

ANALYSIS OF THE WELDING RECONDITIONING POSSIBILITIES OF MEDICAL PROSTHESIS

Corneliu Rontescu¹, Dumitru-Titi Cicic², Cătălin-Gheorghe Amza³,

¹ Politehnica University of Bucharest, 313 Splaiul Independentei, 060042, Bucharest, Romania, corneliu.rontescu@upb.ro

² Politehnica University of Bucharest, 313 Splaiul Independentei, 060042, Bucharest, Romania, dumitru.cicic@upb.ro

³ Politehnica University of Bucharest, 313 Splaiul Independentei, 060042, Bucharest, Romania, catalin.amza@upb.ro

ABSTRACT: Improper development of primary manufacturing processes can cause defects in finished products. The paper presents a comparative analysis of two reconditioning technologies used for an interlocking intramedullary nail type prosthesis, made of titanium alloy Ti-6Al-4V, using Tungsten Inert Gas (TIG) welding. Based on the results obtained for the first reconditioning technology, the second technology was developed. By modifying the joint's shape and the welding current used in the first reconditioning technology, resulted a proper joint in terms of operating characteristics. After analyzing the results obtained it can be stated that welding reconditioning technologies can be a reliable solution for technological loss caused by defects occurred in the manufacturing process of medical prosthesis.

KEYWORDS: reconditioning, welding, medical prosthesis, titanium alloys

1. INTRODUCTION

The metallic materials used in the manufacture of prostheses and medical devices must meet a number of conditions that prevent the human body from rejecting the implant.

Most of metallic materials, Fe, Cr, Co, Ni, Ti, Ta, Mo and W, used for medical prosthesis, are tolerated by living tissues in very small amounts, although some metallic elements are essential for cellular functions

A special category of material is that of "shape memory" alloys which, after plastic deformation, return to the original form by heating (medical applications for intracranial aneurysms, vein filters, orthopedic implants, etc.) [1,2].

The quality of a material used in an implant must meet the following two criteria: the biochemical criterion and the biomechanical criterion. According to the biochemical criterion, the applicability of a material is determined by its biocompatibility, and biomechanically by its fatigue resistance, the most important parameter but not the only one.

The type of material, process and manufacturing standards, chemical composition, processing conditions and mechanical properties significantly influence the interaction between the material and the bone tissue. The long-term stability of the implant is closely related to its ability to integrate into adjacent bone tissue [3,4].

One of the biocompatible materials used to make prostheses and medical devices is titanium and

titanium alloys. Titanium and titanium alloys have high mechanical properties (resistance to friction, torsion and pressure), low specific weight (about half of the specific weight of steel), is not toxic (by comparison, stainless steel can cause a series of allergies) is not ferromagnetic (allows imaging investigations using the magnetic resonance method) [5,6,7,8].

The addition of alloying elements in titanium alloys has a powerful influence on its mechanical properties, as follows:

- aluminum, as the main alloying element, stabilizes phase α by increasing the transformation temperature $\alpha \rightarrow \beta$;
- vanadium, chromium, copper, molybdenum, stabilizes phase β , lowering the transformation temperature $\alpha \rightarrow \beta$.

Processing of titanium alloy semi-finished products is performed by hot and cold plastic operations, followed by recrystallization, hardening and improvement treatments. Lately, Ti-Mo, Ti-Mo-Zr alloys have been studied, characterized by their low elastic modulus, which have martensite-type β or α -structure and have excellent biocorrosion resistance and improved resistance properties.

Another alternative for medical prostheses, especially for customized prostheses, is the use of the new additive manufacturing processes (Direct Metal Laser Sintering, Selective Laser Melting, Selective Laser Sintering etc.) [9].

In case of custom prosthesis, manufactured by additive manufacturing processes, it is possible that the complex shape of the prosthesis cannot be obtained in one piece. In such situations the prosthesis can be made of several components that can easily be obtained by the additive manufacturing process, and then be assembled by welding. At the moment, there are no such services on the Romanian market for the creation of prostheses, which include the welding reconditioning in the process of optimizing the structural shape of custom made prostheses [10,11].

Using welding reconditioning technologies, geometrical and shape configuration changes can be made for different type of prosthesis. Better than that, the areas containing crack or pore type nonconformities can be removed and rendered. After processing the loaded areas and bringing them in conformity with technical specifications, defective parts can be recovered [12,13].

Some of the advantages offered by welding processes are cost reduction, that can be achieved for prostheses manufacturing and long-term use of surgical instruments or aesthetic prosthesis [14,15].

2. EXPERIMENTAL DATA

The medical prosthesis undergone welding reconditioning is an interlocking intramedullary nail. It is inserted into the medullary channel of a long bone (tibia, femur) as a result of a fracture and provides rigid immobilization of bone fragments, temporarily or permanently, in order to heal the injuries suffered.

