Archives of Materials Science and Engineering
Volume 44
Issue 2
August 2010
Pages 112-119
International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Plasma furnace for smelting and casting metal up to 3000 K

M. Žitňanský [a,*], S. Demian [a], Ľ. Čaplovič [a], Ľ. Rehák [b], R. Dorschfeld [c]
[a] Faculty of Materials and Technology, Slovak University of Technology in Bratislava, J. Bottu 25, Trnava, Slovak Republic
[b] I-st Department of Orthopaedics and Traumatology, Medical Faculty, Comenius University and UHB, Ružinovská 6, 82606 Bratislava, Slovak Republic
[c] MediMet Precision Casting and Implants Technology GmbH, Ohle Ring 23–25, 21684 Stade-Wiepenkathen, Germany
* Corresponding author: E-mail address: marcelzit@gmail.com

Received 30.05.2010; published in revised form 01.08.2010

ABSTRACT

Purpose: The aim of our investigation was a development of plasma furnace for preparing castings of titanium alloy Ti64 ELI by remolding in laboratory at our research workplace. The reason of this paper writing was publishing of innovative information to the technical society.

Design/methodology/approach: The objectives were achieved by solution of much research and development works in the very long time interval. The main methods used for our research was study of physic-chemical interaction between a liquid metal and surrounding atmosphere. The approach to the topic of our research was the elimination of interactions between the C, O, N and H and Ti, Al, V, Y, Zr in liquid metal. Contemporary we have solved also the acute ceramic mould for casting of perfect castings from metal of very high affinity to C, O, N and H. The main subject scope of the paper is assignee of very clean materials and much application from that. We are oriented particularly on the preparing parts of cementless total hip joint replacement (THR) and instruments for implantation.

Findings: We have created the new original design of the plasma furnace for smelting and castings of high reaction of metal up to 3000 K. temperature. The main conclusion of our result was a practical using for research on very high level and for production of metal and castings from special metal in the final shape.

Practical implications: It has been found that the quality of castings from Ti and Nb alloys is very good. The quality of casting was tested by metallographic analysis and by notch specimens. We have been finding out that the mass of casting can be approximately 1.00 kg. This is true statement in the first approximation if the new plasma furnace is arranged as smelting – cleaning – casting system. If the new plasma furnace is arranged as continual smelting system, than we can obtain ingot with the mass two or more kilograms.

Originality/value: The design of new plasma furnace is original and also the castings from Ti, Ta and Nb alloys are in our laboratory original resultants and the metallographic analysis as well. In the case, when the castings with a good biocompatibility plays important role, this new plasma furnace can be very useful for preparing implants for body skeleton and spatial casting of material of very high affinity to elements as C, O, H, and N.

Keywords: Technological devices and equipment; Plasma furnace; Titanium castings; Precise castings

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

M. Žitňanský, S. Demian, Ľ. Čaplovič, Ľ. Rehák, R. Dorschfeld, Plasma furnace for smelting and casting metal up to 3000 K, Archives of Materials Science and Engineering 44/2 (2010) 112-119.

MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

This paper has solved the research and development of preparing processes of precise titanium castings with a high utility and quality. It follows the preparing such a castings which are there in mode of implantat in to body skeleton or an animals pertinently of castings from spatial metals as V, Ti, Mo, Ta, Nb a Zr. The challenge for such a research was done by Office of government of SR [1], what has been pushed an applicable research and utilization of biocompatible alloys in medicine. The top of that research is oriented on the preparing of total hip joint replacement (THR). The research team has been used it for solving that problem of original design [1-3].

For preparing of Slovak cementless total hip joint replacement was selected titanium alloy with commercial denomination as Ti64 alloy ELI [4-7]. The research workplaces [8, 9] have been got for this solution of grant [9]. The result of that grant was Slovak cementless hip joint replacement which lastly was named ZRM®. For that grant solution the research team has used a modern computer graphics [9] and parallel solved processes of preparing whole spectrum of THR by smelting and casting from alloy Ti64 ELI. For overachievement of our research we have decided of reconstruction plasma furnace, what was installed in 1972 on our workplace on the Slovak University of Technology in Bratislava. This plasma furnace was constructed by V. Dembovský from TU Ostrava – VŠB Ostrava Poruba. In this paper we are present our results, gained in laboratory conditions on the workplace of institute of material engineering. It includes the proposal of a method of manufacturing of precise castings with a mass up to 1 kg of alloy Ti64 ELI. On our research workplace we have in comparison with the world-wide level certain possibilities of melting and casting of the mentioned alloy. We are speaking “only” because the theoretical capacity of the plasma burner was 45 kW. The aim of our research was the development of the method of preparing titanium alloy Ti64 ELI by remodeling in laboratory conditions on our research workplace. The objectives were achieved by doing a wide spectrum of experiments. We have used different heating sources of remolding of Ti64 ELI alloy. We are using e.g. melting in vacuum and pouring in to ceramics or copper moulds. As main method used for our research was remolding, purification, casting in the vacuum or in the air atmosphere. The quality of microstructure was investigated by electron microscopy and tested by notch impact.

