DETERMINATION OF ENERGY ABSORPTION CAPACITY OF FIBER REINFORCED SPRAYED CONCRETE

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ABSTRACT

The paper presents experimental research performed on fiber reinforced concrete slabs. For the preparation of the concrete elements, three different dosages of polypropylene fibers were used. The size of the specimens and the test methodology were established according to the SR EN 14488-5 - *Testing sprayed concrete. Part 5: Determination of energy absorption capacity of fiber reinforced slab specimens*. The slabs were tested in the Central Laboratory of the Faculty of Civil Engineering, Cluj-Napoca, using a flexural frame and the Advantest 9 console, capable of applying load in displacement control. Using the area under the load-displacement diagram, the energy absorption capacity of the fiber reinforced slabs was determined, at the age of 28 days.

Keywords: polypropylene; fibers; sprayed; concrete; energy

REZUMAT

Lucrarea prezintă cercetările experimentale care a fost efectuate pe elemente din beton armat cu fibre. Pentru prepararea elementelor din beton au fost utilizate trei dozaje diferite de fibre de polipropilenă. Dimensiunea elementelor şi metodologia de încercare au fost stabilite în conformitate cu SR EN 14488-5 - *Încercări pe beton care se aplică prin pulverizare. Partea 5: Determinarea capacității de absorbție a energiei de eşantioanele de fâşii armate cu fibre*. Plăcile au fost testate în Laboratorul Central al Facultății de Construcții, Cluj-Napoca, cu ajutorul unui cadru de încovoiere şi al consolei Advantest 9. Folosind aria de sub diagrama for□ă-deplasare, s-a determinat capacitatea de absorbție a energiei a betonului cu adaos de fibre, la vârsta de 28 de zile.

Cuvinte cheie: polipropilenă; fibre; torcret; beton; energie

1. INTRODUCTION

During the last few years, several studies and tests on the behavior of fiber reinforced concrete have been carried out. Through these experimental a better characterization of Fiber Reinforced Concrete (FRC) programs was achieved, as well as a better understanding of the behavior of this material.

In addition, a large amount of fiber reinforced sprayed concrete (FRS) research has been undertaken by both the civil construction and the mining industries. Fiber reinforced sprayed concrete (FRS) is a concrete containing discontinuous steel or synthetic fibers, which are pneumatically projected at high velocity onto a surface.

Lately, there have been significant technological advances associated with shotcrete materials and their placement. These advances include improved mix design, chemical admixtures, the development of steel and plastic fibers for internal reinforcement, and advances in the equipment used for placement [1].

SR EN 14487-1 [2] mentions the different ways of specifying the ductility of fiber reinforced sprayed concrete in terms of residual strength and energy absorption capacity. The energy absorption value measured on a panel can be prescribed when, in case of rock bolting, emphasis is put on energy that has to be absorbed during the deformation of the rock. This is especially useful for primary sprayed concrete linings [3]. If the energy absorption capacity of FRS is specified, it must be determined, using a slab specimen, according to SR EN 14488-5 [4]. Based on this panel test, three FRS classes (E500, E700 and E1000) are defined, according to EN 14487-1: *Sprayed concrete, definitions, specifications and conformity* [2], as follows:

- 500 Joule for sound ground/rock conditions;
- 700 Joule for medium ground/rock conditions;
- 1000 Joule for difficult ground/rock conditions.

Due to the type of failure, in Finland an additional recommendation for the macro-synthetic fiber reinforced shotcrete is imposed, i.e.:

$$F_{max}/F_1 > 1.2$$

where F_{max} is the maximum load and F_1 is the load at the first crack.

The purpose of this study is to evaluate the behavior of fiber reinforced shotcrete from the mechanical point of view, considering shotcrete as the support structure in the first stage of tunnel lining.

