DISC LASER WELDING OF MG ALLOY AZ61A

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Abstract

Material AZ61A of thickness 1 mm was laser welded by disc laser without using filler wire. Laser welding w/o filler wire is very demanding on sheet metal edges preparation, so different methods of edge preparation, e.g. shearing, milling, were done. Mg alloys have susceptibility to porosity, evaporation of alloying elements, spattering hot cracking and other. The research focused on finding optimum laser welding parameters for butt and lap welds. Welds were evaluated by optical metallography, visual and penetration test, SEM, microhardness and tensile strength etc. The sheet metal edges for butt welds must be prepared by milling, otherwise porosity was found. Edge quality proved not important for lap joint welds, which is an advantage. Laser welding proved to result in very good weld quality, without any defect, yet the processing window was narrow.

Keywords: magnesium alloy, laser beam welding, AZ61A

1. INTRODUCTION

Mg alloys are the lightest industrially used metals with potential to replace to certain extent Al alloys and steels. Mg alloys are used in aerospace, automotive and electronics. Also nuclear industry uses Mg alloys thanks to their neutron absorptivity and thermal conductivity.

This research article is preceded by literature survey on Mg alloys weldability and proved need to focus on welding pool instability, spattering, porosity during laser welding [1]. Mg alloys weldability is focused by many researchers, yet not all data are known yet. From this reason we focused on laser weldability of AZ61A.

2. EXPERIMENTAL

Rolled sheets of alloy AZ61A thick 1 mm were used in all experiments. This Mg alloy with Al and Zn is also known as „Elektron“. Chemical and mechanical properties are stated in Tab. 1, 2.

Table 1 Chemical composition of AZ61A

Elements	Al	Zn	Mn	Si	Fe	Ca	Cu	Fe	Mg
Wt. %	6.37	0.67	0.21	0.01	0.004	0.005	0.0005	0.004	Bal.

Table 2 Mechanical properties of AZ61A

$R_{p0,2}$ [MPa]	R_m [MPa]	A_5 [%]	Hardness [HV0,1]
217	271	15	51 - 61

AZ61A consists of 2 phases – delta phase, i.e. solid solution and gama precipitate –eutectic $Mg_{17}Al_{12}$. Precipitates of gamma phase are 3x harder than delta phase. After casting, welding, these are at the grain boundaries, so Mg alloys should undergo heat treatment to improve properties. At Fig. 2 matrix of delta phase with fine intermetallic particles (black dots) is visible.

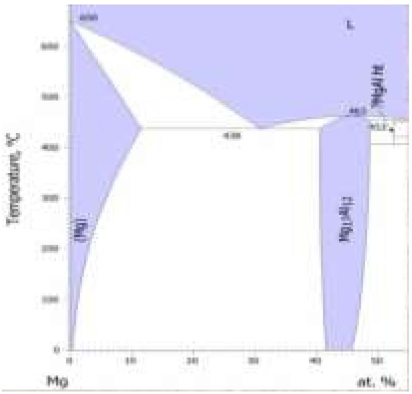


Fig. 1 Binary diagram Mg-Al

Fig. 2 Microstructure of AZ61A

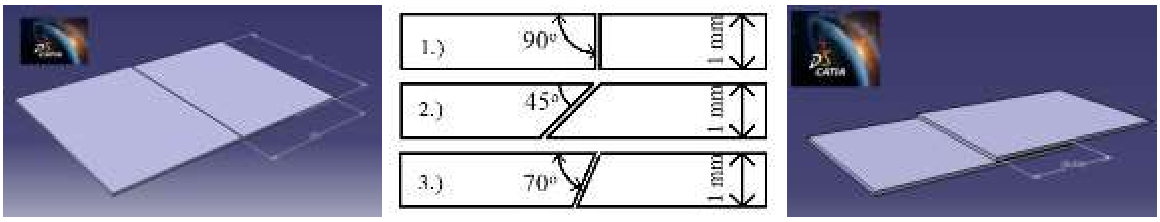
Disc laser from Trumpf, type TruDisk 4002 was used. Details are in the Tab. 3.

