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Composite Rebars

Abstract: Economic development urges design engineers to search for alternative structural materials enabling the fast erection of structures without incurring high investment costs and, afterwards, high running costs. Reinforcement bars are indispensable elements to most civil engineering structures. The article presents information concerned with composite rebars, i.e. their mechanical and physical properties, production technologies and application areas as well as compares composite rebars with their steel equivalents.

Keywords: rebars, composites, reinforced-concrete structures.

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Introduction

Engineers, when selecting materials to be used in a reinforced concrete structure, primarily take into consideration requirements connected with transmitted loads, environmental conditions the structure will be exposed to and technologies employed to erect a given structure. In addition, the investor needs to take into account both investment and running costs. The most common solutions include the use of concrete reinforcement bars (rebars) made of unalloyed steels [1]. Cases requiring higher resistance to corrosive factors or extended service life without repair and maintenance involve the use of rebars made of corrosion resistant steels [2]. Steel rebars often have to be joined using (usually manual metal arc) welding technologies. An alternative solution involves the use of composite rebars, not joined by means of welding technologies. Usually, composite rebars are supplied in coils having lengths of tens of metres. In view of the growing interest in the above-named structural material, it is worth knowing what composite rebars are available on the market, what their properties are and where they can be applied.

It is expected that by 2021 the global market of composite rebars will have reached 91 billion USD, with an accumulated growth rate of 11.4% in the years 2016-2021. The dynamic growth is primarily connected with the increasing demand for renovation works of already existing structures and the need for erecting structures exposed to seawater or strong electromagnetic fields, i.e. conditions preventing the use of rebars made of unalloyed steels [3].

Composite rebars

Fibre-reinforced polymer (FRP) composite rebars have been used in building structures for over two decades. High corrosion resistance, high tensile strength, electromagnetic inertness and the ease of cutting are primary factors encouraging the use of the above-named composite rebars as elements reinforcing concrete structures. Numerous investments involving

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the use of the above-named reinforcement technology and positive test results demonstrate that composite rebars constitute an interesting alternative to "classic" rebars made of steel [4]. Figure 1 presents examples of composite rebars.

Fig. 1. Examples of composite rebars [5]

Composite rebars are usually fabricated using the process of pultrusion (Fig. 2), i.e. continuous press moulding.

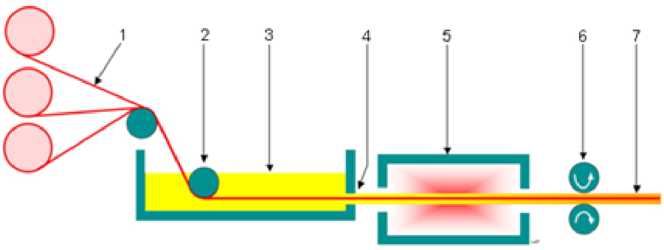

Fig. 2. Schematic diagram of the pultrusion process: 1) rowing, 2) tension rolls, 3) fibre saturated with resin, 4) shaping, 5) heating and hardening, 6) drawing mechanisms and 7) ready hardened product [6]

The process of pultrusion involves the pulling of a fibre through a bath filled with thermohardening resin (the stage of impregnation) and, next, through a system of moulds providing an appropriate shape and hardening the resin thermally. The final stage of the process involves cutting fibres into sections of required lengths. The use of the above-presented technology combined with the unidirectional arrangement of fibres results in the obtainment of rebars characterised by significant longitudinal strength. Fibres make up approximately 80% of the rebar volume, whereas resins constitutes the remaining 20% (Fig. 3).

