Energy Dissipation Capacity of Concretes Reinforced with Recycled PET Fibers

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SUMMARY – *We investigate on the strength and ductility properties of recycled PET fiber-reinforced concretes (RPETFRCs) showing different mix-designs and PET filaments with variable mechanical and geometric properties. Available literature results of compression tests and four-point bending tests on such materials are reviewed comparing laboratory results in terms of compressive strength, first crack strength and ductility indices. The examined tests highlight that most relevant effects of the recycled PET fiber reinforcement are concerned with material toughness and ductility. In the case of low-strength concretes, significant compression and flexural strength enhancements due to the addition of recycled PET fibers are also observed.*

Keywords: PET, FRC, recycling, compressive strength, first crack strength, structural ductility

1. Introduction

Fiber-reinforced concretes (FRCs) are being used increasingly for the construction of new structures with energy dissipation capabilities, and the retrofitting of existing constructions. It has been recognized that plastic filaments extruded from polyethylene terephthalate flakes recovered from post-consumer bottles (R-PET) are well suited to manufacture eco-friendly and crack-resistant mortars and concretes, which can be profitably used to manufacture industrial floors, tunnel coatings, and for structural retrofitting [1] [2] [3] [4] [5] [6] [7] [8] [9] [10]. The effects of the addition of R-PET fibers to cementitious materials with different mix-designs are not fully understood at present, but there is some evidence that highest strength enhancements are produced by adding R-PET fibers to low-strength concretes, while ductility improvements are more uniform over concretes with different water/cement ratios and particle sizes [1] [2] [3] [4]. We deal in the present work with a review of available literature results on the concrete reinforcement with R-PET fibers. We examine different mix-designs and fiber properties, focusing our attention on the compressive strength, first crack strength, energy absorption capacity and ductility indices of RPETFRCs. Our final goal is to investigate on how the effects of the R-PET reinforcements vary with the nature of the binder, the water/cement ratio and the geometrical and mechanical fiber properties. We carry out such a comparative analysis by examining experimental results recently presented in [1] [2], and previous results given in [3] [4]. We begin in Sect. 2 by diffusely describing the examined RPETFRCs. Next, we review the experimental setup and the outcomes of the examined laboratory tests (Sect. 3). We end in Sect. 4 with a summary of the present study and guidelines for future research.

2. Materials

We examine concretes reinforced with plastic fibers produced through industrial extrusion lines in the plants of Techno Plastic (TP) S.r.l. (Castelfranco Emilia, Modena, Italy) and FHP S.a.s. – Plastic Division (Roncello, Milan, Italy). The examined fibers include several plastic filaments obtained through R-PET flakes extrusion lines, which show different mechanical properties, cutting and aspect, as well as polypropylene (PP) filaments extruded from virgin material (cf. Tab. 1 and Fig. 1).

Concrete specimens were prepared using the mix-designs shown in Tab. 2 and Tab. 3, which respectively make use of the Portland limestone cement CEM II/A-LL 32.5 R and the pozzolanic cement CEM IV/B 32.5 R (European standard UNI EN 197-1 [11]). Hereafter, we name UNRC1 and UNRC2 the unreinforced concretes realized according to the mix-designs given in Tabs. 2 and 3, respectively. Simi-

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Tab. 1. Properties of PET and PP fibers examined in the present study.
Proprietà delle fibre di PET e di PP prese in considerazione in questo studio.

Property	PET/a	PET/b	PET/c	PP
Specific gravity	1.34	1.34	1.34	0.90
Cross section	Circular	Circular	Circular	Oval
Aspect	Straight	Straight	Crimped	Embossed
Diameter (mm)	1.10	0.70	0.70	0.80 x 1.30
Length (mm)	40	52	52	47
Tensile strength (MPa)	550.00	263.72	274.29	250.00
Ultimate strain (%)	27	26	19	29

