereby ensuring the financial viability and environmental benefit of recycling fiber-reinforced polymer carbon [38].

Studies that have been carried out show that there are currently several recycling and re-manufacturing processes in an advanced stage, with commercial scale implementations of recycling processes, production of recycled CFRP with competitive structural performance, and demonstration components that have been manufactured [39].

One of the most widespread uses in building is the use of carbon fiber sheets or fabrics (CFRP) for the reinforcement of concrete structures because their physicochemical properties are even better than those of traditional materials and also they weigh very little [40].

The reuse of recycled CFRP in the form of fibers is one of the recycling alternatives for this kind of waste. These fibers, taken from CFRP sheets or fabrics and added to concrete either on their own or combined with other types of fiber, slightly improve its compressive strength, while its ductility, flexural toughness, impact resistance, and energy absorption capacity significantly improve. Previous studies show that increasing the volume fraction and length of the recycled carbon fiber improves the mechanical properties and impact resistance of the reinforced mix compositions, while reducing workability [41–43]. Other aspects to bear in mind are that the workability of the concrete is reduced when the length and content of the fibers is increased and that an increase in porosity may be caused, particularly, when what are known as "soft" CFRP fibers are added [41,42]. The addition of recycled CFRP fibers also increases the electrical conductivity of the concrete, which is a starting point for manufacturing multi-functional materials [44].

The recycled CFRP fibers made from polymers reinforced with carbon fibers ex-tracted from structural elements are obtained from semi-rigid sheets that have been appropriately cut in the shape of fibers or small irregular pieces. Research shows an improved performance with the addition of the small FRP pieces, with better flexural strength, although compressive strength is not improved when compared with concretes without additives. Similar behavior is seen in cement mortars [43,45].

The need to recycle this type of waste has led researchers to study its behavior when hybridized with other recycled materials, such as tires, wherein the compressive strength of mixed compounds was observed as improving slightly, while ductility, resistance to bending, impact resistance, and energy absorption capacity were significantly improved [46]. Their behavior has also been compared with other recycled fibers, such as recycled glass fibers, wherein recycled carbon fibers were observed as having higher rates of gain in compressive strength than recycled glass fibers, while recycled glass fibers had higher rates of increase in flexural strength than recycled carbon fibers [47].

Taking the above premises into account, the objective of this research is to determine whether the addition of recycled CFRP fibers, which have been hardened using epoxy resin, improves the behavior of concrete and whether its properties are comparable to those achieved by adding polypropylene fibers, which would result in a viable recycling alternative for this type of waste.

2. Materials and Methods

In order to perform the experiments required for the present research, the materials listed below were used:

- CEM II/B-L 32.5 N cement, prepared according to regulations UNE-EN 197 [48] and RC-16 [49] with regard to conformity, composition, and specification criteria, and in accordance with the quality management and environmental management standards ISO 9001 [50] and ISO 14001 [51].
- Fine graded washed silica sand with a particle size of 0–4 mm. The aggregate used complies with regulations UNE-EN 12620:2003 + A1 [52] and UNE-EN 13139 [53].
- Coarse graded washed silica aggregate with a particle size of 4–12 mm. The aggregate used complies with regulations UNE-EN 12620:2003 + A1 [52] and UNE-EN 13139 [53].
- Drinking water from the Canal de Isabel II Madrid region's main water supply, which complies with the technical specifications for its use in structural concrete.
- Macro synthetic polypropylene fibers (SikaFiber T-48). These fibers comply with the specifications of regulation UNE-EN 14889-2: 2008 [54] with regard to the conformity requirements for polymer fibers for concrete.
- Recycled carbon fibers manually extracted from wooden elements measuring 80 mm × 155 mm × 1000 mm. It was previously tested in the materials laboratory at the Escuela Técnica Superior de Edificación as part of the doctoral thesis of Enrique Gómez and used by way of reinforcement in U-shaped flexural test [55].
- Superplasticizer based on polycarboxylates (MasterGlenium SKY 604), adding 0.7% of the superplasticizer in relation to the cement weight. The additive used complies with regulation UNE-EN 934-2:2010 + A1 [56].

