Polish Society of Composite Materials
Polskie Towarzystwo Materiałów Kompozytowych

15: 4 (2015) 250-254

COMPOSITES THEORY AND PRACTICE

Agnieszka Ślosarczyk*, Wojciech Wierzbicki

Poznan University of Technology, Institute of Structural Engineering, ul. Piotrowo 5, 60-965 Poznań, Poland
**Corresponding author. E-mail: agnieszka.slosarczyk@put.poznan.pl*

Received (Otrzymano) 11.03.2015

INFLUENCE OF POLYESTER MACROFIBERS ON SELECTED PHYSICAL AND MECHANICAL PROPERTIES OF CEMENT COMPOSITES

The research proved that polyester fibres, when added to concrete (2% of volume), improved its fracture resistance, however, the effectiveness of the fibres depended greatly on the strength class of the concrete. Much better co-operation of the fibres with the cement matrix was observed in the case of C25/30 class concrete. The application of higher class concretes (C35/45) results in decreased ability of the fibre to transfer loads after the cement matrix cracks. The addition of fibres seems to be positive in terms of the compressive strength. Depending on the concrete formula, for composites with polyester fibres a 6 to 15% increase in compressive strength was observed, as well as a decrease in abrasibility by 20÷50%.

Keywords: concrete, polyester fibers, physical and mechanical properties

WPŁYW MAKROWŁÓKIEN POLIESTROWYCH NA WYBRANE WŁAŚCIWOŚCI FIZYKOMECHANICZNE KOMPOZYTÓW CEMENTOWYCH

Beton osiąga wysoką wytrzymałość na ściskanie, ale jest materiałem kruchym o niskiej wytrzymałości na rozciąganie. Jednym ze sposobów poprawy wytrzymałości na rozciąganie przy zachowaniu lub poprawie pozostałych właściwości fizykomechanicznych kompozytu cementowego jest zastosowanie równomiernie rozproszonych włókien. Powstały kompozyt cechuje się wyższymi wytrzymałościami na ściskanie i rozciąganie, mniejszym skurczem oraz większą odpornością na rysowanie i pękanie powierzchni poddawanej obciążeniom dynamicznym. Coraz częściej obok włókien stalowych jako wzmocnienie matrycy cementowej stosuje się włókna syntetyczne wytworzone z polimerów. Najpopularniejszymi włóknami syntetycznymi są włókna polipropylenowe. Stosowane są głównie jako włókna przeciwskurczowe, chociaż coraz częściej na rynku pojawiają się również włókna polipropylenowe konstrukcyjne, cięte z folii lub skręcane z pojedynczych fibryl. Intensywny rozwój produkcji i przetwórstwa polimerów w ostatnich latach sprawia, że na rynku światowym pojawia się coraz więcej włókien z innych materiałów polimerowych, np. polietylenu, polichlorku winylu czy poliestru. Materiały te wykazują znacznie lepsze parametry fizykomechaniczne niż polipropylen, a ich efektywność w poprawie odporności na pękanie kompozytów cementowych jest znacznie wyższa. W niniejszym artykule jako zbrojenie matrycy cementowej zastosowano konstrukcyjne włókna poliestrowe. Przeprowadzone badania wykazały, że włókna poliestrowe dodane do betonu w ilości 2% obj. poprawiają odporność kompozytu cementowego na pękanie, przy czym efektywność włókien w znacznej mierze zależy od klasy wytrzymałości zastosowanego betonu. Znacznie lepszą współpracę włókna z kompozytem cementowym zaobserwowano w przypadku klasy wytrzymałości C25/30. Zastosowanie betonów o wyższych klasach wytrzymałości (C 35/45) sprawia, że spada zdolność włókien do przenoszenia obciążeń po zarysowaniu matrycy cementowej. Pozytywny efekt dodatku włókien odnotowano w przypadku wytrzymałości na ściskanie. W zależności od zastosowanej receptury betonu dla kompozytów z włóknem poliestrowym obserwowano 6÷15% wzrost wytrzymałości na ściskanie oraz o około 20÷50% mniejszą ścieralność.

