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# Tests of selected elements of building components in the light of compulsory requirements

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Abstract:

A procedure of standard strength tests of reinforcement bars conducted at present at the ITG KOMAG is discussed. Taking advantage of the bibliographic review, concerning tests of reinforced concrete with steel reinforcement bars, a possibility of using the KOMAG testing infrastructure to broaden the scope of tests of reinforcement bars was analyzed. Due to a more and more common use of composite bars for reinforcing and strengthening concrete structures, the methods of testing their strength properties are discussed. The conditions enabling to conduct strength tests of composite reinforced concrete bars at the ITG KOMAG are determined.

Keywords: steel reinforcement bars, strength tests, composite reinforcement bars, pullout test of bars, bar adhesion test to concrete

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## 1. Introduction

The KOMAG Laboratory of Tests, apart from a broad scope of tests of mining machines and equipment, also conducts tests for other branches of economy. Among others, based on the agreement concluded with Regional Building Supervision Inspectorates, the Laboratory realizes strength tests of reinforcement bars. A necessity of conducting such tests results from the Act [1]. Simultaneously, a development of materials used for reinforcing concrete elements, causing a need of conducting tests of cognitive character, can be noticed. New grades of steel for reinforcing concrete are used which generates a necessity of experimental check-up of requirements as regards their suitability. Impact tests of some physical features of reinforcement bars on the parameters of reinforced structure forces e.g.: a need of testing the strength of reinforced beams [2] are indispensable. Composite reinforcement bars are implemented more and more frequently. An identification of mechanical properties of such bars is connected with a need of conducting laboratory tests not only of the composite but also of the reinforced concrete element, where a composite bar is used.

This publication is oriented onto an analysis of possibilities of performing strength tests concerning both reinforcement bars made of steel and composite as well as complete reinforced concrete elements with such bars.

## 2. Materials and Methods

### 2.1. Procedure of strength testing of steel reinforcement bars realized at the ITG KOMAG

Tests of steel for reinforcing concrete are conducted on the basis of the agreement with Regional Building Supervision Inspectorates. According to [1] and [3] the procedure of tests includes:

– the information about the producer of the building product under testing,
– the identification data of the element under testing,
  a) the designation of the series or production lot,
  b) the size of production lot, from which a sample is taken,
  c) the data concerning date of sampling and manner of its packaging.

The data, mentioned above, in a form of the minutes, are forwarded to the Laboratory together with the samples, which are to be subject to tests, in a form of reinforcement bars of the length 0.5 m, taken at the construction site.

In the Laboratory, after having conducted a visual inspection and having confirmed that their number and condition enable to conduct the ordered tests, the tensile test of all the delivered samples is conducted to determine the following parameters:

– sample strength in the yield point – $R_e$,
– sample tensile strength – $R_m$,
– ratio of stresses:

$$k = \frac{R_m}{R_e} \tag{1}$$

– total elongation at the maximum force – $A_{gt}$.

An exemplary set of measurement results of the parameters, mentioned above, is given in Table 1. Using the obtained measurement results, it is possible to check if the marked strength parameters of samples meet the declared useful properties determined in the minutes of sampling the construction product.

In the case of samples whose test results are presented in Table 1, the declared properties of the construction product, subject to the tests of a given scope, are:

– sample strength in the yield point – 500 MPa ≤ Re ≤ 625 MPa
– ratio of stresses – 1.15 ≤ $k$ ≤ 1.35
– total elongation at the maximum force – $A_{gt}$ ≥ 8 %.

In the case under consideration, it was stated that the tested samples met the declared properties of a construction product.

