EVALUAREA CAPACITĂȚII DE ABSORBȚIE A ENERGIEI DE CĂTRE BETONUL ARMAT CU FIBRE MACRO SINTETICE ŞI FIBRE DE OȚEL
EVALUATION OF ENERGY ABSORPTION OF MACRO SYNTHETIC AND STEEL FIBER REINFORCED CONCRETES

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This study aims to determine the energy absorption of concrete slabs (60×60×10cm) using polyester, polypropylene and steel fiber reinforced (SFRC, PYFRC, PPFRC) according to EN 14488-5. Significant differences in the energy absorption were observed between the concrete slabs strengthened with different fibers. The highest gain in energy absorption was observed in SFRC. Furthermore, concrete slabs strengthened with PPFRC and PYFRC showed 23.4% and 14.8% less energy to SFRC. Although the SFRC showed the highest energy absorption under directly negative conditions, it is important to evaluate the durability issues associated with SFRC, such negative conditions.

Keywords: *Fiber reinforced concrete, steel fiber, synthetic fiber, energy absorption, slab test*

1. Introduction

The ductility and mechanical properties of concrete can be improved by using internal fibers. Fiber reinforced concrete (FRC) has been widely used in structural concrete slabs, for example, ceilings, pedestrian bridges, industrial pavements and small non-structural precast elements or sprayed in tunnels and on industrial floors[1-3].

Many studies have shown that fibers can improve significantly the performance of concrete, especially steel fibers. Steel fibers improve flexural strength, crack resistance and energy absorption [4, 5]. However, corrosive environments have an adverse effect on concrete made with steel fibers (Fig. 1).

In this instance, macro synthetic polyester and polypropylene fibers can be utilized to prevent durability issues associated with steel fibers such as corrosion and alkaline reactions, as well as the effects of acidic water, salt, chlorine, chemicals and micro-organisms. Macro synthetic polyester and polypropylene fibers also have water repellent properties and provide maximum adherence owing to their wavy shape and hooks at both ends [5-12].

The tensile behavior of fiber-reinforced concrete can be classified as strain-softening (a quasi-brittle material) or pseudo strain-hardening, as presented in Figure 2 [13-16]. In strain-softening materials (synthetic fibers), a localized single crack determines post-peak behavior and once the matrix

Fig. 1 - The expose to negative condition of steel fibers and rebars in concrete.

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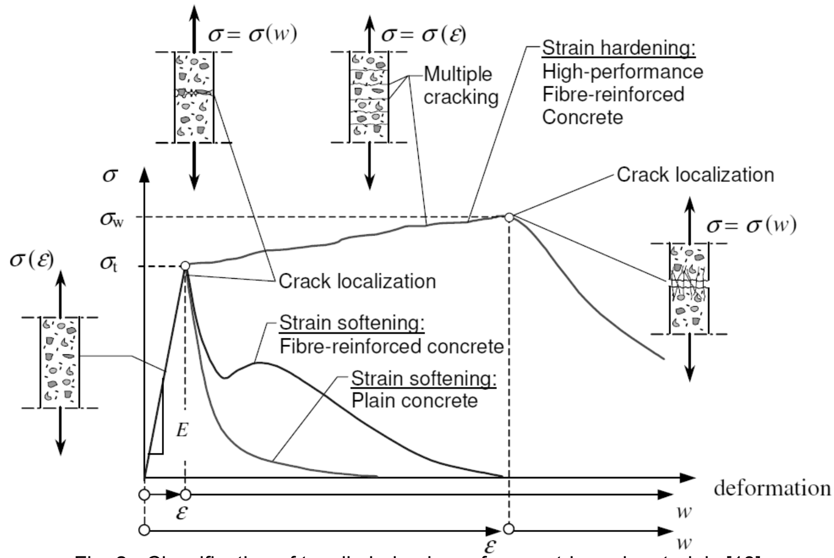

Fig. 2 - Classification of tensile behaviour of cement-based materials [13].

cracks, the stress will start to decrease. In pseudo strain-hardening material (steel fibers) the stress-strain curve shows quasi-strain hardening (or pseudo-strain hardening) behavior (i.e., a post-cracking strength larger than the cracking strength, or elastic/plastic response) [17]. Based on this classification, tensile properties for strain-softening materials will be discussed.

2. Energy Absorption Evaluation

Normally, the flexural strength and the energy absorption of concrete are determined with tensile strength tests. The energy absorption of fiber reinforced concrete is determined using beam flexural strength for plaque-shaped concretes; however, the suitability of this test is contoversial, as the results of 2-dimensional testing is affected by the specific area (3 dimension) of plaque concretes in practice [18]. This can be seen in that when the load is applied to a hotspot in the beam tests (2-dimensional), it is effected. [19].