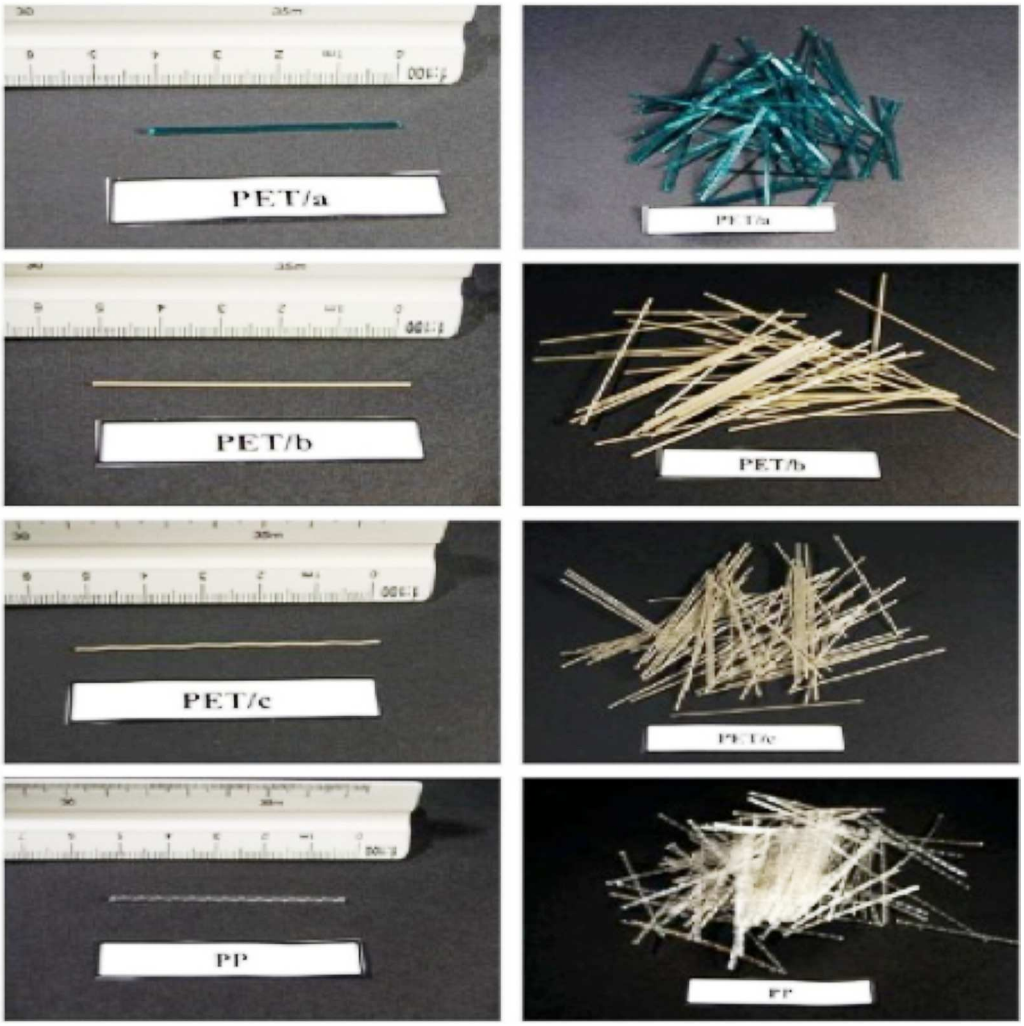

Fig. 1. *Illustrations of the examined PET and PP fibers [2].*
Illustrazione delle fibre di PET e di PP.

Tab. 2. Mix design of UNRC1 and RPETFRC1 [1].
Composizione del conglomerato UNRC1 e RPETFRC1.

Concrete Type	Coarse Aggregate (10-20 mm)	Medium Aggregate (4-10 mm)	Sand (0-4 mm)	CEM II A-LL 32.5	Fluidizing Additive SKY 624	Water	Water/ Cement Ratio	Fibers
Portland cement CEM II/A-LL 32.5 R	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	Lt./m^3		Kg/m^3
UNRC1	605.0	170.0	944.1	496.0	4,35	187.9	0.38	–
RPETFRC1/a	605.0	170.0	944.1	496.0	4,35	187.9	0.38	13.4
RPETFRC1/c	605.0	170.0	944.1	496.0	4,35	187.9	0.38	13.4

Tab. 3. Mix design of UNRC2 and RPETFRC2 [2].
Composizione del conglomerato UNRC2 e RPETFRC2 [2].

Component	Dosage (kg/m^3)
Pozzolanic Cement CEM IV/B 32.5 R	340
Sand (0-4mm)	923
Medium aggregate (4-10 mm)	185
Coarse aggregate (10-20 mm)	743
Water	181
Water/cement ratio (%)	53
Fluidifying agent	2.4

larly, we name RPETFRC1 and RPETFRC2 the fiber reinforced concretes based on such mix designs and the PET/a,b,c fibers shown in Tab. 1, at 1% volume content. Finally, we name PPFRC the fiber reinforced concrete using the mix design in Tab. 3 and the PP fibers described in Tab. 1 (1% volume content). It is worth noting that UNRC1 has a considerably smaller water/cement ratio (0.38 vs 0.53), and greater compressive strength class (C30/37), as compared to UNRC2 (C25/30, cf. Tabs. 2 and 3). Reinforcing fibers and concrete were mixed through a concrete mixer. The specimens were unmolded within 3 days after casting and cured for a period of 28 days. Materials and mixing devices were kindly provided by Calcestruzzi Irpini S.p.A. (Avellino, Italy).

