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Laser beam welded joints of dissimilar heat treatable aluminium alloys

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ABSTRACT

A serious number of critical aspects have to be considered when aluminium and its alloys, especially if heat treated, are welded. These drawbacks, to date, limit the application of the welded joints in the aeronautical sector. The possibility of overcoming these limitations is focused in current paper by studying the mechanical performance of two types of dissimilar laser beam welds in T-joint configuration. The dissimilar joints, planned for aeronautical applications, combine the same skin, made of AA 6156 alloy, with two different base materials for the stringers, namely the AA 2139 and the non-standard alloy PA765. The alloys under investigation are characterized by enhanced weldability if compared to the standard AA 2024, widely used in aeronautic. Due to the contemporary presence of dissimilar heat treatable aluminium alloys, both joints have been subjected to dedicated multi-step heat treatments.

Metallurgical and microstructural analysis were carried out in order to highlight the influence of both chemical composition and thermal cycles experienced on the final microstructures of different zones of the joints, governing the mechanical properties of the joint itself.

Vickers micro-hardness measurements were performed to fully characterize the heterogeneity in mechanical properties across the different zones of the dissimilar welds. Strain data acquisition by Digital Image Correlation (DIC) allowed to assess the influence of local weld properties on joints strength in tensile loading. The important role of the temper conditions of the parent materials, resulting from the different joint pre and post-welding heat treatment options, on the tensile behaviour of the skin and, in this way, on the global strength of the connection was showed. The dramatic role played by the Heat Affected Zone and the influence of the distribution of the strengthening elements on examined joints mechanical properties has been put in evidence, according to mechanical test results.

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1. Introduction

Many critical phenomena, such as the development of porosity, oxide inclusions and hot cracking, may occur during the welding of aluminium and its alloys, resulting in a decay of welded joints mechanical properties as reported by Mathers (2002). According to the literature reviews by Ion (2000) and Sekhar and Bjorneklett (2002), to minimize these problems, a strong and focused heat source, such as that provided by the Laser Beam Welding (LBW) technologies, should be used. Moreover, Cao et al. (2003) showed that LBW also provides high productivity, high weld quality, low distortion, manufacturing flexibility and ease of automation. Further welding processes, such as Friction Stir Welding (FSW), are also considered very promising in solving the above mentioned problems. However, Astarita et al. (2012) proved that the FSW technology seems to be ineffective when the objective is fabricating T-joint configurations of the same type of that analysed in current paper.

Mandal (2002) found that during welding of heat treatable aluminium alloys, further weldability issues can arise due to the metallurgical transformations induced by the welding thermal cycle in the heat-affected zone (HAZ). A more detailed discussion of this critical phenomena is reported in Kou (2003).

Braun (2006) showed that improved performances for these kind of alloys are achieved by means of dedicated heat treatments. In case of welded components, benefits are possible if heat treatments are carried out after the welding process, in order to both minimize residual stresses within the joints and to partially recover

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desired properties. However, in dissimilar welding, such a procedure is very difficult since the different alloys need different heat treatments. Badini et al. (2009) performed laser beam welding of dissimilar aluminium alloys of the 2000 and 7000 series and analysed the effect of pre and post-welding thermal treatments on T-joints strength. They concluded that different thermal treatments resulted in different final strengths of the joint. In spite of this important finding, works analysing the influence of pre and post-welding heat treatments on dissimilar joints strength are still very scarce. The most recent studies carried out by Yang et al. (2012) are concerned with the analysis of important welding parameters, such as the incident beam position, incident beam angle or beam separation distance on weld quality. Single-sided laser beam welding of T-joints was also subject of analysis in a recent study by Enz et al., 2015. However, pre or post-welding treatments of the welds were not addressed in any of these studies since the main objective of both works was process optimization.