The characteristics and appearance of the fibers are described in Table 1 and Figure 1.

Table 1. Characteristics of the fibers used.

Materials	Characteristics
Two-way CFRP fabric (0°/90°)	Grade: 160 ± 5% (g/m^2) Length: 48 mm Thickness: 0.04 mm Width: 2 mm Modulus of elasticity: 208,590 N/mm^2 Tensile strength: 4757 N/mm^2
Polypropylene fibers	Density: 0.91 kg/L (+20 °C) Quantity (units/kg): 102 million Length: 48 mm Equivalent diameter: 0.93 mm Slenderness ratio: 51.61 Tensile strength: 400 N/mm^2 Modulus of elasticity: 6.2 N/mm^2 Melting point: 170 °C

Figure 1. Polypropylene fibers and recycled carbon fibers.

In order to be able to assess the performance of the concrete, 5 mixes were produced: one reference mix and four mixes containing added polypropylene or recycled carbon fibers in quantities of 3 kg/m^3 and 6 kg/m^3, and in accordance with Annex 14 of the EHE [57]. The dosages for each mix and types of specimens made are set out in Tables 2 and 3.

Table 2. Types of specimens made.

Specimen/Mix	Reference	Carbon Fiber 3 kg/m^3	Carbon Fiber 6 kg/m^3	Polypropylene Fiber 3 kg/m^3	Polypropylene Fiber 6 kg/m^3
Cylindrical specimens ϕ100 mm × 200 mm	6	6	6	6	6
Cubic specimens 100 mm × 100 mm × 100 mm	6	6	6	6	6
Prismatic specimens 500 mm × 50 mm × 50 mm	6	6	6	6	6
Slabs 520 mm × 100 mm × 30 mm	6	6	6	6	6
TOTAL	24	24	24	24	24

Table 3. Dosages of mixtures.

Specimen/Mix	Reference	Carbon Fiber 3 kg/m^3	Carbon Fiber 6 kg/m^3	Polypropylene Fiber 3 kg/m^3	Polypropylene Fiber 6 kg/m^3
Cement (kg)	12.21	12.21	12.21	12.21	12.21
Sand (kg)	25.43	25.43	25.43	25.43	25.43
Gravel (kg)	44.20	44.20	44.20	44.20	44.20
Water (L)	5.60	5.60	5.60	5.60	5.60
Additive (g)	85.5	85.5	85.5	85.5	85.5
Addition (g)	—	73.80	147.60	73.80	147.60

The nomenclature used and the tests performed on the different specimen types are displayed in Table 4.

Table 4. Nomenclature and specimens.

