Archives of Materials Science and Engineering

Volume 77
Issue 2
February 2016
Pages 65-71

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Characteristics of titanium Grade 2 and evaluation of corrosion resistance

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ABSTRACT

Purpose: The paper attempts to improve the properties of titanium Grade 2 by the use of the injection casting method with rapid cooling.

Design/methodology/approach: Microstructural observations by using an optical microscope, microhardness studies, X-ray qualitative analysis as well as corrosion resistance tests were carried out. Corrosion resistance tests were conducted by measuring the open circuit potential and measuring the resistance to corrosion by the method of anodic polarization curves in a potential range close to the corrosion potential.

Findings: Studies have shown that the application of the abovementioned preparation method affect the microstructure of the finished item. There has been a fragmentation of the structure and the formation of dendrites. Those changes have improved corrosion resistance and increase microhardness. There were no changes in the phase composition.

Research limitations/implications: Studies were performed only in the Ringer's solution indicating a potential use of this material as a biomaterial. Further research should be conducted in more aggressive environments especially for the energy industry and chemical industry.

Practical implications: The application of injection casting carries some complications, which mainly relate to quartz capillary where ingot is melted. Titanium as a reactive element strongly absorbs silicon out of the capillary causing changes in the chemical composition in the surface layer of the final element. The addition of silicon in the surface layer may affect on obtained results.

Originality/value: Using the production method indicates its use in future in many industries.

Keywords: Titanium Grade 2; Injection casting; Corrosion resistance; Pressure casting

Reference to this paper should be given in the following way:

J. Klimas, A. Łukaszewicz, M. Szota, K. Szota, Characteristics of titanium Grade 2 and evaluation of corrosion resistance, Archives of Materials Science and Engineering 77/2 (2016) 65-71.

PROPERTIES

1. Introduction

The chemical composition of pure titanium Ti99.2 (Grade 2 ASTM) contains a small amount of oxygen and iron (max. 0.5%), which determines the satisfactory properties of the material. It is characterized by a great ratio of density to mechanical properties. It has a tensile strength in the range of 210-1380 MPa, which is equivalent to the properties of alloy steels while density dropped up to 40%. The thermal expansion coefficient is slightly lower than for steel and less by a half of aluminium. Titanium has a low modulus of elasticity. Titanium can be treated by cutting with low speeds and rapid cooling. It can be hot and cold-formed as well as welded. Titanium has a very high melting point ~1660°C and excellent resistance to corrosion. Titanium is biocompatible and non-toxic and does not cause allergies [1-8].

Those properties determine the range of applications of titanium, as: condensers, steam condensers, heat exchangers in power plants and CHP, process apparatus in the chemical industry, desalination installations in the paper industry, the elements in sewage treatment plants, fuel gas desulphurization installations, the material in the aerospace and automotive industries [2,9].

The paper attempts to improve the properties of titanium Grade 2 by the use of injection casting method with rapid cooling. In the production process prepared ingots of titanium are placed in a quartz crucible which is inductively melted. The liquid titanium is injected under gas pressure to copper mould, copper mould is radially cooled [10-15].

2. Materials and methodology

Studied samples were titanium Grade 2 (acc. to ASTM), their chemical composition is shown in Table 1.

Table 1.
Chemical composition of titanium Grade 2 [16]

Elements	Contents of elements, %
Ti	rest
Fe	0.3
O	0.25
C	0.08
N	0.03
H	0.012

Corrosion resistance of samples was carried out in Ringer's solution. Tests for corrosion behaviour of materials were carried out at temperature of 37±2°C. Immediately before starting the measurements fresh portion of the solution venting in argon with a purity of 99.9999% for 60 minutes. Corrosion tests were carried out in a classic three-electrode system which scheme is shown in Figure 1. During the measurements the studied material was a working electrode, a counter electrode was platinum net and reference electrode was NEK type R-20 Hydrometr. At temperature of 25°C NEK potential is equalled 244.4 ± 1 mV. The reference electrode was introduced to the system by capillary Lugina.

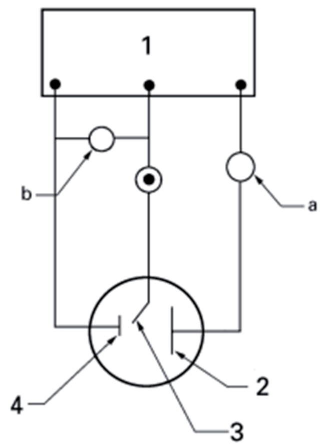

Fig. 1. Scheme of three-electrode system; 1 – potentiostat, 2 – counter electrode, 3 – reference electrode, 4 – working electrode, a – current measurement, b – potential measurement

Samples were subjected to the observation of the microstructure with a light microscope Axiovert 25 Carl Zeiss.

