POSSIBILITIES OF SURFACE FIXING THE CONCRETE AND FIBRE REINFORCED CONCRETE ELEMENTS

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Abstract

Concrete and fibre reinforced concrete are materials with very heterogeneous structure and there behaviour varies under different types of loading. This paper deals with the possibilities of force load transfer of concrete and fibre reinforced concrete elements through their surface layers. It allows the surface fixing of these elements. Due to properties of the material (limited hardness and abrasion) this way of concrete fixing is more difficult than for steel. By the surface loading of concrete and fibre reinforced concrete there is a mechanical damage of surface layer, which reduces the rigidity of the fixing. Therefore several variants of fixing the specimens were experimentally tested and the resistance and rate and form of material damage under extreme loads were compared. It was also investigated the contribution of fibres for the resistance of the connection. The obtained knowledge can be used in cases of additional and temporary fixing the structural elements or fixing the concrete and fibre reinforced concrete specimens in laboratory experiments.

Keywords: concrete, fibre reinforced concrete, surface layer, transfer of surface forces, fixing of specimens, damage of material

1. Introduction

The surface layer of concrete and fibre reinforced concrete elements represents the upper part of the concrete thickness 25-50 mm. It is an area that is exposed to the ambient environment and is sensitive to its changes. There is usually initiation of failure of elements either during power or non-power load. The quality of the surface layer has a significant influence on the durability of the whole element and depends mainly on the composition of concrete and the method of storing and curing. In terms of protection of reinforcement bars permeability, alkaline pH and mechanical resistance (based primarily on the strength characteristics of the material) are very important parameters of surface layer. For a comprehensive resistance analysis of particular parts of concrete and fibre reinforced concrete surface layer it is necessary to quantify other characteristics (hardness, porosity and permeability, chemical resistance, etc.) by which it would be possible to describe these problems in detail. This paper, however, deals only with the possibility of surface transfer of power load in a direction parallel to the surface.

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2. Resistance of surface layer of concrete and possibilities of transfer of surface forces

The term resistance of surface layer of concrete can be understood both its structural resistance, when the effects of external mechanical influences leads to its destruction, and also the ability to maintain compactness with the inner layers of concrete. In terms of mechanical load resistance of the surface layer is given by the compressive, tensile and shear strength. Strength characteristics depend on the concrete class, its porosity and in case of fibre reinforced concrete also on the type, dosage, homogeneity and orientation of fibres. Composition and structure of the surface layer is slightly different compared to the inner parts, a it is reflected in the surface loading of element. When the load is applied perpendicular to the surface, there is transverse stress and pressure deformation of the surface layer. When the load is applied parallel to the surface, there are shear forces and surface layer can break away or by slip of the element it leads to its abrasion.

Problems of transfer of surface forces is practically problem of surface fixing of the element. With regards to the nature of the material and some its limiting factors (e.g. reduced hardness and abrasion of concrete and fibre reinforced concrete compared to steel) 2-3 possible approaches to surface clamping elements can be used :

a) appropriate use of variable-shaped body

b) friction at the interface between the concrete and the clamping device (usually steel)

c) local fixing elements

In the case of variable-shaped element a vector decomposition of the clamping force to normal and tangential components may be used (Fig. 1). Compressive force applied perpendicularly to the surface is directly transferred to the mass of body and efficiency of fixing depends only on the rigidity of the clamping device.

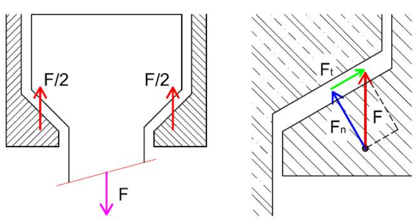

Fig. 1 Vector decomposition of clamping forces

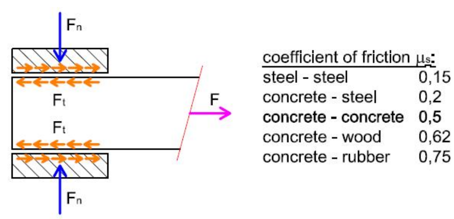

Fig. 2 Friction at the interface concrete - steel

A second possibility is based on the physical principle of friction when the normal compressive load of surface generates surface forces that precludes movement parallel to the surface. Size of friction is directly proportional to the normal load and roughness of material interface (coefficient of friction).

