Autoreferat przedstawiający opis dorobku i osiągnięć naukowych – w języku angielskim
Summary of professional accomplishments in the field of research and scientific activities

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Basic terms and their definitions

Reinforcement delamination	Loss of adhesion (delamination) between the composite and the concrete or between the layers of the composite. Delamination occurs through loss of cohesion between the component layers of reinforcement.
FRCM	*Fiber Reinforced Cementitious Matrix* – matrix (mortar) cement (mineral) reinforced with fibers in the form of composite meshes.
FRP	Fibre Reinforced Polymers – Plastic made of fiber-reinforced polymer, such as carbon fibers (CFRP), glass fibers (GFRP), aramid fibers (AFRP) or basalt fibers (BFRP).
Composite	The material formed from two or more different materials in such a way that it has unique and/or better properties in relation to the components taken separately or from a simple summation of their properties. Components are intentionally connected and separable by mechanical methods; they are distributed in a controlled manner in order to give optimum properties for the new materials. The continuous component of the composite is a matrix or warp, filled for example with fibers.
Composite laminate	Finished element in the form of a strip or molding, in which all the bundles of composite fibers are arranged unidirectionally and parallel to the length of the element and are embedded in (usually) a polimer matrix.
Composite mat	Uni- or bidirectional sheet of composite fibers, woven on the polyester matrix, wherein the individual fiber bundles adjacent to each other.
Matrix or warp	Composite filling material; it can be metallic, ceramic or polymer. The matrix binds the fibers in the laminate, transfers the load to the fiber and protects the fiber from damage due to external factors. It combines the composite with reinforced substrate.
PBO-FRCM	Reinforcement system, wherein the cement (mineral) matrix (mortar) is reinforced with a PBO-fiber mesh.
Composite mesh	Bidirectional woven sheet of composite fibers, wherein each fiber bundle are not adjacent to each other.
PBO fibres	*p-Phenylene BenzobisOxazole* - synthetic fibers made of a polymer from the group of polyamides, and more specifically aramids, from which the synthetic fibers are spun. PBO fibers have twice the tensile strength and twice the tensile modulus than Kevlar. PBO fibers are characterized by very high resistance to fire compared to other polymeric fibers.
Mineral mortar	The material formed from a combination of a hydraulic binder obtained from fired and ground minerals (mostly sedimentary rocks), and in this case the cement and filler additives (e.g. fibers). In these materials, after adding water, chemical reactions take place, resulting in the process of setting and hardening.

1. Personal details

Tomasz Trapko, PhD Eng.
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2. Diplomas and academic degrees

1994: construction technician with a specialization in construction, Secondary Technical School of Building at the Jan III Sobieski Building and Electrical School Complex in Świdnica. Diploma project title: "Defensive and fortified structures in Lower Silesia". Project supervisor: Krystyna Kowalonek, MSc. Eng.

1 July 1999: Master of Science, main field of study building construction with a specialization in construction engineering, Faculty of Civil Engineering at the Wroclaw University of Technology. Thesis title: "Technical designs supporting structures of concrete for overhead power lines with a voltage of 30 kV". MSc thesis supervisor: Aleksy Łodo, PhD Eng.

16 February 2005: Doctor of Technical Sciences in the construction of concrete structures, Institute of Building Engineering at the Wroclaw University of Technology. Thesis title: "Load capacity of RC columns strengthening with CFRP strips and wraps". PhD thesis supervisor: Prof. Mieczysław Kamiński, PhD Eng. Peer reviewers: Prof. Maria E. Kamińska, PhD Eng. of Lodz University of Technology and Prof. Jerzy Hoła, PhD Eng. of Wroclaw University of Technology. The research paper was awarded by the Council of the Institute of Civil Engineering at the Wroclaw University of Technology.

3. Employment in research units

Since 1 October 2000, PhD Student at the Faculty of Civil Engineering Wroclaw University of Technology, at the Department of Concrete Structures, Institute of Civil Engineering at the Wroclaw University of Technology.

Since 16 February 2005, Assistant Lecturer at the Department of Concrete Structures, Institute of Civil Engineering at the Wroclaw University of Technology.

Since 1 February 2006, Assistant Professor, at the Department of Concrete Structures, Faculty of Civil Engineering at the Wroclaw University of Technology.

4. Indication of achievements resulting from Article 16 para. 2 of the Act of 14 March 2003 on Academic Degrees and Titles and on Degrees and Title in the Art (Journal of Laws No. 65 item. 595 as amended):

4.1. Scientific achievement title

The basis for applying for the award of the PhD degree is a series of thematically related publications, entitled:

"Reinforcement of selected concrete elements with PBO
fiber mesh based on mineral mortar"

4.2. Thematically related publications included in the scientific achievement

Table 1. List of publications included in the scientific achievement

No.	Author, title, journal, date of issue, volume, page	Points by MS&HE *	*Impact factor*
1	**Trapko T.**: Fibre Reinforced Cementitious Matrix confined concrete elements. Materials & Design. 2013, vol. 44, s. 382-391.	A(2013)= 35	IF(2013)= 3,171
2	**Trapko T.**: Stress-strain model for FRCM confined concrete elements. Composites. Part B: Engineering. 2013, vol. 45, nr 1, s. 1351-1359.	A(2013)= 45	IF(2013)= 2,602
3	**Trapko T.**: The effect of high temperature on the performance of CFRP and FRCM confined concrete elements. Composites. Part B: Engineering. 2013, vol. 54, p. 138-145.	A(2013)= 45	IF(2013)= 2,602
4	**Trapko T.**: Deformability of compressed concrete elements strengthened with FRCM composite materials. The paper from the 59th Scientific Conference of the Committee of Civil Engineering, Polish Academy of Sciences and the PZiTB Lublin – Krynica 2013. Budownictwo i Architektura. 2013, vol. 12, No. 1, p. 163-170.	B(2013)= 3	-
5	**Trapko T.**: Behaviour of fibre reinforced cementitious matrix strengthened concrete columns under eccentricity compression loading. Materials & Design. 2014, vol. 54, p. 947-954.	A(2014)= 35	IF(2014)= 3,501
6	**Trapko T.**: Effect of eccentricity compression loading on the strains of FRCM confined concrete columns. Construction & Building Materials. 2014, vol. 61, p. 97-105.	A(2014)= 40	IF(2014)= 2,296
7	**Trapko T.**: Confined concrete elements with PBO-FRCM composites. Construction & Building Materials. 2014, vol. 73, p. 332-338.	A(2014)= 40	IF(2014)= 2,296
	Total:	**243**	**16,468**

* Ministry of Science and Higher Education.

All papers included in the series of thematically related publications are independent, 100% share.

4.3. Overview of the scientific purpose in submitted publications and their main results

a) Introduction

The reinforcement of building structures is a common term for both classic activities aimed at reinforcement structural components, as well as steps taken to repair them. We deal with the first case, when there is a need to increase the load capacity of the structural elements, due to the increase in the load values in relation to design assumptions. On the other hand, activities aimed at restoring the damaged structural elements to their original load bearing capacity involve their repair. The compatibility of both activities resulted in their classification under a common term – “reinforcing the structure”.

The subject of reinforcing concrete structures using FRP (*Fibre Reinforced Polymers*) composite materials has been of interest for over two decades to many research centers in the world. For more than a decade, the subject has also been present in several Polish universities. It is evidenced by the growing number of publications, appearing in monographs, reputable scientific journals and at thematic conferences. The first laboratory work, engineering applications and computational models related mainly to bent beam elements. Materials used in them were based on *Carbon Fibre Reinforced Polymers* (CFRP), *Glass Fibre Reinforced Polymers* (GFRP) and *Aramid Fibre Reinforced Polymers* (AFRP). In subsequent years, cognitive activities were extended to: external and internal reinforcement of elements subjected to bending, shearing, torsion and compression, reinforcement enhanced with pre-compressed FRP composites, FRP reinforcement of seismically loaded structures, hybrid structures and many others. Simultaneously, with the progress of the research work, algorithms, guidelines and regulations specified by standards are being developed for the design of this type of reinforcements.

Since 2000, I have been dealing with reinforcement of the compressed concrete elements using composite materials. The FRP reinforcement technology was then a novelty in Poland, and one of the research groups dealing with this issue was the team from the Department of Concrete Structures at the Technical University of Lodz. The issue of reinforcing the compressed concrete elements was then little recognized worldwide and was almost non-existent in our country. Over the last several years the issue of reinforcing compressed concrete elements became present and current among researchers in the world, although in Poland it is still overlooked in academic papers.

My thesis was focused on the possibility of using composite fiber strips as external longitudinal reinforcement of concrete columns. In my research, I have applied the system of CFRP strips, where the epoxy resin constitutes a matrix for fibers in the laminate, as well as a bonding layer between the strip and the concrete. In the experimental studies I have analyzed the impact of the intensity of longitudinal reinforcement with CFRP strips on the functioning of model reinforced concrete columns (scale ~1:5), subjected to temporary axial compression. In addition, I have studied reinforced concrete columns in the full scale, subjected to temporary axial and eccentricity compression, for which I have applied one, maximum possible intensity of the longitudinal reinforcement with CFRP strips, resulting from the assumption of the single-layer reinforcement. In these elements, I have used the two types of lateral reinforcement – in the form of clamps made of the CFRP sheet or in the form of the single, complete wrapping in the CFRP sheet. In turn, in theoretical analyzes I have suggested the relationship to the determination of the load-bearing capacity of the axially compressed, stocky reinforced concrete columns, reinforced with carbon fiber strips. In the summary of the thesis I have defined – according to me – the most important directions for further research, which greatly expand the subjects included in the doctorate. A detailed description of my scientific and research achievements, prior to obtaining a PhD degree, is presented in section 5.1. of the summary of professional accomplishments.

After obtaining a doctor‘s degree, I expanded my research on the effects of the intensity of longitudinal reinforcement with CFRP strips on the load-bearing capacity and deformability of reinforced concrete columns subjected to temporary axial and eccentricity loads. This research was performed on full-scale columns, for which I applied three levels of the intensity of the longitudinal reinforcement and single, complete wrapping in the CFRP sheet. I also undertook research activities to determine and evaluate the rheological parameters of concrete reinforced with CFRP strips and mats. I also took up new study on the impact of repeatedly variable load on the functioning of concrete and reinforced concrete elements, strengthened with composite materials. In addition, I became interested in the subject of technical condition assessment, diagnosis of causes of damage and repair of concrete structures. Currently, together with Dorota Urbańska, MSc. Eng., a PhD Student at the Department of Concrete Structures, Faculty of Civil Engineering at the Wroclaw University of Technology, I have been researching concrete beams reinforced to shearing by means of composite materials. The purpose of these studies is to evaluate the contribution of composite reinforcement in the load bearing capacity to shearing, depending on the method of its construction and anchorage. A detailed description of my scientific and research achievements, after obtaining a PhD degree, is presented in section 5.2. of the summary of professional accomplishments.

After obtaining a PhD degree, the studies of composite reinforcements to the effects of high temperatures became a new area of my interest. I got particularly interested in this subject when I carried two research projects (for the Committee for Scientific Research, and the Vice-President for Research and Cooperation with the Economy at the Wroclaw University of Technology) concerning the study of rheological features of concrete elements reinforced with external CFRP composite reinforcement.

As we know, in the FRP systems, regardless of the type of fibers used, epoxy resin (matrix) is the crucial element for the stability and efficiency of reinforcement. Both, in the system that uses carbon fibers (CFRP), glass fibers (GFRP) and aramid fibers (AFRP), the composite is combined with concrete using epoxy resins. As it has been shown in many studies (including my own [18, 23 in Z6]), the parameter deciding about the reinforcement efficiency is the glass transition temperature T_g at which the reinforced element is being used. The limit temperature for the FRP systems is the glass transition temperature for epoxy resin, after which the adhesive loses its properties. Under the increasing temperature, the elastic properties of the elements [23, 34 in Z6] are further enhanced, but beyond the glass transition temperature the resin undergoes structural changes that are irreversible, even after it has cooled. The values of resin glass transition temperature T_g are given by the manufacturers in their technical data sheets for FRP systems, and – as I have observed over the years in successive editions of these sheets – they are reduced by several more degrees. Eliminating this problem is possible in two ways: first, by applying thermal protection on reinforced elements, which is also of interest in the literature, or by eliminating the resin as a binder that combines the composite with the concrete.

I have addressed this second solution, namely the elimination of the resin, as a binder that combines the composite with the concrete. Hence my interest in the FRCM (*Fiber Reinforced Cementitious Matrix*) system, which was created in order to eliminate the main disadvantage of epoxy resin, which is its poor thermal compatibility with concrete. In the case of the FRCM system, we are dealing with a different approach to reinforcement than in the FRP systems. In the *Fibre Reinforced Polymers,* the finished laminate in which the fibers are embedded in an epoxy resin, is attached to the concrete also by means of epoxy resin. In this system, the laminate can also be made directly during the application of the reinforcement by simultaneous wetting and attaching slender composite mats to the concrete using epoxy resin. Hence the name *Fibre Reinforced Polymers*. In turn, in the *Fibre Reinforced Cementitious Matrix,* the mineral mortar, which is applied to the reinforced element, is reinforced with fibers. Thanks to its structure, the mortar, is combined with the fibers and ensures adhesion of the composite to the concrete. It must be remembered that we are not dealing here with a stiff laminate, as is the case with FRP reinforcement, but with the layer of mineral mortar filled with fibers. Because of the granularity of the mortar, it is unable to adequately fill the fiber and ensure such good adhesion to the concrete, as is the case with epoxy resins. Therefore, mats were replaced with mesh, which has appropriate loops and mortar can penetrate into individual fibers, ensuring their good connection with the concrete.

b) Subject, purpose and scope of thematically related series of publications

The subject of the submitted thematically related series of publications are the results of the experimental and theoretical studies of selected concrete elements, reinforced with **PBO fiber mesh** (*p-Phenylene BenzobisOxazole*), commonly known as **PBO mesh**, combined with the concrete using mineral mortar. In literature, the symbol of this system is **PBO-FRCM**. In my studies, I focused on concrete and reinforced concrete elements, model elements as well as full scale elements. Experimental work was implemented in four stages, where elements having different construction of the transversal and longitudinal reinforcement, were subjected to temporary monotonic axial and eccentricity compression. Research programs in subsequent stages, were developed based on the experience I have gained implementing the earlier stages of research.

