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Comparative analysis of metal reinforcement and fibre-reinforced plastic rebar

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ABSTRACT



Today reinforced concrete is material most widely used in construction. Many manufacturers offer to reduce the cost of this product by replacing the steel reinforcement to the fiber-reinforced plastic bar. However the effectiveness of such replacement raises the question. The article provides a comparative analysis of metal reinforcement and fiber-reinforced plastic bar (FRP). The main characteristics for comparison were defined based on the analysis of national and foreign publications. As a result of this comparison advantages and disadvantages of FRP using were defined. The article also provides metal reinforcement on FRP replacement economic efficiency analysis. The research is accomplishing by list of constructions in which using of FRP is more effective than metal reinforcement.

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1. Introduction

From the primitive time caves and other natural covertures were used by man as habitation. But these places can't satisfy all early people necessities. Changes of climate and fall of temperature made people constructing of their own habitation. With a lack of special tools, wood and animals bones became a constructional material. One of the oldest houses was built approximately 10,000 B.C. of bones of mammoth.

The development of mankind necessities lead to construction not only houses but different facility buildings, temples and other. Buildings became more complex, higher and wider than ever before. And it demand to increase stiffness of constructions. Even in the beginning of A.D. on Cecilia Island were attempts to make building walls stiffer by placing metal bars into brickwork. However, this technology became wide spread only from the middle of the XIX century, when a great number of concrete constructions began. The combination of stiffness and compression of concrete with tension of reinforcement opened the new age of construction. In modern time reinforced concrete is most popular construction material. The reinforcement is made of separate bars, wire-meshes, cages and embedded parts. The reinforcement bars may have different shape to improve contact with concrete.

In the middle of XX century the science of polymers appeared which is bound with physics and chemistry. Research of polymer properties has a great influence to construction. It allowed not only to improve properties of existing materials but also to create a new ones such as fiber-reinforced plastic rebar.

Replacement of old building materials by modern with same characteristics is important, because it leads to significant cost savings. In particular modern materials allow not only reducing the consumption of expensive raw materials, such as steel, but also to facilitate the production process and significantly reduce the transportation and installation costs due to its light weight.

The study of the construction market in Russia revealed that fiber-reinforced plastic (FRP) production is well established, while its use is not so extensive [1-3].

This paper presents a comparative analysis of the metal reinforcement on FRP replacement effectiveness by making a comparison of their characteristics and cost.

2. Literature review

Fiber-reinforced plastic is made of glass, basalt, carbon or aramid fibers. To provide tight bound fibers are impregnated with a thermosetting or thermoplastic polymer binder. The roughness of the rebar surface is provided by transverse or spiral ribs. In case of metal reinforcement, ribs are knobs on the surface of the metal bar. In case of composite reinforcement, ribs are twisted windings of glass, basalt, carbon or aramid fibers with a polymer coating. Windings may be one-way or bidirectional. Also for better adhesion to concrete sand deposition can be used. [4-6]

For comparison of FRP and metal reinforcement a literature review was conducted. During the analysis of Russian literature authors faced with the trend of displacement information about traditional metal reinforcement and replacement of it with information about modern composite. [7-9]

International sources usually contain complex analysis of FRP properties based not only on experimental data but also on long-term practical experience and observation of existing constructions. In last decades in USA [10-11], Europe [12-13], Canada [14-17], Japan [13] and China [13] FRP is widely used. So there is a large field of that kind of research.

The first study of FRP was conducted in Russia in the 1960s, and since the early 2000s FRP is becoming more widespread in our country. Taking into account change in the economic structure and uprising business competition frequently researches of FRP are initiated by manufacturers [18-21] who wants to prove advantages of their product. A lot of Russian publications consist of constructive properties description, field of application and excellent qualities of FRP. [3, 8]

There is a group of Russian researchers which demonstrate the results of their own experiments on different qualities of FRP [22-24] and those who propose new FRP applications [25-27].

Among the most important characteristics of FRP authors include the following ones:

- temporary tensile strength,
- modulus,

- load elongation behavior,
- density,
- temperature range,
- corrosion resistance to aggressive environments,
- thermal conductivity,
- electrical conductivity,
- magnetism,
- durability,
- adhesion to concrete.

Now in Saint-Petersburg Polytechnical University the research of contact FRP and metal rebar with concrete is in progress [22-24].

Based upon literature analysis was received data to the comparison of metal reinforcement and FRP can be made.

3. Research objectives

The aim of this study is to make recommendations on the FRP and metal reinforcement use.