The produced samples were subjected to X-ray qualitative analysis to determine the phase composition. X-ray diffraction was performed using an X-ray apparatus Seifert 3003 T – T using filtered radiation of cobalt lamp where length of beam radiation equal $\lambda = 0.179$ nm heater current was 30 mA and voltage 40 kV.

Microhardness was carried out by Vickers method with FUTURE-TECH FM-7 apparatus under load of 980.7 mN (HV0.1).

3. Results and discussion

3.1. Measurement of corrosion resistance by measuring the open circuit potential

Table 2 summarizes the values of the open circuit potential of the studied materials.

Table 2.
Value of the open circuit potential of studied materials E, V

Sample	Grade 2	Grade 2 produced by injection casting
Potential value, V	-0.345	-0.211

The summary of the characteristics of the open circuit potential for studied samples in Ringer solution at temperature of 37°C are presented in Figures 2 and 3.

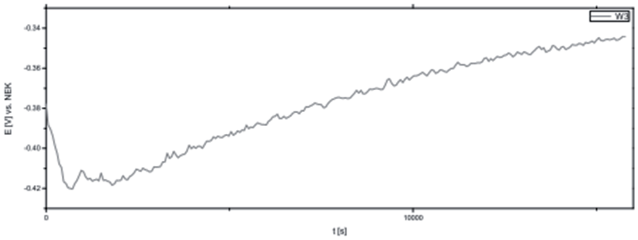

Fig. 2. Curve of open circuit potential E = f(t) for material Grade 2 at baseline

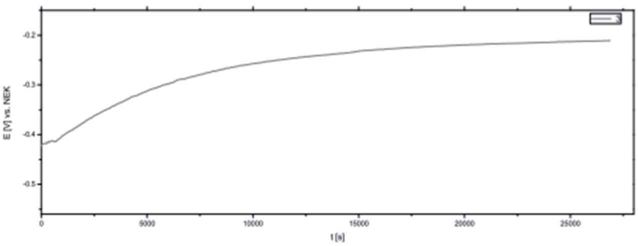

Fig. 3. Curve of open circuit potential E = f(t) for material Grade 2 produced by injection casting

Stationary potential measurement as a function of time allows to determine tendency to corrosion or lack thereof for metallic materials. It is a simple way to evaluate the protective properties of passive layers forming on the surface of the alloy. Growth of potential in the positive direction suggests the formation of a protective passive layers.

A shift of the corrosion potential in the positive direction for titanium sample produced by the injection method in relations to sample produced in baseline shows better corrosion resistance.

3.2. Measurement of resistance to corrosion by anodic polarization curves in the potential range close to the corrosion potential

On the basis of polarization curves log j = f(E) registered in the potential range close to the corrosion potential Tafel extrapolation was made.

Figures 4 and 5 showed the summary of Tafel extrapolations for polarization curves j = f(E) obtained by the potentiodynamic method in the range of potentials ±50 mV in relations to E_{oc} for studied samples in Ringer solution at the temperature of 37°C.

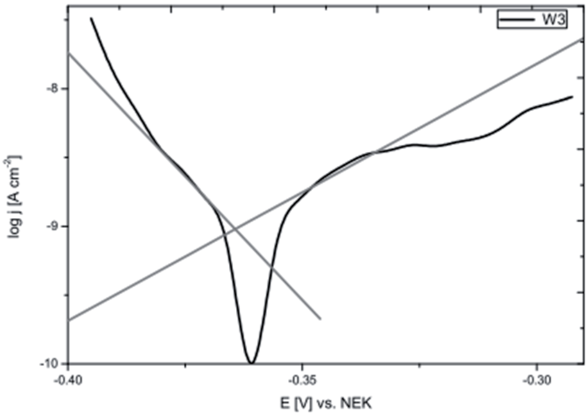

Fig. 4. Extrapolation of Tafel straight for polarization curve j = f(E) obtained by potentiodynamic method for titanium Grade 2 in baseline

