Application of the FRP rebar in constructions for reduction of thermal bridges – new insights

J Prokeš

PREFA KOMPOZITY, a.s., Kulkova 4231/10, 61500 Brno, Czech Republic
Email: prokes@prefa.cz

Abstract. The paper describes usage of composite rebar in applications with reduction of thermal bridges. There are described benefits of the composite solution without metal parts. The composite elements are used for tensile, compressed and also shear reinforcement. Technical solution of assembly and the basic mechanical properties and thermal insulating characteristics are described.

1. Introduction

1.1. The issue of breaking the thermal bridges in the reinforced concrete constructions

Thermal bridge is 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 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 are balcony slabs, where problems occur when no serious consideration is given to the connections.

The thermo-photograph (Figure 1) below shows the situation, when thermal bridges at balconies were not taken care of, the balconies act as the cooler ribs; the heat is conducted off the building and the rooms adjacent to the balconies are cooled [1].

1.2. The effect of thermal bridges

1.2.1. Higher energy consumption. Due to the thermal loss at the balcony connection, heat is drawn from inside, which results in a significant increase of heating costs and energy consumption.

1.2.2. Mould formation. Interior temperatures of the adjacent rooms can drop easily below the dew point. This leads to condensation, deterioration of plaster and paintwork and also mould formation. Long term exposure to condensation can lead in serious deterioration of the building.

1.2.3. 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 ceiling slab and balcony slab, and usage of materials with lower thermal conductivity.

Typically, load-bearing thermal insulation elements made from austenitic steel and thermal insulation [2] are used. These elements form a thermal break between the balcony and the interior floor while transferring load and maintaining full structural integrity. Also, the warmer interior temperature is maintained decreasing condensation, and preventing the formation of mould. Compare Figure 2 and Figure 3 or Figure 4.

Application of only FRP rebar is quite new. No other studies dealing with only FRP rebar 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 on steel. No patent claims usage of only FRP rebar.

2. Properties of load-bearing thermal insulation elements made from FRP rebar

2.1. Types of rebar

There are several types of FRP (Fiber Reinforced Polymer) rebar: glass fiber FRP (GFRP), carbon fiber FRP (CFRP), glass & carbon fiber FRP (C-GFRP) [2] or other types (e.g. basalt FRP). The used fibers have an effect on mechanical properties, environmental resistivity [3] and price. The basic mechanical properties of FRP rebar are described in Table 1. The structure of glass fiber reinforced rebar is illustrated in Figure 5. As shown in Table 1, the FRP rebars have higher tensile strength and lower modulus of elasticity and density.
**Table 1.** Typical mechanical properties of FRP rebars (volume content of fibers is 50–75%), comparison with steel rebar [3] and PREFA KOMPOZITY FRP rebar.

| Characteristic/rebar material | Steel | GFRP | C-GFRP | CFRP |
|------------------------------|-------|------|--------|------|
| Module of elasticity longitudinal [GPa] | 200   | 50   | 80     | 140  |
| Tensile strength longitudinal [MPa] | 550   | 1000 | 1150   | 1870 |
| Density [kg/m^3] | 7850  | 2100 | 2000   | 1600 |

**Figure 2.** Construction where thermal bridges are not solved. The ceiling and balcony slabs are connected through the concrete and reinforcing steel [2].

**Figure 3.** Construction where load-bearing thermal insulation elements from austenitic steel [2] are used. The thermal bridge is restricted by insulation layer, but heat can flow through the austenitic steel reinforcement.
2.2. Thermal conductivity

The characteristic feature of the composite reinforcements is the low coefficient of the thermal conductivity. Table 1 shows the values of the coefficient of commonly used steel reinforcement (different types of steels), the experimentally determined value of this coefficient for the individual reinforcement element, thermal coefficient of extruded polystyrene (data supplied by the extruded polystyrene manufacturer) and the average thermal coefficient of load bearing thermal insulation element made from FRP (Figure 6).