However the Ti and Ti64 ELI alloy have very high affinity to C, O, N and H the surrounding atmosphere must be very clean. It means the surrounding atmosphere must be vacuum or very clean argon.

The other problem is potential very danger physical - chemical reaction between the liquid metal and the surface of the ceramic mold. Parallel with other problems we are solving also this question.

In order to prepare very good quality of the surface of castings and fill up the whole volume of the mold it must be solved also the heating of mold. From this reason we have solved also the heating processes of the ceramic mold.

For expectation it is possible by using such a process of production special micro castings from Ti64 ELI alloy. The mean idea of this paper will be practical implications.

The result of this paper should be made some changes in practice e.g. as savings of turning with connection of using of Rapid Prototyping method.

The original value of our paper is the testimony above quality of alloy Ti64 ELI as cast.

The quality of alloy Ti64 ELI as castings must be comparable with certified Ti64 ELI from abroad. We present here with the achieved results in our laboratory of plasma and vacuum metallurgy. From the aspect of physical metallurgy it is well-known that, in the course of treating of the alloy Ti64 ELl into its final shape of a micro-casting, it is necessary to eliminate series of potential physical-chemical reactions.

When taking into consideration that, the chemical composition of the alloy Ti64 ELI consists of elements: Ti, Al, V, Fe, Y, C and in the liquid state there react with the liquid metal also gases as O, N and H, it is clear that, the process of melting is extremely complicated. According to the using melting device, there can appear some or all physical-chemical reactions.

2. Material and technology

As model testing alloy was Ti64 alloy ELLI. The initial idea above exploitation plasma furnace for smelting, refining and casting originated still in 1982. In Fig. 1 is representing the principle arrangement of such processes [10].

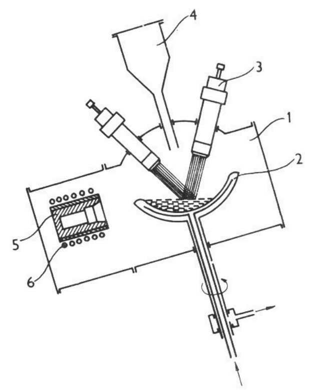

Fig. 1. The configuration of plasma furnace [10]: 1 - Recipient, 2 - Cu crucible, 3 - plasma burner, 4 - supplementation of material, 5 - mold, 6 - origin of heating

In the Fig. 2 is another configuration for continually smelting and crystallization of spatial metals under the molten slag. It was a very interesting result of my student from postgraduate study of welding in 1972.

As can be seen in Fig. 2 a good result was the break of processes smelting and than continuation. This can be seen on the grain boundary, which was creating by isotherm of temperature at repeatedly follow-through processes. From this principle was derived configuration represent in Fig. 3. The realization of design in Fig. 3 is full realistic and a “little after” in 2010 was finished by our scientific researcher [10]. The order of processes of smelting crystallization gives very good mixing of liquid metal. The torch on which is making of ingot pulled down has also such a possibility to circulate about his vertical axis. It is a good alternative solution. In Figs. 3 and 4 the yellow color represents the flam of plasma burner. Another arrangement of processes after (Fig. 4) represents the smelting in crucible with the vertical axis.

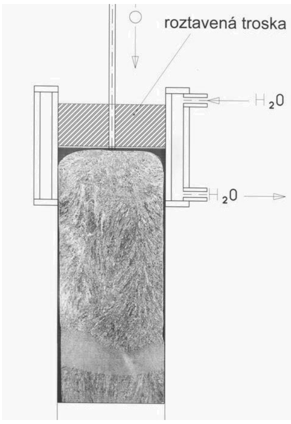

Fig. 2. The configuration of continual processes of smelting and crystallization: (roztavená troska =) molten slag

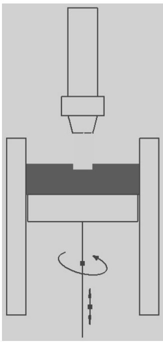

Fig. 3 Alternative arrangement of continual processes of smelting with the possibility of turning of ingot – the yellow color is plasma arc

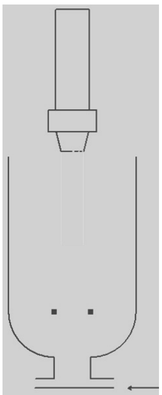

Fig. 4. Alternative arrangement of smelting, refining and poring of liquid metal through hole opening in the bottom of smelting crucible

