# Laser welding process of stainless steel used for bio-medical applications

K. Colić[1], S. Petronic[1], A. Sedmak[2], A. Milosavljević[2], Z. Kovacević[3]
[1] Innovation Center, Faculty of Mechanical Engineering, University of Belgrade, Serbia
[2] Faculty of Mechanical Engineering, University of Belgrade, Serbia
[3] Institute for testing materials-IMS Institute, Belgrade, Serbia
*E-mail: kbojic@mas.bg.ac.rs*

**Keywords**

Stainless steel, biomedical applications, laser welding, biomedical devices, grade 316L steel, pulsed Nd:YAG laser

## 1. Introduction

Due to the fact that they are introduced into a biological environment, metallic materials for biomedical applications are called biomaterials. Required properties of such biomaterials differ greatly, depending on the region where they are to be implanted and the function to be provided. Basically, materials which are to be used for biomedical applications should cause minimal degradation in the body; they should be compatible with the biological environment; they should also be strong enough for the intended purpose [1]. In order to investigate the applicability of laser welding to the fabrication of biomedical devices, stainless steel materials that are used in biomedical applications were analyzed.

There are many stainless steel alloys available for use in biomedical applications, each with individual characteristics that make it a good solution to a certain problem [1]÷[3]. However, by making one characteristic better, other characteristics may become weaker. The first stainless steel material utilized for a biomedical application - implant fabrication - was type 302 in modern classification, which is stronger and more corrosion resistant than vanadium steel. 18-8sMo stainless steel was introduced later on, containing a small percentage of molybdenum, which was added to improve corrosion resistance in chloride solution. During the last several decades, several stainless steel alloys have been developed for biomedical use, but the most often used steel alloy in biomedical applications is grade 316 L.

In biomedical applications, welded S 316 L finds its uses in the medical device-manufacturing sector, including making products such as pacemakers, stents, defibrillators, implants, medical batteries, and a myriad of surgical and other medical tools [4].

Implanted medical devices must provide flawless functioning, without tissue irritation. The welds on these implants must be a hermetic seal often positioned very close to heat-sensitive components. Since the value of the implant before welding is high, the yield from the welding process must also be high. Laser welding meets these requirements, as this welding method produces a smooth hermetic seal. Laser welding of stainless steel biomaterials can be used for all biomedical applications, when it is imperative that parts should be joined with smooth welds without pores [5].

Other applications of laser welding in biomedical applications include medical tools, probes, and leads that must be joined with smooth welds without pores, so that they can undergo the repeated sterilization process in the autoclave. In some cases the tools have very small dimensions, requiring an almost microscopic weld [6]. Surgical tools, such as biopsy devices, use laser welds to attach axle pins to components and to weld the assembly to a lead. Dental tools use laser welding to attach grind and drill bits to the tool housing [7]. Minuscule vascular clamps are laser welded during assembly, in order to produce smooth, consistent welds. Stents, cardiac catheter assemblies, and other arterial therapy tools use laser welding for assembly, and to add X-ray opaque markers to the components, in order to facilitate X-ray observation during procedures. Rigid endoscopes are often assembled from stainless steel tubes with hermetic laser welds at tube transitions.

Laser welding has very low heat input, and such weld and can be placed very close to polymer seals, glass-to-metal seals, and other heat-sensitive parts, such as soldered components and electronic circuits.

## 2. Materials and methods

The alloys of choice for the making of many medical tools in biomedical applications are austenitic stainless steels, most widely used among them the 316 L stainless steel. The 316 L is easy to weld, does not crack easily, and does not corrode near the weld zone like other stainless steel alloys with higher content of carbon. However, under certain circumstances, even 316L stainless steels may corrode inside the body, e.g. in highly stressed and oxygen-depleted regions, such as contact points under the screws of the bone fracture plate. This steel is suitable for temporary implants, such as fracture plates, screws, and hip nails, and for manufacturing certain medical devices. Methods for surface modification, such as glow-discharge nitrogen implantation, anodization and passivation are often used to improve corrosion and wear resistance, and fatigue strength of 316L stainless steel. It has excellent forming and welding characteristics, thus it is commonly used for a variety of parts for applications in the industrial fields [8]÷[9]. Formability and weldability of the S 316 L alloy are important factors for the fabrication and biomedical application of these components.