3. Review of Available Experimental Results on RPETFRCS

Table 4 shows the results of compression strength tests presented in [1], which were conducted on cubic UNRC1 and RPETFRC1 specimens (three cubes with 150mm side for each examined material), in accordance with the European standard UNI EN 12390-1 [12]. The results in Tab. 4 provide the specific gravity and cube compression strength ($f_{c,cube}$) of each tested specimen. The same table also provides the mean value ($\bar{f}_{c,cube}$), the standard deviation and the coefficient of variation of ($f_{c,cube}$) for UNRC1, RPETFRC1/a and RPETFRC1/b. Analogous results on UNRC2, RPETFRC2 and PPFRC specimens are presented in Tab. 5, which provides 95% Confidence Intervals (CI) and percentage variations of ($f_{c,cube}$) over UNRC2 (FRR, cf. [2]).

The results in Tab. 4 highlight that the UNRC1, RPETFRC1/a and RPETFRC1/c exhibit $\bar{f}_{c,cube}$, equal to 42.4 MPa, 40.0 MPa and 38.9 MPa, respectively, after 28 days of curing. We observe a reduction of $\bar{f}_{c,cube}$, equal to 5.66% in RPETFRC1/a and 8.25% in RPETFRC1/c, as compared to UNRC1. Such results significantly deviate from those competing to RPETFRC2, which instead shows 35.14% and 0.03% increments of $\bar{f}_{c,cube}$ in RPETFRC2/a and RPETFRC2/c, respectively, against UNRC2. Ochi et al. [3] recorded 8.41%, 13.79% and 5.99% increases of $\bar{f}_{c,cube}$, in the case of R-PET reinforcements at 1% fiber volume fraction of concretes with water/cement ratios equal to 65%, 60% and 55%, respectively; while Kim et al. [4] observed a 7% decrease of $\bar{f}_{c,cube}$, or the R-PET reinforcement at 1% fiber volume fraction of ordinary Portland cement-based concretes with water/cement ratio equal to 0.41 (always comparing to UNRC). It is possible to recognize a general trend indicating a decrease of the RPETFRC compressive strength with the water/cement ratio, at constant fiber volume ratio (1%). This might imply that the beneficial effects of the R-PET reinforcement in terms of compressive strength are more pronounced in presence of low strength class concretes.

Let us now pass to examine the results of the four point bending tests presented in [1], which were conducted on three prismatic 150 mm x 150 mm x 600 mm specimens of UNRC1, RPETFRC1/a and RPETFRC1/c after 28 curing days, according to the Italian standards UNI 11039-1 [13], and UNI 11039-2 [14] (cf. Tabs. 6 and 7). Each specimen was preliminary notched at the midspan (notch width 2 mm at the mouth; notch depth: a_0 = 45 mm [14]). The crack tip opening displacement (*CTOD*) was measured through two displacement transducers placed on the opposite faces of the specimen (denoted as *CTOD*1 and *CTOD*2 in Fig. 2), in correspondence with the crack tip. Hereafter, we denote the mean value the displacements measured by such transducers by $CTOD_m$ (mean crack tip opening displacement). The midspan deflection d was measured through a vertical displacement transducer (denoted as DT in Fig. 2). A 50 kN load cell was used to measure the total load P applied to the top surface of the specimen. The test setup and the employed instrumentation are shown in Fig. 2. The results of similar four point bending tests performed on UNRC2, RPETFRC2 and PPFRC specimens are given in Tab. 8 [2].

Tab. 6 provides the individual values of the peak load $P_{\max}$; the $CTOD_m$ corresponding to $P_{\max}$; the first-crack load P_{If}; and the first-crack strength f_{If}, which were observed for each different specimen of UNRC1, RPETFRC1/a and RPETFRC1/c, together with the mean values of $P_{\max}$ and f_{If}. According to UNI 11039-2 [14], we let $CTOD_0$ denote the mean value of $CTOD_m^{P_{\max}}$ for the UNRC (plain concrete). In addition, we define P_{If} as the maximum load observed in the $CTOD_m$ range [0, $CTOD_0$]. The first crack strength was computed according to the following formula (UNI 11039-2 [14])

$$f_{If} = \frac{P_{If}\, l}{b(h - a_0)^2} \qquad (1)$$

where l is the clear span of the specimen, while b and h are the width and the height of the specimen cross-section, respectively (cf. Fig. 2).

By analyzing the results presented in Tab. 6, we notice a slight decrease of $P_{\max}$(–4.34%) and f_{If}(–2.65%) in RPETFRC1/a, as compared to UNRC1. Differently, we record remarkable increases of $P_{\max}$ approximately show twice greater tensile strength than PET/c fibers (550 MPa vs 274 MPa). The results in Tab. 6 suggest that the waviness of the fiber profile might play a greater role than the tensile strength, for what concerns

Tab. 4. Results of compression strength tests on RPETFRC1 and UNRC1 [1].
Risultati dei test di resistenza a compressione per RPETFRC1 e UNRC1.

