MOGUĆNOST UPOTREBE MIKROARMIRANOG BETONA U KONSTRUKCIJAMA ZA DOBIJANJE OBNOVLJIVE ENERGIJE

POSSIBILITY OF USING FIBER REINFORCED CONCRETE IN STRUCTURES FOR RENEWABLE ENERGY HARVESTING

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Dodavanje mikroarmature betonu blagotvorno utiče na integritet i trajnost konstrukcije, omogućava uštede u troškovima i vremenu izvođenja radova. Zbog ovih prednosti, povećano je interesovanje za razvoj i upotrebu mikroarmiranog betona kako u izgradnji novih, tako i prilikom sanacija, rehabilitacije i ojačanja postojećih konstrukcija. Kako bi se utvrdile karakteristike mikroarmiranog betona, neophodne za projektovanje prema aktuelnim preporukama, sprovode se standardizovana ispitivanja – najčešće ispitivanje prizmatičnih uzoraka na savijanje. U radu su prezentovani rezultati i analiza ispitivanja čvrstoće pri savijanju uzoraka mikroarmiranog betona sa čeličnim vlaknima. Ovakav beton ima potencijal za upotrebu u elementima konstrukcija koji su pod uticajem napona zatezanja u eksploataciji.

Ključne reči: *mikroarmirani beton; čelična mikroarmatura; čvrstoća pri savijanju;*

Adding fibre reinforcement to concrete has a beneficial effect on the structural integrity and durability, enables construction cost&time savings. Because of these advantages, fibre reinforced concrete is gaining an increasing interest in development and use both in novel structures, as well as for repair, rehabilitation and strengthening of the existing structures. In order to determine the properties of the fibre reinforced concrete, that are necessary for design according to current guidelines, standardized tests are performed - most often flexural (or bending) test, conducted on the prismatic samples. The paper presents the results and analysis of flexural strength tests of samples made of steel fibres reinforced concrete. This concrete has potential for use in elements of the structures which are under tensile stresses in exploitation.

Key words: *fibre reinforced concrete; steel fibres reinforcement; flexural strength testing*

1 Introduction

Plain concrete is known as quasi-brittle material that is strong in compression but with low tensile strain and strength capacities. In order to overcome this weakness, the use of reinforcement in tensile zones of concrete structures was introduced almost two centuries ago. Nevertheless, earliest known technique to reinforce concrete is by adding discrete fibres [1,2]. Short and discrete fibres that are randomly but uniformly dispersed in cementitious matrix improve both structural integrity and durability.

Contemporary fibres for concrete reinforcement are categorized in two main groups, natural (of plant or animal origin) and synthetic (steel, glass, carbon, polymeric etc). The use of synthetic fibres is more prominent, but the sustainable construction makes the possibility of natural fibres use ever actual. Among the synthetic fibres, the steel and polypropylene fibres are the most common, but the selection of the specific fibres for the application is governed by the expected effect to be obtained in every single case. The fibres for concrete reinforcement vary widely in their physical and mechanical properties, geometry, areas of application and methods of use.

The use of fibres in concrete structures for renewable energy harvesting is common in the cases where such concrete has to possess certain physical, mechanical properties, resilience and durability. All the stated parameters depend on the type of the structure, specific structure element made, actions

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on structures, and environmental conditions. The method for characterization of the concrete reinforced by fibres will be described in the paper, in order to illustrate the modelling process of the material used in such concrete structures for renewable energy harvesting.

2 Advantages of fibre reinforced concrete (FRC)

Various types of fibres can be used for concrete reinforcement. The enhancement of the composite depends on factors such as fibre mechanical properties, quantity, shape and length. For the structural purposes, steel fibres are the most useful, and can be added to concrete in order to complement the conventional reinforcement, but also, in some circumstances, as a main reinforcement [3, 4].

