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Influence of high frequency wobbling parameters on the weld quality of aluminium LBW

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Abstract

Currently available commercial remote laser beam welding (LBW) scanners allow a fast laser beam manipulation up to 1 KHz. In this work, wobbling (fast laser beam oscillation) was applied to weld aluminium alloy (5754) sheets of 1.6 mm thickness that are subjected to stamping processes later on. Influence of process parameters (laser power and speed, incidence angle and wobbling frequency and amplitude) in weld quality of T joint and edge lap joint configurations was studied. In T joint configuration, the use of 4047 wire filler metal of 1.2 mm of diameter was beneficial to avoid excessive undercuts and provide good penetration, weld shape and dimensions. Metallographic characterisation confirmed the absence of other defects such as lack of fusion, pores or cracks. In addition, wobbling led to optimal results without removing the protective coating of Ti/Zr from the sheets. Finally, mechanical characterisation for post-welding stamping suitability assessment of the welds was performed using shear and bending tests.

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1. Introduction

Nowadays, weight reduction in transport vehicles powered by fossil consumables and their components is critical. Number of vehicles has increased in high amount in the last 40 years and this, along with other transport and industries contributed to increase the levels of CO₂ released to the atmosphere. Apart from emissions, the price of materials is increasing, the management of waste is still difficult and costly and air and water pollution are a big concern all over the world. In the automotive sector, the thickness of bodywork has been reduced notoriously while increasing the security, thanks to the advances in materials engineering field. In this work a new route to reduce thickness using stringer-stiffened sheet metals, obtained by the hybridization of two processes: welding and stamping, is investigated. This entails new challenges regarding the performance of the welds and stringers during stamping. On

one hand, welds need to withstand strain during stamping without breaking and on the other hand, distortion of stringers must be avoided.

T-joint and lap joint are main welding joint designs that are used when reinforcing a metal sheet with stringers. When these stringers are subjected to stamping, bending of stringers, plastic deformation at the end of stringers and tear of the sheet, are the typical observed defects [1]. Laser beam welding (LBW) is a promising solution for reinforcement of thin metal sheet with stringers, due to the minimal induced residual stress and distortion. Moreover, the heat affected zone (HAZ) with LBW is small, reducing the possibility to appear cracks. If distortion appear after laser beam welding of stringers in a T-joint configuration, they can be compensated with laser straightening [2]. Due to the described advantages, nowadays, some car models have more than 75 % of their welds chassis and bodywork welds made by LBW.

Normally, the selection of the stamping strategy for panels stiffened with stringers requires the knowledge of admissible strain in the HAZ. Stamping is the most typical process of sheet forming. The main problem arises forming concave shapes due to compression of stringers, being more problematic when stringers are taller [3]. Hydroforming is an advanced solution that uses pressure to avoid defects in the stringer, however it is a costly process and requires expensive tool. After this process incremental forming can be applied [4].

Fast laser beam oscillation or wobbling has been one the main technological breakthroughs in LBW in the last years [5]. Current industrially available remote laser welding scanners allow a fast laser beam manipulation up to 1 KHz. This improves energy efficiency with lower heat input that reduces HAZ and hence distortion. Benefits of using wobbling for LBW of aluminium have reported previously [6]. Aluminum alloys are very interesting to face the challenges stated at the beginning: reducing weight. Due to this, aluminum alloys have substituted in the last years a great part of steel parts in the automotive sector [4]. Normally aluminum has protective coatings to avoid its oxidation. This can cause defects when welding like porosity or alignment of oxides, so the alternative is to remove the coating physically before welding which can be a tedious work difficult to automate. Beam oscillation can present a solution to this issue, removing porosity issues.

In this work, wobbling was applied to weld aluminum alloy (5754) sheets of 1.6 mm thickness by LBW in T joint and lap joint configurations, in order to study the influence of process parameters in weld quality and check their suitability for post-welding stamping process.

2. Experimental

2.1. Materials and process parameters

The welding equipment consisted of a disk laser source of 5 KW with 0.2 mm of fibre diameter with a Remote Laser Welding - Adaptative (RLW-A) system from Scansonic (Magnification 2,9) and mounted in a Gantry industrial robot type RLP60-60-RSVI from REIS-KUKA. The setup of the equipment and tooling used for welding is shown in Fig. 1.