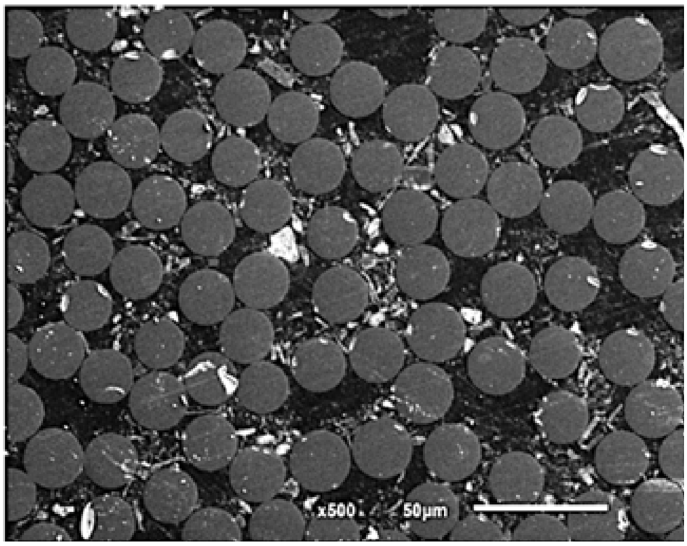

Fig. 3. Cross-section of a glass fibre-reinforced polymer (GFRP) rebar [7]

The use of fibres aims to provide appropriate strength and rigidity of the composite, whereas the resin is responsible for the joining of the fibres, the maintaining of appropriate distance between the fibres, the protection of fibre surface against mechanical and chemical damage as well as transmitting stresses to the fibres. The most commonly used fibres include glass fibre-reinforced polymer (GFRP), carbon fibre-reinforced polymer (CFRP), basalt fibre-reinforced polymer (BFRP) or aramid fibre-reinforced polymer (AFRP). Three rebar surface finishing types used to improve the adhesion of bars to the concrete matrix include, similar to steel rebars, the making of ribs, the coating of the bar surface with a sand layer or winding an additional layer of fibres around the bar [8, 9].

The mechanical parameters of FRP bars vary significantly from those of traditional steel rebars. The tensile strength of composite rebars depends primarily on reinforcement fibres and is restricted within the range of 483 MPa (in terms of glass fibre-reinforced polymer) to as many as 3690 MPa (in relation to carbon glass fibre-reinforced polymer). In turn, the compressive strength of composite rebars is restricted within the range of 20% to 78% of their tensile strength. In general, compressive strength is higher in relation to rebars characterised by higher tensile strength. An exception to the above-named rule is observed in rebars made of AFRP, revealing non-linear behaviour during compression in relation to a relatively low level of stresses. One of the disadvantages of non-metallic composite rebars is their low modulus of longitudinal elasticity. The modulus of elasticity of GFRP rebars is restricted within the range of 35 GPa to 51 GPa, whereas that of AFRP bars is restricted within the range of 41 GPa to 125 GPa. Only in terms of CFRP rebars, the modulus of elasticity amounts to 580 GPa [10]. A significant disadvantage of composite rebars is the lack of plasticisation before rupture (Fig. 4); the diagram of the stress-strain ratio is nearly ideally linear both in terms of bars and single fibres. As a result, rupture following the exhaustion of load-carrying capacity is abrupt and not signalled before. For this reason, the FRP-based reinforcement is not recommended in cases requiring the redistribution of moments. It is suggested that elements be designed so that failure takes place through the crushing of the compressed zone and not through the rupture of rebars; the overloading of an element would be signalled by scratches on concrete and excessive bends.

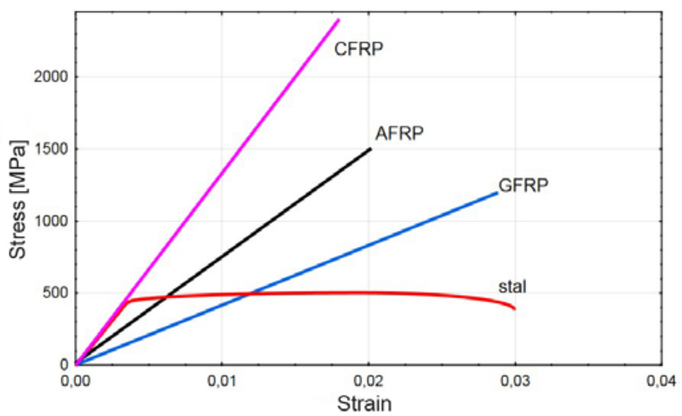

Fig. 4. Stress-strain ratio in relation to steel and composite rebars [12]

The primary properties of GFRP, FRP and AFRP rebars, compared with similar properties of steels bars, are presented in Table 1.