The key contribution of fibres is enhanced post-cracking behaviour. Capacity of fibres to bridge the crack faces contributes to the residual tensile strength enhancement, higher failure strain and toughness of the composite. The last property results in improved resistance to impact and fatigue, while increased ductility and energy dissipation ability makes such composite convenient for use in high seismic regions [5]. Fibres are very effective in control of crack propagation and reduction of crack width, preventing water and contaminants penetration into concrete. Consequently, addition of fibres has a substantial positive influence on the durability of concrete. In addition to that, short and discrete fibres rarely overlap so continuous conduction pathway is impossible, significantly reducing the corrosion potential in FRC elements [2, 4].

Concretes' versatility is one of the reasons why it is the most widely used material. Fibre reinforcement can be used in the cases where conventional reinforcement cannot fit, providing the possibility of thinner and more complex concrete elements to be made. In addition to the statements above, fibres reduce the construction time, and labour costs, making the FRC prominent material [5].

3 Possibility of using FRC in renewable energy structures

There is a number of concrete structures specialized for renewable energy harvesting, but the hydropower structures and wind turbines can be regarded as such where the use of the fibre reinforcement shows its' biggest potential. The addition of fibres can have considerable positive effect on concrete used in hydropower structures. For instance, the discharge elements of dams are placed where concrete is subjected to cavitation, abrasion and significant impact load. Due to the good resistance to all of the above mentioned loads, the steel fibre reinforced concrete (SFRC) is successfully used in repair of concrete surfaces damaged by the waterborne forces [6].

Harnessing wind energy is rapidly growing, making the wind one of the most widely used renewable energy sources of electricity generation [7, 8]. Development of increasingly larger wind turbines with higher capacity opens the possibility for various countries to meet the given renewable energy commitments. On the other hand, bigger turbine blades demand taller and stronger towers with larger foundations, making the supporting structure costs more and more significant. Keeping in mind that steel and cement productions are highly energy-intensive processes followed by substantial CO_2 emission, the costs of foundations and tower are not only economical challenge, but environmental as well [9]. In such cases the material consumption optimization is essential, in order to achieve a cost-competitive design.

Concrete towers for wind turbines are usually designed as vertically prestressed tapering tubes made of prefabricated thin-walled shell units [10]. In order to reduce weight of tower as well as costs, the wall thickness has to be minimized, which can be accomplished by using FRC. Prestressing of the tower ensures that only compression occurs in the concrete for ultimate limit state, while FRC provides resistance in case of secondary effects and highly improves durability by crack control. Keeping in mind that minimum thickness of concrete section with conventional reinforcement is limited, among other factors, by the need for thick cover (providing the sufficiently reliable structural durability), thickness reduction can be enabled by using FRC.

The construction of wind turbine foundations involves substantial consumption of the reinforced concrete, considerably increasing the embodied carbon footprint of these renewable energy facilities [9, 10]. Rotor operation and waves present a significant source of periodic loading on wind turbine supporting structures, making them fatigue-prone [11]. Constructing sections thicker and introducing the additional amount of reinforcement is a conventional way to increase the fatigue resistance. The use of steel fibres improves mechanical properties, possibly reducing the amount of bar reinforcement required, and increasing the fatigue resistance, without the need to thicken the section. Therefore, steel fibres offer a possibility of design optimization, providing the cost-effective solutions for fatigue-critical supporting structures, and making concrete more attractive in terms of energy consumption and carbon emissions.

4 Post-cracking characterization of FRC

Most important aspect of FRC is its behaviour when subjected to tension loads, and improvement in terms of ductility and post-cracking properties that addition of fibres to the cementitious matrix can provide. In order to evaluate the post-cracking behaviour of FRC, several test methods are developed. The most direct way to characterize toughness is through the uni-axial tensile test, but the more practical bending (flexural) test is the most common. Depending on the applied standard, three-point or four-point bending test on notched or un-notched prisms is performed. For example, the European Standard EN 14651 specifies a method to obtain the tensile behaviour of metallic fibre concrete [12]. Test specimen is the 600 mm long prism with cross section of 150x150 mm^2, notched in the middle of the span. The bending test is performed by applying a centre-point load on a simply supported prism with 500 mm span. Deformation is expressed in terms of mid-span deflection or crack mouth opening displacement – CMOD. Load and deformation values should be measured continuously at the same time. This test is deformation-controlled, meaning that the loading is applied in such manner to provide the increase of the deformation at a constant rate, defined by the standard. The tensile behaviour of the tested specimen is evaluated, based on the load-deflection curve or load-CMOD curve.

