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APPLICATIONS OF FIBRE REINFORCED COMPOSITE POLYMER IN CONSTRUCTIONS

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ABSTRACT: fibrere in forced polymer composites, developed primarily for the aerospace and defence industries, are a class of materials with great potential to use in civil infrastructure. Since the construction of the first all-composite bridge superstructure in Miyun, China, in 1982, they have been gradually gaining acceptance from civil engineers as a new construction material. During these 30 years, their proved to be useful in a few areas of application: mostly in form of sheets and strips for strengthening existing bridge structures, and to some extent, as reinforcing bars substituting steel as concrete reinforcement. Also, a number of constructions have built, in which FRP composites replaced traditional materials for structural elements (girders, bridge decks, stay cables). Among these constructions there is a relatively big amount of hybrid bridge structures, where only a part of the superstructure is made of FRP composites, and a much smaller amount of all-composite bridge structures, with superstructures made exclusively of this material.

The purpose of this paper is to present the state of the art in the use of FRP composites in bridge engineering with the focus on hybrid and all-composite structures. Firstly, the paper will present the basic information about FRP composites, including the definition, description of the components, mechanical properties and general areas of application. Then, it will focus on FRP composites as the material of which structural elements are made, describing manufacturing processes relevant to civil engineering applications, assortment of structural profiles, cables, tendons and bridge deck systems, presenting the problem of codes and design guidelines that refer to the use FRP composites as the construction material, and methods of joining structural elements. Thirdly, it will compare the properties of FRP composites with those of traditional materials. Finally, there are presented some examples of hybrid and all composite bridge structures and a list of 355 constructions made of this material around the world, with basic data and references providing more information.

Keywords: modern materials, FRP composites, fibres, polymers, GFRP, CFRP, all composite bridge structures, hybrid bridge structures

1. Introduction and objectives

The aim of this paper is to present FRP composites as the new material used for the purposes of civil engineering and prepare the state of the artin bridge structures using FRP composites for structural elements as the substitution of traditional materials. The body of the project consists of 12 chapters: five of the m focusing on the description of the material and general application are as in bridge engineering, and the rest-on issues referring to two particular uses: hybrid and all-composite bridge structures.

Chapter one gives a general idea on FRP composite, defines it as a construction material and compares it to similarly working tradition al materials.

Chapter two focuses on the components of FRP composite, presents various kinds of fibres used as reinforcement and compares the ir properties. It describes the ingredients of a matrix: resins, fillers and additives, as well as the importance of fibre- matrix bond

Chapter three lists a number of properties of FRP composites common for these kind of materials and then presents some of them, such as density, modulus, Poisson´s ratio and tensile strength with more details, giving simplified formulas to determine the irvalues basing on the properties of the components.

Chapter four briefly describes general area so f application of FRP composites in bridge engineering: repair and retro fitting of existing bridge structures, concrete reinforcement, hybrid bridge structures and all-composite bridge structures.

Chapter five focuses on manufacturing methods relevant to civil engineering applications, dividing the min to manual, semi- automated and automated processes .Of special interest is the pultrusion process, which provides the possibility to produce FRP composite elements on a bigger scale.

Chapter six presents the assortment of structural profiles, cables/tendons and bridge decks made of FRP composites, produced by various companies around the world.

Chapter seven gives a brief explanation of current status of codes and design guidelines referring to the use FRP composites as the construction material.

Chapter eight presents and compares various kinds of connections between FRP composite elements: adhesive, mechanical and mixed.

Chapter nine compares FRP composites to traditional materials, presenting their advantages and is advantages (uncertainties).

Chapter ten and eleven presents one examples of existing, representative hybrid and all-composite bridge structures, respectively. Chosen examples are constructions varying instructural type, year of construction and FRP composite system used. Finally, chapter twelve presents a list of 355 FRP-using bridges, specifying the name of the structure, location, year of assembly and some basic available data, usually including the length and width of the bridge and the manufacturing company, as well as references providing more information (articles, photos, additional data, etc.).

2. Introduction to the material. Definition.

Composite is defined same chanically separable combination of two or more component materials, different at the molecular level, mixed purposefully in order to obtain anew material with optimal properties, different han the properties of the components (definition basedon [1],[2],[3]).

