ANALYSIS OF PROPERTIES OF THE FRP REBAR TO CONCRETE STRUCTURES

Kinga Brózda[1*], Jacek Selejdak[1], Peter Koteš[2]

[1]Czestochowa University of Technology, Faculty of Civil Engineering, Czestochowa, Poland
[2]University of Žilina, Civil Engineering Faculty, Žilina, Slovakia

Abstract:
The application of the FRP (Fiber Reinforced Polymer) rebar is presented in this paper. The various kinds of fibers, depending on the types of the FRP rebar and types of matrix of FRP are listed. The main tasks of matrix and fibers are specified. The two methods of FRP bars production are explained. The selected physical and mechanical properties of the various types of the FRP rebar are shown and compared. The long-term properties of the FRP rebar, as relaxation and creeping processes, are also introduced. The FRP properties were compared to conventional steel reinforcement properties. Moreover, the typical disadvantages of traditional reinforced concrete, as the susceptibility to corrosion were presented. It is shown that the FRP reinforcement is quite opposite, since it has almost total resistance to corrosion. The corrosion factors, to which the FRP is resistant, are presented and explained.

ARTICLE HISTORY
Received 18. February 2017.
Accepted 21. Mart 2017.
Available 30. Mart 2017.

KEYWORDS
FRP rebar, structure, production process, corrosion resistance, long-term, physical and mechanical properties.

1. INTRODUCTION

Due to the high susceptibility to technological and material innovations, and huge development ability as well, civil engineering represents a significant aspect for development of the material engineering. Building and engineering structures are often implemented and operated in very difficult environmental conditions. In an aggressive environment, in which reinforced concrete elements do not comply with the application requirements, the polymer reinforcements are used increasingly [1]. In order to develop an alternative to conventional reinforcing steel, the Fiber Reinforced Polymer (FRP) rebar, reinforced with long fibers, were introduced in use. The first use of fiber reinforced materials, such as glass fiber, carbon fiber or aramid fiber, were implemented in the concrete industry in the late nineteen seventies.

Very good strength properties, low self-weight and high durability in aggressive environment, generate an intensive development of verifying the possibility of applying the FRP rebar as the main reinforcement in concrete structures [2,3]. Furthermore, due to easy and rapid assembly under any weather conditions, the composite reinforcement finds its application in many areas of the construction industry. Thanks to its non-magnetic characteristics, this reinforcement is also used in industrial objects, particularly exposed to electromagnetic waves. In this situation the FRP rebar can be used as a reinforcement of, among others, electrolytic baths or foundations for transformers of special building and engineering objects [2].

1.1 Structure of the material

The FRP bars, used as reinforcement of concrete structures, consist of a matrix (usually thermosetting resins as polyester, epoxy, vinyl ester, phenolic etc. or thermoplastic resins as polyetheretherketone PEEK or PPS polyphenylene sulphide) and the embedded continuous fibers, which are internal reinforcement of the composite.

*CONTACT: Kinga Brózda, kbrozda@bud.pcz.czest.pl

The main task of the matrix is to take over the transmission of stresses caused by external loads on the fibers, but also to provide the proper separation of reinforcing fibers, to protect them from damage. In general, the fiber content is between 30 and 70% by volume of the overall composite. The fibers' type and their contents depend on the expected properties of strength and stiffness of the finished product. Depending on the used kind of fiber four types of the FRP bar are distinguished [4-6]:

- GFRP (Glass Fiber Reinforced Polymers) – polymer composites reinforced with glass fibers E-glass, S-glass and resistant to alkalis – AR-glass (Fig. 1.);
- CFRP (Carbon Fiber Reinforced Polymers) – polymer composites reinforced with graphite and carbon fibers (Fig. 2.);
- AFRP (Aramid Fiber Reinforced Polymers) – polymer composites reinforced with aramid fibers Kevlar 29, Kevlar 49, Kevlar 149, Technora H and SVM (Fig. 3.);
- BFRP (Basalt Fiber Reinforced Polymer) – polymer composites reinforced with basalt fibers (Fig. 4.).