Table 3 Welding source

Type	TruDisc 4002
Laser wavelength	1030 nm
Max. power	2000 W
Beam quality	8 mm.mrad
Fiber diameter	200 µm
	400 µm

Weld joints

For 1 mm thick sheets butt welds and lap welds were prepared, as at Fig. 3a, b, c.



a) b) c)

Fig. 3 Weld joint : a) butt joint - 3D model b) variations of butt weld edges: 1) milled edge, 90° angle, 2) milled with 45° angle, 3) milled with 70° angle, c) 3D model of lap weld

Quality check

All welds were subdued to visual testing, that led to adjustment of welding parameters. Also penetration test was used to evaluate weld quality. Metallography served to evaluate inner defects and shape of the weld.

3. RESULTS

The evaluation of importance of laser welding parameters was done on bead-on-plate welding. These show the most important parameters to observe in the experiment. The parameters with crucial importance were:

- Laser power (W),
- welding speed ($mm.s^{-1}$),
- focal spot position (mm),
- shielding gas flow ($l.min^{-1}$).

Firstly, the samples for butt welding of size 70 mm x 50 mm were prepared by shearing. Generally for steel materials, shearing of sheet metal as preparation for laser welding is satisfactory as the ductile material shearing edge deformation is advantageous. By an experiment, the as sheared edge quality (at fig. 4a, b) proved unsatisfactory as it led to burn through, as at fig. 4c. This was caused by brittle shearing of Mg alloy, fig. 4a, and inability to assemble sheets close enough, fig. 4b. For butt welding, the root gap has big importance. Especially for autogenous welding without filler wire, the minimum gap, max 0.1 – 0.2 mm is needed. The as sheared weld edge led to unacceptable weld, so further milling with several angles was applied to improve welding results, fig. 3b.

a) b) c)

Fig. 4 As sheared samples, a) sheared edge, b) butt weld assembly, c) weld with sheared edges (P = 600 W, f = +5 mm)

Edge preparation

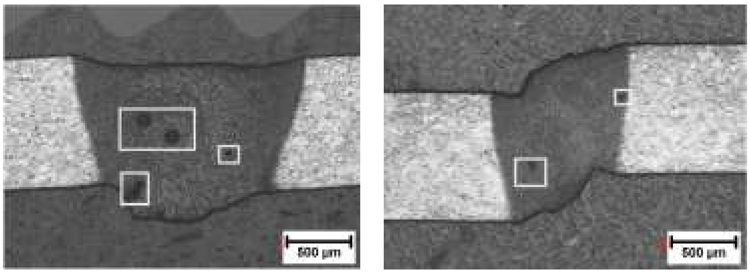
Butt joint-milled edges

The sample with edges milled perpendicularly, welded with parameters v = 80 $mm.s^{-1}$, P = 650 W, shielding by 4.6 Ar 12 $l.min^{-1}$, root 4 $l.min^{-1}$, at focus, are shown at Fig. 5a, these are the most optimum parameters found. High quality joint, full penetration, no porosity, without spatter and underfill was reached, Fig. 5b. Increasing the power to P = 750 W led to burn through, as at Fig. 5c.

a) a) c)

Fig. 5 Butt joint – perpendicular milled edges, a) P = 650 W, v = 80 $mm.s^{-1}$, b) macrograph, c) at P = 750 W

Milling the edges with an angle lead to easier sample set up, as it enabled setting without gap and without misalignment. Yet this edge inclination leads to longer joint edge, longer, wider than laser beam diameter (1 mm), so that lack of fusion would occur, when welding with laser beam at focus. This was done and the penetration test proved lack of penetration at the root of the weld for joints prepared by milling with angle 45°, the edges were incompletely melt. To accommodate for the higher joint width, the welding was done with laser out of focal point, yet even defocused distance did not lead to acceptable. joints for angle 45°. The increase of necessary power to P = 1000 W resulted in burn through, sagging, porosity and uneven melting. Such defects are visible at Fig. 6. Fig. 6a shows porosity and weld sagging.

