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The laser beam welding of titanium grade 2 alloy

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Abstract The paper deals with the laser beam welding of titanium grade 2 alloy. Titanium alloys have a wide utilisation mainly in automotive and aerospace industry, because of good mechanical properties, low weight and good corrosion resistance. The results of the experiment proved that the solid-state laser beam welding of the titanium can produce the joints of good quality, although the further research activity is still to come.

Keywords: Titanium, Laser beam welding , Mechanical Properties

1. INTRODUCTION

Nowadays, the attention of all the industries is focused on the enhance of the material quality with the main objective of increase its lifetime and reliability, and reduction of its cost [1].
The titanium is well known in two allotropic modifications: up to temperature 888 °C is stable α phase with hexagonal structure H12. Among the 888 °C is stable β phase with body-centered cubic structure K8. The titanium has a high affinity to oxygen, oxide TiO_2 is created on the surface and the thickness of the oxide layer rises together with the temperature.
The ultimate tensile strength of the titanium is similar to the tensile strength of the mild steel. On the other hand, the titanium is lighter than steel by more than 43 %. Although the titanium is heavier than aluminium by 60 %, its tensile strength is higher in comparison to the aluminium alloys [2]. The physical properties comparison of titanium, magnesium and aluminium is referred in Table 1.

Table 1 The properties of pure titanium, magnesium, and aluminum at their melting points [3, 4]

	Titanium	Magnesium	Aluminum
Ionization energy (eV)	6.8	7.6	6
Specific heat (J kg^{-1} K)	540	1360	1080
Specific heat of fusion (J/kg)	4.2×10^5	3.7×10^5	4×10^5
Melting point (°C)	1 666	650	660
Boiling point (°C)	3 287	1090	2520
Surface tension (Nm^{-1})	0.855	0,559	0.914
Thermal conductivity (Wm^{-1} K^{-1})	20	78	94.03
Thermal diffusivity (m^2 s^{-1})	5.0×10^{-6}	3.73×10^{-5}	3.65×10^{-5}
Coefficient of thermal expansion (1/K)	8.5×10^{-6}	25×10^{-6}	24×10^{-6}
Density (kgm^{-3})	4.506	1590	2385
Electrical resistivity (μΩm)	0.420	0.274	0.2425
Vapor pressure (Pa)	0.49	360	10^{-6}

The low density, excellent mechanical properties and good corrosion resistance of titanium and titanium alloys have led to a diversified range of successful applications for the demanding performance and reliability requirements of the medical, aerospace, automotive, petrochemical, nuclear and power generation industries. When the operation temperature exceeds 130 °C, the titanium alloys can be used as the replacements for aluminium-based materials to achieve improved mechanical properties at elevated temperatures for applications such as the external shells of turbines, the power units for avionics and the landing gear structural components in Boeings 747 and 757 [5]. Alternatively, as titanium is exhibit very low corrosion rates in human body fluids [6], other applications that are relevant to the medical industry include prosthetic devices such as artificial heart pumps, pacemaker cases (see Fig. 1), heart valve parts as well as load bearing bone such as for hip bone replacement [7].

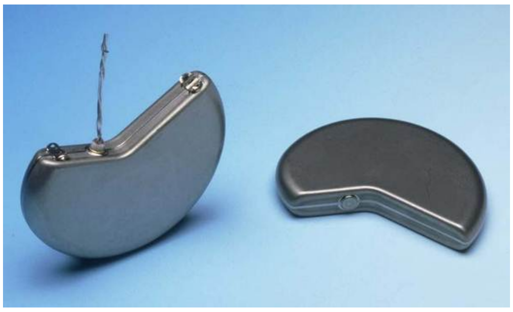


Fig. 1 Laser beam welding of titanium pacemaker cases provides a smooth, low heat input, hermetically acceptable and reliably producible weld joint [8]

To preserve the mechanical properties of titanium alloys during laser beam welding, gas shielding represents a crucial importance to prevent embitterment of the weld region and the ensuing losses in ductility. Protection of the weld pool against atmospheric contaminations is performed by using shielding gas, which also has been reported to improve the coupling of the laser beam to the material [9].
Titanium alloys can be welded using a pulsed and continuous wave (CW) mode laser. In pulsed laser applications, a small molten pool is formed by each laser pulse and within a few milliseconds it resolidifies. When the peak power is low or the spot size is

increased, welding occurs in conduction mode and a shallow and smooth weld pool is produced. On the other hand, when the peak power is increased or the spot size is reduced, a much deeper weld pool is obtained that is characterized as penetration or keyhole mode welding as reported [10].