The energy absorption potential of fiber composites can be utilized in various applications, especially where considerable deformations may be subjected to the concrete structure. For underground structures such as tunnels, where the medium used can impose such deformations, more flexibility of the structure will reduce the cross section of the tunnel. In order to provide higher energy absorption capacity in fiber reinforced composites, it is normally required that a higher fiber content, which will increase the cost of the concrete [20].

If the capacity of energy absorption of FRC is specified, it must be determined using a panel specimen according to EN 14488-5. Based on this panel test, the FRC is classified under the following three categories [20,21]:

- 500 Joules for sound ground/rock conditions
- 700 Joules for medium ground/rock conditions
- 1000 Joules for difficult ground/rock conditions

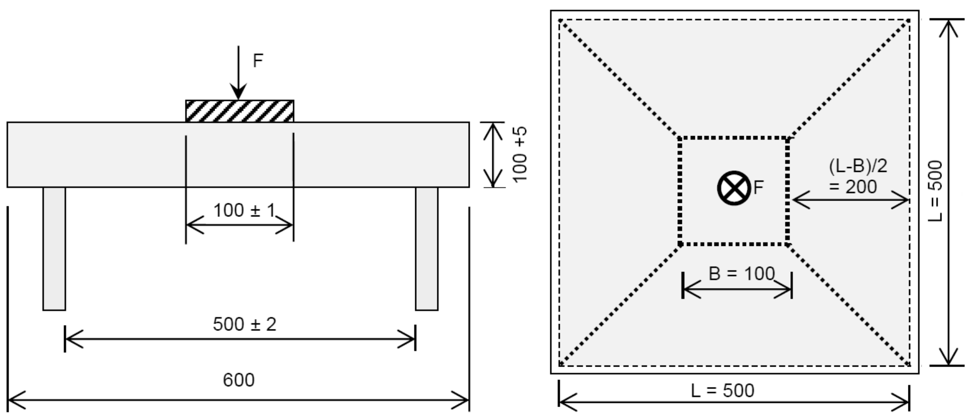

Fig. 3 - Slab test mechanism for energy absorption according to EN 14188-5 (dimensions are in mm) [23].

To purpose of the slab test of fiber reinforced concrete is to determine the energy absorption in accordance with EN 14188-5, as presented in Figure 3. This method was used for determining energy absorption in this study [5]. The objective of this study was to measure the flexural toughness of concrete slabs by measuring the energy absorption of the specimen when it reached a predefined failure state. The energy absorbed by the slab (E) is simply the area under the load vs. the deflection curve until a deflection limit of 25 mm is achieved [22].

3. Materials and Methods

3.1. Materials

3.1.1. Concrete

Four types of concrete were used in accordance with TS802 and EN 10505 including steel fiber, reinforced concrete (SFRC), polyester fiber reinforced concrete PYFRC, polypropylene fiber reinforced concrete PPFRC and reference concrete without fibers [24, 25]. CEM I 42,5R cement was used with crushed aggregates and tap water. Two chemical admixtures, including air entraining agent and superplasticizer retarder complying with EN 934-2 standard were used [26]. Mixture designs of concrete in 1 m^3 volume are presented in Table 1. The water/cement ratio was kept constant at 0.45.

Dry materials were mixed form a homogeneous distribution of aggregates, cement and fibers used in the production of concretes. Water with chemical admixtures, including 0.1% entrained air agent and 1.5% superplasticizer retarder of cement weight was added to the prepared dry mixture. After approximately 10 minutes of mixing, fresh concrete were poured into molds and compacted by using an external vibrator for 30 seconds. Production of fresh concretes was performed in compliance with TS 802, EN 10514 [27] and EN 10515 standards.

3.1.2. Fibers

A volume of 4.25 dm^3/m^3 (0.425%) was used for each fiber type. The polyester (PY), polypropylene (PP) and steel (S) fibers are shown in Figure 4 and their properties are shown in Table 2.

3.2. Methods

3.2.1. Determination of fresh concrete properties

After the concretes had been prepared, slump tests complying with EN 12350 – 2 [28] were conducted; the amount of air experiments and unit weight experiments complying with ASTM C138 [29] were conducted. Slump and the amount of air and unit weight were measured for each concrete type six, three and six times, respectively; results were then averaged.

