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Experimental and theoretical analysis of deflections of concrete beams reinforced with basalt rebar

A. Lapko[a], M. Urbański[b,*]

[a] Chair of Building Structures, Faculty of Civil & Environment Engineering, Bialystok University of Technology, Wiejska St. 45e, Bialystok PL-15 351, Poland

[b] Institute of Building Engineering, Faculty of Civil Engineering, Warsaw University of Technology, Armii Ludowej St. 16, Warsaw PL-00 637, Poland

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ABSTRACT

This paper presents a comparative analysis of experimental and theoretical deflections of simply supported beams reinforced with BFRP rebar (Basalt Fiber Reinforced Polymers). The tested BFRC model beams have been made of concrete class C30/37 and reinforced with flexural basalt bars of 8 mm in diameter with the characteristic identified in strength tests in tension. During the investigation of model beams there were registered beam deflection, concrete strains and width cracks, as well as critical forces. It has been shown that much lesser cross-sectional stiffness of basalt BFRP bars produces higher deflections and crack widths compared to the beams reinforced with steel bars of the same cross-section. The results of theoretical analysis of BFRC beam deflections on the basis of the known formulas showed some significant discrepancies compared to experimentally obtained deflections, especially for lower level of loading forces. The results clearly show that basalt rebar having full resistance against corrosion may be good alternative for the reinforcement of concrete structures, like RC bridge girders subjected to environmental attack.

1. Introduction

Many of concrete structures, like bridges or underground tanks reinforced with traditional steel rebar are constantly subjected by the corrosion attack due to environmental conditions. In the USA thousands of highway bridges are unsafe due to deterioration caused by corrosion of steel reinforcement. Experience has demonstrated that concrete bridges reinforced with conventional steel rebar are very sensitive to damage from environmental attack mainly due to de-icing salt or induced by freeze–thaw and alkali-silica reactions. Measures of corrosion protection in a new designed bridge construction by the use of corrosion resistant non-metallic rebar may be fully reduce this problem.

In the second half of the twentieth century occurred the evolution of composite materials on the basis of FRP (Fiber Reinforced Polymer). Initially these materials were used in the military and aerospace industries. Gradually, over the last 30 years, FRP materials are being used in building construction.

* *Corresponding author*. Tel.: +48 22 2346578.
E-mail addresses: lapko@pb.bialystok.pl (A. Lapko), m.urbanski@il.pw.edu.pl (M. Urbański).
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Composite materials based on FRP significantly increase the economic viability and durability of buildings and bridges constructions [1].

Wherever a decisive role in the construction of civil engineering plays a strength, stiffness and resistance to environmental factors, composite materials based on FRP become outstanding replacement for conventional steel reinforcement. Service life of concrete slabs with steel reinforcement for use in bridges, expected to be 25 years. However, the service life of panels with FRP reinforcement is usually expected to be at least 75 years, i.e. the period of use of the bridge [2].

Basalt FRP bars are an excellent alternative as the reinforcement of bridge girders due to minimizing the weight of the slab having excellent resistance to corrosion effects, reducing repairs and a significant increase in usability.

Nevertheless, BFRP reinforcing bars are a quite new material which mechanical properties are not yet completely defined. Due to the anisotropic structure of composite materials and isotopic steel reinforcement, the modified stress–strain relationships have to be considered.

The results of research described in this paper carried out at the Warsaw University of Technology are concerned with a pilot experimental and theoretical analysis of deformations and stresses in model concrete beams reinforced with flexural basalt fiber composite bars (BFRP) to determine the strength parameters and acceptable cracking and deflections of such elements.

It should be noted that the modulus of elasticity of basalt bars (≈40 GPa) is about 5 times smaller than the modulus of elasticity of steel bars, which results in a greater reduction in BFRP beam cross-section stiffness after cracking [3]. In the flexural beams the concrete tensile strength (due to adhesion of concrete and reinforcing bars between the cracks) depends on the tension stiffening effect [4,5]. The share of tension stiffening effect depends on the ratio of the uncracked element's moment of inertia to the moment of inertia after cracking. The moment of inertia at the cracked cross sections in the basalt reinforced beams is about four times smaller than the same property in the beams with steel reinforcement [6]. As a result, the serviceability analysis reveals significantly higher strains in concrete, beam deflections and width of cracks [7].

2. The results of experimental studies

The main objective of this study was to obtain the deformational characteristics of the concrete beams reinforced with BFRP bars. The primary objective was to identify the main mechanical properties of reinforcing bars made of BFRP basalt fiber, and to determine their suitability as reinforcement for the concrete beams subjected to bending. Determination of mechanical properties of BFRP bars 8 mm in diameter consisted of determining the tensile strength, strains at fracture limit, the average modulus of elasticity and determining the stress limits of bond between the reinforcing bars and the surrounding concrete.

The research program consisted of flexural tests of three model beams with bottom flexural reinforcement made of BFRP bars with a diameter of 8 mm and, for comparison, three reference RC beams with bottom traditional steel reinforcement. All the tested model beams have the following dimensions $b \times h \times L = 80\ \text{mm} \times 140\ \text{mm} \times 1200\ \text{mm}$ (see Fig. 1).

The middle part of tested beams was without stirrups and top reinforcement. In the support regions the beams were reinforced using two top steel bars diameter of 8 mm and steel stirrups. In all the beams the central bottom basalt bar was protruded on both end sides (as presented in Fig. 1) to enable the measurement of the slip during the loading process. The bottom reinforcement was located at a distance of 20 mm from the bottom of the beam. On the side surface of the beams, there were arranged 7 pairs of bench-marks, located at the levels every 20 mm from the bottom edge of the section. Registration of concrete strains was made with an extensometer with a measuring base of 100 mm.

The actual average strength of concrete was tested on cubic samples – $f_{ck,cube} = 41.02$ MPa, after conversion into cylindrical samples $f_{ck,cyl} = 0.8 \times 41.02 = 32.82$ MPa. Fig. 1 shows an arrangement of BFRP bars of reinforced concrete beams. Modulus of elasticity of basalt bars is determined equal $E_f = 39.05$ GPa and it was calculated from the empirically obtained stress–strain relationship, assuming complete linearity in the range of 20–50% of the tensile strength. Modulus of elasticity of steel bars is equal $E_s = 200$ GPa. More details of these tests are presented in the paper [3].

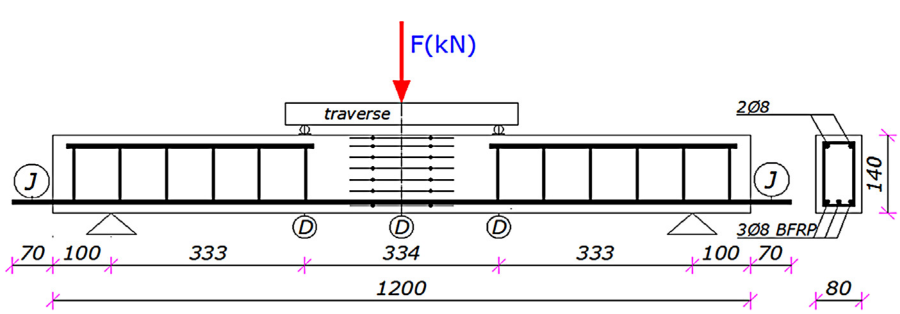

Fig. 1 – Tested model beam with bottom reinforcement (BFRP bars) with distribution of bench-marks used to measure the concrete strains with an extensometer, J – slip measurement sensor, D – deflection measurement sensors, dimensions in mm.