Specimen ID	Specific Gravity	Cube compression strength $f_{c,cube}$			
		Specimen strength	Mean Value	Standard Deviation	Coefficient of Variation
	[Kg/m^3]	[MPa]	[MPa]	[MPa]	[%]
UNRC1 -1	2222	40.6			
UNRC1-2	2311	42.6	42.4	1.6	3.85
UNRC1-3	2207	43.9			
RPETFRC1/a-1	2299	40.6			
RPETFRC1/a-2	2258	39.1	40.0	0.8	1.94
RPETFRC1/a-3	2214	40.3			
RPETFRC1/b-1	2228	37.6			
RPETFRC1/b-2	2252	38.5	38.9	1.6	4.02
RPETFRC1/b-3	2240	40.6			

Tab. 5. Results of compression strength tests on UNRC2, RPETFRC2 and PPFRC [2].
Risultati dei test di resistenza a compressione per RPETFRC2 e UNRC2 [2].

Material	# Specimens	Specific gravity	Compressive strength MPa		
			$f_{c,cube}$	95%Cl	FRR(%)
UNRC2	8	2.27	31.50	4.85	0.00
RPETFRC2/a	6	2.32	42.57	2.72	+35.14
RPETFRC2/b	6	2.31	38.44	3.16	+22.03
RPETFRC2/c	6	2.28	31.51	1.69	+0.03
PPFRC	6	2.30	36.80	4.91	+16.83

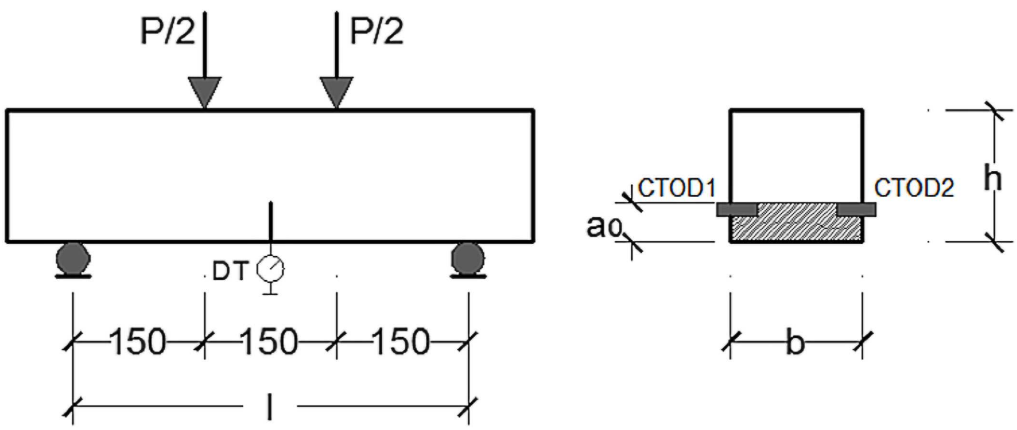

Fig. 2. *Four point bending test setup and instrumentation.*
Configurazione e strumentazione di prova a flessione.

Tab. 6. Results of four point bending tests on UNRC1 and RPETFRC1 [1].
Risultati di prove a flessione su UNRC1 e RPETFRC1 [1].

Specimen ID	P_{max}	$CTOD_m$ at P_{max}	Mean Value of P_{max}	$CTOD_0$	P_{lf}	f_{lf}	Mean Value of f_{lf}
	[N]	[mm]	[N]	[mm]	[N]	[MPa]	[MPa]
UNRC1-1	13366	0.084			13289	3.6	
UNRC1-2	15241	0.079	13910	0.077	15144	4.1	3.77
UNRC1-3	13124	0.069			13124	3.6	
RPETFRC1/a-1	13813	0.076			13813	3.8	
RPETFRC1/a-2	12268	0.078	13331	0.077	12218	3.3	3.67
RPETFRC1/a-3	13913	0.063			13919	3.8	
RPETFRC1/c-1	13591	0.079			13520	3.7	
RPETFRC1/c-2	16740	0.086	15181	0.077	16680	4.5	4.07
RPETFRC1/c-3	15212	0.084			14720	4.0	

Tab. 7. Energy absorption capacities and ductility indices of RPETFRC1 specimens [1].
Capacità di assorbimento di energia e indici di duttilità per provini RPETFRC1 [1].

Specimen ID	$[CTOD_0, CTOD_0 + 0.6mm]$			$[CTOD_0 + 0.6mm, CTOD_0 + 3mm]$			Total Post-Crack Energy
	U_1[Nmm]	$f_{eq}(0-0.6)$[MPa]	D_0	U_2[Nmm]	$f_{eq}(0.6-3)$ [MPa]	D_1	$U_1 + U_2$[Nmm]
RPETFRC1/a-1	3217	1.5	0.4	11608	1.3	0.4	14825
RPETFRC1/a-2	3338	1.5	0.5	10517	1.4	0.4	13855
RPETFRC1/a-3	4530	2.1	0.5	17049	2.5	0.5	21579
RPETFRC1/c-1	3443	1.6	0.4	12530	1.8	0.4	15973
RPETFRC1/c-2	2273	1.0	0.2	11334	1.6	0.3	13607
RPETFRC1/c-3	2805	1.3	0.3	12521	1.8	0.4	15326

Tab. 8. Results of four point bending tests on UNRC2, RPETFRC2 and PPFRC [2].
Risultati di prove a flessione su UNRC2, RPETFRC2 e PPFRC [2].