Table 1

Mix designs of concretes in 1 m^3

Concrete Components	SFRC-PYFRC-PPFRC (dm^3)	R1 (dm^3)
Water	175	175
Cement	126	126
Pressed air (%0.1) + Entrained air (%3.5)	45	45
Fibers	4.25	-
0 - 0.25 mm aggregate	160	160
0.25-4 mm aggregate	130	130
4-11.2 mm aggregate	220.44	224.69
11.2-22.4 mm aggregate	134	134
Superplasticizer retarder (%1.5 – weigh of cement)	4.93	4.93
Air entrained agent (%0.1 weigh of cement)	0.38	0.38
Total	**1000**	**1000**

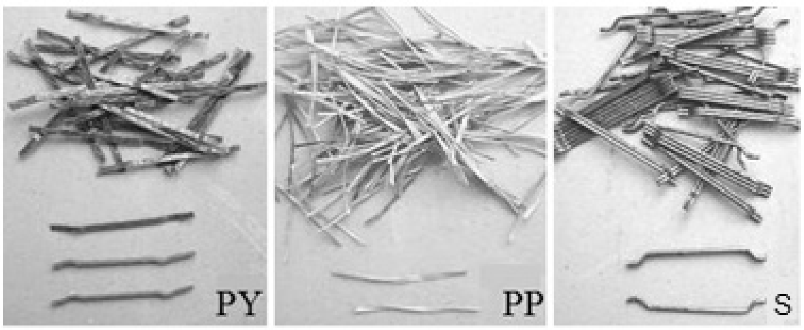

Fig. 4 - Polyester, Polypropylene and Steel fibers.

Table 2

Properties of fibers

Fibers Properties	PY	PP	S
Length (mm)	30	30	30
Width (mm)	1	1	-
Thickness (mm)	0.6	0.35	-
Diameter (mm)	-	-	0.9
Specific Gravity (g/cm^3)	1.36	0.95	7.87
Tensile Strength (MPa)	400-800	600-750	~1100
Young's Modulus (MPa)	17237	3800	200000
The final elongation (%)	> 8	10	< 2
Ignition temperatures (^{0}C)	537	537.78	-
Melting. oxidation and deterioration temperature (^{0}C)	253	180	800
According to ASTM D 570 Water absorption (% - weight basis)	0.4	0.01	0

3.2.2. Determination of mechanical properties

All concrete samples tests of mechanical properties were conducted after 28 days. They were cured at 18±2 ^{o}C into the cure pool until the day of testing.

Compressive Strength: the compressive strengths of concretes were determined via uniaxial destructive method (σ_{UA}). σ_{UA} was determined on 10x20cm dimensions and five numbers of cylindrical samples for each type of concrete according to EN 12390-3 [30] principles. Equation 1was calculated as follows:

$$f_{cs} = F/Ac \qquad (1)$$

Where: f_{cs}:The compressive strength (MPa), *F*: Total maximum load (N), *Ac*: The area of loaded surface, (mm^2).

Flexural strength: Measured by loading two points on 10x10x50cm dimensions and five numbers of concrete beams for each type of concrete according to TS 10515. The flexural strength is equal to the stress calculated at maximum load and was calculated as follows:

$$f_{ts} = \frac{P_u.L}{b.h^2} \qquad (2)$$

Where, f_{ts}: flexural strength (MPa), P_u: the maximum load at prior to the moment of crack or break (N), *L*: span, in (mm), *b*: width of beam tested, in. (mm), *h*: depth of beam tested (mm).

Splitting Tensile Strength: determined according to ASTM C 496 [31] on 10x20cm dimensions and six numbers of cylindrical samples for each type of concrete. It was calculated as follows:

$$f_{st} = 2P/\pi ld \qquad (3)$$

Where, f_{st}: splitting tensile strength (MPa), *P*: maximum applied load indicated by the testing machine, (N), *l*: length (mm), and *d*: diameter (mm).

Modulus of Elasticity: determined on 10x20cm dimensions and six numbers cylindrical samples for each type of concrete according to ASTM C 469. For the determination of elasticity, the modulus Secant method was used. Using the Secant method, which calculates the static modulus of elasticity, unit deformation value can be obtained, which correspond the stress that corresponds to 40% of the maximum stress value. It was calculated as follows:

$$E_m = (S_2 - S_1) / (\varepsilon_2 - 0.000050) \qquad (4)$$

Where E_m: chord modulus of elasticity (MPa), S_2: stress corresponding to 40 % of ultimate load, S_1: stress corresponding to a longitudinal strain (MPa), and ε_2: longitudinal strain produced by stress S_2.

Poisson ratio: determined according to ASTM C 469 on the same samples used for modulus of elasticity. It was calculated as follows:

$$\mu = (\varepsilon_{t2} - \varepsilon_{t1}) / (\varepsilon_2 - 0.000050) \qquad (5)$$

Where μ: Poisson's ratio, ε_{t2}: transverse strain at midheight of the specimen produced by stress S_2, and ε_t: transverse strain at midheight of the specimen produced by stress S_1.

