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Comparative Studies of the Strength Characteristics of Concrete Blocks with Titanium and Iron Rods (Bars)

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***Abstract*. The relevance of the topic of the work was shown by the accident of a multi-storey residential building in Miami, which was caused by corrosion of steel reinforcement in reinforced concrete.**

There is a need to maintain the bearing capacity of structures for a long time in a humid climate, aggressive environmental influences and temperature fluctuations with a lower consumption of materials used.

The use of titanium will allow changing some parameters of titanium concrete structures in comparison with reinforced concrete structures. The protective layer of concrete, which serves to protect the reinforcement from the effects of the external environment, will be significantly reduced. This will help to reduce the mass of concrete structures while maintaining strength properties and will allow you to create lighter structures that can withstand heavy loads.

Strength tests were carried out on concrete blocks reinforced with smooth iron or titanium rods Ø10 mm, which showed the prospects of replacing steel reinforcement with titanium reinforcement in reinforced concrete.

Keywords: Concrete, Bending test, Concrete reinforced with titanium and iron bars, Durability.

INTRODUCTION

Due to the high cost of titanium production, it is currently used only in those industries, where the use of such an expensive material is economically justified. When justifying the use of titanium, not only its strength and lightness are taken into account, but also corrosion resistance which is comparable to the strength and durability of precious metals. Titanium is mainly used in the aircraft and transport industries, where the combination of strength and lightness is of particular importance [1,2,3].

In construction industry, titanium is used in the form of titanium cladding, roll roofing and facade cladding [4,5].

The utilization of titanium alloys in civil engineering is not common, but its applications are becoming more prevalent. This is due to two significant reasons: firstly, the cost of titanium has considerably decreased over time: Although, like other commodities, it is subject to price changes, when adjusted for inflation, prices generally tend to fall. As of January 2016, the price was $3,750 per metric ton. In 2005, the price was $21,000 a ton (Figure 1).

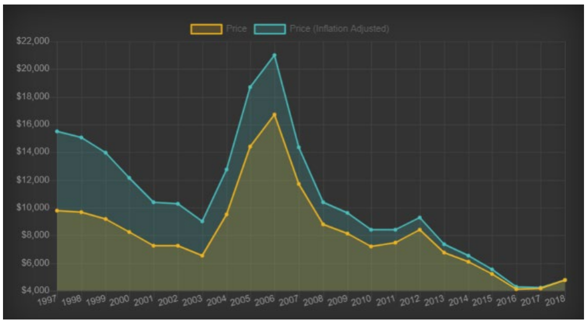

Fig. 1. Inflation adjusted cost of titanium: as of January 2016, the price was USD 3750 per ton; in 2005, the price was USD 21,000 a ton. [6].

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Secondly, there have been occurrences of civil infrastructure collapses which have highlighted the inadequacies of using carbon steel in structures that are exposed to outdoor environments. Civil structures and infrastructures generally have a longer design life compared to aerospace or medical applications. In several developed nations, concrete bridges constructed during the economic boom of the 1950s and 1960s were often insufficiently reinforced with steel and require repair or replacement (as shown in Figure 2). These bridges are usually still functional even after 70 years, and the drawbacks of replacement are high, not only in terms of economic costs but also with regards to carbon emissions and sustainability. Recently, titanium has been utilized to renovate and prolong the life of bridges, resulting in savings in costs and time compared to replacement methods [7,8,9].

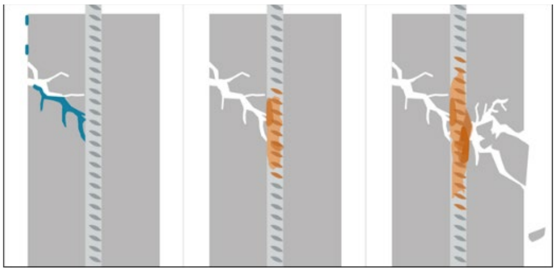
a) b) c)

Fig. 2. Becent collapses of reinforced concrete bridges due to the corrosion of steel: a) Igaly (Genova), b) Taiwan, c) USA (Pittsburgh).