2. MATERIALS AND METHODS

2.1. Materials

In this study, macro polypropylene (PP) fibers, Sikafiber® T60, were used (Fig. 1), designed to be mixed in the shotcrete mass in order to improve durability and avoid cracking, conferring thus the necessary structural characteristics. Typical properties and the amount of polypropylene fibers are presented in Table 1.

Three batches of fiber reinforced shotcrete were studied. Batch No. 1 has a content of 6 kg/m³ of polypropylene fibers, while batches No. 2 and No. 3 have a content of 5 kg/m³ and 4 kg/m³ of polypropylene fibers, respectively.

The specimens were cast on site, using the same properties and conditions as recommended for the works.

Fig. 1. Type of polypropylene fiber (Sikafiber® T60)

Table 1. *Properties of polypropylene fibers*

Properties	
Length (mm)	60
Unfolded length (mm)	65
equivalent diameter (mm)	0.93
Specific gravity (kg/l)	0.91
Tensile strength (MPa)	>560
Elastic modulus (GPa)	20.5
Deformation temperature (°C)	110
Decomposition temperature (°C)	280

2.2. Specimens dimensions and curing conditions

For the tests square specimen with dimensions of 600x600 mm and a thickness of 100 mm were used, in accordance with SR EN 14488-1 [6].

The specimens were cured according to SR EN 12390-2 [5], for at least three days before the tests and kept moist until the test began.

2.3. Test

The slabs were tested according to SR EN 14488-5 [4], in the Central Laboratory of the Faculty of Civil Engineering, Cluj-Napoca.

Three elements were tested for each composition, at the age of 28 days, using a flexural frame and Advantest 9 console (Fig. 2) capable of applying load in displacement control. During the test, the slab was supported on its four edges and a central point load was applied through a contact surface of 100 × 100 mm², at a constant speed of 1 mm/min.

The load deflection curve was recorded and a 50 mm LVD was used for measuring the deflection at the central point of the slab. The absorbed energy was determined as the area under the load-deflection curve.

Fig. 2. Flexural frame and the Advantest 9 console

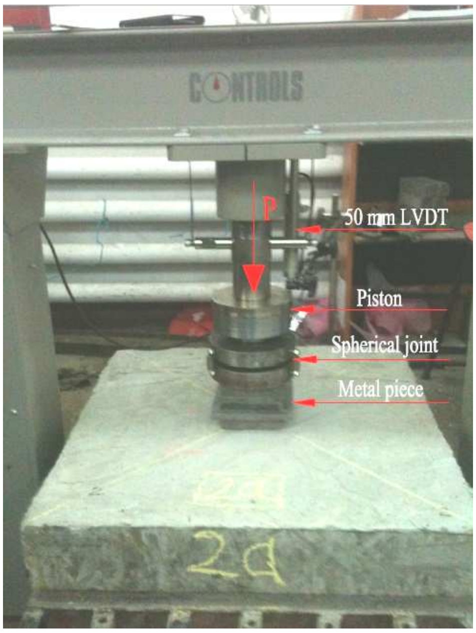

Fig. 3. Set up of the specimen

3. RESULTS AND DISCUSSIONS

3.1. Absorbed energy

Figures 4 - 6 show the load-deflection curves for each composition.

Figure 4 shows the curves for the specimens that belong to batch No. 1 and contain 6 kg/m³ polypropylene fibers.

Figure 5 shows the curves for the specimens that belong to batch No. 2 and contain 5 kg/m³ polypropylene fibers, while Figure 6 shows the curves for the specimens that belong to batch No. 3 and contain 4 kg/m³ polypropylene fibers.

In Figure 7, the average values of the energy absorption capacity are shown (E_{tot} – total value of the energy absorption capacity and E_a – value of energy absorption capacity measured up to 25 mm deflection), for all compositions.

It can be seen that the values increase proportionally with the fiber content. For the specimens with 6 kg/m³ polypropylene fibers, a 5% increase in value of the energy absorption capacity was obtained, as compared to the specimens with 4 kg/m³ polypropylene fibers.

