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ANALYSIS OF THE WELDING PARAMETERS AND MECHANICAL PROPERTIES IN A BUTT JOINT OF AA2198 T851 ALLOY LASER WELDED FOR USE IN THE AIRCRAFT INDUSTRY

Willem Vieira Nascimento
Lindolfo Araújo Moreira Filho
Technological Institute of Aeronautics - Praça Mal. Eduardo Gomes, 50 Vila das Acácias12228-900 - Sao Jose dos Campos, SP – Brasil.
e-mails: willem.vieira@hotmail.com, lindolfo@ita.br

Renan Augusto Perez
Technological Institute of Aeronautics - Praça Mal. Eduardo Gomes, 50 Vila das Acácias12228-900 - Sao Jose dos Campos, SP – Brasil
e-mail: renanperez@msn.com

Hélcio José Izário Filho
Universidade de São Paulo, Escola de Engenharia de Lorena - EEL. Rodovia Itajubá/Lorena, km 74,5 Campinho12600-000 - Lorena, SP - Brasil - Caixa-postal: 116
e-mail: helcio@dequi.eel.usp.br

Abstract. *The present study has as objective perform welding AA 2198T851 alloy by laser welding, according to several parameters that directly influence the performance and excellence of welding. The parameters investigated were: Flow rate of shielding gas, focal length and speed this were kept constant, varied the number of passes, Power and laser diameter. The specimen were collected in an aerospace company place and then made up laser welding of components in the Institute of Advanced Studies (IEAV). The regions of the weld were analyzed using nondestructive testing, metallographic and chemical analysis to determine the dimensions of the cross section weld beads, possible defects in the weld even as tensile tests to determine mechanical properties base material and welded joints. The chemical analysis weld bead was realized chemistry lab at the University of São Paulo (USP) / Lorena in order to determine possible volatilization elements such as: lithium and magnesium. With the results obtained was possible to observe that the mechanical strength even as quantity and size of defects are directly related to the welding parameters and volatilization part of the Lithium.*

Keywords: *Laser welding, AA 2198 alloy, welding parameter, tensile tests and chemical analysis*

1. INTRODUCTION

The aerospace industry is characterized by innovation and technological development, what enables to develop larger aircraft, lighter, durable and comfortable. One of the techniques that are being explored for joining aeronautical component is laser welding. This technique is used to substitution a large part of the rivets, in order to reduce the weight of the structure, but also make it more resilient, furthermore increases the manufacturing speed of the aircraft. In addition to that, the weld bead and heat affected zone are very strict, unlike other traditional processes by arc. However, the major problem of this process is the control of different welding parameters.

Another important segment in weight reduction and increased reliability in aircraft structures is the development of new materials. These must have low density, considerable mechanical strength and higher damage tolerance, such as AA 2198 alloy, used in coatings fuselage. It consists mainly of: Aluminum (Al), copper (Cu) and lithium (Li) and other elements in less concentration (Rioja and Horn, 2012a). The lithium is one of the main alloying elements, which is responsible for reducing weight, because exhibits low density (0, 534 g/cm^3) and increased mechanical resistance due to be a strong former precipitates (Chen and Gupta 2010a).

The welding of the AA2198 alloy, as well as most of the aluminum alloys is difficult by the refractory oxide layer which forms on the surface. This oxide layer is one of the barriers to overcome in welding, because while the pure aluminum melts at 660^{o}C, the oxide layer melts with temperatures above 2000^{o}C, beside that, high thermal conductivity and reflectivity of aluminum requires greater thermal energy (kostrivas, 1999).

Laser welding is an alternative to that type of material, since this process deliver a large amount of energy in an extremely small area, producing better weld bead, being necessary welding parameters extremely strict to prevent defect formation such as cracks, pores etc (Alam, et al., 2011). As result of these factors the present study have aims welding AA 2198T85 alloy with laser welding, according to the various parameters that directly influence on weld quality such as: Flow rate of shielding gas, focal length, number of passes, speed, power and laser diameter.