**Table 1.** Exemplary tests results of bar samples made of ribbed steel for reinforcing concrete [4]

| No. of sample | Yield point | Tensile strength | Ratio of stresses | Total elongation at maximum force |
|---|---|---|---|---|
| | $R_e$ [MPa] | $R_m$ [MPa] | $R_m/R_e$ | $A_{gt}$ [%] |
| 1 | 570 ± 2.9 | 675 ± 3.4 | 1.18 | 10.0 ± 0.1 |
| 2 | 578 ± 2.9 | 674 ± 3.4 | 1.17 | 10.4 ± 0.1 |
| 3 | 573 ± 2.9 | 673 ± 3.4 | 1.17 | 10.3 ± 0.1 |
| 4 | 575 ± 2.9 | 677 ± 3.4 | 1.18 | 10.2 ± 0.1 |
| 5 | 583 ± 2.9 | 675 ± 3.4 | 1.16 | 10.6 ± 0.1 |
| 6 | 580 ± 2.9 | 675 ± 3.4 | 1.16 | 10.1 ± 0.1 |
| 7 | 573 ± 2.9 | 679 ± 3.4 | 1.19 | 10.6 ± 0.1 |
| 8 | 581 ± 2.9 | 675 ± 3.4 | 1.16 | 10.9 ± 0.1 |
| 9 | 581 ± 2.9 | 675 ± 3.4 | 1.16 | 10.7 ± 0.1 |
| 10 | 585 ± 2.9 | 677 ± 3.4 | 1.16 | 10.5 ± 0.1 |

Since 2020 in total 41 sets of samples of steel reinforcement bars have been subject to tests. It should be highlighted that no samples, characterized by the strength properties differing from the values declared by the producer in the minutes of forwarding samples for tests, have been identified. The samples for tests have usually been taken from the steel lot for reinforcing concrete which has just been delivered to the construction site. In the conclusion it can be stated that positive results of performed tests confirm reliable work of producers of reinforcement bars.

### 2.2. Tests of steel reinforcement bars in the light of standards and research projects

The scope of tests of reinforcement bars, recommended by the Regional Building Supervision Inspectorates, does not encompass all the tests included in the standards [5] and [6], for example the tests of the bar adhesion to concrete. In appendices of the standard [5] two methods of testing an adhesion of bars – the beam method and the pullout method are described in detail. The described methods differ from each other significantly which causes that the results, obtained with their use, serve mainly for a qualitative comparison of adhesion of bars having a similar diameter but different shape of the surface [7].

A diagram of a rig for testing an adhesion with use of the beam method for testing bars of the diameter smaller than 16 mm (according to [5] – beam of A) type is presented in Fig 1.

The reinforcement bar under testing is fixed centrally in the bottom part of two concrete blocks 6, situated on supports 3 and connected with a steel articulated joint 4 in the top part. The articulated joint enables bending of the beam without transmitting an additional load to blocks 6. The reinforcement bar adheres to the concrete only on two sections of the total length of 20·d (where: d – bar diameter). The system of blocks under testing is subject to bending until a total loss of adhesion or a bar break occurs. A general view of the test rig is presented in Fig. 2. A way of fixing the displacement recorder of the bar end is shown in Fig. 3.

