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EFFECT OF FIBERS REINFORCEMENT ON SHEAR CAPACITY OF DOUBLE SPAN REINFORCED CONCRETE BEAMS

WPŁYW DODATKU ZBROJENIA ROZPROSZONEGO NA NOŚNOŚĆ STREF ŚCINANIA W DWUPRZĘSŁOWYCH BELKACH ŻELBETOWYCH

A b s t r a c t

Fifteen double-span reinforced concrete beams (RC) with the addition of dispersed reinforcement were examined to determine the effect of the reinforcement on the shear resistance at the support area. Asalt fibers, whose mechanical properties (especially high tensile strength) have a beneficial effect on the behavior of components under load were used. Beams were subjected to a constant load forces gathered in the middle of the span of each bay. The study aimed to determine the deflection of beams, measuring the crack width perpendicular and diagonal capacity and determination of shear and/or bending. Almost all the beams have reached a shear failure mode. The addition of basalt fiber in each of a series of research results in diverse growth destructive force beam and a corresponding increase in the lateral force on the supports. The maximum strength increase of at 54%, as compared to the reference beam without the fibers was observed for the beam A-III 50/50.

Keywords: basalt fiber reinforced concrete, BFRC beams, steel stirrups, shear capacity

S t r e s z c z e n i e

Zbadano piętnaście żelbetowych belek dwuprzęsłowych z dodatkiem zbrojenia rozproszonego w celu określenia wpływu tego zbrojenia na nośność na ścinanie stref przypodporowych. Wykorzystano włókna bazaltowe, których właściwości mechaniczne (głównie wysoka wytrzymałość na rozciąganie) wykazują korzystny wpływ na zachowanie elementów pod obciążeniem. Belki poddano stałemu obciążeniu siłami skupionymi w środku rozpiętości każdego przęsła. Badania miały na celu określenie ugięcia belek, pomiar szerokości rys prostopadłych i ukośnych oraz określenie nośności na ścinanie i/lub zginanie. Niemal we wszystkich belkach osiągnięto model zniszczenia poprzez ścinanie. Dodatek włókien bazaltowych w każdej z serii badawczych powoduje zróżnicowany przyrost siły niszczącej belkę i odpowiedni przyrost siły poprzecznej na podporach. Maksymalny przyrost siły wynoszący 54%, w porównaniu do belki referencyjnej bez włókien zaobserwowano dla belki typu A-III 50/50.

Słowa kluczowe: fibrobeton, włókna bazaltowe, belki żelbetowe, nośność na ścinanie

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1. Genesis of fiber reinforced concrete

A long time ago, cut straw or hair calf were added to the manufacturing process of clay, then there were already-banned asbestos fibers. In 1910, the idea of adding small steel wires which were to improve the homogeneity of thick reinforced concrete rods. After more than 50 years, Romuldi and Batson seriously took up the addition of steel fibers [1]. Their argument for improving the properties of concrete with the addition of steel fibers holds true and has been confirmed in a number of test results. We know that the fibers prevent initiation of cracks and prevent their propagation, increase tensile strength and toughness of concrete. The development of materials technology has allowed for the production of fibers with new materials, such as synthetic (polypropylene, aramid fibers), glass, carbon and basalt. Depending on the characteristics of the fibers, they fulfill different functions and have an extensive range of applications. Most relevant to the construction industry are steel fibers. They are affordable and have good material parameters (high tensile strength, high modulus of elasticity). Modern basalt fibers coated with polymers may also work effectively in building construction. The modulus of elasticity is greater than the cement matrix and the tensile strength is three times greater than the steel fibers [2].

Numerous studies have shown that the use of steel fibers in RC beams can enhance their shear and flexural capacity. In support regions of the beams the presence of fibers can resist diagonal tensile stresses and bridging tensile diagonal cracks. Some previously undertaken studies concerned simply supported SFRC beams showed that steel fibers can be used in RC beams as a replacement of shear diagonal or vertical shear reinforcement.