In current paper the mechanical performance of two types of dissimilar aluminium T-joints, double-side laser beam welded, with higher welding properties and very promising in the aeronautical field, is analysed. Both types of joints were welded using the same type of Al-Si filler material and subjected to multi-step heat treatments planned according to the specificities of each base materials combination (AA 6156-AA 2139 and AA 6156-PA765). Prisco et al. (2008) carried out a preliminary study on these types of joints in order to globally characterize their mechanical performances. In this work, a deeper analysis has been carried out with more accurate and detailed results, especially concerning the microstructure and the consequent influence of alloying elements and the way they govern mechanical performances. Due to the dissimilar combination of base materials and dedicated heat treatments, the chemical composition and microstructure of the welds cannot be predicted beforehand; for this reason, deep microstructural and chemical analyses were performed. The distribution of strengthening elements, across the welds, was determined with the purpose of assessing its effect on the metallurgical and mechanical properties of the joints. Local mechanical properties and global welds strength was determined using hardness measurements and tensile testing. Strain data acquisition by Digital Image Correlation was used to evaluate the strain distribution in the samples and to establish local loading paths. The results obtained point to the important influence of the HAZ of the skin on joints strength. The properties of this critical region, which occurs when the peak temperatures are too low to cause melting, but high enough to cause substantial changes of the microstructure and properties of the materials being welded, are closely dependent of the welding conditions and pre and post-welding heat-treatments.

2. Experimental methods

In this work two types of T-joints were analysed as schematized in Fig. 1. As shown in the figure, both joints were double-side laser welded. However, meanwhile the skin was made of AA 6156 T4 rolled sheet with a thickness of 3 mm, for both joints, the stringer, in the form of an extrusion and with a thickness of 2.7 mm, was made of AA 2139 T3, in the case of the 2139 joint, and of a non-standard alloy PA765 T4, in the case of the PA765 joint. For both types of joints, AA 4047 wire was used as filler material. The compositions of the base materials and filler wire are given in Table 1. The initial temper condition of the base materials, as well as the pre and post-welding heat treatments performed to each of the joints are summarized in Table 2. As it is possible to conclude from the table, before welding, both base materials were in naturally aged conditions (T4 and T3) in the case of the 2139 joint. On the other hand, in the case of the PA765 joint, the AA 6156 skin was subjected to aging, before welding, in order to achieve, at the end of the whole manufacturing process the desired T6 condition; the stringer was in naturally aged condition (T4).

Table 1
Nominal chemical composition of base and filler materials.

	Cu (wt-%)	Mg (wt-%)	Mn (wt-%)	Si (wt-%)	Zn (wt-%)	Ag (wt-%)
AA 6156	0.7–1.1	0.6–1.2	0.4–0.7	0.7–1.3	0.1–0.7	//
AA 2139	4.5–5.5	0.2–0.8	0.2–0.6	//	//	0.15–0.6
PA765	0.73	3.42	0.16	//	10.26	//
AA 4047	///	//	//	11–13	//	//

According to both alloys producer and user (i.e. aircraft industries), the best final temper conditions for each alloy are those reported in the paper: T8 for the AA 2139 and T79 for the PA 765 (for the two investigated stringers) and T6 for the AA 6156. These final temper states are intended to maximize the mechanical performances provided by the alloys. In order to save these desired conditions at the end of the whole manufacturing process (especially keeping into account that the thermal cycle of the welding process deeply affects the alloys), we need to start from a different temper state. Obviously, since the weld joint will consist of different alloys with different parent temper conditions, a unique post weld heat treatment could not be able to realize the desired final state. In this case (see the joint with PA765) a further heat treatment before welding has to be carried out in such a manner that the sum of all the treatments experienced by the alloys lead to the final desired condition. Table 2 summarizes the starting and final temper state for each part of two joints and, if the case, the intermediate hate treatments carried out.

The welding parameters were previously optimized in order to obtain free of defects double-sided welds (Prisco et al., 2008): for each combination of materials, a huge experimental campaign was carried out in order to achieve the optimal process parameters, i.e. the set of parameters enabling to avoid the occurrence of defects (hot cracks, pores, undercut, and so on). The best selected set of welding process parameters, for each couple of alloys, has then been defined and relative welding conditions are reported in Tables 3 and 4.

A sketch of the welding process is shown in Fig. 2 in order to better explain noticeable details of the process itself.

Specimens for microstructural analysis were mounted in epoxy conductive resin, polished to mirror like finishing following standard procedure reported in Geels et al. (2007), etched with Keller

Table 2
Pre and post-welding heat treatments.

Heat treatment matrix										
	Initial condition					Final condition		Before welding		After welding
	Skin		Stringer			Skin	Stringer	Skin	Stringer	Joint
	Alloy	Temper	Alloy	Temper	PWHT	Temper	Temper	Aging	Aging	Aging
2139 joint	6156	T4	2139	T3	YES	T6	T8	NO	NO	16 h 175 °C
PA765 joint	6156	T4	PA765	T4	YES	T6	T79	4 h 190 °C	NO	9 h 110 °C+ +20 h 124 °C

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