2. EXPERIMENTAL PROCEDURES

The material used in this study is the alloy AA 2198T851 developed by Alcan and provided by Embraer, the alloy composition percent by weight (wt%) is shown in Table 1, this analysis was accomplish in chemistry laboratory of AMR materials division of the Institute of Aeronautics and Space (IAE) and compared with specified by the manufacturer.

Table 1. Chemical Composition of Alloy (wt%).

Elements	Li	Cu	Mg	Si	Cr	Fe	Zn	Ni	Ag	Al
(wt%)	1,00	3,28	0,32	0,02	0,01	0,03	0,03	0,03	0,19	0.19 Bal.

The initial dimensions of the sheet received 1100 x 1200 mm (width and length), thickness of 2.2 mm. This was cut according to the dimensions of 200 x 200 mm in the direction perpendicular of rolling direction. After the faces of the plates surface were machined in order to remove imperfections and even to obtain the best contact between the faces, in order to avoid hole therebetween.

The existence of hole would harm the welding process because the laser diameter is very small of 0.1 mm, if there are empty, the most of this radiation would be lost to going through these spaces, in addition to generate instability keyhole caused by evaporation of the materials, therefore no melt uniformly the material, resulting in generation of defects in the weld (Ho, J. et al., 2009). The Fig 1 shows part of the equipment used in welding as well as plates.

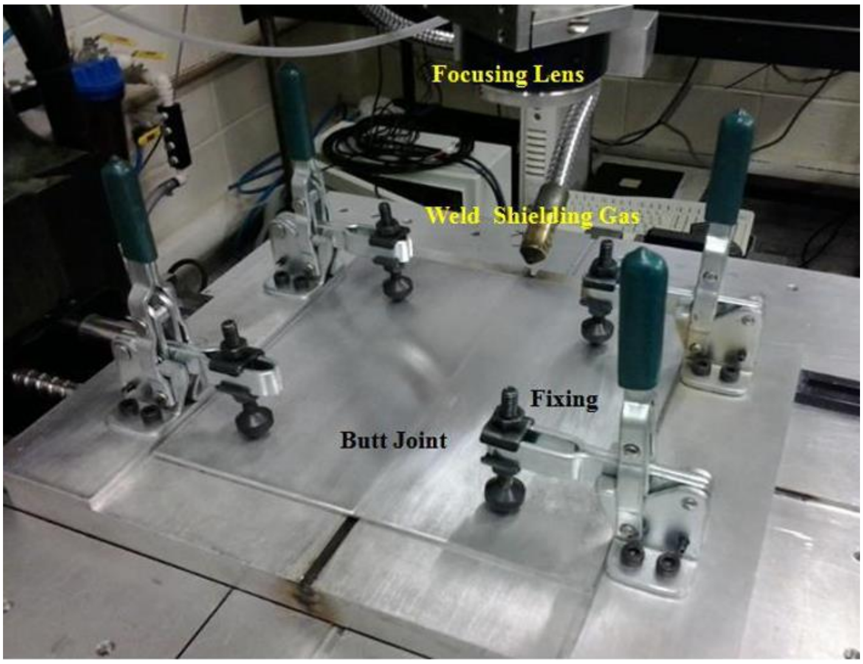

Figure 1. System for fixing plates for carrying out the butt welding

The equipment used to welding, is located in the Institute of Advanced Studies IEAv-DCTA in Development and Multi-User Lab Laser and Optics Applications (DEDALO). The welding is autogenous, without filler metal, and was used a laser fiber in the solid state with an average power of 2000 Watts (2 kW) IPG Model YLR - 2000 doped with Ytterbium.

The welded joints were produced varying the principal process parameters as shown in Tab. 2 the focal length is 160 mm. The helium was used as weld shielding gas during the process, with flow rate of 20 L/min, and N_2 gas for optical protection of focusing.