The interlocking intramedullary nail was made of titanium alloy Ti-6Al-4V, an alloy often used in prosthesis and medical devices manufacturing. The chemical composition of the material as well as its mechanical properties are presented in table 1 and table 2, according to the ASTM standards F67 [16] and F136 [17].

After examining the interlocking intramedullary nail type prosthesis, obtained by a classic manufacturing process, a crack type imperfection was identified. Imperfection appearance resulted in product classification as scrap. Through welding reconditioning, it was sought to remove the imperfection by removing the affected area and restoring the initial shape by welding.

The welding process chose for welding reconditioning was Tungsten Inert Gas (TIG), a welding process that offers good control of the arc and also a very good quality of the welded seam. The chemical composition and mechanical

properties of the used filler material (ERTi-5 type rod) are presented in table 1 and table 2, in accordance with the ASTM standards AWS 5.16 [18].

Table 1. Mechanical properties of the base and filler material

Material	Ti6Al4V	ERTi-5
Tensile Strength R_m [N/mm ²]	950	895
Yield Strength $R_{p0.2}$ [N/mm ²]	880	828
Elongation A [%]	14	10
Reduction of Area Z [%]	25	22

Two welding reconditioning technologies were used in order to repair the interlocking intramedullary nail. The technological parameters of the first welding technology used for welding reconditioning of the interlocking intramedullary nail are presented in table 3. The joint preparation was made in accordance with the geometrical parameters presented in figure 1 [11].

Table 2. Chemical composition of the base and filler material

Material	Ti-6Al-4V	ERTi-5
C [%]	0.10	0.05
O [%]	0.20	0.120.20
N [%]	0.05	0.03
H [%]	0.125	0.015
Fe [%]	0.3	0.22
Al [%]	5.5-6.75	5.5-6.75
V [%]	3.5-4.5	3.5-4.5
Ti [%]	Bal.	Bal.

Table 3. Welding parameters

Parameter	Value
Welding current, I_s [A]	40÷45
Arc voltage, U_a [V]	12÷14
Filler material diameter, d_c [mm]	2.00
Gas flow, D_g [l/min]	10
Travel speed, v_s [cm/min]	12÷14
Type of gas protection	II (Argon 100%)

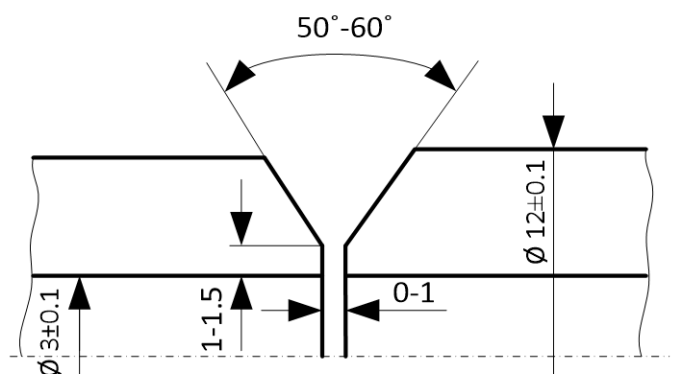


Figure 1. Single 'V' butt joint used in the first case of welding reconditioning

After welding, the sample was subjected to destructive and nondestructive testing. After analyzing the metallographic images (figure 2), it can be noticed that in the central area there is an incomplete melted area. These imperfections cannot be accepted in the operating conditions of the product. This nonconformity may be caused by inadequate processing of the joint or by the too low values of the welding current. Also, for increasing the penetration it is recommended to use a mix of argon and helium gas [14,15].



Figure 2. Metallographic image of the first sample reconditioned by welding

Taking into account the possible causes of occurrence of the detected nonconformities, a second welding reconditioning technology was developed for the interlocking intramedullary nail. For centering the two components, it was used a centering pin made of Ti-6Al-4V material, welded by one of the components, which also has the role of supporting the molten metal bath (figure 3)

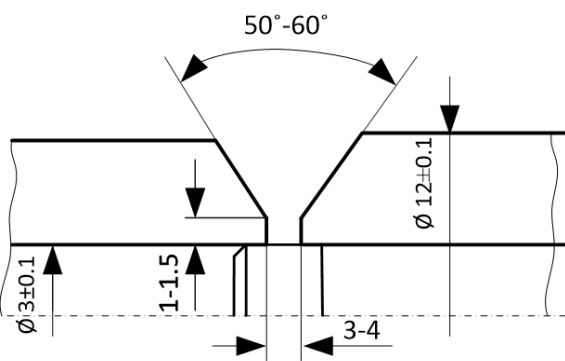


Figure 3. Single 'V' butt joint used for the second case of welding reconditioning

The technological parameters used for the second welding reconditioning technology are presented in table 4. In order to ensure full penetration at the root, the root opening was increased and also the welding current.