Composite materials have been used in construction for centuries. One of the first was the use of stra was reinforcement in mud and clay bricks by the ancient Egyptians [4]. The combination of reinforcing steel and concrete has been the basis for a number of structural systems used for construction for the last century. The new class of composite materials, gradually gaining acceptance from civil engineers, both for the rehabilitation of existing structures and for the construction of new facilities, are Fibre Reinforced Polymer composites, primarily developed for the aerospace and defence structures.

Fibre Reinforced Polymer composites are the combination of polymer icresins, acting as matrices or binders, with strong and stifffibre assemblies which act as the reinforcing phase[2]. The combination of the matrix phase with are in forcing phase produces a new material system, analogous to steel reinforced concrete, although the reinforcing fractions vary considerably (i.e., reinforced concreteing eneralrarely contains more than 5% reinforcement, where as in FRP composites, according to various sources([1]-[5]), reinforcing volume fraction ranges from 30-70%).

3. Components and function

A fibre is a material made into along filament. According to[5], a single fibre usually has a diameter upto15um. Bigger diameters generally increase the probability of surface defects. The aspect ratio of length and diameter can be ranging from thousand to infinity in continuous fibres. They usually occupy 30-70% of the volume of the composite and 50% of its weight.

The main functions of fibres are to carry the load and provide stiffness, strength, thermal stability and other structural properties to the FRP [2]. To perform these functions, the fibres in FRP composite must have high modulus of elasticity, high ultimate strength, low variation of strength among fibres, highst ability of the irstrength during handling and high uniformity of diameter and surface dimension among fibres.

4. Forms of fibres

There are various forms of fibres used as a reinforcement of polymer composites. Manufacturers of structural elements made of FRP composites usually present the variety of reinforcement techniques in specifications/design guides (for instance, Fiber line Composites in [6]). Basically, there are two forms of reinforcement: Rovings and fabrics [5].

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Roving as a one-dimensional reinforcement of polymer composites:

Smooth roving- bundle of filaments arranged longitudinal lyina free manner; interlace droving-bundle of filaments arranged longitudinally with elementary fibres inter lacedina loop to mechanically connect neighbouring roving,

tangle droving-bundle of filaments arranged longitudinally, inter laced mutually in order to provide better co-operation of the neighbouring filamentsina single roving,

Stapled fibres- short filaments made for example by cutting the smooth roving; minced fibres-very short filaments obtained by milling and sifting stapled fibres.

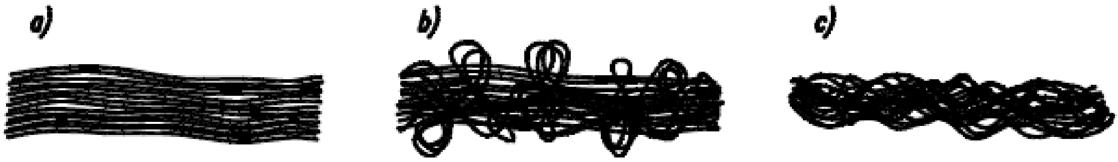

Fig.1. Various forms of roving: a) smooth roving, b) interlaced roving, c) tangle droving[5]

In order to strengthen the surface elements in more than one direction of reinforcement (although unidirectional surface reinforcement is also produced), the following forms are applied;

Smooth roving fabrics – fabrics made of interlaced roving;

Interlaced roving fabrics-interlaced rovins connect neighbouring fabrics;