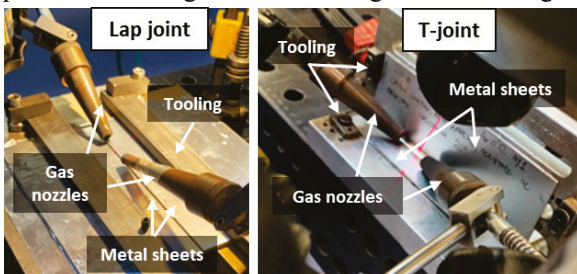


Fig. 1. Setup for LBW: tooling and gas protection for welding of coupons.

Welding parameters used for T-joints and lap joints are summarised in Table 1 and Table 2, respectively. The spot size was fixed at 0.6 mm. Power (P), welding speed (W_s), wire feed speed (WFS), shielding gas type (He and Ar) and flow, and incidence angle was changed. In T-joints, wire was added by a flexible feeding hose and welds were done at both sides of the stringer. Finally, wobbling was applied and compared with

fixed spot. Wobbling amplitude (A) and frequency (F) was changed in different welds.

Table 1. Process parameters studied for T-joint configuration.

SPECIMEN	P (W)	WFS (m/min)	W_s (m/min)	Gas type and flow (L/min)	A (mm)	F (Hz)	Angle (°)
T-1	4500		5	He 30 (double)	Ax=0.12 Ay=1	700	25
T-2	4500		5	He 30 (double)	Ax=0.12 Ay=1	700	45
T-3	2500		2	He 30 (double)	Ax=0.12 Ay=1	275	25
T-4	2500		2	He 30 (double)	Ax=0.12 Ay=1	275	45
T-5	2300	2.5	2	He 15	Ax=0.12 Ay=0.5	275	30
T-6	2300	2.5	2	He 15	Ax=0.12 Ay=0.5	275	25
T-7	2400	2.5	2	He 15	Ax=0.12 Ay=0.5	275	25
T-8	2400	2.5	2	Ar 15	Ax=0.12 Ay=0.5	275	25
T-9	2000	2.1	2	He 15			25
T-10	2000	2.1	2	Ar 15			25

Table 2. Process parameters studied for edge lap joint configuration.

SPECIMEN	P (W)	W_s (m/min)	Gas type and flow (L/min)	A (mm)	F (Hz)	Angle (°)
L-1	4500	5	He 30 (double)	Ax=0.12 Ay=1	700	90
L-2	4500	5	He 30	Ax=0.12 Ay=1	700	45
L-3	4500	5	He 30 (double)	Ax=0.12 Ay=1	700	45
L-4	4500	5	Ar 15 + Ar30	Ax=0.12 Ay=1	700	30

In this work, sheets of 5754 aluminium alloy with 1.6 mm thickness have been used. This material has a Ti/Zr based conversion coating for corrosion protection. Standard chemical compositions and mechanical properties of the material from the supplier are given in Table 3 and Table 4. In some T-joints 4047 aluminium wire of 1.2 mm diameter was used as filler metal. This combination of materials strengthens the joint without the need of heat treatment due to the precipitation of Mg_2Si in the fusion zone. The chemical composition of the wire can be seen in Table 5.

Table 3. Chemical composition of 5754 metal sheet in Wt. %.

Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
Bal	0.18	0.32	0.04	0.29	2.9	0.03	0.01	0.02

Table 4. Mechanical properties of 5754 metal sheet as received.

Rp 0.2 (MPa)	Rm (MPa)	Ag (%)	A80 (%)	N-5	R-10
108	228	21	26	0.34	0.65

Table 5. Chemical composition of 4047 wire in Wt. %.

	Al	Si	Fe	Cu	Mn	Mg	Zn	Be	Others
Min	Bal	11							
Max	Bal	13	0.8	0.3	0.15	0.12	0.2	0.0003	0.15

The sheet dimensions were 150 x 50 mm and over them stringers of 90 x 20 mm cut by laser were welded.