The smelting crucible is from copper and water cooled. Liquid metal is admitted in to mold through opening in the bottom after what the slide valve is mowing on the right hand side. In Fig. 5 is in the implicit mode represented another alternative arrangement of the processes of smelting refining and casting in such as mode that liquid metal is poring from crucible through the edge of crucible after what the crucible is turned above his horizontal axis in to mould. As from Fig. 5 arise it was constructed smelting crucible with the vertical axis. The crucible is produced from copper and it is water cooled. From booth hand sides in horizontal direction have the flanges which are there connected with electric transformer to be flowing the electric current and also with feed of cooling water. In Fig. 6 is design of the second configuration of plasma furnace with the vertical axis of smelting crucible. This design was in that mode realized. Than follows one series of experiments in different versions arrangements of processes smelting and casting of Ti64 alloy ELI [11-20]. From that works step by step it was developed idea of definitive conception a new plasma furnace (Fig. 7 and Fig. 8). Fig. 8. represents extraordinary important element of new plasma furnace, it means the plasma burner with a power above 200 kW. This was very heavy and important problem to produce plasma burner with high enough power. With this power it is possible to prepare of quality castings from Ti64 alloy ELI with the mass in to 1 kg. That it is the mass of very bright spectrum of implants or necessary equipments. In Fig. 7 the new PF is shown.

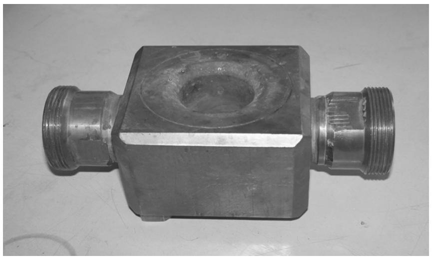

Fig. 5. The configuration of processes of pouring through the edge of smelting crucible

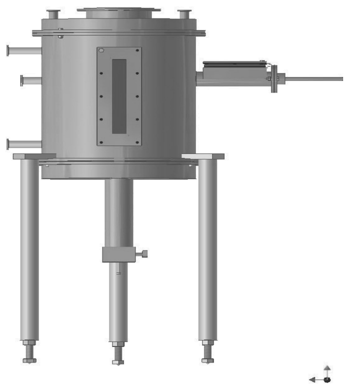

Fig. 6. The second realized design of PF with vertical axis of smelting crucible

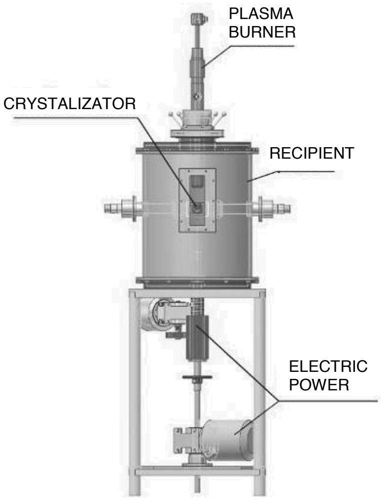

Fig. 7. Third realized design of PF with vertical axis of smelting crucible [10]: crystalizator, plasma burner, recipient, electric power

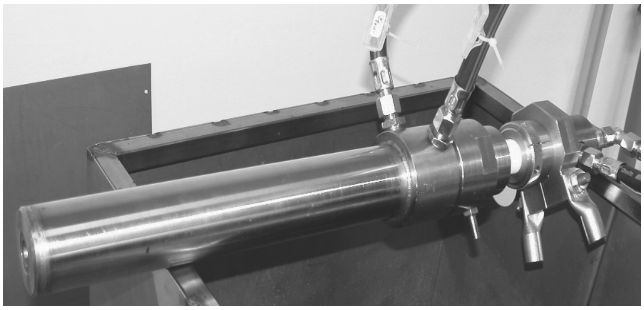

Fig. 8. New plasma burner with power above 200 kW [14]

2.1. Development 3D model of castings

The first version of wax model of femoral part of THR ZRM® for one employing is in Fig. 9. Design virtual 3D model of implantat and real model of casting we have been constructed by using modern computer graphics. The real model of casting after some time reaches a destination shape, which follows after what we are using different work procedure. At last we have remarked in to modern technology preparing of perfect model by processes Rapid Prototyping. With the cooperation with workplaces [21, 22] we have obtained the models of femoral part with the high quality of our ZRM®. This models were made from black ceramic with commercial denomination (ZP150 + ZB150Black) (Fig. 10), from white ceramic with commercial denomination (ZP150 + ZB150Clear) (Fig. 11) and from high quality of wax of turquoise color with commercial denomination (InduraCast) (Fig. 12). The whole models are there only for one employing. From ceramic mould they are removed by burning or by smelting. With the cooperation with firm [23] we are obtain the mould for the preparing of high quality wax models, i.e. of femoral part of TEP ZRM®. The form is made from spatial silicon gummy.