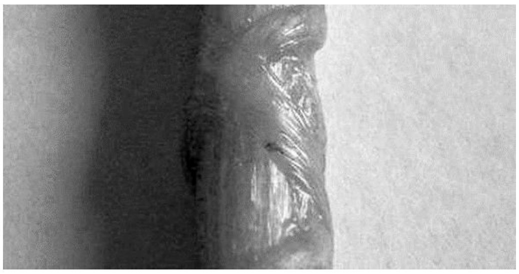

Fig. 1. GFRP bar [7]

Fig. 2. CFRP bars [8]

Fig. 3. AFRP bars [9]

Fig. 4. BFRP bars [7]

1.2 The production process

The two types of production methods of the FRP bars are distinguished mainly, depending on the applied matrix [4,10]. Those methods are:

- The composites made of thermoplastic resins – produced by the injection and extrusion methods;
- The composites based on thermosetting resins – produced in two stages: I – the so-called molding compositions (resins with additives) are prepared by wet or dry method, II – the molding compositions are processed into finished products.

To obtain the continuity of physical and mechanical parameters and to guarantee the highest quality of the composite rebar in production the pultrusion method is used. A scheme of the pultrusion process is presented in Fig. 5. In this method, before the reinforcing fibers are pulled through the chamber, where the fibers are impregnated with a synthetic resin, the fibers are pulled from fiber (roving) creels controlled by the pulling system. The fibers exit the resin bath and enter the performer where material is shaped. Subsequently, the composite passes through the heated die where the final cross-section is determined and cured. Finally, the product is cut to desired length [10,11].

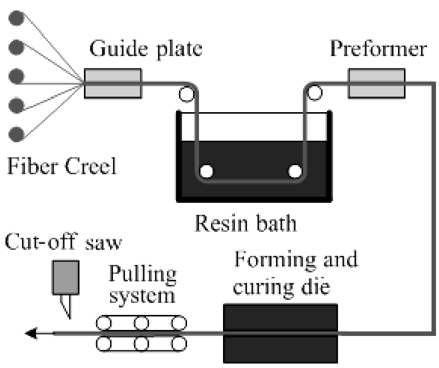

Fig. 5. Scheme of the pultrusion process [11]

2. PROPERTIES OF FRP BARS

Considering the mechanical and physical characteristics of the FRP rebar it should be noted that they are directly related not only to the type of used fibers, but also to the direction of fibers orientation, its percentage content of the entire volume of the composite and the diameter of the rebar. The type of used polymer matrix and the method of production can also significantly affect the physical and mechanical properties of the FRP rebar [6,10].

2.1 Physical and mechanical properties

The selected basic physical and mechanical characteristics of the FRP reinforcement, based on the product data sheets and American design recommendations, are presented in the Table 1.

Table 1. The selected physical and mechanical properties of the FRP rebar [7, 13, 14]

Properties	Type of rebar depends on used fibers			
	GFRP [7]	BFRP [7]	CFRP [14]	AFRP [13]
Density[g/cm3]	1.85 – 2.04	1.99 – 2.26	1.6	1.25 – 1.40
Tensile strength [MPa]	≤ 1250	≤ 1450	≤ 3100	≤ 2540
Tensile modulus of elasticity [GPa]	≤ 55	≤ 78	≤ 148	41-125
Elongation at rupture along the fiber [%]	2.2 – 2.8	2.2 – 2.6	> 1.7	1.9 – 4.4
Tensile strength/density ratio	613	642	1938	1814

In comparison to the reinforcing steel, wherein the density is from 7.5 to 8.7 g/cm3 (usually the average value 7.85 g/cm3 is taken), [15], the FRP bars are characterized by nearly fourfold lower density and therefore – much less dead load. The highest density of the FRP bars have basalt fiber reinforced (BFRP). In turn, bars reinforced by carbon fibers (CFRP) are characterized by the largest tensile strength/density ratio – for steel bars this ratio is approx. 88.

The strength properties of the FRP bars in tension have linear elastic characteristics until rupture. Since there is no plastic deformation, the destruction takes place suddenly, without any prior indications [6,7]. Furthermore, the tensile strength of the reinforcing steel, in comparison to the FRP bars, is considerably lower, whereas the tensile modulus is relatively low (except for the CFRP bars).

2.2 The long-term properties

The properties of the FRP bars, which are under the long-term action of load, are significantly different from the characteristics of those under the short-term action [6]. It is estimated that after 50 years the load reduction, as a result of relaxation, is 2 – 10% for the CFRP rebar, 4 – 14% for the AFRP and 11– 25% for the GFRP [16]. In turn, the susceptibility to creeping process increases with the intensification of the load level. The environmental factors, i.e. high temperature or UV radiation, also contribute to intensification of creep. The lowest susceptibility to creep, after 500 000 h, have the CFRP bars (reduction of the short-term tensile strength at rupture is approx. 7%) and the next is for the AFRP bars (53% reduction). The most susceptible are the GFRP bars, where reduction is up to 77% [17]. Moreover, the concrete elements reinforced with FRP bars have very good fatigue properties, under the assumption that the load acts parallel to the direction of fibers [12].