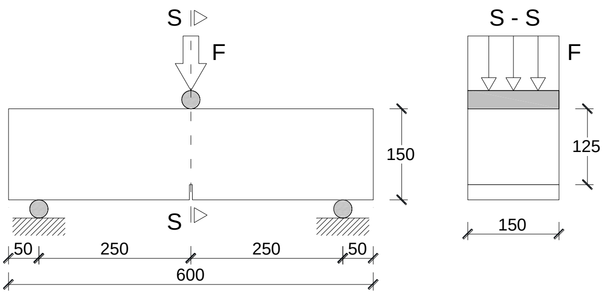

Figure 1 – Arrangement of loading of test specimen according to EN 14651

Design parameters – limit of proportionality (LOP) and residual flexural strength values are obtained from corresponding load values from load-deformation curve. The load value corresponding to LOP is the highest load value on load-deformation diagram in the interval of 0.05 mm CMOD or 0.08 mm deflection depending on quantity that expresses the deformation. The key composite property that has to be determined by testing are residual tensile strength values. These values are determined based on load values corresponding to the specified values of CMOD or deflection. Residual tensile strength values characterize the material behaviour at ultimate limit state (ULS) as well as serviceability limit state (SLS). According to that, the ability to substitute conventional reinforcement (partially or completely) by fibres can be assessed.

5 Conclusions

Randomly oriented fibres that are uniformly distributed throughout the cementitious matrix that reinforce the concrete can, depending on the properties and dosage of fibres, overcome the concretes' quasi-brittle deficiencies. In relation to that, fibre reinforcement has a beneficial effect on the post-cracking performance, enhancing the concretes' tensile behaviour. Thanks to the crack bridging ability of fibres, the performance improvements are significant in terms of residual tensile strength, failure strain and toughness, as well as control of crack propagation and width. Usually, bending tests such as described in the paper are conducted in order to evaluate FRC's tensile behaviour and to determine the design parameters.

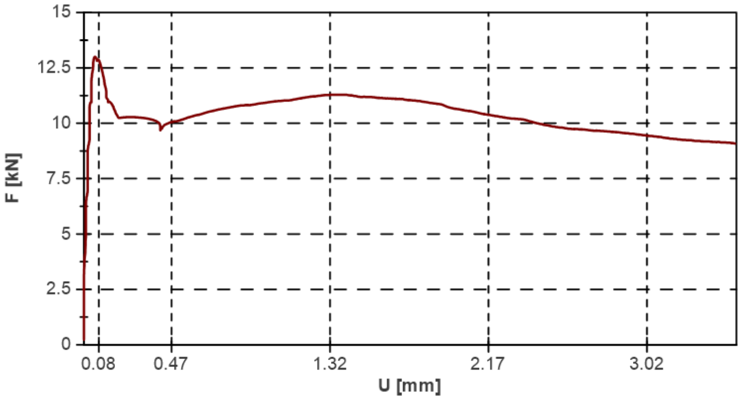

Figure 2 – example of load-deflection curve obtained in the laboratory test

Harvesting wind and hydropower energy demands structures that are resistant to the aggressive and corrosive environment, and should withstand specific loads. The use of fibre reinforcement has a potential to satisfy these requirements. SFRC has proven its resistance to cavitation, abrasion and impact loads, making it appropriate solution for the use in hydropower structures, especially in construction or repair of their discharge elements. Mechanical properties enhancement opens up the possibility of obtaining optimized design of fatigue-prone structures, reduction of concrete and conventional reinforcement consumption, which leads to minimization of embodied energy, and carbon footprint of wind turbine supporting structures.

The addition of fibre reinforcement to concrete improves its structural integrity and durability, while reducing the environmental impact as well as construction-time, material and labour costs.

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