D. JEVREMOVIC, T. PUSKAR, B. KOSEC, Đ. VUKELIC, I. BUDAK,
S. ALEKSANDROVIC, D. EGBEER, R. WILLIAMS

ISSN 0543-5846
METABK 51(2) 171-174 (2012)
UDC – UDK 669.14.018.298:669.18=111

THE ANALYSIS OF THE MECHANICAL PROPERTIES OF F75 Co-Cr ALLOY FOR USE IN SELECTIVE LASER MELTING (SLM) MANUFACTURING OF REMOVABLE PARTIAL DENTURES (RPD)

Received – Prispjelo: 2011-07-23
Accepted – Prihvaćeno: 2011-09-03
Original scientific paper – Izvorni znanstveni rad

The presented work discusses the applicability of the selective laser melting technique (SLM) in manufacture of removable partial denture (RPD) frameworks with the emphasis on material properties. The paper presents initial results of a conducted test of the mechanical properties of the F75 Co-Cr dental alloy used with selective laser melting.

Key words: mechanical properties, selective laser melting, removable partial dentures, Co-Cr alloy

Analiza mehaničkih svojstava F75 Co-Cr legure za primjenu kod selektivnog laserskog topljenja (SLT) izrade djelomičnih zubnih proteza. Dana istraživanja se odnose na primjenljivost tehnike selektivnog laserskog topljenja (SLT) u proizvodnji djelomičnih zubnih proteza, pri čemu je posebna pažnja usmjerena na svojstva materijala. Rad prikazuje inicijalne rezultate sprovedenog testiranja mehaničkih svojstva F75 Co-Cr dentalne legure za primjenu kod selektivnog laserskog topljenja.

Ključne riječi: mehaničke karakteristike, selektivno lasersko topljenje, djelomične zubne proteze, Co-Cr legura

INTRODUCTION

During the last several years, numerous novel technologies which allow the design and manufacture of precision, custom-made, optimal dental restorations have been introduced in the field of dental prosthetics. Recent, efforts have concentrated on the development of modelling and manufacture of dental restorations by introducing contemporary computer-aided (CA) techniques and state-of-the-art materials in order to improve weaknesses of the traditional manual approaches in design and manufacture which are prone to numerous subjective errors [1-4].

Removable partial dentures (RPD) represent a special type of dentures, designed for functional or aesthetic reasons for partially edentulous dental patients who cannot have a fixed partial denture i.e., a bridge. Traditionally, RPD frameworks are manufactured through so-called lost-wax technique that is, though in use for decades, prone to human induced errors [5].

In the modern approaches, modelling of dental restoration is based on the application computer-aided design (CAD) systems and reverse engineering (RE). RE, a modelling technique widely used in different engineering fields [6], has been increasingly applied to the field of dental prosthetics during the last several years, mainly because of the rapid development of dental 3D digitization systems and corresponding modelling software [2,7]. Realizing the benefits of RE, recently there have been several research projects aimed at further developing this technique in the design of RPDs [8,9].

In the field of computer aided manufacture (CAM) of dental restorations, rapid manufacture (RM) technologies have been increasingly applied in recent years as presented by Eyers and Dotchev [10]. Moreover, Bibb et al. [11] have showed the results of RM application in the manufacture of surgical guides for dental surgery. Selective laser melting (SLM) is a RM technique based on layer-wise material addition that allows the generation of complex 3D parts by selectively melting successive layers of metal powder on top of each other. This technology is very suitable for dental applications, due to the complex geometry of the produced parts, as shown by Vandenbroucke and Kruth [12] for the case of personalized frameworks that support artificial teeth. However, application of SLM in RPD framework fabrication is still in the investigation phase. Though case studies on RPD framework fabrication by SLM presented by Williams et al. [13] showed promising results, there is still a lot of work that needs to be accomplished before studies are finalised.

The applied material, i.e., the alloy, is one of the most important issues in dental prosthetics [4,12,14,15].

D. Jevremovic, Clinic for Prosthodontics, School of Dentistry Pančevo, University Business Academy, Novi Sad, Serbia. T. Puskar, Department of Dentistry, Medical Faculty, University of Novi Sad, Serbia. B. Kosec, Faculty of Natural Sciences and Engineering, University of Ljubljana, Ljubljana, Slovenia. Đ. Vukelic, I. Budak, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia. S. Aleksandrović, Faculty of Mechanical Engineering, University of Kragujevac, Kragujevac, Serbia. D. Egbeer, R. Williams, Centre for Dental Technology and the National Centre for Product Design and Development Research, University of Wales Institute, Cardiff, United Kingdom.