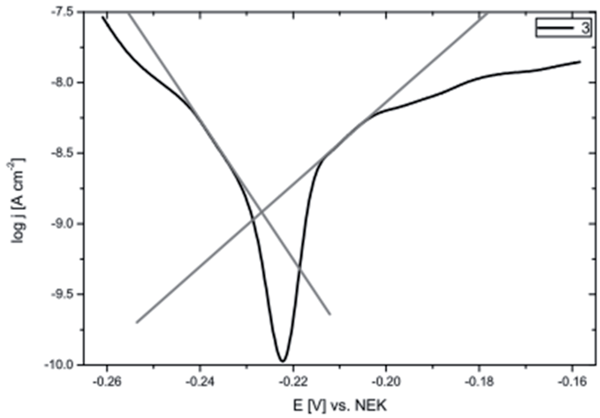

Fig. 5. Extrapolation of Tafel straight for polarization curve j = f(E) obtained by potentiodynamic method for titanium Grade 2 produced by injection method

Following parameters were appointed for samples in the baseline form as well as for samples produced by the injection method: a corrosion potential E_{cor} [mV], density of corrosion current j_{cor} [mA/cm^2], polarization resistance R_p [Ω], a factor cathode b_k [mV/dec] and anode b_a [mV/dec] of Tafel straight and corrosion rate CR in the corrosion potential [mm/year]. The designated information are placed in Table 3.

Values of corrosion rate were conducted according to norm ASTM G 102-89.

Table 3.
The determined parameters on the basis of extrapolations of Tafel straights for titanium Grade 2

Parameter	Grade 2 in baseline	Grade 2 produced by injection method
Corrosion potential, E_{cor}, mV	-354	-222
Density of current potential, j_{cor}, A/cm^2	$1.09 \cdot 10^{-9}$	$1.08 \cdot 10^{-8}$
Polarization resistance, R_p, Ω	$4.06 \cdot 10^{5}$	$3.07 \cdot 10^{5}$
Cathode factor, b_k, V/dec	0.016	0.06
Anode factor, b_a, V/dec	0.012	0.02
Corrosion rate in E_{cor}, CR, mm/year	$9.52 \cdot 10^{-6}$	$9.43 \cdot 10^{-5}$

Corrosion potential is widely recognized as a parameter allowing a preliminary assessment of the corrosive properties of metals and alloys. A shift of the corrosion potential in the positive direction for titanium sample produced by injection method in relations to sample produced in baseline shows better corrosion resistance.

Other parameter that characterizes corrosion resistance is polarization resistance (R_p) (known as corrosion resistance). The designated value of R_p studied samples is relatively high.

The corrosion rate based on a scale of corrosion resistant of metals (Table 4) is no high and shows good resistance to corrosion of studied materials. The sample of titanium Grade 2 produced by the injection method has slightly lower value of polarization resistance in relations to sample in the baseline, however, both are in the range 1 of the level of corrosion resistance thus they show the highest level of corrosion.

Table 4.
The scale of the corrosion resistance of metals [17]

Group of corrosion resistance		Level of corrosion resistance	Rate of corrosion, mm/year
Definition	Mark		
Completely resistant	I	1	<0.001
Very resistant	II	2	0.001-0.005
		3	0.005-0.01
Resistant	III	4	0.01-0.05
		5	0.05-0.1
With lower resistant	IV	6	0.1-0.5
		7	0.5-1.0
Low resistant	V	8	1.0-5.0
		9	5.0-10.0
Non resistant	VI	10	> 10.0

In Figure 6 microstructures of titanium Grade 2 in baseline were shown while in Figure 7 – microstructures of titanium Grade 2 produced by injection method.

