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Laser welded titanium cubesats

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Abstract

Cubesats are a type of nanosatellites with wide use in applications such as earth observation, deep space missions and the military. This work intends to present the fabrication and characterization of a 1U titanium-made cubesat frame. The cubesat was built from laser weld two Ti6Al4V plates to four cp-Ti tubes. The microstructure of the plate-to-tube weld is characterized by martensitic titanium in the fusion zone and to a partially reverted β-phase in the plate heat-affected zone. The hardness of the fusion zone attained 300 HV and is intermediary between both base materials. The yield strength of the plate-to-tube component was 220±10 MPa, which is much higher than the maximum hydrostatic pressure during the launching by a VBS30 vehicle. As a conclusion, the cubesat frame could be considered for more specific mission-targeted tests.

Keywords: laser beam welding; cubesat; titanium alloys.

1. Introduction

This contribution belongs to the first construction and tests for a titanium 1U-cubesat at the Institute for Advanced Studies, Brazil. Titanium lies among the materials suitable for space exploration (Ghidini, 2018). Although titanium density is double than aluminum (Chiranjeeve et al., 2014), the service temperature of Ti is about 600°C compared to about 250°C of Al. Titanium alloys have also two advantages compared to aluminum: good chemical compatibility with carbon-based composites and they could be used as shape memory actuators.

This work presents the manufacture procedures and testing of a 1U-type titanium cubesat laser welded specifically designed for the VLM launcher. The components consisted of cp-titanium tubes and Ti6Al4V

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plates joined by circular laser welds. In this work, the microstructure and tensile mechanical behavior will be reported.

2. Materials and Methodology

The cubesat project is presented in Fig. 1 with the dimensions in millimeters. The up and down faces consisted of two machined plates of Ti6Al4V doted of four 6 mm diameter holes and a 60 mm wide aperture each. These plates are designed to accommodate sensing components such as solid state sensors or cameras. Four 6 mm external diameter cp-Ti tubes were welded to the plates in order to build a one liter volume (1U). The tubes are designed to accommodate the internal devices and electronic components which could be placed before or after the weld. Four lateral faces of the cubesat (Fig. 1) could accommodate solar panels for the required power generation.

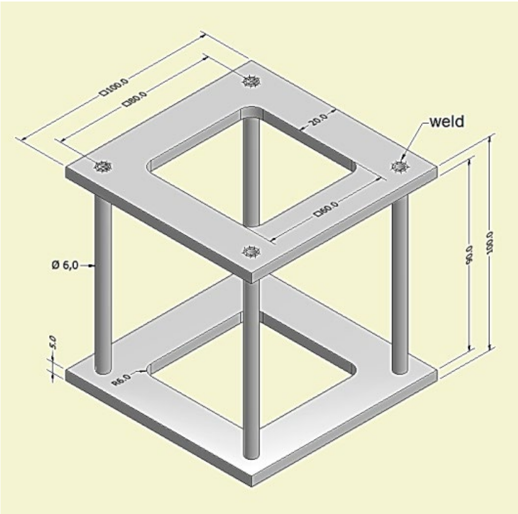


Fig. 1. Current 1U cubesat schematic representation (dimensions in mm).

The components of the frame were machined according to the dimension drawn in Fig. 1 and then mounted within a fixture. The eight circular welds per cube were carried out using a fiber laser (IPG YLR-2000) and a three-axis CNC table. The welds were characterized by light optical microscopy (LOM), Vickers hardness (HV) and uniaxial tensile testing.

3. Results and discussion

The 1U cubesat frame was fabricated with good fit of the model, Fig. 2. Several laser parameters had been tested in order to produce good visual aspect welds and the choose parameters were 1300 W laser power, 40 mm/s relative linear speed and focus on the upper surface (beam diameter of 0.1 mm). Using these parameters each weld takes 0.5 seconds. The laser welds produced in this way shown minimal oxidation and distortion of the frame.