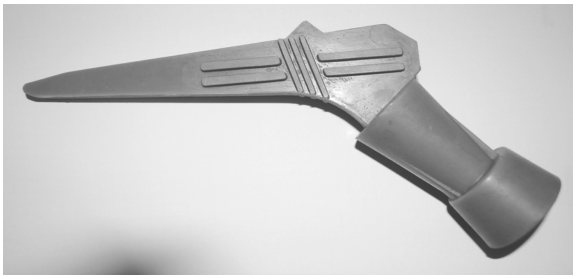

Fig. 9. The first version of wax model of femoral part for one employing

Fig. 10. The second version of model of femoral part for one employing made from black ceramic with commercial denomination (ZP150 + ZB150 Black) [21]

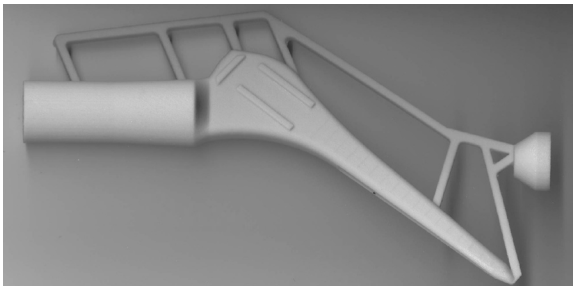

Fig. 11. The third version of model of femoral part for one employing made from white ceramic with commercial denomination (ZP150 + ZB150 Clear) [21]

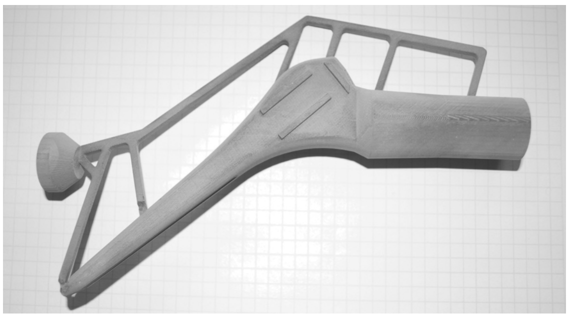

Fig. 12. The fourth version of model of femoral part for one employing made from high quality of wax of turquoise color with commercial denomination (InduraCast) [22]

2.2. Development of mould

We have been experimentally tested copper form and other materials for the preparing of casting. Lastly we have obtained the help from BRD. Suitable ceramic forms we have obtained in frame of cooperation with firm [24]. This firm has many years' experiences with the production of perfect castings from Ti64 alloy ELI. The look on the series of ceramics form is in Fig. 13. There is a very high quality form, which is confirmed by one part of such form after remotion of casting from Ti64 alloy ELI (Fig. 14). Unfortunately in time of their exploitation we had not any good possibility to heat the ceramic mould before pouring. Processes of the heating form was simulated so, that the forms was heated on air on the temperature above 400 °C and than they were imported in to recipient PF. We can suppose that by poring of liquid metal, the forms have had the temperature above 150 – 200 °C. By inspection of casting it was found that such temperature was not high enough. The form was not with liquid metal full fill.

Fig. 13. Look at series of ceramics forms [24]

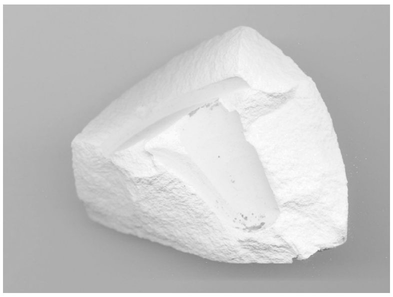

Fig. 14. Look at the upper surface of the ceramic forms after remotion of casting from Ti64 alloy ELI [24]

2.3. Metallographic analysis of titanium alloy

Metallographic analysis was made on the casting in cross-section mark in the Fig. 15. The specimen was prepared by standard manner by metallographic technique using for titanium alloys and consequential etched in the solution of 3 ml HNO_3, 1.5 ml HF and 10 ml H_2O. For documentation was used metallographic light microscope NEOPHOT 32.

In the first step it was inspected the cleanness and directivity of the casting on the polished of metallographic sections. In the any case of selected sections was not detected presence of inclusions or porous or cavities. Inspected casting was not perfect in the whole volume.

