

Fiber Lasers Application for Welding of Titanium Alloys With 16 mm Thickness

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Abstract. This article illustrates the use of fiber laser welding of a titanium alloy with 16 mm thickness. The basic advantages of the laser welding process over the traditional methods of arc welding of titanium are demonstrated. Destructive testing of welds was performed to confirm the quality of the welding. The results of the static tensile tests, static bending and toughness at room temperature are presented. All tests confirmed the high quality of the welded joint.

1. Introduction

Titanium and its alloys are successfully used in many spheres of industry because they have lots of advantages and unique properties, such as: low specific weight, high toughness, excellent corrosion resistance, high melting point. Titanium and titanium alloys are widely used, for example, in aircraft, space, shipbuilding, chemical industries, nuclear power, and in the medicine.

Welding of pure titanium and its alloys is in most cases complicated because of its high reactivity with atmospheric gases. Titanium is an extremely active chemical element and at a high temperature it easily absorbs harmful gases from ambient air (oxygen, nitrogen, hydrogen), making the weld much worse. The activity of titanium takes place provided the temperature of titanium alloys is above 300° C. And in case of poor protection, heated titanium surface absorbs harmful gases from ambient air resulting in the formation of brittle phases of titanium: carbides, oxides, nitrides. Brittle phases lead to increase in hardness and decrease in ductility. As a result, strength and resilience of the fusion zone and the heat affect zone decrease [1].

Another feature of titanium welding is the tendency to grain growth. Large volume of weld pool, occurring during arc welding, leads to grain growth in the fusion zone metal and in the heat affected zone. As a result, brittle phases are formed in cooling phase, which leads to reduction in weld strength [2].

Laser welding is one of the modern methods of welding, and it has a number of advantages relevant to the titanium alloys treatment: low heat input, low residual stress, minimum temperature limits, and high physical and mechanical properties of weld.

2. Equipment and materials

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A complex for laser welding on the basis of the fiber laser production company OOO NTO “IRE-Polus” was used. Technical titanium, with a titanium content of at least 99 percent, was selected as a material for laser welding, and the wire feed had similar chemical composition. Inert gas argon was used for protection of welding pool and liquid metal during laser welding.

3. Results

A 16 mm thick titanium weld joint was obtained by selecting an optimal mode for laser welding process. Sample back-to-back weld was performed with a special edge preparation for multi-pass laser welding technology. Principle of a multi-pass technology of laser welding is described in [3]. Titanium weld joint 16 mm thick plates are shown in Figure 1.

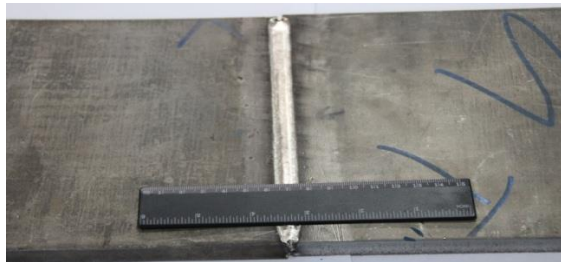


Figure 1. Right side of the weld joint of titanium alloy.

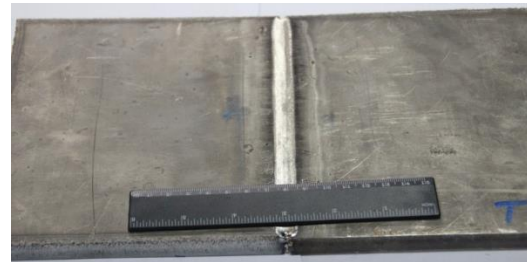


Figure 2. Reverse side of the weld joint of titanium alloy.

4. Macro- and microstructure of the 16 mm thick titanium alloy weld

Figure 3 shows a macrosection of the welded titanium. The width of the weld is about 13–14 mm from the surface, and 6 mm in the central part of the seam. Heat affected zone (HAZ) is about 1.0–1.5 mm. Defects in form of scores on the front and back sides do not exceed 0.4 mm.

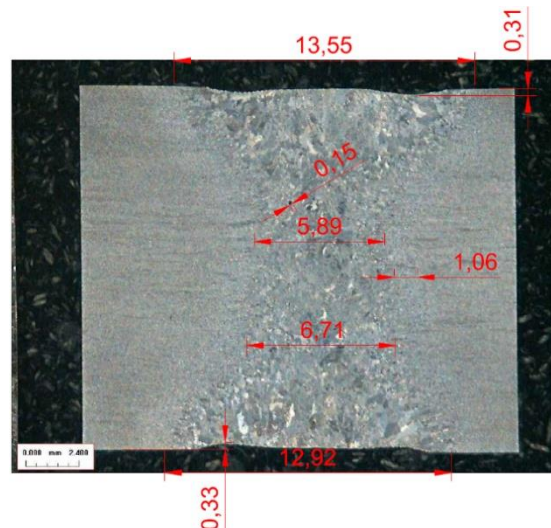


Figure 3. Macrosection of welded joint.