Specimens/Test	Reference	Carbon 3 kg/m^3	Carbon 6 kg/m^3	Polypropylene 3 kg/m^3	Polypropylene 6 kg/m^3
Cylindrical specimens Compression tests	C-1	C-FC3-1	C-FC6-1	C-PP3-1	C-PP6-1
	C-2	C-FC3-2	C-FC6-2	C-PP3-2	C-PP6-2
	C-3	C-FC3-3	C-FC6-3	C-PP3-3	C-PP6-3
	C-4	C-FC3-4	C-FC6-4	C-PP3-4	C-PP6-4
	C-5	C-FC3-5	C-FC6-5	C-PP3-5	C-PP6-5
	C-6	C-FC3-6	C-FC6-6	C-PP3-6	C-PP6-6
Cubic specimens Compression tests	CU-1	CU-FC3-1	CU-FC6-1	CU-PP3-1	CU-PP6-1
	CU-2	CU-FC3-2	CU-FC6-2	CU-PP3-2	CU-PP6-2
	CU-3	CU-FC3-3	CU-FC6-3	CU-PP3-3	CU-PP6-3
	CU-4	CU-FC3-4	CU-FC6-4	CU-PP3-4	CU-PP6-4
	CU-5	CU-FC3-5	CU-FC6-5	CU-PP3-5	CU-PP6-5
	CU-6	CU-FC3-6	CU-FC6-6	CU-PP3-6	CU-PP6-6
Prismatic specimens Flexural tests	P-1	P-FC3-1	P-FC6-1	P-PP3-1	P-PP6-1
	P-2	P-FC3-2	P-FC6-2	P-PP3-2	P-PP6-2
	P-3	P-FC3-3	P-FC6-3	P-PP3-3	P-PP6-3
	P-4	P-FC3-4	P-FC6-4	P-PP3-4	P-PP6-4
	P-5	P-FC3-5	P-FC6-5	P-PP3-5	P-PP6-5
	P-6	P-FC3-6	P-FC6-6	P-PP3-6	P-PP6-6
Slabs Impact tests	L-1	L-FC3-1	L-FC6-1	L-PP3-1	L-PP6-1
	L-2	L-FC3-2	L-FC6-2	L-PP3-2	L-PP6-2
	L-3	L-FC3-3	L-FC6-3	L-PP3-3	L-PP6-3
	L-4	L-FC3-4	L-FC6-4	L-PP3-4	L-PP6-4
	L-5	L-FC3-5	L-FC6-5	L-PP3-5	L-PP6-5
	L-6	L-FC3-6	L-FC6-6	L-PP3-6	L-PP6-6

In order to start the process of producing the concrete, all materials were prepared in the materials laboratory at the Escuela Técnica Superior de Edificación of the Universidad Politécnica de Madrid. Once the materials were weighed, the cement, sand, and gravel were poured into the IBERTEST vertical planetary concrete mixer, model CIB-701 updated to IB32-040V0, and dry mixed. Subsequently, with the mixer switched on, the mixing water was gradually added, followed by the superplasticizer, in accordance with the instructions on the specification sheet [58]. After ensuring that the mixture was uniform, the fibers were added. All mixes underwent slump testing in line with regulation UNE-EN 12350-2 [59] using the Abrams Cone. The cylindrical and cubic specimens were produced using standardized steel molds in accordance with regulation UNE-EN 12390-1:2001 [60]. The prismatic specimens and slabs were produced using detachable wooden molds. Once the molds were filled, compacted, and evened out, they were left for 24 h at laboratory temperature (22 °C ± 3 °C with an approximate relative humidity of 60%). Once this period passed, they were placed in the humidity chamber (at 20 °C ± 2 °C with a relative humidity of ≥95%) and left to set and harden for 28 days, in accordance with regulation UNE-EN 12390-2 [61].

Both the cylindrical and cubic specimens underwent facing and compression testing following regulation UNE-EN 12390-3 [62]. The compression testing was performed in an IBERTEST MIB-60/AM universal press at a compression speed of 0.5 mm/min for all specimens, as can be seen in Figure 2a.