In the manufacture of RPD frameworks, this issue is even more important as the application is limited to cobalt-chromium (Co-Cr) alloys due to the low rigidity of titanium (Ti) alloys that are otherwise widely used in the fabrication of other dental restorations, as explained in detail by Aridome et al. [16]. The manufacture of RPD frameworks by SLM involves some additional material requirements related to its mechanical properties and biocompatibility as presented by Vandenbroucke and Kruth [12]. Though Co-Cr alloys have been used in dentistry for years, little is known about the influence of the SLM process on their biocompatible and mechanical behaviour. Investigation of the biocompatibility of F75 Co-Cr dental alloy, presented in [17], showed positive initial results. However, further studies, including 'in vivo' tests and tests of mechanical properties have to be conducted before the final release of the alloy into mass production.

With respect to the above discussion, this research focuses on the applicability of SLM techniques to the manufacture of RPD frameworks with emphasis on the mechanical properties of the used alloy. The paper presents initial results of a test of the mechanical properties of the F75 Co-Cr dental alloy used with SLM.

MATERIALS AND METHODS

Materials used for RPD framework fabrication have to fulfil strict requirements regarding mechanical properties. In testing an alloy's mechanical properties related to its applicability in the fabrication of RPD frameworks, special attention is focused on the preparation of the samples, in this case, tensile bars. The tensile bars (Figure 1) were manufactured by the SLM system Realiser, MTT-Group, UK and the software used was Magics 9,5, Materialise NV. The layer thickness of the Co-Cr build was 0,075 mm, with a laser maximum scan speed of 300 mm/s, and a beam diameter of 0,150-0,200 mm. F75 Co-Cr alloy (Sandvik Osprey Ltd., UK) used in this study is supplied as a spherical powder with a maximum particle size of 0,045 mm (particle size range 0,005 – 0,045, mean size approx. 0,030 mm). The chemical structure of the F75 Co-Cr alloy is given in Table 1, together with the chemical structure of the alloy Remanium GM 380+ that is widely used in conventional investment casting of RPD frameworks.

During the SLM process, powdered material is spread by a roller over the surface of a build cylinder. Subsequently, the powder is deposited incrementally on top of each solidified layer, and then sintered again. To accommodate a new layer of the material, the cylinder has to move down, while a laser beam is traced over the surface of the compacted powder (Figure 2).

After the SLM process was finished and specimen supports removed, bars were finished by polishing according to the usual dental laboratory procedure (Figure 3).

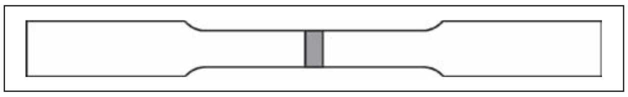

Figure 1 Tensile bar geometry

Table 1 **Composition of the Remanium GM 380+ and Sandvik Osprey F75 alloys**

Ingredients / wt %	Remanium GM 380+	Sandvik Osprey F75
Co	64,6	Balance
Cr	29	27-30
Mo	4,5	5-7
Si	<1	<1
Mn	<1	<1
N	<1	/
C	<1	<0,35
Fe	/	<0,75
Ni	/	<0,5

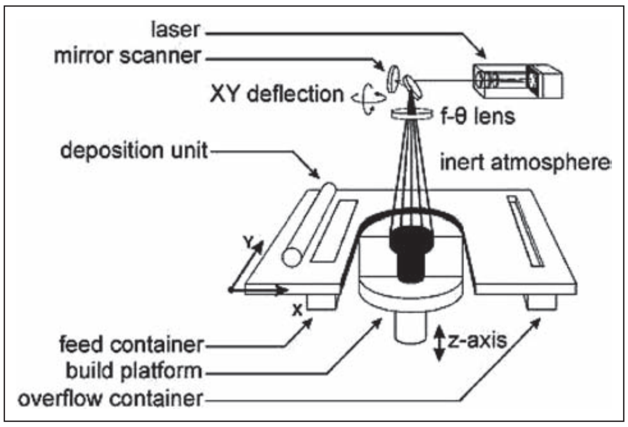

Figure 2 Principle of the SLM [18]

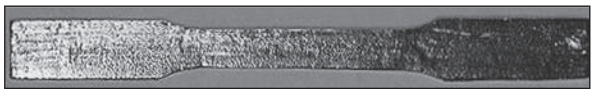

Figure 3 SLM fabricated tensile bar

RESULTS AND DISCUSSION

The mechanical characteristics of the F75 alloy produced by the SLM process were tested on the ZWICK-ROELL Z 100 testing system (Figure 4). Experimental testing was conducted according to standard EN10002 Part 1. Tests were performed at the deformation velocity of 10 mm/min. The measuring accuracy of the tensile force was 1 N, while the measuring accuracy of displacement and elongation equalled 0,001 mm. The testing was performed on a total of three sample tensile bars with geometric characteristics (initial specimen length L_0, thickness a_0, width b_0, cross-section surface area S_0), shown in Table 2.