The scientific purposes of the study and analysis included:

1. assessment of the possibilities of using the PBO mesh based on mineral mortar to reinforce compressed concrete elements, both in the neutral temperature, which is assumed as the temperature of + 20°C, as well as in high-temperature conditions,
2. impact assessment: the intensity of transverse reinforcement with PBO mesh (the number of reinforcement layers), the method of formation of the transverse reinforcement using the PBO mesh (the length of the final overlapping zone), simultaneous longitudinal and transverse reinforcement using the PBO mesh to load bearing capacity and deformability of the axially and eccentrically compressed concrete elements and reinforced concrete elements,
3. replying the question of whether the longitudinal and transverse reinforcement using the PBO mesh interacts with concrete and steel in the transfer of compressive stress and tensile stress in the compressed concrete and reinforced concrete elements,
4. creating a mathematical description of the behavior of compressed concrete elements reinforced with an outer PBO mesh shell.

At every stage of the research, I reviewed the state of the art. It was referring mainly to the description of the behavior of the reinforced elements in the FRP systems, because the literature lacks publications dedicated to reinforcement of the compressed concrete elements using the PBO mesh. Along with the knowledge acquired by me, the first external publications began to appear, whose authors dealt with similar subjects, although it is still only a few articles.

In a series of seven thematically related publications [32-37, 41 in Z6] entitled: **"Reinforcement of selected concrete elements with PBO fiber mesh based on mineral mortar",** I have presented experimental studies that verify theoretical assumptions and reflect the actual behavior of the compressed reinforced concrete elements in the PBO-FRCM system, under the influence of temporary, monotonic axial and eccentricity load. I have carried out experimental analyses of the impact of these parameters for scientific purposes on the load-bearing capacity and deformability of the test pieces. Based on my own research findings, I have proposed a mathematical model to calculate the strength of concrete confined with the PBO mesh and I have verified that.

In the first three publications [32, 33, 34 in Z6], I have presented tests and comparative analyses, both in samples reinforced with the CFRP sheet, and with the PBO mesh. These tests were conducted in a neutral temperature of +20°C, as well as in conditions of high temperatures: +40°C, +60°C, +80°C, +120°C and +180°C. The paper [35 in Z6] is the result of the observations made from the previous stages of the tests described in [32, 33 and 34 in Z6]. It focuses on the issue of the impact of length and load-bearing capacity of the final overlapping zone of the composite on the value and distribution of the peripheral limit strain. After a series of tests on samples of concrete, I decided to test the PBO-FRCM system on full-scale columns, which were subjected to the temporary axial and eccentricity compression. The publication [36 Z6] is dedicated to the analysis of the limit load-bearing capacity and the description of the mechanisms of column destruction. I have also presented measurements of horizontal displacements of columns that show the tendency of these elements to plastic strain. In turn, the publication [37 in Z6] presents an analysis of the deformability of the columns compressed eccentrically, reinforced in the PBO-FRCM system. The publication [41 in Z6] is a summary of the current knowledge of the reinforcement of selected concrete elements with the PBO mesh based on mineral mortar, gained by me on the basis of experimental research. I have rated the efficiency of the reinforcement and the behavior of the reinforced elements. I have compared the impact of the intensity and manner of constructing the reinforcement on functional efficiency of the compressed elements. I have based my analyses, both on my own research results, as well as on the results available in the literature studies by *Ombres* performed at the University of Calabria and *Colajanni* with a team from the University of Messina in Italy.

c) Overview of the achieved results

The advantages of wrapping the concrete with the CFRP outer shell are well-known. However, when introducing a new reinforcement system, it was necessary to assess the effectiveness of the reinforcement and compare the behavior of the elements confined in the CFRP sheet and the PBO mesh. The benefits that are to be obtained from the application of the PBO-FRCM system required testing it under adverse temperature conditions. However, to understand the material that I was dealing with, I first assessed the impact of the number of the layers of the transverse reinforcement with the CFRP sheet and the PBO mesh, without exposure the samples to high temperatures. Next, the cylindrical elements (ϕ113x300 mm) with one layer of the transverse reinforcement with the CFRP sheet and the PBO mesh were subjected (prior to the destructive test) to high temperatures: +60°C, +120°C and +180°C, and the very test took place after cooling the samples (Figs. 1 and 2).

Fig. 1. Element reinforced with one layer of CFRP sheets on the test bench [32 in Z6]

Fig. 2. Element reinforced with one layer of PBO mesh on the test bench [32 in Z6]

As expected, the CFRP system produced noticeable effect of number of the mat layers circumscribing the section on the increase in the load-bearing capacity (Fig. 3). The thickness of the composite coat and the type of fibers applied affect the measured limit load-bearing capacities. When applying one layer of the CFRP sheet, I have obtained the similar value of the failure load to the one with the application of the three layers of the PBO mesh. In the case of the elements subjected (prior to the destructive test) to high temperatures: +60°C, +120°C and +180°C, I have not found the essential impact of exposure to the recorded load-bearing capacity (Fig. 4).

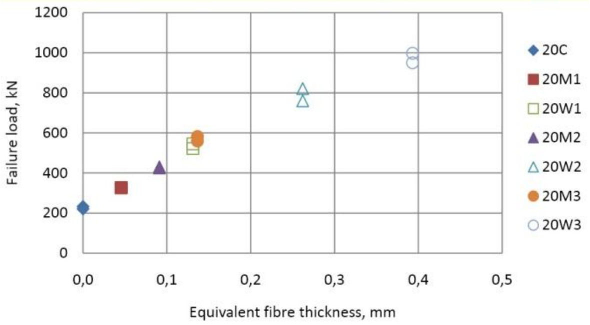


Fig. 3. Limit load-bearing capacity (failure load) elements without prior exposure to temperature [32 in Z6]

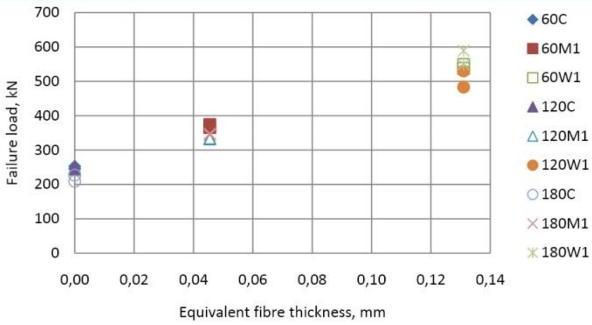


Fig. 4. Limit load-bearing capacity (failure load) elements with initial exposure to temperature [32 in Z6]

Designations: *TWi*: *T* – temperature of the initial exposure, W – CFRP sheet, *i* – number of mat layers
*T*M*i*: *T* – temperature of the initial exposure, M – PBO mesh, *i* – number of mat layers
*T*C: *T* – temperature of the initial exposure, C – reference sample without reinforcement

Table. 2. Technical parameters of the PBO mesh and CFRP sheet [32 in Z6]

No.	Fiber type	Tensile strength	Modulus of elasticity	Strain at break	Density	Fiber thickness
		[MPa]	[GPa]	[%]	$[g/cm^3]$	[mm]
1	PBO	5270 (a)/5800 (b)	270	2,15	1.56	0.0455
2	CFRP	2670 (a, c)/4300 (b, d)	238	1,80	1.76	0.1310

(a) as per own research; (b) as per manufacturer's data; (c) data for laminate; (d) data for fibers

The comparison of tensile strength of the fibers in the PBO mesh and CFRP sheet (Table 2) suggests that the PBO-FRCM system should give even better reinforcement results. However, as I have demonstrated in my studies, greater tensile strength of the PBO mesh does not translate directly into greater increase in load-bearing capacity and the value of the compressive strain. It is caused by the aforementioned graininess of the mortar and filling the composite with it as well as adhesion to concrete and between its layers.

From the destruction mechanism (Figs. 5 and 6), to the nature of the paths of strain (Figs. 7 and 8), to the limit values of load-bearing capacity and strain, research has shown that these two systems cannot be compared to each other at the same intensity of reinforcement (number of layers). All elements reinforced with the CFRP sheet were destroyed in a violent manner, by breaking the shell. The mechanism of destruction of the elements reinforced with the PBO mesh was quite different. None of the attempts resulted in breaking the fiber and the initiation of destruction always occurred on the external overlapping zone.

Fig. 5. Image of destruction of the element reinforced with one layer of CFRP sheet [32 in Z6]

Fig. 6. Image of destruction of the element reinforced with two layers of PBO mesh [32 in Z6]

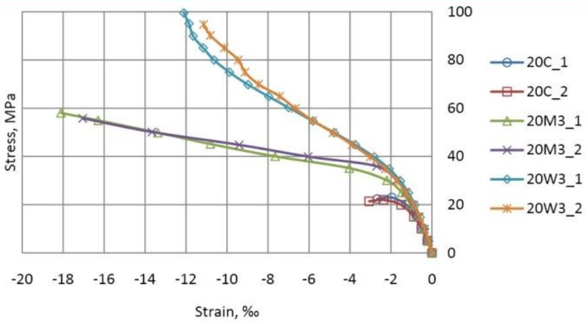


Fig. 7. Example σ-ε relationship of the elements without the initial exposure to temperature and reinforced with three layers of the composite [32 in Z6]

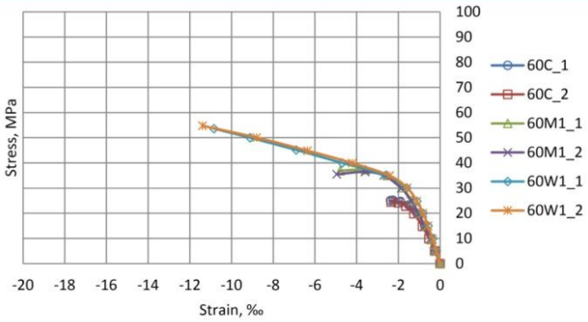


Fig. 8. Example σ-ε relationship of the elements with the initial exposure to temperature and reinforced with one layer of the composite [32 in Z6]

Designations: *T*W*i_j*: *T* – temperature of the initial exposure, W – CFRP sheet, *i* – number of mat layers, *j* – sample number
*T*M*i_j*: *T* – temperature of the initial exposure, M – PBO mesh, *i* – number of mat layers, *j* – sample number
*T*C_*j*: *T* – temperature of the initial exposure, C – reference sample without reinforcement, *j* – sample number

The best results of using an external wrapping were obtained with single reinforcement (Fig. 9). Along with an increase of reinforcement intensity (number of layers) the efficient use of another layer of reinforcement decreases.

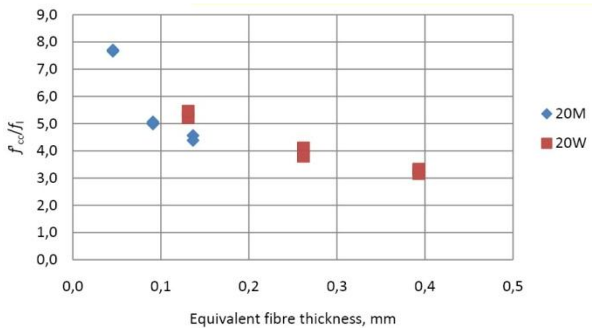


Fig. 9. f'_{cc}/f_l relationship depending on the equivalent fiber thickness [32 in Z6]
Designation: 20 – test temperature, M – PBO mesh, W – CFRP sheet

Undoubtedly, the PBO-FRCM system is competitive with the CFRP system. The nature of functioning of the elements reinforced with the PBO mesh is more predictable to use in more complex structural systems rather than separate compressed elements. The indicated and slow increase in strains in the area of the destructive load allows the redistribution of the internal forces and joining of other, less stressed elements.

The paper that starts a series of thematically related publications, where I have described the first results of the experiments on the elements confined with the PBO mesh, compared with elements confined with the CFRP sheet, is an article in the Materials & Design entitled: "Fibre Reinforced Cementitious Matrix confined concrete elements [32 in Z6]. The article was published in 2013 and it is the world's first publication that presents the use of the PBO mesh based on mineral mortar as a concrete winding. The article has 11 references according to the *Web of Science* database (including 7 external references), 12 references according to the *Scopus* database (including 7 external references) and 15 references by the *Publish or Perish* (including 9 external references).

Another natural question arising on the basis of the previously carried-out research was how the samples behaved when exposed to high temperature and examined at these temperatures. I have reinforced concrete cylindrical samples (ϕ113x300 mm) in two groups: two layers of CFRP sheets or two layers of PBO mesh. I subjected them to high temperatures: +40°C, +60°C, +80°C, for 24 hours. Immediately after removing the samples from the climatic test chamber, they were loaded to failure. Before, during and after testing the elements, I took infrared temperature measurements.