Mats- made of discontinuous, random fibres

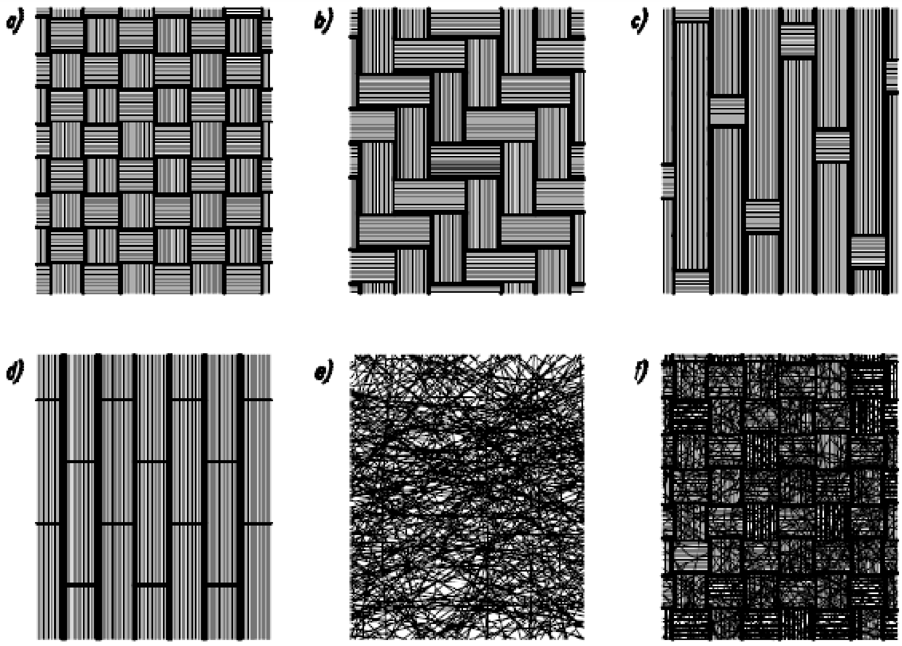

Fig.2. Examples of surface reinforcement: plain roving fabrics: a) weave, b) oblique, c), satin, d) smooth unidirectional roving fabric, e) mat, f) roving plain interlaced weave fabric [5]

5. Types of fibres

The type of fibres used as the reinforcement is the basics for classification of FRP composites. There are three types of fibres dominating civil engineering industry: glass, carbon and aramid fibres. The table below presents properties of various kinds of fibres.

Tab.1.Properties of glass, aramid and carbon fibres [5]

Typical properties	**Fibres**					
	Glass		**aramid**		**carbon**	
	E-Glass	**S-Glass**	**Kevlar29**	**Kevlar49**	**HS (High Strength)**	**HM (High Modulus)**
Density ρ [g/cm^3]	2,60	2,50	1,44	1,44	1,80	190
Young´s Modulus E[GPa]	72	83	100	124	230	370
Tensile strength R_m[MPa]	1,72	2,53	2,27	2,27	2,48	1,79
Extension[%]	2,40	2,90	2,80	1,80	11,00	0,50

6.Glass fibres

Glass fibres are a processed form of glass, which is composed of a number of oxides (mostly silica oxide), together with other raw materials (such as limestone, fluorspar ,boric acid, clay). They are manufactured by drawing those melted oxides into filaments ranging from3 µmto 24 µm. There are five forms of glass fibres used as the reinforcement of the matrix material: chopped fibres, chopped strands, chopped strand mats, woven fabrics, and surface tissue. The glass fibre strands and woven fabrics are the forms most commonly used in civil engineering application. Relatively low cost comparing to other kinds of fibres makes E-glass fibres the most commonly used fibres available in the construction industry. The disadvantages of glass fibres are are latively low Young´s modulus, the low humidity and alkal ineresistance as well as low long- term strength due to stress srupture. For applications involving concrete a more alkaline- resistant so-called AR fibre (also called CemFil fibre) has been developed with increased zircon oxide content[2].

