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COMPARATIVE ANALYSIS OF FINITE ELEMENT MODELLING AND EXPERIMENTAL RESULTS OF BONDING STRENGTH BETWEEN COMPOSITE BARS AND CONCRETE

ПОРІВНЯЛЬНИЙ АНАЛІЗ МОДЕЛЮВАННЯ КІНЦЕВОГО ЕЛЕМЕНТА І ЕКСПЕРИМЕНТАЛЬНІ РЕЗУЛЬТАТИ СЦЕПЛЕННЯ КОМПОЗИТНОЇ АРМАТУРИ З БЕТОНОМ

СРАВНИТЕЛЬНЫЙ АНАЛИЗ МОДЕЛИРОВАНИЯ КОНЕЧНОГО ЭЛЕМЕНТА И ЭКСПЕРИМЕНТАЛЬНЫЕ РЕЗУЛЬТАТЫ СЦЕПЛЕНИЯ КОМПОЗИТНОЙ АРМАТУРЫ С БЕТОНОМ

Annotation. Composite bars are currently used to reinforce concrete in an attempt to overcome the corrosion issue encountered with ordinary steel. Different types of surface treatment were applied to the smooth rods in order to increase bonding with concrete. Experimental results show that using bars coated with jute fiber notably improve the bond strength.. the bars coated with finer jute fiber lead to a stronger chemical adhesion with concrete. experimental results it is difficult to filter out the influences of material and geometrical parameters on the bond behavior. Therefore, to better understand the bond behavior, a reliable bond model (simulation of the transmission of forces in the bond zone) that can be employed in a three-dimensional finite element, an analysis is needed.
Keywords: jute fiber, composite reinforcement, bond strength, chemical adhesion, concrete, 3D model.
Анотація. В даний час композитні арматури використовуються для посилення бетону в спробі подолати проблеми корозії, яки зустрічається в звичайній стали. Для гладких стрижнів застосовувалися різні типи обробки поверхні, щоб збільшити зчеплення з бетоном. Експериментальні результати показують, що використання стрижнів, покритих джутовим волокном, помітно покращує міцність зчеплення. Композитні арматури, які покриті більш тонким джутовим волокном, призводять до більш сильної хімічної адгезії з бетоном. Тільки експериментальним результатом важко визначити вплив матеріальних і геометричних параметрів на процес зчеплення арматури з бетоном. Тому для кращого розуміння цього процесу, була розроблена 3D модель для зчеплення композитних арматур з бетоном (моделювання передачі сил в зоні зв'язку), яка може бути використана в тривимірному кінцевому елементі для проведення порівняльного аналізу.
Ключові слова: джутове волокно, композитна арматура, міцність зчеплення, хімічна адгезія, бетон, 3D модель.
Аннотация. В настоящее время композитные арматуры используются для усиления бетона в попытке преодолеть проблему коррозии, встречающуюся в обычной стали. Для гладких стержней применялись различные типы обработки поверхности, чтобы увеличить сцепление с бетоном. Экспериментальные результаты показывают, что использование стержней, покрытых джутовым волокном, заметно улучшает прочность сцепления. Композитные арматуры, которые покрыты более тонким джутовым волокном, приводят к более сильной химической адгезии с бетоном. Экспериментальным результатом трудно определить влияние материальных и геометрических параметров на процесс сцепления арматуры с бетоном . Поэтому для лучшего понимания этого процесса , была разработана 3D модель для сцепления композитных арматур с бетоном (моделирование передачи сил в зоне связи), которая может быть использована в трехмерном конечном элементе для проведения сравнительного анализа.
Ключевые слова: джутовое волокно, композитная арматура, прочность сцепления, химическая адгезия, бетон, 3D модель.

Introduction

In modern world practice, along with traditional metal fittings, the composite non-metallic is increasingly used, which is being actively introduced in the construction of the USA, Canada, Japan, and Europe [1]. The use of fiber-reinforced polymers (FRP) as reinforcement in concrete structures is considered to be a possible alternative to steel in those situations where corrosion is present. FRP bars have many distinct advantages over steel reinforcement; including a high strength-to-weight ratio, high durability, easier handling due to their light weight, high tensile strength, excellent fatigue characteristics and electromagnetic neutrality [2]. Typical applications of FRP composites include rehabilitation projects, including column strengthen-ing, [3,4] seismic retrofitting,[5,6] repair of corrosion-damaged columns, [7,8] as well as improvements in strength and stiffness of deteriorated structures by the use of CFRP composites [9–11]. The FRP rebars are generally made of glass, carbon and aramid fiber reinforced composites can be readily formed into complex shapes through the pultrusion manufacturing process (Wallenberger et al. 2001, Walsh, 2001). The most common manufacturing process is the pultrusion process, when the longitudinal fibers are drawn through a resin bath and then passed through a die, which gives the rebar of a final shape.