$$F_f = m_s \cdot F_n , \qquad (1)$$

where F_f is friction force between materials, acting parallel to the surface

m_s is coefficient of friction between two materials

F_n is normal force, acting perpendicular to the surface of the specimen

For the common case of contact concrete - plain steel is the coefficient of friction $m_s = 0{,}2$. When using a roughened surface of the steel (e.g. rasp) the friction coefficient $m_s = 0{,}6$ can be achieved. Achieving higher levels is limited by resistance of the surface concrete structure. The total size of friction force is therefore limited by the maximum achievable value of the coefficient of friction and the resistance to pressure and transverse tensile.

A third possibility is fixing of the body using local fixing elements, but insight to their character they disturb the integrity of the surface layer of concrete. Examples are metal pins elements that are recessed in the surface layer of concrete. Resistance of this connections depends not only on the quality of the concrete, but also on the specific number, shape and placement of pins, the method of their mounting and rigidity of clamping device. A variant of clamping should be selected with regard to labour and acceptable degree of damage to the body (temporary anchorage of concrete).When the specimens are fixing in the laboratory at the destructive tests, degree of damage may not affect experimental results.

3. Experimental program

The experimental program tested influence of the quality, shape and location of clamping device on the resistance of the surface layer of concrete and the resistance of fixing the element. There were used cubes 150 × 150 × 150 mm of plain concrete and fibre reinforced concrete with steel fibres in dosage 0,5% and 1,0% of volume. Specimens were clamped by fixing elements, supported and loaded with pressure force (Fig. 3). This arrangement of experiment simulates the real type of loading of surface fixed concrete structural elements with sufficient cogency. It was observed an increase of load force dependence on the slip of the specimen in clamping and subsequently evaluated the rate and form of damage of the specimen.

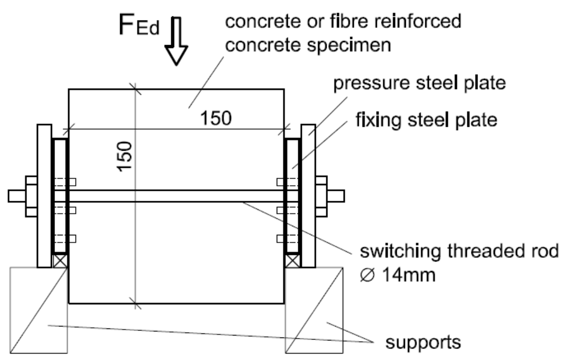

Fig. 3 Scheme of the experiment

3.1 Variants of clamping of specimens

Three variants of clamping of specimens were successively tested:

1) transverse grip of specimen with steel plates with coarsened surface - a friction joint

2) impressing of fixing plates with local protrusions (spikes, rivets)

3) fixing plates with steel pins mounted into predrilled holes

In the first variant steel fixing plates in the form of rasps for wood were used (Fig. 4). Maximal transverse grip of concrete and fibre reinforced concrete specimen was made with threaded rods and specimen was tested in punching (stiffness of the mounting).