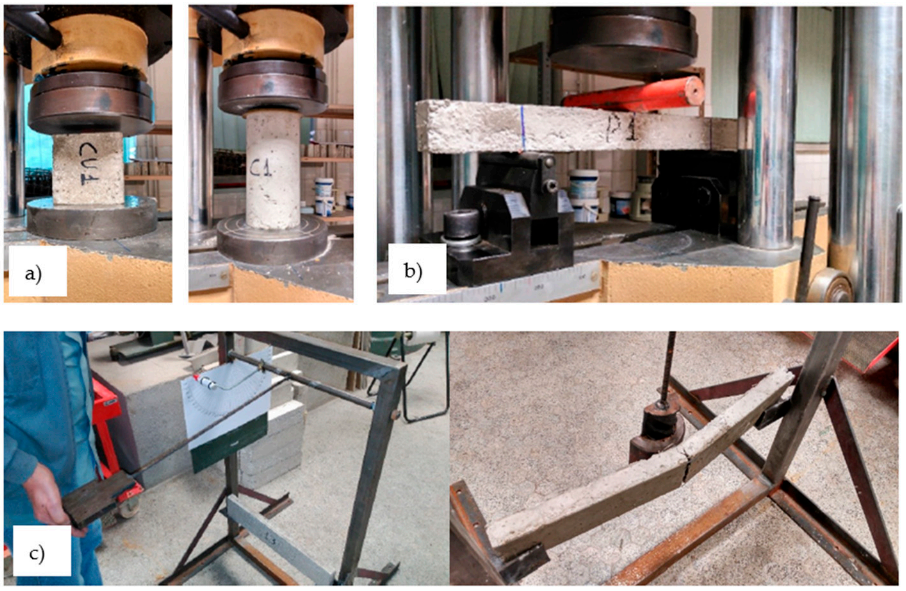


Figure 2. Tests performed: (**a**) compression; (**b**) flexural; and (**c**) impact.

The flexural test was performed under three-point loading conditions with a distance of 31 cm between the supports and while applying the load in the center of the specimens, in accordance with the instructions set out in regulation UNE EN 12390-5 [63], as can be seen in Figure 2b.

The impact resistance testing was performed using the Charpy Pendulum (Figure 2c), which makes it possible to calculate the fracture energy by means of the following formula:

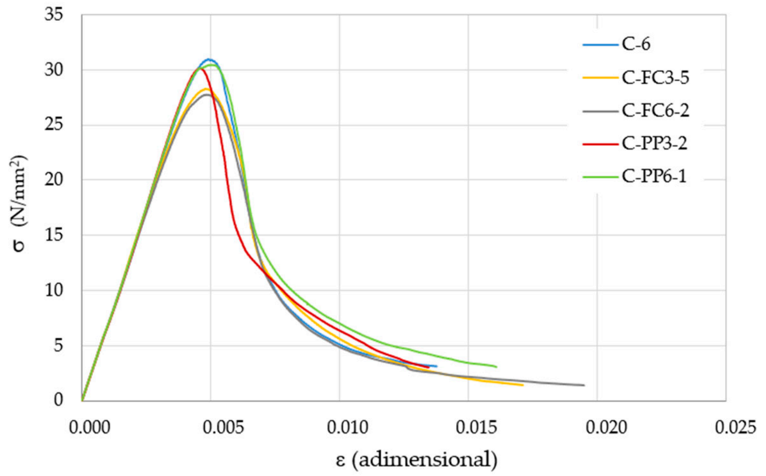
$$\tau = P\,(h - h')\,g = PL\,(cos\beta - cos\alpha)\,g \quad (1)$$

where

τ = fracture energy expressed in joules;
P = pendulum mass expressed in kilograms (2.70 kg);
L = length from the pendulum arm to its point of impact (0.64 m);
β = initial pendulum height from which it is released;
α = final height reached by the pendulum after hitting the specimen; and
g = gravitational acceleration (9.80665 m/s^2).

3. Results and Discussion

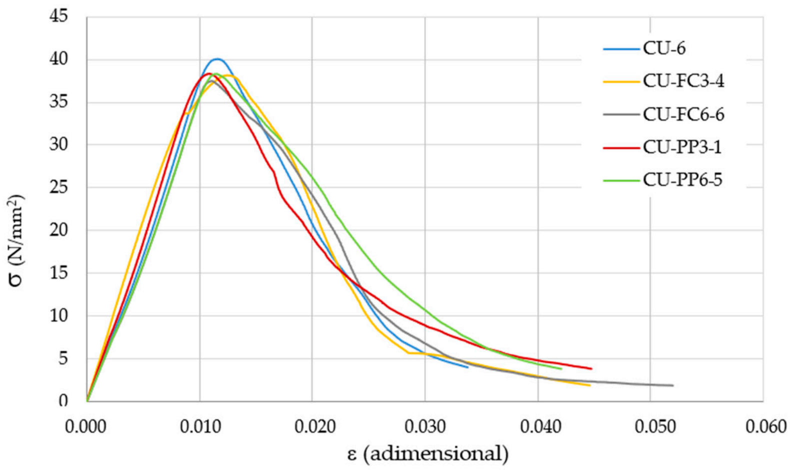
Figure 3 shows the results obtained in the compression testing of the cylindrical specimens, displaying the most representative graph for each dosage with polypropylene fibers, recycled carbon fibers, and without fibers. As can be observed, the concrete containing recycled carbon fibers displayed a slightly lower compressive strength than the concrete without added fibers. It was observed that in the specimens containing fibers, adding a greater amount of fibers did not reduce the compressive strength and similar performances were noted for both addition amounts.