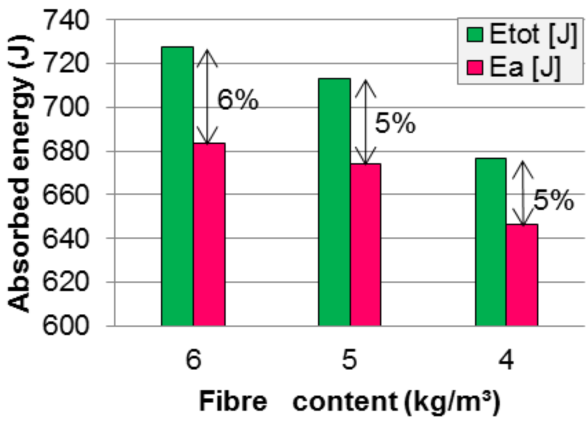

Fig. 7. Energy absorption capacity

The energy - deflection curves are shown in Figures 8-10.

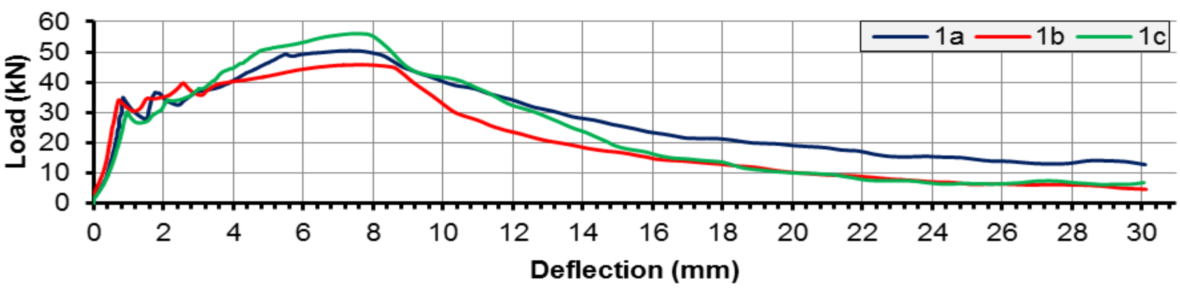

Fig. 4. Load - deflection curve for the batch with 6 kg/m³ polypropylene fibers

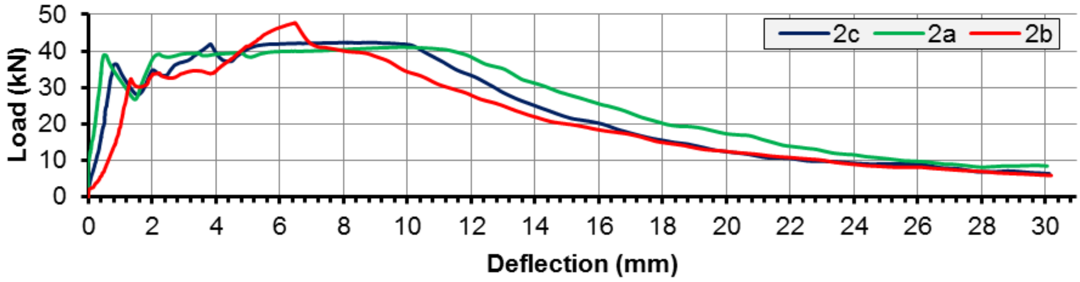

Fig. 5. Load - deflection curve for the batch with 5 kg/m³ polypropylene fibers

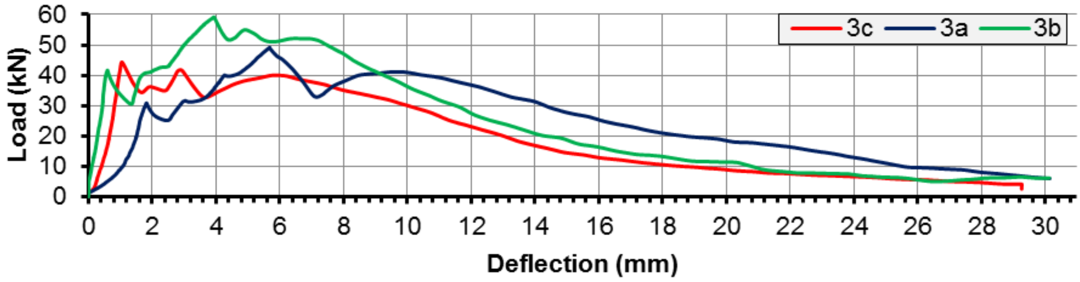