Table 1. Primary properties of GFRP, CFRP and AFRP rebars in comparison with steel rebars [11]

Property	Material			
	Steel	GFRP	CFRP	AFRP
Density [g/cm^3]	7.85	1.25÷2.10	1.50÷1.60	1.25÷1.40
Thermal expansion coefficient [1/°C] in parallel to fibres ×10^{-6} transversely in relation to fibres ×10^{-6}	 11.7 11.7	 6÷10 21÷23	 -2÷0 23÷32	 -6÷-2 60÷80
Yield point [MPa]	270÷550	-	-	-
Tensile strength [MPa]	483÷690	483÷1600	600÷3690	1720÷2540
Modulus of longitudinal elasticity [GPa]	200	35÷51	120÷580	41÷125
A_5 [%]	13÷24	-	-	-
Percentage total elongation in relation to maximum force A_{gt} %	2.5÷5	1.2÷3.1	0.5÷1.7	1.9÷4.4

Composite rebars are characterised by numerous properties different from those characteristic of steel rebars. The advantages of composite rebars are the following [13]:
- high tensile strength,
- corrosion resistance,
- electromagnetic inertness,
- low thermal and electric conductivity (GFRP and AFRP),
- high fatigue strength (depending on a fibre type),
- low density,
- ease of cutting.

The disadvantages of composite rebars are the following [13]:
- lack of elasticity margin,
- low shear strength,
- low modulus of elasticity (depending on a fibre type),
- low resistance to UV radiation,
- short service life of glass fibres in a humid environment,
- short service life of glass fibres and aramid fibres in an alkaline environment,
- high thermal expansion coefficient in the direction transverse in relation to fibres,
- potentially low fire resistance (depending on the type of resin and the thickness of a concrete cover),

– high price (depending on types of fibres, between 2 and 10 times higher than the price of rebars made of unalloyed steels).

Because of the foregoing, composite rebars should not be automatically used in any structures and treated as fully equivalent to bars made of unalloyed steels or corrosion-resistant steels. The primary factors to be taken into consideration when selecting composite rebars should include the intended use of a designed structure and the environmental conditions it will be exposed to during operation. Composite rebars should not be used to reinforce concrete in structures of frameworks having rigid nodes, in elements requiring the redistribution of bending moments or as the reinforcement of the compressed zone of concrete cross-section. Some of the primary advantages of composite rebars include their low specific gravity (Fig. 5) and high tensile strength (Fig. 6).

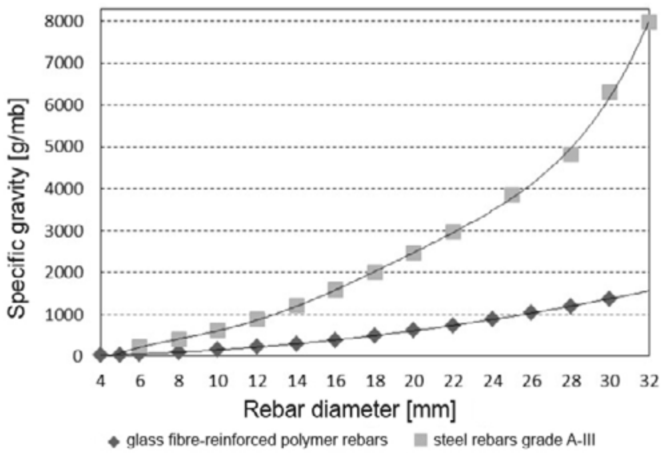

Fig. 5. Correlation between specific gravity of selected rebars and the rebar diameter [14]

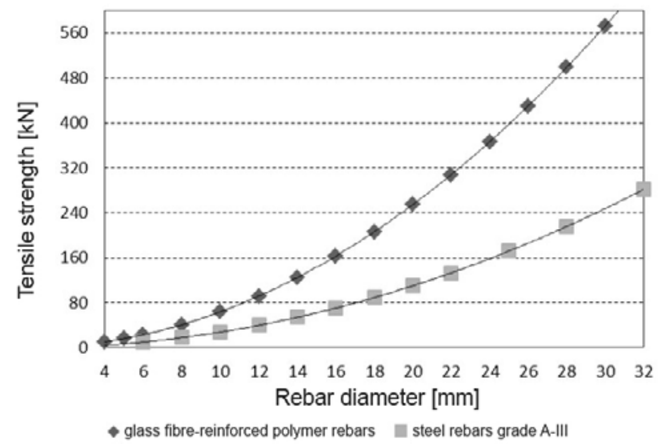

Fig. 6. Correlation between tensile strength transferrable by selected rebars and the rebar diameter [14]