	C	C-FC-3	C-FC-6	C-PP-3	C-PP-6
σ_{max} (N/mm^2)	30.633	28.019	27.454	29.251	29.972
Standard deviation	2.080	1.647	0.564	1.450	0.936

Figure 3. Strength–strain graph from the compression tests on the cylindrical specimens.

The results of the compression testing of cubic specimens are displayed below (Figure 4) and they exhibited similar behaviors to the cylindrical specimens in that the addition of fibers did not substantially change their compressive strength but rather improved their ductility.



	CU	CU-FC-3	CU-FC-6	CU-PP-3	CU-PP-6
σ_{max} (N/mm^2)	39.810	37.425	36.805	38.600	38.289
Standard deviation	0.463	1.700	0.933	0.614	1.212

Figure 4. Strength–strain graph from the compression tests on the cubic specimens.

As can be seen in Figures 3 and 4, the behavior of concrete with polypropylene fibers and recycled carbon fibers was very similar, not offering different behaviors, with both addition percentages.

Figure 5 shows the most representative mean values of the compression tests of the cylindrical and cubic specimens, which are the following: maximum strength (σ_{max}), strain associated with the maximum strength (ε_{max}), ultimate strength (σ_u), ultimate strains (ε_u), maximum strain energy density (E_{max}), and ultimate strain energy density (E_u). As can be seen in Figure 5, the behavior shown by concretes was similar in the cylindrical and cubic specimens, with the difference corresponding to the geometry of the specimens. The ultimate strengths were lower in the concretes containing recycled carbon fibers than in the concretes containing polypropylene fibers or those without fibers. Where the maximum strains were concerned, the values were similar for all concrete types, while the ultimate strains were higher for the concretes containing fibers. The highest ultimate strains were achieved in concretes containing recycled carbon fibers in a quantity of 6 kg/m^3.