Słowa kluczowe: beton, włókna poliestrowe, właściwości fizykomechaniczne

INTRODUCTION

Concrete has a high compressive strength, but it is a brittle material with low tensile strength. One way to improve its tensile strength, while keeping or enhancing other physicomechanical properties of the cement composite, is the application of evenly distributed fibres. The composite is then characterised by higher compressive and tensile strength, lower shrinkage and higher scratch and fracture resistance of the surface subject to dynamic loads [1-3]. At the moment, steel fibres are the additives most commonly applied in cement composites, which is related to the high bending and compressive strength of the fibre composite, as well as to the easy availability and low price of steel fibres. Their disadvantage however, is the higher weight of the cement composite and construction elements made of this composite, as well as low chemical resistance to the alkaline environment of the cement matrix. Those negative results are not observed in the case of applying synthetic fibres. Synthetic fibres, according to the norms are divided into singular or fibril microfibers with a diameter below 0.30 mm, and microfibers with a diameter over 0.30 mm [4]. The most popular synthetic fibres on our home construction material market are polypropylene fibres. They are applied mostly as anti-contraction fibres, although polypropylene construction fibres are becoming increasingly more common on the market. They are cut out from foil or rolled from singular fibrils. Recent intensive development in the production and processing of polymers is the reason why on the world market there are increasingly more fibres from other polymer materials, such as polyethylene, PVC or PES [5-8]. Those materials have much better physicomechanical properties than polypropylene, and their efficiency in improving the fracture resistance of cement composites is much higher. In the following research structural polyester fibres were applied as the reinforcement of the concrete. They are characterised by a higher tensile strength and higher elastic modulus in comparison with commonly applied polypropylene fibres.

EXPERIMENTAL PART

The following components were used to make the concrete mixture: cement CEM II B/S 32.5 R (Górażdże), stone aggregate: coarse gravel 8-16, fine gravel 2-8, sand, superplasticizer Sika® ViscoCrete® 20 GOLD and polyester macrofibers GRAMINFLEX® 30/0.45. The mixture formulae are given in Table 2. In order to test the efficiency of the polyester fibres, two concrete mixtures were designed that differed in strength class between C25/30 and C35/45.

TABLE 2. **Concrete mix recipes**
TABELA 2. **Receptury mieszanek betonowych**

	Recipe			
Component [kg]	**R1**	**R1+PES**	**R2**	**R2+PES**
Cement	360	360	320	320
Gravel 8-16	560	560	570	570
Gravel 2-8	560	560	570	570
Sand	840	840	855	855
Water	144	144	144	144
Superplasticizer, [% cement mass]	2	2	2	2
Polyester fibers PES [vol. %]	-	2	-	2

These concrete classes are commonly used in concrete floors. The two concrete mixtures were marked as R1 and R2, and to each mix polyester fibres in 2 vol.% were added. According to ref. [2], the selected amount of PES fibres is the minimal value which guarantees improvement of composite toughness. The samples with fibre additives were marked respectively as R1+PES and R2+PES. After 28 days the control formulae achieved the concrete classes R1 C35/45, and R2 C25/30. Aggregates were chosen in the method of successive approximations so as to receive the maximum tight aggregate composition. The contents of other components were set experimentally. The physicomechanical properties of the applied polyester macrofibers are presented in Table 3.

TABLE 3. **Technical data of GRAMINFLEX® fibers**
TABELA 3. **Dane techniczne włókien GRAMINFLEX®**

Properties	Value
Density	1.36 g/cm^3
Color	Grey
Material	Polyester
Tensile strength	400÷800 MPa
Young elastic modulus	11.3 kN/mm^2
Length	30.0 mm
Diameter	0.45 mm
Minimum elongation	8%
Water absorption	0.04%

Fig. 1. GRAMINFLEX® polyester fibers
Rys. 1. Włókna poliestrowe GRAMINFLEX®

Tests on bending strength were conducted after 56 days of hardening, on cuboid samples 100×100××400 mm. For each formula 4 samples were made. The samples were air-dried before the test, which was performed with the use of an Instron 8505 machine. During the test the concrete beams were loaded in three points, and in the lower part of the sample (stretched) an Epsilon extensometer was assembled and thus the crack opening could be measured precisely. An example of a sample after bending with the extensometer is presented in Figure 2. During the test the following fibre composite parameters were defined: tensile strength while bending with the maximum bending tension [MPa], maximum vertical displacement [mm] and maximum crack opening [mm]. The tests were performed until 25% of the maximum bending tension was achieved with a displacement increment of 0.4 mm/min. On the basis of the stress-displacement figure, the value of destruction energy of the fibre composites was defined [J] in points referring to 75, 50 and

25% of the maximum bending tension, which enabled the comparison of fracture strength in the tested fibre composites.

