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Reinforcement made of glass fibre reinforced plastic – Basics and Application

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ABSTRACT: Mechanically high-loaded ceiling and floor constructions made of reinforced concrete are very often subject to special requirements, e.g. with regard to corrosion resistance, resistance against chemical attacks or installation of inductive control systems. In these cases, reinforcing bars made of glass fibre reinforced plastic (GRP) represent an alternative to non-corrosive steel or statically operant fibre reinforcements. After a short introduction to the elemental basics for design of floor constructions fit for traffic and reinforced with GRP-bars, examples of applications carried-out will be presented. In this connection, the issue of the relevant requirements for the construction in each case as well as the difference regarding material properties of the GRP reinforcement compared to conventional construction steel will be addressed in particular.

1 INTRODUCTION

Roof respectively floor constructions have - particularly in the field of commercial construction - a significant cost-share of the total construction costs. In this respect they are also of high significance as to the fact that the sufficient load-bearing capacity and/or serviceability are tied up with numerous complex constructive boundary conditions with concurrently occurring effects of different nature. These are normally highly dependent on the utilization of the floor surfaces. Multistorey car park ceilings as well as floor slabs in multistorey car parks, industry halls, aircraft hangars etc. shall be stated as examples at this point. On the other hand mineral oil, fatty acids (food industry), large mobile mechanical loads (transport of goods with fork-lift trucks) or similar can have an effect on the construction during utilization. Installation of special electronic systems in the areas concerned, for example for the control of transport vehicles over induction loops, give reason for consideration of further boundary conditions.

The demands on floor constructions will be summarized as requirement profiles in the course of the planning phase. If a stainless reinforcement is required or the effect of chloride would make a large cover of customary structural steel armouring coupled with a suitable surface protection system necessary, reinforcing bars from glass-fibre reinforced plastic (GRP) represent a useful alternative. The same applies, if non-metal reinforcements are required for installation of induction loops on account of concurrently existing strong mechanical loads. Table 1 shows an example of a requirements profile for a floor slab of high mechanical load capacity.

Table 1: Requirements profile for a floor construction of high mechanical load capacity

Feature	Requirement
constructive	40 cm thick, one-layer, elastically embedded reinforced concrete construction, smooth finish, no metal reinforcement
area load - traffic	≤ 75 kN/m²
single load - traffic	≤ 1800 kN/m² on 40 x 40 cm² (load situation 1) ≤ 5900 kN/m² on 40 x 40 cm² (load situation 2)
coating	none, sprinkling of hard aggregate
footfall sound	no requirements known
heat protection	80 mm thick heat insulation made of XPS (extruded polystyrene), WLG 040 (heat conductivity class 040)
moisture protection/ special requirements	- resistant to liquids in accordance with the specification's list - sealed area for groundwater protection, which is subject to the mandatory requirements of water conservation law (WHG, DAfStb-guideline "Betonbau beim Umgang mit wassergefährdenden Stoffen" etc.)
fire protection	no requirements for composition of ground known in this case
utilization/ wear and tear	- maintenance hall - highly hardwearing concrete (XM3 acc. to DIN 1045-1)

2 REINFORCEMENT WITH GRP-BARS

2.1 *Properties*

GRP-bars are made of a multitude of glass fibres tailored to direction of force (diameter approx. 20 μm), which are embedded in a resin matrix. While the fibres guarantee the stiffness and solidity of the bars, the resin serves as safeguarding for their position and protection from harmful exterior influences as well as for transmission of load. This composition results in a high tensile strength in direction of the fibres with concurrently low lateral compression strength and lateral tensile strength. The material shows high corrosion resistance, a high resistance to chemical substances and a low heat conductivity. It can be easily chipped, is electrically non-conductive and non-magnetic.