Lp	Name of the Bridge	Location	Country/ State	Year	USE of FRP composites	Basic information and references
307	Friedberg Bridge over B3 Highway	Friedberg	Germany	2008	deck	Knippers, J. and Gabler, M., *New Design Concepts for Advanced Composite Bridges - The Friedberg Bridge in Germany*, IABSE Report, Vol. 92, 2007, 332-333 Knippers, J. and Gabler, M., *The FRP road bridge in Friedberg Germany – new approaches to a holistic and aesthetic design*, in Proc. 4th Inter. Conf. on FRP Composites in Civil Engineering (CICE2008), Empa, Duebendorf, 2008, Paper 7.D.6 p. 6. (CD-ROM). ISBN 978-3-905594-50-8 Knippers, J., Pelke E, Gabler M, and Berger, D., *Bridges with Glass Fibre Reinforced Polymers (GFRP) decks - The new Road Bridge in Friedberg (Hessen, Germany)*, Stahlbau, 787, 2009, 462-470 en.structurae.de/structures/data/index.cfm?id=s0021440 www.fiberline.com/structures/profiles-and-decks-bridges/profiles-road-bridges/case-stories-road-bridges/german-highway/german-highways-agency-comb
308	Footbridge over road no. 11 n. Gadki	Gadki	Poland	2008	deck	Manufactured by Fiberline Composites.
309	Holländerbrücke	Reinbeck	Germany	2009	deck	Length: 98,0 m. Width: 3,5 m. Manufactured by Fiberline Composites. Sobek W.; Trumpf H.; Stork L.; Weidler N.: *The Hollaenderbruecke. Economic and architecturally sophisticated design employing steel and GFRP*, In: Steel Construction 1 (2008), vol. 1, pp. 34–41 en.structurae.de/structures/data/index.cfm?id=s0043136 www.youtube.com/watch?v=CFqX9oFkB8I
310	Belle Glade Bridge	Belle Glade	USA, Florida	2009	deck	Manufactured by ZellComp, Inc. http://www.zellcomp.com/highway_bridge_instal.html
311	Lafayette Bridge	Lafayette, Tippecanoe	USA, Indiana	2009	deck	Manufactured by ZellComp, Inc. http://www.zellcomp.com/highway_bridge_instal.html
312	Lunetten Footbridge	Utrecht	The Netherlands	2010	deck	Length: 12,0 m. Width: 5,0 m. www.netcomposites.com/newspic.asp?6075

329	Birdie Bridge	Ibaraki	Japan	1990	tendons	Length: 54,6 m. Width: 2,1 m. Manufactured by Tokyo Rope Mfg. Ltd. and Mitsubishi Chemical
330	Talbus Bridge	Tochigi	Japan	1990	tendons	Length: 9,5 m. Width: 5,5 m. Manufactured by Shinko Wire Co.
331	Sumitomo Demonstration Bridge (1)	Oyama Works, Tochigi	Japan	1990	tendons	Length: 12,5 m. Width: 4,0 m. Manufactured by Teijin Ltd.
332	Sumitomo Demonstration Bridge (2)	Oyama Works, Tochigi	Japan	1990	tendons	Length: 25,0 m. Width: 4,0 m. Manufactured by Teijin Ltd.
333	Schiessbergstrasse Bridge	Leverkusen	Germany	1991	tendons	Length: 53,0 m. Width: 9,8 m. Manufactured by Bayer AG
334	Oststrasse Bridge	Ludwigshafen	Germany	1991	tendons	Length: 81,7 m. Width: 11,3 m. Manufactured by Tokyo Rope.
335	Bridge #15 Hakui Kenmin Bicycle Route	Ishikawa	Japan	1991	tendons	Length: 10,7 m. Width: 4,3 m. Manufactured by Tokyo Rope Mfg. Ltd.
336	Rainbow Bridge	Tokyo	Japan	1991	tendons	Manufactured by Shinko Wire Co. en.wikipedia.org/wiki/Rainbow_Bridge_(Tokyo)
337	Access Road to Rapid City Cement Plant	Rapid City	USA, South Dakota	1991	tendons	Length: 9,1 m. Width: 5,2 m. Manufactured by South Dakota School of Mines.
338	Takahiko Pontoon Bridge	Ibaraki	Japan	1992	tendons	Length: 73,2 m. Width: 3,0 m. Manufactured by Shinko Wire Co.
339	Amada Bridge	Ishikawa	Japan	1992	tendons	Length: 7,3 m. Width: 3,4 m. Manufactured by Tokyo Rope Mfg. Ltd.
340	Hishinegawa Bridge / Hakui Kenmin Bicycle Route	Ishikawa	Japan	1992	tendons	Length: 14,0 m. Width: 12,2 m. Manufactured by Tokyo Rope.
341	Beddenton Trail Bridge / Central Street	Calgary	Canada, Alberta	1993	tendons	Length: 42,0 m. Width: 15,2 m. Manufactured by Tokyo Rope Mfg., Ltd.
342	Yamanaka Bridge	Tochigi	Japan	1993	tendons	Length: 9,4 m. Width: 5,5 m. Manufactured by Shinko Wire Co. Ltd.
343	Slab Bridge	Mie	Japan	1995	tendons	Length: 10,7 m. Width: 3,7 m. Manufactured by Tokyo Rope Mfg. Ltd.
344	Sone Viaduct	Hyogo	Japan	1995	tendons	Manufactured by Teijin Ltd.
345	Mukai Bridge	Ishikawa	Japan	1995	tendons	Length: 14,9 m. Width: 14,3 m. Manufactured by Tokyo Rope.
346	Seisho Bridge Bridge	Kanagawa	Japan	1996	tendons	Length: 10,7 m. Width: 3,7 m. Manufactured by Tejin, Ltd.
347	Storchenbruecke	Winterthur	Switzerland	1996	tendons	Length: 123,7 m. Width: 6,1 m. Manufactured by BBR Ltd. en.structurae.net/structures/data/index.cfm?id=s0006274