Tests on the compressive strength [MPa] were carried out on cubic samples (sides of 10 cm), which were loaded until destruction with a stress increment of 0.6 MPa/s. The research was done on a machine after 56 days of hardening. A resistance test of the matrix to an abrasive was conducted according to norm PN-EN 13892-3. For each formula three cubic samples (sides of 71 mm) were tested. The research began after the samples were air-dried. Before starting the grinding wheel, 20 g of abrasive was put on the belt and the sample was loaded with an axial force of 294 ±3 N. Each sample underwent 16 cycles of 22 turns. The measure of abrasibility is the loss of height of each sample.

Fig. 2. Stand for concrete beam testing

Rys. 2. Stanowisko do badania belek betonowych

RESULTS AND DISCUSSION

Figures 3 and 4 present exemplary stress - displacement curves, registered for concrete samples with and without the addition of polyester fibres, depending on the of the concrete formula. At the maximum bending stress, on the curves registered for pure cement matrices R1 and R2, a strong decrease in stress was observed, which is characteristic for the brittle cracking of the cement matrix. In the case of the cement composite with the addition of polyester microfibers, for each formula, R1 and R2, after the maximum stress, in the post-cracking zone, first a decrease in stress was observed, and then its increase, which is related to the load transfer by the fibres and gradual movement of the fibre from the cement matrix.

Table 4 presents the values of the tensile strength by bending, and compressive strength of the tested fibrocomposites. The presence of polyester fibres in the cement matrix in the amount of 2 vol.% slightly decreases the tensile strength by bending of the fibrocomposite, irregardless of the concrete class. A positive influence of the polyester fibres on the cement matrix can be seen in the analysis of the stress-displacement curve, and the destruction energies defined on its basis in points referring to 75, 50 and 25% of the maximum bending stress. In both cases the cement matrix with polyester fibres presented an improved fracture resistance in comparison with the matrix without fibres.

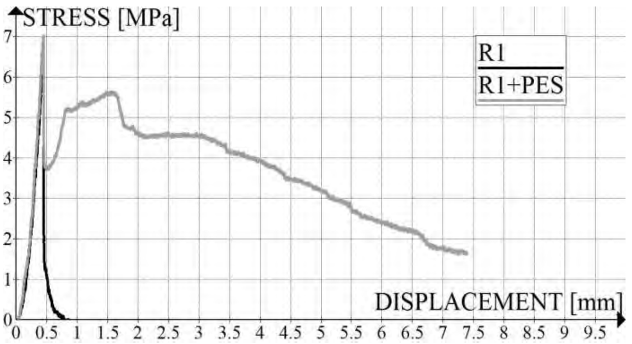

Fig. 3. Stress-displacement curves recorded for R1 and R1 + PES fibers

Rys. 3. Krzywe naprężenie-przemieszczenie dla R1 and R1 + włókna PES

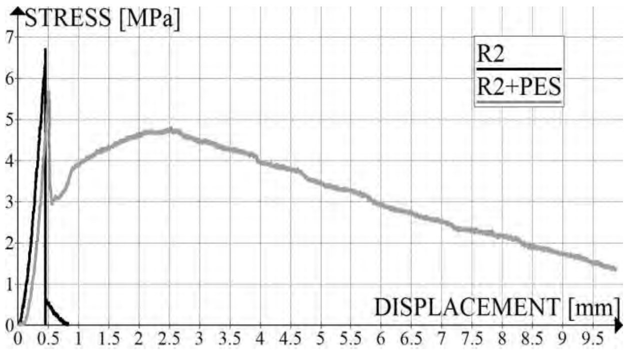

Fig. 4. Stress-displacement curves recorded for R2 and R2+ PES fibers

Rys. 4. Krzywe naprężenie-przemieszczenie dla R2 and R2 + włókna PES

TABLE 4. **Average values of flexural strength, compressive strength and average height loss of samples subjected to abrasive tests**

TABELA 4. **Średnie wartości wytrzymałości na zginanie, wytrzymałości na ściskanie oraz średni ubytek wysokości próbek poddanych ścieraniu**