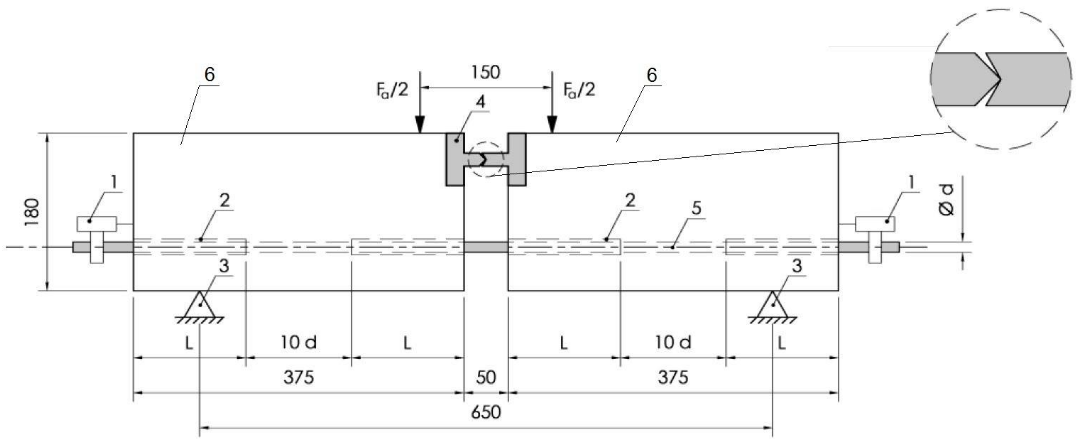


**Fig. 1**. Rig for testing an adhesion of a reinforcement bar with use of the beam method [7]
1 – measurement system, 2 – plastic sleeve, 3 – support,
4 – steel articulated joint, 5 – reinforcement bar under testing, 6 – concrete block
$F_a$ – force loading the beam, d – bar diameter, L– sleeve length

**Fig. 2.** View of a test rig [8]

**Fig. 3.** Fixation of the displacement recorder of the bar end [8]

During the test the graph: force – slip (of the bar) is recorded and an average stress of the adhesion at slip– $\tau_b$ [5] is determined:

$$\tau_b = \frac{\sigma_s}{40} \tag{2}$$

where:
$\sigma_s$ – stress in the bar determined from the relationship:

$$\sigma_s = \frac{1.25 \cdot F_a}{A_n} \quad \text{for } d < 16 \text{ mm} \tag{3}$$

$$\sigma_s = \frac{1.50 \cdot F_a}{A_n} \quad \text{for } d \geq 16 \text{ mm} \tag{4}$$

$F_a$ – force loading the beam (see Fig. 1) for a given value of slip,
$A_n$ – rated area of the bar cross-section.

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Using the graph: force – slip and values of adhesion stresses at slip, an assessment of the bar adhesion is conducted. A preparation of the rig for a test is extremely time – consuming, and according to [5] the test should be performed for 25 samples of the bar.

The method of testing an adhesion of a reinforcement bar to concrete with use of pullout method is presented schematically in Fig. 4. The bar under testing is placed inside a concrete cube 1, touching the concrete only at the top section of the length equal to „5·d". The cube 1 is situated on a steel support 6 with a hole, where a longer, bottom section of the bar is put through.

The test consists in loading the bar bottom end with tensile force, generated by the MTS machine 4, until the sample is damaged or the bar is broken. The force, tensioning the bar – $F_a$ and a displacement of the bar top end – $\Delta_a$ are recorded. An adhesion of the bar to concrete is assessed based on the graph $F_a = f(\Delta_a)$ [5].

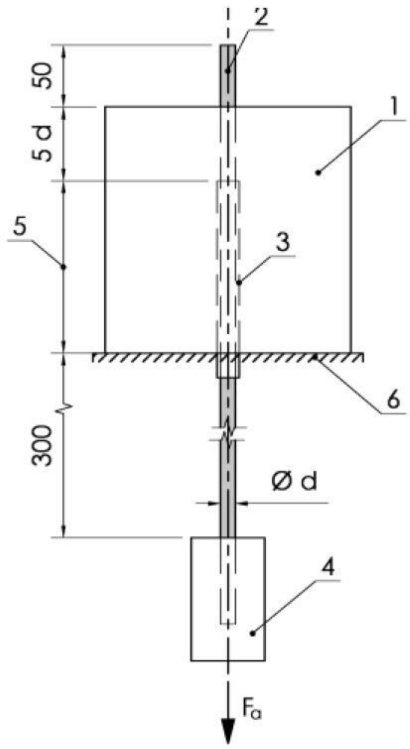


**Fig. 4.** Diagram of test of reinforcement adhesion using the pullout method [7]
1 – concrete cube, 2 – bar under testing, 3 – plastic sleeve, 4 – grip of the MTS machine, 5 – free length of bar, 6 – support with hole

The attempts of pulling out a reinforcement bar from a concrete block, described in the literature, differ as regards the method of preparing a sample and the conditions at the contact: concrete-steel platen [9]. A diagram of the test rig is shown in Fig. 5.