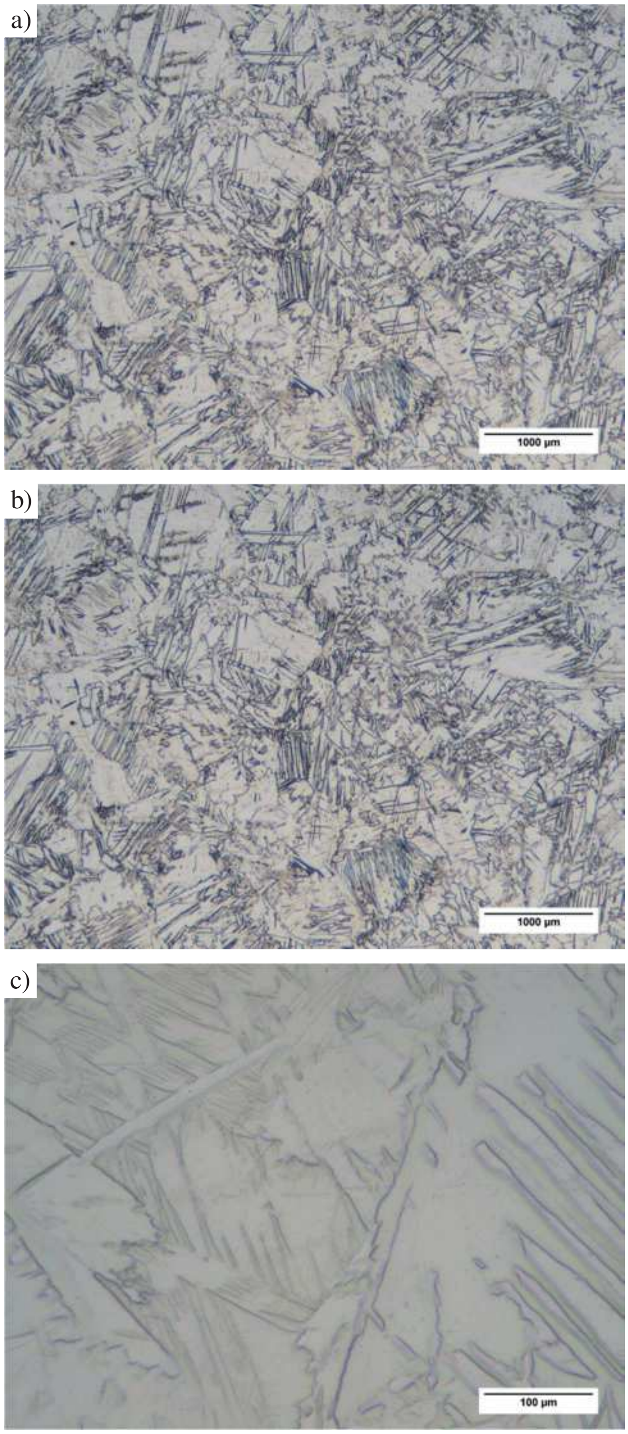

Fig. 6. Microstructures of titanium Grade 2 in baseline; magnitude: a) 50x, b) 50x, c) 500x

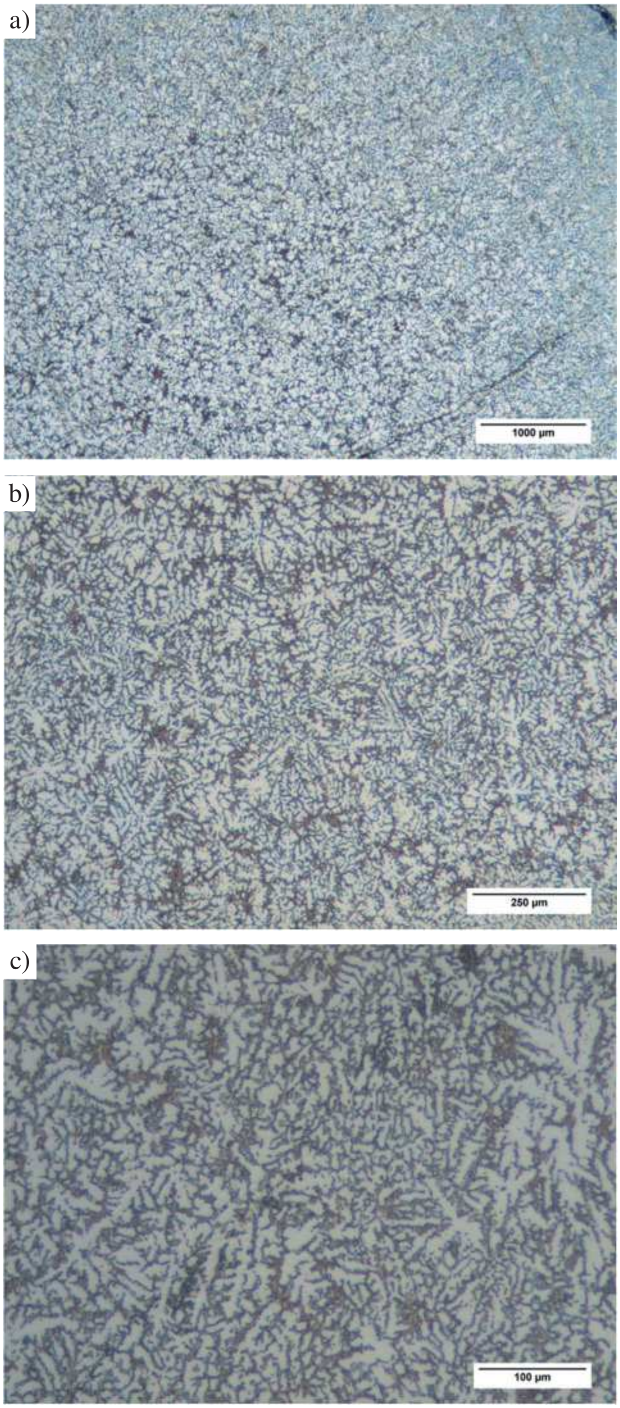

Fig. 7. Microstructures of titanium Grade 2 produced by injection method; magnitude: a) 50x, b) 200x, c) 500x

Diffraction patterns show results of X-ray studies. In Figure 8 diffraction patterns of titanium Grade 2 in baseline were presented and in Figure 9 – diffraction patterns of titanium Grade 2 produced by injection method.