For samples reinforced with the CFRP sheet, along with temperature increase, there was a marked decline in failure stress. In turn, for samples reinforced with the PBO mesh the effect of high temperatures was no so clearly visible (Fig. 10). Based on the analysis of own and external research, I have found that at high temperatures, not exceeding the glass transition temperature T_g for resin, it underwent the plasticizing process without losing its adhesive properties. With the increase in temperature, the modulus of elasticity of the resin decreases and the stiffness of the composite shell reduces. The CFRP shell becomes more deformable and capable of carrying a much greater stress (Figs. 11 and 12). A similar effect was observed in previous studies that served as the genesis for a series of thematically related publications [18, 23 in Z6]. The positive trend fades in temperatures well above the glass transition temperature, when the degradation of the matrix occurs.

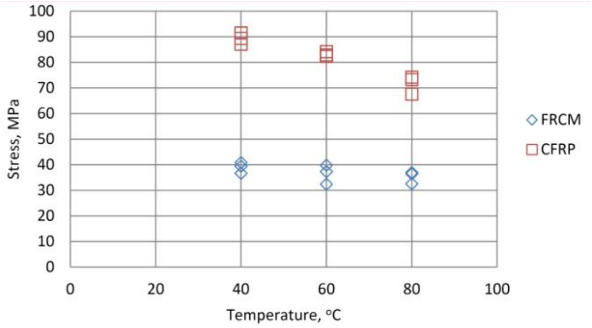


Fig. 10. Stress of reinforced elements in relation to the sample temperature [34 in Z6]

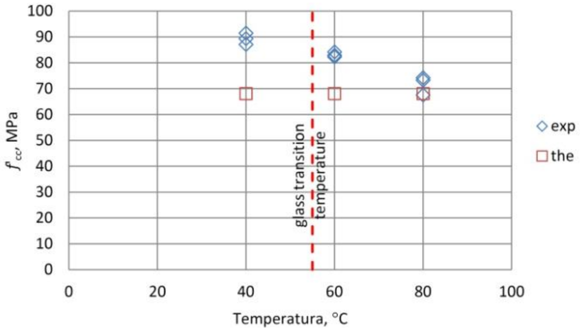


Fig. 11. Experimental and theoretical strength of concrete in a triaxial stress state f'_{cc} depending on the temperature - own research [34 in Z6]

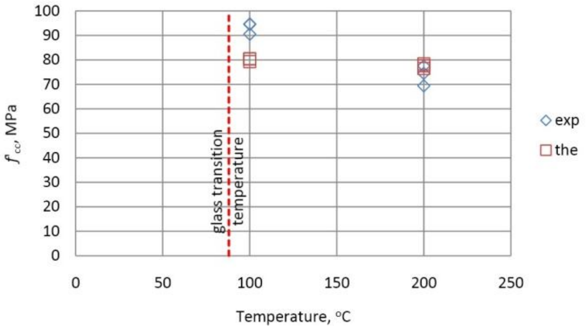


Fig. 12. Experimental and theoretical strength of concrete in a triaxial stress state f'_{cc} depending on the temperature - *Al-Salloum* research [34 in Z6]

Composite fibers, oriented perpendicular to the generating line of the cylinder, shrink under the influence of high temperatures, ($\varepsilon_{\Delta T}$), exerting further pressure on the concrete core. In turn, the concrete core and the matrix, under the same temperature expand, exerting additional transverse stresses ($f_{l\Delta T}$). This interaction results in additional reinforcement of the cross-section, which is similar to the idea of the transverse compression of the element (Fig. 13).

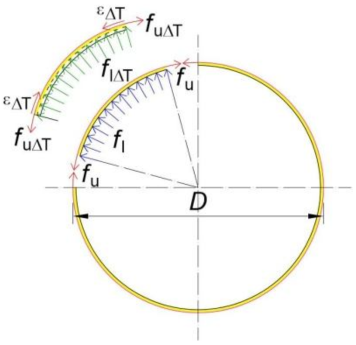


Fig. 13. An additional effect of reinforcement [34 in Z6]

The increase in the stress and compressive strain are clearly visible in the tests (Figs. 14 and 15). However, it should be noted that this is accurate only in temperatures below the glass transition temperature $T < T_g$ of the matrix.

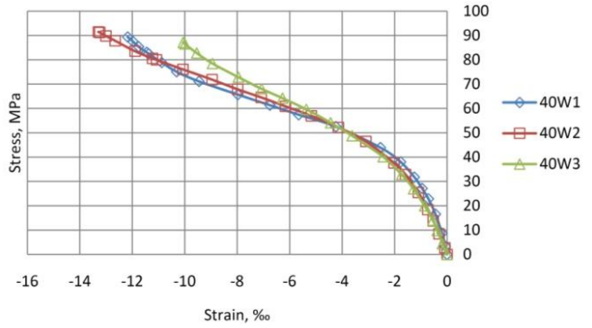


Fig. 14. The σ-ε relationship of elements reinforced with two layers of CFRP sheets, tested at a temperature of 40°C - own research [34 in Z6]

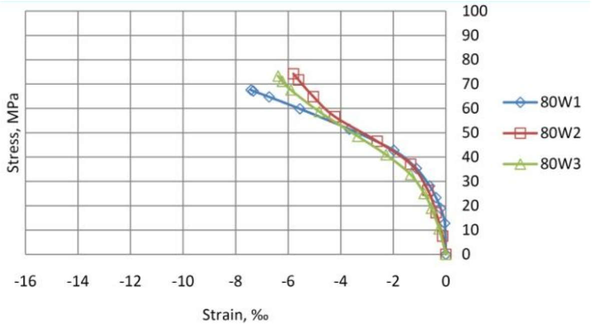


Fig. 15. The σ-ε relationship of elements reinforced with two layers of CFRP sheets, tested at a temperature of 80°C - own research [34 in Z6]

Designation: *TWj*: *T* – test temperature, W – CFRP sheet, *j* – sample number

The results of testing samples subjected to high temperatures and studied at these temperatures is described in an article in Composites. Part B: Engineering, entitled: "The effect of high temperature on the performance of CFRP and FRCM confined concrete elements" [34 in Z6]. The article has 6 references according to the *Web of Science* database (including 3 external references), 7 references according to the *Scopus* database (including 3 external references), and 8 references according to the *Publish or Perish* database (including 4 external references).

Confining the concrete with outer composite winding (in this case, the PBO mesh or the CFRP sheet combined to the concrete using a suitable binder) results in the increase of its strength. This depends on the number of reinforcement layers, the composite tensile strength and the cross-sectional shape of the element. Confining the concrete with transverse winding makes the concrete core is in a complex state of stress, which translates directly into an increase in the strength of the concrete.

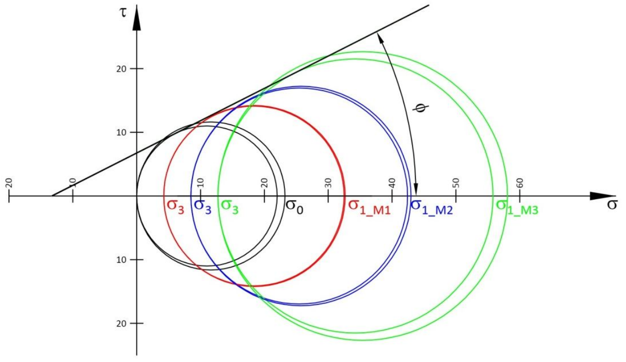


Fig. 16. The envelope of the Mohr's limit stress circles of the 20M elements [33 in Z6]
Designations: M*i*: M – PBO mesh, *i* - the number of mesh layers

Based on the acquired knowledge, I have proposed a calculation model based on the *Coulomb – Mohr* theory, in which the state of stress in the destruction phase can be represented by the limit stress circles that have a common envelope – a limiting curve. With experimental data, I determined limit stress circle for all types of elements described in [32, 34 in the Z6] and on the basis of their envelope I chose the appropriate Mohr's limiting curves and set their inclination angles ϕ to the longitudinal axis σ (Fig. 16).

The compression strength of concrete in the triaxial stress state f'_{cc} (σ_1) is the sum of the cylindrical compressive strength of concrete in the uniaxial stress state f'_{co} (σ_0) and the product of the transverse stresses occurring at the interface between the concrete and the winding f_l (σ_2=σ_3 for the round cross-section) and of the concrete reinforcement coefficient k_1. I have determined the values of coefficients k_1 on the basis of the inclination angles ϕ and the relationship between stresses in the spatial stress state in the wound cylindrical element:

$$\sigma_1 = \sigma_0 + k_1\sigma_3, \tag{1}$$

$$f'_{cc} = f'_{co} + k_1 f_l. \tag{2}$$

The f_l stress depends on the diameter of the wound core D, tensile strength of the composite f_u and the thickness t of the composite shell. Through the determination of the transverse stress at the interface between the concrete and the outer winding f_l (3) it is assumed that the maximum stress in the composite reaches the value of its tensile strength f_u. This assumption is valid only for round cross-sections, and for polygonal cross-sections with rounded corners a different approach is required, which takes into account the stress concentration on the winding bends.

$$f_l = \frac{2 \cdot t \cdot f_u}{D} = 2 \cdot \rho_f \cdot f_u. \tag{3}$$

I have determined the coefficients k_1 of concrete reinforcement for both the elements without exposure to temperatures, as well as those subjected (before a destructive test) to temperatures: +60°C, +120°C and +180°C and tested at temperatures of +40°C, +60°C, +80°C. In Figure 17 I have presented the limiting curve for the elements measured at + 20°C, reinforced with the PBO mesh and the CFRP sheet. In turn, in Figure 18 I have shown the limiting curve for different elements subjected to high-temperature and tested immediately after removal from the climatic test chamber. Finally, I have proposed the reinforcement coefficient k_1= 2.5 for elements reinforced with the PBO mesh, regardless of the temperature and for the elements reinforced with the CFRP sheet operating in normal conditions at +20°C, even if they have been previously exposed to high temperatures. For elements reinforced with the CFRP sheet subjected to continuous exposure to high temperatures, but not exceeding significantly the glass transition temperature T_g of the matrix, I suggest the coefficient k_1 = 3.5. I have compared the concrete strength in the triaxial stress state f'_{cc} obtained from theoretical calculations for the adopted reinforcement coefficients k_1 , with the experimental values and the coefficient of determination – i.e. model match – is R^2=0.97.

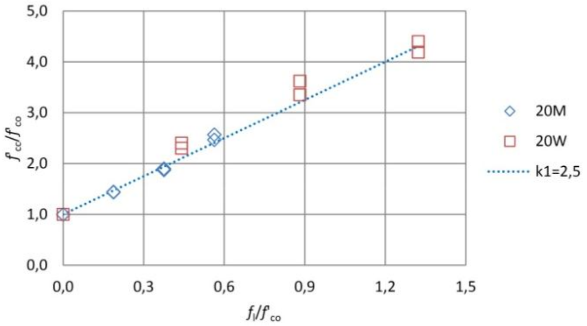


Fig. 17. The strength of concrete in the triaxial stress state f'_{cc} in relation to the stresses f_l for elements without exposure to high temperature [33 in Z6]

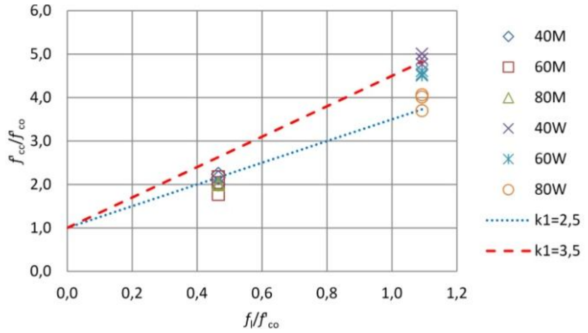


Fig. 18. The strength of concrete in the triaxial stress state f'_{cc} in relation to the stresses f_l for elements exposed to high temperature [34 in Z6]

Designations: *T*M or *T*W: *T* – test temperature, M – PBO mesh, W – CFRP sheet

In the paper [34 in Z6] I have presented the relationship of the value of the coefficient of discontinuity to the reinforcement k_e, which takes into account a possible discontinuity of the transverse discontinuity, along the side surface of the cylindrical element, through the use of composite clamps.