A soft rubber washer and a layer of plastic, decreasing friction, are placed between the block and the plate to minimize a disadvantageous impact between the concrete block and the rig as well as the differences in the state of stresses in the concrete and the steel platen [10]. A slip of the bar is measured directly with use of two displacement transducers (LVDT). Due to a modified setup of the rig a significant reduction of random fluctuations of measurement results is obtained.

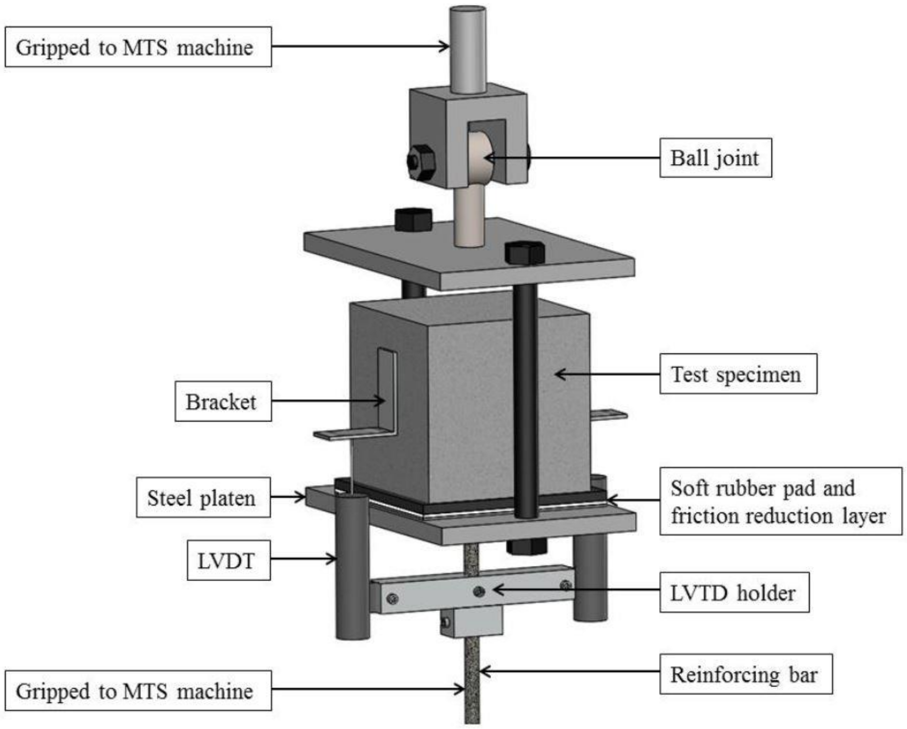


**Fig. 5.** Schematic diagram of pullout test setup [9]

Apart from adhesion tests of the reinforcement bar to the concrete, the mechanical properties of steel in relations to reinforcement and prestressing of concrete, according to [5] and [6], are also determined in the following tests: fatigue test, bend test, rebend test and fatigue test at axial loading. A diagram of the device used for a realization of transverse bend and rebend tests are shown in Fig. 6 and a course of the rebend test is shown in Fig. 7.

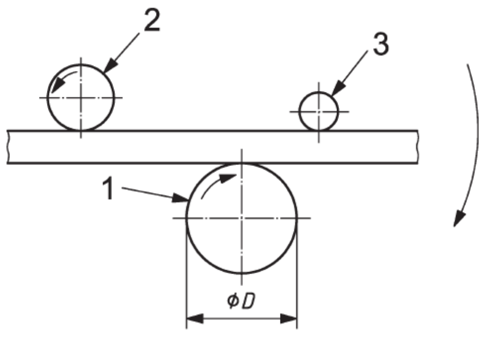


**Fig. 6**. Operational principle of the device for the bar bending and rebending [6]
1 – mandrel, 2 – support, 3 – carrier