For an exemplarily quoted product there are, according to technical data sheet, comparable bonding properties given as for reinforcing steel on account of the corresponding ribbed shape. The material does not show any flow behaviour, the characteristic tensile strength is stated at f_{tk} = 1000 N/mm². The structural design strength for use in the field of concrete building is suggested at f_{GFKd} = 435 N/mm², for breaking elongation at 7.25 mm/m (modulus of elasticity = 60.000 N/mm²). Due to the high corrosion resistance a constructional concrete cover of merely 10 mm + d_s (bar diameter) has to be adhered to.

The thermal strain in longitudinal direction amounts to $\alpha_T = 6 \cdot 10^{-6}$ 1/K and in transverse direction (caused by the high resin portion) $\alpha_T = 22 \cdot 10^{-6}$ 1/K. From the background of temperature stability it is recommended that a maximum operating temperature for permanent use of 60 °C is adhered to.

2.2 *Structural safety*

If the GRP-bars described above are used as statically necessary reinforcement of concrete construction units, the question regarding proof of the sufficient load bearing capacity of such a construction unit arises. According to DIN 1045-1 GRP-bars are not approved as reinforcement. Thus, a proof of suitability by general national technical approval (AbZ) or by approval for the individual case (ZiE) is necessary according to building regulations in Germany.

As evident from section 2.1 describing the characteristics of the example product made of GRP, the calculation of a GRP-reinforced construction unit can be done principally following the proceeding with reinforced concrete according to DIN 1045-1. As is the case with reinforced concrete, the synergy between concrete and GRP-bars results in a ductile load bearing behaviour with early indication of failure noticeable by a corresponding increase of deformation and crack width. The definition of the characteristic strength must consider influences from loads of long-term standing and/or alternating loads. The aforementioned values are based on investigations, which were made within the framework of the currently ongoing approval proceedings for the example product.

The proof of sufficient load bearing capacity shall not be treated here any further out of consideration for other contributions.

2.3 *Serviceability*

The guarantee of a sufficient serviceability of GRP-reinforced concrete construction units is of substantial importance particularly with ceiling and floor constructions. Here above all the elastic modulus of GRP-bars, approx. around factor 3 lower in comparison to steel reinforcement, is to be considered, which has a substantial impact on the limitation of ceiling deflections, condition II, as well as on restriction of crack width. In the following two approaches to the proof of the maximum crack width are presented. A comparison between the use of steel and GRP reinforcement is shown in the context of an example:

As already addressed in the preceding chapter, the fundamental comparability of the characteristics of reinforcing steel and profiled GRP-bars of the presented quality suggests a procedure for proof of the maximum crack width that is analogous to the procedure in compliance with DIN 1045-1. Based on that, the first approximation of the arithmetic value for crack width w_k is:

$$w_k = s_{r,\max} \cdot (\varepsilon_{sm} - \varepsilon_{cm}) \tag{1}$$

with $s_{r,max}$ = maximum interspace between cracks with completed crack formation
ε_{sm} = medium extension of reinforcement under the decisive combination of loads (contribution of the concrete on tension between the cracks)
ε_{cm} = medium extension of the concrete between the cracks.

Regarding the arithmetical definition of the individual computation terms it is referred to the appropriate section of DIN 1045-1.

At the Technical University Kaiserslautern tests were made with the described GRP product and in comparison to that with steel reinforcement on the pullout behaviour and, additionally to that, computations on the bonding behaviour were carried-out (Kurz 2007). As a result the following table 2 makes a comparison between reinforcements made of reinforcing steel and GRP in view of their pullout-deformation, measured with respect to the concrete surface, and anchoring length considering the calculation values of the bonding behaviour:

Table 2: Comparison between reinforcements made of reinforcing steel and GRP based on calculation values (quantile values) of the bonding behaviour, for concrete C 30/37, age of ≥ 28 d (Kurz 2007)

Force in kN	3.0	5.0	8.0	10.0	12.0
Pullout-deformation reinforcing steel ∅ 6 in mm	0.013	0.029	0.061	0.088	0.117
Pullout-deformation GRP ∅ 8 in mm	0.017	0.038	0.082	0.117	0.156
Anchoring length reinforcing steel in mm	62	89	121	140	156
Anchoring length GRP in mm	47	66	88	101	113

On the basis of a simple example the content of reinforcement to limit crack width for both, reinforcing steel and GRP-bars, is determined and compared in accordance with the above procedures. For this purpose a 20 cm thick, nonstructural concrete floor plate C 30/37 with surface reinforcement (cover 20 mm) will be examined. The arithmetic value of crack width (bending constraint) to be adhered to as a result of the deformation gradient over thickness from shrinking is set at w_k = 0,2 mm. It is to be considered that the double pullout-deformation corresponds to the crack width w.