	Flexural strength [MPa]	Compressive strength [MPa]	Height loss [mm]
R1	7.5±0.9	50.5±4.3	3.01±0.25
R1+ PES	7.0±0.5	57.9±0.9	2.00±0.34
R2	5.8±0.8	44.8±3.5	2.56±0.27
R2 + PES	5.6±0.4	47.6±2.6	2.06±0.22

The destruction energy of the fibrocomposite increased by 13 times for formula R1, and by 20 times for formula R2. Furthermore, the research proved that the effectiveness of the polyester microfiber depended greatly on the strength of the cement matrix itself. In the case of cement matrix R2, the destruction energy was almost 15% higher at the point referring to 25% of the maximum load (42.4 J for formula R1, and 48.3 J for R2). Moreover, the research proved that in the whole measurement range, and also at points referring to 75 and 50% of the maximum bending strength, the matrix of the lower class had much better co-operation with the fibres. Similar relations were discovered in the analysis of the maximum displacement values and the maximum crack opening, which is presented in Figures 7 and 8. After achieving the point of 25% of the maximum bending strength, higher values of the maximum displacement and crack opening were registered for the fibrocomposites made of the lower class concrete.

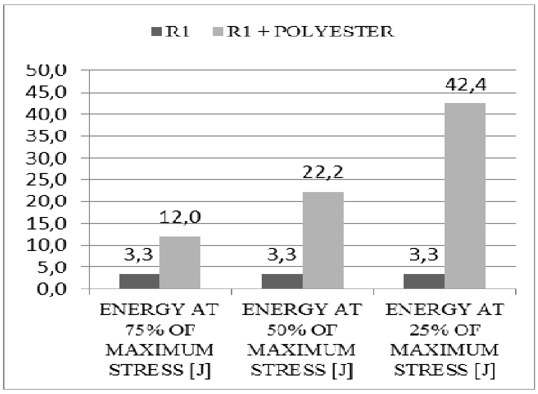

Fig. 5. Average values of failure energy for R1 and R1+PES composites at points corresponding to 75, 50 and 25% of maximum bending stress

Rys. 5. Średnie wartości energii zniszczenia dla kompozytów R1 i R1+PES w punktach odpowiadających 75, 50 i 25% maksymalnego naprężenia zginającego

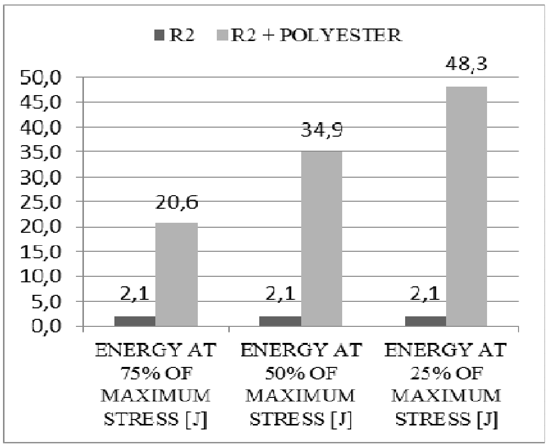

Fig. 6. Average values of failure energy for R2 and R2+PES composites at points corresponding to 75, 50 and 25% of maximum bending stress

Rys. 6. Średnie wartości energii dla kompozytów R2 i R2+PES w punktach odpowiadających 75, 50 i 25% maksymalnego naprężenia zginającego

Contrary to the results gained in the tensile strength tests by bending, in the case of the compressive strength tests this parameter was improved. The presence of polyester fibres in the cement matrix resulted in improvement in the compressive strength by almost 15% for the R1 formula fibrocomposites and by 6% for the R2 formula. A higher compressive strength also resulted in a higher wear strength for the matrices with the fibres. The analysis of the height loss in the samples proved that the control samples were the most prone to wear; especially those made according to the lower strength class formula, R1 - for them the average height loss equalled 3.01 mm. After adding fibres to formula R1, the height loss equalled 2.00 mm, and the result was better by 34%. For the R2 formula samples, the results were a little bit worse and thus the height loss in the sample without the fibre addition equalled 2.56 mm, and after fibre addition it was 2.11 mm. The average height loss in the samples with fibres was about 20% lower than in the case of samples without fibres.