Table 2 **Tensile bars dimensions**

Specimen No.	L_0 / mm	a_0 / mm	b_0 / mm	S_0 / mm^2
1	40,00	2,92	7,45	21,75
2	40,00	2,91	7,51	21,85
3	40,00	2,93	7,53	22,06

Figure 4 Testing system

The results obtained are shown in Table 3. The results were gained by the uniaxial tension of three square specimens. Testing of mechanical properties conducted within this research included analysis of yield strength ($R_{p0,2}$), tensile strength (R_m) and elongation (A).

Table 3 **Mechanical properties of alloy F75 obtained by SLM process**

Specimen No.	$R_{p0,2}$ / MPa	R_m / MPa	A / %
1	689,24	1383,41	4,26
2	724,41	1472,26	4,11
3	672,18	1363,89	1,76

The results obtained for the mechanical properties of F75 SLM dental alloy are presented in Figures 5-7.

The Figures show tensile curve diagrams for all the three tested specimens. The shape of the curves indicates a very tensile material and pronounced elastic deformation. At specimen break, the recorded plastic deformation for the first specimen was 4,26 %; total deformation was 7 % or 2,8 mm. For the second specimen, plastic deformation was 4,11 %; total deformation was 7,3% or 2,9 mm. For the third specimen plastic deformation was just 1,76 %; while total deformation was 4,5 % or approximately 1.8 mm. These data indicate a small

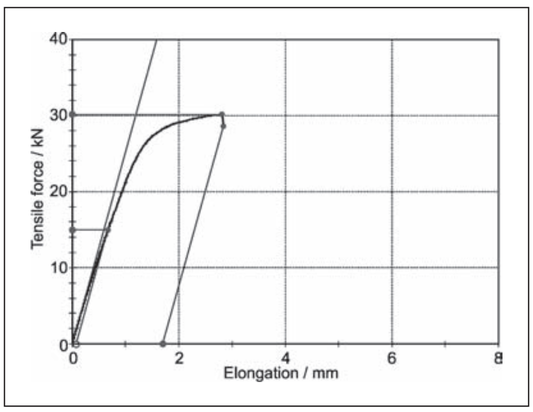

Figure 5 Tensile curve for specimen No. 1

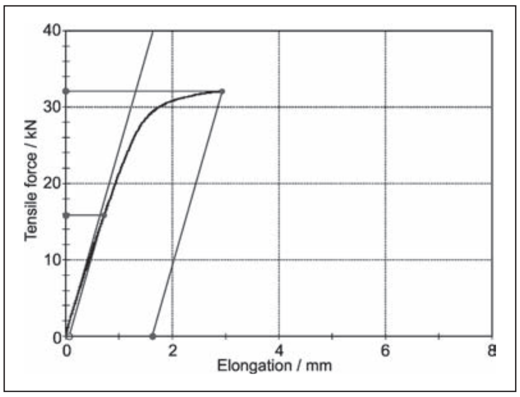

Figure 6 Tensile curve for specimen No. 2

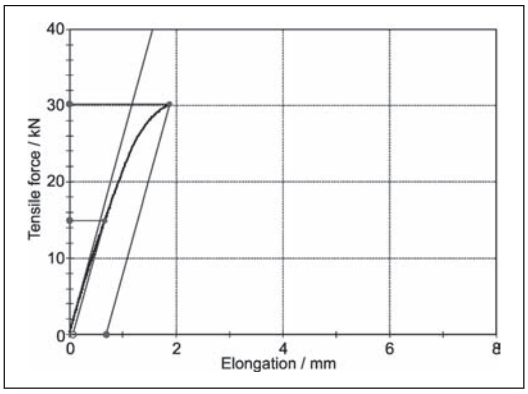

Figure 7 Tensile curve for specimen No. 3

plasticity or deformability of the tested material, i.e., high stiffness and an extremely pronounced brittleness.

Table 4 **Mechanical properties of the material Remanium 380+, manufactured by precision casting**

Alloy	$R_{p0,2}$ / MPa	R_m / MPa	A / %
Remanium GM 380+	640	900	6,5

Relative to the mechanical properties of Remanium GM 380+ (Table 4) - which is the material commonly used for dental replacements and is manufactured by precision casting - the tested material exhibited extremely high tensile strength (approximately 1 400 MPa). In comparison with Remanium GM 380+ which has nominal tensile strength of 900 MPa, the increase exceeds 50%. Yield strength $R_{p0,2}$ at around 700 MPa represents an increase of 10 % compared to Remanium GM 380+. This indicates that the stresses required for permanent deformation are nearly the same, while the tensile strength is significantly higher for the F75 alloy. The total elongation at break for alloy F75 equals 7 % which is nearly equal to Remanium's 6,5 %.