Figure 4. The processing of the components in order to realize the second welded sample

Table 4. Welding parameters

Parameter	Value
Welding current, I_s [A]	50÷45
Arc voltage, U_a [V]	10÷12
Filler material diameter, d_e [mm]	2.00
Gas flow, D_g [l/min]	10
Travel speed, v_s [cm/min]	10÷12
Type of gas protection	I1 (Argon 100%)

3. RESULTS

The welding reconditioning was made in accordance with the second welding technology recommendations. Throughout the welding process, an inert protection atmosphere was provided in the joint area and adjacent areas to avoid contamination of the molten metal bath. The prosthesis resulted after using the second welding reconditioning technology is presented in figure 5.

After welding, the reconditioned sample, as in the first case, was subjected to optical examination and penetrant testing. It can be noticed that the sample doesn't have any surface or surface connected imperfections (figure 6).



Figure 5. The welded seam obtained through the second welding reconditioning technology

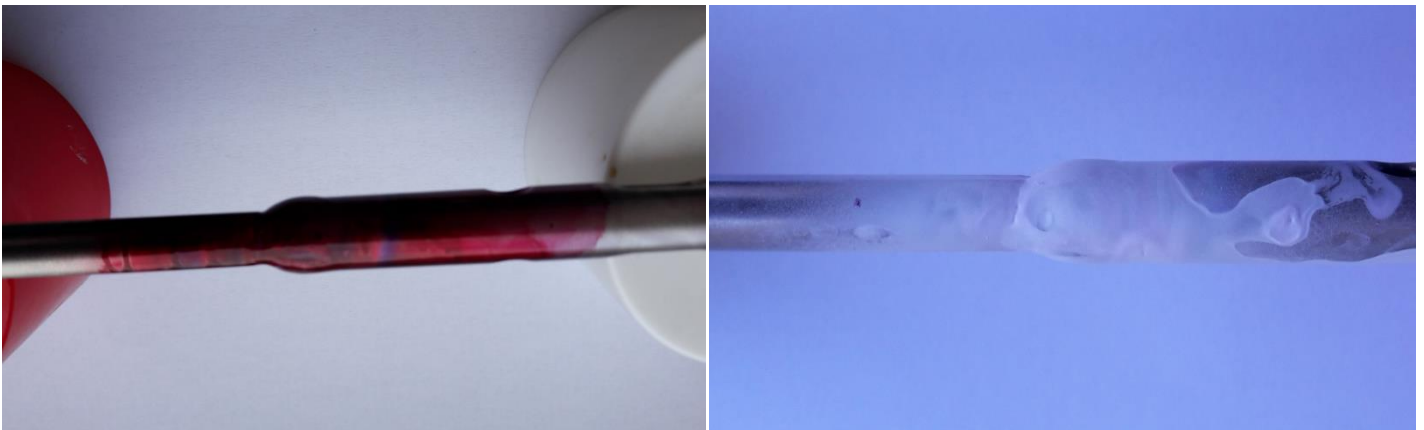


Figure 6. Penetrant testing of the second reconditioned sample: a - penetrant appliance , b - developer appliance.

In order to highlight possible imperfections from inside the welded joint, the sample was subjected to macro graphic examination. After analyzing the metallographic images (figure 7) it can be noticed that the centering pin succeeded in supporting the molten metal bath and at the same time participated in forming the welded seam. In the reconditioning process, after finishing the welding process, the interior of the interlocking intramedullary nail will be processed at the nominal value of the inner diameter.

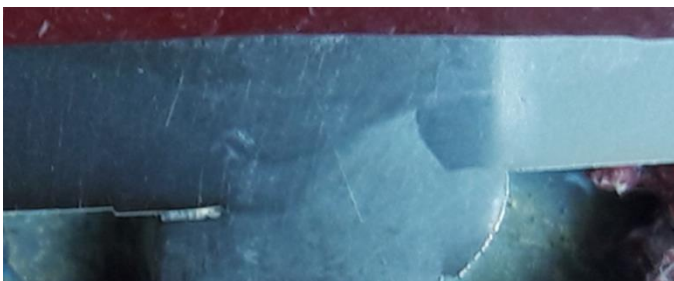


Figure 7. Metallographic image of the second sample reconditioned by welding

After analyzing the metallographic image presented in figure 7, it can be noticed that the welded joint doesn't have any nonconformities. Changing the technological parameters made it possible to have no imperfections, like lack of melting or lack of penetration like in the case of the sample

reconditioned in accordance with the technological parameters presented in table 3.