Applications of composite rebars

The properties of composite rebars make them usable in buildings, where structures made of steel rebars do not satisfy related requirements. It is often necessary to apply solutions alternative to the use of corrosion-resistant steel rebars or to apply special and very expensive additional technical solutions, such as special screens or additional protective coatings. The use of composite rebars enables the avoidance of the above-named activities and reduce (several times) reinforcement-related costs. High-power equipment (e.g. transformers) used in industry may, in close contact with reinforced concrete, induce current in steel rebars, accelerating their corrosion and quickening the loss of strength by the entire structure. The phenomenon of induction does not occur in composite rebars as these do not conduct electric current. As a result, electric devices operated near composite bars do not generate losses. In objects where steel could adversely affect (impede or even preclude) the operation of electronic equipment, it is necessary to use rebars made of non-metallic and non-magnetic materials. Apart from being electric insulators, composite rebars are entirely inert electromagnetically. For this reason, they satisfy the above-named requirements to a significantly greater extent than corrosion resistant steel (being, at the same time, several times cheaper). Because of their properties, composite rebars are often used in bridge decks, kerbs, parapet walls, barriers and pavements on bridges, acoustic barriers, (railway) sleepers, screens and foundations in transformer stations and rectifiers, industrial floors and metallurgical furnace foundations. They are also frequently used when building hospitals, nanotechnological centres, research laboratories, airports, harbours, water dams, swimming pools, waste-water treatment plants, carparks, breakwaters, soft-eye (cavity) walls in underground tunnels (made using boring shields) and temporary buildings [15, 16, 17].

One of more interesting applications of composite bars is connected with the making of soft-eye (cavity) walls used, among other things, during underground (metro) construction works, at sites penetrated by the boring shield. Figure 7 presents the reinforcement of a soft-eye wall made using composite rebars, whereas Figure 8 presents the site penetrated by the boring shield.

Fig. 7. Reinforcement of the soft-eye wall made using composite rebars (21 metres in height) [18]

Fig. 8. Penetration of a soft-eye wall by the Maria boring shield; construction of the north-east section of Warsaw underground line II [19]

Another popular application of composite rebars is connected with the making of bridge floors. The Joffre bridge was built in Canada in 1997. This five-span bridge (extreme spans being 25.90 metre-long each, internal spans having a length of 37/50 m) is composed of primary girders (steel plate girders) made of steel and a 260 mm thick concrete plate resting on the girders. The axial spacings of the four girders are equal in length and amount to 3.70 m, whereas the outreach of cantilevers is 1.00 m. The substantial part of the concrete plate was reinforced using CFRP bars. The Wotton Bridge was also built in Canada, in 2001. The concrete plate rests on four girders made of pre-tensioned pre-stressed concrete; girder spacings amount to 2.65 m, whereas the span of (freely supported) beams amounts to 30.60 m. In the longitudinal axis, the bridge plate was reinforced using GFRP rebars, whereas the lower part of the reinforcement was partly made of CFRP rebars. The kerbs and concrete barriers were reinforced using GFRP rebars, whereas the second half of the bridge was reinforced with steel [20]. Figure 9 presents an example of bridge reinforcement made using composite bars in Morristown, Vermont.

Fig. 9. Bridge in Morristown, Vermont; the reinforcement was made using GFRP composite rebars [21]

Table 2 presents exemplary applications of composite rebars in various structures, whereas Table 3 presents the use of composite rebars in soft-eye (cavity) walls.

Table 2. Exemplary applications of composite rebars [21, 22, 23]