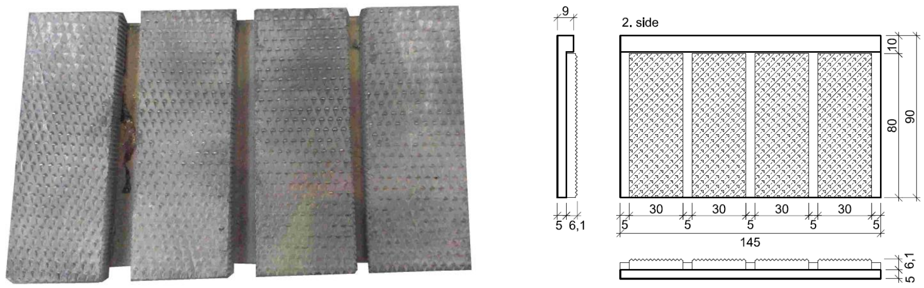

Fig. 4 Fixing plates in the form of rasps

In the second case steel fixing plates with local protrusions were used. The plates were pressed into the surface layer of concrete before the experiment. Different variations of the shape, number and arrangement of protrusions were tested (Fig. 5). Phases of the experiment are shown in Fig. 6. A weak spot of this procedure is the process of pressing, which often leads to failure of concrete specimen due to transverse tension in this phase of experiment (Fig. 6c). Fibre reinforced concrete specimens show better results, because their structure is reinforced with fibres. Detail of fixing protrusions pressed into the surface layer is shown in Fig. 6d.

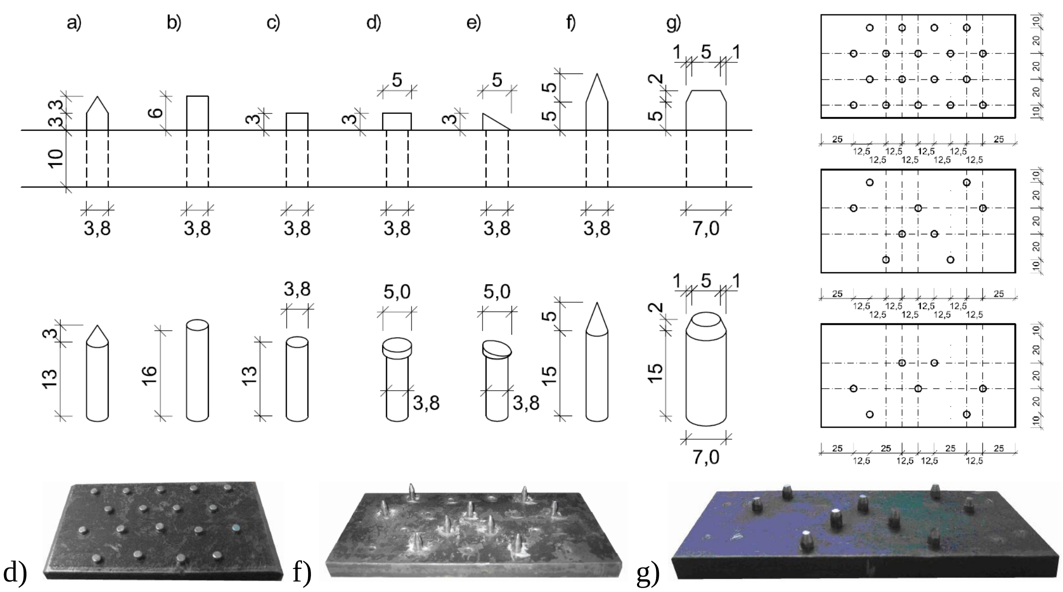

Fig. 5 Variations of the shape and placement of fixing pins

A third alternative of clamping represented fixing plates with steel pins, that were mounted into the predrilled holes in the surface layer of the concrete specimen. This procedure eliminates the risk of failure of specimens before starting the test, however, there are high standards of precision positioning of drill holes. Therefore, it is necessary to create a drilling pattern and machinery drilling is recommended. Due to the tolerance diameter of drilled holes was 1,0 mm longer than the diameter of mounted pins.

