Impact of Steel Fibre Reinforcement on the Strength of Steel Anchors

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Abstract. The paper presents methods of fastening using expansion fasteners and concrete screws anchored in conventional concrete and in fibre reinforced concrete. It addresses ways to determine the strength of such joints based on the EOTA (European Organisation for Technical Assessment) Guidelines and US Recommendations. Results from laboratory tests of strength of joints under tensile loads have been presented. It has been demonstrated that fastenings in fibre reinforce concrete achieve better strength parameters than those installed in conventional concrete bases.

1. Introduction

Continuous development of the construction industry relies on introducing new state-of-the-art structural and material solutions and execution technologies, including proper assembly methods, into common practice. Traditional work-intensive fastenings are being replaced by a wide range of products used to connect various elements, such as expansion and adhesive anchors, self-tapping and self-drilling screws and other specialised fasteners. They allow for fast and safe execution of connections with strength of up to 30 kN per fastener [1]. The building designer’s choice of fastening method depends mainly on the type of connected materials and the nature of the loads which will be applied to the fastenings during their life in the long term. Depending on the method of bonding the fastener with the base, three main types of fastenings are distinguished: friction fastenings, shape fastenings, adhesive fastenings [2]. The most common fastening system installed in pre-drilled holes is that consisting of steel torque-controlled and deformation-controlled expansion anchors (Figure 1).

![Figure 1. Steel anchors: a) torque-controlled expansion, b) deformation-controlled expansion](image-url)
Expansion anchors are usually used as fasteners in solid construction base of appropriate strength. Tensile loads are transferred to the base via friction forces occurring at the contact of the side surface of the fastener with the surface of the drill hole. The value of friction forces depends primarily on the expansion force generated during expanding the anchor, the material from which it was made, the tolerance of the drill hole as well as on the structure and strength of the base material. In this type of fasteners, the expansion force is obtained due to forced movement of a conical expansion element or by applying an appropriate torque moment to the fastener’s screw head [3]. As a result of this, elements moving on the conical surface increase their original circumference, forcing deformation of the expansion sleeves. The expansion force formed in this process acting along the circumference and along the expansion sleeves keeps the fastener in the base mainly due to friction at the contact with the surface of the drill hole. In the fastenings using those fasteners, the expansion force is insignificantly reduced over time as a result of creep and shrinkage of the concrete base. It is estimated that the expansion force may decreases by 10% to 15 % in relation to initial value [4].

![Figure 2. The distribution of stress trajectories around an installed expansion anchor: a) before, b) after](image)

Fibre reinforced concrete is a new type of product and is among special concretes with rapidly increasing use, boasting unique technical parameters. Modern fibre reinforced concrete is a material made up of bonding material, aggregate, sand, water and fibres added to the cement matrix. The addition of these fibres in the concrete mix fundamentally changes the behaviour of the traditional brittle concrete to a quasi-plastic material [5].

As a result of using the fibres, the concrete, which is hard but brittle, becomes strong but flexible at the same time. Additionally, the uniformly distributed fibres transfer loads across gaps in the structure of the concrete, such as cracks and fractures, resulting from external loads – they additionally take over the load. As a result, the stresses at the end of the fracture are reduced due to a significantly higher Young’s modulus of the fibre reinforcement compared to the matrix of the surrounding concrete. This phenomenon inhibits development of micro-cracks in the concrete. Consequently, no brittle failure is observed in building elements made of fibre reinforced concrete, even after first cracks appear. It is also widely known that the fibres used in place of reinforcement cause, among other effects: increased resistance to development of cracks and fractures, increase of fatigue strength and impact resistance, increase in tensile and shear strength (Table 1).
Table 1. Change in concrete properties after addition of steel fibres

| Property                | Property change                  |
|-------------------------|----------------------------------|
| shrinkage               | approx. 20 to 40% increase      |
| compressive strength    | approx. 10% increase            |
| tensile strength        | 10 to 30% increase              |
| flexural strength       | 20 to 40% increase              |
| modulus of elasticity   | practically unchanged           |
| impact resistance       | 4-8 times increase              |
| abrasion resistance     | practically unchanged           |
| water absorption        | unchanged or slight increase     |
| frost resistance        | 20 to 50% increase              |
| watertightness          | practically unchanged           |