Table 2. Welding Parameters.

Parameters	Specimen 1	Specimen 2	Specimen 3
Power (W)	1000	1500	1000
Speed (mm/s)	50	50	50
N0 passes	1	1	2
Diameter (mm)	0,1	0,1	0,27

The welding parameters were selected researching in the literature for aluminum alloys like AA2198, but suffering some modification. Experiments were performed with attempts and errors. However, are being researched statistical models and computational for selection of the parameters appropriate, in order to reduce costs and time.

After the welding, it was made non-destructive testing of X-ray longitudinal weld direction in the Aeronautics and Space Institute (IAE) of the welded joint for all the selected parameters in order to verify the possible discontinuities. Later defined the dimensions of the specimens for tensile tests accordance with ASTM E8, using water jet to manufacture specimens, because it does not change the microstructure characteristics.

The mechanical tests were performed in the Mechanical Testing Laboratory (LEM) in the materials division of the Aeronautics and Space Institute (IAE). For these tests used a universal testing machine, INSTRON 5500R, with 30 kN load cell and extensometer brand INSTRON model 2630-038.

To visualize the microstructure, depth and width of the weld beads, as well as discontinuities, the samples were preparation by sanding abrasives in silicon carbide in sizes 600, 800 and 1200 mesh, and polished in colloidal silica. The microstructure was observed after with Keller reagent (2 ml of HF, 10 ml of HNO3 and 88 ml of H_2O) for 10 seconds and observed scanning electron microscope (SEM) model VEGA 3 TESCAN the electron micrograph Laboratory Scan (LAMEV-ITA) and optical microscopy.

Second Yan, J assigns as a factor for the formation of porosity in Al-Li alloys evaporation elements such as lithium and magnesium, due this factor was done a chemical analysis weld bead (Yan, J. et al., 2012). Fig. 2 shows a Buehler Isomet Saw low-speed model with a thickness of 0.3 mm cutting disc used to remove the weld bead.

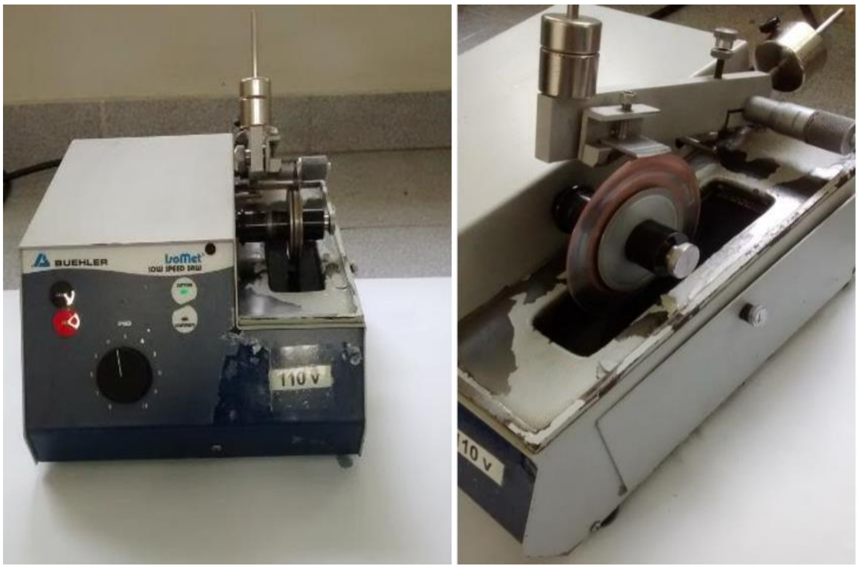

Figure 2. ISOMET cutting

The Chemical analysis of welding bead was accomplished in the chemical laboratory of Lorena USP, to determine possible volatilization elements such as lithium and magnesium. The specimens were removing from different regions along weld bead for condition P = 1.0 kW with single pass, as can be seen in Fig. 3, the porosities are visible along of the weld bead.