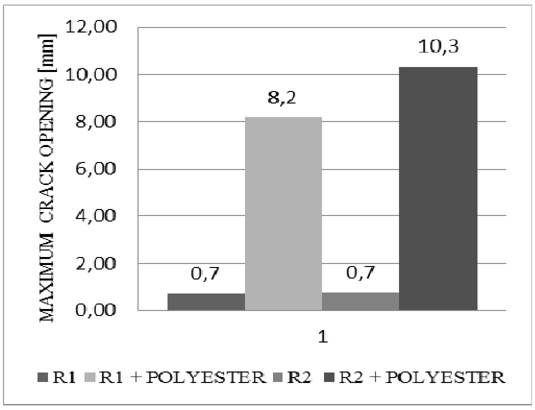

Fig. 5. Average values of maximum crack opening

Rys. 5. Średnie wartości maksymalnego rozwarcia rys

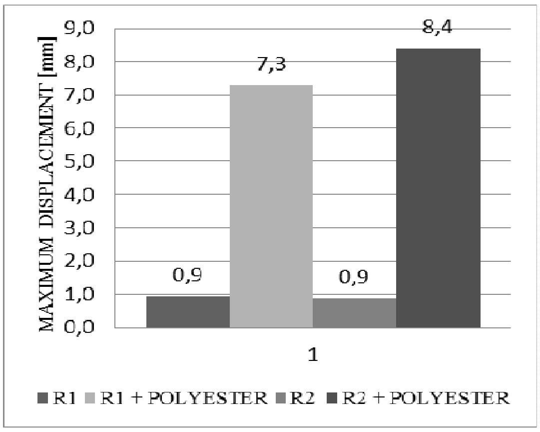

Fig. 6. Average values of maximum vertical displacement

Rys. 6. Średnie wartości maksymalnego przemieszczenia pionowego

CONCLUSIONS

The increase in the strength of fiber reinforced cement composites is possible when the fiber modulus of elasticity is greater than that of the cement matrix. In the case of a low modulus of polyester fibers, this condition is difficult to fulfil. However, even in such an example the increase in strain capacity, toughness, impact resistance and crack control of FRC composites is possible. For the tested composites the minimal amounts of PES fibers required to improve the composite toughness was applied. The stress-displacement curve indicates the low slope of the curve in the post-cracking zone, which is a consequence of the low modulus of elasticity of the PES fibers. For each formula, R1 and R2, after the maximum stress, in the post-cracking zone, first a decrease in stress was observed, and then its increase, which is related to the load transfer by the fibres and gradual movement of the fibre from the cement matrix. In the case of FRC composites with higher strength (C35/45), the effectiveness of the PES fibers in transferring load was much lower. However, despite little improvement in the load-bearing capacity, the strain capacity was high and led to improvement of the total toughness of the composite. The addition of fibres seems to be positive in terms of the compressive strength. Depending on the concrete formula, for the composites with polyester fibres a 6 to 15% increase in compressive strength was observed, as well as a decrease in composite abrasibility by 20÷50%. Moreover the PES fibers exhibited very good wettability and easily mixed with the cement matrix. In successive research, higher amounts of fibers up to 3 vol.% should be tested as a reinforcement of cement composites.

REFERENCES

[1] Jamroży Z., Betony ze zbrojeniem rozproszonym, Materiały XVII Ogólnopolskiej Konferencji Warsztaty Pracy Projektanta Konstrukcji, Tom I, Ustroń 2002.

[2] Bentur A., Mindess S., Fibre Reinforced Cementitious Composites, Taylor & Francis, London and New York 2007.

[3] Zollo R.F., Fiber-reinforced concrete: an overview after 30 years of development, Cem. Concr. Comp. 1997, 19, 107--122.

[4] PN-EN 14899 Włókna polimerowe - Definicje, wymagania i zgodność.

[5] Zheng Z., Feldman D., Synthetic fibre-reinforced concrete, Prog Polym Sci 1995, 20, 185-210.

[6] Ślosarczyk A., Jasiczak J., Alternative ways of reinforcing cement composites, Composites Theory and Practice 2012, 4, 266-267.

[7] Wang Y., Backer S., Li V., An experimental study of synthetic fibre reinforced cementitious composites, J. Mater. Sci. 1997, 22, 4281-4291.

[8] Gupta S., Kanta Rao V.V.L., Sengupta J., Evalution of polyester fiber reinforced concrete for used in cement concrete pavement works, Road Materials and Pavement Design 2008, 9, 441-461.