Aim of the study.

1 – Improve the bond strength of composite rebar with concrete by coating jute material on the surface of rebar

2 – To expression of bond-slip relationship is selected and the pull-out test with slip and without slip modeled by finite element software (SCADOffice 21.1.) in 3d mode and then the obtained results are presented and compared with experimental data from pullout test.

Relevance of study

Additional techniques are required to improve the bond between the rebar and the surrounding concrete. Several techniques can be used, including surface deformations, sand coating, over-moulding a new surface on the bar or a combination of the techniques. Many researchers have brought up various formulae to estimate the bond strength of deformed composite reinforcement and studied experimentally and numerically the use of composite rebars as reinforcement in the concrete structures.

The mechanics of stress transfer by bond between FRP rebars and concrete was investigated by many authors. From the experimental results it may be concluded that the bonding of the FRP to concrete depends on the following factors: chemical bond, friction due to surface roughness of FRP rods, mechanical interlock of the FRP rods against the concrete, and induced interfacial pressure due to temperature change and concrete shrinkage during curing. However, with a more detailed study of the properties of basalt plastic reinforcement, it turns out that there is no information in the literature on the magnitude of its adhesion to concrete and its dependence on the treatment of the external surface of basalt plastic and glass fiber plastic reinforcement in various ways to increase its adhesion to concrete. In order to increase the bond strength of the composite reinforcing bars to concrete, jute fiber was used as the main material. Jute is a plant fiber made from a Malvovia plant. The plant grows in the tropics of Asia, Africa, America, Australia, India and Bangladesh. Jute is used for making sackcloth, twine and other common products. A new study shows that jute can also be used as an inexpensive reinforcing fiber for cement mortars [23]. In this case, the use of jute makes concrete more crack-resistant, which in some cases is especially important, for example, in regions with sharp temperature changes, such as Jordan [15]. In the scientific literature, there are data on the introduction of jute fiber into the composition of non-pressure concrete pipes [19], to increase the strength of reinforced concrete beams [20], to concrete instead of glass fibers [21]. These studies show that jute slows down the hardening of concrete, and allows in many cases to do without the use of specialized formwork. The addition of jute fibers to the mixture slows down the setting time of the concrete. The characteristics of the jute fiber are shown in Table 1.

Table 1.

The main characteristics of jute fibers

Characteristics of jute fiber	
Specific gravity	1,3
Tensile strength, MPa	442
Modulus of elasticity, MPa	60
Diameter, mm	4

Experiments and results

The experiment was carried out in the laboratory of the Department of building Materials and Products of the Kharkov National University of Civil engineering and Architecture.): the composite rebars were coated by epoxy resin as an adhesive substrate, then the rods were separately wrapped with jute thread, from 1.5 mm to 2 mm . The rods are held for 48 hours for complete adhesion (Fig. 1).

The samples were made – cubes «15x15x10» cm, composition C: S: G = 1: 2: 4, (aggregate-sand Mk = 1.5 and crushed stone up to 10mm), mixture moisture (W / C) – 0.5. The bars of the reinforcement were installed vertically along the axis into the cubes-shapes to a depth of up to 10 cm together with the laying of the concrete mix and its subsequent vibration compacting. The rods were stacked in cubes in such a way that the destruction of the sample occurred as a result of punching. The first type of samples of basalt plastic reinforcement with a single screw thread of the jute thread, and the second control sample, with 4 samples of each type, the finished sample cubes are shown in Figure 1.

Fig. 1. Manufactured samples – cubes

Tests on the bonding strength of composite reinforcement with concrete by pull out were carried out on the experimental installation shown in Figure 2 .

Fig. 2. Laboratory installation for pull test

Loading of samples at the age of 28 days, was carried out step by step from 0.1 of the estimated boundary load of 3100 kg of pushing the reinforcing bar from concrete to failure. The load was controlled by a dynamometer with an indicator of the arrow type. The shift of the free ends of the reinforcing bar under investigation was measured by a dial gauge with a measurement limit of 1 mm and an accuracy of 0.001 mm. At each load step, 15 seconds were maintained, during which the indicators were taken, and the readings were recorded. Determination of the strength of the adhesion of reinforcing bars to concrete was carried out according to the recommendations of the ACI industry (departmental standards-USA) [16]:

$$\tau = F / C_b . l \qquad (1)$$

где τ – Average bonding strength, F – load, C_b – length of rebar surface, l – length of the composite bar.

The results of the strength evaluation are presented in Table 2.

Table 2.