316L is the modified molybdenum-bearing grade steel, the low carbon version of 316, with maximum carbon content of 0.03%. This leads to better corrosion resistance in chloride solution, and sensitization minimization.

Chemical composition of the specimens used in this experimental analysis was determined by gravimetrical analysis, and is presented in Table 1.

Table 1. Chemical composition of 316 L steel

| Element | C | Mg | P | S | Si | Ni | Cr | Mo |
|---|---|---|---|---|---|---|---|---|
| [%] | 0.03 | 1.95 | 0.25 | 0.03 | 0.70 | 12.5 | 17.5 | 3.0 |

To impart corrosion resistance in stainless steels, minimum effective concentration of chromium is 11%. The maximum molybdenum amount of 4% gives the 316L alloy better overall corrosion resistance than other austenitic stainless steels, and higher resistance to pitting and crevice corrosion in chloride environments in particular. The addition of 2% to 3% molybdenum increases this alloy's resistance to pitting corrosion and improves its creep resistance at elevated temperatures. The low carbon content reduces the risk of intergranural corrosion during welding, thus reducing the need for post-weld annealing.

The nickel stabilizes the austenitic phase [γ], face centered cubic crystal (fcc) structure at room temperature and enhances corrosion resistance. The austenitic phase formation can be influenced by both the Ni and Cr contents, and the minimum amount of Ni for maintaining austenitic phase is approximately 10%.

316L stainless steel cannot be hardened by thermal treatment. However, its hardness and strength can be substantially increased by cold working, with subsequent reduction in ductility.

When welding thin sections, post-weld annealing is not required, since the 316L has excellent forming and welding characteristics.

Pulsed YAG lasers can be successfully used for welding in biomedical applications. They can handle different alloys, and produce low heat with high peak power [10]÷[12]. The beam is commonly delivered via fibber-optics. The energy distribution of YAG lasers helps to obtain a good yield when performing large welds. Tight beam focusing enables production of fine welds in the 40-60 μm range. Laser welding process, owing to its inherently narrow HAT, offers potentional solution for producing crack-free welded joints in S316L. This process can be effective up to 12 mm thick material [13].

Laser welding has specific advantages over conventional fusion welding processes, e.g. high welding speed, narrow heat affected zone, low distortion, ease of automation, single-pass thick section capability and enhanced design flexibility.

One of the many features of laser welding is the capability to weld without filler materials (autogenous welding) and it offers distinct advantages [14]÷[17]. Laser welding produces smooth, pore-free welds for minimum distortion and reliable autoclave sterilization.

Since the laser welding is a non-contact process, weld energy is delivered only where it is needed. The main advantage of this welding method in biomedical applications is strong and clean welds in products that are easier to sterilize and fit into other assemblies. Using lasers provides high degree of strength with minimum number of welds. Unlike soldering or brazing, lasers can provide hermetic welds essential to many biomedical components.

## 3. Experiment

The experiment was carried out on stainless steel 316L sheets; heat treated by Annealing - heat to 1010-1120°C and cooled rapidly.

Stainless steel 316L sheets were welded by pulsed Nd: YAG laser type HTS Mobile LS-P160 (OR Laser), without filler material. Laser specifications are listed in Table 2.

Table 2. Specification of ND3+: YAG LASER - Type HTS Mobile LS-P160S

| Laser parameter | Parameter range |
|---|---|
| Max. mean laser power | 160W |
| Pulse peak power | 7.5 kW |
| Max. pulse energy | 80 J |
| Pulse duration | 0.2 - 20 ms |
| Pulse frequency | 1.0 - 20 Hz |
| Focal diameter | 0.2 - 2.0 mm |

As presented in Table, mean laser power was 160 W, peak power was 7.5 kW, and max energy was 80 J. The parameters of the laser process were: laser energy 48 J, pulse duration 6.0 ms and pulse frequency 5.5 Hz. (62 J, 5.0 ms, 6.0 Hz).

Specimens for the metallurgical and mechanical tests were sampled from the weld joints. Dimension of samples were 50 x 50 x 0.7 mm.

Tensile tests were carried out at room temperature according to relevant ISO specifications. Tensile testing machine used in this experiment was electro-mechanical type SCHENCK TREBEL RM 400, and parameters that were determined were tensile strength, yield strength and elongation.