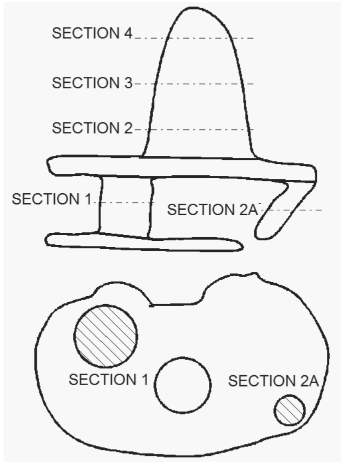

Fig. 15. The Sampling points of casting

Microstructure analysis have been confirmed that the casting was created by grains of the original β phase with the dimension 500 - 800 μm, in which were reconstructed the grains of phases α a α'. Owing to quickly cooling (form was not heated up to necessary temperature) this phases have typical Widmanstätten morphology. This type of structure was observed almost in the whole inspected sections of castings.

From Fig. 16 - Fig. 20 it can be seen that the grain boundaries of origin coarse-grained phase β are decorated by α phase and in volume of grains are morphological similar laminar formation α phase. On the surface of casting was observed morphological different type of flabelliform microstructure with the thickness up to 200 μm (Fig. 17 - Fig. 20).

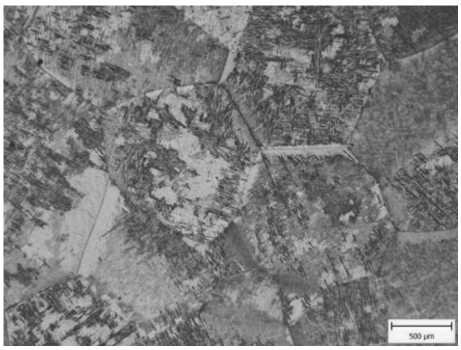

Fig. 16. Macrostructure in place of Section 1

Metallographic analysis of individual parts of casting confirmed morphological modifications of coexisting phase's that they are strongly impacted by thickness of the wall of casting. In the keys of section 1 where was the maximal thickness and in consequence of it also relatively minimal speed of cooling we are identified in microstructure flabelliform morphology (Fig. 21).

Extending of the sped of cooling in the thin overhang (cross section 2A) have been caused origin morphological different of the Widmanstätten structure (Fig. 20). Transitionally character has microstructure in Fig. 21 observed in cross sections 2 and 4. On the grains of the original β phase was indentified phase thin meshed morphology α phase and in volume of grains mixture of laminar of Widmanstätten microstructure α phase.