In Poland, there are many studies on the use of extruded fiber. Silesian University of Technology has been tested reinforced concrete flat slabs, in which fiber supplement showed a significant increase in capacity [3]. Research conducted by J. Katzer indicates that fibers have a beneficial effect on fatigue and shock [4]. Pogan found that the addition of fibers in concrete construction leads to a reduction of longitudinal steel reinforcement bars, as well as the transverse reinforcement stirrups [5]. Studies on the reduction of shear reinforcement by the addition of steel fibers for concrete have been carried out in the USA by Dinh and others [6] and last time in Canada in the McGill University [7].

However, only very few experimental tests have been conducted on the RC two span beams with non-metallic fibers, especially with basalt fiber reinforced polymers BFRP, having very high resistance against corrosion.

It should be noted that the behavior of BFRP beams with steel flexural and shear reinforcement is not fully understood due to a very complex mechanism of failure, depending on several material and load factors, such as fiber properties and content in the concrete mix and also on the ratio of steel longitudinal and shear reinforcement. Therefore, for the structural use of BFRP in the RC beams, proper tests are required to clarify the effects of basalt fibers on the shear and flexural response of two span beams.

2. Assumptions for the experimental studies

A two-span beam with fiber reinforcement as an alternative to traditional reinforcement stirrups was used as the research case study. Five test series, based on the spacing of stirrups (Fig. 1), were designed. In the first series of A-I 100/100 stirrup spacing, designed in accordance with PN-EN, each subsequent series of stirrups amount was reduced by 50%, until the last series of A-V 0/0, which is without stirrups [8]. All beams have the same structure of the longitudinal reinforcement and dimension 80 × 160 × 2000 mm The research program assumed concentrated load in the middle of the each span. Shear ratio is a/d = 2.89. The concrete contains two different amounts of fibers: the first type of concrete contained 2.5 kg/m^3 basalt fibers tested for compressive strength $f_{c,\mathrm{cube}}$ = 30.80 MPa and tensile strength of f_{ctm} = 4.65 MPa, the second 5 kg/m^3 of $f_{c,\mathrm{cube}}$ = 31.90 MPa and f_{ctm} = 5.89 MPa. In addition, the reference beam (without fibers) is tested for compressive strength $f_{c,\mathrm{cube}}$ = 28.0 MPa and tensile strength of f_{ctm} = 4.01 MPa. Fiber reinforcement was finally added to the concrete and mixed for a few minutes until a uniform distribution of fibers could be seen. Even though good workability was obtained for all mixtures, fiber congestion was observed along the flexural reinforcement if the clear spacing between reinforcing bars was substantially less than the fiber length. Basalt fibers had a diameter of 20 μ and a length of 50mm. The fiber density is 2.65 t/mm^3. High tensile strength and Young's modulus 1680 MPa 90 GPa was observed. Basalt fibers are resistant to corrosion and acid and also to alkaline environment. They are characterized by resistance to high and low temperatures from –260°C to +750°C. They are coated with a polymer affecting the optimum adhesion to concrete. An additional advantage of fiber is its high hardness (8.5 Mosh), which greatly affects the increase in concrete's resistance to abrasion. Material is 100% organic. The big advantage of basalt fiber, as compared to steel fiber, is its low weight (3 times lighter than steel).

The overall behavior of the test beams was evaluated based on their crack distribution, average shear stress (load) versus displacement response, ultimate strength, failure mode, and strain field in the critical shear span. At each load level, deflection, deflection in the compression zone and the layout and width of the opening figure were measured.

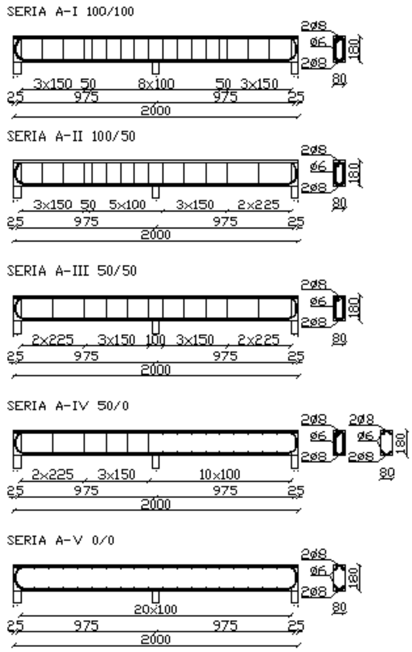

Fig. 1. Schematic of the reinforcement bars research

3. The test results

Table 1 shows the experimental braking forces and their growth. While short-term studies measured stress reactions at the supports, internal and total failure load,the presence of basalt fibers in each series showed an increase of destructive forces, and the according reaction. Table 1 shows the results of the destructive forces and their growth compared to the values obtained for the destructive forces of the reference beams Maximum increase the critical load is 54% for a series of A-III 50/50 5 kg/m^3 fiber content. The increase in shear strength was significant when basalt fibers were added in a 5 kg/m^3 fraction compared to the beams with no fibers.