2. MATERIAL AND METHODS

The titanium grade 2 alloy with the thickness of 0.8 mm and the dimensions of 100 × 50 mm was used for the experiment. The material was chosen due to its mechanical properties and the suitability to the automotive and aerospace industry. The chemical composition of the material is referred in Table 2.

Table 2 The chemical composition of the titanium grade 2 alloy [11]

ASTM Grade	Fe_{max} [%]	O_{max} [%]	N_{max} [%]	C_{max} [%]	H_{max} [%]	Ti
Grade 2	0.3	0.25	0.03	0.1	0.0125	Rest

The weld joints were produced in the PGS Automation, plc. in Trnava. As a laser source, TRUMPF TruDisk 1000 with wavelength of 1030 nm and maximal output power of 1000 W was used. The laser beam was guided by the optical cable to the laser head with the focal length of 140 mm; the diameter of the laser spot in the focal point was 420 μm. The laser head was placed in the shoulder of 6 axis robot FANUC M-6iB 2HS.

3. THE RESULTS OF EXPERIMENT

The specimens were manufactured in both continual and pulse mode. In the pulse mode, the pulse frequency was altering. In the continual mode, the output power together with the shielding gas flow rate and the welding speed were changing. For the weld protection, the pure argon (99.996%) was used. The parameters of the welding processes are referred in Tables 3, 4 and Table 5.

Table 3 The parameters of the pulse mode

Specimen No.	Power (W)	Welding speed (mm/s)	Focusing (mm)	Shielding gas flow rate (l/min)	τ (ms)	Frequency (Hz)
1.1	900	50	0	7	6	70
1.2	900	50	0	7	6	100

Table 4 The parameters of the continual mode with the output power changing

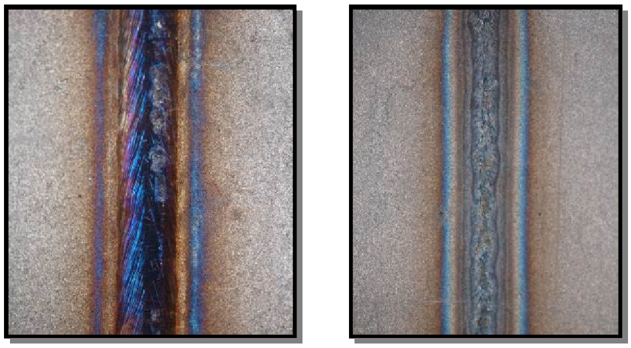
Specimen No.	Power (W)	Welding speed (mm/s)	Focusing (mm)	Shielding gas flow rate (l/min)
1.3	540	50	0	7
1.4	650	50	0	7
1.5	900	50	0	7
1.6	750	50	0	15
1.7	850	50	0	15

Table 5 The parameters of the continual mode with the welding speed changing

Specimen No.	Power (W)	Welding speed (mm/s)	Focusing (mm)	Shielding gas flow rate (l/min)
1.8	850	30	0	15
1.9	850	70	0	15
1.10	850	90	0	15
1.11	850	60	0	15

3.1 Macrostructure of joints

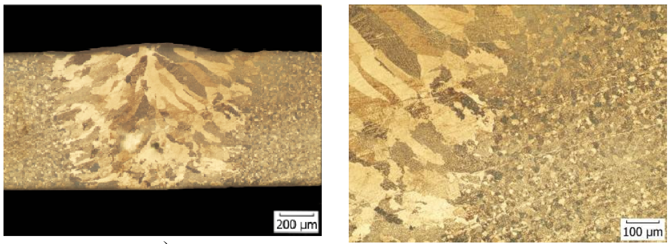
The macrostructure of the specimen No. 1.11 is documented in Fig. 3. The weld had an appropriate shape, it was spatter-free and no porosity and other visible defects weren´t detected. The molten structure at the face and the root side of the weld can be seen as well. Due to the high titan to the oxygen reactivity at high temperatures, the argon with the flow rate of 15 l/mm was used. The violet colour (see Fig. 3a) proved the gas shielding of the weld was unsatisfactory. The weld metal so as the heat affected zone had to be perfectly shielded by the inert gas or by the vacuum as the temperature reached the 450 °C.



a) b)

Fig. 2 The macrostructure of the specimen No. 1.11
a) face side of the joint b) root side of the joint

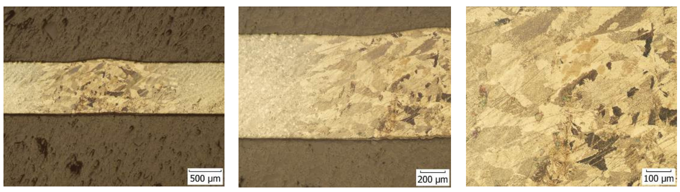
The macrostructure of the specimen No. 1.10 is showed in Fig 3. In the weld metal area (see Fig 3a), the molten structure was observed. The dendrites were growing from the centre of the joint with the dihedral angle lower than 180°, which had a major effect on the cracks formation. In the weld metal-heat affected zone transition (see Fig. 3b), no coarse-graining was observed.