The pull-off resistance, in accordance with the mentioned guidelines, depends mainly on the anchorage depth for single types of steel anchors, regardless of the assembly parameters. In fact, these connectors work in various assembly systems, provided by system operators (manufacturers), which translate into the final load resistances of the steel anchors. In addition to different anchorage depths, the assembly systems are also characterized by different diameters of drilled holes caused by installation moments and cracks zones.

Anchor pull-out strength is determined based on laboratory tests or using calculation method CCFM [6]. For strengths determined through tests in which steel anchors are subjected to static or quasi-static loads, mean pull-out resistance [6] is calculated using the formula (1):

\[ F_{Ru,cone} = F_{Ru} \cdot \left( \frac{f_c}{f_{c,test}} \right)^{0.5} \]  \hspace{1cm} (1)

Where:
- \( F_{Ru,cone} \) – average pull-out resistance [kN],
- \( F_{Ru} \) – test failure force [kN],
- \( f_c \) – standard compressive strength of the concrete base [MPa],
- \( f_{c,test} \) – compressive strength of the concrete base from tests [MPa].

2. Scope and aim of the research, analysis

Steel expansion anchors on M10 diameters and steel screw M12, selected for the tests (Table 2). The tests were carried out on C20/25 concrete substrates. Tests of steel anchors consisted in determination of maximum destructive forces, fasteners fastened under the action of static tensile forces, in non-cracked concrete substrates in which steel anchors were installed. In order to determine the impact of fibre reinforcement in concrete on the strength of expansion fasteners and concrete screws, tests were carried out at the Building Research Institute on fastenings made with their use. The base material was C20/25 concrete with the addition of Steelbet 50/0.8 steel fibres; the amount used was between 10 kg/m³ and kg/m³ (Figure 3). The steel fibres were dispensed into concrete mixes and mixed for approx. 15 minutes before laying the mixture in moulds.
Figure 3. Fibre reinforced concrete: a) shape of the steel fibres, b) concrete mix in forms

Table 2. Installation parameters of anchors

| Anchor   | Steel fibres [kg / m³] | Concrete $f_{c, test, C20/25}$ [MPa] | Nominal Embedment Depth $h_1$ [mm] | Effective Embedment Depth $h_{ef}$ [mm] | Installation Torque $T_{inst}$ [Nm] | Drill Hole Diameter $d_{cut}$ [mm] |
|----------|------------------------|--------------------------------------|-----------------------------------|----------------------------------------|-----------------------------------|---------------------------------|
| Expansion M10 |                       |                                      |                                   |                                       |                                   |                                 |
| 0        | 33,7                   | 45 / 60                              | 35 / 50                           | 30                                    | 10,30                             | 10,30                           |
| 0        | 31,7                   | 45 / 60                              | 35 / 50                           | 30                                    | 10,30                             | 10,30                           |
| 15       | 31,9                   | 45 / 60                              | 35 / 50                           | 30                                    | 10,30                             | 10,30                           |
| 20       | 31,1                   | 45 / 60                              | 35 / 50                           | 30                                    | 10,30                             | 10,30                           |
| 30       | 30,1                   | 45 / 60                              | 35 / 50                           | 30                                    | 10,30                             | 10,30                           |
| 0        | 33,7                   | 50                                   | 50                                | -                                     | 12,30                             |                                 |
| 10       | 31,7                   | 50                                   | 50                                | -                                     | 12,30                             |                                 |
| 15       | 31,9                   | 50                                   | 50                                | -                                     | 12,30                             |                                 |
| 20       | 31,1                   | 50                                   | 50                                | -                                     | 12,30                             |                                 |
| 30       | 30,1                   | 50                                   | 50                                | -                                     | 12,30                             |                                 |
| Screw M12 |                       |                                      |                                   |                                       |                                   |                                 |
| 0        | 33,7                   | 45 / 60                              | 35 / 50                           | 30                                    | 10,30                             | 10,30                           |
| 10       | 31,7                   | 45 / 60                              | 35 / 50                           | 30                                    | 10,30                             | 10,30                           |
| 15       | 31,9                   | 45 / 60                              | 35 / 50                           | 30                                    | 10,30                             | 10,30                           |
| 20       | 31,1                   | 45 / 60                              | 35 / 50                           | 30                                    | 10,30                             | 10,30                           |
| 30       | 30,1                   | 45 / 60                              | 35 / 50                           | 30                                    | 10,30                             | 10,30                           |