Figure 3. Material removed of weld bead for chemical analysis

3. RESULTS AND DISCUSSION

The Figure 4 shows the analysis of X-rays for the selected parameters, the samples presented a significant quantity of pores, this amount was slightly higher for power 1.0 and 1.5 kW with single pass. For the condition of double pass and P = 1.0 kW, observed a decrease in the number and size of pores. It is important to note only the dark spots of the radiographic film are pores.

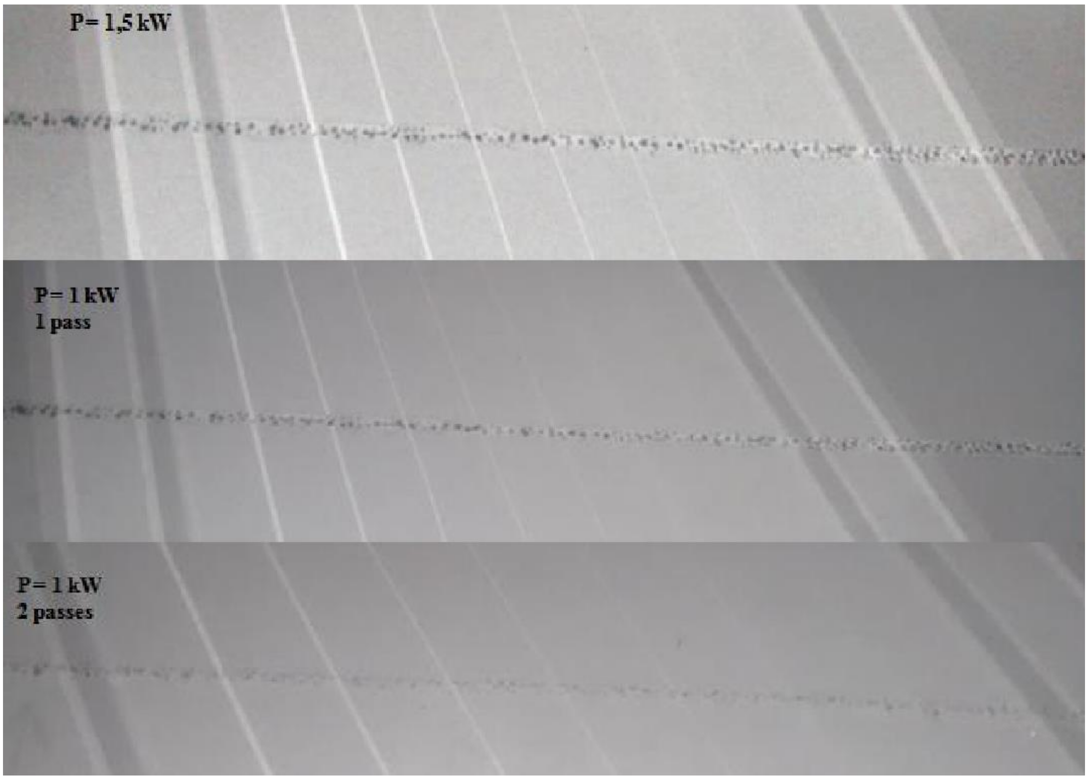

Figure 4. X-rays for all welding parameters longitudinal section

In general, the porosity is associated the presence of gases in the weld bead. In the case of Al-Li alloys evaporation Li due to the low boiling point also contributes. Some studies involving welding Al-Li alloys assigns high porosity, volatilization of elements such as Mg and especially Li (Yan, J. et al., 2012). The table 3 shows the chemical analysis of the weld bead just for these two elements.

Table 3. Shows the chemical composition of the weld bead and base material in percent by weight.

Elementos	Specimen (1)	Specimen (2)	Specimen (3)	base Material
Li	0,78	0,81	0,81	1,00
Mg	0,31	0,32	0,32	0,32

The Li content that volatilizes is about 0.2%, the most Li remains in the material which implies that will act to form precipitates of type Al2-Cu-Li, Al2Li among others. The Mg in weld bead has similar composition of base material. This analysis reinforces the hypothesis that large amounts of pores also are related volatilization of Li.