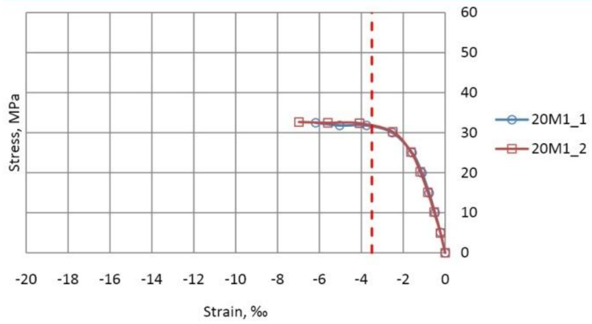


Fig. 19. σ-ε relationship of the 20M1 elements [32 in Z6]

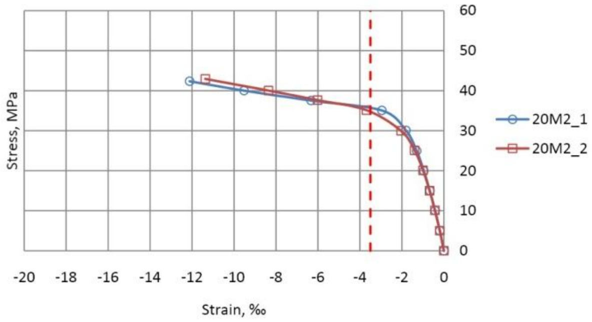


Fig. 20. σ-ε relationship of the 20M1 elements [32 in Z6]

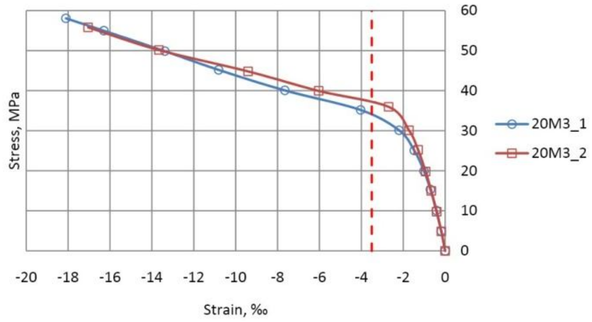


Fig. 21. σ-ε relationship of the 20M1 elements [32 in Z6]

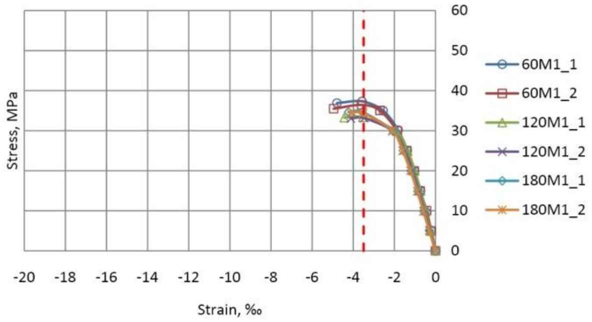


Fig. 22. σ-ε relationship of the 60M1, 120M1 and 180M1 elements [32 in Z6]

Designations: *T*M*i*_*j*: *T* – temperature of the initial exposure, M – PBO mesh, *i* – the number of mesh layers, *j* – sample number

When analyzing the paths of strain of the elements reinforced with the PBO mesh, I have noticed that regardless of the intensity of the transverse reinforcement, initial exposure temperature or test temperature, the change in the curve σ-ε occurs at strains equal to approx. 3.5 ‰. I called this value "critical strains ε_k". The limit of the critical strains ε_k is marked in figures 19-22 with a dotted line. The observed reinforcement of the element, at the effort corresponding to the critical strains should be explained by the full integration of the composite winding. In the first phase, the utilization of the composite winding is relatively small; after the first stage of the element’s operation, full integration of the PBO mesh occurs (Figs. 19-21). For elements with an initial thermal treatment, it may be noted that the change in the course of the compression curves occurs at critical strains equal to approx. ε_k=3.5 ‰ and it does not depend on temperature. Critical strains are matched by maximum compressive stress $\sigma_k=\sigma_{max}$, upon reaching which the load-bearing capacity is exhausted (Fig. 22).

On this basis, I have proposed a description of the σ-ε relationship of the elements reinforced with the PBO mesh (Fig. 23). The proposed σ-ε calculation model for the concrete wound with the PBO fibrous composites based on mineral mortar corresponds to the results obtained in the experiment. I have obtained satisfactory compatibility of both the theoretical model for the calculation of the strength of concrete in the triaxial stress state f'_{cc} and the forecast of the course and state of strain. In Figure 24, I have presented a comparison of the compression curves σ-ε of the samples selected from the experiments without exposure to temperature (solid lines) in comparison with the theoretical paths determined from the relationships (4) and (5) (dashed lines).

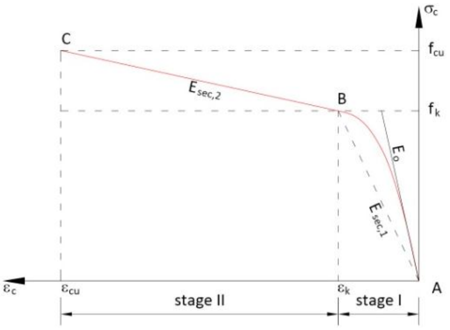


Fig. 23. σ-ε relationship of the elements reinforced with PBO mesh [33 in Z6]

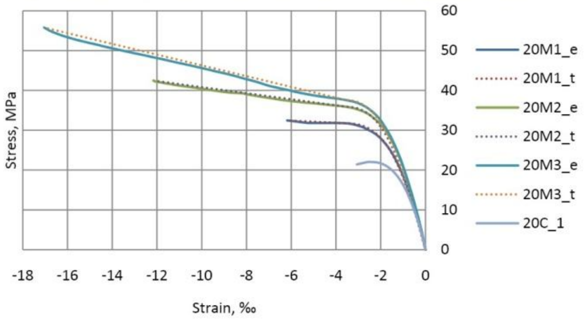


Fig. 24. Comparison of σ-ε relationship of the 20M elements [33 in Z6]

$$\begin{cases} f_c = \dfrac{f'_{co} \cdot x \cdot r}{r-1+x^r} \rightarrow \text{if } 0 \le \varepsilon_{cc} \le \varepsilon_k, & (4) \\ f_c = f'_{co} + E_{sec,2} \cdot (\varepsilon_c - \varepsilon_{co}) \rightarrow \text{if } \varepsilon_{cc} > \varepsilon_k. & (5) \end{cases}$$

$$x = \frac{\varepsilon_c}{\varepsilon_{co}}, \tag{6}$$

$$r = \frac{E_o}{E_o - E_{sec,1}}, \tag{7}$$

$$E_o = 2700 \cdot (f'_{co})^{1/3}, \tag{8}$$

$$E_{sec,1} = \frac{f_k}{\varepsilon_k}, \tag{9}$$

$$E_{sec,2} = \frac{f'_{cc} - f'_{co}}{\varepsilon_{cc} - \varepsilon_{co}}. \tag{10}$$

E_0, f'_{co} and ε_{co} – respectively: modulus of elasticity, maximum stress and strain of concrete in uniaxial stress state,
f'_{cc} and ε_{cc} – respectively: maximum stress and strain of concrete in triaxial stress state,
E_{sec} – secant modulus of elasticity of the reinforced concrete.

I have described the proposed calculation model in an article in Composites. Part B: Engineering entitled: "Stress-strain model for confined concrete elements FRCM" [33 in Z6]. The article has 5 references according to the *Web of Science* database (including 1 external reference), 6 references according to the *Scopus* database (including 2 external references) and 8 references according to the *Publish or Perish* database (including 2 references).

A very interesting issue is the transverse deformability of the element confined with the PBO mesh. As I have mentioned before, concrete failure model in the external PBO shell is always initiated by the delamination of the mesh connection on the outer overlapping zone (Fig. 6). This type of destruction is classified in the group, for which the matrix is responsible and it is called *seam debond*.

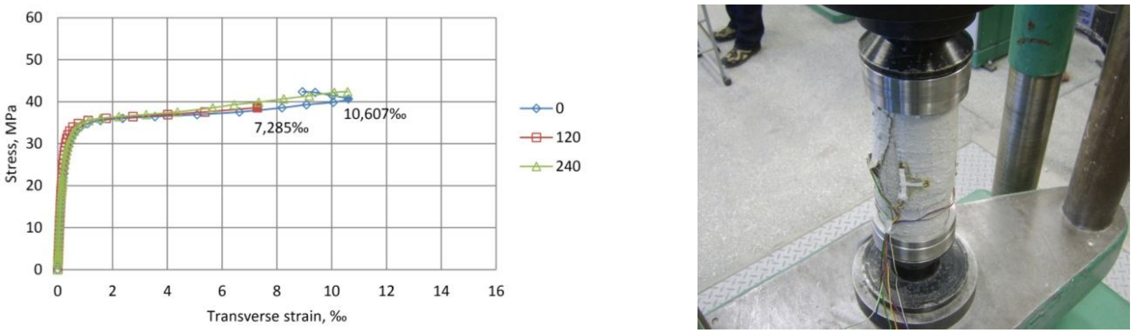


Fig. 25. Paths of transverse strains as a function of the load and the image destruction of the 20M2_1 element [35 in Z6]

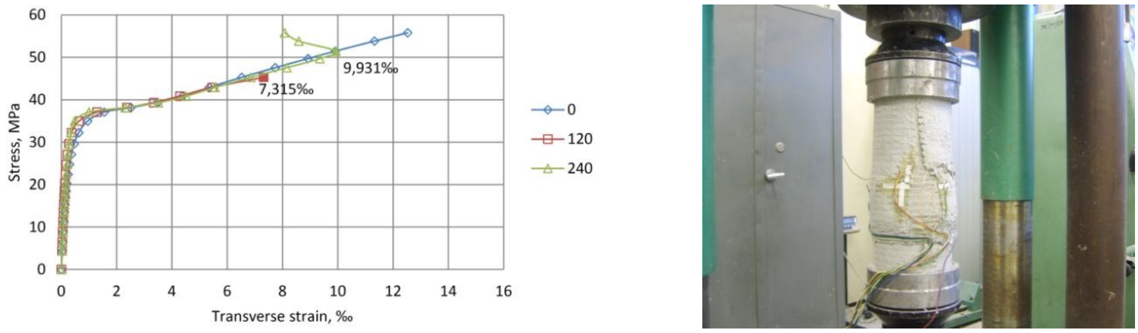


Fig. 26. Paths of transverse strains as a function of the load and the image destruction of the 20M3_2 element [35 in Z6]

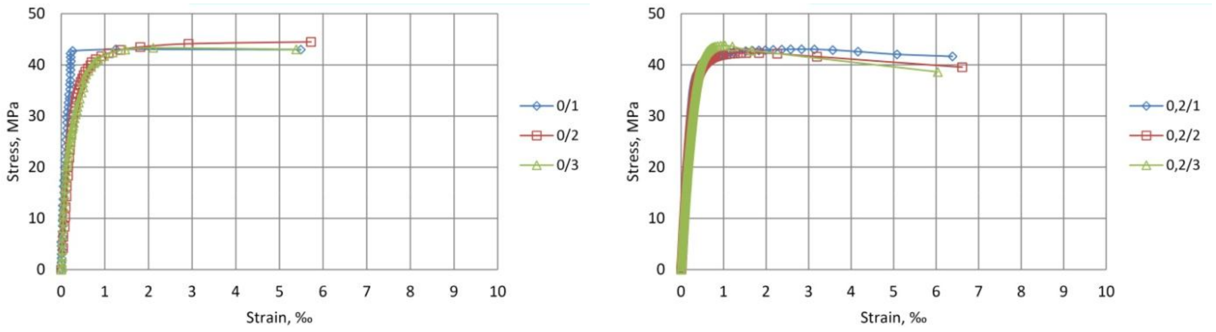
Designations: *T*M*i*_*j*: *T* – temperature of the initial exposure, M – PBO mesh, *i* – the number of mesh layers, *j* – sample number

With the arrangement of strain gauges at 120° around the periphery of the PBO-FRCM sample, I have managed to register the level of strains initiating the delamination of the mesh. In Figures 25 and 26, I have presented the transverse strains of the elements as a function of stresses for strain gauges at positions: 0˚, 120˚ and 240˚. The destruction of the elements reinforced with the PBO mesh always began with the external overlapping zone of the mesh, where a slip between the layers of composite and the delamination of the composite jacket occurred. By attaching horizontal strain gauges on the overlapping zone, I managed to register the moment of breaking the connection and the values of strain at which this occurs – approx. 7.3‰. In these elements (20M2 and 20M3), I applied the overlapping zone z = 70 mm, where

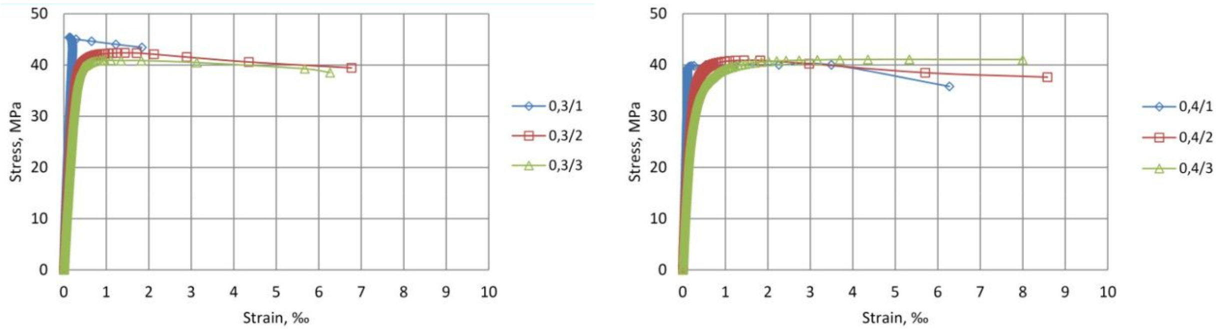
z/u= 0.2 (u – perimeter of the sample). The relationship of maximum and medium peripheral strains is 0.77-0.99. It is the lowest for the single reinforcement and it increases along with the increase in mesh layers.

The observation of the mechanisms of destruction in the previous studies prompted me to look into the impact of the length of the final overlapping zone of the PBO mesh on the limit value of the net transverse strains. For this purpose, I have carried out tests, in which cylindrical samples (ϕ113x300 mm) were reinforced with one layer of PBO mesh having different lengths of the final overlapping zone. The relative overlapping zone of applied as the relationship of the length of the overlapping zone to the periphery of the sample (z/u) = 0÷0.4.

The value of the limit peripheral strains depends essentially on the length of the overlapping zone (Fig. 27) and the factors that determine delamination are the smallest strains at the length of the overlapping zone. At the same time, it should be noted that the distribution of the strains along the length of the composite overlapping zone is non-linear, as shown in the MES analysis presented in the third-party literature. Along with the increase of the overlapping zone, delamination strains (Fig. 27) increase. The coefficient of utilization of the PBO mesh in the end zone of the overlapping zone is within the range of 0.28-0.44, depending on its length. At the same time, by analyzing the strains of the transverse outside the overlapping zone (Figs. 25 and 26), it can be seen that the coefficient of utilization of the PBO mesh is 0.55-0.80.



a) elements z/u=0 b) elements z/u=0,2



c) elements z/u=0,3 d) elements z/u=0,4

Fig. 27. Paths of transverse strains as a function of the load depending on the relative length of the overlapping zone [35 in Z6]

The analyses of transverse strain pattern in the elements confined with the PBO mesh were presented by me at the 59th Scientific Conference of the Committee of Civil Engineering, Polish

Academy of Sciences, and the PZiTB Lublin - Krynica 2013. The paper was published in conference materials in an article entitled: “Deformability of compressed concrete elements strengthened with FRCM composite materials” in the journal Budownictwo i Architektura [35 in Z6]. The article has 2 references according to the *Publish or Perish* database (including 0 external references).