3. Results and discussions
After the 28-day curing period, the concrete’s compressive strength and residual strength were tested and the actual content of steel fibres was verified (Table 3). Figure 4 and 5 present characteristic failure fasteners under tensile loads. Initial results of mean ultimate loads obtained for anchors are presented in Figure 6.

Table 3. Change in concrete properties after addition of steel fibres

| Concrete type                                      | Compressive strength at 28 days [MPa] | Residual strength at CMOD = 3.5 mm [MPa] | Actual content of steel fibres in the concrete [kg/m³] |
|---------------------------------------------------|--------------------------------------|------------------------------------------|-------------------------------------------------------|
| Non-fibre concrete                                | 33,7                                 | -                                        | -                                                     |
| Concrete with the addition of steel fibres; assumed quantity 10 kg/m³ | 31,7                                 | 0,84                                     | 9,4                                                   |
| Concrete with the addition of steel fibres; assumed quantity 15 kg/m³ | 31,9                                 | 1,03                                     | 14,3                                                  |
| Concrete with the addition of steel fibres; assumed quantity 20 kg/m³ | 31,1                                 | 1,27                                     | 19,1                                                  |
| Concrete with the addition of steel fibres; assumed quantity 30 kg/m³ | 30,1                                 | 1,24                                     | 29,0                                                  |
For fastenings made with M10 expansion fasteners embedded in fibre reinforced concrete with design class C20/25, an increase in strength was recorded in comparison to fastenings in concrete with no steel fibre reinforcement by approx. 5% with steel fibre content equal to 10 kg/m³ and up to approx. 10% with a higher amount of fibres. With a higher content of steel fibres in the concrete, failure of the fastening occurred as a result of damage to the steel structure of fasteners. Image of failure of a screw joint due to tensile loads consisting in stripping the mechanical interlock of the screw’s thread with the surface of the hole in the concrete, with detachment of surface concrete cone. The dimensions of detached concrete cone were significantly smaller than the one in the case of joints using expansion fasteners. The height of the detached cone did not exceed 20 mm, while its base diameter was c. 50% larger than for fastenings in conventional concrete.
Figure 6. Mean ultimate load in a test for concrete non-cracked C20/25 for tested anchors

4. Conclusions
Fastenings with M10 expansion fasteners embedded in fibre reinforced concrete displayed increased strength compared to fasteners in concrete lacking the fibre reinforcement by approx. 5% at 10 kg/m³ of steel fibres and approx. 10% at the higher amount – 20 kg/m³ of fibres in the concrete. It should be noted that the fastenings in fibre reinforced concrete were executed at a much smaller embedment depth (even by approx. 50% in relation to the requirements for conventional concrete). At higher embedment depth of expansion fasteners in fibre reinforced concrete, failure occurred in the form of damage to the steel structure of the fasteners. For joints made with ø 12 mm screw fasteners, there was also a clear increase in strength when the fastening was made in fibre reinforced concrete. With steel fibre content equal to 10 kg/m³, the strength of the fastenings was ca. 20% higher than for corresponding fastenings in conventional concrete, and in the case of 20 kg/m³ of steel fibres in the concrete, the increase in strength was recorded to be up to 30%. The increase in strength of expansion fasteners and screw fasteners in fibre reinforced concrete recorded in the tests is particularly beneficial whenever there is a need to make “shallow” fastenings, in thin bases, as is the case with widely used industrial floors with additional fibre reinforcement.

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