2.3 The corrosion resistance

The undoubted disadvantage of traditional reinforced concrete is susceptibility to corrosive factors. The building and engineering structures are often exposed to the influence of frequent wetting, temperature changes, impact of large external loads etc. Those interactions often cause the destruction of protective coating of reinforcement, which can lead to corrosion. Expansion of corrosion products results in thedestruction of concrete elements [18,19].

During the designof engineering structures (especially bridges), it is necessary to use repeatedly the construction and materials solutions, which have possibly the highest corrosion resistance. This is largely possible to achieve by application of the FRP rebar [12,20]. The properties of the FRP bars allow for their use in structures, in which the use of conventional reinforced concrete does not meet the set requirements. For example, the industrial equipment, which produces strong power and is placed close to the reinforced concrete element can cause the induced current in the steel rebar. The result is rapid corrosion and loss in load carrying capacity of the whole structure [12].

The undeniable advantage of the FRP reinforcement is its total resistance to corrosion. The composite rebar does not conduct electricity and electrical equipment that properly operate near works. In addition, structural elements reinforced with FRP bars are free of defects that appear in reinforced concrete structures, i.e. they are resistant to the harmful effects of water, salt water or acid environment [21]. The corrosion resistance is a common feature of the fiber reinforced rebar. To obtain such an effect is possible by using the polymer matrix. The polymer fibers, used to produce the FRP rebar, are characterized by very high chemical resistance to oxidation, but also to corrosion, which is caused by chlorides, sulfates, mold, rust, etc. This is a particularly important feature, especially in the case of aggressive environment impact, caused by vicinity of the sea water or influence of the heavy industrial area [12].

3. SUMMARY

In order to eliminate the typical defects and disadvantages of conventional reinforced concrete the FRP rebar are increasingly investigated and used in the construction industry. The reason is multitude of very good physical and mechanical properties of this material, such as high tensile strength and resistance to corrosion, low density, electromagnetic, electrical and electro-static neutrality. All of these properties are related to the internal structure of the rebar. It consists of embedded continuous long fibers (carbon, glass, basalt, aramid), which act as internal reinforcement of the composite and matrix (thermosetting or thermoplastic resins), which provide not only the proper separation of reinforcing fibers and protection from damage, but also the proper transmission of stresses on the fibers.

The mechanical and physical properties of the FRP rebar depend on the used type and content by volume of fibers, direction of these fibers (i.e. load acts parallel to the direction of the fibers) and chosen method of production (e.g. pultrusion). Because of materials used in production, the density and self-weight of the FRP is much lower than steel. The differences in density appears also between types of bars. The basalt fiber reinforced bars (BFRP) are characterized by the highest density and thus, the highest self-weight. On the other hand, the largest tensile strength/density ratio is a characteristics of the CFRP bars (approx. 22 times more than reinforcing steel). In comparison to the reinforcing steel, the tensile strength of the FRP bars is very high and has linear elastic characteristics until rupture. Moreover, with exception of the CFRP bars, the tensile modulus is relatively low. However, the attention should be paid to the fact that properties of the FRP bars under the long-term action of load are different from those at the short-term. It is expected that the highest load reduction, as a result of relaxation has the GFRP rebar (11–25%) and the lowest the CFRP – 2 – 10%. The CFRP bars also have the lowest reduction of the short-term tensile strength at rupture (approx. 7%) as a result of creep.

The fact that the FRP rebar has the high corrosion resistance should not be left out. It is one of the properties of the FRP bars, which contributes to reducing the traditional reinforced concrete defects, i.e. the influence of acid environment or action of water. The high corrosion resistance is provided by the polymer matrix, which is characterized by very high chemical resistance to oxidation and corrosion caused by chlorides, sulfates, mold and rust. The corrosion resistance is one of the most important characteristics of reinforcing materials, especially when the concrete structure works in an aggressive environment.

ACKNOWLEDGEMENT

This work was supported by the Slovak Research and Development Agency under the contract No. SK-PL-2015-0004“.

REFERENCES

[1] C. Bywalski, M. Drzazga, M. Kamiński, Zbrojenie GFRP w zginanych elementach betonowych. Materiały budowlane, - (6), 2015: pp.68-69.

[2] M. Drzazga, M. Kamiński, Pręty kompozytowe FRP jako główne zbrojenie zginanych elementów betonowych – przegląd zaleceń i efektywność projektowania. Przegląd budowlany, - (3), 2015: pp.22-28.