The frame was sectioned at each corner in order to observe the microstructure of the weld joint by LOM. Fig. 3a presents LOM of the weld when the surface of the plate is polished and etched with a Kroll solution. The cp-Ti tube melted under laser heating and fused to the Ti6Al4V frame without a gap or porous line, fusion zone – FZ in Fig. 3a. The heat-affected zone (HAZ) at the plate size was about 0.3 mm. As presented in

Fig. 3b the fusion zone (FZ) is characterized by martensitic alpha grains as a result of fast cooling (Ahmed and Rack, 1998). The HAZ is divided into two regions, marked A and B in Fig. 3b, dependent of the closeness to the fusion line (FL). The light grey zone (A) belongs to the grains heated about the β transus and characterized by small β grains. The dark grey zone (B) belongs to temperatures in the $\alpha+\beta$ range and to a partial transformation to α phase.

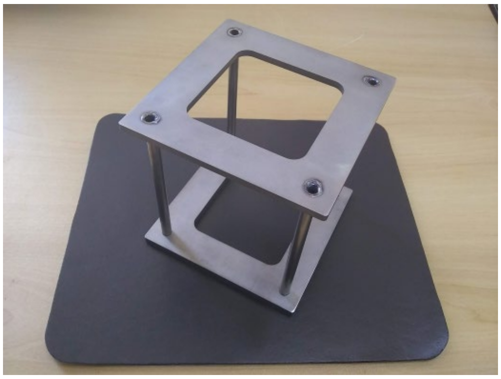
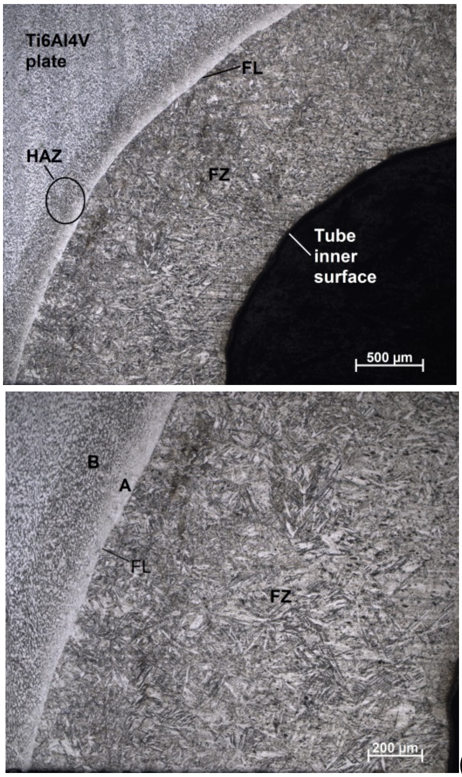


Fig. 2. The mounted cubesat frame.



(a)

(b)

Fig. 3. LOM of the upper surface of the weld: (a) low and (b) high magnification.

Fig. 4 shows the hardness (HV) as a function of the distance from the welded region. The indentations started parallel to the tube wall and crossed the weld attaining the plate size after 3 mm. The indentation path is presented in the detail photo of Fig. 4. The hardness of the weld attained around 300 HV, intermediary between the tube and the plate, with good correspondence with the estimated martensite content (Ahmed and Rack, 1998). The Ti6Al4V plate base material presents an average hardness of 340 HV, corroborating the literature data (Matweb, 2109). At the HAZ of the plate, the hardness rose to 400 HV, as a result of solid state hardening. The continuous transition from a ductile (tube) to a more resistant (plate) given by the weld could be considered a positive factor, as stress could be better distributed over the entire component.