Material	First crack strength		D_0	D_1	Class
	f_{lf}(MPa)	f_{lf}-FRR(%)			
UNRC2	3.39	0	0.71	0.09	DS0
RPETFRC2/a	4.78	+41.00	0.82	0.68	DS1
RPETFRC2/b	3.46	+2.06	0.77	0.45	DS0
RPETFRC2/c	3.65	+7.67	0.95	0.58	DS1
PPFRC	3.73	+10.03	0.92	0.73	DS2

the bending response of RPETFRC1 (we remind that PET/c fibers have crimped profile, while PET/a fibers have straight profile, cf. Tab. 1). An opposite trend is instead observed in Tab. 8, for RPETFRC2. As a matter of fact, the flexural strength of RPETFRC2/a is about 40% greater than that of UNRC2, while the flexural strength of RPETFRC2/c is about 8% greater than the f_{lf} of UNRC2 [2]. Interestingly, the increase in f_{lf} of RPETFRC1/c (over UNRC1) remains approximately the same in RPETFRC2/c. Ochi et al. [3] recorded 7.85%, 2.18% and 15.20% increases of the bending strength of fiber reinforced concretes with 1% R-PET fiber volume fraction and water/cement ratios equal to 65%, 60% and 55%, respectively (over UNRC). Kim et al. [4] observed a 32% increase in the value of P_{max} of 200mm x 300mm x 2000mm concrete specimens reinforced by R-PET fibers at 1% volume fraction plus steel rebars, as compared to concrete specimens reinforced by rebars only (mix-design based on an ordinary Portland cement and 0.41 water/cement ratio). Interestingly, the representative load-deflection curve of concrete specimens reinforced by rebars only shows slightly greater turning point (P_{cr}), as compared to the representative load-displacement curve of specimens reinforced by 1% R-PET fiber volume fraction plus steel rebars (cf. Tab. 4 and Fig. 11 of [4]).

Fig. 3 shows the $P - CTOD_m$ curves that were obtained for RPETFRC1/a and RPETFRC1/c specimens, respectively [1]. Fig. 4 illustrates the analogous curves obtained for RPETFRC2/a,b,c and PPFRC [2]. The results presented in [1][2] point out that both UNRC1 and UNRC2 exhibit brittle failure with practically zero energy absorption capacity after crack onset (first-crack load). Regarding the post-crack behavior, we introduce the following fracture energies, U_1 and U_2, which are associated with the $CTOD_m$ ranges $[CTOD_0, CTOD_0 + 0.6\text{mm}]$ and $[CTOD_0 + 0.6\text{mm}, CTOD_0 + 3\text{mm}]$ of the $P - CTOD_m$ curves, respectively (UNI 11039-2 [14])

$$U_1 = \int_{CTOD_0}^{CTOD_0 + 0.6mm} P(CTOD_m)\, dCTOD_m \qquad U_2 = \int_{CTOD_0 + 0.6mm}^{CTOD_0 + 3mm} P(CTOD_m)\, dCTOD_m \tag{2}$$

According to UNI 11039-2 [14], we characterize the energy absorption capacity of the examined materials through the following "ductility indices" D_0 and D_1

$$D_0 = \frac{f_{eq(0-0.6)}}{f_{lf}} \qquad D_1 = \frac{f_{eq(0.6-3)}}{f_{lf(0-0.6)}} \tag{3}$$

where $f_{eq}(0-0.6)$ and $f_{eq}(0.6-3)$ are the following equivalent stresses associated with the $CTOD_m$ ranges $[CTOD_0, CTOD_0 + 0.6\text{mm}]$ and $[CTOD_0 + 0.6\text{mm}, CTOD_0 + 3\text{mm}]$, respectively

$$f_{eq(0-0.6)} = \frac{l}{b(h-a_0)^2}\frac{U_1}{0.6} \qquad f_{eq(0.6-3)} = \frac{l}{b(h-a_0)^2}\frac{U_2}{2.4} \tag{4}$$

It is worth noting that the above ductility indices measure the ratios between the equivalent strengths of the material in two different post-crack regimes ($[CTOD_0, CTOD_0 + 0.6\text{mm}]$ and $[CTOD_0 + 0.6\text{mm}, CTOD_0 + 3\text{mm}]$, respectively) and the first-crack strength, which can be understood as dimensionless indicators of the nature of the post-crack response (or "ductility class") of the material ("hardening"