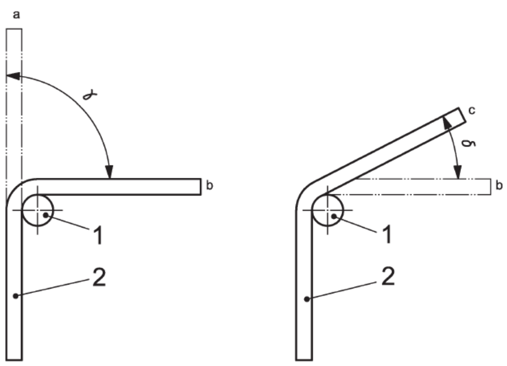


**Fig. 7.** Course of the bar rebend [6]
1 – mandrel, 2 – test piece,
a – initial position, b – position after bend test,
c – position after rebend test

The test piece is bend around the mandrel 1. Conditions of conducting the test (environmental temperature, angle of the test piece bending and the mandrel diameter) and the procedure of interpreting the results are determined in the product standards. If, as it is in the case of the reinforcement bars, detailed requirements related to the test results are not determined, then lack of cracks detected by

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a person having normal or corrected eye sight, are regarded to be a proof that the bar test piece passed the bend test.

The procedure of rebending the bar consists of three stages: bending at the γ angle, artificial ageing and rebending at the δ angle. If the product standards do not determine the parameters, artificial ageing process of the test pieces, the following parameters are applied: heating to the temperature of 100°C, keeping the test piece in this temperature during 1 $h^{+15\ min}$, and then its cooling in motionless air to the environmental temperature. It is confirmed that the test piece passed the rebend test, if a person having normal or corrected eye sight does not notice any cracks on the test piece surface.

Fatigue test at an axial load consists in subjecting the test piece to a sinusoidal wave-form, varying cyclically. The test sample stays in the elastic state. Values $F_{up}$ – maximum force, $F_r$ – scope of the force variability and $f$ – frequency of variables are determined in the product standards. The test is carried out till the test piece gets cracked or till the number of cycles without the test piece cracking, specified in the product standard, is achieved.

Innovative brands of construction materials are used more and more frequently both in the machine industry as well as in the building industry [11]. However, an implementation of new reinforcement steel grades, causes a necessity of additional tests of complete reinforced concrete elements. For example, testing a ductility impact of newly produced reinforcing steel on the wall of reinforced concrete elements is presented in [2]. The subject of tests includes reinforced concrete beams of a rectangular cross-section, whose reinforcement, both reinforcement bars as well as clevises are made of two grades of steel:

- newly produced steel S1 of high ductability – $A_{gt} \geq 8\%$, whose mechanical properties are obtained in the process of hot-rolling,
- steel S2, cold-rolled, whose strength properties are obtained through cold work.

Both steel grades are characterized by the strength in the yield point of $R_e$=500 MPa. A diagram of loading test beams is shown in Fig. 8.

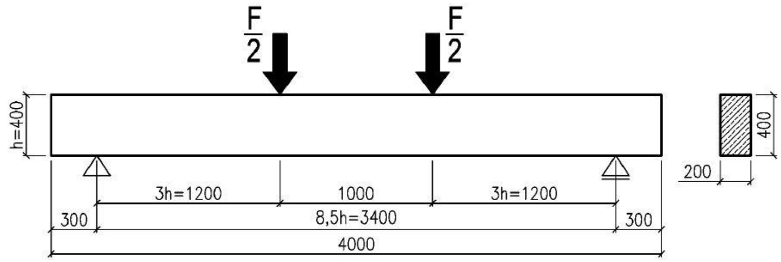


**Fig. 8.** Diagram of loading the test beam [2]

The tests were conducted until the beam damage. The following parameters were recorded: load value – F, beam deflection and a location of cracks crevices. A loss of the beam load-carrying capacity, due to shear, was connected with scratching the compressed zone of the beam cross-section as well as with bending out of clevises and in one case with a rapid break of both crevice arms. The test results confirmed a need of elaborating principles of applying crevices of the S1 steel in beams which can be damaged by shear [2].