Fig. 6 Load - deflection curve for the batch with 4 kg/m³ polypropylene fibers

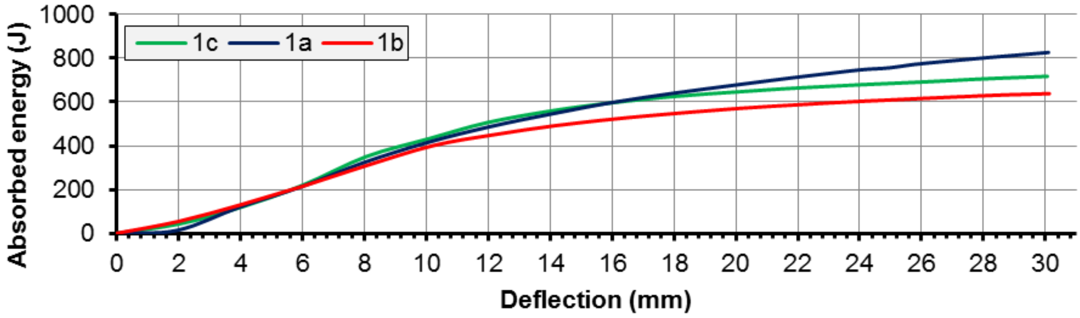

Fig. 8. Energy - deflection curve for the batch with 6 kg/m³ polypropylene fibers

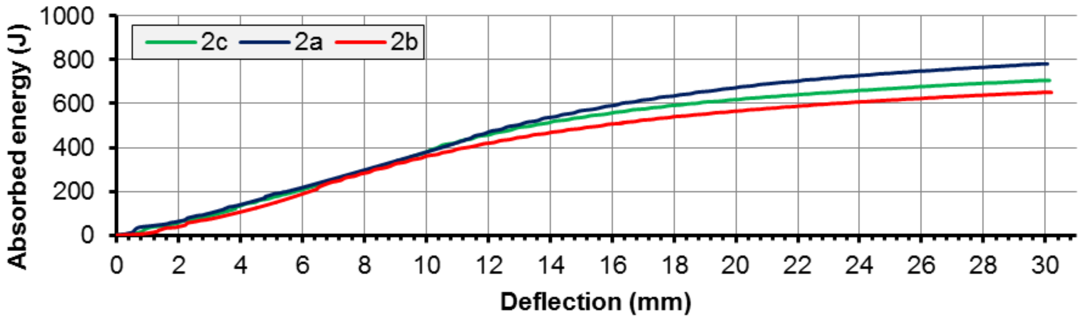

Fig. 9. Energy - deflection curve for the batch with 5 kg/m³ polypropylene fibers

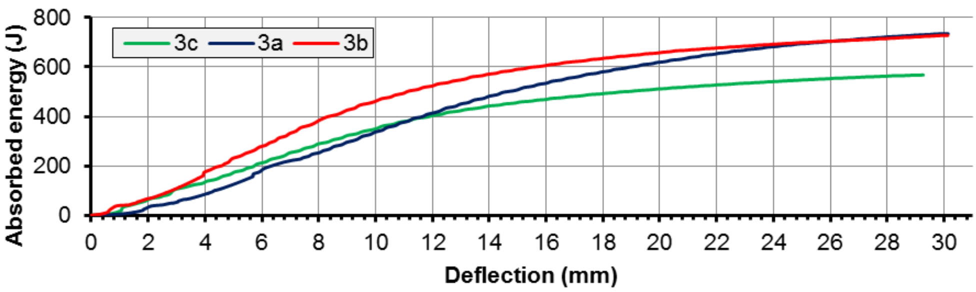

Fig. 10. Energy - deflection curve for the batch with 4 kg/m³ polypropylene fibers