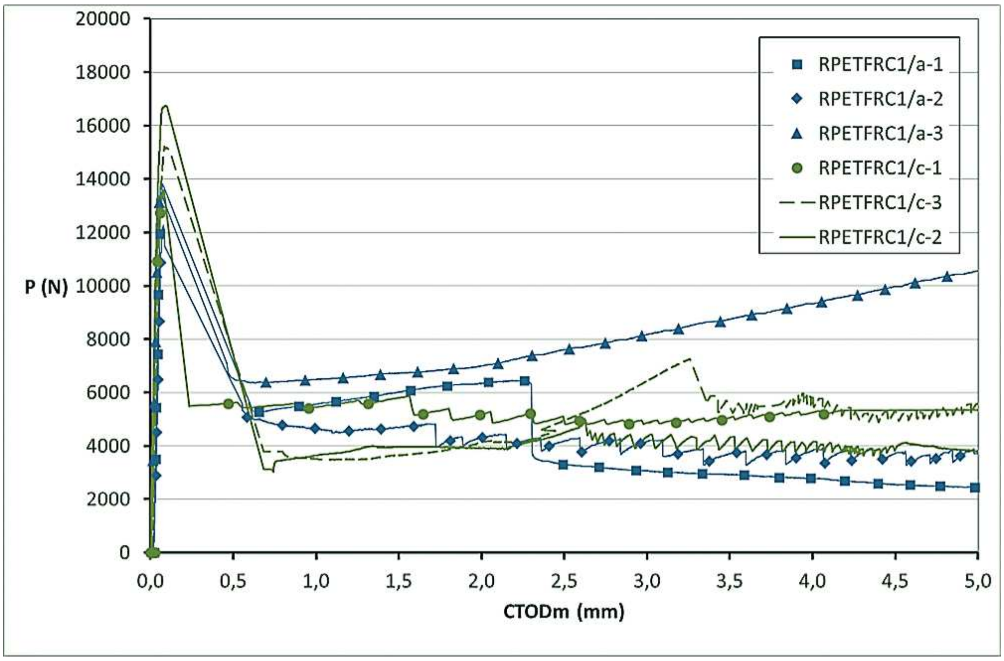

Fig. 3. *Total applied load vs* CTDO$_m$ *curves for RPETFRC1/a and RPETFRC1/c specimens [1].*
Carico totale applicato in funzione di $CTDO_m$ per provini RPETFRC1/a e RPETFRC1/c [1].

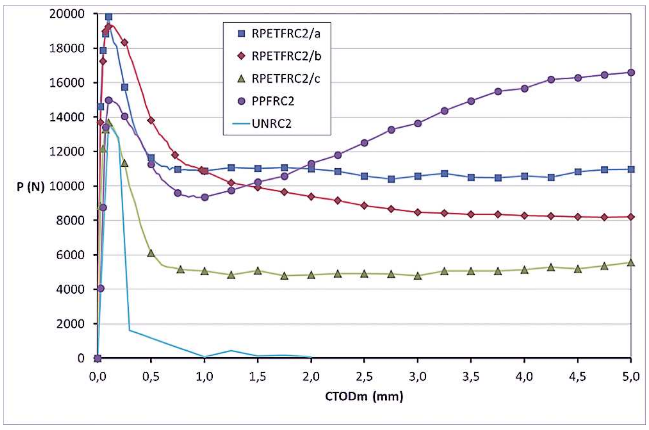

Fig. 4. *Total applied load vs* CTDO$_m$ *curves for UNRC2, RPETFRC2 and PPFRC specimens [2].*
Carico totale applicato in funzione di $CTDO_m$ per provini UNRC2, RPETFRC2 e PPFRC [2].

behavior corresponds to ductility indices greater than one; while "softening" behavior corresponds to ductility indices smaller than one). In particular, D_0 characterizes the "ductility" of the material (defined as above) in the $CTOD_m$ range that immediately follows the crack onset ("first crack ductility"), while D_1 characterizes the "ductility" in a heavily cracked regime ("ultimate ductility"). Tab. 7 summarizes the results obtained in terms of energy absorption capacities and ductility indices, for each of the examined RPETFRC1 specimens [1]. It is easy to recognize that RPETFRC1/a exhibits average values of D_0 and D_1 that are equal to 0.47 and 0.43, respectively, while RPETFRC1/c exhibits average values of D_0 and D_1 equal to 0.30 and 0.37, respectively (cf. Fig. 3). RPETFRC2/a instead shows $D_0 = 0.82$ and $D_1 = 0.68$, while RPETFRC1/c features $D_0 = 0.95$ and $D_1 = 0.58$ (Tab. 8). It is evident that RPETFRC2 exhibits much lower ductility indices (and, consequently, much lower fracture toughness), as compared to RPETFRC1. We also notice that the RPEFTRC/a exhibits higher ultimate ductility than RPETFRC/c, both in correspondence with the mix-design of Tab. 2, and in correspondence with the mix-design of Tab. 3 (cf. Figs. 3 and 4). This can be explained by a fiber-debonding-type failure mode of RPETFRC/a (due to the high strength and straight aspect of PET/a fibers, which are expected to not break up to material failure), and a fiber-rupture-type failure mode of RPETFRC/c (due to the relatively low tensile strength of PET/c fibers, and the enhanced bonding strength induced by the crimped aspect of such fibers). Ochi et al. [3] measured relative energy capacities (average energies absorbed by the analyzed RPETFRCs divided by the average energy absorbed by the unreinforced concrete) equal to 5.14, 5.70 and 5.95 for RPETFRCs with 1% R-PET fiber volume fraction and water/cement ratios equal to 65%, 60% and 55%, respectively. Kim et al. [4] observed relative energy capacity equal to 4.34 for concrete specimens reinforced by 1% R-PET fiber volume fraction and steel rebars (ordinary Portland cement-based concrete with 0.41 water/cement ratio).