The following problems have to be solved for this purpose:

- to carry out the comparison of metal reinforcement and FRP characteristics;
- to define the types of constructions, in which the use of FRP is preferred;
- to determine the conditions of FRP and metal reinforcement application;
- to carry out the economic analysis of FRP and metal reinforcement application.

4. Research description

The study was conducted on the basis of the available literature data, as well as on the basis of experimental data of Saint-Petersburg Polytechnical University. According to the received information FRP can be subdivided into following types depending on the type of continuous reinforcing filler [28] (see Table 1).

Table 1. Species of Fibre-reinforced plastic.

No.	Name	Abbreviation	The type of reinforcing fiber
1.	Glass-reinforced plastic	GRP	Fibers formed from a melt of inorganic glass.
2.	Basalt-reinforced plastic	BRP	Fiber formed by melt basalt and gabbro diabase.
3.	Carbon-reinforced plastic	CRP	Fiber is formed by organic fibers by pyrolysis of precursor and containing at least 90% by weight carbon.
4.	Aramid-reinforced plastic	ARP	A fiber formed from the linear fiber-forming polymers in which at least 85% of the amide groups directly linked to two benzene rings.
5.	Combined-fiber-reinforced plastic	CFRP	GRP, BRP, CRP or ARP additionally filled with continuous reinforcing filler of another type or types of fiber.

The study revealed that the most popular types of composite reinforcement are glass-reinforced plastic (GRP) and basalt-reinforced plastic (BRP) [29;30], hence the authors carried out a comparative analysis of these two types of composite reinforcement characteristics and metal reinforcement, which is shown in Table 2.

Table 2. Comparative analysis of metal reinforcement (MR), Glass-reinforced plastic and Basalt-reinforced plastic

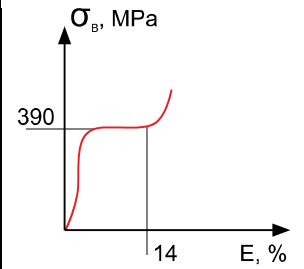
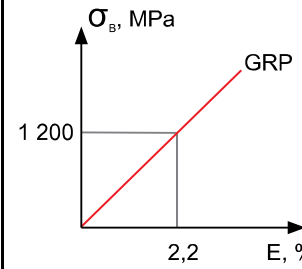
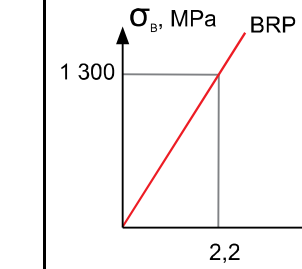
Characteristic	MR	GRP	BRP
Material	Steel	Glass fiber of 13-16 microns diameter bond with polymer.	Basalt fiber of 10-16 microns diameter bond with polymer.
Tensile strength, σ_b , MPa	360	600-1200	700-1300
Modulus of elasticity, E, MPa	200,000	45,000	60,000
Elongation, δ , %	25	2.2	2.5
The load elongation behavior ("stress-strain" dependence)			
Density, t/m^3	7.85	1.9	2.0
Operating Temperature Range	from -60 °C to + 650 °C	from -60 °C to + 650 °C	from -260 °C to + 982 °C
Corrosion resistance to aggressive environments	Corrodes with rust-release products.	Stainless material. Resistance to alkaline medium of concrete.	Stainless material. Resistance to alkaline medium of concrete.
Thermal conductivity, $Vt/(m^*K)$	56 for reinforcement of ordinary carbon steel; 17 for stainless steel reinforcement.	<1.0	< 0.46
Electro conductivity	Electro conductive	Dielectric (if necessary, may imparting electrical properties).	Dielectric (if necessary, may imparting electrical properties).
Magnetic behavior	Magnetic	Non magnetic	Non magnetic
Produced sections, mm	6-80	4-20 (in Russia); 4-40 (foreign suppliers)	4-20 (in Russia); 4-40 (foreign suppliers)
Length, m	6-12	Any length on request.	Any length on request.
Lifetime	~ 40 years.	~ 80 years.	~100 years.
Usage in prestressed concrete	Does not involve additional difficulties.	Requires special anchor.	Requires special anchor.