Table 3: Comparison of determined content of reinforcement

	following DIN 1045-1, see equation (1)	Arithmetic bonding behaviour, see Table 2[1)]
req. reinforcing steel armouring in cm²/m	2.5	2.7[2)]
req. GRP-reinforcement in cm²/m	4.6	5.8

[1)] adapted to age of concrete less than 28 d [2)] steelbar diameter 6 mm

The result is remarkable in two different ways: On one hand there is an approximate ratio of 2 each between the GRP reinforcement quantity and the steel reinforcement quantity. This was more or less already determined for other examples of use. On the other hand, the adapted direct approach of the computationally, on the basis of test results determined bonding behaviour amounts to an approx. 10 to 25 % larger quantity of steel reinforcement respectively of GRP-reinforcement compared to the computation method according to DIN 1045-1 for the example above. This is especially to be caused by the rather simple approximation of the effective tensile strength of the concrete (start of shrinking with age of concrete less than 28 d) in the context of the computationally determined bonding behaviour.

The exemplary computations to ensure the serviceability of GRP-reinforced concrete construction units give first indications of the required additional reinforcement quantity when using GRP-bars in comparison to steel and which goes back on the whole to the elastic modulus that is lower by factor 3. It is expressly remarked that the results pointed out here go back to first assessing computations and they require further back-up for general application.

3 EXAMPLES OF APPLICATION

3.1 *Floor slab of a logistics centre*

In a logistics centre a floor construction was to be applied onto a support plate from reinforced concrete, which serves as roadway for an induction-steered transport system. For this reason a metallic reinforcement could not be used for limiting the width of possibly occurring cracks.

A reinforcement with reinforcing bars made of glass-fibre reinforced plastic was suggested. Its preliminary design was based on the following conditions:

- Industry floor with allowable calculated crack width w_k = 0.3 mm made of concrete C 20/25 (low-shrink, cement content ≤ 300 kg/m³, w/c-value ≤ 0.5, no exceeding strength,
  thickness of roadway plate 13 cm, carried by a load bearing concrete bottom on dividing layer, reinforcement with one layer of bars ∅ 8 mm,
  upper concrete cover 4.5 cm,
  30 mm high induction loops milled into the ground
- <u>no</u> mounting of the floor section edges,
  Decoupling of the floor by dividing layer from underground so that <u>no</u> significant centric restraint is to be considered
- standard areas with a size of approx. w x l = 7.75 x 15.00 m²
- Driving with vehicles of the kind fork-lift trucks, wheel load max. 2 t, hard rubber wheels with a width of 80 mm, swinging/impact factor 1.4
- careful subsequent treatment of the concrete.

On this basis bending constraint was to be regarded first as determining load in the inner zone of the slabs due to uneven exsiccation throughout the construction unit height (shrink). On the other hand the load scheme “bending by influence of single loads at the free edge which has stripped due to uneven exsiccation throughout the construction unit height” was to be considered.

The assessing computation of the calculated crack width w_k following “Heft 400” and/or DIN 1045-1 resulted in reinforcement contents of a_{BZ} = 4.6 cm²/m for the load scheme "bending constraint" and a_B = 7.7 cm²/m for the load scheme "bending". It was suggested to stagger the reinforcement between edge and field range since the bending constraint is clearly smaller than the bending load due to the load effect at the transient area between field and edge range. The insertion of a bottom reinforcing layer (1.5 cm cover) with A = 4.0 cm²/m was recommended to increase the safety level. Figure 1 and 2 exemplify the erection of the floor construction.