Table 1

Ultimate forces and their percentage increase for each test series

SERIES	AMOUT OF FIBRE [kg/m^3]	ULTIMATE FORCE [kN]	INCREASE IN FORCE [%]
A-I 100/100	0.0	80.6	–
	2.5	95.3	18.2
	5.0	106.7	32.4
A-II 100/50	0.0	57.8	–
	2.5	70.2	21.5
	5.0	75.3	30.3
A-III 50/50	0.0	60.7	–
	2.5	69.3	14.2
	5.0	93.5	54.0
A-IV 50/0	0.0	29.9	–
	2.5	33.5	12.0
	5.0	44.1	47.5
A-V 0/0	0.0	33.1	–
	2.5	37.9	14.5
	5.0	49.4	49.2

Beams of each series were destroyed by shear. Diagonal crack appeared with section where a smaller amount of stirrups at higher shear strength was used. Figure 2 shows a model of the destruction of the beams. There are three types of damage to beams: diagonal tension, a combination of diagonal tension and shear-tension and a combination of shear-compression and shear-tension. For the failure mode that was considered: a combination of shear-compression and shear-tension failures, the widening of the critical crack started at the reinforcement level and extended upwards, toward the loading point. Beam failure was triggered by the crushing of the concrete in the beam compression zone adjacent to the loading point, accompanied by a significant splitting along the top layer of longitudinal tension reinforcement.

The crack patterns for the RC and BFRC beams were distinctly different. While the RC beams without transverse reinforcement exhibited a single inclined crack followed by a brittle shear failure, all BFRC beams showed at least two diagonal cracks. The presence of fibers, however, allowed the development of multiple diagonal cracks and the widening of at least one of them prior to a shear failure, which provided some warning about the imminence of failure. Even for these beams the failure was rather sudden.

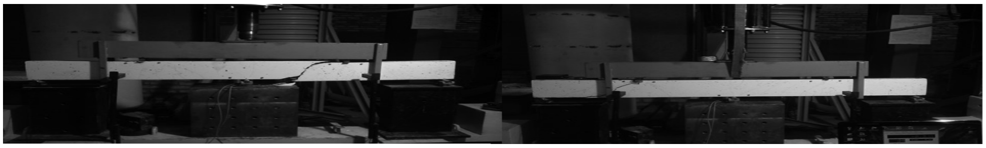

Fig. 2. Shear failure of the beams

4. Conclusions

The following conclusions can be drawn from the results of this experimental investigation. The use of basalt fibers in a mass fraction greater than or equal to 5 kg/m^3 led to an enhanced inclined cracking pattern (multiple cracks) and improved shear strength in beams without stirrup reinforcement. The increase in shear strength associated with an increase in fiber content beyond 2.5 kg/m^3 by mass, however, was relatively small. A comparison of the behavior of the BFRC beams with that of the RC beam with stirrup reinforcement satisfying the minimum requirement indicates that basalt fibers evaluated in this investigation, when used in a mass fraction greater than or equal to 2.5 kg/m^3, can be used in place of the minimum stirrup reinforcement.

Pilot studies conducted on the model: BFRC two span beams with different steel stirrups, clearly showed a beneficial effects of basalt fibers on BFRC beam behavior under short time loads. The addition of basalt fibers in each of a series of tested beams visibly influenced destructive forces and the corresponding values of support reactions. The maximum increase of ultimate load, equal to 54% compared to the reference beam without basalt fibers, was observed for the beam of Series A-III 50/50 with fiber content of 5 kg/m^3.

Further experimental and numerical studies are planned to clarify the use of BFRC double spans beams on full scale.

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