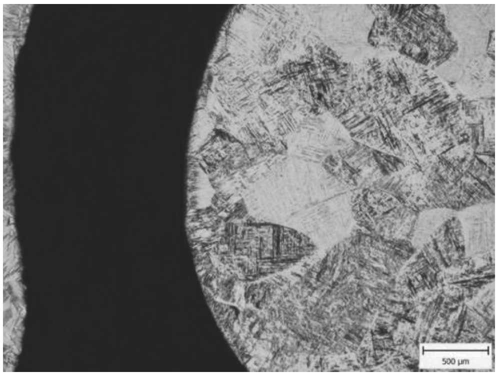

Fig. 17. Macrostructure in place of Section 2A

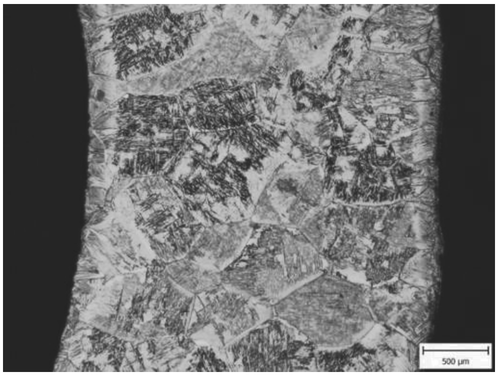

Fig. 18. Macrostructure in place of Section 4

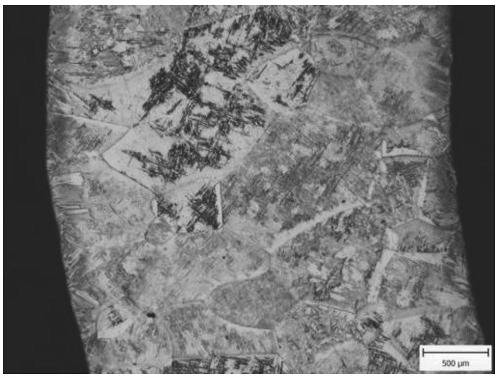

Fig. 19. Macrostructure in place of Section 3

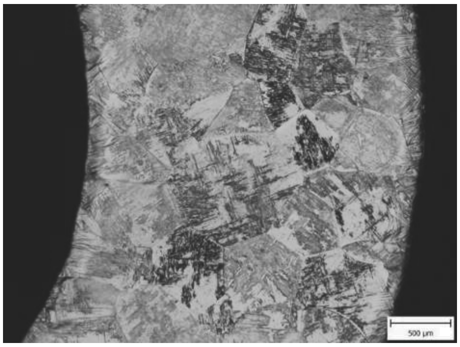

Fig. 20. Macrostructure in place of Section 2

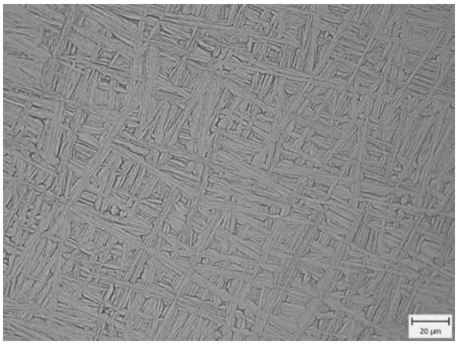

Fig. 21. Microstructure in place of Section 1

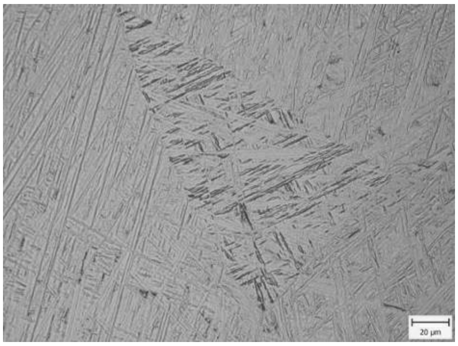

Fig. 22. Microstructure in place of Section 2A

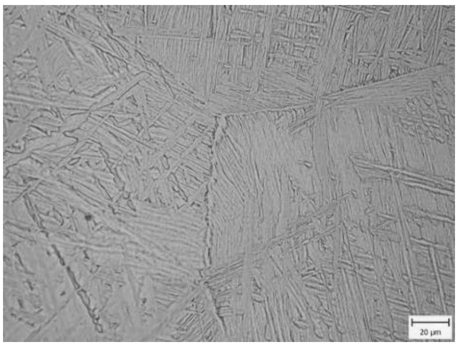

Fig. 23. Microstructure in place of Sections 2 to 4

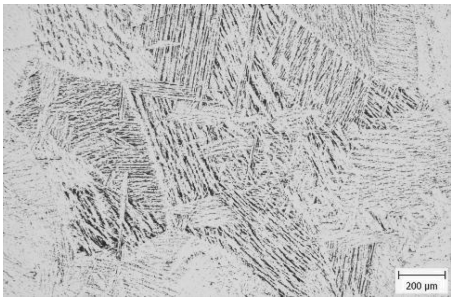

Fig. 24. Etched in 10 % HF

2.4. Metallographic analysis of Zr – Nb alloy

The specimen of alloy Zr 5 mass.-% - Nb 95 mass.-% was observed by this same mode as titanium alloy. Macrostructure analysis this alloy shoved that dimension of grayness is equal as in that foregoing fall on the level 500 µm. In Fig. 25 there are in polarized light represented typical polyedric grayness with differently orientation.

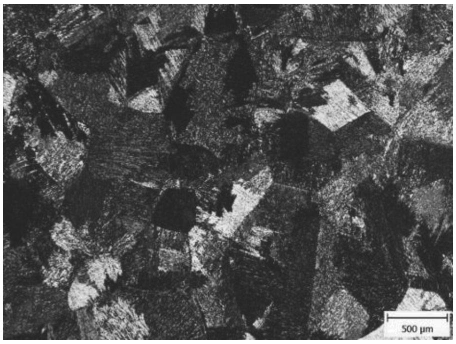

Fig. 25. Macrostructure of alloy Zr-Nb (polarized light)

Microscopic analysis documented in Fig. 26 confirmed existence reciprocally collinear lamellas or slats reconstructed from original polyedric grains. Detailed analysis by raster electron microscope JEOL JSM 7600F shoes that microscopic regularly oriented lamellas are created by blocs of short parallel acicular formations bent under angel 45° to direction grow of lamella (Fig. 27 - Fig. 28). Detail of morphology this acicular formations is documented in Fig. 27 - Fig. 28.