By increasing the welding current, a full penetration of the welded seam was possible along with obtaining a smooth cross between the welded seam and the samples subjected to the welding reconditioning process.

Increasing the root opening offered access to the lower part of the welded seam, allowing full melt of the components and root support.

4. CONCLUSIONS

The technological parameters of the welding reconditioning technology influence the quality of the welded joints obtained.

By increasing the welding current it was possible to obtain a full penetration welded joint, without any imperfections.

Choosing the appropriate geometrical parameters for the joint offers access to the lower area of the welded seam, leading to the possibility of adequate melting of the edges of the two components undergone the welding reconditioning process.

The welding reconditioning processes can be applied with success in the case of welding/repairing/reconditioning medical prosthesis made out of titanium or titanium alloys.

The titanium alloys Ti-6Al-4V shows good weldability under the conditions of adherence to technological recommendations specific to the type of material.

5. ACKNOWLEDGEMENTS (HEADING 1)

This work was supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI - UEFISCDI, project number PN-III-P2-2.1-CI-2018-1413, within PNCDI III.

6. REFERENCES

1. Information on www.tuiasi.ro/user/112/V.Bulancea - *Materiale Metalice Avansate utilizate în Medicină*, accessed on: 17.02.2018.
2. I.L. Gligor, *Cercetări asupra unor biomateriale cu bază titan pentru implanturi*, Editors eds., Cluj Napoca, Phd. Degree, (2011).
3. A. Clark, A. E., Hench, L. L., & H.A. Paschall, Fox, T.Q., Dog, T.L., The influence of surface chemistry on implant interface histology: A theoretical basis for implant materials selection, *J. Biomed. Mater. Res.*, 10, p. 161–177. (1998).
4. D.F. Williams, Definitions in Biomaterials, *Proceedings of a Consensus Conference of the European Society for Biomaterials*, Elsevier (Vol. 4), New York, p.525-533, (1992),
5. D.F. Williams, On the mechanisms of biocompatibility (*Biomaterials* Vol. 29) pp 2941-2953, (2008).
6. N. Dumitrașcu, *Biomateriale și Biocompatibilitate*, Ed. Univ. Al. I. Cuza Iași, (2007).
7. Angelescu R M , et al. Mechanical, Structural And Corrosion Analysis Of A Ti-Nb-Zr-Fe Alloy Esignated To Oral Implantology *U.P.B. Sci. Bull.*, Series B, Vol. 77, (2015).
8. H.J. Rack, J.I. Qazi, Titanium alloys for biomedical applications, *Materials Science and Engineering C* 26 Elsevier, p. 1269 – 1277, (2006).
9. R. Boboescu, R. Laslău, Analyze of welding regime in laser welding with full factorial design experiments, *Nonconventional Technologies Review / Revista de Tehnologii neconventionale* . Sep2012, Vol. 16 Issue 3, p4-9. 6p
10. Mohsin T M, Zahid A K and Arshad N S Beta Titanium Alloys: The Lowest Elastic Modulus for Biomedical Applications, *International Journal of Chemical, Nuclear, Materials and Metallurgical Engineering* Vol.8, (2014).
11. Bajenaru-Georgescu D., Ionita D., Prodana M and Demetrescu I., Electrochemical and antibacterial characterization of thermally treated titanium biomaterials, *U.P.B. Sci. Bull.*, Series B, Vol. 77, (2015).
12. Cao J, et al. Welding and Joining of Titanium Aluminides, *Materials*, (2014)
13. Ramirez J E Mechanical Behavior of Titanium Clad Steel Welded Joints, *Welding Journal* vol.93 (2014).
14. Rontescu C., Cicic D.T., Vasile I.M., Bogatu A. M.n Amza C.G., Reconditioning medical prostheses by welding”, *ModTech International Conference - Volume 227, Issue 1, pag 413...418*, (2017).
15. C. RONTESCU, D.T. CICIC, A.M. BOGATU, C.M. DIJMARESCU, The optimization of the reconditioning possibilities for interlocking intramedullary nail made of titanium alloy, *17th International Multidisciplinary Scientific GeoConference*, Vol. 17, Issue 61, pp. 413-418, (2017).
16. ASTM F67–13 2013 Standard Specification for Unalloyed Titanium for Surgical Implant Applications (UNS R50250, UNS R50400, UNS R50550, UNS R50700) (American Society for Testing Materials: West Conshohocken, PA, USA).
17. ASTM F136–13 2013 Standard Specification for Wrought Titanium-6 Aluminum-4 Vanadium, Alloy for Surgical Implant Applications (UNS R56401) (American Society for Testing Materials: West Conshohocken, PA, USA)
18. AWS A5.16 Titanium & Titanium-Alloy Welding Electrodes & Rods