3.2.3. Determination of energy absorption

Energy absorption is determined using a slab test after 28 days. Six samples of each type of concrete according to EN 14488-5 were used and slabs were square with 600 mm each sides and thickness of 100 mm; they were simply supported on four sides by a rigid steel frame with a span of 500 mm and tested under a center point load through a contact surface of 100 mm x 100 mm, as shown in Figure 5.

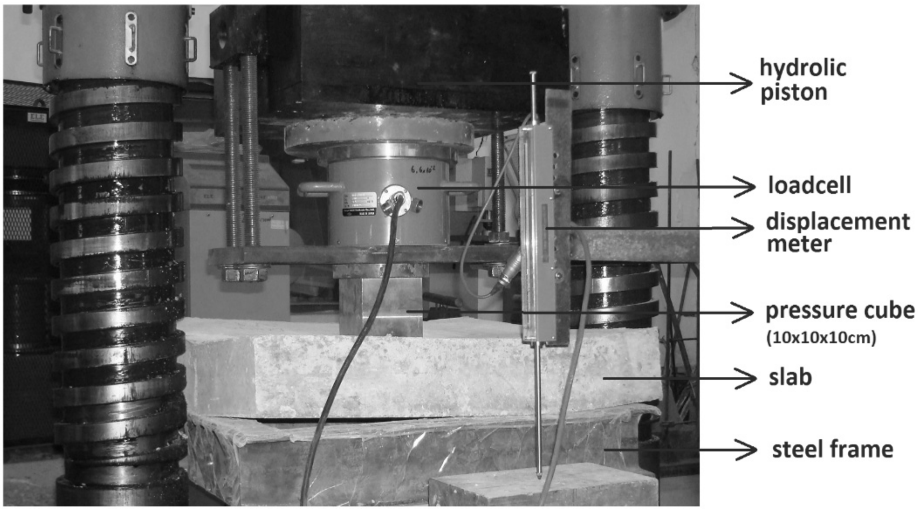

Fig. 5 - Slab test mechanism used in this study

Tests were conducted for differ fiber types and the average specific absorbed energy was measured. All the tests were performed under displacement controls and at a gradient of 1.5mm per minute. One extensometer was fixed outside the test rig on each specimen to evaluate mid-deflection (Figure 5). To avoid possible damages and failure of the specimen or the test equipment, all tests were stopped when a mid-displacement of about 25-30 mm was achieved. The energy absorbed by the specimen (E) was simply the area under the load vs. the deflection curve up to a deflection limit (25mm). This was calculated as follows [22]:

$$E = \sum_{i=0}^{i=\delta_m} \left[(\delta_{i+1} - \delta_i) \frac{F_i + F_{I+1}}{2} \right] \qquad (6)$$

Where, E: Energy absorption (Joule: 1N=1J/m), F_i: is the load corresponding to a deflection equal to δ_i, δ_m: is the upper deflection limit [mm]

4. Results and discussion

4.1. Fresh concrete properties

Mean values slump, air quantities and unit weight of concretes are shown in Table 3. The planned slump according to TS 802 is 12 cm. According to planned slump results that R1 and PPFRC had 8% and 2% higher, respectively; SFRC and PYFRC had 11% and 42% lower, respectively. The reasons for PYFRC to have a lower slump was possibly because polyester fibers, as shown in Table 2, have water retention capability 0.4% of their weight, the number of fibers is much higher than steel fibers and surface texture is different than polypropylene fibers.

A 32% higher air rate was found in SFRC, a 21% higher rate in PPFRC and a 29% higher rate in PYFRC, with respect to R1 were found. It was thought that the superplasticizer used in the study, as well as the fibers and external vibration duration had increased the amount of squeezed air in the concrete fibers.

Table 3

Slump, air quantities and unit weight of concretes

Tests	N	R1	PYFRC	PPFRC	SFRC
Slump (cm)	6	13	7	12.2	10.7
Air quantities (%)	3	2.8	3.7	3.4	3.6
Unit weight (kg/m^3)	6	2417.2	2420.4	2402	2440.1

Unit weights of all concretes were found to be ~100 kg higher than expected. The reason for this may be that the aggregate granulometry of concrete fibers was different than the aggregate granulometry of normal concretes. It was observed that other concretes had unit weights with differences smaller than 1% with respect to R1. The higher unit weight of SFRC was thought to be due to steel fiber intensity.

4.2. Mechanical properties

Mechanical properties of concretes are presented Table 4. There was no major difference in concrete *compressive strengths*. The highest compressive strength was seen in SFRC, with an increase of 12.4%, while the smallest compressive strength was seen in PPFRC, with a decrease of 4.4% with respect to R1. In conclusion, it can be said that steel fibers have positive, polypropylene fibers have negative and polyester fibers have slightly positive effects on the compressive strength of concrete.