[3] O. Gunnarsson, J. Hjalmarsson, Aramid Fiber Rods as Reinforcement in Concrete. Lund Institute of Technology, Report TVBK-5067, Lund, 1993.

[4] K. Baszkiewicz, J. Selejdak, Zastosowanie wybranych materiałów kompozytowych w konstrukcjach mostowych, in: R. Nagórski (Ed.), Wybrane interdyscyplinarne zagadnienia budownictwa. Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa, 2015, pp.423-432.

[5] K. Brózda, J. Selejdak, Metody zwiększania właściwości wytrzymałościowych zbrojonych belek betonowych, in: W. Biały, M. Mazur (Ed.), Techniczne aspekty inżynierii produkcji, Oficyna Wydawnicza Stowarzyszenia Menedżerów Jakości i Produkcji (SMJiP), Częstochowa, 2016, pp.35-46.

[6] M. Szumigała, D. Pawłowski, Zastosowanie kompozytowych prętów zbrojeniowych w konstrukcjach budowlanych, Przegląd budowlany, - (3), 2014: pp.47-50.

[7] Polprek Sp. z o.o. products. http://polprek.pl/ (accessed 13.12.2016).

[8] Haining Anjie Composite Material Co., Ltd. Products. http://www.anjiezj.com/ (accessed 23.11.2016).

[9] Takenoiri Seisakusho Co., Ltd. Products. http://www.takeiri-seisakusyo.jp/tafrod/produ cts/ (accessed 23.11.2016).

[10] Schöck products catalog, Schöck ComBAR – Technical Information. http://www.schoeck.com/upload/files/download/Product_Catalogue%5B4753%5D.pdf (accessed 20.10.2016).

[11] The technical information contained on the website: http://www.substech.com (accessed 13.12.2016).

[12] P. Mossakowski, Pręty z kompozytów polimerowych z włóknami do zbrojenia betonowych konstrukcji inżynierskich. Drogi i mosty, - (1), 2006: pp.35-52.

[13] ACI 440.1R-06 Guide for the design and construction of concrete reinforced with FRP bars.

[14] Sika AG products catalog, Sika® CarboDur® BC – Technical Information. https://pol.sika.com/dms/getdocument.get/56fbcc9b-9507-36f5-a8d7-b59a3ea3d407/KI_Sika_CarboDur_BC_Rods_pol.pdf (accessed 13.12.2016).

[15] EN 1991-1-1: Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings.

[16] G.L. Balazs, A. Borosnyoi, Long-term behavior of FRP, Proceedings of the International Workshop Composites in Construction: A reality, American Society of Civil Engineers, Reston, 2001, pp.84-91.

[17] T. Yamaguchi, Y. Kato, T. Nishimura, T. Uomoto, Creep rupture of FRP rods made of aramid, carbon and glass fibers. Proceedings of the Third International Symposium on Non-Metallic (FRP) Reinforcement for concrete structures, Japan Concrete Institute, Vol.2, Tokyo, 1997, pp.179-186.

[18] K. Baszkiewicz, J. Selejdak, Comparison of selected properties of reinforced concrete and prestressed concrete structures for bending structural components, in: S. Borkowski, M. Ingaldi (Ed.) Toyotarity. Management of Technology, Aeternitas Publishing House, Alba Iulia, 2014, pp.176-189.

[19] K. Baszkiewicz, J. Selejdak, M. Gawron, Wpływ wybranych zabezpieczeń antykorozyjnych na jakość betonowych konstrukcji mostowych, in: A. Czajkowska (Ed.), Różne aspekty jakości materiałów i procesów stosowanych w budownictwie, Wydawnictwo Politechniki Świętokrzyskiej, Kielce, 2015, pp.23-35.

[20] Michigan Department of Transportation, First CFRP Bridge in the USA Michigan Researchers and Consultants Using Tomorrow’s Technology Today. Construction & Technology, 2 (97), 2003: pp.1-4

[21] J. Selejdak, K. Brózda, Zastosowanie kompozytów w budownictwie zrównoważonym, in: A. Rak, V. Boychuk, W. Baran (Ed.), Zagadnienia inżynierii środowiska w budownictwie, Wydawnictwo Polski Związek Inżynierów i Techników Budownictwa, Oddział w Opolu, Opole, 2016, pp.99-110.

The shorter version of this research was presented at the "22nd International Seminar of PhD Students SEMDOK 2017", 25-27 January 2017, Western Tatras, Zuberec, Slovakia.