Laser welding microassembly housing from titanium alloys in inert atmosphere with excess pressure

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Abstract The publication is devoted researching of the influence welding parameters on a quality formation, geometry and tensile strength of the welds at the laser welding titanium alloy VT1. About 500 microassemblies housing were welded with local shielding and total shielding with excess pressure 0.2 Bar using experimental results. Hermetic chamber was designed and made for laser welding using total shielding with excess pressure.

1. Introduction

Development of the aircraft industry connects with decrease in weight of the aircraft. Titanium and titanium alloys possess of unique physical properties: strength-to-weight ratio comparable with steel at the about two times less density, high melting temperature and corrosion resistance in aggressive chemical environment, atmosphere and water. Therefore titanium alloys are using for creation of the load-bearing unit elements [1, 2] and others aircraft components.

Welding technology of the titanium alloys has some features: titan interacts with atmosphere gases actively at the temperature 350°C and higher. And mechanical properties of the welds decrease as result. Titanium alloys sensible to thermal cycle because of sharp growth of the grain at the heating and cooling in the β phase area. Therefore laser welding of the alloys [3] and laser-arc welding [4] with high power density of the laser beam and thermal efficiency and productivity is more preferable in comparison traditional methods of welding [5].

So a microassembly insuring signal transfer for aircraft identification is made from titanium alloy VT1. Welds of microassembly consisted from housing and one-two covers. Welds must be have depth penetration 0.35±0.05 mm and width on the surface 0.5-1 mm without external defects as undercuts, melting and burning. Housing is welded in complete with chip therefore minimal welding heating zone must be provide for prevention chip crash. Welds must be hermetic at the excess pressure 0.2 Bar in the inner chamber at the negative temperature also therefore have necessary tensile strength.
Laser welding is more actually method for production microassembly because of laser beam has high concentration energy providing high productivity of the welding at the minimal heat input. Therefore research of influence regimes parameters on a geometry, quality formation and tensile strength of the welds at the laser welding titanium alloy VT1 is described in the work.

2. Set-up of experiments
2.1. Experimental equipments and welding materials
Ytterbium fiber laser (IPG Photonics) with 5kW output power and wave length 1070 nm was used at the laser welding of the titanium alloys. Laser head YW50 ZK (Precitec) with focus distance 400mm and focal spot diameter 0.6 mm equipped one axis scanator DC-Scanner with maximal frequency 600Hz at the amplitude 10mm was used for laser beam focusing.

Welding of the plates from titanium alloy VT1 was carried out in the work. Chemical compositions of the welding material are shown in the Table 1.

| Steel grade | Fe  | C   | Si  | N   | O   | H   | Ti  |
|-------------|-----|-----|-----|-----|-----|-----|-----|
| VT1         | ≤0.25 | ≤0.07 | ≤0.1 | ≤0.04 | ≤0.2 | ≤0.01 | Base |

Welding of samples with overall dimensions 50x30 mm and thickness 1mm was realized for research. Welding on plates was carried out by rectilinear welded joints in the PA welding position. Inert gas argon and mixture of argon and helium in proportion 80%-20% were used for local and total shielding welding pool accordingly. Surfaces of the plates were cleaned mechanically and defatted by acetone.

2.2. Technological fixtures
2.2.1. Laser welding with local shielding. Jaw plates with grooves similar microassembly housings dimensions were created using CNC milling machine for their strong fixing with necessary accuracy in horizontal and vertical positions at the laser welding with local shielding, Figure 1.

![Figure 1. Photo of jaw plate for welding of the one type of the microassemblies](image)

Groove depth and distance between welding butt joint of the microassembly and the upper edges of the jaw plates was 3 mm. It was enough for precision basing of the microassemblies and covers with minimal gap and necessary accuracy.

2.2.2. Laser welding with total shielding. Hermetic chamber for laser welding of the microassemblies with total shielding was created. Total shielding atmosphere consisted from mixture of the argon and helium in proportion 80%-20% with excess pressure 0.2 Bar in the chamber, Figure 2.
The main components of the chamber are founding (1), a lower piece of the chamber (2), fittings (3), a windlace (4), a fixture plate (5), a support of the microassembly (6), a microassembly (7), a cover of the chamber (8), a packing ring (9), a protective glass (10), an upper fixture plate (11). The main components of the chamber (founding (1), lower piece of the chamber (2) and cover of the chamber (8)) are made from aluminum alloy 2024. The upper fixture plate (11) is made from Plexiglas. Founding (1) designed for mounting the chamber to welding table using four screws. The cover of the chamber (8) designed for mounting the protective glass (50 mm diameter and 2 mm thick) which transparent laser radiation with length of wave 1,07 μm.

The principle of the chamber work.
Air has been pumped from chamber due to fittings (3) for forevacuum creation (up to 0.13 mbar) using electromagnetic valve. Then mixture from inert gases (argon and helium in proportion 80%-20%) was fed in the chamber for excess pressure 0.2 Bar ± 0.1 Bar creation. The pressure was controlled using pressure sensor FestoSPAN-B11R-G18M-PNLK-PNVBA-L1. Chamber approved for work at the excess pressure up to 6 Bar.