All *tensile strength* of fiber reinforced concretes were higher than R1; tensile strength in SFRC was 52.2%, in PYFRC 53.1% and in PPFRC 79% higher than R1, respectively. The reason for PPFRC to have a highest tensile strength is possibly that because the number of polypropylene fibers is much higher than the others.

Table 4.

Mechanical properties of concretes

Mechanical properties	SFRC	PYFRC	PPFRC	R1
Compressive Strength (MPa)	34.35	31.60	29.23	31.07
Flexural strength (MPa)	3.41	3.43	4.01	2.24
Splitting Tensile Strength (MPa)	3.92	3.42	3.96	3.36
Modulus of Elasticity (MPa)	33047.8	32292.6	31283.1	32086.4
Poisson ratio	0.221	0.264	0.287	0.255

All *splitting tensile strength* of fiber reinforced concretes were higher than R1; splitting tensile strength was higher in SFRC by 16.7%, in PYFRC by 1.8% and in PPFRC 17.9% higher than R1, respectively. The reason for PPFRC had the highest splitting tensile strength with the same level of tensile strength. SFRC and R1 showed important differences with respect to tensile strength. Consequently, it can be said that sample size and shape have an effect on tensile strengths.

Modulus of elasticity and *poisson ratio* were affected by fibers especially steel fibers. Thus, such, it can be said that modulus of elasticity and poisson ratio are directly related to the number of fibers and fiber rapture strength in concrete.

4.3. Slab Test and Energy Absorption

All concrete samples' load, energy and deflection values determined in the first crack (crack of concrete), second crack (rupture of fibers) and at the end of 25 deflections are shown in Table 5. Concrete samples' shapes are shown in Figures 5-8 after cracking during the slab tests. Samples' load – deflection and energy – deflection graphics are shown in Figures 6-9.

The most different result was seen in PPFRC and the others same results in first crack values. PPFRC was show to have the highest first crack load, energy and deflection, possibly because the number of polypropylene fibers was higher than in the other samples. Additionally, tensile strength and splitting tensile strength results were shown to be similar.

After concretes cracked, they continued to carry load until the rupture of fibers (second crack). Only SFRC load, energy and deflection were increased after the second crack. PPFRC and PYFRC were decrease. R1 was completely separate four pieces in first crack.

The biggest differences in load and energy results were seen in SFRC at the end of the 25mm deflection. The energy absorptions determined of

Table 5

Slab test results

		SFRC	PPFRC	PYFRC	R1
First crack	Load (kN)	45.3	51.5	46.1	48,5
	Energy (Joule)	15.5	44.8	26.1	31
	Deflection (mm)	0.62	2.63	1.44	1.39
Second crack	Load (kN)	59.3	34.2	38.5	-
	Energy (Joule)	886.6	85.2	59.6	-
	Deflection (mm)	18.5	4.21	2.5	-
The end of 25 mm deflection	Load (kN)	18	6.04	1.7	-
	Energy (Joule)	1117	261.1	165.1	-
	Deflection (mm)	25	25	25	-

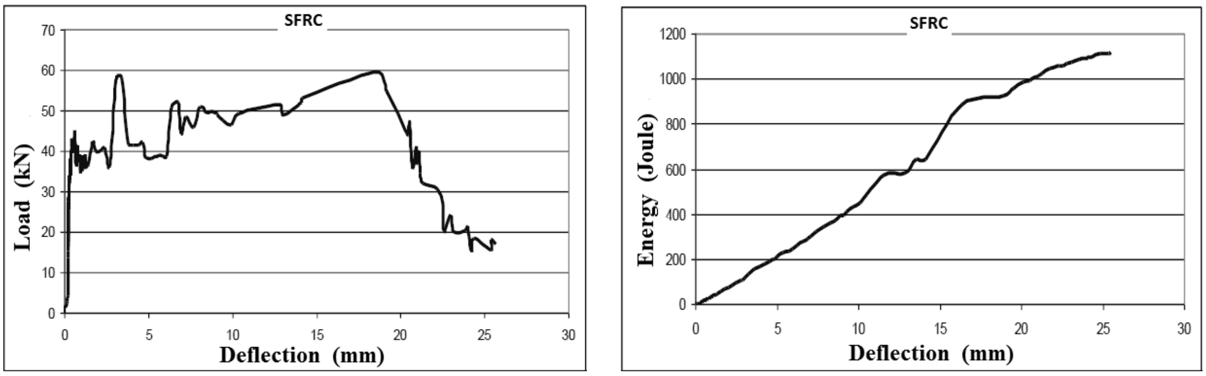

Fig. 6 - SFRC load-deflection and energy absorption-deflection curves from slab test.