Analyzing the dimensions of the cross section for P = 1 kW and single pass, the weld bead has a width of 1877 µm and a penetration of 2086.81 µm as seen in Fig. 5. However, the microstructure showed a defect known technically as shrinkage that is associate a thermal contraction.

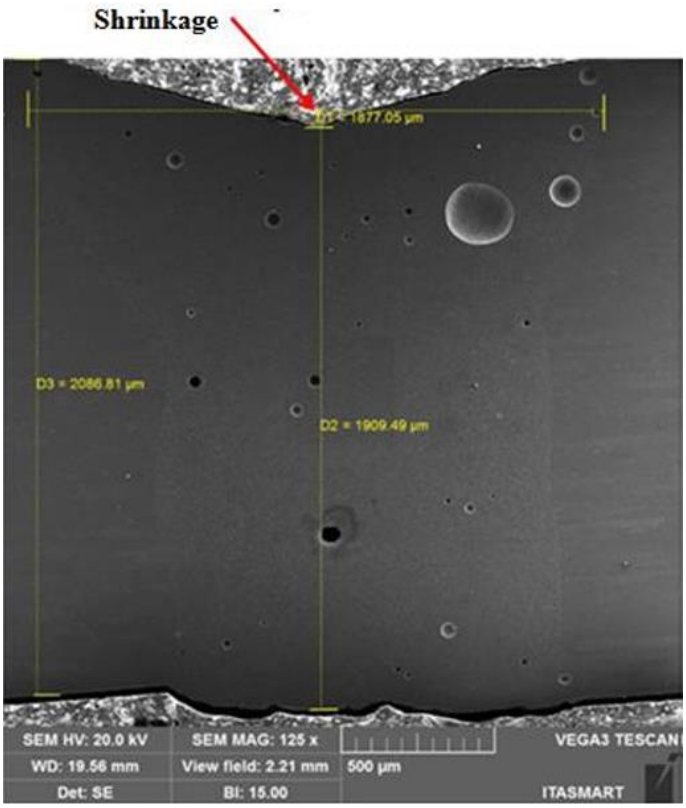

Figure 5. Cross-section dimensions for P = 1 kW condition with single pass

Analyzing image metallographic of Fig 6 for P = 1,5 kW and single pass, show a case of excessive power and low speed, which results in full penetration of 2024.10 µm and a increase of the width of the weld bead around 1931µm as well as a more pronounced shrinkage. When laser power is increases, the temperature of liquid metal also and consequently increases thermal contraction.

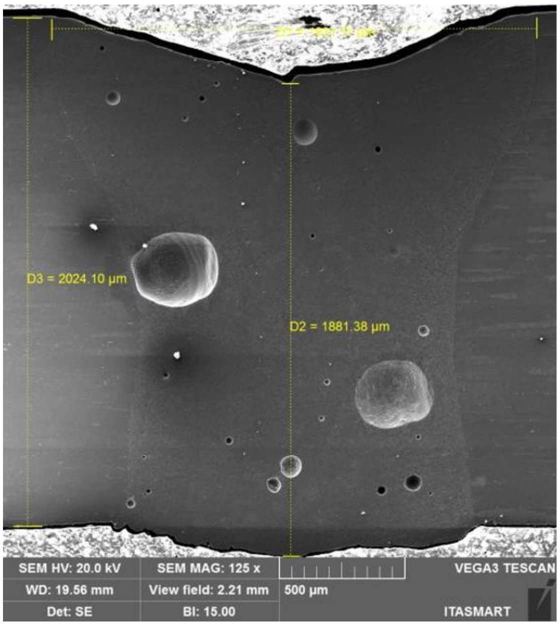

Figure 6. Cross-section dimensions of weld for P = 1.5 kW and single pass

One way to eliminate this type of defect is making use of filler metal. In the case of autogenous welding a way to avoid it is to minimize the thermal effects with decreasing power or increasing the laser diameter and keeping fixed a value for speed.