Country	City	Structure
Austria	Kaprun	foundations of a transformer station
Belgium	Antwerp	Liefkenshoek railway tunnel
Holland	Enschede	foundation footing at Twente University in the Carré building
Japan	Fukushima Prefecture	bridge
Canada	Windsor	canopies and guard rails on the McHugh Street Bridge
	Irvine Creek	reinforcement of the guard rail of a bridge
	Magog	upper reinforcement of the bridge plate
	Montague	reinforcement of the bridge plate
	Victoria	reinforcement of the bridge plate
	Morristown	reinforcement of the bridge plate
	Nova Scotia	bank protections in the Hall's Harbour
	Waterloo	reinforcement of the floor panelling under the laboratory rooms at Quantum Nano Centre
	Toronto	reinforcement of the internal walls of a laboratory at the Centre for Addiction & Mental Health
Qatar	Doha	waterside wall in a royal villa
	Qatalum	hearth plate of a rectifier in aluminium works
Germany	Jagsthausen	upper reinforcement of the bridge plate
	Darmstadt	swimming pool of the Technical University
	Osnabrück	industrial floor at Coca–Cola AG
	Kelsterbach	edge reinforcement at Park & Fly carpark
	Munich	partition between transformers at Isar plant – Amperwerke
	Marl	foundations of reactive current compensation system at Swiss Steel AG in Chemiepark
	Mannheim	reinforcement of floors for power plant conduit penetrations

Country	City	Structure
Germany	Berlin	floor of the Forum Steglitz carpark
	Berlin	reinforcement of floor panelling in the microscope laboratory of Technical University
	Gatersleben	reinforcement of foundations under nuclear magnetic resonance equipment at the Leibnitz Institute for Plant Genetics
	Münster	floor panelling and foundation blocks of two laboratories TEM CeNTech II
	Peine	transformer foundations at Peine Träger GmbH
	Karlsruhe	reinforcement of foundation piles
	Manching	compass rose on the airport apron
Norway	Hamneset	transformer foundations
Poland	Gdańsk	reinforcement of tunnel wall (under Martwa Wisła)
	Warszawa	floor reinforced with composite rebars - Instytut Lotnictwa (Aviation Institute)
	Nowy Sącz	platform of a foot and bike bridge over the Kamienica river
USA	York, Maine	hospital, magnetic resonance room
	Walla Walla Washington	haven
	Lahaina, Maui Hawaii	breakwater
	Pearl Harbour	dry dock
	Palm Beach	breakwater
	Honoapiilani Highway	breakwater
Switzerland	Basel	reinforcement of a railway line foundation plate
	Bern	non-ballasted at the railway station
Great Britain	Wotton Bridge	upper reinforcement of Wotton Bridge plate
	Blackpool	bank protection along waterside promenade
	London	luggage tunnel in Terminal 5 at Heathrow airport

Table 3. Exemplary applications of composite rebars in soft-eye (cavity) wall [24]

Country	City	Structure
Saudi Arabia	Makkah	tunnel
Denmark	Copenhagen	underground
Philippines	Angat	tunnel
France	Cessy	CERN LHC – Nuclear European Laboratory
Greece	Thessaloniki	underground
Spain	Sant Adrià de Besòs	underground
	Girona	tunnel
	Barcelona	underground
Canada	Toronto	underground
Germany	Coesfeld	slope protection
Panama	Panama	underground
Poland	Warszawa	underground
Romania	Bucharest	underground
	Sighişoara	tunnel
Slovenia	Ljubljana	tunnel
USA	Las Vegas	tunnel
Switzerland	Vaumarcus	tunnel
Turkey	Ankara	underground
	Istanbul	tunnel
Italy	Naples	underground
	Roma	underground
	Brescia	underground
	Milan	underground
	Sparvo	tunnel
	Florence - Santa Lucia	tunnel
	San Benedetto Val di Sambro	tunnel

Composite bars are non-toxic and easy to dispose of. Elements which are old or damaged beyond repair are easier to demolish and generate less waste than their equivalents containing steel rebars. The fabrication of composite rebars consumes approximately 20–30% of energy needed to produce the same amount of reinforcement steel. The possibility of reducing the cover of rebars using glass fibres and decreasing cross-sectional dimensions of building structures makes it possible to reduce the amount of concrete in a given element and, consequently, reduce the consumption of energy and the emission of carbon dioxide. The estimated service life of composite rebars is restricted within the range of 70 years to 100 years. Because of their unique features and relatively easy transport, composite rebars also find applications in housing [22].