Although the highest value of energy absorption capacity was obtained for the slabs with 6 kg/m³ polypropylene fibers, in terms of ultimate load we can observe (Fig. 8) that the values obtained for the composition with 6 and 4 kg/m³ are almost equal.

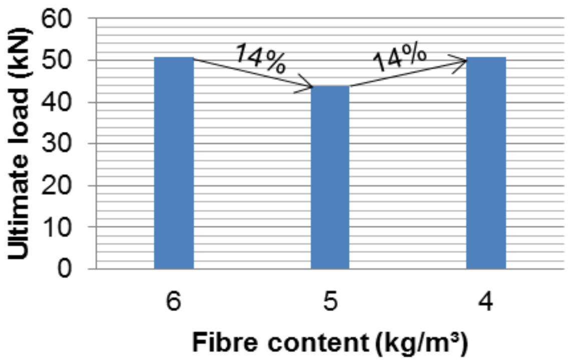

Fig. 11. Ultimate load

The rupture force is not correlated to the peak force, which is defined as the maximum force recorded during the test. The failure modes generated by this test are shown in Figures 12 - 14.

Fig. 12. Failure mode. Slab with 6 kg/m³ PP fibers

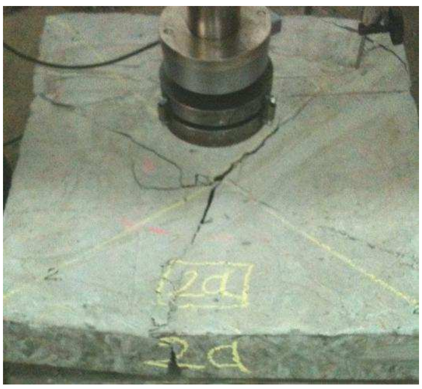

Fig. 13. Failure mode. Slab with 5 kg/m³ PP fibers

Fig. 14. Failure mode – Slab with 4 kg/m³ PP fibers

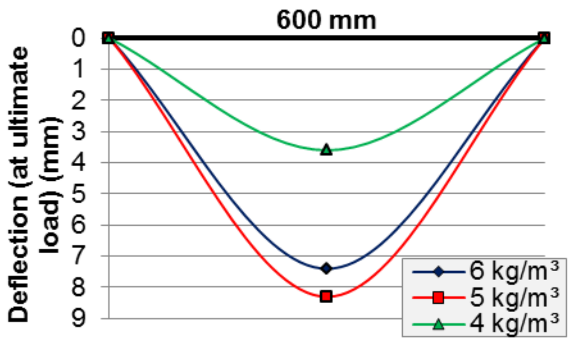

Fig. 15. Deflection of the slabs

In terms of deflection (recorded at ultimate load), the highest values were obtained for the compositions with 6 kg/m³ and 5 kg/m³ polypropylene fibers.

4. CONCLUSIONS

Based on the obtained results, the following conclusions were drawn:

- The value of energy absorption capacity increased proportionally with fiber content;
- For a classification as resistance in the E500 class, a dosage of 4 kg/m³ is sufficient;
- A fiber content of 5 kg / m³ is optimal from the point of view of energy absorption capacity value and of deflection;
- For all three compositions, the maximum load was at least 1.2 greater than the load at first crack, thus ensuring ductile behavior after cracking.

Further investigations of shotcrete are required, including determination of physico-mechanical properties of fiber reinforced concrete with various fiber percentages, determination of energy absorption capacity of concrete at younger ages and determination of optimum fiber content of this type of polypropylene fibers for the three classes of resistance (E500, E700 and E1000).

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