The influence of speed and laser power is virtually the same in different metals. It is observed that the penetration depth decreases exponentially with increasing speed for a given average power. The size of the bead width also decreases with increasing speed. However, this should reach a constant value which can is associated with the thermal diffusion length of the material (Cappela, 2011).

For condition double pass, P = 1.0 kW and laser diameter of 0,27 mm, the results were better, there wasn't thermal contraction as illustrated in Fig. 7. The amounts of microporosity are lower for this condition. It is known that to larger laser diameter smaller the penetration of weld for an average power.

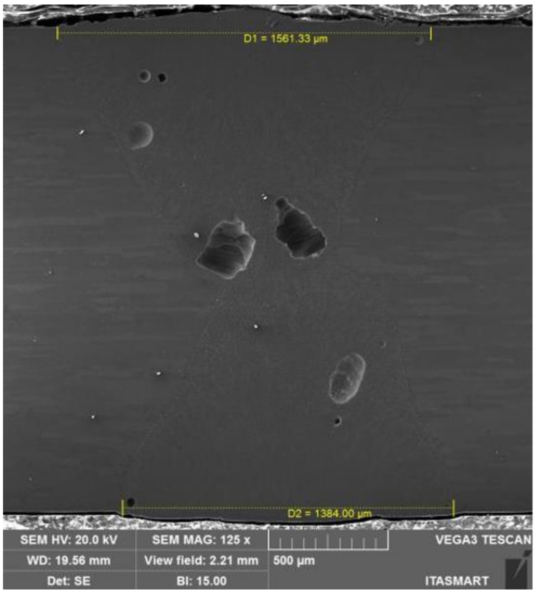

Figure 7. Dimensions of the transversal profile of the joint with duble Pass and P = 1,0 kW

In order to compare the mechanical properties of the base material and the welded joint make the tensile tests the curves are shown in Fig. 8. The deformation to the base material is above 8%, and rupture stress is 500 MPa. These values are according to the specified in the literature for the AA 2198 T851 alloy.

Analyzing the curves of welded joints, it is found that the mechanical properties are slightly higher for the condition p = 1.0 kW and double pass, compared to other welding parameters. This is mainly due to lower thermal contraction of alloy. The rupture stress approximately (240 MPa) and the strain (1.8%).