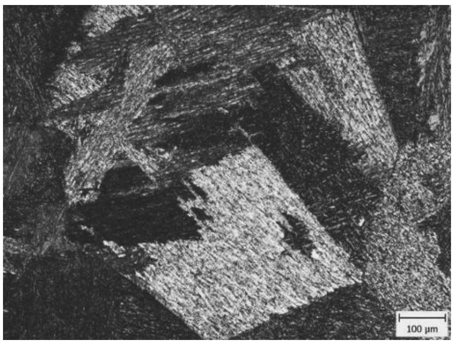

Fig. 26. Microstructure of alloy Zr-Nb (polarized light)

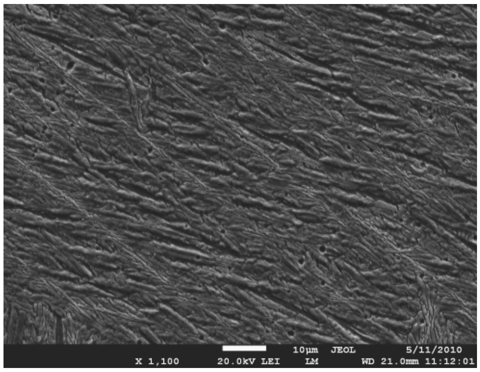

Fig. 27. Microstructure of alloy Zr-Nb (SEM)

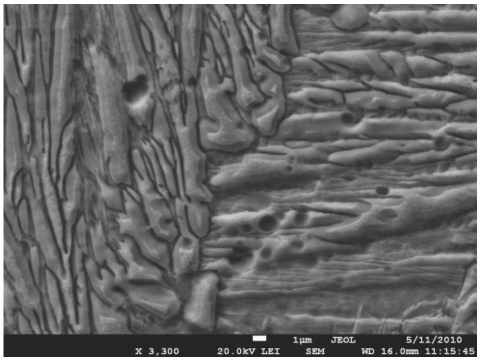

Fig. 28. Microstructure of alloy Zr-Nb (SEM)

3. Results

In the end we can establish that arranged goal we have been reach a destination. It was developed and realized processes of peppering of castings from Ti64 alloy ELI, which was bayed from abroad. This alloy as casting state has very good utilitarian qualities. They are comparable with quilt of Ti64 alloy ELI which was bayed from abroad. The most important result is research and development and the produce of the new plasma furnace for smelting, refining and poring metals up to temperature 3000 K. Parallel with developing of plasma furnace we have been authenticate the mode preparing of ceramics forms of high quality for castings from Ti64 alloy ELI. In connecting on processes of Rapid Prototyping we have been authenticate the preparing of models of high quality of femoral part developed TEP ZRM®. From this reason we have been prepared gummy form for some series of wax models. Together with plasma furnace we have been developed also the node of heating of ceramic forms in the recipient of plasma furnace. The new plasma furnace has some variations of configurations of processes smelting, purification and pouring of metals with high affinity to O, C, N and H. In this plasma furnace it is possible to smelt metals with high point of smelting as i.e. V, Ti, Mo, Zr, Nb, Ta. It has been experimental realized by smelting model alloys such as Ti – Al – Ta, Ti64 alloy ELI and Zr – Nb. Metallographic analysis confirmed that after conditions of cooling mode in form may be obtain good quality of microstructure. By test of notch specimens was established that material of castings from Ti64 alloy ELI has very good values which are comparable with that values of imported Ti64 alloy ELI.

4. Conclusions

On the research workplace of Slovak technical University in Bratislava has been developed and produce modern new plasma furnace with some variations smelting, purification and casting metal up to 3000 K with argon plasma. The plasma burner has power above 200 kW. By that power it is possible to prepare castings from Ti64 alloy ELI up to 1 kg. In the arrangement as continual smelting processes it is possible to obtain ingot with diameter of D – 50 mm some kg. It has been developed the processes preparing of precise casting from alloy Ti64 ELI.

It was tried-and-true of way of preparing forms for the casting of alloy Ti64 ELI. With the connection to Rapid Prototyping processes it was tried-and-true of preparing of models of femoral part of developed THR ZRM® .With the connection to Rapid Prototyping processes it was tried-and-true of preparing of gummy form of femoral part of developed THR ZRM® .

It was developed way of heating ceramic form in the recipient of plasma furnace. The new plasma furnace has some variation for smelting, pouring and casting of metals with the high affinity to O, C, N and H. In the new plasma furnace it is possible to smelt metals with the high temperature of smelting as V, Ti, Mo, Nb, and Ta. It was presented by experiments of smelting of model alloy as Ti – Al – Ta, Ti64 ELI and Zr – Nb.

The metallographic analysis proves that by conditions of cooling of castings in form it may be obtain suitable microstructure. By test of notch specimens was found out that the castings from alloy Ti64 ELI have good values which are comparable with value of alloy Ti64 ELI imported from abroad.