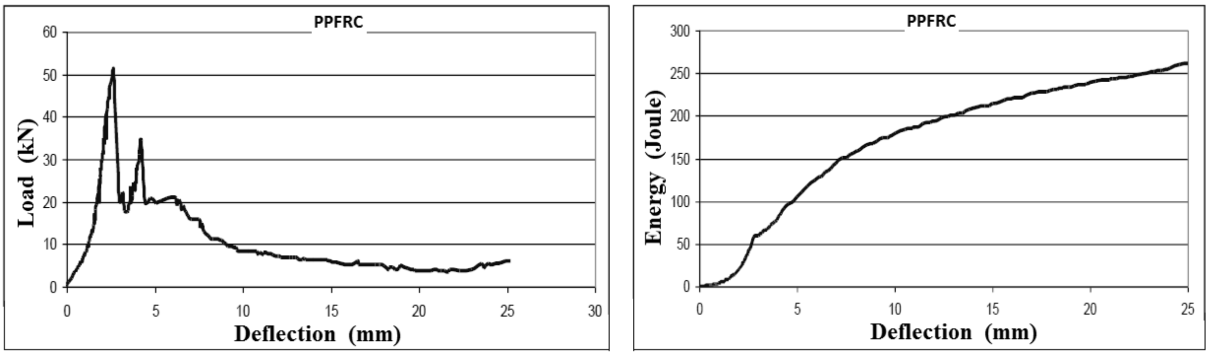

Fig. 7 - PPFRC load-deflection and energy absorption-deflection curves from slab test.

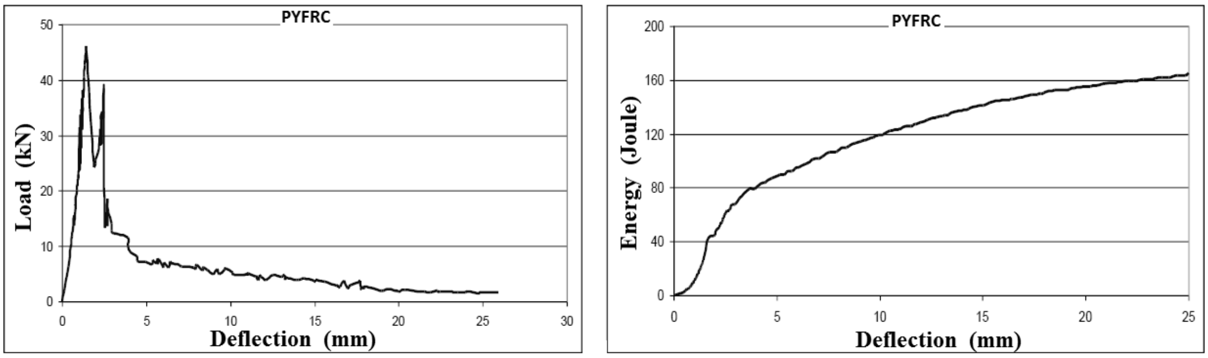

Fig. 8 - PYFRC load-deflection and energy absorption-deflection curves from slab test.

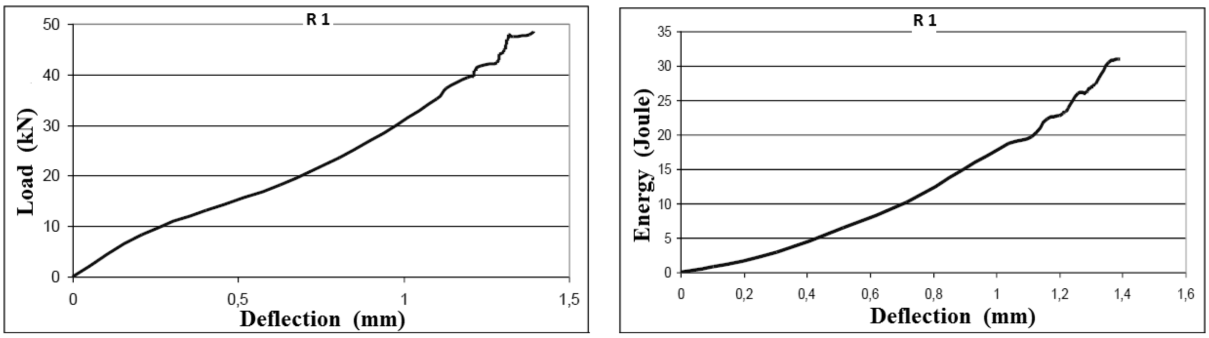

Fig. 9 - Reference (non-fiber) load-deflection and energy absorption-deflection curves from slab test.

PPFRC at the level of SFRCs was 23.4%; of PYFRC, energy absorption was 14.8%. The loads determined of PPFRC was 33.6% and for PYFRC 9.4% at the level of SFRCs. While the concrete had 25 mm deflection, it was still able to carry the load.