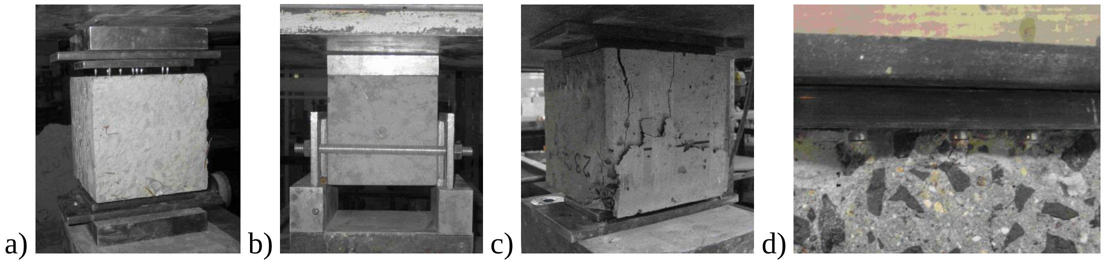

Fig. 6 Course of the experiment - a) pressing of fixing plates, b) test of fixing resistance, c) failure of specimen due to transverse tensile in the phase of pressing, d) detail of impressing fixing pins

Variants with 7, 9 and 18 fixing protrusions on one fixing plate were tested, when clamping was always carried out from two opposite sides. Variables of the tests were strength of fixing elements, their shape, size, number and distribution. Strength of protrusions varied from ordinary structural steel S235 to high strength steel S690.

3.2 Calculations of the experiments

Executed range and variability of experiments required a number of theoretical calculations. In the design of variants it was need to monitor the following four parameters that affect the final resistance of the connection.

- bruise resistance of concrete : $F_{Ed,1} \leq V_{R,1C,d}$ (2)
- bruise resistance of pin : $F_{Ed,1} \leq F_{b,Rd,1}$ (3)
- resistance of pin at the combination of bending and shear :

$$\left[\frac{M_{Ed,1}}{M_{Rd,1}}\right]^2 + \left[\frac{F_{Ed,1}}{F_{v,Rd,1}}\right]^2 \leq 1 \quad (4)$$

- bruise resistance of fixing plates : $F_{Ed,1} \leq F_{b,Rd,s}$ (5)

Roughly speaking, the resulting resistance of clamping is determined by resistance of its weakest link. Bruise resistance of concrete depends partly on its compressive strength and on the geometry of the investigated area. Resistance of pins elements and fixing plates depends on the using material, their number and distribution. From theoretical conclusions it was possible in many cases to optimize the design of fixing, without performing experiments.

4. Analysis of results

Two moments were primarily observed during the process of loading :

1) first slip of the specimen
2) maximum load force

In both moments the value of load force was recorded, in case of the maximum load force the approximate value of the slip was recorded too. Some results are shown in Fig. 7. The test was stopped after subsequent drop of the load force, clamping device was taken down and the degree and type of damage the surface layer of concrete was visually assessed (Fig. 8).

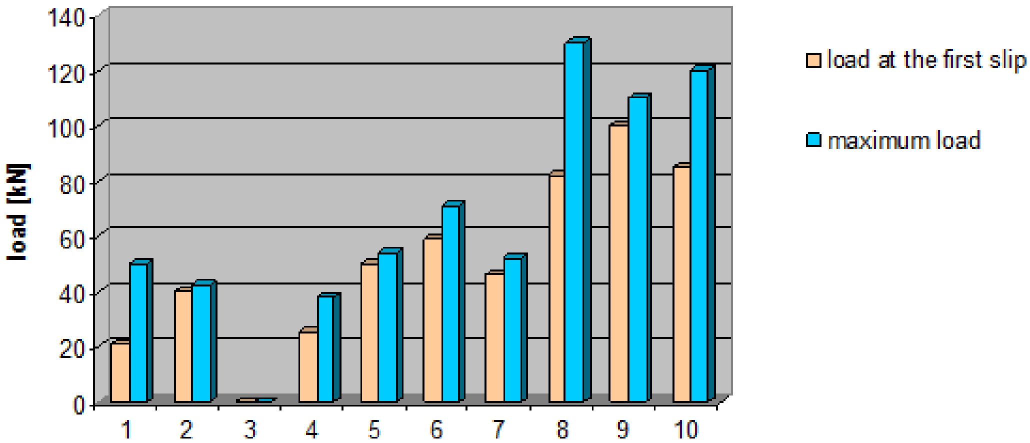

Fig. 7 Resistance of clamping of concrete and fibre reinforced concrete specimens

