Application of the FRP Rebar in Constructions for Reduction of Thermal Bridges – Compressed elements

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Abstract. The paper describes usage of a composite rebar in applications with reduction of thermal bridges, with emphasis on compression reinforcement. The paper focuses on several areas: The mechanical tests, resulting mechanical properties and temperature behaviour of compressed reinforcement. Compression elements with short fibres of length 6 and 50 mm or long fibres and with or without a rebar were tested. The comparison between materials and results of behaviour of a simple compressed rebar at elevated temperatures is shown. The critical temperature of usage FRP material as a compression element was found.

1. Introduction

1.1. The issue of breaking the thermal bridges in the reinforced concrete constructions
Thermal bridge is a phenomenon of construction which occurs when materials with different thermal conductivity are used for exterior surfaces or parts. It means that the thermal bridges are weaknesses within a building's construction where heat and/or cold is transferred at a significantly higher rate than through the surrounding envelope parts. There are basically two types of this phenomenon: geometric thermal bridges where a part of the structure projects through the building envelope, and material thermal bridges where materials with different conductivity are used in combination. In practice, these effects are often combined. A classic example of this is the balcony slab, where problems occur if the connection is not taken into serious consideration.

1.2. The effect of thermal bridges
The effect of thermal bridges in constructions are:

- Higher energy consumption. Due to the thermal loss at the connection, heat is drawn from inside resulting in a significant increase in heating costs and energy consumption.

- Mould formation. Interior temperatures of the adjacent rooms can drop well below the dew point. This leads to condensation, deteriorates plaster and paintwork and also mould formation. If there is sustained exposure to condensation, the building is subjected to serious deterioration.

- Uncomfortable living space. Cold surface temperatures cause uncomfortable living space for occupants.
1.3. Current methods of solution

Current methods include creating of a gap between main building structure and attached structure, and usage of materials with lower thermal conductivity.

Typically, load-bearing thermal insulation elements made from austenitic steel and thermal insulation are used. These elements form a thermal break between the exterior and the interior construction, while transferring load and maintaining full structural integrity. Also, the higher interior temperature is maintained decreasing condensation, and preventing the formation of mould.

1.4. FRP solution

Application of only FRP (Fiber Reinforced Polymer) rebar in load bearing insulation element is quite new. No other studies dealing with only FRP rebar in load bearing insulation element (it means tensile, shear and compressed reinforcements made only from FRP) are known to the author of this paper. State of the art is described in patents DE 4 102 332 (A1), EP 2 138 641 (A2), DE 1 9711 813 (A1), DE 19508292 (A1), DE 4 040 433 (A1). These patents describe usage of FRP and steel rebar together. At least, shear reinforcement is made of steel. No patents claim usage only FRP rebar. Only our former work is published in the previous article [1] and describe usage of FRP rebar (without steel rebar) in load bearing insulation element.

Reinforcement of most structures with reduction of thermal bridges consist of pulled, compressed and shear elements. The amount of information is published on the pulled FRP reinforcement, but there is a lack information on the compressed FRP rebar.

It is generally not recommended to use FRP rebar as a compressed reinforcement [2], due to lack of information. There is a very low quantity of articles or studies on usage FRP reinforcement as a reinforcing material for compressive loaded concrete constructions. The study [3] describes usage of glass-fiber-reinforced-polymer bars and spirals as reinforcing materials in hollow concrete columns. The crushing strain of the FRP bars embedded in a concrete column was found in study [4]. Another paper [5] describes strength of compression lap-spliced FRP bars in concrete columns with different splice lengths. There are another studies for example [6], which describes usage of FRP rebar in compressed part of beam. But these tests were performed in room temperature and do not utilize insulation material. There is an absence of information on possible solutions, comparison of fiber position in the compressed element and corresponding mechanical properties and temperature resistance. For this reason the article focuses on this topic.

2. Materials and Methods

The shape and positioning of a compressed rebar in structure is shown in Figure 1. Only case where reinforcement is used in element with reduction of thermal bridges (see Figure 1, case B) is solved in this paper.

The cylinder of composite material can be formed at the FRP rebar (see Figure 2). The cylinder may be of different composition. The main component are fibers and polymeric binder (resin). Inorganic fillers can be also added.

The mechanical properties of the cylinder and whole compressed elements depend on
- amount of fibers,
- the length of fibers,
- fiber arrangement,
- resin properties.

For this test the materials were used as follows:
- short fibers (the length of fiber was 6 mm, content of fibers was 25% by weight, position of fibers is random)
- sheet FRP material made of mat (the length of fiber was 50 mm, content of fibers was 50% by weight, position of fibers is random in the plane of the mat),
- sheet FRP material made of woven roving (plain weave, content of fibers was 60% by weight),
- the rebar in the middle of the cylinder is composed of 80% of unidirectional oriented fibers.

The glass transition temperature (Tg) of resin is 120°C.

Methods of measurements differs for testing in room temperature (chapter 3.1) and in higher temperatures (chapter 3.2).

The cylinders were tested according to the standard [7] in room temperature. The test specimens were placed between the plates of 400 kN test press and then pressure testing was performed with a continuous loading at a constant speed of about 1 mm / min. The obtained working diagram was used to evaluate the compressive strength and modulus of elasticity.

The method for testing the cylinders at the higher temperature has been designed with regard to the standard for fire testing [8]. The test specimens were placed between the load plates and then pressure testing was performed with a constant load and increasing temperature according the standard [8]. The tested samples and pressing equipment were inside the insulation shield to protect them from direct flame, according the considered application (see Figure 3). The load, temperatures of sample and testing chamber were recorded. Specific experimental temperature condition was used because of modeling real conditions during the fire. The temperature rise parameters in the test furnace defined in the standard [8] were used. The temperature was set according to equation:

\[
T = T_0 + 345 \log(8t + 1)
\]  

Where T is temperature in °C in furnace in time t, T_0 is initial temperature in °C in furnace, t is time in minutes from beginning of the test.