It is clear from Table 1 that the coefficient of thermal conductivity of composite reinforcements is about 2 orders of magnitude lower than in case of steel reinforcements. The resultant, experimentally determined, ratio of 0.066 W·m⁻¹·K⁻¹ is thus in the same order of magnitude as the coefficient of the insulating element.
Table 2. Overview of the coefficients of thermal conductivity of individual materials.

| Material                                      | Coefficient of thermal conductivity [W·m⁻¹·K⁻¹] |
|-----------------------------------------------|-----------------------------------------------|
| Steel                                         | 50 – 100                                      |
| GFRP Rebar                                    | 0.49                                         |
| Extruded Polystyrene                          | 0.032                                        |
| Load-bearing thermal insulation elements made from FRP | 0.066                                        |

2.3. Technical solution

The load-bearing thermal insulation element made from FRP was used according to the patent [5]. The basic structure is shown in Figure 6 and 7. This element contains:
- Pulled reinforcement (Figure 6, position 1),
- Compressed reinforcement with auxiliary element (Figure 6, position 2 and 6),
- Shear reinforcement with auxiliary element (Figure 6, position 3 and 5),
- Load distribution reinforcement (Figure 6, position 4),
- Thermal insulation material (Figure 6, position 7).

These basic parts can differ in number, diameter, angle, etc. The desired load capacity and stiffness can be achieved by changing of mentioned parameters.

There are several parts of FRP load-bearing element that are not listed in patent [5] and aforementioned list. FRP rebars are flammable and above critical temperature (glass transition temperature) lose mechanical properties. The critical for usage of this element are fire-proof properties. The necessary part of this element is a fire insulation, which should be used at the bottom of the element at least. All parts must be assembled into one piece, which enables easy handling at construction site.

Figure 6. Load-bearing thermal insulation element made from FRP. Symbols: 1 – pulled rebar, 2 – compressed element, 3 – shear element, 4 – auxiliary reinforcement for load distribution, 5 – auxiliary element for increasing of cohesion strength of shear rebar, 6 – auxiliary element for increasing of compression strength of compressed rebar, 7 – insulation material.
2.4. Testing of mechanical properties of element

The designed FRP load-bearing thermal insulation element was tested experimentally in order to determine the ultimate load bearing capacity of the assembly and its rigidity [6]. The thickness of the thermal insulation layer was 60 mm. The FRP reinforcement arrangement is shown in Figure 8. The load was applied until sample failed at the end of the slabs. The test samples were subjected to a flexural static loading test (see Figure 9). Than the feasibility of this solution under normal construction conditions was critically evaluated. The dependence of the applied force and the measured deflection of the end of the balcony slab is shown in Figure 10. It can be stated that both the behavior of the elements and failure mode were expected in the course of the load test.

Figure 7. Load-bearing thermal insulation element made from FRP in construction. FRP reinforcement – red colour, steel reinforcement – black colour.

Figure 8. Arrangement of FRP reinforcement in the concrete sample [6].
Figure 9. Arrangement of the experiment [6].

Figure 10. The dependence of the applied force $F$ and the measured deflection $u_c$ of the end of the balcony slab (blue line). Without the influence of its own weight. [6]

2.5. Calculations of the long-term load-bearing capacity of the element

Technical feasibility study [7] was carried out according above-mentioned experiments and parameters. The influence of the reinforcement and height of the load-bearing insulation element on the resulting bend and shear bearing capacity was calculated. Five reinforcement variants and nine heights (see Figure 11 and Table 3) were calculated and assessed. The minimum technical possible height is 160 mm and there is downward trend of the shear bearing capacity above 300 mm. Calculation was carried out according to the standard EN 1990 [8].
Variants A to E (Table 3) for heights H 160 to 300 mm (Figure 11) were calculated. The resulting long-term (50 years) bend and shear bearing capacity is shown in Table 4 and Figures 12 and 13.

**Figure 11.** The design of reinforcement for the repeating unit 250 mm and 300 mm. The height H is parameter of the calculation. [7]