The first variant of fixing was transverse grip of specimen with steel plates with coarsened surface. Due to the inequalities surface of the concrete in the friction joint there is very difficult to achieve full activation of the contact fixing surfaces. This fact, combined with a low coefficient of friction between the concrete and steel, limits a rigidity and resistance of clamping. The fixing plates fit during loading, therefore the switching power declines. It is possible to increase a resistance of clamping due to tighten threads of threaded rods during the experiment. When the specimen slips in the clamping, there is soft surface grooving of concrete, depending on the roughness of the contact plate (Fig. 8a). Due to the shallow active zone there was not recorded positive contribution of fibres at the fibre reinforced concrete elements.

The variant of impressing fixing plates with local protrusions causes considerable damage of the surface layer of concrete (Fig. 8b, c). In many cases it leads to a failure of concrete elements due to transverse tension in the phase of pressing. The resultant resistance of clamping is approximately the same as the resistance of the friction joint. When slenderness of local protrusions is $l = L/d \geq 1{,}5$, there is failure due to combination bending and shear. When slenderness is lesser, there is more bruise of protrusions or concrete, in the case of soft material of fixing plate, there is bruise of plates. Degree of damage of surface layer is given by press-dept, the depth of the grooves decreases with increasing slip - plates emerge from the surface and it leads to self-prestressing of connection. Nevertheless, its resistance decreases with increasing slip. At the fibre reinforced concrete there is positive contribution of fibres in the surface layer.

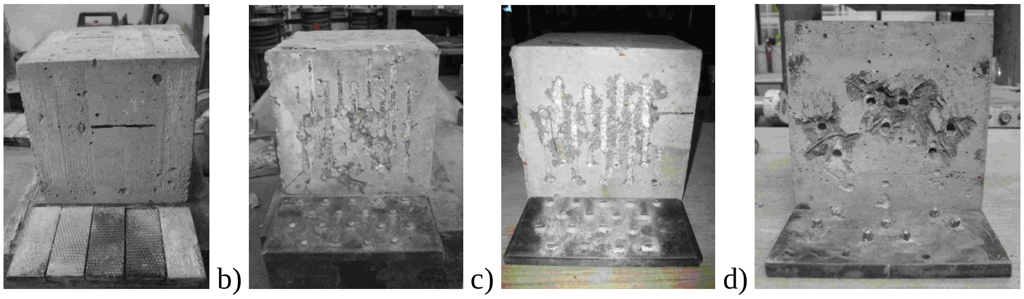

Fig. 8 Examples of damage to the specimens after the experiment

a) lateral clamping + coarsened plates, b) impressing rivets with whole headers, c) impressing rivets with skewed headers, d) pins to predrilled holes

The variant of pins mounted into predrilled holes reports to 2,5 times greater resistance and significantly less damage of specimen under extreme load compared with two previous variants. In the initial phase damage is only local (predrilled holes), its increase is only after reaching limit load. In the case of a service load (70 - 80% of limit load) there was no slip in the clamping device observed, the only observed deformation was due to fit of the connections. In the event that fixing protrusions (pins) are not too long (in this case 6,0 mm) there is no flexure or shear stain of pins in loading process of concrete specimen, weakest link of arrangement is bruise resistance of concrete.

5. Conclusion

Due to the low coefficient of friction between the concrete and steel transverse grip of concrete elements isn't sufficiently effective or leads to their failure due to transverse tension. Inserting of contact elements with higher roughness doesn't bring significant increase the resistance. Due to the small depth of active zone contribution of fibres is insignificant in this case.

A variant of impressing steel plates with spikes or rivets damages the structure and compactness of specimens and the process of the pressing is technologically (moving with the specimen) and time consuming. Cyclic repetition of clamping test leads to excessive wear of the clamping device.

Experiments have shown that the most appropriate way of surface fixing of direct concrete and fibre reinforced concrete specimens is the use of high-strength steel pins mounted into predrilled holes. Connecting between fixing plates and the remaining part of clamping device must be resolved for practical using. Future research will be focused on the practical application of knowledge gained in this study.

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