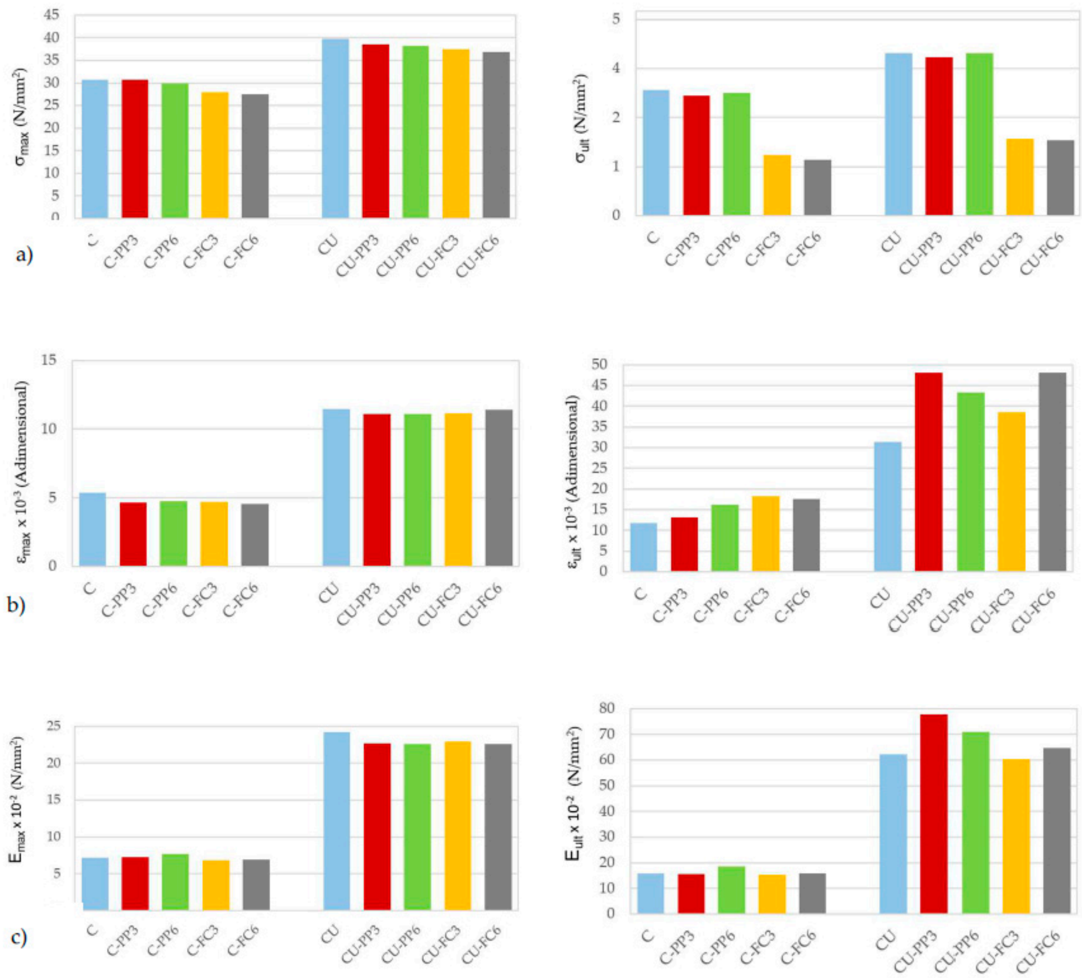


Figure 5. Most representative mean values of the compression tests: (**a**) maximum and ultimate strengths; (**b**) maximum and ultimate strains; and (**c**) maximum and ultimate strain energy densities.

With regard to the strain energy density, the values were similar for all concrete types, except for those obtained for the cubic specimens, for which the ultimate strain energy densities were higher for the concretes containing fibers.

The analysis of all the variables that define the behavior of concrete in compression shows that the addition of fibers does not improve its characteristics, but the loss of resistance experienced by the addition of recycled carbon fibers was compatible with the requirements of concrete.

According to the EHE standard (Spanish Structural Concrete Code), there is a correlation between the compressive breaking strengths obtained for the cylindrical and cubic specimens, and the strengths in standard conditions, which would be associated with the compressive strength test performed on cylindrical specimens measuring 15 cm in diameter and 30 cm in height after 28 days [57]. The theoretical conversion coefficients for the cylindrical specimens measuring 15 cm in diameter and 30 cm in height would be 0.8 and 0.97 for both the cubic specimens with 10 cm sides and for the cylindrical specimens measuring 10 cm in diameter and 20 cm in height, respectively. Table 5 displays the results obtained in the laboratory tests along with their conversion in line with the EHE, as well as the real coefficient for each mix compared to the theoretical value for the standard specimens without additions.

Table 5. Conversion values for the compressive strength in different types of specimens.

Specimens	Mean Value	EHE Coefficient	Conversion	Real Coefficient
C	30.663	0.970	29.743	0.970
C-PP3	29.251	0.970	28.373	0.925
C-PP6	29.972	0.970	29.073	0.948
C-FC3	28.019	0.970	27.178	0.886
C-FC6	27.454	0.970	26.630	0.868
CU	39.812	0.800	31.849	0.800
CU-PP3	38.600	0.800	30.880	0.776
CU-PP6	38.280	0.800	30.624	0.769
CU-FC3	37.425	0.800	29.940	0.752
CU-FC6	36.805	0.800	29.444	0.740

Having observed these strengths in standard specimens in accordance with the regulations, it is important to mention that by using CEM II/B-L 32.5 N cement, minimum strengths of around 27 N/mm^2 were obtained for concretes containing recycled CFRP, which, according to the Spanish Structural Concrete Code, makes it viable as a concrete for building construction.