4. **Concluding remarks**

We have reviewed the results of recent experimental studies on the mechanical properties of different concretes reinforced with recycled PET fibers at 1% fiber volume content, examining the compressive strength, first-crack strength, energy absorption capacity and ductility indices of the examined materials. An extended comparative study based on the results given in [1] [2][3][4] has allowed us to draw some conclusions about to-date available results on the mechanical performance of concretes reinforced by R-PET fibers.

All the results taken into account in the present work point out that the effects of the R-PET reinforcement are highly beneficial in terms of energy absorption capacity of the material. As a matter of fact, the outcomes of the laboratory tests given in [1][2][3][4] indicate that the addition of R-PET fibers to the mix design dramatically increases the relative energy capacity of concrete (from 400% up to 700% increases in the energy absorption capacity). We are therefore led to conclude that RPETFRCs might be a good match for earthquake resistant structures.

More complex is the analysis of the material response in terms of compressive strength and first-crack strength. The results presented in Sect. 3 allow us to recognize a general trend indicating the reduction of the compressive strength of RPETFRC with the water/cement ratio for fixed fiber volume content (1%). We also record reductions of the first-crack strength with the water/cement ratio in RPETFRCs showing the same reinforcing fibers and two different mix-designs (Tabs. 2 and 3). In particular, for one particular material (RPETFRC1/a), we have observed a slightly negative effect of R-PET fibers in terms of first-crack strength, in presence of Portland limestone cement and 0.38 water/cement ratio. A comparative analysis between the results given in [1] and [2] also indicates that high tensile strength R-PET fibers (PET/a) appear to be the most beneficial in terms of compressive and tensile properties of the final material in the case of pozzolana cement-based concretes with high water/cement ratio (0.53), while, on the contrary, fibers with crimped aspect and relatively low tensile strength (PET/c) appear to be the most beneficial in terms of compressive strength and first-crack strength of Portland limestone cement-based concretes with low water/cement ratio (0.38). Overall, we are led to conclude that the addition of R-PET fibers to cementitious materials needs to be accurately tailored to the employed mixed-design, both for what concerns the choice of the fiber properties, and in relation to the desired strength and ductility properties of the final material (cf. also [10] for what concerns the R-PET reinforcement of cement mortars). An experimental study on the durability and seawater curing of RPETFRC has been recently presented in [1].

We address to future work the mechanical modeling of elastic stability and crack propagation in RPETFRC structural elements, to be conducted through free-discontinuity models, the quasicontinuum method and mesh-free approaches [15-30]; as well as the study of multiaxial prestess [31], and the formulation of tensegrity models of RPETFRC structures [32-34]. Such studies are expected to provide useful information about the load carrying capacity of RPETFRC structural members, under service and ultimate loads.

Acknowledgments

The authors gratefully acknowledge the great technical support received by Mauro Mele and Calcestruzzi Irpini S.p.A. during the course of the present work. FF also acknowledges financial support from the Italian Network of Seismic Engineering Laboratories (ReLUIS-DPC grant 2014-2016).

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Capacità di dissipazione energetica di calcestruzzi rinforzati con fibre PET da riciclo

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Parole chiave: calcestruzzo fibro-rinforzato, PET da riciclo, tenacità, resistenza a compressione, resistenza di prima fessurazione, indici di duttilità.

