



Effect of laser beam welding parameters on morphology and strength of dissimilar AA2024/AA7075 T-joints

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ABSTRACT

This paper investigates the effect of laser welding parameters, such as beam power, welding speed, incident beam angle, incident beam position and beam diameter, on the weld geometry, microstructure, porosity and mechanical properties of successive double-sided laser beam welded AA2024-AA7075 T-joints using 4047 filler wire. A change in the welding parameters influences the weld geometry and porosity, but does not cause significant variations in the weld microstructures, though some liquation cracking was observed in the heat-affected zone of alloys AA7075 and AA2024. The macroporosity occurs more in the second weld seam than in the first one. The pull-out test results presented higher values than those obtained by other authors. The ultimate tensile load in pull-out test is influenced by the laser power, laser beam diameter and incident beam position. Macroporosity plays a relevant role in fracture initiation during pull-out tests. Porosity and liquation cracking influenced the fracture mode of the pull-out test specimens, but they do not significantly affect the results.

1. Introduction

Some aircraft manufacturers are exploring the possibility of replacing riveting by LBW as joining technology in manufacturing of aluminum alloy stiffened panels in lower fuselage [1]. The goal is to achieve weight reduction and an increase in strength of the airplane's structure as well as time and cost reduction in aircraft production [2]. The aeronautical industry considers both, simultaneous and successive double-sided LBW, as acceptable methods for joining skin-stringer T-joints, since they can produce defect-free and symmetrical weld seams [3].

Porosity is a common defect in aluminum alloys welded by fusion techniques. The main reason for this is the rejection of hydrogen during weld pool solidification due to the much higher hydrogen solubility in molten aluminum than in solid aluminum [4]. Furthermore, the highest cooling rate of LBW is harmful for weld degassing [5]; however, it also reduces the nucleation and growth rates of hydrogen pores [6], generating microporosity. Micropores might be formed by vaporization of alloying elements [7] as well. Another reason for porosity formation in LBW is keyhole instability [6]. This type of porosity is characterized by its large size, irregular shape and rough walls [8]. For bead-on-plate weldments, Yu et al. [9] observed that susceptibility to macroporosity is higher in laser welding with filler wire than in autogenous laser welding when the keyhole does not penetrate the full thickness of the

plate. According to them, one of the reasons for this is the fluctuation in wire feeding rate and/or position during the welding process which leads to a fluctuation in laser energy that might cause keyhole instability. Moreover, the gap between the skin and stringer plates that is not covered by the weld bead affects the keyhole instability leading to macropore formation in an autogenous single-sided laser welded T-joint [10]. For a single-sided laser welded T-joint, Ventzke et al. [11] verified that the macropores were formed mainly on the rear side of the T-joint. This occurred because the solidification rate is higher in this region than on the side where the laser irradiation occurs. Thus, the gas bubble formed due to the collapse of the keyhole does not have enough time to escape from the molten pool, it therefore becomes entrapped as a macropore in the weld seam.

The porosity is significantly affected by the welding parameters. Thus, Tao et al. [1] stress that the amount of porosity increases with the wire feeding angle and it is higher when the filler metal is added in the trailing direction than in the leading direction. The reduction of the incident beam angle (from 25° to 11°), that is the angle formed by the laser beam and the skin surface, also reduces the porosity significantly [11]. Other authors report a narrower range (10° to 15°) of this angle to obtain welds with reduced porosity in an autogenous one-sided T-joint of AA6013-T4 [10]. Leo et al. [7] state that the microporosity caused by magnesium vaporization increases with the laser power in butt joints of AA5754-H111 welded by arc assisted fiber laser with ER5356 as filler

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Nomenclature

a	distance between weld toes
α	incident beam angle
b	weld penetration depth
BM	base material
c	weld bead leg length
d	weld bead penetration width
D	laser beam diameter
δ	incident beam position
FL	fusion line
FZ	fusion zone

LBW	laser beam welding
OAZ	over-aged zone
P	laser beam power
PMZ	partially melted zone
R	feed rate of filler wire
s	welding speed
SEM	scanning electron microscope
SkHAZ	skin heat-affected zone
StBM	stringer base material
StHAZ	stringer heat-affected zone
UTL	ultimate tensile load

wire. On the other hand, the porosity due to collapse of keyhole in butt joints of AA5754-H111 welded by arc assisted fiber laser reduces with the increase in laser power since the increase in vaporization of magnesium raises the metal vapor pressure in the keyhole [12]. Moreover, Ola and Doern [13] mention the use of Ar as being more effective in minimizing porosity than He in the welding of AA7075-T651. Furthermore, increasing the beam diameter is beneficial for degassing the melted material due to the enlargement of the keyhole [3]. Additionally, Yang et al. [14] state that supplying the filler wire and shielding gas on the same plane as the laser beam stabilizes the welding process, thereby reducing the keyhole-porosity.