a) b)

Fig. 3 The macrostructure of the specimen No. 1.10
a) overall view, b) weld metal – heat affected zone transition

The microstructure of the specimen No 1.7 is showed in Fig. 4. In the weld metal area (see Fig. 4c), the coarse-graining, and typical to the arc welding methods, was observed. This was mainly due to the lower welding speed in comparison to the specimen No. 1.10.



a) b) c)

Fig. 4 The microstructure of the specimen No. 1.7
a) overall view, b) base material-heat affected zone-weld metal transition, c) heat affected zone-weld metal transition

3.2 The tensile tests

The specimens given to the tensile tests were weld joints No. 1.7, 1.2, 1.5, 1.8, 1.11 and 1.10. The dimensions of the samples were 100 × 10 mm. As a testing device, LABTEST 5.250 SP1-WM was used.

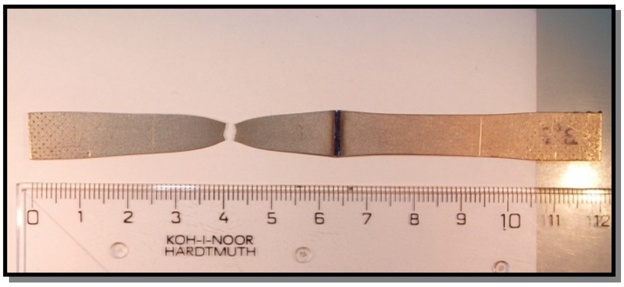


Fig. 5 The sample after the tensile test (Specimen No 1.7)

The force-to-failure of the specimen No. 1.7 was 3.8 kN, the force-to-failure of the specimen No. 1.10 was 3.3 kN (see Fig. 6). The failure occurred out with the weld area as it is documented in Fig. 5. Based on results it can be stated, that the weld joints was satisfactory regarding the mechanical properties. The same results were observed in all the specimens, chosen to the tensile tests.

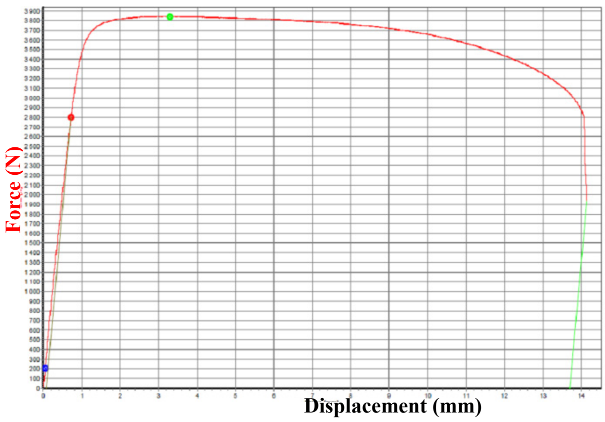


Fig. 6 The tensile test diagram (Specimen No. 1.10)

3.3 The microhardness measurements

The microhardness measurements according to Vickers 0.01 were done on Buehler IndentaMet series 1100 testing equipment. The testing load was F = 981 mN and the loading time was t = 10 s. The typical microhardness trend is documented in Fig. 7. From the picture, it is noticeable, that the microhardness values were similar in the weld metal area and in the base metal area. This was mainly due to the appropriate flow rate and the type of the shielding gas.

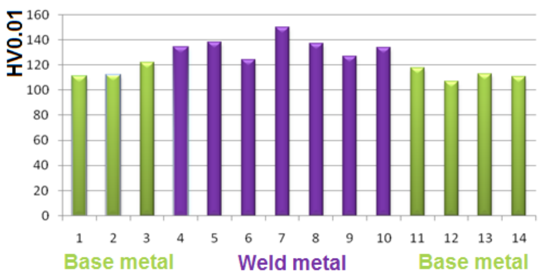


Fig. 7 Microhardness trend (Specimen No. 1.10)

4. CONCLUSION

By the today's trend, it may be expected, that the laser beam welding will represent an important part of the joining of the new materials, so as the material's combinations, which are very difficult to join. The leading power will be the development and the availability of the laser beam [12].

The present work dealt with the welding of titanium grade 2 alloy by solid state laser beam welding. According to the results, the joints with satisfactory mechanical properties were produced. The microhardness measurements proved the correct shielding of the weld joints. The research activity in this field is still in progress, the next part of research will be focused on laser beam parameters optimising and testing the possibility of gas laser beam welding of titanium grade 2 alloy.

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