Detailed investigation of microstructural changes was performed by optical microscope - model KEYENCE VH-Z100, scanning electron microscopes (SEM) model: JOEL JSM-5800. Tensile specimen fracture surfaces were observed using a scanning electron microscope (SEM).

## 4. Results and discussion

Examination of various aspects of pulsed laser welding of steels and superalloys show that through proper control of welding parameters, especially with pulse heat tailoring and manipulation of plasma location, weld seam shape and thermal history may vary.

The aim of our investigation was to find optimal parameters of laser welding process that would produce crack-free weld seam and good mechanical properties. In this paper are presented results for two different specimens, welded with different laser welding process parameters.

Mechanical properties of welded joint for sample 1 and 2 were determined by tensile test. Results of tensile tests for the welds are presented in Figures 1 and 2, and they show load-displacement curves for various tensile specimens. As presented on Figure 1, maximum load of 4300 N and tensile strength of 551 MPa were determined for optimal welding process parameters used for sample 1.

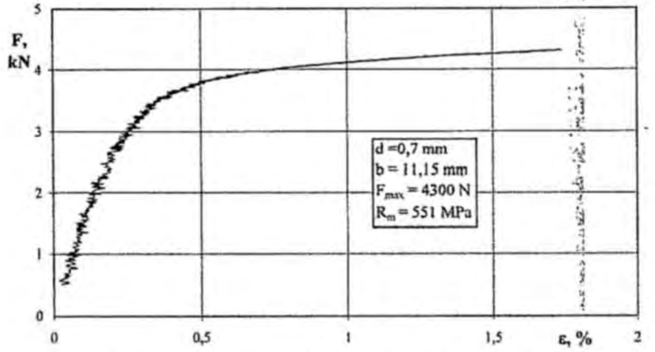

Figure 1. Diagram of tensile tests for sample 1

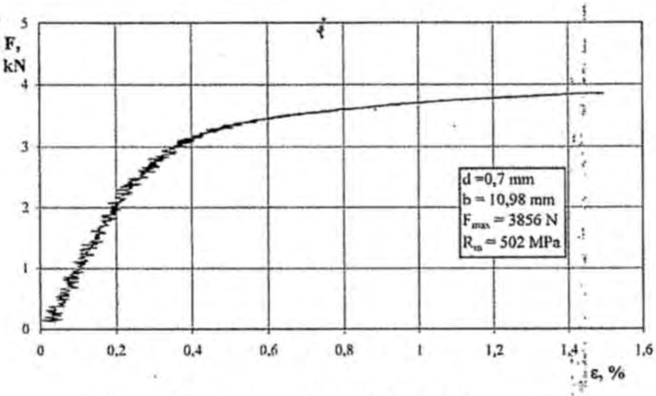

Figure 2. Diagram of tensile tests for sample 2

As presented on Figure 2, maximum load of 3856 N and tensile strength of 502 MPa were determined for badly chosen welding process parameters used for sample 2.

The microstructural changes were observed by optical and scanning electron microscope.

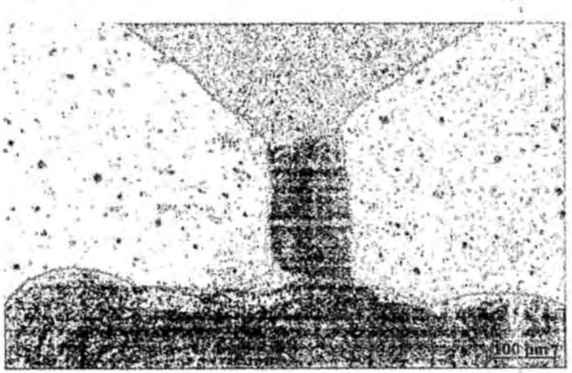

Figure 3. Macroscopic view of the 316L weld. for sample 1

Figures 3 and 4 show macroscopic views of the 316L/316L welds. As shown in Figure 3 for the 316L/316L weld, there were no harmful defects such as overlap, undercut, or macro-cracks. As those views show, no micro-crack is apparent at around the bond, and no marked change occurs in the grain size.

As shown in Figure 4, non optimal laser welding process parameters produced visible micro cracks.