**Table 3.** Calculated variants of FRP load-bearing unit. [7]

| Variant | Tensile Reinforcement | Compression element | Shear reinforcement |
|---------|------------------------|---------------------|--------------------|
| A       | 2 pc φ14, type GFRP    | 2 pc φ30, FRP composite with short glass fiber | 2 pc φ6, type CFRP |
| B       | 3 pc φ14, type GFRP    | 3 pc φ30, FRP composite with short glass fiber | 2 pc φ6, type CFRP |
| C       | 3 pc φ18, type GFRP    | 3 pc φ30, FRP composite with short glass fiber | 2 pc φ6, type CFRP |
| D       | 2 pc φ14, type GFRP    | 2 pc φ30, FRP composite with short glass fiber | 2 pc φ8, type CFRP |
| E       | 1 pc φ14, type GFRP    | 1 pc φ30, FRP composite with short glass fiber | 2 pc φ8, type CFRP |
Table 4. Calculated bend $M_{rd}^{LT}$ and shear $V_{rd}^{LT}$ bearing capacity. [7]

| Height H [mm] | A    | B    | C    | D    | E    |
|---------------|------|------|------|------|------|
|               | $V_{rd}^{LT}$ | $M_{rd}^{LT}$ | $V_{rd}^{LT}$ | $M_{rd}^{LT}$ | $V_{rd}^{LT}$ | $M_{rd}^{LT}$ | $V_{rd}^{LT}$ | $M_{rd}^{LT}$ |
| 160           | 5.44 | 3.93 | 5.44 | 6.11 | 5.44 | 6.11 | 7.26 | 3.78 | 7.26 | 1.60 |
| 180           | 6.83 | 4.75 | 6.83 | 7.37 | 6.83 | 7.37 | 9.10 | 4.59 | 9.10 | 1.97 |
| 200           | 7.75 | 5.59 | 7.75 | 8.64 | 7.75 | 8.64 | 10.34 | 5.42 | 10.34 | 2.37 |
| 220           | 8.62 | 6.43 | 8.62 | 9.92 | 8.62 | 9.92 | 11.49 | 6.25 | 11.49 | 2.76 |
| 240           | 9.27 | 7.27 | 9.27 | 11.20 | 9.27 | 11.20 | 12.35 | 7.08 | 12.35 | 3.16 |
| 250           | 9.57 | 7.70 | 9.57 | 11.85 | 9.57 | 11.85 | 12.76 | 7.51 | 12.76 | 3.37 |
| 260           | 9.87 | 8.14 | 9.87 | 12.50 | 9.87 | 12.50 | 13.16 | 7.95 | 13.16 | 3.59 |
| 280           | 10.29 | 8.99 | 10.29 | 13.79 | 10.29 | 13.79 | 13.72 | 8.79 | 13.72 | 4.00 |
| 300           | 10.55 | 9.85 | 10.55 | 15.08 | 10.55 | 15.08 | 14.07 | 9.64 | 14.07 | 4.41 |

Figure 12. The dependence of bend bearing capacity and height of element. The line B is overlapped by C. [7]
The linear dependence of bend bearing capacity and height of element is shown in Figure 12. The breakage of tension and compression reinforcement is checked in the calculation.

It can be seen that despite the increase of the tension reinforcement in the variant C compared to the variant B, there was no increase in bearing capacity – the compression bearing is limiting in both cases (Variants B and C are overlapped). However, when the deflection of the end of the slab is calculated, increasing the cross-section of the reinforcement in variant C will increase the bending stiffness and achieve a lower deflection.

The change in shear reinforcement has a negligible effect on the bending resistance, compare variant A to variant D in Figure 12.

The comparison of two different shear reinforcements shows dependence of shear bearing capacity on the angle between shear compression reinforcement (see Figure 13).

The shear bearing capacity is increased when the cross-section of shear reinforcement is increasing, however, when the reinforcement area is increased by about two times (2 pieces of $\phi 6$ in variant A or 2 pieces of $\phi 8$ in variant D), the load bearing capacity is increased only about one third.

3. Conclusions
The calculations have shown that the FRP load bearing thermal insulating element exhibits good bending and shear resistance and its behavior has an expected trend. The parametric studies were carried out and the following conclusions were drawn:

Bending capacity of the element is determined by load-bearing capacity of implemented compression reinforcement. To optimize the technical solution, it is advantageous to increase the mechanical characteristics of compressed elements.

The shear capacity of the element is primarily determined by the ability to transfer securely the force generated in the shear reinforcement. To optimize the technical solution, it is advantageous to strengthen the element anchoring, as only to increase the cross-section of shear reinforcement is not sufficient and cannot be fully utilized.

There is also necessary to verify calculated dependencies by means of long-term tests, especially tests of compression elements.
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