Microstructure is shown in Figure 4. Welded joint has a fine grain structure. Basic metal (BM) comprises α phase, the HAZ zone – α , α' , β phases, and the fusion zone (FZ) consists of α' and β phases. A single pore has a transverse dimension of 150 μ m, which is 0.94% of thickness of the welded joint shown in Figure 3.

Single-phase α alloys show no plasticity and they are not embrittled by the heat treatment. Phase of fusion zone and phase of HAZ are more durable, well forged, stamped, and amenable to thermal

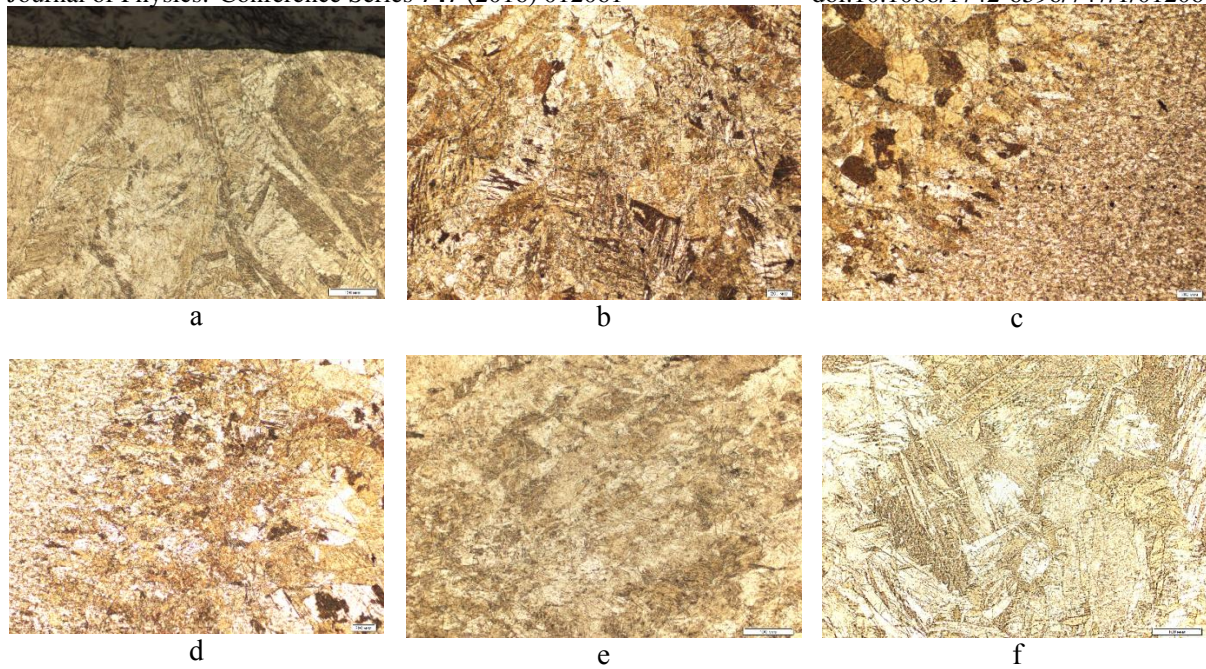


Figure 4. Photographs of the microstructure of different areas: a) Near-surface structure, 200× magnification; b) Center of fusion zone, 50× magnification; c) Area of transition zone FZ-HAZ-BM, 50× magnification; d) Area of transition zone BM-HAZ-FZ, 50× magnification; e) Heat affected zone, 200× magnification; f) Center of fusion zone, 200× magnification.

treatment than alloys with single α phase. Bar in the designation “ α ” indicates the formation of martensitic structure of alpha phase.

It should be noted that α -titanium alloys in the martensite do not lead to embrittlement of the welded joint. [4].

5. Microhardness measurement of the weld

Microhardness measurements were performed on 70 DuraScan devices. Measurements were made across the weld at a 300 μm distance between dots. Figure 5 below shows the results of the microhardness measurements: for the “up” case at a depth of 2 mm and for the “down” case to a depth of 14 mm.