Testing of concrete samples, confined with the composite shell of the PBO mesh showed high plasticity and a signaled and slow increase in strains in the area of the destructive load, which allows redistribution of internal forces in complex structural systems, e.g. with eccentrically compressed columns. After a series of tests on model elements, drawing on knowledge and experience gained, I have decided to test the PBO-FRCM system on reinforced eccentrically compressed full- scale concrete columns (Fig. 28).

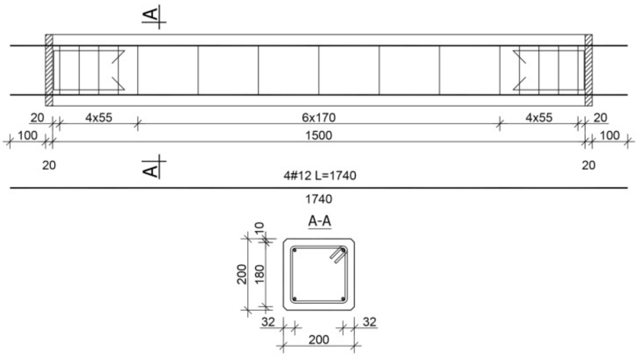


Fig. 28. Column reinforcement [36 in Z6]

Fig. 29. Element on the 32 mm eccentricity ($h/6$) at the test bench [36 in Z6]

I have analyzed the effect of eccentricity loads and the method of reinforcement the PBO mesh on the behavior of reinforced concrete columns. I have implemented three positions of the longitudinal load – axial load, $h/12$ and $h/6$ (h – dimension of the cross-section). I have tested 15 slender reinforced concrete columns (Fig. 28), 12 of which had been previously reinforced with the PBO mesh (Fig. 29). I have divided the columns into three groups depending on the value of eccentricity. In each group, there were five columns differing in their reinforcement. The two elements were reinforced, respectively: with one or two layers of transverse PBO mesh. The next two elements were reinforced longitudinally with one layer of mesh (in bending plane), and also transversely, respectively: with one or two layers. One column in each group was left out, as a reference without reinforcement.

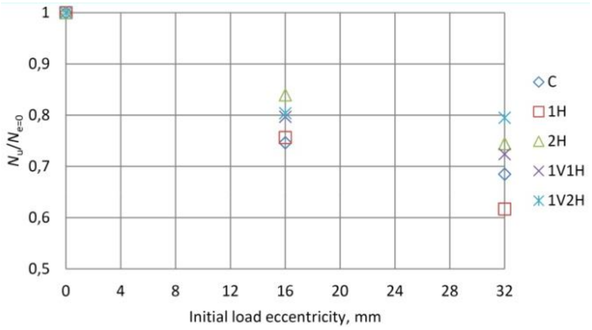


Fig. 30. Relative increase/decrease of load-bearing capacity in relation to the eccentricity [36 in Z6]

The method of the longitudinal and/or transverse reinforcement significantly affects the load-bearing capacity of the eccentrically compressed columns reinforced with the PBO mesh. The smallest decrease in the load-bearing capacity along with the increase in the eccentricity forces was recorded for the most reinforced elements (Fig. 30). When analyzing the behavior of the columns in the given group of the eccentricity load, I have noticed that for the elements longitudinally and transversely reinforced with two layers of the PBO mesh, compressed axially and eccentrically *h/12* (*e* = 16 mm), we must introduce the term "weakening of the element". For those columns, I have recorded a decline in load-bearing capacity compared to the reference elements (Figs. 31 and 32). This is due to the increase in the longitudinal stiffness of the columns, as the effect of the use of the multilayer composite reinforcement. The presence of the longitudinal reinforcement of the composite reduces the deformability of the longitudinal elements, which is rather disadvantageous. This is seen especially in elements compressed axially or with little eccentricity.

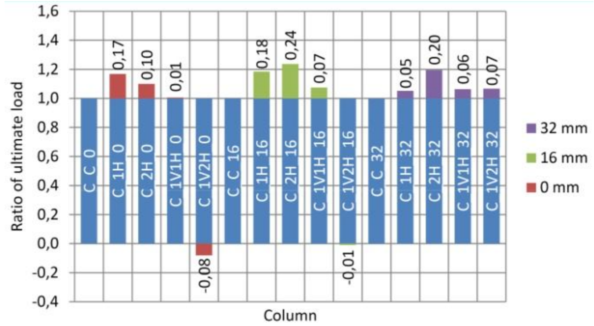


Fig. 31. Coefficient of reinforcement/weakening, in relation to the column type [36 in Z6]

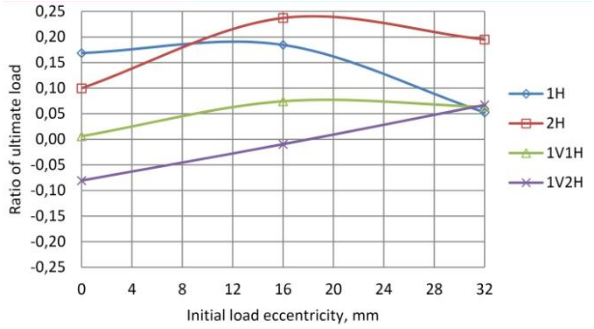


Fig. 32. Coefficient of reinforcement/weakening, in relation to the column type [36 in Z6]

Designations: *i*H: *i* – number of the layers in the transverse reinforcement-, *j*V*i*H: *j* – number of the layers in the longitudinal reinforcement (in the plane of bending), *i* – number of the layers in the transverse reinforcement

For the PBO-FRCM system, where mineral mortar serves as binder, it is difficult to suitably combine the composite with the concrete as is the case for the FRP systems. I have observed an unfavorable strain of the PBO mesh shell on the side of the load. The composite shell expanded transversely faster than concrete, stretching the mesh to the opposite sides of the cross-section.

From the sensor located at the side of the load (Fig. 29, a horizontal sensor on the left) I have recorded negative readings, which means that the sensor was pressed. There can be no strain of the columns in the opposite direction, but only about the result of the compression and buckling of the PBO mesh shell. This effect is noticeable only for the elements transversely reinforced with both eccentrics. As the load increases, we can observe the secondary (delayed) fusion of the PBO mesh shell with the concrete caused by the stress destruction of concrete (Figs. 33 and 34). The development of micro-cracks in the concrete, which we can observe on the basis of the increase in the Poisson's ratio (Figs. 35 and 36), causes fusion and cooperation of the two materials and the creation of a triaxial stress state. Up to this point the concrete is in the uniaxial stress state. This is a similar effect to the one observed in the CFST columns (Concrete Filled Steel Tubes). Similar conclusions were reached by *Ombres* and *Veere*, in a work entitled: "Structural behavior of Fabric Reinforced Cementitious Matrix (FRCM) Strengthened concrete columns under eccentricity loading", which I reviewed in December 2014 for Composites. Part B: Engineering.

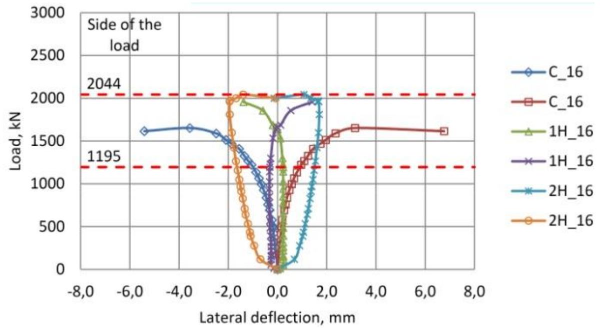


Fig. 33. Strain curve in relation to the load of the elements in the 16 mm eccentricity ($h/12$) [36 in Z6]

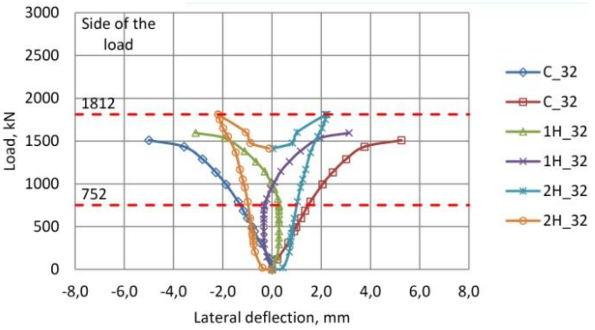


Fig. 34. Strain curve in relation to the load of the elements in the 32 mm eccentricity (($h/6$) [36 in Z6]

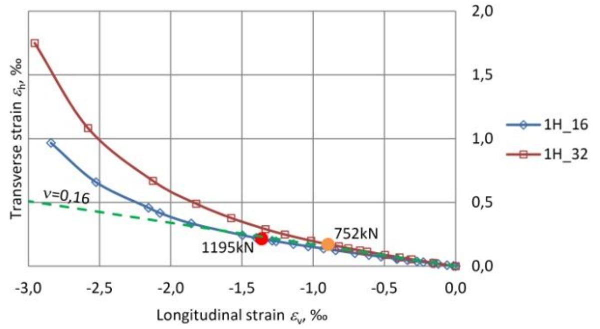


Fig. 35. Poisson's ratio for elements with a single layer of transverse reinforcement [36 in Z6]

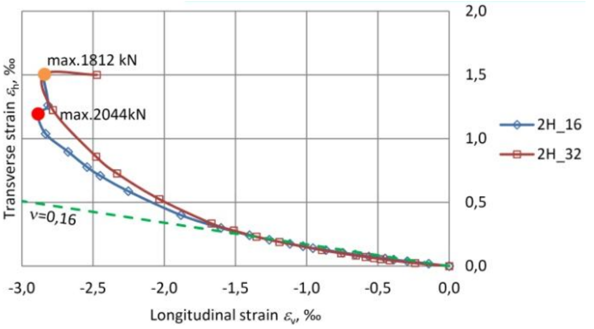


Fig. 36. Poisson's ratio for elements with two layers of transverse reinforcement [36 in Z6]

As I have already mentioned, the application of the reinforcement along the axis of the columns resulted in an increased longitudinal stiffness of the elements. For columns with the longitudinal layer of the PBO mesh, there was no similar strain in the shell, as was the case for columns only with the transverse reinforcement. Eccentrically compressed columns reinforced longitudinally and transversely show a much higher plasticity than the corresponding longitudinal columns without reinforcement.

Table 3. Test results of the eccentrically compressed columns reinforced with the PBO mesh [37 in Z6]

Column	Load capacity	Vertical strain at peak load		Energy of destruction
	N_u (kN)	ε_{v2} [‰]	ε_{v1} [‰]	E_u [kN mm]
C_C_0	2213.76	-2.121	-1.752	135.0
C_C_16	1651.96	-3.183	-0.052	167.2
C_C_32	1516.37	-3.135	+0.369	143.7
C_1H_0	2586.85	-2.736	-2.459	222.8
C_1H_16	1956.77	-2.845	-0.622	164.5
C_1H_32	1596.00	-2.962	+0.283	149.5
C_2H_0	2434.32	-3.200	-1.489	222.3
C_2H_16	2043.65	-2.907	-0.715	179.3
C_2H_32	1812.19	-2.827	+0.106	140.7
C_1V1H_0	2227.03	-2.392	-1.762	155.2
C_1V1H_16	1774.81	-2.941	-0.115	144.4
C_1V1H_32	1612.51	-3.112	+0.460	152.5
C_1V2H_0	2035.35	-1.734	-1.510	94.9
C_1V2H_16	1636.16	-1.842	-0.903	82.5
C_1V2H_32	1618.11	-2.890	+0.477	138.7

Designations: C_C_e – column without reinforcement on the eccentricity e, C_iH_e: i – number of transverse reinforcement layers, e – value of eccentricity, C_jViH_e: j – number of longitudinal reinforcement layers (in the plane of bending), i – number of transverse reinforcement layers, e – value of eccentricity,
ε_{v2} – strain on the more compressed side, ε_{v1} – strain on the less compressed/stretched side

In the columns confined only with the PBO mesh, destruction occurred at a comparable compressive strain level (Table 3). Neither the value of the eccentricity located within the limits of the core cross-section, nor the intensity of the transverse reinforcement (number of the PBO mesh layers) affected the limit compressive strain of these elements. For rectangular columns, the so beneficial effect of confinement is not observed, as was the case for round elements [32-35 in Z6]. The measure of destruction energy is the field between the axis ε (horizontal), and the strain graph. The values of destructive energy are summarized in Table 3. For columns confined only with the PBO mesh shell, the destructive energy decreases along with the increase in the eccentricity and it is not dependent on the number of layers of the perimeter reinforcement.

The presence of the longitudinal reinforcement reduces the limit compressive strains in the axially compressed columns, at which the cross-section is destroyed, which is rather disadvantageous. In turn, the eccentrically compressed elements are able to transfer much greater compression strains on the side of the acting force than the axially compressed elements. This phenomenon has already been observed in the literature for FRP columns. I have noticed the impact of longitudinal layer reinforced with the PBO mesh on the values for the energy of destruction of the columns reinforced both longitudinally and transversely (Table 3). No drop in the destruction energy value along with an increase in eccentricity can be explained by the presence of the longitudinal reinforcement. The concrete in the compression zone is further reinforced, thereby the elements demonstrated a larger longitudinal deformability at the subsequent eccentrics. Also, the impact of double wrapping and high stiffness of reinforcement can be noticed.