The test methodology of adhesion forces of reinforcement bars to concrete in the case of test pieces, coming from the constructions withdrawn from use, are discussed in the work [12]. The tests were oriented onto an impact assessment of corrosion on the bar strength and onto a collection of data enabling an improvement of the method for assessing wear of reinforced concrete constructions.

### 2.3. Tests of composite reinforcement bars

Limited possibilities of using steel in disadvantageous environmental conditions forced a search of alternative solutions for concrete constructions. Among others, a high resistance to corrosion and changeable environmental conditions caused that non-metallic reinforcement mainly composite bars

GFRP (Glass Fiber Reinforced Polymer), BRFP (Basalt Fiber Reinforced Polymer) or CFRP (Carbon Fiber Reinforced Polymer) became an alternative for reinforcement steel [13]. Undoubtful advantages of GFRP bars are: resistance to corrosion, lack of heat, electric and magnetic conduction, a small coefficient of thermal expansion along fibres, an early cuttability and a small density. In comparison with reinforcement bars disadvantages of GFRP bars include: lack of elastic reserve, small strength to shear, Young's modulus - 20÷30% of the Young's modulus of steel. A view of surfaces of exemplary GFRP and BFRP bars are presented in Fig. 9.


**Fig. 9.** View of surfaces of composite bars [8]
a) GFRP bar, b) BFRP bar

Testing of FRP bars is more difficult than testing of steel bars. Due to a small resistance of a composite to transverse forces, it is not possible to fix the composite directly in the MTS machine jaws but it is indispensable to install special anchors. A diagram of the FRP bar test piece, prepared for tests is shown in Fig. 10.

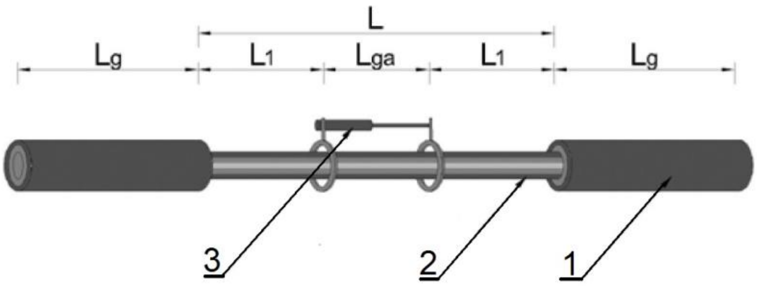


**Fig. 10.** Diagram of a sample prepared for testing [14]
1 – anchor, 2 – FRP, 3 – extensionmeter

Values of characteristic geometric dimensions of the sample, marked in Fig. 10, depend on the applied standard requirements [13].

Although for more than two decades FRP bars have been available on the market in the USA and Canada, so far there have been no verified methods of quality control of their production (QC) [15]. Generally speaking, the tests of FRP bars are related to well-known methods of testing steel bars. Up till the present time, a standard concerning the FRP bars has not been elaborated. However, they can be approved for an application, using technical approvals edited by the Building Research Institute (Instytut Techniki Budowlanej) [16] and the Road and Bridge Research Institute (Instytut Badania Dróg i Mostów) [17, 18]. In scientific investigations, conducted both in Poland [7, 8, 14], as well as abroad [19, 20], the recommendations of the ISO standards 10406 [21] and ACI 440.3R [22], embracing all the

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basic experimental tests, are mainly applied. For example, diagrams of test methods of GFRP bars, included in the American Standard [22] are presented in Fig. 11.