Table 2 shows that with increase of reinforcement bar diameter temporary tensile strength decreases. So for example GRP of 8mm diameter possess temporary tensile strength of 1200 MPa, while the GRP of 16mm diameter – is 900 MPa, and for diameter 20mm – 700 MPa. [4]

Also it should be remarked; that the metal reinforcement have significantly higher modulus and elongation than composite rebar [31]. Graphs of load elongation behavior shows that FRP has no plot point. Thus, in the case of tensile strength approaching the distraction of reinforcement happens instantly. However, this disadvantage is compensated by considerably bigger GRP and BRP tensile strength compared with metal rebar.

Small density and significantly lower thermal conductivity, compared with metallic reinforcement may be defined as advantages of FRP [32]. Also GRP and BRP resistance an alkaline environment of concrete doubles their life compared to steel [33].

Also composite rebar is nonmagnetic and dielectric [34], what makes it very useful in the construction of such facilities as rooms for magnetic resonance imaging in hospitals and toll fees, which uses radio frequency identification of pre-paid customers.

Due to the composite reinforcing bars can be manufactured with any length and shape, they can be effectively used in the construction of complex architectural forms, for which usage of metal reinforcement is often impossible. [35]

At the same time, the use of composite reinforcement in prestressed concrete is related with considerable difficulties. To fix the FRP additional anchoring requires. Without using anchors destruction of fixed parts observed. [36-37]

The heterogeneous composite reinforcement structure gives the opportunity to include in it materials with additional properties. Thus, using a metal core one can impart conductive properties to FRP. And integration of optic sensors to the reinforcement fiber allows remote monitoring of structures and pavement state. [38]

For comparison of technical and economic characteristics composite reinforcement economic efficiency calculation was conducted. Such characteristics as weight and price per meter of bar were selected as a basis for the calculation. 1 meter metal reinforcement weight is determined according to GOST 5781-82* [39]. 1 meter composite reinforcement weight is determined according to the manufacturers' data. Cost of 1 meter reinforcement is defined as the average value of the market prices. [40-45].

Difference of cost characteristics was determined by the following formulas:

1. Comparison of 1 m metal rebar and GRP:

$$\Delta_1 = \frac{(MR - GRP)}{MR} \cdot 100\%$$

where MR – the cost of metal rebar, GRP – the cost of glass-reinforced plastic.

2. Comparison of 1 m metal rebar and BRP:

$$\Delta_2 = \frac{(MR - BRP)}{MR} \cdot 100\%$$

where MR – the cost of metal rebar, BRP – the cost basalt-reinforced plastic.

3. Comparison of 1 m GRP and BRP cost

$$\Delta_3 = \frac{BRP}{GRP}$$

where GRP – the cost of glass-reinforced plastic, BRP – the cost basalt-reinforced plastic.

Average values from the tables defined as the arithmetic mean.

Results of calculation are shown in the following tables (see Tables 3 – 6).

Table 3. Replacement of MR on FRP

MR		GRP		BRP	
Type	Weight of 1 lm (kg)	Type	Weight of 1 lm (kg)	Type	Weight of 1 lm (kg)
6A-III*	0.222	GRP-4**	0.026	BRP-4**	0.026
8A-III	0.395	GRP-6	0.040	BRP-6	0.040
10A-III	0.617	GRP-8	0.072	BRP-8	0.072
12A-III	0.888	GRP-8	0.072	BRP-8	0.072
14A-III	1.210	GRP-10	0.110	BRP-10	0.110
16A-III	1.580	GRP-12	0.184	BRP-12	0.184

* N A-III: N – rebar diameter, mm; A-III – class of reinforcement according to GOST 5781-82* (Yield point σ_m 390 N/mm²)

** GRP- N, BRP- N: N – rebar diameter, mm.

Table 3 shows that the GRP and BRP have the same mass per meter. At the same time, depending on the type, they are 9-12 times lighter than steel rebar.

Table 4. Comparison of 1lm metal reinforcement and GRP

MR		GRP		Difference (Δ_1 , %)
Type	Price (rub/meter)	Type	Price (rub/meter)	
6A-III	7.00	GRP-4	7.00	0
8A-III	12.00	GRP-6	9.50	20.8
10A-III	17.21	GRP-8	14.50	15.7
12A-III	23.89	GRP-8	14.50	39.3
14A-III	32.56	GRP-10	22.00	32.4
16A-III	42.67	GRP-12	30.00	29.7
The average value				23.0

Table 5. Comparison of 1lm metal reinforcement and BRP

MR		BRP		Difference (Δ_2 , %)
Type	Price (rub/meter)	Type	Price (rub/meter)	
6A-III	7.00	BRP-4	8.91	-27.3
8A-III	12.00	BRP-6	15.12	-26.0
10A-III	17.21	BRP-8	23.31	-35.4
12A-III	23.89	BRP-8	23.31	2.4