Figure 5 shows the welded joint produced by laser process parameters: laser energy 48J, pulse duration 6.0 ms and pulse frequency 5.5 Hz. The microcracks are not visible.

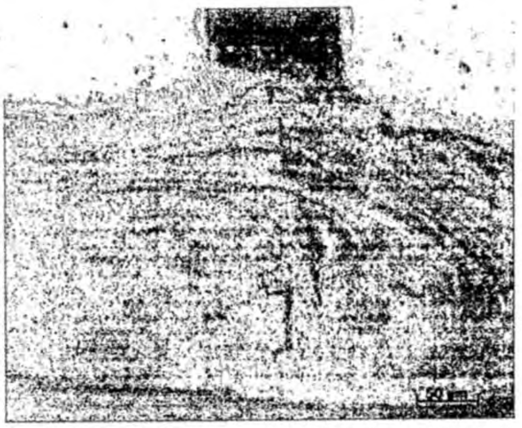

Figure 4. Macroscopic view of the 316L weld for sample 2

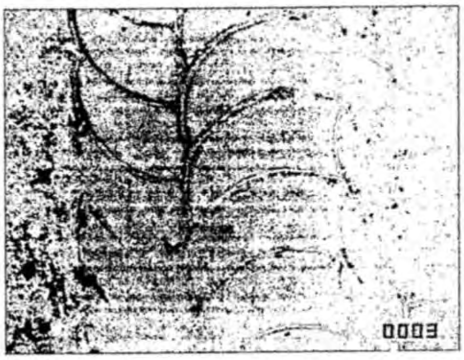

Figure 5. SEM of welded joint of sample 1 (x50)

Figure 6 presents the crack of approximately 300-400 µm, arisen due to nonoptimal process parameters.

Tensile specimen fracture surfaces were observed using a scanning electron microscope (SEM). Figure 7 shows fracture surface of welded joint of sample 1. As presented in Figure 7, microstructure is rather homogenous, and dimples are apparently equivalent. Furthermore, the dimple of the 316L/316L sample 1 specimen is markedly smaller than those of samples welded using badly chosen laser parameters used in this experiment.

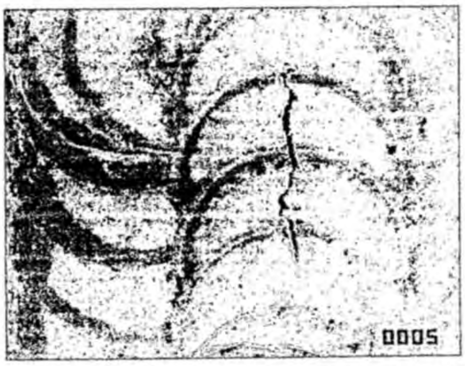

Figure 6. SEM of welded joint of sample 2 (x50)

Figure 8 shows the fracture surface of welded joint of sample 2. As presented in Figure 8, several large cracks were observed at the fracture surface. It is obvious that these cracks didn't occur during tensile testing, and it can be concluded that they are consequence of badly chosen laser welding process parameters. Also, microstructure is nonhomogenous. Furthermore, several large voids of about 0.1-0.4 μm in size are also visible at the fracture surface of the 316L/316L specimen 2.

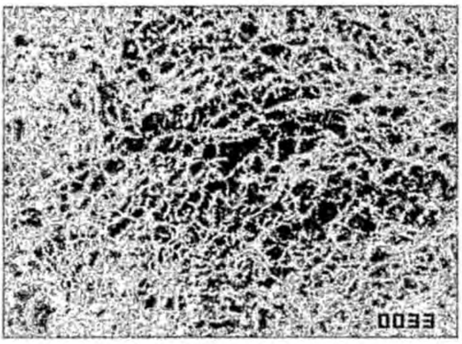

Figure 7. SEM image of fracture surface of welded joint of sample 1

Figure 8. SEM image of fracture surface of welded joint of sample 2

## 5. Conclusion

Laser welding is a good choice of technology for many biomedical applications, because of its very low heat input, and computer-controlled repeatability. Through proper control of welding parameters, especially pulse energy and pulse duration, it is possible produce crack-free weld joints with good mechanical properties.