![Figure 1. Load-bearing compressed element made from FRP. Symbols: 1 – concrete, 2 – insulation material or gap, 3 – compressed rebar with compression element.](image-url)
3. Results and Discussion

3.1. Strength and structure of FRP compressed elements – room temperature testing

Samples of different length and roller diameter ratios were prepared (Figure 4). Also, during the experimental study, the influence of FRP reinforcement on mechanical properties was tested. Only results with short fiber samples are evaluated in this paper.

The compression strength and modulus of the cylinder were measured according to the standard [7], but some parameters (e.g. length to diameter ratio) had to be changed.

The results of mechanical test are shown in Figure 5. Compressive strength and modules are strongly affected by the presence or absence of the rebar. The compressive strengths of the cylinder with FRP rebar of diameter 14 mm is about three to four times higher than strength of the cylinder with FRP rebar of diameter 6 mm or without a rebar. Similarly, the modulus of elasticity is about two times higher for the cylinder with FRP rebar of diameter 14 mm.

The ratio of length and diameter of the cylinders also affects the strength. For example the strength of the cylinder with FRP rebar of diameter 14 mm is decreased about 25% when the length to diameter ratio is 2.00 resp. 2.33.

Figure 2. Load-bearing compressed element made from FRP. FRP rebar diameter 14 mm with molded cylinder diameter 30 mm.

Figure 3. The testing chamber of the furnace.
Figure 5. Compressive strength and modulus of elasticity of FRP cylinders. Length to diameter ratio (L/D ratio) 2.0 and 2.33.

3.2. Critical temperature and structure of FRP compressed elements – high temperature testing. Samples made of short fibers, mats, mats and rebar, woven roving and woven roving and rebar were chosen for testing at high temperatures. The goal of tests was to find critical temperatures when the collapse of a loaded sample occurs. The load was 20, 30 and 40 MPa.
Experimental load was applied and then the heating of the furnace started. There were measured temperatures at the cylinder surface and inside the cylinder, temperature in the furnace and compression load. Example of results for load 40 MPa and the cylinder made of woven roving and rebar of diameter 14 mm is shown in Figure 6.

![Graph showing load, temperature in furnace, surface, and inside](image)

**Figure 6.** Test of load bearing capacity of FRP cylinders made of woven roving and rebar of diameter 14 mm. Test of critical temperature for compressive force 40 MPa. [9]

The aim of the experiment was to determine critical temperatures, when the cylinder collapses. Overview of these temperatures for compressive force 30 MPa is shown in Figure 7. It can be seen that critical temperatures for these materials is in a narrow area 210 – 220 °C (except samples with short fibers). It is because the failure of samples with long fibers is controlled by material of binder. Although the cylinder made of woven roving and rebar has the lower critical temperature than the cylinder made of mat, the reliability was very good and the residual strength after reaching the critical temperature was best.

Unfortunately, very low amount of experiments was published in the literature and these results cannot be compared with similar research.

The tests of dependency of load intensity and critical temperature were performed only for samples with woven roving and rebar (Figure 8). It is clear that the load intensity in the range from 20 to 40 MPa does not affect the critical temperatures in this solution.

Against expectations, the press elements retain their properties even at significantly higher temperatures than the glass transition temperature (Tg) of the resin. Although the Tg is 120°C only, the critical temperature is above 200°C. Even the samples with short fibers reach critical temperature about 170°C. This temperature is 50°C above the Tg.

The results of these measurements describe the performance of composite materials under pressure at both room temperature and fire conditions. Such experiments have not been published yet. Some authors [3], [4] or [5] conducted interesting pressure tests at room temperature but their experiments did not contain contribution of fire conditions. The used method of fire testing is very interesting with regards to the finding the parameters for design the members of reinforced concrete. The method is relatively cheap and very fast and provides important results describing the behavior of FRP material in fire conditions.
**Figure 7.** Test of load bearing capacity of FRP cylinders made of short fibres, mat, mat and rebar of diameter 14 mm, woven roving and woven roving and rebar of diameter 14 mm. Test of critical temperature for compressive force 30 MPa. [9]

**Figure 8.** Test of load bearing capacity of FRP cylinders made of woven roving and rebar of diameter 14 mm. Test of critical temperature for compressive force 20, 30 and 40 MPa. [9]
4. Conclusions

Loading capacity of the element reinforced with FRP rebar is determined by load-bearing capacity of the implemented compression reinforcement. To optimize the technical solution, we need to know the mechanical characteristics of the compressed elements. The results of experiments showed the properties of FRP reinforcement applied as the compressed reinforcement.

It was found that the critical temperature is above 200°C. Except material with short fibers. Its critical temperature is about 170°C.

The critical temperature samples from woven roving and 14mm rebar is not affected by load 20, 30 or 40 MPa.

The load bearing capacity of compressed element from short fibers and 14mm rebar is significantly affected by length to diameter ratio. The compression strength of samples is reduced about 25% when this ratio is changed from 2 : 1 to 2,33 : 1.

Compressive strength and modules samples from short fibers and 14mm rebar are strongly affected by the presence or absence of the rebar. The compressive strengths of the cylinder with FRP rebar of diameter 14 mm is about three to four times higher than strength of the cylinder with FRP rebar of diameter 6 mm or without a rebar. Similarly, the modulus of elasticity is about two times higher for the cylinder with FRP rebar of diameter 14 mm.

Future research will be focused on finalization of the long-term compression tests of all materials in room temperature and finding the maximum load bearing capacity of the compression element for higher temperatures, especially for temperatures close to critical temperature.

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