Lp	Name of the Bridge	Location	Country/ State	Year	USE of FRP composites	Basic information and references
348	Taylor Bridge	Headingley	Canada, Manitoba	1997	tendons	Length: 132,0 m. Width: 17,0 m. Manufactured by Tokyo Rope Mfg., Ltd.
349	Milbridge Bridge	Milbridge	USA, Maine	1997	tendons	Length: 4,9 m. Width: 7,3 m. Manufactured by South Dakota School of Mines.
350	Herning Stibro	Herning	Denmark	1999	tendons	Length: 79,9 m. Width: 3,0 m. en.structurae.de/structures/data/index.cfm?ID=s0004909
351	Parker @I-225 Bridges	Denver	USA, Colorado	2000	tendons	Length: 10,7 m. Width: 11,0 m. Manufactured by Marshall Industries Composites.
352	Ikeishima Island Bridge	Okinawa	Japan	2001	tendons	Length: 37,8 m. Width: 4,0 m.
353	Route 141 over Willow Creek	Guthrie	USA, Iowa	2001	tendons	Length: 64,0 m. Width: 7,9 m. Manufactured by Fiber Reinforced Systems Inc.
354	Passerelle de Laroin	Laroin	France	2002	tendons	Manufactured by Soficar. en.structurae.de/structures/data/index.cfm?id=s0004676
355	I-225 & SH83 Interchange	Aurora	USA, Colorado	2002	tendons	Length: 410,0 m. Width: 12,8 m. Manufactured by Hughes Bros., Inc.