With the arrangement of horizontal strain gauges I confirmed that the place, from which the progressive delamination of the composite starts is the composite's final overlapping zone. The peripheral strain value depends on the effort of the concrete inside the shell of the composite and its strain due to degradation of the concrete. The value of these strains depends on the pattern of its reinforcement and the eccentric value.

Test results of the eccentrically compressed columns reinforced with the PBO mesh based on mineral mortar are presented in two papers. The first paper is entitled: "Behaviour of fibre reinforced cementitious matrix strengthened concrete columns under eccentric compression loading" published in the Materials & Design [36 in Z6]. It concerns the load-bearing capacity and strain of the columns. The article has 5 references according to the *Web of Science* database (including 3 external references), 5 references according to the *Scopus* database (including 2 external references) and 6 references according to the *Publish or Perish* database (including 3 external references). Another paper is entitled: "Effect of eccentricity eccentric compression loading on the strains of FRCM confined concrete columns" and it is dedicated to the deformability of the elements and was published in the Construction & Building Materials [37 in Z6]. The article has: 2 references according to the *Web of Science* database (including 1 external reference), 3 references according to the *Scopus* database (including 1 external reference) and 3 references according to the *Publish or Perish* database (including 1 external reference).

After several years of research, having my own database, as well as using external studies, which have appeared in the course of my research, I attempted to make the first summary of knowledge on the reinforcement of the concrete elements with PBO mesh based on mineral mortar. I have used the studies of two authors who are the only ones in the world, who deal with similar subjects: *Ombres* of the University of Calabria and *Colajanni* with a team of the University of Messina in Italy.

Confined concrete with transverse winding makes the concrete core is in a complex state of stress, which directly translates into an increase in its strength. The resulting reinforcement efficiency is affected by the initial compressive strength of the concrete. The lower the compressive strength of concrete, the better the effects of the winding of the PBO mesh (Fig. 37). The best results of the reinforcement with the same number of reinforcement layers with the PBO mesh are obtained for concrete with lower compressive strengths (Fig. 38). However, it must be borne in mind that the larger the cross-sectional diameter with the same number of reinforcement layers, the smaller the effect of reinforcement. The increase in strength increases linearly along with the increase in the coefficient of reinforcement ρ:

$$\rho = \frac{4 \cdot n \cdot t}{D}, \tag{11}$$

where: n - number of reinforcement layers, t - thickness of the composite, D - diameter of the cross-section.

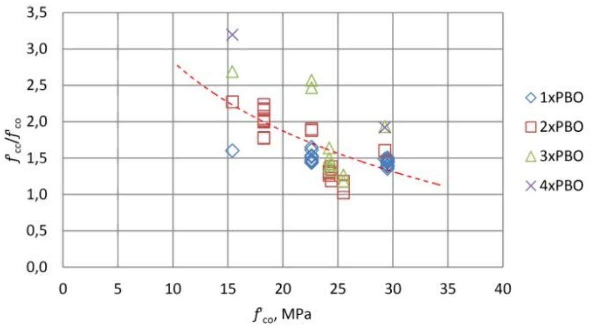


Fig. 37. Relative increase in compressive strength (f'_{cc}/f'_{co}) in relation to f'_{co}. [41 in Z6]

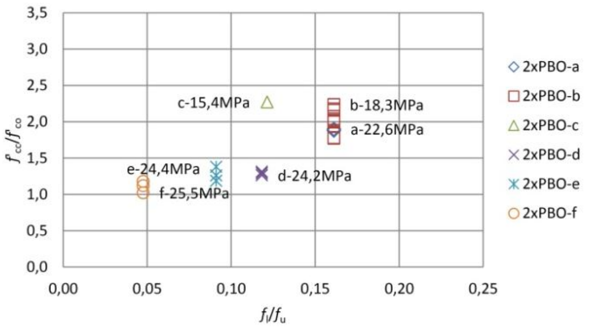


Fig. 38. Relative increase in compressive strength (f'_{cc}/f'_{co}) in relation to (f_l/f_u) of the elements reinforced with two layers of the PBO mesh [41 in Z6]

Designation: *i*xPBO: *i* – the number of transverse reinforcement layers

The concrete core has limited compressibility, beyond which a decrease in the capacity of the core for conveying increasing stress occurs, which leads to destruction of the element. Until the longitudinal stresses in the concrete do not exceed the value of concrete compressive strength in the uniaxial state of stress f'_{co}, strains in the composite remain small. From the moment, when $\sigma_z > f'_{co}$, an increase in the transverse stress of the composite occurs and impact of the PBO mesh on the concrete core increases. The decisive factor of the reinforcement effectiveness is also its stiffness, which affects the relationship of transverse (circumferential) strains to the longitudinal strains. The smaller the stiffness of reinforcement, the greater the tendency to plastic strains and redistribution of internal forces. This is demonstrated in the analysis of the change in the Poisson's ratio carried out in [41 to Z6].

This summary was published in the Construction & Building Materials under the title: "Confined concrete elements with PBO-FRCM composites" [41 in Z6]. The article has: 1 reference according to the *Scopus* database (including 1 external reference), 1 reference according to the *Scopus* database (including 1 external reference) and 1 reference according to the *Publish or Perish* database (including 1 external reference)

d) Summary

The subject of reinforcing concrete structures using composite materials that I have been dealing with since 2000 is still present in civil engineering. This is evidenced by the numerous, regularly published results of experimental and theoretical analyzes, as well as engineering applications in construction works. The expansion of knowledge on the subject coincided with a period, in which I deal with this subject. In many research centers around the world and in Poland, research has been conducted to even better learn the impact of the composite reinforcement on the load-bearing capacity and operation of concrete structures.

Research on reinforcement of concrete elements using the PBO mesh based on mineral mortar, which began in 2009 was the first one in Poland. Currently, based on the latest publications from the years 2013-2015, I can say that the leaders in this domain are the three research centers – University of Calabria and the University of Messina in Italy, Wroclaw University of Technology and Faculty of Civil Engineering thereof.

The most important scientific achievements presented a series of thematically related publications entitled: **"Reinforcement of selected concrete elements with PBO mesh based on mineral mortar"**, which are my contribution to the development of the construction discipline, are:

1) the initiation in Poland of experimental and theoretical studies on the strength of concrete reinforced with the PBO mesh based on mineral mortar,
2) experimental description of the mechanism of destruction of the axially and eccentrically compressed concrete elements and reinforced concrete elements reinforced with the PBO mesh based on mineral mortar,
3) both the experimental and theoretical description of the σ-ε relationships of the axially compressed concrete elements, reinforced with the PBO mesh based on mineral mortar,
4) conducting a comparative analysis of behavior of the axially compressed concrete elements, wound with the CFRP sheet and PBO mesh, tested in the neutral temperature of +20°C and at high temperatures: +40°C, +60°C, +80°C, as well as those subjected (prior to the destructive test) to high temperatures: +60°C, +120°C and +180°C,
5) determining the impact of the pattern of shaping the transverse reinforcement on the load-bearing capacity and the deformability of the axially compressed concrete elements, reinforced with the PBO mesh based on mineral mortar,
6) determining the effect of longitudinal and transverse reinforcements with the PBO mesh based on mineral mortar, to the operation of the eccentrically compressed reinforced concrete columns,
7) describing the impact of the destruction of concrete on the operation and efficiency of the reinforcement in the axially and eccentrically compressed concrete elements, reinforced with the PBO mesh based on mineral mortar,
8) describing the phenomenon of the secondary (delayed) fusion of the PBO mesh with concrete from the moment, when the longitudinal stresses in the concrete σ_z are greater than the concrete strength to compression in the uniaxial state of stress f'_{co} ($\sigma_z > f'_{co}$).

Therefore, the PBO-FRCM system is not intended to replace or eliminate the FRP resin composites. However, the papers presented by me demonstrate great potential of the composites based on mineral mortar as the reinforcement of concrete structures. Both systems -

FRP and PBO-FRCM differ a lot, even though both of them derive from the same idea involving the restriction of freedom of stretched and compressed concrete element strains.

The conscious decision to choose the reinforcement system must be dictated by the fact that the selected system can ensure the achievement of those objectives both temporarily and in a long term. This selection should be accompanied by full knowledge of the reinforced element, including one which will help predict potential threats to the reinforced structure and help choose the most suitable system. On the basis of the acquired knowledge it is important to take into account what benefits and risks are offered by both technologies – FRP and PBO-FRCM, and the fact that there is no perfect system, and for each one you can specify both the number of advantages, as well and defects.

The presented series of publications is not exhaustive on the subject of reinforcing concrete elements with the PBO mesh based on mineral mortar. In my opinion, the most important issue for the future is to develop an effective method of anchoring the PBO mesh on the external overlapping zone, in order to fully utilize its strength properties. Only then will it be possible to analyze, among others, rheological characteristics, the impact of variable loads, the impact of large eccentricities and slenderness of the reinforced elements. This subject is very up-to-date.

5. Overview of other research and scientific achievements

5.1. Research and scientific activity before obtaining a PhD degree

On 1 July 1999 I defended my master's thesis entitled: “Technical designs supporting structures of concrete for overhead power lines with a voltage of 30 kV”, at the Faculty of Civil Engineering, Wroclaw University of Technology, majoring in building construction. MSc thesis supervisor: Aleksy Łodo, PhD Eng.

After graduation, I took up a job as an assistant designer at the Construction Design Companies PREDOM in Wroclaw, where I worked until February 2001. At the same time in October 2000, I started PhD studies at the Faculty of Civil Engineering, Wroclaw University of Technology in the Department of Concrete Structures at the Institute of Civil Engineering. In June 2001, I was admitted into the PhD program at the Institute of Civil Engineering at the Wroclaw University of Technology with the theses entitled: „Load capacity of RC columns strengthening with CFRP strips and wraps”. PhD thesis supervisor was Prof. Mieczysław Kaminski, PhD. Eng. I submitted my PhD thesis for review in September 2004. Reviewers were Prof. Maria E. Kamińska PhD. Eng. of the Lodz University of Technology and Prof. Jerzy Hoła PhD. Eng. of the Wroclaw University of Technology. On 16 February 2005, I defended my PhD thesis with distinction at the request of both reviewers.

The PhD thesis presented the results of experimental research and theoretical analyses of the opportunities to use the longitudinal composite reinforcement in the form of CFRP fibers, to strengthen axially and eccentrically compressed reinforced concrete columns. The subject proved to be very timely and interesting both in terms of scientific and practical aspects, which was noted by both Reviewers. In my dissertation, I made a critical review of the extensive source material, on the basis of which I proposed three original theses. The first claimed that it is possible to identify the most common mechanism of destruction of the compressed reinforced concrete columns strengthened with the CFRP strips, and on this basis it is possible to define the limits of compressive strain. Another thesis assumed that the strengthening of the reinforced concrete columns with CFRP strips lengthwise increases their limit load-bearing capacity, which depends on the intensity of the longitudinal reinforcement. The third thesis argued that it is possible to identify the relationship to calculate the load-bearing capacity of the stocky, axially compressed reinforced concrete columns strengthened with the CFRP strips.

The basis of considerations, intended to prove the theses, were experimental studies divided into four stages, in which I have examined a total of 31 elements with a rectangular cross-section. These were reinforced concrete elements, model, elements, as well as full-scale elements.

The most important research and scientific achievements of the PhD dissertation were:

1. experimental demonstration of the most common mechanism of destruction of the compressed concrete columns strengthened with CFRP strips and mats and determination of the longitudinal strain limit values for these elements,
2. the definition of the impact of the intensity of the longitudinal reinforcement with CFRP strips, which affects the limit load-bearing capacity of the elements, provided that it is accompanied by peripheral composite reinforcement,
3. demonstration that the reinforcement only with sections of the CFRP strip, whose fibers are oriented parallel to the axis of the column, is disadvantageous because of the premature loosening of the composite concrete,
4. proposing the relationship to determine the load-bearing capacity of axially compressed, stocky reinforced concrete columns strengthened with CFRP composites.

These are the original achievements documented by scientific publications [3, 5, 7, 13, 15, 16, 19, 20 and 22 in Z6]. An article in the Journal of Civil Engineering and Management entitled: "Experimental behaviour of reinforced concrete column models strengthened by CFRP materials" [5 in P6] in 2006 has 16 references according to the *Scopus* database (including 9 external references) and 28 references according to the *Publish or Perish* database (including 13 external references). The work [15, 16 and 19 in Z6] was presented at the official conference of *The International Institute for FRP in Construction* (IIFC) in Zurich and Seoul.

5.2. Research and scientific activity after obtaining a PhD degree, not forming part of the main scientific achievement

After obtaining a PhD degree, from 16 February 2005, I took up job as assistant at the Department of Concrete Structures, Institute of Civil Engineering at the Wroclaw University of Technology. Since 1 February 2006, I have been working as Assistant Lecturer, initially at the Department of Concrete Structures, at the Faculty of Civil Engineering Wroclaw University of Technology. Developing my scientific interests, I took up the subject matter defined in the dissertation, greatly expanding it.

In 2008, I became a member of *The International Institute for FRP in Construction* (IIFC). It is an international forum of specialists in the field of application of composite materials in construction. By participating in the official conferences IIFC, as well as following the activity of the organization, I state that the subject of my scientific interest has been present in the global and Polish civil engineering, as evidenced by the growing number of publications and practical applications.