The other welding parameters have influence on the weld strength as well. The welding speed and the feed rate of the filler wire affect the strength of the welds, because they influence the weld build up [15] but, Cicalà et al. [16] mention that the second factor is more relevant for the T-joint's mechanical strength. Furthermore, weld penetration can be reduced, and mechanical strength improved in T-joints, by using AA4047 filler wire instead of AA5356 [17].

Solidification cracking was the main defect observed by Siqueira et al. [18] in autogenous one-sided laser welded T-joints of AA6013 alloy. This difficulty can be avoided by using filler wire with a high silicon content [19]. Nevertheless, cracks will arise even with this metal filler if its feed rate is not enough to compensate the formation of cracks during the solidification [16]. For autogenous welds, solidification cracking can be avoided by decreasing the welding speed or enlarging the diameter of the laser beam [20].

Aluminum alloys of 2xxx and 7xxx series have been widely used in the manufacturing of riveted aeronautic structures due to their high strength to weight ratio, but both are considered not easily weldable by fusion welding [2], due to defect formation during welding. Apart from the porosity caused by hydrogen during molten pool solidification [21], one of the main defects observed during the laser and hybrid laser-arc welding of these aluminum alloys was macro-porosity, caused by the instability of the keyhole [22]. Besides this, 7xxx alloys have high hot cracking susceptibility in welding, increasing significantly with the Cu content [23]. In the same way, the AA2024 alloy is also susceptible to hot cracking [21].

According to Tan et al. [24], the investigation in advanced structural engineering has given great attention to dissimilar joints of metals with very different melting points, being the laser welding-brazing an alternative joint technique for this kind of metal combination. In the case of dissimilar joints of aluminium alloys, the majority of works about laser beam welding have addressed weldable alloys such as the

Al-Mg-Si or Al-Cu-Li series [15] and special alloys which have their weldability improved by modification of their chemical composition [25]. On the other hand, few works have studied dissimilar laser welded T-joints of 2xxx and 7xxx series but focus on single-sided LBW [3] or on autogenous successive double-sided LBW [26].

Thus, the main objective of this study is to investigate the effect of laser welding parameters, on the morphology, microstructure and mechanical properties of dissimilar AA2024-T3/AA7075-T6 T-joints performed successively on both sides using a high-power disk laser and a filler wire.

2. Materials and experimental methods

2.1. Base materials and filler wire

Dissimilar T-joints composed of AA2024-T3 skin and AA7075-T6 stringer materials were welded using a high Si content filler wire AA4047 of 1 mm diameter, in order to prevent hot cracking [27]. The skin and stringer sheets of 500 mm x 160 mm x 2 mm and 500 mm x 40 mm x 2 mm, respectively, were removed perpendicular to the sheet rolling direction. Table 1 shows the chemical composition of the aluminum alloys and filler wire used in this study and Table 2 shows the mechanical properties of the base materials.

2.2. Experimental set-up and welding conditions

Before carrying out the welding, the oxide and contaminated layers were removed from the work-piece surfaces by burnishing with a steel brush and then the surfaces were cleaned with acetone. These procedures were performed to minimize hydrogen porosity [28].

Then, the skin and stringer sheets were fastened as shown in Fig. 1. The successive double-sided laser beam welded T-joint was performed using a continuous wave disk laser TruDisk 16002 with a focusing optic BEO D70. The maximum power of the laser equipment was 12 kW. The wavelength of the laser beam was 1.030 μm . Moreover, the focal position was on the stringer surface (0.0 mm) and the focal length was of 200 mm. Therefore, the enlargement of the laser beam's diameter was carried out by replacing the optical fiber for one with a larger diameter. The shielding gas used was argon with a flow rate of 10 l/min. Fig. 2a shows the incident beam position, and the incident beam angle α , which is 5° lower than the angle formed by the skin's surface and the supply plane. The filler wire and the shielding gas were supplied on that plane according to the scheme presented in Fig. 2b. This figure also

Table 1
Chemical composition of the base materials and filler wire (Wt. %).

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
AA2024	Max 0.50	Max 0.50	3.80 4.90	0.30 0.90	1.20 1.80	–	Max 0.25	Max 0.15
AA7075	Max 0.40	Max 0.50	1.20 2.00	Max 0.30	2.10 2.90	0.18 0.28	5.10 6.10	Max 0.20
AA4047	11.00 13.00	Max 0.6	Max 0.30	Max 0.15	Max 0.10	–	Max 0.20	Max 0.15

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