Figure 6 shows the results obtained in the flexural tests. As can be seen, the addition of fibers to concrete improved its ductility, the best performance being achieved by the specimens containing 3 kg/m^3 of recycled carbon fibers, this type of concrete exceeding the load borne by more than 20% when compared to concretes containing polypropylene fibers or to conventional concretes. It is important to mention that greater strengths were achieved despite finding very few fibers in the region of rupture in all the specimens. The specimens featuring more fibers in the region of rupture, such as specimen P-PP6-1, were able to bear an even greater residual load. The specimens with 6 kg/m^3 of recycled carbon fibers reached the maximum deformation before breaking, showing the capacity that this type of fiber confers on concrete. This detail greatly expands the options for using recycled CFRP fibers, making it possible to produce concretes that are stronger, cheaper, and have a much lower environmental impact than conventional concretes or those containing polypropylene fibers by ensuring that there are a higher number of fibers in the region of rupture.

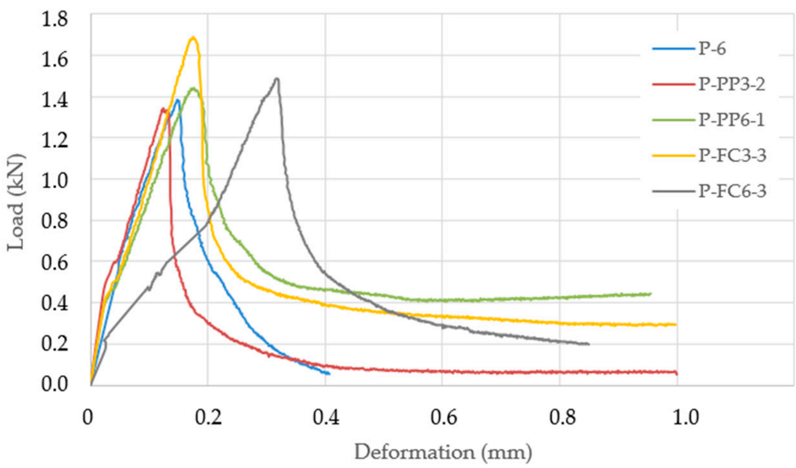


Figure 6. Load-deformation graph from the flexural tests.

Figure 7 shows the mean values for the energy absorbed in the impact test for each concrete type.

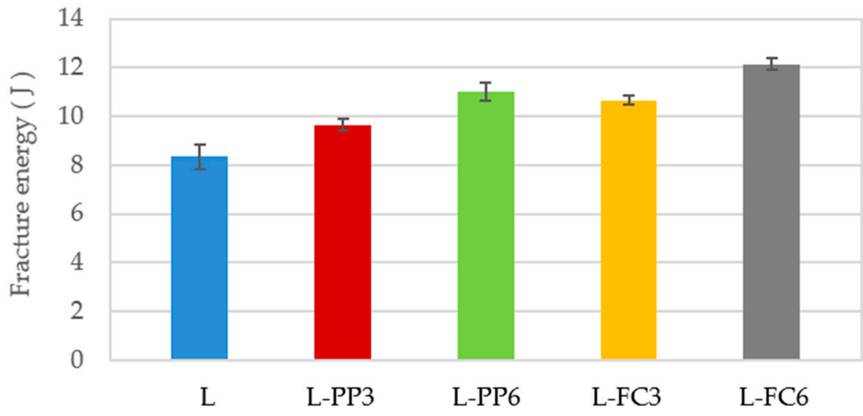


Figure 7. Mean values for the fracture energy in the impact testing for each concrete type studied.