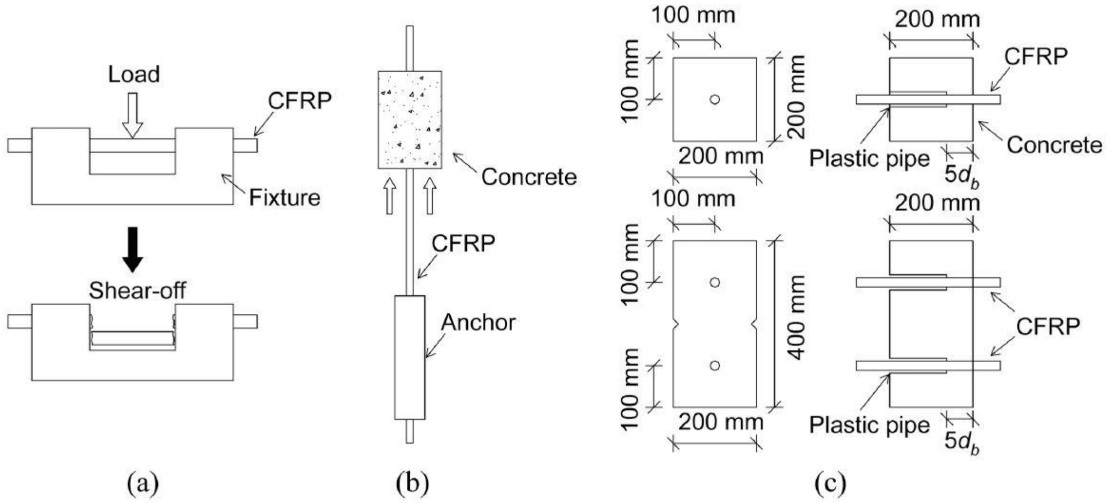


**Fig. 11.** Various test methods [19]
(a) – transverse shear, (b) – pullout, (c) – bond strength

It should be highlighted that mechanical properties, determined during the test, do not refer to a given type of FRP, but to the bar of the nominal diameter under testing. Mechanical properties of the bar depend not only on a content of fibres in the bar resin matrix but also on the method of finishing its surface (single-stranded, cross-stranded plait, mineral powder etc.)

As the results always refer only to the type of bar of a determined diameter subject to testing, so it is indispensable to obtain information from the producer about the strength properties of the applied FRP bar [13] at the stage of designing beam elements reinforced with FRP bars.

## 3. Results

Discussed test examples of reinforcing elements of reinforced concrete beams have been analyzed in the aspect of expanding the scope of tests realized at the KOMAG Laboratory of Tests.

At present in the case of standard tests of steel reinforcement bars, mentioned in [5] and [6], there is a possibility to conduct tests for tension, bending and rebending of a bar. In this scope the Laboratory possesses indispensable testing infrastructure and a realization of tests according to an external client's order is possible without any need for undertaking additional preparatory activities.

There is also a possibility of conducting tests of strength properties of complete reinforced concrete beams. The rig for testing kinematics of powered roof support units can be used for applying external load of the value up to 10 MN, to the beam of the length up to 7.5 m subject to tests. The mentioned test rig has already been used for testing building elements [23].

A commencement of adhesion tests of reinforcement bars to concrete requires separate preparations. It mainly concerns a preparation of anchors for the FRP test piece ends.

Although the tests of composite reinforcement bars [19] are conducted similarly to the tests of steel bars, but a specificity of these tests and lack of the Polish standard concerning the tests of FRP bars cause a necessity of elaborating specific testing procedures by the Laboratory.

## 4. Conclusions

An extension of the scope of services, offered by the Laboratory, including tests for other branches of economy, is usually connected with a need of undertaking a series of activities, both of formal-and-legal character as well as of technical character. In the case of testing bars for reinforcing and

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prestressing concrete structures, discussed in this publication, special additional technical activities are connected with conducting adhesion tests of a reinforcement bar to concrete and with a preparation of test pieces of composite reinforcement bars for tests.

It would be also recommended to start research work oriented onto an elaboration of the Polish standard concerning tests of mechanical properties of composite reinforcement bars.

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