After obtaining a PhD degree, my research and scientific interests (beyond the subject matter covered in a series of thematically related publications) were focused on the following issues:

1. in relation to the subject matter included in the doctorate, the assessment of the impact of the intensity of the longitudinal reinforcement with CFRP strips on the load-bearing capacity and deformability of reinforced concrete columns subjected to temporary axial and eccentric loads,
2. determination and evaluation of rheological parameters (end-creep factor) of the reinforced concrete using CFRP strips and mats,
3. the impact of the repeatedly variable loads on the operation of concrete and reinforced concrete elements strengthened with composite materials,
4. the evaluation of the technical condition, diagnostics of the causes of damage and repair to concrete structures,
5. the evaluation of the role of the PBO mesh reinforcement in the load-bearing capacity on the shear capacity of the reinforced concrete beams, in relation to the pattern of its construction and anchorage.

Ad. 1.

The analysis of the impact of the intensity of the longitudinal reinforcement with CFRP strips on the load-bearing capacity and deformability of the reinforced concrete columns subjected to temporary axial and eccentric load, was the subject of the research grant of the specialties of the scientific units at the Technical University of Wroclaw. The grant was awarded to me by the Vice-President for Research and Economic Co-operation at the Wroclaw University of Technology. I carried it alone in 2008-2009.

The intensity of the reinforcement is defined here as the relationship of the surface areas attached along the element of the CFRP strip to the surface area of the concrete cross-section. In the study I have used three intensity levels of the longitudinal reinforcement of the CFRP – 2.10%, 1.68% and 1.26%. For all reinforced components, I have used a single, complete winding with the CFRP sheet. I have conducted research on full-scale columns, which were temporarily loaded axially and on eccentrics within the core cross-section. I analyzed the results of the tests of the load-bearing capacity of the columns in relation to the intensity of the longitudinal reinforcement. I have described the mechanisms of destruction and provided the destructive forces and maximum values of the strain of the longitudinal elements. The application of the longitudinal reinforcement increases the rigidity of the elongated columns, which in turn reduces the rate of the increase in the compressive strain in relation to the control elements at equal increments of the longitudinal force. Along with the increase in the intensity of the longitudinal reinforcement, the limit load-bearing capacity increases, provided that it is accompanied by circumferential composite reinforcement. For rectangular columns without significant rounding of the corners, the increase in the load-bearing capacity should be attributed almost entirely to the longitudinal CFRP reinforcement, rather than transverse CFRP reinforcement. One has to be skeptical when it comes to triaxial state of stress caused by the constrainment of the concrete in the rectangular cross-sections, especially with sharp edges (or with small roundings) confined up several times with a composite mat. The longitudinal reinforcement becomes more efficient in the eccentrically compressed elements, where at the eccentricity of the force on the border of the core cross-section (studied by me) it may be integrated to co-operate at tension, at the stage of the column’s destruction.

These are the original achievements, documented in scientific publications [24, 27 in Z6]. An article in the Archives of Civil and Mechanical Engineering entitled: "The effectiveness of CFRP materials strengthening of eccentrically compressed reinforced concrete columns" [24 in Z6] from 2011 has 7 references according to the *Web of Science* database (including 3 external references), 8 references according to the *Scopus* database (including 4 external references) and 10 references according to the *Publish or Perish* database (including 5 external references).

Ad. 2.

The designation and evaluation of the rheological parameters of the reinforced concrete by means of CFRP strips or mats is covered in the 7 of my papers [2, 10, 17, 18, 23, 25 and 28 in Z6]. I have conducted multistage studies within the two research projects. The pilot grant was awarded to me by the Vice-President for Research and Economic Co-operation at the Wroclaw

University of Technology. I implemented it alone in 2007-2008. The second grant was awarded to our team by the Committee for Scientific Research (N506 039 32/4179). We implemented it in 2007-2009 as a team: Prof. Mieczysław Kaminski, PhD. Eng. – manager, Tomasz Trapko, PhD. Eng. – executor, Czesław Bywalski, PhD. Eng. – executor.

The purpose of the multistage research was the evaluation of the impact of longitudinal and/or transverse CFRP composite reinforcement on the final value of the end-creep factor of the elements under long-term axial compression. On the basis of the tests of the elements reinforced only by wrapping the CFRP sheet, I have found that the intensity of the transverse reinforcement affects the increase in of medium, short-term longitudinal strains at the time of the first load after reinforcement, while limiting the increase in the long-term compressive strain should be attributed mainly to the transverse composite reinforcement. The end-creep factor does not depend on the intensity of the CFRP transverse reinforcement. The presence of the CFRP transverse reinforcement reduces the end-creep factor by approx. 30% compared to the reference elements. On the other hand, in elements, in which I have applied the longitudinal and transverse CFRP reinforcement, the number of transverse reinforcement layers does not affect the increase in the long-term compressive strain. In such elements, reducing the rate of increase in the longitudinal strain must be attributed almost entirely to the longitudinal reinforcement of the composite. For elements without reinforcement, the end-creep factor is approx. 55% higher compared with the elements reinforced with longitudinal CFRP strips and transverse CFRP sheet. Notwithstanding the reinforcement of the intensity of the longitudinal and transverse reinforcement, it is characterized by similar values of the creep factor.

An article in Composites. Part B: Engineering entitled: "Investigations on rheological strains of compressed concrete elements strengthened with external composite reinforcement CFRP" [28 in Z6] from 2012 has 4 references according to the *Web of Science* database (including 1 external reference), 5 references according to the *Scopus* database (including 2 external references) and 7 references according to the *Publish or Perish* database (including 3 external references). The paper [10 Z6] was presented at a conference of *The International Institute for FRP in Construction* (IIFC) in Patras in Greece.

Ad. 3.

The impact of the multiple repeatedly variable loads on the load-bearing capacity and strain of the compressed concrete elements, reinforced with CFRP materials is covered in one publication [30 in Z6]. This issue is currently extended by the analysis of the operation of the reinforced concrete discs strengthened with the PBO mesh based on mineral mortar subjected to the repeatedly variable loads. Currently, collective research is being conducted in the laboratory on solid discs and discs with a bore.

In studies of the behavior of the compressed concrete elements reinforced with CFRP straps and/or mats, subjected to monotonic and frequently variable loads, we have demonstrated possibility the capability of mapping the monotone curve with the cyclical curve envelope, in relation to the type of reinforcement. We have analyzed the effect of reinforcement type and condition of the effort on the modulus of elasticity and the residual strain values. We have noticed that adaptability to the multiple variable loads of the compressed elements reinforced with CFRP materials depends on the manner and intensity of the reinforcement. In the case of components reinforced only with transverse CFRP winding, the co-operation of the concrete core and an outer shell depends essentially on the stiffness of the reinforcement. In these elements I can recommend the use of only single reinforcement with the mat, while the use of more layers of the composite should be considered unfavorable due to the difficulty in predicting strains and micro cracks occurring in the concrete core.

The use of the longitudinal and transverse CFRP reinforcements increases the rigidity, which has a beneficial effect on the state of strain and load-bearing capacity of the elements subjected to variable loads. In the elements subjected to cyclic compression, we recommend the use of the composite reinforcement in the form of longitudinal strips with a minimum of two layers of the CFRP sheet winding.

An article in the Journal of Civil Engineering and Management entitled: "Load-bearing capacity of compressed concrete elements subjected to repeated load strengthened with CFRP materials" [30 in Z6] from 2012 has: 3 references according to the *Web of Science* database (including 2 external references), 4 references according to the *Scopus* database (including 3 external references), and 6 references according to the *Publish or Perish* database (including 5 external references).

Ad. 4.

When collaborating with Prof. Mieczysław Kamiński, PhD. Eng., I had the opportunity to be part of the expert team, which in the years 2003-2013 conducted the assessment of the technical condition and diagnosis of the resulting damage to the reinforced concrete structure in Turzyn Shopping Mall in Szczecin. I had the opportunity to use my knowledge of composite reinforcements and developed several designs for CFRP reinforcements of the prefabricated roof bolts and designs of strengthening the monolithic walls of the fire tanks in this facility. Co-authored works from the reviews of the structures and implemented reinforcements were published in [8 and 12 in Z6].

In addition, I dealt with the diagnostics of materials and building structures. This involved the assessment of the technical condition of the construction products, modern engineering facilities, as well as historical buildings. As part of this activity, I have published a chapter in the book [9 in Z6] and four articles in journals reviewed by the MNiSW [31, 39, 40 and 44 in Z6], and I have co-authored expert opinions mentioned in section III, subsection M in Annex 5.

Ad. 5.

In collaboration with Dorota Urbańska, M.Sc., a PhD Student at the Department of Concrete Structures at the Faculty of Civil Engineering Wroclaw University of Technology, I participate in research, in which we analyze the work of reinforced concrete beams strengthened to shearing by external PBO mesh stirrups based on mineral mortar. Under my supervision, Dorota Urbańska, MSc. Eng. wrote her master's thesis: "Influence of the way of construction of transverse steel and composite reinforcement on the effectiveness of behaviour of shearing beams". Experimental studies, carried out as part of this work show that the key factor in the PBO-FRCM system is to provide adequate anchorage of the external PBO mesh stirrups. As shown by preliminary studies, we have found no positive impact of the PBO fibers arranged at an angle smaller than 90° to the longitudinal axis of the beam on the load-bearing capacity. The greatest load-bearing capacity was obtained for the reinforcement with PBO stirrups arranged at an angle of 90°. We have found that the PBO mesh stirrups should be sufficiently close together to prevent the propagation of too many cracks between them. Drawing on the experience gained at the initial stage of research, we have developed a program of further studies, in which we are going to test different patterns of shaping and anchoring the PBO mesh stirrups based mineral mortar in beams with a T-shaped cross section.

We published the results of the initial studies in an article in Composites. Part B: Engineering entitled: "Shear strengthening of reinforced concrete beams with PBO-FRCM composites" [42 in Z6] of 2015 and in an article in journal Materiały Budowlane entitled: "Shear capacity of RC beams strengthened with PBO-FRCM" [43 in Z6] of 2015.

6. Summary of the research and scientific, educational, organizational and engineering activity after obtaining a PhD degree

6.1. Research and scientific activity

In Table 4, I have listed in summary all publications, detailing these after I obtained a PhD degree. In Table 5, I have listed all the publications, scored by the MS&HE with *impact factors* and information on the number of authors.

I have published 12 articles in journals included in the JCR database, including 6 publications included in the cycle of thematically related publications [32, 33, 34, 36, 37, 41 in Z6] and 6 articles not included in the scientific achievement [5, 24, 28, 29, 30, 42 in Z6]. The 10 of these publications have been assigned an impact factor [24, 28, 30, 32, 33, 34, 36, 37, 41, 42 in

Z6], 6 of which are included in the series of thematically related publications.

Table 4. Summary of published works in the form of a total after obtaining the PhD degree

No.	Type of publication	No. of publications in summary	Number of publications after obtaining the PhD degree
1	Total publications	47	44
2	Articles in journals in the JCR database	12	12
3	Articles in international journals not included in the JCR database	1	1
4	Articles in national journals	16	14
5	Chapters in books	4	3
6	Presentations at international conferences	9	9
7	Presentations at national conferences	5	5

Table 5. Summary of all publications scored by the MS&HE, *impact factor* and number of authors

No.	Journal	Position in the Annex Z6	Year	Authors	Points by MS&HE *	*Impact Factor*
1	Inżynieria i Budownictwo	3	2006	2	6	-
2	Journal of Civil Engineering and Management **	5	2006	2	2	-
3	Materiały Budowlane	6	2006	4	6	-
4	Materiały kompozytowe w budownictwie mostowym	7	2006	3	2	-
5	Materiały Budowlane	21	2010	1	6	-
6	Journal of Materials Science and Engineering	22	2010	2	2	-
7	Inżynieria i Budownictwo	23	2010	1	6	-
8	Archives of Civil and Mechanical Engineering	24	2011	2	20	0,855
9	Kompozyty	25	2011	1	9	-
10	Przegląd Budowlany	26	2011	2	6	-
11	Inżynieria i Budownictwo	27	2011	1	6	-
12	Composites. Part B: Engineering	28	2012	3	45	2,143
13	Przegląd Elektrotechniczny	29	2012	2	15	-
14	Journal of Civil Engineering and Management	30	2012	2	50	2,016
15	Przegląd Budowlany	31	2012	3	3	-
16	Materials and Design	32	2013	1	35	3,171
17	Composites. Part B: Engineering	33	2013	1	45	2,602
18	Composites. Part B: Engineering	34	2013	1	45	2,602
19	Architektura i Budownictwo	35	2013	1	3	-
20	Materials and Design	36	2014	1	35	3,501
21	Construction & Building Materials	37	2014	1	40	2,296
22	Materiały Budowlane	38	2014	2	6	-
23	Materiały Budowlane	39	2014	4	6	-
24	Materiały Budowlane	40	2014	3	6	-
25	Construction & Building Materials	41	2014	1	40	2,296
26	Composites. Part B: Engineering	42	2015	3	40	2,983
27	Materiały Budowlane	43	2015	3	6	-
28	Materiały Budowlane	44	2015	3	6	-
				Razem:	**497**	**24,465**

* Ministry of Science and Higher Education.

** Journal of Civil Engineering and Management located in the JCR base since 2009.

I have published 1 article in the international journal, which is not included in the JCR database [22 in Z6]. I have published 16 articles in national journals, 14 articles after I obtained my PhD [3, 6, 21, 23, 25, 26, 27, 31, 35, 38, 39, 40, 43, 44 in Z6], including one forming part of the series of thematically related publications [35 in Z6]. I am the author of 4 chapters in books, including 3 after I obtained a PhD degree [7, 8, 9 in Z6].