Values of bonding strength of composite rebar with concrete

Sample type	Pull out load, F, kg	Bond strength τ, MPa
Basalt-plastic rebar coated by jute fibers	3100	16,45
basalt plastic rebar coated by a single spiral wound jute yarn	2950	15,56
Basalt rebar reference	1700	9 ,02
Fiber glass -plastic rebar coated by jute fibers	2800	14,86
Fiber glass -plastic rebar coated by a single spiral wound jute yarn	2600	13,80
Fiber glass-plastic rebar reference	1550	8,22

Finite Element Modeling of Pullout Test

To study the bond behavior of steel reinforcement in a concrete matrix, we use pull-out tests of a steel bar (Ø12mm) with ribs (see Figure 3) which was performed by Eligehausen (2003) [9]. To investigate the performance of the cohesion layer, numerical investigations on pullout specimens have been carried out. The specimen is an anchor of a reinforcing bar db=12 mm in a well confined cubic of concrete of 150mm height which corresponds to anchorage length of 5 bar diameters (embedment length lE=5 db =60 mm).For the numerical investigations the finite element software (SCADOffice 21.1.) has been used and a detailed FE model in 3D mode with and without bond-slip effect as cohesion layer to simulate bond have been employed. Since rib of reinforcement are being simulated, the mesh size close to the rib in steel bar, concrete and cohesion layer should be small enough to accurately describe the deformation and stress gradients. However, for the remaining regions coarse mesh can be used in order to reduce the computational costs. The results of these numerical investigations are compared with the results of the experimental investigations [24]. The test specimen used in the finite element model is shown in Figure 3. Finite element model In determining the bond strength of composite reinforcement with concrete of natural experiments, theoretical experiments were carried out by modeling the samples with the help of finite elements. SCADOffice 21.1 was used to model the sample. The design scheme (Figure 1) was composed of three-dimensional finite elements of type 36 (8-node isoparametric element).

The load was applied to the sample, distributed over the upper edge of the reinforcing bar. The values of the loads are taken from experimental results. As a result of the calculations, the values of displacements (Figure 4) and stresses were obtained (Fig. 5). When analyzing the results obtained, it can be concluded that they sufficiently accurately repeat the results of experimental results.

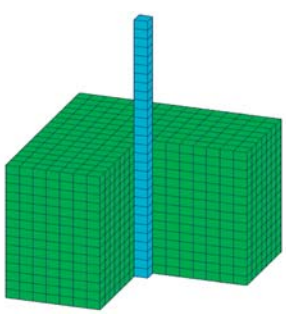

Fig. 3. General view of the finite element model of the sample

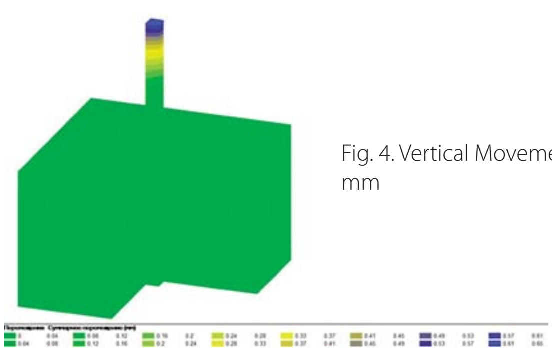

Fig. 4. Vertical Movements, mm

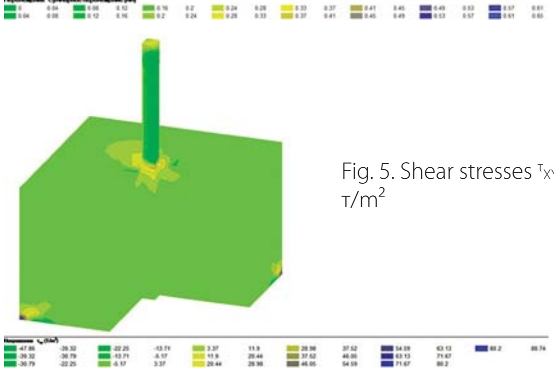

Fig. 5. Shear stresses τ_{XY}, т/m^2

Table 3 shows the summary of the basic material variable used in the experimental and numerical investigations.

The bond stress-slip relation obtained in the finite element calculation when the three dimensional modeling of the reinforcement is used are substantially corresponding to the curves of the experimental investigations.

In case of The comparison analysis of bond stress-slip graph in 3D finite and experiment for basalt plastic reinforcing bar coated by jute fiber , When analyzing the results obtained in 3D finite, it can be concluded that they sufficiently accurately repeat the results of experimental results but with some deviations .see in fig .6.