Figure 1: Installation of reinforcement

Figure 2: Pouring of concrete

3.2 *Roadway slab of a multi-storey car park*

In a multi-storey car park of a shopping centre a load distribution plate fit for traffic had to be built to serve as parking deck on a floor ceiling which was provided on the upper side with insulation, sealing and drainage mat, see Figure 3. The construction measure had to be carried out in an existing project, whereby substantial constructional restraints arose due to existing connection and passage heights as well as maximum structure weights. In order to obtain a possibly high effectiveness of the crack width limiting reinforcement with a comparatively small thickness of the load distribution plate of 10 cm, it was given up to use steel reinforcement in connection with a surface layer system for the purpose of a possibly low concrete cover.

It was suggested to use a reinforcement with reinforcing bars made of glass-fibre reinforced plastic, which has substantial advantages particularly in view of the necessary cover on account of its insensitivity to any chloride influence. Its preliminary design was based on the following conditions:

- Load distribution plate with allowable calculated crack width w_k = 0.3 mm made of concrete C 30/37
  (low-shrink, low w/c-value, no exceeding strength),
  thickness roadway slab 10 cm, floor superstructure acc. to Figure 3, total bedding module k_C = 40.000 kN/m³,
  reinforcement with one layer of bars each ∅ 8 mm bottom and top,
  cover top and bottom nom c = 2.0 cm
- decoupling of floor by dividing layer from underground
- standard areas with a size of approx. w x l = 5.50 x 6.60 m²
- driving with passenger vehicles, wheel load acc. to DIN 1055-3, swinging/impact factor 1.4
- careful subsequent treatment of the concrete.

A substantial load on the floor structure in this case is driving with passenger vehicles. Especially on the edges of the slab at the upper side this results in tensile strain and comparatively high pressure on the adjoining heat insulation. Therefore, the reinforcement content at the upper side of the slab was doubled in this area compared to the mid area. Furthermore, the edges in this area were reinforced by an additional reinforcing bar. Additional bars with sufficient anchoring lengths were added around the openings of adjoining floor drains in comparison with the standard procedure with reinforcing steel reinforcement. See Figure 4.

It is again expressly pointed out here that the concrete prescription as well as the subsequent treatment of the concrete are of extraordinarily great significance for floor constructions like these. Forces arising from an unsatisfactory subsequent treatment can very fast reach orders of magnitude, which reduce the assessment for determining the reinforcement quantities to limit the crack widths to absurdity.

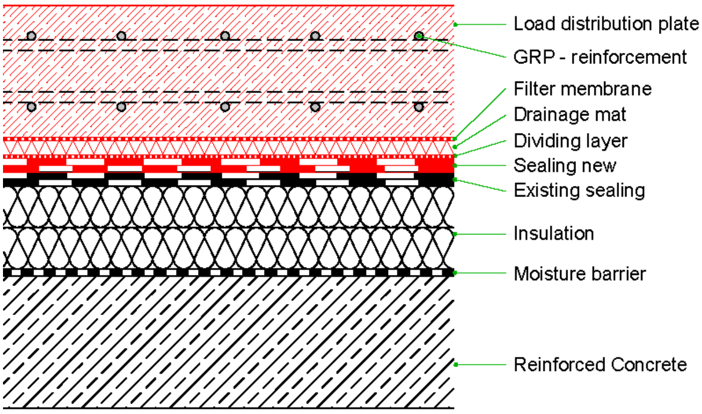

Figure 3: Floor structure

Figure 4: Installation of reinforcement

4 PERSPECTIVE

This article dealing with the use of GRP reinforcement bars as alternative to reinforcement bars made of structural steel resp. stainless steel provides first indications of the necessary additional reinforcement content in concrete construction units when using GRP-bars from comparisons of assessing computation results on the serviceability. The additional cost emerging from the aforementioned is up against advantages for example from savings of surface protection systems requiring additional maintenance. For reliable statements in this connection the calculation advances for GRP-bars are to backed up further by appropriate reflections.

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