Certain differences in the mechanical characteristics of the F75 and Remanium GM 380+ alloys can be related to its composition and the specifics of the manufacture processes. Though the composition of the alloys used for SLM and conventional investment casting generally match however they differ by a small percentage of basic ingredients (Table 1). It has been shown that modification in the composition and pre-treatment of an alloy can influence the mechanical properties by a large degree [12,16]. SLM as a complex thermo-physical process can vary the final product depending on several factors, e.g., material, laser, scan and parameters of the environment. Changeable variables include laser power, layer thickness, scan speed and hatch spacing. These variables can be adjusted accordingly, optimizing some aspects that can have a negative effect on the mechanical properties of the material. For example, porosity is related to low energy input, as successive scan tracks may not be fully molten leaving large pores along the scan lines.

CONCLUSIONS

The research presented in this paper is focused on the analysis of the mechanical properties of the F75 SLM dental alloy. The results of the uniaxial tension testing of three specimens from F75 dental alloy fabricated by SLM are presented. The major characteristics of the F75 alloy are extremely high strength and high brittleness. A comparison of the mechanical characteristics of this alloy and Remanium GM 380+ shows similar yield strengths and maximum elongation, while F75 features significantly higher tensile strength.

On the basis of the results obtained, within the limitations of the study, it can be concluded that the F75 dental alloy used for SLM manufacturing showed positive initial results regarding its mechanical properties.

Further studies will be focused on the testing of the additional mechanical characteristics as well as on the analysis of SLM process parameter adjustment.

REFERENCES

[1] A. Cernescu, N. Faur, C. Bortun, M. Hluscu, Engineering Failure Analysis, 18 (2011) 5, 1253-1261.
[2] M. Germani, R. Raffaeli, A. Mazzoli, Rapid Prototyping Journal, 16 (2010) 5, 345-355.
[3] M. Colic, D. Gazivoda, D. Vucevic, I. Majstorovic, S. Vasiljic, R. Rudolf, Z. Brkic, P. Milosavljevic, Journal of Dental Research, 88 (2009) 11, 997-1002.
[4] K. Raic, R. Rudolf, B. Kosec, I. Anzel, V. Lazic, A. Todorovic, Materials and Technologies, 43 (2009) 1, 3–9.
[5] D. Eggbeer, R. Bibb, R. Williams, Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine, 219 (2005) 3, 195-202.
[6] D. Eggbeer, P. L. Evans, R. Bibb, Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine, 220 (2006) 6, 705-714.
[7] I. Budak, M. Sokovic, J. Kopac, J. Hodolic, Journal of Mechanical Engineering, 55 (2009) 12, 755-765.
[8] R. J. Williams, R. Bibb, D. Eggbeer, Practical Procedures and Aesthetic Dentistry, 20 (2008) 6, 349-351.
[9] R. J. Williams, D. Eggbeer, R. Bibb, Quintessence Journal of Dental Technology, 6 (2008) 1, 42-50.
[10] D. Eyers, K. Dotchev, Assembly Automation, 30 (2010) 1, 39-46.
[11] R. Bibb, D. Eggbeer, P. Evans, A. Bocca, A. Sugar, Rapid Prototyping Journal, 15 (2009) 5, 346-354.
[12] B. Vandenbroucke, J. P. Kruth, Rapid Prototyping Journal, 13 (2007) 4, 196-203.
[13] R. J. Williams, R. Bibb, D. Eggbeer, J. Collis, Journal of Prosthetic Dentistry, 96 (2006) 2, 96-99.
[14] K. Raic, R. Rudolf, A. Todorovic, D. Stamenkovic, I. Anzel, Materials and technologies, 44 (2010) 2, 59-66.
[15] R. Rudolf, T. Zupancic Hartner, L. Kosec, A. Todorovic, B. Kosec, I. Anzel, Metallurgy, 47 (2008) 4, 317-323.
[16] K. Aridome, M. Yamazaki, K. Baba, T. Ohyama, The Journal of Prosthetic Dentistry, 93 (2005) 3, 267-273.
[17] D. Jevremovic, V. Kojic, G. Bogdanovic, T. Puskar, D. Eggbeer, D. Thomas, R. Williams, Journal of the Serbian Chemical Society, 76 (2011) 1, 43-52.
[18] http://www.mtm.kuleuven.be/Onderzoek/a2p2/researchtopics/SLM

Note: The responsible for English language is R. Williams, University of Wales Institute, Cardiff, United Kingdom.