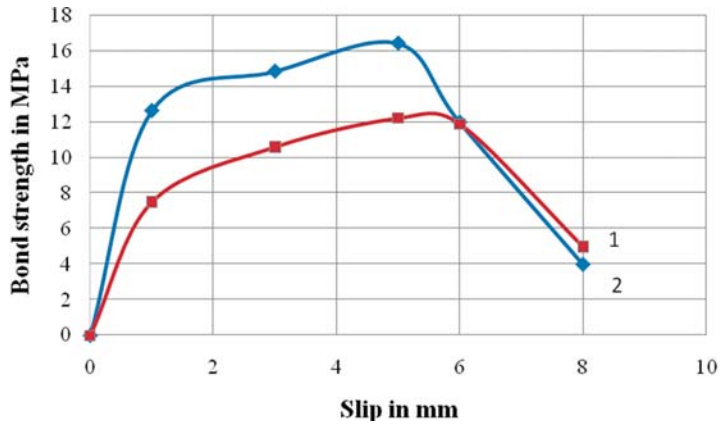

Fig. 6. Comparison bond stress-slip graph in 3D finite analysis and experiment for basalt plastic reinforcing bar coated by jute fibers

In case of The comparison analysis of bond stress-slip graph in 3D finite and experiment for glass fiber plastic reinforcing bar coated by jute fibers. When analyzing the results obtained in 3D finite, it can be concluded that they sufficiently accurately repeat the results of experimental results but with some deviations .see in fig. 7.

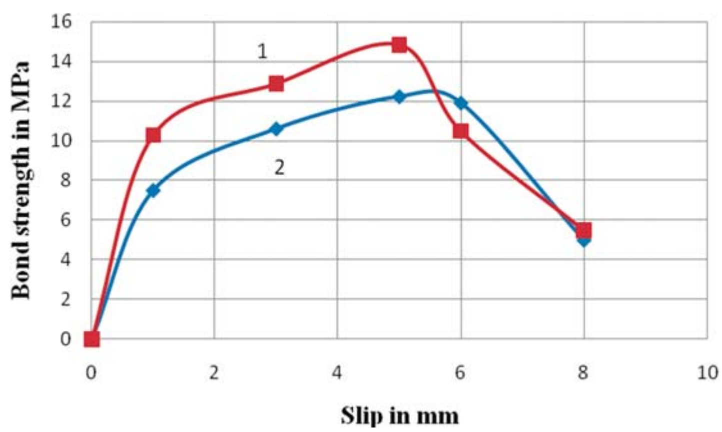

Fig. 7. Comparison bond stress-slip graph in 3D finite analysis and experiment for glass fiber plastic reinforcing bar coated by jute fibers

In case of The comparison analysis of bond stress-slip graph in 3D finite and experiment for reference composite reinforcing bars. When analyzing the results obtained in 3D finite, it can be concluded that they sufficiently accurately repeat the results of experimental results. see in fig. 8.

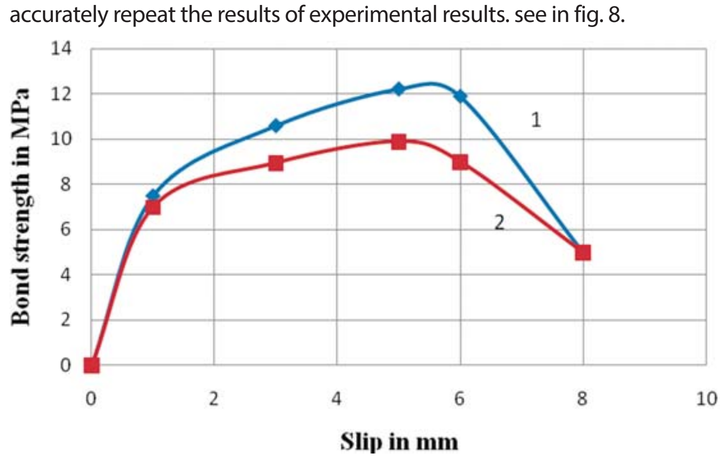

Fig. 8. Comparison bond stress-slip graph in 3D finite analysis and experiment for reference composite reinforcing bars

Table 3.

Summary of the material parameters

Material properties	Values (kg/cm²)
Concrete compressive strength	300
Concrete tensile strength	30
Concrete E modulus	273664
Concrete Poisson's coefficient	0.2
Composite reinforcing bar E modulus GPa	130
Steel yield stress MPa	1500

Conclusion

1. When using an impregnated organic fiber bundle and fiber, it is possible to increase the bond strength to 13.80 and 16.45 MPa due to the high degree of intermolecular interactions at the interface.

2. In this paper the methods of modeling of bond-slip models between composite reinforcing bars and concrete in the finite element program is described. Then one analytical expression of bond-slip relationship is selected and the pull-out test with slip and without slip modeled by finite element software (SCADOffice 21.1.) in 3d mode and then the obtained results are presented and compared with experimental data from pullout test. It was found that stress distribution in the steel bar and concrete of pull-out tests may principally be influenced by the properties of the interface.

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