MR		BRP		Difference (Δ_2 , %)
Type	Price (rub/meter)	Type	Price (rub/meter)	
14A-III	32.56	BRP-10	35.91	-10.3
16A-III	42.67	BRP-12	47.88	-12.2
The average value				-18.1

Table 6. Comparison of GRP and BRP prices

GRP		BRP		Difference (Δ_3 , %)
Type	Price (rub/meter)	Type	Price (rub/meter)	
GRP-4	7.00	BRP-4	8.91	1.3
GRP-6	9.50	BRP-6	15.12	1.6
GRP-8	14.50	BRP-8	23.31	1.6
GRP-8	14.50	BRP-8	23.31	1.6
GRP-10	22.00	BRP-10	35.91	1.6
GRP-12	30.00	BRP-12	47.88	1.6
The average value				1.55

Based on the calculated data analysis of Tables 4-6 authors conclude, that 1 m GRP on average cheaper than metal reinforcement by 23%, while the BRP is contrariwise expensive than metal rebar by 18.1%.

Also GRP is cheaper than BRP in 1.55 times. Higher costs determined by BRP durability (20 years longer than GRP) and a large range of operating temperatures.

5. Conclusions

Advantages and disadvantages of FRP

The research showed the following advantages of FRP:

- High stiffness.
- Low specific weight.
- Low thermal conductivity.
- High corrosive resistance inside aggressive environment.
- Wider than metal reinforcement operating temperature range. (In case of BRP)
- The possibility to manufacture bars of any length and shape on request.
- Durability is 2-3 times higher than for metal reinforcement.
- Low cost in comparison with metal reinforcement. (in case of GRP)
- Possibility to include optic sensors in the reinforcement fiber that allows remote monitoring of structures.

Following limitations of FRP was reveal as well:

- Low modulus in comparison with metal reinforcement.
- No possibility of structural folds during reinforcement works. However, this is offset by ability to make curved fiber reinforcement directly during production process in accordance with the certain project.
- Inconvenient to use in prestressed concrete.
- The high cost compared with metal reinforcement.(In case of BRP)

Recommendations for application of FRP

As the result of conducted research the following use of FRP can be recommended:

- for the reinforcement of concrete structures and mixed concrete reinforcement.
- in the reinforced structures affected by aggressive environment, corrosive for steel reinforcement (chloride salts, high concentrations of corrosive gas, etc.).
- in the elements of road construction, which are exposed to aggressive anti-icing agents.
- in the repair of concrete structures damaged by exposure to corrosive environments.
- in cases with no possibility to provide the regulatory requirements for the thickness of the protective layer (thin-walled structures for various purposes, such as panels of noise protection structures, fences, architectural design and other purposes).
- for reinforcing masonry, especially in winter time when curing accelerators and antifreeze are adding to mortar (chloride salts that cause corrosion of steel reinforcement).
- in the design of bridges, as they are the most susceptible to corrosion. (The support because of constant contact with the water, and the upper part of the slab due to the application of anti-icing agents).
- in areas for magnetic resonance imaging in hospitals.
- in traffic booth uses radio frequency identification of pre-paid customers. Usage of steel reinforcement in this case is not possible, because it interacts with the electromagnetic signals generated by the equipment.
- in building structures of complex shape, where difficult to use metal reinforcement.
- in the constructions requiring their internal state monitoring.

In the common case for building structures is recommended to use metal reinforcement. Due to the fact that it has the higher modulus and elasticity, what in the emergency case provides a longer collapse period of constructions. And this, in turn, allows people to safely leave the dangerous area.

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Сравнительный анализ металлической арматуры и арматуры из композитных материалов

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Информация о статье	История	Ключевые слова
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АННОТАЦИЯ



На сегодняшний день железобетон является самым широко используемым материалом в строительстве. Многие производители предлагают снизить себестоимость этого материала за счет замены металлической арматуры на композитную. Однако встает вопрос об эффективности этой замены. В статье проведен сравнительный анализ традиционной металлической и композитной арматуры. На основе анализа отечественных и зарубежных публикаций были определены основные характеристики для сравнения. В ходе исследования этих характеристик выявлены достоинства и недостатки композитной арматуры в сравнении с металлической. Также в статье проведен экономический анализ эффективности замены металлической арматуры на композитную. Итогом исследования является определение перечня конструкций, в которых использование композитной арматуры является эффективным.

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