As can be observed, the lowest amount of energy absorbed on impact was associated with the concrete specimens without added fibers. The concrete containing polypropylene fibers displayed an improved performance of as much as 32% with the addition of 6 kg/m^3, although the best performance was achieved by the concrete containing 6 kg/m^3 of recycled carbon fiber, which displayed an improvement of 45.68%.

Figure 8 shows the symptomatology of concrete when it was subjected to the different tests. In Figure 8a, associated with the compression testing of cylindrical specimens, it can be seen that the addition of fibers reduced the spalling effect, as the concrete that did not contain fibers was the only type to have suffered degradation after the test. The addition of the fibers decreased the cracking of the concrete, producing concretes with greater ductility, which translates into greater absorption of the load without detaching. Figure 8b shows the flexural test, in which it was observed that the higher the number of fibers in the region of rupture, the more ductility increases. Figure 8c shows the case of specimen P-PP6-6, where, due to the large amount of fibers concentrated in the region of rupture, the pendulum was unable to fracture the specimen. These results show the importance of fiber distribution in concrete [22].

The relationship between the most representative values obtained in the different tests is shown in Table 6, taking conventional concrete as the reference value. As may be observed, the addition of recycled carbon fibers in quantities of 3 kg/m^3 and 6 kg/m^3 improved the behavior of concrete subjected to flexural or impact compared to conventional concrete and, more importantly, when compared to concretes containing the same amounts of polypropylene fibers. This represents an improvement from an environmental point of view both due to the possibility of recycling carbon fiber fabrics and due to the reduction in energy as well as in raw materials required to manufacture the polypropylene fibers.

Table 6. Relationship between strengths as a percentage depending on the addition type and amount.

	Compression Test (Cylindrical Specimens)					**Compression Test (Cubic Specimens)**					
	C	**C-PP3**	**C-PP6**	**C-FC3**	**C-FC6**	**CU**	**CU-PP3**	**CU-PP6**	**CU-FC3**	**CU-FC6**	
C	—	−4.60	−2.25	−8.62	−10.46	—	−3.04	−3.84	−5.99	−7.55	CU
P	—	−1.81	+3.99	+22.76	+6.10	—	+15.82	+32.01	+27.93	+45.68	L
	P	P-PP3	P-PP6	P-FC3	P-FC6	L	L-PP3	L-PP6	L-FC3	L-FC6	
	Flexural test					Impact test					

Figure 8. Symptomatology of the concrete: (**a**) compression tests; (**b**) flexural tests; and (**c**) impact resistance tests.

4. Conclusions

Based on the results contained in this article, in which the mechanical behavior of concretes containing recycled carbon fibers has been compared to that of concretes containing polypropylene fibers and with conventional concretes, it has been possible to draw the following conclusions:

- Despite displaying worse compressive behavior than concretes without added fibers, those containing recycled carbon fibers do not differ greatly from concretes containing polypropylene fibers, achieving strengths of more than 25 N/mm^2 and thus making them viable for use in building construction.
- Adding fibers to concrete reduces the spalling effect; concretes that do not contain fibers display greater premature cracking as well as greater flaking of surface fragments during testing.
- The flexural tests offered encouraging results for recycled carbon fibers, as these obtained the best results for maximum strengths and good results for residual strengths, with a minimum number of fibers present in the region of rupture.
- The impact resistance test results for concretes containing recycled carbon fibers displayed great uniformity in addition to substantially improving the energy absorption capacity when compared to conventional concretes and those containing polypropylene fibers.

– The results obtained have revealed the good performance of these fibers despite their reduced number in the region of rupture of some of the specimens. Ensuring a larger quantity of fibers in the areas experiencing greater strain by reducing their size or adding a larger amount of fibers per m^3 makes it possible to increase the potential that these fibers can offer.

For all these reasons, it may be concluded that recycled CFRP fibers in quantities of 3 kg/m^3 and 6 kg/m^3 represent an alternative to the use of polypropylene fibers, which constitutes progress from both a mechanical and an environmental point of view.

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