L'industria edilizia contribuisce notevolmente al degrado ambientale, anche più del traffico automobilistico e di altre rinomate attività inquinanti, ma gli imprenditori edili negli ultimi anni hanno fatto passi da gigante verso una significativa riduzione dell'impatto ambientale del processo di costruzione. Nel contesto di un crescente interesse verso il riciclo di materiali derivanti da rifiuti solidi urbani ed industriali e la cosiddetta architettura "sostenibile" o "verde", una sempre maggiore attenzione viene rivolta ai giorni nostri alla sperimentazione ed allo studio del rinforzo del cemento armato con aggregati e/o fibre ottenuti dal riciclo di materiali recuperati dai rifiuti solidi urbani e/o industriali. Diversi materiali recuperabili dai rifiuti solidi, quali, ad esempio, le materie plastiche, il vetro, la cellulosa, il legno, ecc., sono dotati di estrema versatilità e/o peso contenuto, durabilità, resistenza agli attacchi chimici, eccellenti proprietà di isolamento termico ed elettrico. Tali proprietà possono essere utilmente sfruttate per costruire nuovi materiali compositi innovativi ed eco-sostenibili. Particolarmente interessante è il caso del rinforzo dei conglomerati cementizi (armati e non) con fibre ricavate da materiali da riciclo, che si configura come una tecnica di rinforzo a basso costo in grado di migliorare significativamente la resistenza meccanica, la duttilità strutturale e l'isolamento termico della matrice cementizia. Il miglioramento della duttilità è particolarmente significativo nelle zone sismiche, dove gli edifici e le infrastrutture necessitano di avere a disposizione una notevole capacità di dissipazione di energia e di deformazione plastica, soprattutto in presenza di importanti eventi sismici. D'altra parte, la ridotta conduttività termica del calcestruzzo rinforzato con fibre plastiche da riciclo, rispetto ad un calcestruzzo non rinforzato, consente di produrre componenti strutturali in grado di ridurre l'impatto ambientale e migliorare il rendimento energetico degli edifici.

Fibre di rinforzo in materiale riciclato possono essere estratte, ad esempio, da scarti di polietilene tereftalato (PET), polipropilene (PP), polietilene, nylon, aramide, poliestere, vetro, gomma e cellulosa. Il crescente interesse della comunità scientifica internazionale verso il rinforzo del calcestruzzo con fibre di materie plastiche riciclate è illustrato nel recente articolo di Siddique et al. [5] e nei riferimenti ivi citati, che analizzano gli effetti di tale rinforzo in termini di un gran numero di proprietà del materiale, quali la densità, il contenuto d'aria, la lavorabilità, la resistenza a compressione, la resistenza a trazione, il modulo di elasticità, la resistenza all'urto, la permeabilità e la resistenza all'abrasione.

Per quanto riguarda specificamente il rinforzo del calcestruzzo mediante fibre di PET da riciclo, si distinguono, tra gli altri, lavori [3-7]. Ochi et al. descrivono in [3] la tecnologia di produzione di fibre di rinforzo del calcestruzzo a partire da bottiglie PET da riciclo. Gli stessi autori analizzano anche gli effetti benefici derivanti dall'aggiunta di tali fibre al mix-design del conglomerato cementizio, in termini di duttilità, di resistenza a flessione e di resistenza a compressione del materiale. Nello studio di Kim S.B. et al. [4] fibre di PET di vario aspetto (lisce, ondulate e goffrate) sono impiegate per indagare sulla fessurazione da ritiro plastico in materiali compositi a base cementizia. Kim J.J. et al. esaminano in [6] il rinforzo del calcestruzzo con di fibre di PET riciclato, esaminando diverse percentuali volumetriche delle fibre (0,5%, 0,75% e 1%). Le fibre di PET esaminate da questi ultimi autori sono realizzate attraverso macchine di taglio e di deformazione, partendo da bobine ricavate dalla lavorazione di bottiglie di PET da riciclo. Kim J.J. e coautori misurano la resistenza a compressione ed il modulo elastico di provini di RPETFRC, nonché la resistenza a flessione di provini di calcestruzzo rinforzato con fibre di PET da riciclo e barre di acciaio. I risultati presentati in [6] mettono in luce aumenti significativi della resistenza a flessione e della duttilità del RPETFRC e, talvolta, a lievi diminuzioni della resistenza a compressione e del modulo elastico, rispetto al calcestruzzo non rinforzato ("Unreinforced Concrete" o UNRC). Foti esamina in [7] un processo economico di produzione di scaglie di PET riciclato per il rinforzo del calcestruzzo, che si basa sul semplice taglio di bottiglie recuperate dai rifiuti. Il rinforzo di malte cementizie con fibre PET da riciclo è trattato in [8,9].

Il presente lavoro mette a confronto i risultati dei recenti studi sperimentali sul rinforzo del calcestruzzo con fibre di R-PET [1-2]. Si prendono in esame due diverse miscele di calcestruzzo, che utilizzano rispettivamente un cemento Portland calcareo (classe di cemento CEM II/A-LL 32.5 R) ed un cemento pozzolanico (CEM IV/B 32.5 R) e diversi tipi di fibre R-PET. L'attenzione è concentrata sulla resistenza a compressione, sulla resistenza di prima fessurazione, sulla capacità di assorbimento di energia e sugli indici di duttilità degli RPETFRC esaminati, con l'obiettivo finale di indagare su come gli effetti dei rinforzi R-PET varino con la natura del legante, il rapporto acqua/cemento e le proprietà geometriche e meccaniche delle fibre di rinforzo.