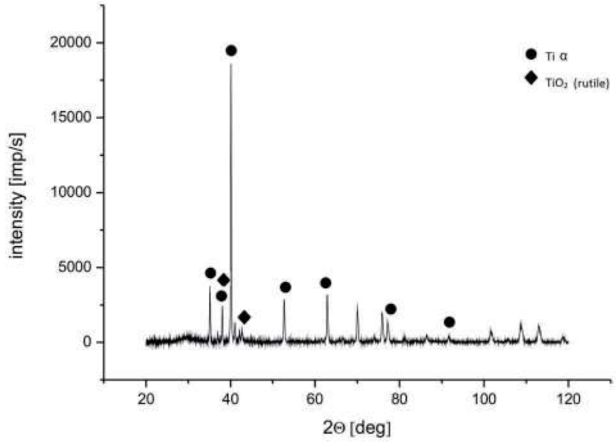

Fig. 8. Diffraction pattern of titanium Grade 2 in baseline

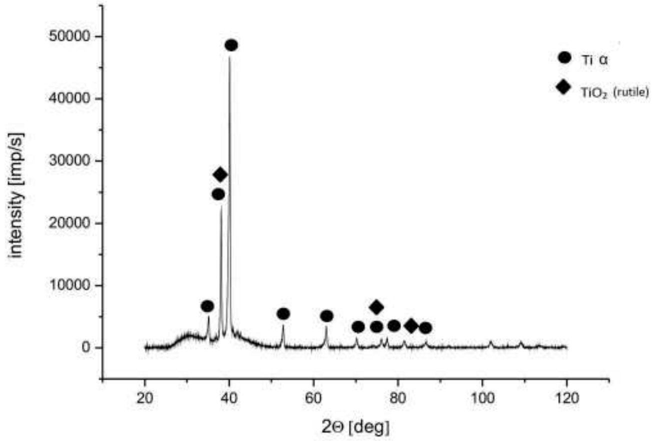

Fig. 9. Diffraction pattern of titanium Grade 2 produced by injection method

Microstructural observations allowed to determine the microstructural differences between samples of titanium Grade 2 produced by the injection method and in the baseline form. Titanium Grade 2 in baseline has coniferous monophasic structure Tiα. The phase is stabilized by nitrogen and carbon which form interstitial solid solutions in Tiα.

After the injection process of titanium Grade 2 microstructure changes while the phase remains the same. X-ray qualitative studies have shown peaks form 2 phases: Tiα and rutile.

Results of microhardness studies summarized in Table 5.

The study has showed that the sample produced by injection is more than three times harder. Average microhardnes of titanium Grade 2 produced by injection equals 930 HV0.1 and titanium Grade 2 in baseline equals 220 HV0.1.

Table 5.
Summary of microhardness studies

	Titanium Grade 2 in baseline	Titanium Grade 2 produced by injection method
Microhardness, HV0.1	229.0	957.0
	201.1	882.6
	222.5	978.8
	231.9	927.6
	215.7	917.4
Average, HV0.1	224.0	932.7

4. Conclusions

The injection casting method allows to change microstructure. Rapid cooling during production process indicates grain refinement.

Grain refinement significantly improves the mechanical properties. The study of microhardness showed that the sample produced by injection is more than three times harder.

Microstructural changes did not effect on the phase composition. X-ray phase analysis confirmed the presence of the same peaks for both analysed cases.

The measurement of corrosion resistance by measuring the open circuit potential and measurement of resistance to corrosion by anodic polarization curves in the potential range close to the corrosion potential showed that titanium tends to form passive layers on the surface.

A shift of the corrosion potential in the positive direction for titanium sample produced by the injection method in relations to sample produced in baseline shows better corrosion resistance.

The corrosion rate based on a scale of corrosion resistant of metals (Table 4) is no high and shows good resistance to corrosion of studied materials.

The injection casting method allows to modify properties of existing materials which allows to obtain better parameters.

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