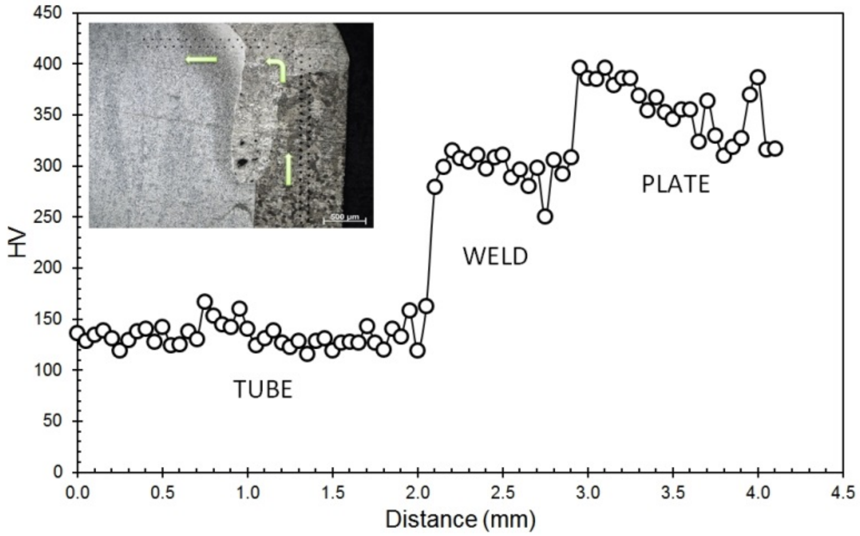


Fig. 4. Vickers hardness (HV) profile of the weld with the indentations following the curves.

In order to verify the tensile strength of each tube-to-plate joint, uniaxial mechanical tests were carried out. Fig. 5 presents the engineering tensile strain-stress curve for a component. The component was fixed as presented in the cross section drawing, so the tube is free to flow and the weld (at the bottom side of the plate) has been tested at the maximum shear stress. For the three coupons tested, the striction (marked by an arrow in Fig. 5) occurred in the tube and the weld resisted to the fracture of the component. According to the tests, the yield strength, maximum tensile strength and strain to rupture were: 220±10 MPa, 389±2 MPa and 0.48mm/mm, respectively. These values are by far sufficient to resist the loading during launching in a VLM Brazilian rocket. According to the VSB30 flight record (comparable to the VLM envelop) the maximum speed is 2071 m/s, attaining an acceleration of 13g at 25.3 km altitude. This should be the maximum loading because the maximum acceleration for the 1^{st} stage is 7.7g decreasing continually up to the apogee (264.5 km). For example, considering the whole cubesat weighting half kilogram, at 13g the overall load could be 60 N, or 15 N per tube. These 15 N divided by the tube cross sectional area (15.71 mm^2) is about 1 MPa, representing approximately 0.4% of the yield strength.

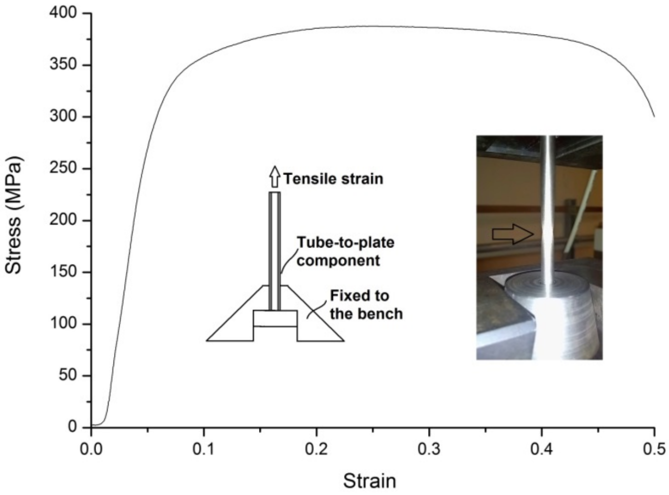


Fig. 5. Engineering strain-stress result for a tube-to-plate component as depicted in the schematic drawing. The photo at right represents the tube where the striction is apparent (arrow).

4. Conclusions

After the completion of the work, the following conclusions could be drawn:

A 1U cubesat frame was constructed of laser weld two Ti6Al4V plates to four tubes of cp-Ti. The structure closely resembles the electronic model and present low distortion and oxidation of the fusion zone.

The microstructure of the welds is characterized by martensitic Ti phase and the heat-affected zone corresponds to the partial transformation of the primary β to α Ti phase. Few pores were observed as a result of entrapped gases at the joint.

The hardness of the fusion zone is intermediary between the plate and the tube base materials. Consequently the weld is probably a low stress concentrator for the frame structure.

The uniaxial tensile strength of the tube-to-plate components showed a yield strength of 220±10 MPa, a maximum tensile strength of 389±2 MPa and strain to rupture of 48±2%. According to the flight data of the launcher VSB30, these values are by far sufficient to assure the integrity of the cubesat up to deployment.

Acknowledgements

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