In Figures 10-13, SFRC, PPFRC, PYFRC and R1 specimens are shown respectively after testing. All specimens were similarly cracked in the slab tests. Generally all specimens cracked into four pieces and only R1 was separated into four pieces. Figure 13 (R1) shows the specimen failure mechanism of the referenced concrete slab and

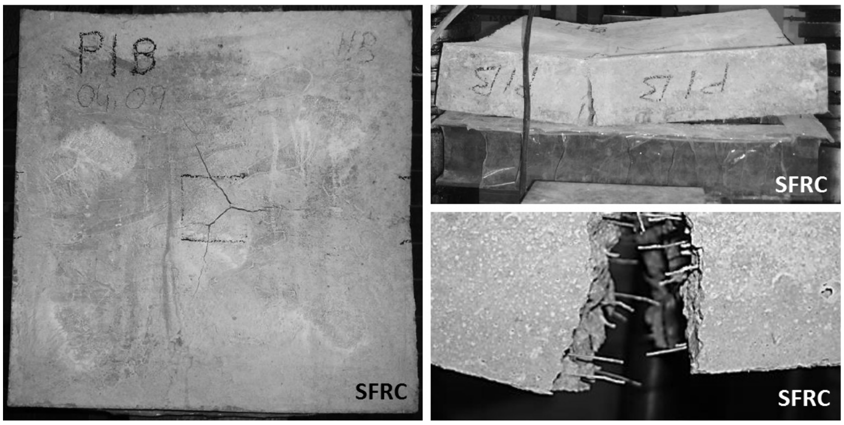

Fig. 10 - SFRC specimen at the end of the test.

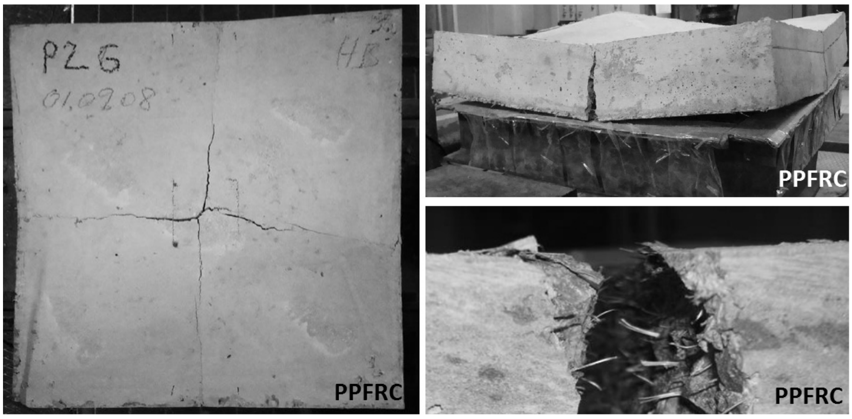

Fig. 11 - PPFRC specimen at the end of the test.

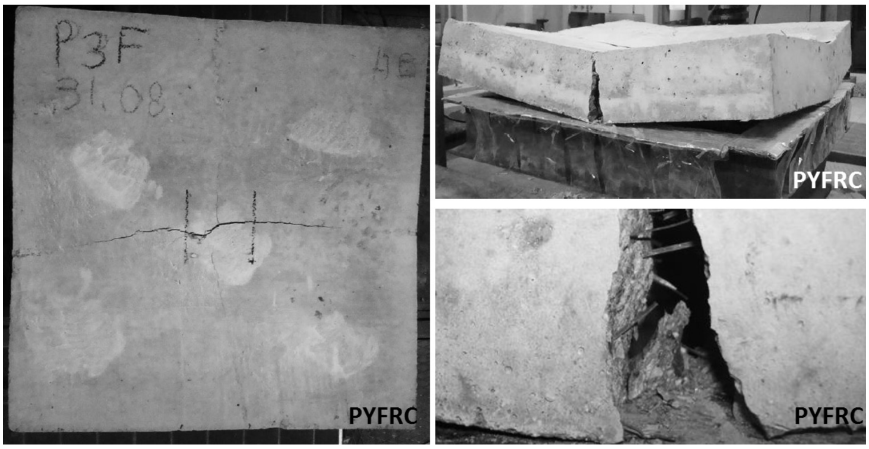

Fig. 12 - PYFRC specimen at the end of the test.