The durability of titanium is its main advantage, surpassing that of other materials such as stainless steel or composite materials. Typically, interventions on heritage masonry buildings or existing masonry structures are intended to endure for many decades, and sometimes even for centuries. These buildings are exposed to various atmospheric conditions, such as high temperatures, frost, solar radiation, humidity, and acid rain, among others, as well as the worsening impacts of climate change, resulting in new threats from natural disasters. These effects have been underestimated to some extent, not just by industry and professionals, but also by the scientific community working in conservation engineering. Numerous interventions carried out in the 1990s and 2000s using FRPs or stainless-steel exhibit signs of mechanical wear, reinforcement debonding from the masonry substrate, and corrosion. In certain instances, these impacts have caused irreparable damage to the masonry structure [10].

When investigating in the framework of ERDF No. 1.1.1.1./16/A/85 "Electroslag process for better titanium sediment morphology", the technology for the production of titanium and titanium alloys and semi-finished products from them allows the production at small and medium-sized plants similar to foundry at industrial plants. [11,12]

A large amount of accumulated titanium scrap does not find secondary use for the production of high value-added titanium products due to the large number of grades of titanium alloys alloyed with a wide range of additives, which does not allow a correct selection of one grade of titanium alloys due to the small dimensions and weight of individual parts of titanium scrap. The main use of scrap titanium and titanium alloys is to produce ferrotitanium, which is used during steel smelting for degassing. But the entire volume of titanium scrap exceeds the needs of the steel industry. One of the possible applications of excess titanium scrap is the manufacture of rebar from titanium alloys, averaged over the chemical composition during the remelting process.



a) b) c)

Fig. 3. Damage to reinforcement in reinforced concrete blocks in a humid environment.
a) Water enters the concrete.
b) Steel reinforcement starts to rust, corrosion expands.
c) The concrete starts to crack and destroys.

The use of titanium will make it possible to change some parameters of titanium-concrete structures if compared with reinforced concrete structures. The protective layer of concrete which serves to protect the reinforcement from the external environment will be significantly reduced. This will allow to decrease the weight of concrete structures while maintaining their strength properties and to produce lighter structures that can withstand higher loads [13].

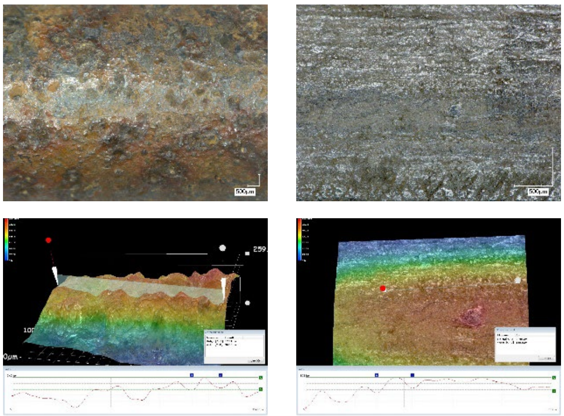
One of the directions for the effective use of titanium and titanium alloys in the construction industry is the development and implementation of methods to reduce the cost of the material. Methods for extracting cheap titanium are discussed in [14]. It has been shown that it can economically produce pure titanium metal and alloys for applications such as automobiles and electronics. Another way is to increase the strength properties of the material [15].

MATERIALS AND METHODS

The experimental part of the work provides for the manufacture of concrete beams 100x100x500 reinforced with steel and titanium bars. Reference mix was designed to produce concrete with strength grade C40/45 and workability class S3 (in accordance with standard LVS EN 206). The following ingredients proportions (related to 1 m3 of fresh mix) were provided: Portland cement CEM I 42,5 N - 450 kg, gravel 0/8 mm – 1620 kg, water 216 kg, polycarboxilate superplasticizer 2,3 kg, water-cement ratio 0.48.