After obtaining a PhD degree, I have published 14 presentations in conference materials, including 9 at international conferences [10-12, 15-20 in Z6] and 5 at national conferences [1, 2, 4, 13, 14 in Z6]. 4 presentations were published in the conference materials for the *International Institute for FRP in Construction* (IIFC) in Zurich and Seoul [15, 16, 19, 20 in Z6], 1 presentation was published in the materials of the conference co-organized by the *International Institute for FRP in Construction* (IIFC) in Patras [10 Z6]. In addition, 3 papers were presented at national conferences, after obtaining a PhD degree, and they appeared as mentioned earlier, chapters in books [7, 8, 9 in Z6]. 2 papers were presented at national conferences, after obtaining a PhD degree and appeared as mentioned earlier as articles [31, 35 in Z6].

In Table 6, I have summarized the papers scored by the MS&HE along with an impact factor and information on the number of authors, published after obtaining a PhD degree, outside the cycle of thematically related publications.

Table 6. Summary of publications scored by the MS&HE, impact factors and the number of authors, published after obtaining a PhD degree, outside the cycle of thematically related publications

No.	Journal	Position in the Annex Z6	Year	Authors	Points by MS&HE *	*Impact Factor*
1	Inżynieria i Budownictwo	3	2006	2	6	-
2	Journal of Civil Engineering and Management *	5	2006	2	2	-
3	Materiały Budowlane	6	2006	4	6	-
4	Materiały kompozytowe w budownictwie mostowym	7	2006	3	2	-
5	Materiały Budowlane	21	2010	1	6	-
6	Journal of Materials Science and Engineering	22	2010	2	2	-
7	Inżynieria i Budownictwo	23	2010	1	6	-
8	Archives of Civil and Mechanical Engineering	24	2011	2	20	0,855
9	Kompozyty	25	2011	1	9	-
10	Przegląd Budowlany	26	2011	2	6	-
11	Inżynieria i Budownictwo	27	2011	1	6	-
12	Composites. Part B: Engineering	28	2012	3	45	2,143
13	Przegląd Elektrotechniczny	29	2012	2	15	-
14	Journal of Civil Engineering and Management	30	2012	2	50	2,016
15	Przegląd Budowlany	31	2012	3	3	-
16	Materiały Budowlane	38	2014	2	6	-
17	Materiały Budowlane	39	2014	4	6	-
18	Materiały Budowlane	40	2014	3	6	-
19	Composites. Part B: Engineering	42	2015	3	40	2,983
20	Materiały Budowlane	43	2015	3	6	-
28	Materiały Budowlane	44	2015	3	6	-
				Razem:	**254**	**7,997**

* Ministry of Science and Higher Education

** Journal of Civil Engineering and Management located in the JCR base since 2009.

13 of them are independent publications, including 7 included in the series of thematically related publications. The other 31 publications are co-authored.

Currently (July 2015), I have submitted two articles to the 15th Conference "Tanks for bulk solids and liquids, industrial and hydro-technical structures", Karpacz held on 19-21 Oct. 2015. The articles will be published in No. 9/2015 of the Materiały Budowlane journal. I have submitted 1 article to No. 10/2010 of journal Materiały Budowlane, which will be released on the occasion of the 70th anniversary jubilee of the Faculty of Civil Engineering, Wroclaw University of Technology.

I am also the author or co-author of 10 research reports (research paper documentations), including 7 SPR reports, one PRE report and 2 U reports (reports of the Institute of Civil Engineering Wroclaw University of Technology) (Z5, section II, subsection F).

In Annex 5, I have presented a detailed list of published scientific papers or creative professional work and information on the educational achievements, scientific cooperation and popularization of science, after obtaining a PhD degree.

On the other hand, in Annex 6, I have listed the publications broken down by those published before and after obtaining a PhD degree, along with information about the year of publication, MS&HE scoring, the presence in the Journal Citation Reports (JCR) database and the impact factor by year of publication. In the same Annex, I have listed the number of references before and after obtaining a PhD degree according to the three bases - *Web of Science*, *Scopus* and *Publish or Perish*, broken down by own and external references.

In Tables 7 and 8, I have listed, respectively: the number of references and Hirsh index according to the three bases - *Web of Science*, *Scopus* and *Publish or Perish*.

Table 7. Number of references (as at 6 July 2015)

No.	#	*Web of Science* database	*Scopus* database	*Publish or Perish* database
1	Number of publications in the database	10	14	33
2	Total number of references	44	67	156
3	Number of own references	22	33	107
4	Number of external references	22	34	49

Table 8. Hirsch index (as at 6 July 2015)

No.	#	*Web of Science* database	*Scopus* database	*Publish or Perish* database
1	Number of publications in the database	10	14	33
2	Hirsch index	**5**	**5**	**7**

The total impact factor according to the list of Journal Citation Reports (JCR), by year of publication is **24.465**, including **16.468** publications included in the series of thematically related publications, followed by **7.997** other publications beyond the cycle. The total number of points by the MS&HE scoring is **497**, including **243** for the publications included in the series of thematically related publications, and **254** for the remaining publications beyond the cycle.

After obtaining a PhD degree, I have participated in the implementation of three research projects (Z5, section II, subsection J):

1. Grant awarded by the Committee for Scientific Research (N506 039 32/4179), implemented by me from 10 April 2007 to 9 April 2009 as an executor,
2. Grant awarded by the Vice-President for Research and Cooperation with the Economy at the Wroclaw University of Technology, implemented by me in 2007-2008,
3. Grant awarded by the Vice-President for Research and Cooperation with the Economy at the Wroclaw University of Technology, implemented by me from 22 October 2008 to 15 December 2009.

In 2006, I received the award of the President of the Wroclaw University of Technology for PhD dissertation. In the years 2012, 2013 and 2014, I received awards of the President of Wroclaw University of Technology in recognition of distinctive contributions to the University, including for scientific activity.

After obtaining a PhD degree, I gave 4 presentations at international conferences and participated in 5 other presentations at international conferences. After obtaining a PhD degree, I gave 5 presentations at national conferences and participated in 5 other presentations at national conferences (Z5, section II, subsection L).

Currently (July 2015), I have submitted 1 presentation to the official conference of *The International Institute for FRP in Construction IIFC* - APFIS 2015 / FRPRCS-12, which will be held in Nanjing in China, on 14-16 December 2015.

In cooperation with the industry, since 2010, I have been conducting research and analyses of the use of the PBO-FRCM composites for reinforcing concrete elements. Tests are carried in multiple stages. I am the manager of these projects. The result of these papers is a series of thematically related publications (Z5, section III, subsection F).

I have reviewed articles for journals in the JCR database: Journal of Civil Engineering and Management – 1 review, Construction and Building Materials – 3 reviews, Composites. Part B: Engineering – 2 reviews, Engineering Structures – 2 reviews and a foreign journal outside the JCR database: Structural Engineering International – 1 review. In addition, I prepared 1 review to the article for a national journal Materiały Budowlane and several reviews for the national conferences (Z5, section III, subsection P).

In April 2015. I was invited to the group of reviewers of the Civil Engineering and Architecture (ISSN: 2332-1121).

I supervise research on a PhD dissertation of Dorota Urbańska, MSc. Eng., written by her at the Department of Concrete Structures at the Faculty of Civil Engineering Wroclaw, University of Technology under the guidance of Prof. Mieczysław Kamiński, PhD. Eng. (Z5, section III, subsections K).

6.2. Educational activity

I run the following forms of educational activity at undergraduate and post-graduate full-time and part-time university courses: lectures, design classes and laboratory classes, seminars, with subjects such as: Concrete structures – foundations; Concrete structures – components and houses, Concrete Structures – facilities; Failures and repair of concrete structures, Technology of concrete works.

I have developed course curricula: Concrete structures – foundations, undergraduate full-time course; Concrete structures – foundations, undergraduate part-time course. At the: Failures and repair of concrete structures course I convey to students the latest knowledge on repair and reinforcement of composite reinforcements, both acquired from the literature and from my own experience and engineering research.

I have been an adviser of a total of 40 theses at the Uniform Master's Degree Courses, Complementary Master's Degree Courses, part-time engineering courses, full-time undergraduate courses and full-time postgraduate courses. I have prepared over a dozen reviews to theses and diploma papers.

In 2013 and 2014 two of my graduates were awarded for their diploma projects in competitions organized by the Wroclaw Branch of the Polish Association of Construction Engineers and Technicians, under the auspices of the Dean of the Faculty of Civil Engineering, Wroclaw University of Technology.

I have supervised three post-graduates, who are continuing their studies at PhD studies.

6.3 Organizational activity

Since 2008. I have been a member of *The International Institute for FRP in Construction* IIFC, and since 2007, I have been a member of the *Polish Group The International Institute for FRP in Construction* PG IIFC. Since June 2013, I have participated in an international project COST Action TU 1207 „Next Generation Design Guidelines for Composites in Construction".

I took part in the work of six scientific committees at national conferences (Z5, section III, subsection C):

1. in 3 of them as a secretary and a member: Conference of Students and PhD Students of the Faculty of Civil Engineering, Wroclaw University of Technology – Szklarska Poręba 2012, 2nd Conference of Students and PhD Students of the Faculty of Civil Engineering, Wroclaw University of Technology – Szklarska Poręba 2013, 3rd Conference of Students and PhD Students of the Faculty of Civil Engineering KONstruktor2015 – Szklarska Poręba 2015.
2. in 2 of them as secretary: 13th Conference "Reinforced concrete and prestressed concrete

tanks for bulk materials and liquids" – Szklarska Poręba 2007, 15th Conference "Tanks for bulk solids and liquids, industrial and hydro-technical structures" – Karpacz 2015.

3. in 1 of them as a member: Students Nationwide Construction Conference BUDMIKA 2014 – Poznań 2014.

I took part in the work of 7 organizational committees of national conferences (Z5, section III, subsection C):

1. in 3 of them as chairman: the Conference of Students and PhD Students of the Faculty of Civil Engineering, Wroclaw University of Technology – Szklarska Poręba 2012, 2nd Conference of Students and PhD Students of the Faculty of Civil Engineering, Wroclaw University of Technology – Szklarska Poręba 2013, 3rd Conference of Students and PhD Students of the Faculty of Civil Engineering, KONstruktor2015 – Szklarska Poręba 2015,
2. in 2 of them as vice-chairman: 14th Conference "Reinforced concrete and prestressed concrete tanks for bulk materials and liquids, industrial chimneys and hydro-technical structures" – Karpacz 2012, 15th Conference "Tanks for bulk solids and liquids, industrial and hydro-technical structures" – Karpacz 2015,
3. in 2 of them as a member: 13th Conference "Reinforced concrete and prestressed concrete tanks for bulk materials and liquids" – Szklarska Poręba 2007, Conference "Tests of building materials and constructions engineering" – Karpacz 2013.

I have participated in organizing Scientific and Technical Seminars of the Department of Concrete Structures at the Institute of Civil Engineering, Wroclaw University of Technology.

In the years 2012, 2013 and 2014, I received awards of the Rector of Wroclaw University of Technology in recognition of distinctive contributions to the University.

I have co-edited conference materials from 4 national conferences (Z5, section III, subsection G):

1. Scientific and Technical Seminars of the Department of Concrete Structures at the Institute of Civil Engineering, Wroclaw University of Technology "Strengthening and repair of concrete structures and general constructions" – Boszkowo 2005,
2. The Conference of Students and PhD Students of the Faculty of Civil Engineering, Wroclaw University of Technology – Szklarska Poręba 2012,
3. 2nd Conference of Students and PhD Students of the Faculty of Civil Engineering, Wroclaw University of Technology – Szklarska Poręba 2013,
4. 3rd Conference of Students and PhD Students of the Faculty of Civil Engineering KONstruktor2015 – Szklarska Poręba 2015.

I am a member of the Faculty of Civil Engineering, Wroclaw University of Technology for the ongoing 2012-2016 term of office as a representative of academic lecturers.

I am a representative of the Faculty of Civil Engineering, Wroclaw University of Technology in the interdepartmental Research Center for Sustainable Shaping of the Built Environment.

I am Coordinator for Promotion at the Faculty of Civil Engineering, Wroclaw University of Technology from 01 October 2012 to 31 August 2016.

Since 2010. I have been the supervisor of the KONKRET Scientific Society at the Department of Concrete Structures at the Faculty of Civil Engineering, Wroclaw University of Technology.

I organized seminar trips of the KONKRET Scientific Society in March 2011, September 2012, December 2012, May 2013, June 2014 and July 2015.

I have been the supervisor of the team representing the Faculty of Civil Engineering, Wroclaw University of Technology during the 1st (2012) and 2nd (2013-2014) editions of the “Concrete University Górażdże Group”.

Twice, in 2012 and 2014, I conducted the "Human – the best investment" technical workshop for secondary school students as part of the European Social Fund.

In 2013. I was the supervisor of the stand of the Faculty of Civil Engineering, Wroclaw University of Technology at the TARBUD Construction Fair in Wroclaw.

In the years 2013, 2014 and 2015, I organized Open Days at the Faculty of Civil Engineering, Wroclaw University of Technology.

6.4 Engineering activities

As part of the engineering research, I have been involved in testing of construction materials and structures. This included laboratory, as well as *in situ* studies. I am the author or co-author of the reports on laboratory tests, as well as technical expertise and opinions. I am a co-author of the designs of reinforced concrete structural elements using CFRP composite materials. I have participated in the work of design teams for residential buildings, public utility buildings and industrial facilities (Z5, section II, subsection M).

A detailed list of the published scientific papers or creative professional work and information on educational achievements, scientific collaboration and popularization of science is included in Annex 5 (Z5).

Trapko