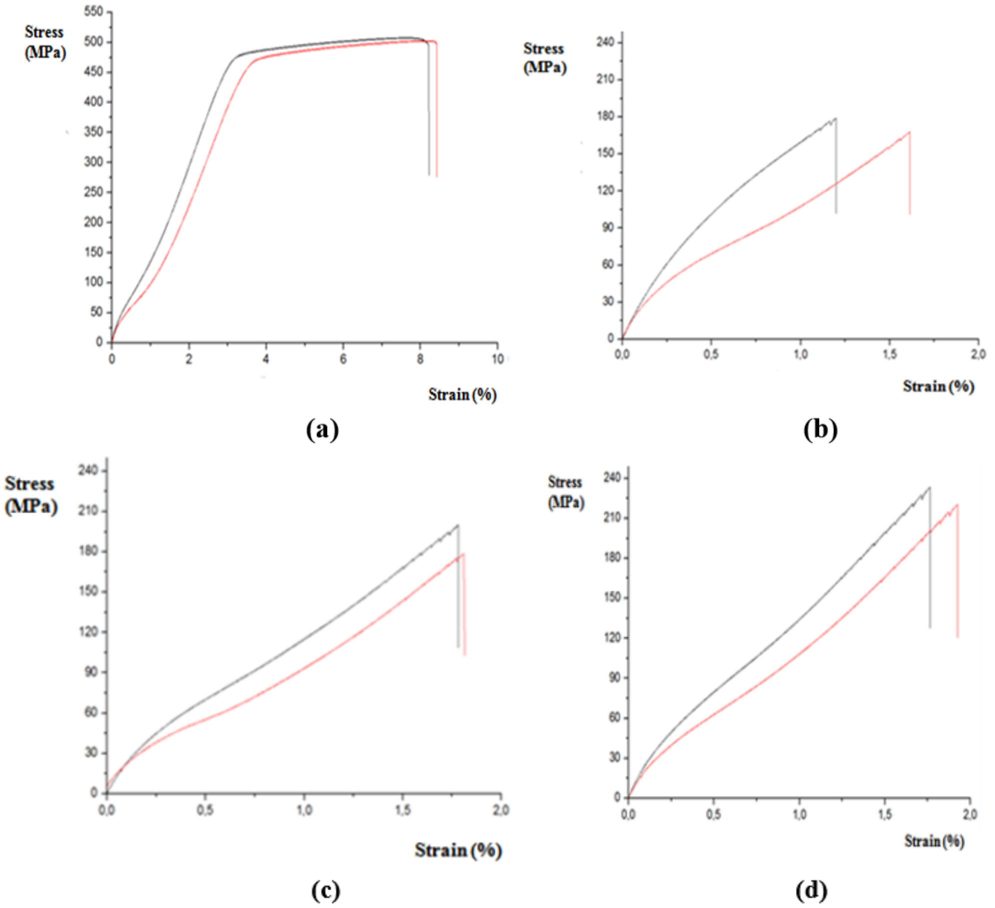

Figure 8. Curves of tensile tests for (a) base material (b) welded joints for P = 1,0 kW and pass uncle (c) welded joints for P = 1,5 kW and pass uncle (d) welded joints P = 1,0 kW, two passes and diameter 0.27 mm

In general all the welded specimens showed a decrease in mechanical properties when compared with base material. This decrease occurs because the porosity, shrinkage and microstructural changes in the weld bead as shown in Fig 9; it is observed in the weld bead gross structure of melt with growth of epitaxial grains, with a microstructure different presented by the base material, as well as decrease of precipitates that influences in strength of the alloy.

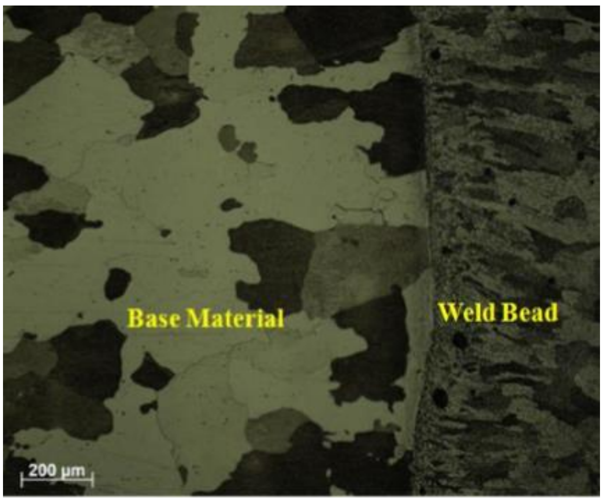

Figure 9: Optical microscopy of the weld bead and base material

4 . CONCLUSION

Analyzing the results of X-rays, as well as metallographic, showed presence of macro and micro porosities for all selected parameters. One of the main factors for lots of pores was the volatilization of lithium as shown in chemical analysis.

For condition single pass and power of 1.0 and 1.5 kW, observed a defect known as shrinkage that occurs due a thermal contraction as a result high laser power and low speed. However, for condition double pass and laser diameter of 0.27 mm not presented problem thermal contraction.

Tensile tests of the welded joints showed a significant decrease in mechanical strength compared with the base material, due the porosity, thermal contraction and microstructural changes in the weld bead.

5. ACKNOWLEDGMENT

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