Smooth reinforcing bars with a diameter of 10 mm were used to reinforce the beams. In the frame of the experiment, the surfaces of steel and titanium bars were compared before concretion works. Optical 3D microscope Keyence 2000 equipped with VHX-20-200 lens was used for visual investigation of the surface of iron and titanium rods before concreting. Images are shown in Figure 2: On the left is steel bar surface, on the right is titanium bar surface. Comparative smoothness of iron and titanium bars showed that titanium bars are much less rough compared to iron ones.

The bars were placed in the lower part of the sample, taking into account the thickness of the protective layer of concrete 5 mm. Two samples were made with the steel reinforcement and two samples with titanium reinforcement. (Figure 4).



a) b)

Fig. 4. Comparison of the surface of iron and titanium rods before concreting. a) iron, b) titanium.

The process of production of reinforced concrete and titanium concrete beams is shown in Figure 5. Samples were tested for three-point bending at the age of 28 days. The load was applied in the middle of the span and the distance between the supports was 420 mm (Figure 4). The load was applied in the middle of the span and during the test the numerical values of the applied force and mid-span deflection were recorded.

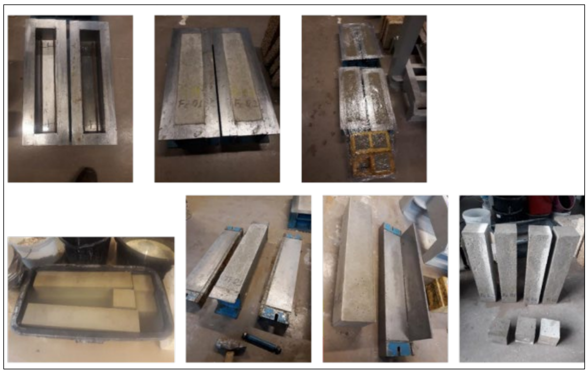


Fig. 5. The process of production of reinforced concrete and titanium concrete beams.

Fig. 6. Testing of concrete beams.

RESULTS AND DISCUSSION

During the experiment, the strength characteristics of concrete samples were tested, the results of titanium and steel reinforced beams were compared. Numerical values of strength properties of concrete cubical samples and reinforced concrete beams are summarized in Table 1. Testing results of concrete samples shoved average compressive strength 54.7 MPa, that confirms to designed strength class C35/45.

Bending testing curves are showed in Figure 7. Ehe results of the bending test indicate that specimens with titanium reinforcement have average bending capacity of 15,78 kN, the specimens with steel reinforcement 25.75 kN. Thus samples with titanium reinforcement have a bearing capacity of 40% less than samples with steel reinforcement. The corresponding recalculated bending strength is 16.2 and 9.9 MPa respectively. This is not a decisive indicator, since titanium grade VT-1 was used without alloying - hardening additives.

Table 1. Strength characteristics of concrete samples and reinforced concrete beams

	Compres-sive strength, MPa	Maximum bending forve, kN	Bending strength, MPa	Residual force at a deformation of 3.5 mm F(3.5), kN	F(3.5) / Fmax, %
Reference concrete	**54.7**				
Steel reinforced beam					
S-1		25.86	16.3	8.0	30.9
S-2		25.64	16.2	8.7	33.9
S-average		**25.8**	**16.2**	**8.4**	**32.4**
Titanium reoinforced beam					
T-1		15.75	9.9	6.8	43.2
T-2		15.81	10.0	9.9	62.6
T-average		**15.8**	**9.9**	**8.4**	**52.9**

Analyzing the typical load – mid-span deflection curve (Figure 7), three characteristic areas can be distinguished. The initial linear and ascending section of the curve corresponds to the joint work of the reinforcement and the concrete matrix. The second characteristic area of the curve is the maximum value of the force at which a concrete crack is formed in the lower tensioned part of the beam and tensile load is redistributed to the reinforcing bars. The third descending section of the curve corresponds to the work of the reinforcement in tension and the concrete work on compression in the upper part of the beam section. Taking into account the above characteristic areas, the following behaviour of steel and titanium reinforced beams can be distinguished:

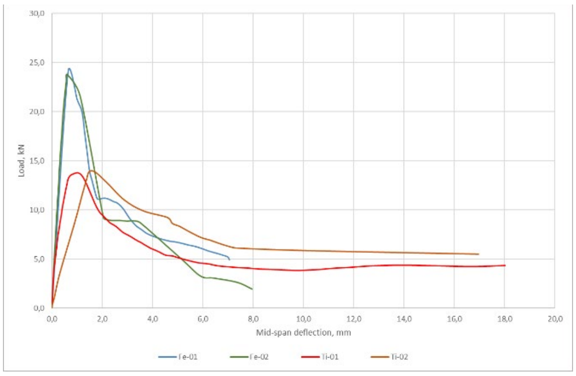


Fig. 7. Strength characteristics of concrete blocks with titanium and iron rods (rods).

In the initial linear area, the curves of specimens with titanium reinforcement have a lower angle of inclination, which can be explained by the lower modulus of elasticity of titanium (110 GPa) compared to the modulus of elasticity of steel (200 GPa).

The lower value of the bearing capacity of samples with titanium could be explained with the lower tensile strength of titanium bar compared to the strength of steel bar. Analyzing the pattern of destruction of samples with steel reinforcement (Figure 8a), it can be noted that the destruction of the beam did not occur from the rupture of steel reinforcement, but destruction occurs due to the action of transverse forces. In the case of titanium reinforcement, the beam destruction take place in the middle part of the beam (in the place with the maximum bending moment). Significant tensile deformations of titanium reinforcement cause high maximum deflection values compared to steel-reinforced beams (Figure 8b).

a) b)

Fig. 8. Destruction mode of beam with steel reinforcement (a) and titanium reinforcement (b).

Evaluating the work of reinforced beams it would be advisable to analyze post-cracking areas. Specimens reinforced with titanium reinforcement, have a more pronounced area of plastic deformations. According to test results (Table 1), beams with titanium and steel carry the same residual load (8.4 kN) at the same mid-span deflection (3.5 mm). However, for beams with steel reinforcement, this load is 32% of the maximum breaking load, but for beams with titanium - 53% of the breaking load. These properties can be an additional safety factor for impact energy absorption.

Furthermore, at elevated temperatures (> 700˚C), titanium bars are characterized by a lower decrease in strength and elastic modulus than steel. This can have a positive effect on the fire safety of structures. An additional factor of reliability is the higher chemical resistance of titanium compared to steel.

Lower strength of titanium reinforcement does not allow its use in heavily loaded reinforced concrete structures. Despite this, titanium reinforcement can find application in moderate loaded structures where high corrosion resistance, durability, impact resistance and fire resistance are required.

Reduction of concrete protective cover will help to reduce the self-weight of concrete structures while maintaining strength properties and will allow you to create lighter structures with the same bearing capacity.

CONCLUSIONS

In this study, laboratory beams were made, using steel and titanium reinforcing bars. Comparative tests on the strength of concrete blocks reinforced with steel and titanium smooth rods showed that:

1. The bearing capacity of steel reinforced concrete beams is greater than that of titanium reinforced (25.8 and 15.8 kN correspondingly). The use of a stronger titanium alloy would have made it possible to obtain higher strength results.

2. Comparative smoothness of iron and titanium bars showed that titanium bars are much less rough compared to iron ones. When titanium bars are artificially roughened, the characteristics may be different, but this requires additional research.

3. A positive property of titanium reinforcement is a higher ductility and the ability to withstand large deformations. At the same mid-span deflection (3.5 mm) steel reinforced beams carry 32% of the maximum breaking load, but for beams with titanium - 53% of the breaking load.

Based on the obtained experimental results, a patent application and an article for publication in a high-indexed journal were prepared.

Additional reliability factors of titanium reinforcement are its significant chemical resistance and possibly higher heat resistance. These questions could be considered in the future stages of this study.

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