2.3. Research equipment and inspection methods
All welds were inspected visually and optically. Cross-sections of the welds were created using grinding preparing system (Buehler). Weld seams geometry (width and depth of penetration) was measured using optical microscope DMI 5000 (Leica). Quality of a formation and tensile strength of the welds was controlled using bubble method at the excess pressure 0.2 Bar and spirit twice: after welding and after all control methods. All welded microassemblies were inspected using next methods:
- resonance structural elements at the diapason of the frequencies 5-40Hz, amplitude of the vibrodisplacement 0.3-0.8 mm and amplitude of the vibroacceleration 0.3-2 g;
- resistance to cycle changing of the environment temperature from limit reduced up to limit increased: 3 consecutive cycles (2 hours, -60°C and 2 hours, +85°C);
- test on a influence at the higher environment temperature (2,5 hours, +20…+80°C);
- test on a influence at the lower environment temperature (26 hours, +20…-60°C);

Microassemblies were pressurized with excess pressure 0.2 Bar after all tests in the case of positive results.
2.4. Design of experiment

Single-factorial experiment was used in the research. As variable factors were used laser power (from 0.9kW to 2.7 kW with step 0.3kW), welding speed (from 60 mm/sec to 100 mm/sec with step 20 mm/sec), impulse time (from 1 msec to 15 msec with step 5 msec) and pause time (from 1msec to 15 msec with step 5 msec). Focal plane of the lens was located on the welding surface.

3. Experimental results

3.1. Laser welding of the samples

The experimental research influence of the laser welding parameters on welds characteristics was created using welding samples. Cross-sections of the some welds are shown on the Figure 3.

![Cross-sections of the welds](image.png)

**Figure 3. Cross-sections of the welds:**

- a – laser power ($P_L$) - 0.9kW, welding speed ($V$) - 120 mm/sec, impulse time ($T_i$) - 5 msec and pause time ($T_p$) - 1msec
- b - $P_L = 1.5$ kW, $V = 100$ mm/sec, $T_i = 1$ msec, $T_p = 1$msec
- c - $P_L = 2.4$ kW, $V = 100$ mm/sec, $T_i = 5$ msec, $T_p = 1$msec
- d - $P_L = 2.4$ kW, $V = 80$ mm/sec, $T_i = 10$ msec, $T_p = 1$msec

Depth penetration of the welds increased at the increasing laser power, impulse time and decreasing welding speed and pause time. It was a reason of the sufficient depth penetration of the welds. Also external defects as undercuts and burns were created in the welds (Figure 1c,d). Depth penetration of the welds decreased at the decreasing laser power, impulse time and increasing welding speed and pause time (Figure 1a). It was a reason of the insufficient depth penetration and tensile strength of the welds as results.

The most beautiful quality of the welds with necessary geometry (depth penetration about 0.35 mm, width about 0.7 mm) without external defects were created at the laser power 1.5 kW, welding speed 100 mm/sec, impulse time 1msec and pause time 1msec (Figure 1b). All regimes (Figure 3) were chosen for laser welding of the real microassemblies.
3.2. Laser welding of the microassembly housings

Edges melting and burns of the microassemblies at the laser welding with highest heat input (Figure 3 c, d) are shown on the Figure 4.

![Figure 4](image)

Figure 4. Welds with external defects: a – melting of the welding edges \((P_l = 2.4kW, V = 80 \text{ mm/sec}, T_i = 10 \text{ msec}, T_p = 1\text{msec})\); b – burns of the welding edges \((P_l = 2.4kW, V = 100 \text{ mm/sec}, T_i = 5 \text{ msec}, T_p = 1\text{msec with local gap about 0.4 mm})\)

Appearance of the welds had good quality without external defects at the decreasing heat input of the laser welding (Figure 3a). But the welds had insufficient depth penetration and tensile strength. Therefore the welds didn’t hermetic at the excess pressure 0.2 Bar and longitudinal cracks created at the bubble control.

Welds were created with necessary appearance, good quality of a formation, tensile strength and without external defects at the using laser welding with laser power 1.5 kW, welding speed 100 mm/sec, impulse time 1msec and pause time 1msec, Figure 5.

![Figure 5](image)

Figure 5. Appearance of a microassembly

The laser welding regime was used for welding about 500 microassemblies including 200 microassemblies from them in the hermetic chamber with excess pressure about 0.2 Bar. All microassemblies satisfied requirement of the control and were welded for 91 hour.
Conclusions
Research of influence regimes parameters on welds geometry, quality formation and tensile strength of the welds at the laser welding titanium alloy VT1 is described in the work. Main results of the work are cited below.
1. Depth penetration of the welds decreased at the decreasing laser power, impulse time and increasing welding speed and pause time. As result insufficient depth penetration and tensile strength of the welds were created. Welds were not hermetic at the excess pressure 0.2 Bar.
2. Depth penetration increased at the increasing laser power, impulse time and decreasing welding speed and pause time. As result sufficient depth penetration of the welds with external defects as undercuts, melting and burns were created. Welds were not hermetic at the excess pressure 0.2 Bar also because of external defects.
3. The welds with depth penetration about 0.35 mm, width about 0.7 mm without external were created at the laser power 1.5 kW, welding speed 100 mm/sec, impulse time 1msec and pause time 1msec.
4. Hermetic chamber was designed and was made for welding microassemblies with excess pressure 0.2 Bar.
5. About 500 microassemblies were welded using the laser welding technological regimes with local and total shielding. All welds were hermetic at the excess pressure 0.2 Bar.

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