Acknowledgements

This work was realized under support of the grant No. APVT – 20 – 050 702 and VEGA SR 1/ 1081//04, where Prof. Dr. Ing. Marcel Žitňanský, DrSc., was the responsible researcher for the technical part, Doc. MUDr. Ľuboš Rehák, CSc., was the responsible researcher for the medical part, Doc. PhD. Ing. Ľuboš Čaplovič was the co-researcher and Dipl.-Ing. Svetozár Demian was researcher.

References

[1] Meeting of the Committee on society strategy development, science and technology – Government Office of Slovak Republic, 14.4.1996, Bratislava.

[2] M. Žitňanský, F. Makai, Ľ. Rehák, patent Nr. 1178765, EU.

[3] M. Žitňanský, F. Makai, Ľ. Rehák, patent Nr. US 6,652,590.

[4] M. Žitňanský, F. Makai, Ľ. Rehák, patent Nr. 284 754, SR.

[5] M. Long, H.I. Rack, Titanium alloys in total joint replacement-a materials science perspective, Biomaterials l9 (1998) 1621-1639.

[6] J. Matthew, Jr. Donachi, Titanium a Technical Guide, Second Edition, ASM International, The Materials Information Society, 225.

[7] D.M. Brunette, P. Tengvall, M. Textor, P. Thomse, Titanium in Medicine, Springer-Verlag, Berlin, Heidelberg, 2001.

[8] B.D. Ratner, A.S. Ho1ffman, F.J. Schoen, I.E. Lemons, Biomaterials Science, Second Edition, Elsevier Academia Press, London, 2004.

[9] Slovak University of Technology, in Bratislava, Nám. Slobody 17, Faculty of Comenius University in Bratislava. Grant APVT-20-0507/ 02, Development of' method for preparation human body anatomical implants INVENTOR 2009.

[10] M. Žitňanský, V. Dembovsky, Patent No. 192 779, 11. 03. 1982.

[11] M. Zitnansky, L. Caplovic, Effect of the thermomechanical - heat treatment on the structure of model titanium alloy Ti6Al4V, Proceedings of the 9th International Scientific Conference "Achievements in Mechanical and Materials Engineering" AMME'2000, Gliwice - Sopot - Gdańsk, 2000, 589-592.

[12] M. Zitnansky, L. Caplovic, M. Greger, The influence of rolling on the structure of Ti Al64V, Proceedings of the 10th Jubilee International Scientific Conference "Achievements in Mechanical and Materials Engineering" AMME'2001, Gliwice – Kraków - Zakopane, 2001,631-636.

[13] M. Zitnansky, M. Kursa, L. Caplovic, Influence of melting by plasma treatment on microstructure of Ti6Al4V, Titan and its alloys, Czestochowa, 2002, 211-220.

[14] M. Zitnansky, C. Fruth, C. Ohldin, L. Caplovic, P. Zubor, Properties of Ti64 alloy made by non-convential casting method, Proceedings of the 11th International Scientific Conference "Achievements in Mechanical and Materials Engineering" AMME'2002, Gliwice - Zakopane, 2002.

[15] M. Zitnansky, L. Caplovic, The preparing of Ti – 6Al – 4V alloy in laboratory conditions, Proceedings of the 11th International Scientific Conference "Achievements in Mechanical and Materials Engineering" AMME'2002 Gliwice – Zakopane, 2002.

[16] M. Zitnansky, L. Caplovic, Effect of the thermomechanical treatment on the structure of titanium alloy Ti6Al4V, Journal of Materials Processing Technology 157-158 (2004) 643-649.

[17] M. Zitnansky, L. Caplovic, The preparing of Ti – 6Al – 4V alloy in laboratory conditions, Journal of Materials Processing Technology 157-158 (2004) 781-787.

[18] M. Zitnansky, L. Caplovic, Development of' method for preparation human body anatomical implants, Grant APVT-20-0507/02.

[19] M. Zitnansky, L. Caplovic, S. Demian, Metamorphosis quality preparing of alloy Ti64 in laboratory conditions, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 135-145.

[20] M. Zitnansky, Research of the method of anatomically implants in to body skeleton, 5. Medical Sciences, Applied investigation, Achievements of Sciences and Engineering promoted by Agency of Agency for support of research and development, 54, 2009, Bratislava, SR.

[21] P. Cecho, BIBUS SK, Trnavska cesta 31, Nitra, SK.

[22] E. Černý, Sales Manager, BIBUS, Brno, CZ.

[23] J. Drápela, RP Sales, MCAE Systéme, Knínická 1771, Kuřim, CZ.

[24] R. Dorschfeld, MediMet Feinguß GmbH, Ohle Ring 23 – 5, 21684 Stade-Wiepenkathen, Germany.