Lp	Name of the Bridge	Location	Country/ State	Year	USE of FRP composites	Basic information and references
313	Redstone Arsenal Bridge	Redstone Arsenal	USA, Alabama	2010	deck	Manufactured by ZellComp, Inc. http://www.compositesworld.com/articles/new-bridge-deck-bests-early-frp-systems
314	Lleida Footbridge (2)	Lleida	Spain	2011	deck	www.tech.plym.ac.uk/sme/composites/bridges.htm#lleida2
315	Fort Amherst Footbridge	Fort Amherst	UK	2011	deck	Length: 25,0 m. Width: 2,0 m. en.structurae.de/structures/data/index.cfm?id=s0059485
316	Kings Stormwater Channel Bridge	Indio / Riverside	USA, California	2000	deck, beam shells, piers shells	Length: 20,1 m. Width: 13,4 m. Manufactured by Martin Marietta Composites. Zhao L., Burgueño R., La Rovere H., Seible F., Karbhari V., *Preliminary evaluation of the hybrid tube bridge system*, Report No. TR-2000/4, California Department of Transportation under Contract No. 59AO032, 2000.
317	St. Johns Street Bridge	St. James	USA, Missouri	2000	deck, tendons	Length: 8,2 m. Width: 7,9 m. Manufactured by Kansas Structural Composites, Inc.
318	Jay Street Bridge	St. James	USA, Missouri	2000	deck, tendons	Length: 8,2 m. Width: 7,9 m. Manufactured by Kansas Structural Composites, Inc.
319	St. Francis Street Bridge	St. James	USA, Missouri	2000	deck, tendons	Length: 7,9 m. Width: 8,5 m. Manufactured by Kansas Structural Composites, Inc.
320	Bridge St Bridge over Rouge River	Southfield	USA, Michigan	2001	deck, tendons	Length: 60,4 m. Width: 9,1 m. Manufactured by Mitsubishi Chemical.
321	Lunenschegasse Bridge	Dusseldorf	Germany	1980	tendons	Length: 6,4 m. Width: 6,1 m. Manufactured by Bayer AG
322	Ulenbergstrasse Bridge	Dusseldorf	Germany	1986	tendons	Length: 46,9 m. Width: 14,9 m. Manufactured by Bayer AG
323	Marienfelde Bridge	Berlin	Germany	1988	tendons	Length: 50,3 m. Width: 4,6 m. Manufactured by Bayem AG.
324	Shinmiya Bridge	Ishikawa	Japan	1988	tendons	Length: 6,1 m. Width: 7,0 m. Manufactured by Tokyo Rope
325	Nakatsugawa Bridge	Chiba	Japan	1989	tendons	Length: 7,9 m. Width: 2,4 m. Manufactured by Tokyo Rope Mfg. Ltd.
326	Bachigawa Minami Bridge	Fukuoka	Japan	1989	tendons	Length: 36,0 m. Width: 12,2 m. Manufactured by Mitsubishi Chemical.
327	Kitakyushu Bridge	-	Japan	1989	tendons	Length: 35,9 m. Width: 12,2 m.
328	Notsch Bridge	Notsch, Karnten	Austria	1990	tendons	Length: 43,9 m. Width: 11,9 m. Manufactured by Bayer AG

7. CONCLUSION

Fibre Reinforced Polymer Composites, thanks to their beneficial properties and various advantages over traditional materials, have great potential as a material used in bridge engineering. During the last 30years, they have proved useful in a few areas: they are commonly used to strengthen existing bridge structures; they can replace steel as concrete reinforcement, and traditional materials for structural elements in hybrid and all-composite bridge structures.

They exercise high specific strength and stiffness, a property particularly interesting from the point of view of designers, as it provides the possibility to consider new design concepts and what´s more, enables dead load savings, which is particularly important while retrofitting existing structures by replacing old bridge decks. Their good corrosion resistance, fatigue resistance, electromagnetic transparency and ability to with stand harsh environment make them a good alternative for traditional materials in particular cases, such as

Lleida Footbridge crossing railway line. Thanks to dimension stability and aesthetic appearance of FRP structural elements, they became popular as components of small- spanned footbridges in National Parks in USA (about 170 of 355 bridges listed in chapter 12) and recently in Moscow parks and train stations. Their light weight, enabling quick assembly without the use of heavy equipment, not only provide cost savings, but also make them preferable to traditional materials as a material for demountable or move able constructions, and in cases where time-savings are crucial, in particular when minimal traffic interruption is allowed.

However, there is a number of uncertainties and disadvantages that prevent from justifying the use of FRP composites instead of traditional materials. Firstly, although the majority of sources (literature) are very optimistic about the long-term durability of FRP materials and predict lower life-cycle costs for constructions made of them, it is not possible to justify the claims, because only alimited number of relevant projects have been built. Much higher initial cost is also a big barrier. The second discouraging issue is the lack of design standards. Works on such standards are said to have been carried away for many years, but they are still far from introducing. The problem seems to be the lack of knowledge on the material: since the properties of FRP composite depend on the quantity and orientation of fibre reinforcement, one cannot separate the design of the material and the design of the structure. As a result, usually the manufacturer has to design both the material and the construction. Finally, mechanical joints adapted from steel constructions are not appropriate for structural elements made of anisotropic FRP and the knowledge on adhesive connections is still too little.
FRP composite scan be successfully used as structural elements in particular cases mentioned above, but they are still far from being accepted as a construction material qual to traditional materials. More projects involving FRP composites, especially those involving material-adapted concepts, still needed to verify their long-term cost-saving and in-service durability.

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