2.2. Mechanical tests: flexion and shear

The T-joint and lap joint samples were mechanically tested for validation of weld quality validation and assessment of forming suitability. The shear strength was measured using a shear tool developed ad-hoc and mounted in a universal testing machine from Instron with a maximum load of 100 kN. The setup is schematically illustrated in Fig. 2. The specimen is clamped horizontally in the tool after being EDM cut to a length of 20 mm and the shear punch is moved with a constant velocity of 1 mm/s. During the test, force and displacement are recorded. The shear bonding strength σ_s can be calculated using equation (1), where the maximum shear force F_{max} is divided by the initial shear area A_s of the reinforcement, as defined by Groche et al.[7].

$$\sigma_s = F_{max} / A_s \quad (1)$$

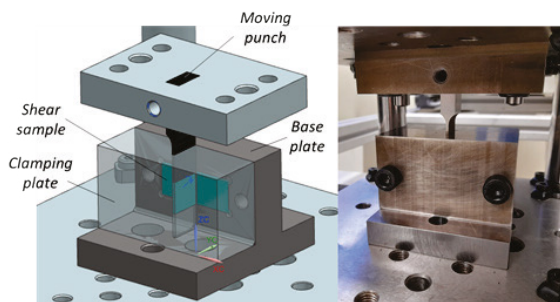


Fig. 2. Experimental setup for the AA5754 T-joints shear testing.

The peeling tendency of the T-joint samples was tested using a three-point bending test. In the lap joint, the tensile-compression stresses produced in the sheet thickness during bending tend to generate shear stresses in the longitudinal welding lines which is a valid criterion to test the formability of the weld lines and patches as it emulates the stress state that occurs during deep drawing of smooth shapes. The test of both configurations is shown in Fig. 3.

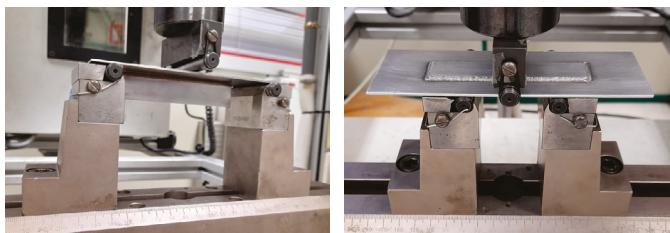


Fig. 3. Three-point bending test for T-joint and lap joint configurations.

In both three-point bending tests the force displacement curve and the final health of the weld lines was inspected.

2.3. Metallographic preparation and characterization

Metallographic characterization was applied to cross sections of the welding of both studied joint configurations. Once cut transversally they were mounted, grinded and polished. Microstructural observations were done by light microscopy using an Olympus GX 51 (Olympus, Hamburg, Germany).

3. Results and discussion

3.1. LBW welding

From the tests done in T-joint configuration, main cross sections are shown in Fig. 4. As it can be observed there, the specimen T-4 without filler metal presented notorious undercuts in both sides of the stringer and partial penetration. Compared to the specimen T-7, wire feeding clearly solves this problem. In T-8, the use of Ar as protective gas instead of He, left porosity inside the weld beads. Finally, in T-9, the spot was fixed to analyse the influence of wobbling, also showing some trapped porosity.

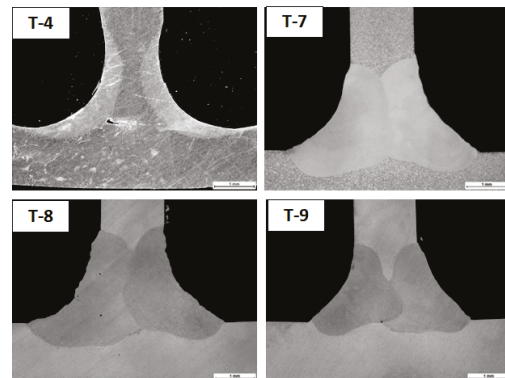


Fig. 4. Cross section of T-joint for different welding parameters.

T-joint external aspect can be observed in Fig. 5, showing regular and smooth surface and bright colour meaning no oxidation occurred.

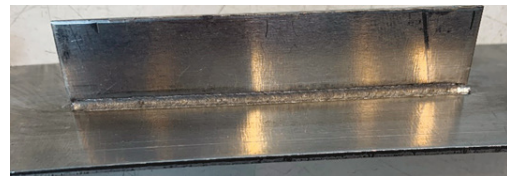


Fig. 5. T-joint external aspect.

The beneficial effect of wobbling was notorious achieving full stringer penetration and avoiding undercutting and porosity defects. The last is also linked to the use of He as protective gas.