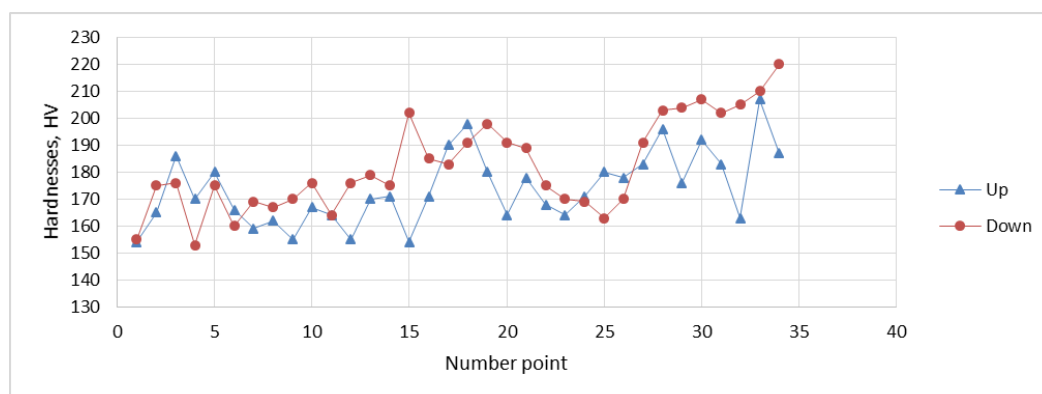


Figure 5. Measurement results of microhardness no. 1.

Measurements showed that microhardness of the weld metal and HAZ zone is in the range of 150 HV – 225 HV. It indicates the absence of oxides, nitrides, carbides and other harmful inclusions

having microhardness higher than 400 HV [2]. Based on these results, the quality of shielding gas may be argued.

6. Destructive testing of welded joints

6.1. Results of mechanical tests on the static breaking.

Tests were conducted in accordance with GOST 6996-66. Results are presented in Table 1.

Table 1. Test results on static breaking.

Specimen №	Width (mm)	Thickness (mm)	Yield (0,2%) (MPa)	Strength limit (MPa)	Relative extension (%)
1	24,6	16,4	358,15	413,24	32,22
2	24,6	16,4	375,74	413,23	33,89
3	24,6	16,4	365,28	410,01	33,33
4	24,6	16,4	376,41	409,70	33,33
Average	24,6	16,4	368,90	411,55	33,19
Standard deviation			1,85	0,37	1,63



Figure 6. Before tests.



Figure 7. After tests.

6.2. The results of mechanical tests on toughness.

Tests were conducted in accordance with GOST 9454-78. Results are presented in Table 2.

Table 2. Test results on toughness.

Specimen №	Place of cut	Impact energy K (J)	Toughness KCV (J/cm^2)
1	Base metal	110,21	138
2	Base metal	112,10	140
3	Base metal	111,99	140
4	Base metal	109,33	137
Base metal average value		110,91	139
5	Weld metal (mid)	153,29	192
6	Weld metal (mid)	126,28	158
7	Weld metal (mid)	144,49	181
8	Weld metal (mid)	132,47	166
9	Weld metal (mid)	141,99	177

10	Weld metal (mid)	145,59	182
Weld metal average value		140,69	176

Average value of toughness of the welded metal was 127% of the toughness of base metal.

6.3. Results of mechanical tests on static bending.

Figures 8 and 9 show that the samples have passed the tests without formation of defects. The maximum bending angle was 70 degrees, indicating high plastic properties of weld.

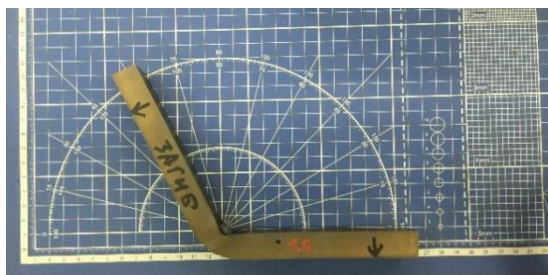


Figure 8. Sample after bending at 70°.



Figure 9. Welded joint after bending. Top sample - face, lower sample - flip side.

7. Conclusion

- The possibility of using fiber lasers for welding of titanium alloy with 16 mm thickness was demonstrated.
- Microhardness measurements revealed no region of increased hardness that indicates good protection of molten bath during solidification of weld.
- Studies of physical and mechanical properties of welded joints on static gap in accordance with GOST 6996 showed that all the samples submitted for testing torn in base metal, which indicates high quality of weld joint.
- Technological bend at an angle of 70° without cracking was shown.
- Studies of the physical and mechanical properties of the welded joints showed increase of the weld metal toughness up to 127% compared to the base metal.

References

- [1] Lahtin Y M 1983 *Metallurgy and heat treatment of metals* (Moscow: "Metallurgy")
- [2] Tretyakov F E 1968 *Fusion welding of titanium and its alloys* (Moscow: "Engineering")
- [3] Evtikhiev N N, Markushov Y V, Grezev N V, Murzakov M A 2015 *Multipass narrow gap of heavy gauge steel with filler wire*, Physics Procedia 71 267–271
- [4] Gulyaev A P 1986 *Metallurgy* (Moscow: "Metallurgy")