Optical and scanning electron microscopy of 316L sheets welded by optimal parameters shows homogenous macro- and micro-structure, without cracks or voids, and apparently equivalent dimples.

According to tensile test results, the mechanical properties of this welded joint are better than the results obtained using the base material.

## Acknowledgements

This work was supported by the Ministry of Science of the Republic of Serbia under contract number TR-35040.

## References

[1]. Park, J.B. and Lakes, R.S.: Biomaterials An Introduction, Plenum Press, New York, 1992.

[2]. Niinomi, M.: Fatigue characteristics of metallic biomaterials, International Journal of Fatigue, vol. 29, pp. 992-1000, 2007.

[3]. Milne, I., Ritcie, R.O., Karihaloo, B.: Comprehensive Structural Integrity, Vol. 9: Bioengineering, Elsevier Ltd, Oxford, 2003.

[4]. Khan, I. and Zhou, Y.: Laser Micro-Welding (LMW) of Crossed 316LVM Stainless Steel Wire", Medical Device Materials IV: Proceedings of the Materials and Processes for Medical Devices Conference 2007, pp. 38-42, Sept. 2007

[5]. Klages, K., Gillner, A., Olowinsky, A., Fronczek, S. and Studt, A.: Laser Beam Micro Welding of Dissimilar Metals, Proceedings of SPIE - The International Society for Optical Engineering, vol. 5063, pp. 303-307, June 2003

[6]. Uenishi, K. et al.: YAG laser micro welding of stainless steel and shape memory alloy, Proceedings of SPIE - The International Society for Optical Engineering, vol. 4830, pp. 57-62, May 2002.

[7]. Bertrand, C. et al.: Optimization of operator and physical parameters for laser welding of dental materials, British Dental Journal, vol. 196, pp. 413 - 418, April 2004.

[8]. Yamada, H. et al.: Re-weldability tests of irradiated 316L(N) stainless steel using laser welding technique, Journal of Nuclear Materials, vol. 307-311, pp. 1584-1589, 2002

[9]. Furuya, K. , Ida, M., Miyashita, M., Nakamura, H.: Mechanical properties of F82H/316L and 316L/316L welds upon the target back-plate of IFMIF, Journal of Nuclear Materials, vol. 386-388, pp. 963-966, 2009.

[10]. Samanta, S.K., Mitra, S.K. and Pal, T.K.: Microstructure and Oxidation Characteristics of Laser and GTAW Weldments in Austenitic Stainless Steels, Journal of Materials Engineering and Performance, vol. 7(6), pp. 908-914, Dec. 2008.

[11]. Sindo, K.: Welding metallurgy, second edition, Wiley Interscience, a John Wiley & Sons, Inc, Publication, 2002.

[12]. Sun, Z. and Ion, J.C.: Laser welding of dissimilar metal combinations, J. Mater. Sci., vol. 30, p.p. 4205-4214, 1995.

[13]. Yeni, C. and Kocak, M.: Fracture toughness analysis of laser-beam-welded superalloys Inconel 718 and 625, Fatigue and fracture of Engineering Materials and Structure, vol. 29, No.7, p.p. 546-557, 2006.

[14]. Xiu-Bo Liu, Ming Pang, Jian Guo and Gang Yu: Transmission electron microscopy characterization of laser welding cast Ni-based superalloy K418 turbo disk and alloy steel 42CrMo shaft, Journal of Alloys and Compounds, Vol. 461, p.p. 648-653, 2008.

[15]. Ojo, O.A., Ding, R.G. and Chaturvedi, M.C.: Heat affected zone microfissuring in a laser beam welded directionally solidified Ni3Al-base alloy, Scr. Mater., Vol. 54, p.p. 2131-2136, 2006.

[16]. Mai, T.A. and Spowage, A.C.: Characterization of dissimilar joints in laser welding of steel-koval, copper-steel and copper-aluminum, Mater. Sci. Eng. A, Vol. 374, p.p. 224-233, 2004.

[17]. xxx: Metal Handbook tenth edition - Vol 1 & Vol 2, Properties and Selection: Iron, Steel, and High- Perf. Alloys, ASMI, Materials Park, Ohio, 2005

---

*Lecture presented at the 5th International Conference "Innovative Technologies for Joining Advanced Materials", Timisoara - Romania (June 16-17, 2011)*