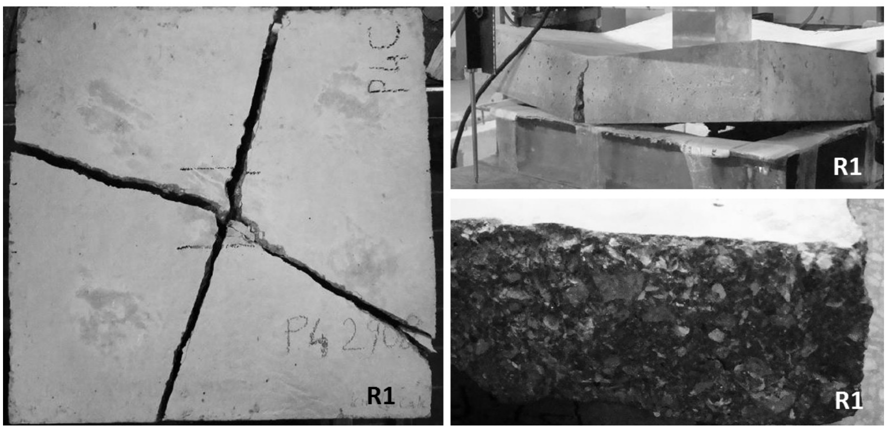

Fig. 13 - Reference (non-fiber) specimen at the end of the test.

the objective load, as well as the deflection curve and provides a specific absorbed energy definition. This result can be compared with the failure mechanism of the fiber reinforced concrete slabs shown in Figures 10-12 and shows a more flexible failure mechanism for fiber reinforced concrete slabs.

5. Conclusion

The influence of macro synthetic (polypropylene and polyester) and steel fibers on the fresh concrete properties, mechanical properties and energy absorption capacity of fiber reinforced concrete have been investigated.

It appears that fresh concrete slump is decreased and air quantities increased when fiber added to the concrete, according to R1 (non-fibers). No significant change in unit weight was found.

The compressive strength of SFRC increased about 12% more than other concrete types. PPFRC, PYFRC and R1 remained approximately the same in terms of compressive strength. It can therefore be said that steel fiber is affected, however macro synthetic fibers are not significantly affected in terms of the compressive strength of concrete.

The flexural and splitting strength of all FRC increased by between 55%-90%, according to R1. It can therefore be said that fibers are affected in terms of tensile strength of concrete. The Modulus of Elasticity results were similar to tensile strength differences. Poisson ratio had a higher than PPFRC and PYFRC with respect to SFRC and R1. It can therefore be said that the steel fibers were more brittle than the synthetic fibers of concrete. As a result, concrete mechanical properties are affected by fiber types and the quantity in which these are applied.

Following the slab tests, fiber reinforced samples were cracked into four to five pieces. However, these were not separated. It is significant for especially slab concretes subjected to heavy load for long term service life. At the end of the slab tests, significant differences were detected in fiber reinforced according to the reference concrete (non-fibrous). The biggest difference was determined in SFRC, which had the highest energy absorption value. PPFRC 23.4% and PYFRC 14.8% was at the level of SFRCs. Even though SFRC had the highest energy absorption, in the event of direct negative conditions, loads should be considered (as shown in Figure 1b), as this energy absorption have an effect in the long service life.

In conclusion, steel fiber has contributed to important positive mechanic and energy absorption results that cannot be compared to synthetic and non- fibrous concretes. However, as SFRC is usually used in open-air conditions (prone to corrosion, chemicals, moisture, wetting-drying cycles, freezing and thawing, fire, etc.) and in heavy load (vehicles, industrial areas, etc.) locations, its properties should be well-known for applying it in the long term service life.

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31. ASTM C 496. Standard Test Method for Split Tensile Strenght of Cylindrical Concrete specimens. Annual Book of ASTM Standards 2004.

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MANIFESTĂRI ŞTIINȚIFICE / SCIENTIFIC EVENTS

Concrete 2015
30 August - 2 September 2015, Melbourne, Australia

Concrete 2015 will focus on the theme Research into Practice. The conference is dedicated to bringing together global leaders in the concrete industry, covering all aspects of concrete design improvements, research, construction, maintenance and repair of concrete projects. Concrete 2015 will offer participants from around the world the opportunity to connect face to face and share innovative and interesting ideas on valuable research outcomes and latest construction practices. Papers are invited that are based on experimental work, research and development, practice or industry application, case studies, innovations and other relevant work of interest.

Themes for submission:

- Concrete Materials and Performance
- Durability and serviceability
- Major Projects/ Case Studies
- Construction Methods
- Geopolymers and non-traditional binder Concrete
- Sustainability
- Repair and Retrofitting
- Structures Research and Applications
- Admixtures and polymers
- Early-age Concrete and Cracking
- Fire resistance of Concrete
- Anchors in concrete
- Fibres/FRP Research and Applications
- Structural Monitoring and Assessment
- Life cycle analysis (LCA) and service life
- Durability of new green products
- Failure mode and risk analysis
- Self-compacting concrete

Contact: http://concrete2015.com.au/

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