LBW carried out in edge lap joints without filler metal did not show critical welding problems or defects as observed in Fig. 6, with minor influence of incident angle. However, in this case, appropriate protection needed to be assured in order to avoid oxidation due to the higher power used compared to T-joint configuration. Apart from standard nozzles, an additional tooling with channels for gas distribution was used to obtain a bright welding.

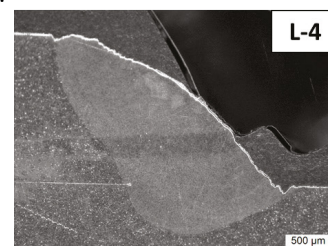


Fig. 6. Cross section of L-4 lap joint obtained for specific welding parameters.

Lap joint external aspect can be observed in Fig. 7, where L-3 presents noticeable oxidation of the weld bead while L-4 present a bright colour, meaning no oxidation. Therefore, additional protection with Ar is recommended with higher power employed in lap joints.

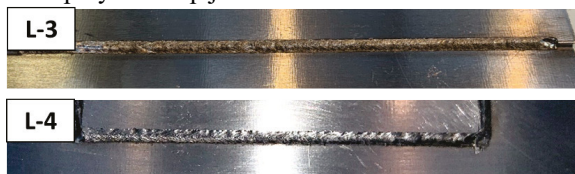


Fig. 7. Lap joint external oxidation: L-3 presents oxidation while L-4 has bright colour.

In both configurations, wobbling avoided the porosity even welding with the protective coating of Ti/Zr of the metal sheets.

3.2. Mechanical tests: flexion and shear

The joint strength was investigated by shear tests of T-7 T-joint samples and calculated according to equation (1). As it is observed in Fig. 8, a maximum shear force is reached at a given punch displacement, which indicates the start of the weld failure. After this peak, a separation of the welded plate occurs and friction force with the tool and deformed sample occurs. The average maximum shear stress for 5 samples is 316.9 ± 5.3 MPa. Maximum displacement at force peak is 4.55 ± 0.05 mm. The shear stress measured during the experimental tests is higher than the theoretical von Mises shear stress of the base material. With an Ultimate Tensile Strength (UTS) of 235 MPa, the theoretical shear stress of the material is 135.9 MPa.

Additionally, three-point bending tests were performed using T-7 T-joint samples and L-4 lap joint samples. In the T-welded samples, collapse of one of the non-reinforced sides occurs after certain punch displacement. Despite this collapse and local plasticity, repeatability of the tests was very high with very small peeling effect, which confirms that the welding process is appropriate for the subsequent deep drawing of components.

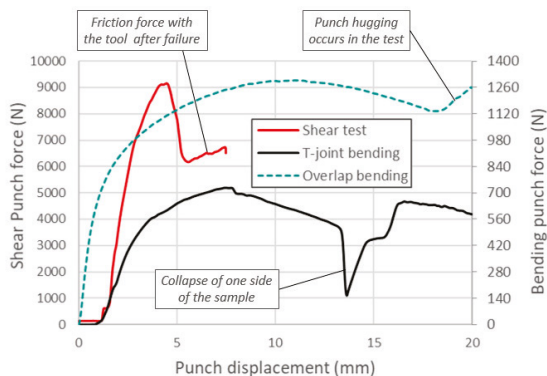


Fig. 8. Exemplary force-displacement curves for all the experimental tests.

During bending test of lap joint samples, punch hugging occurred at a punch displacement of 18 mm. Repeatability of the tests was also high and no cracks appeared, showing a good formability of the reinforced areas.

4. Conclusions

The main conclusions of this study are summarized herein:

- Wire feeding is necessary in T-joint configuration to avoid undercuts and achieve full penetration in double side LBW.
- Wobbling gives rise to regular weld beads and penetration. It helps eliminating pores.
- Helium as protective gas helps in the elimination of pores too.
- In lap joints, the amount of power was higher and hence it needed extra gas protection with Ar gas to avoid oxidation.
- The shear tests confirmed that welding parameters were validated for the subsequent deep drawing of T-joints. Shear stress values well above theoretical values of the base material were achieved.
- The three-point bending tests did not generate cracks in the case of lap joint samples and very small peeling tendency was observed in the three-point bending test of T-joints.

Acknowledgements

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