Summary

Composite bar-based reinforcement constitutes an alternative solution to its widely used steel-based equivalent. High unit prices of composite rebars combined with some of their disadvantages are responsible for the fact that composite bars are not used in massive amounts but only supplement steel reinforcement. However, in many cases it is necessary to make reinforcement using materials not conducting electric current (e.g. to ensure the proper operation of transformer stations). If compared with steel rebars, the primary advantage of composite rebars is their low weight (even 6 times lighter than that of steel bars). As a result, composite reinforcement bars are easier to load, transport and fix. Similar to other composite materials, composite rebars reinforced with various fibres can be joined by (e.g. vibration) welding (it is not practised, though). Composite bars are usually delivered in coils (having lengths of tens of metres). It is worth knowing the properties, advantages and disadvantages of available (also non-weldable) structural materials to ensure their aware and optimum use.

References

[1] Węglowski M. St.: Pręty zbrojeniowe ze stali niestopowej – wytwarzanie. Biuletyn Instytutu Spawalnictwa, 2019, no. 2, doi .

[2] Węglowski M.St.: Pręty do zbrojenia betonu ze stali odpornej na korozję. Biuletyn Instytutu Spawalnictwa, 2019, no. 3, doi .

[3] *https://www.asdreports.com/news-15569/frp-rebar-market-worth-9100-m-usd-2021.*

[4] Szumigała M., Pawłowski D.: Zastosowanie kompozytowych prętów zbrojeniowych w konstrukcjach budowlanych.

Przegląd Budowlany, 2014, no. 3, pp. 47-50.
[5] https://www.pretyzkompozytow.pl/oferta/pretyy-kompozytowe/zalety.html.
[6] http://fiber-plast.pl/pultruzja/.
[7] https://www.liteform.com/wp-content/uploads/2018/03/ACI-SP-Long-Term-Durability-of-GFRP-Internal-Reinforcement-in-Concrete-Structures.pdf.
[8] Rduch A., Rduch Ł, Walentyński R.: Właściwości i zastosowanie kompozytowych prętów zbrojeniowych. Przegląd Budowlany, 2017, no. 11, pp. 43-46.
[9] ACI 440.1R-06 (2006). Guide for the design and construction of concrete reinforced with FRP bars. ACI Committee 440. American Concrete Institute, USA. https://ascelibrary.org/doi/abs/10.1061/40753%28171%29158
[10] Grygo R., Kosior–Kazberuk M.: Zbrojenie konstrukcji betonowych niemetalicznymi prętami kompozytowymi FRP. Civil and Environmental Engineering, 2017, vol. 8, pp. 23-30.
[11] Mossakowski P.: Pręty z kompozytów polimerowych z włóknami do zbrojenia betonowych konstrukcji inżynierskich. Drogi i Mosty, 2006, no. 1, pp. 35-52.
[12] Fico R.: Limit states design of concrete structures reinforced with FRP bars. PH.D. Thesis, 2008.
[13] http://www.frpdistributors.com/gfrp-vs-steel/gfrp-vs-ecr.
[14] Brózda K., Selejdak J.: Metody zwiększania właściwości wytrzymałościowych zbrojonych belek betonowych. Zeszyty Naukowe Quality, Production. Improvement, 2016, vol. 1, no. 4, pp. 28-39.
[15] https://fiberline.com/structural-profiles/combar-fiberline.
[16] http://p-i-m.top/index.php/our-product.
[17] Armstek. Pręty kompozytowe do zbrojenia betonu.
[18] https://www.dextragroup.com/activities/technical-solutions-for-construction/solutions/26-concrete-construction/composite-frp-reinforcement/57-astec-soft-eyes.
[19] https://www.transport-publiczny.pl/wiadomosci/metro-tarcza-maria-przebila-sie-do-stacji-targowek-55557.html.
[20] Mossakowski P.: Pręty z kompozytów polimerowych z włóknami do zbrojenia betonowych konstrukcji inżynierskich. Drogi i Mosty, 2006, no. 1, pp. 35-52.
[21] http://www.radyab.co/en/frpbars/applications.
[22] Jarek B., Kubik A.: Zastosowanie prętów zbrojeniowych z włókna szklanego (GRFP) w budownictwie. Przegląd Budowlany, 2015, vol. 12, pp. 21-26.
[23] Gremel D.: GFRP Rebar for a Longer Lasting Infrastructure. http://ricomposites.com/wp-content/uploads/2016/07/Gremel-FRP-Rebar-for-Longer-Lasting-Infrastructure.pdf.
[24] http://www.comrebars.eu/realizacje.php#.
[25] www.atp-frp.com/Brochure_SOFT_EYE.pdf.