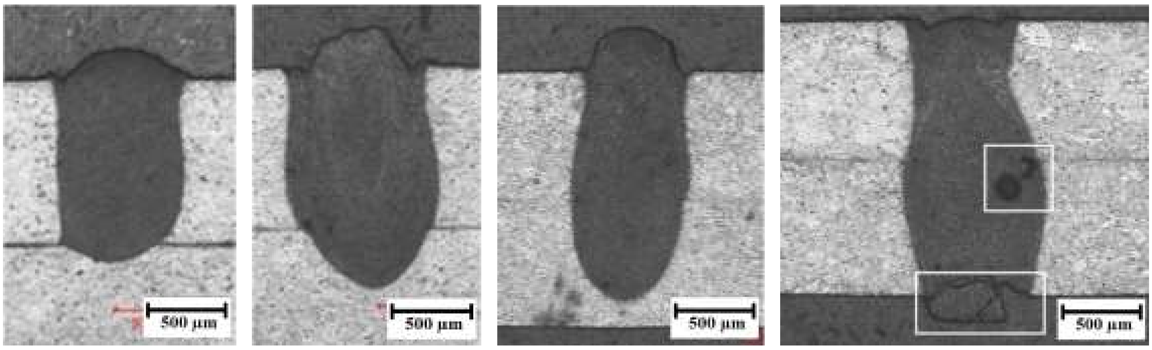


a) b)

Fig. 6 Weld defects present in the butt welds – a) porosity for too high power, P = 1100 W, f = +5 mm, v = 80mm.s^{-1}, b) Weld misalignment P = 650 W, f =0 mm, v = 80mm.s^{-1}

Lap joints

For lap joints the laser power was varied P = 550 - 900 W. Focal spot was on upper weld surface, v = 80 mm.s^{-1}. The sheets surface was ground from oxides and degreased. At Fig. 7 are results for varied laser power. The best results were reached with power P = 600, 700 W.



a) b) c) d)

Fig. 7 Lap joints, macrographs a) P = 600 W, b) P = 650 W, c) P = 700 W, d) P = 800 W

EDX analysis

EDX analysis served to observe chemical composition change due to laser welding. It is known that high energy beam welding leads to uneven changes in presence of some alloying elements due to their low sublimation temperature [1] , e.g. Mg, Zn. At Fig. 8 are shown results for Mg, Al, Mn, Zn concentration after welding of lap joint. The results did not prove any substantial change in chemical composition before and after welding. The sublimation of Mg, Zn and other elements is not having important influence as found in our research.

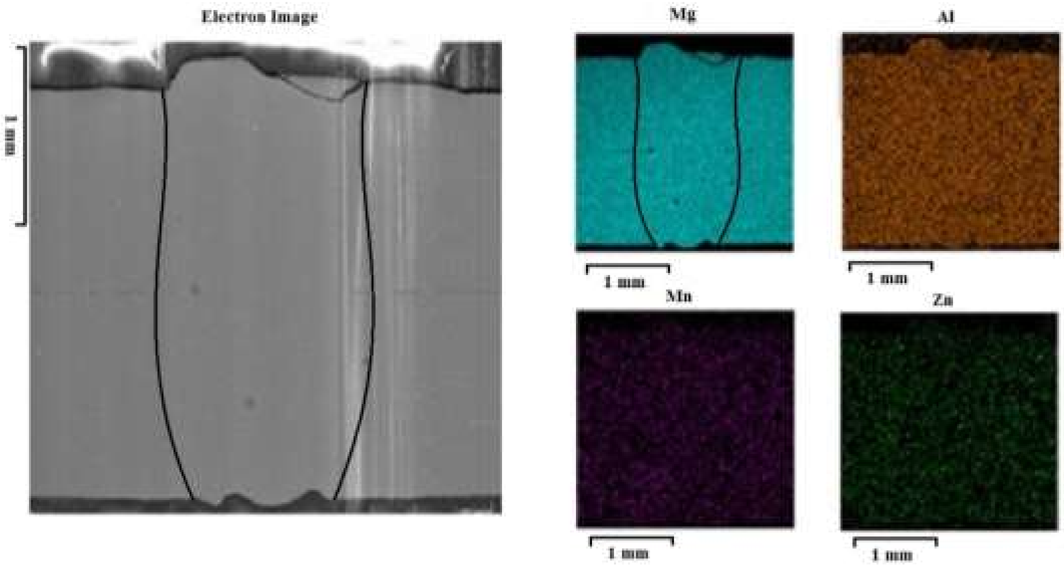


Fig. 8 Surface EDX analysis – lap weld

Microhardness measurement

The butt welds hardness was measured across the joint in 1 line, for lap joints 2 lines of measurement were done. At Fig. 9, increase of hardness in WM (80 HV) and HAZ (75 HV) compared to BM hardness (55 HV) is visible. Similar results were reached for lap joints. Hardness increase is connected with grain refinement caused by fast solidification process.

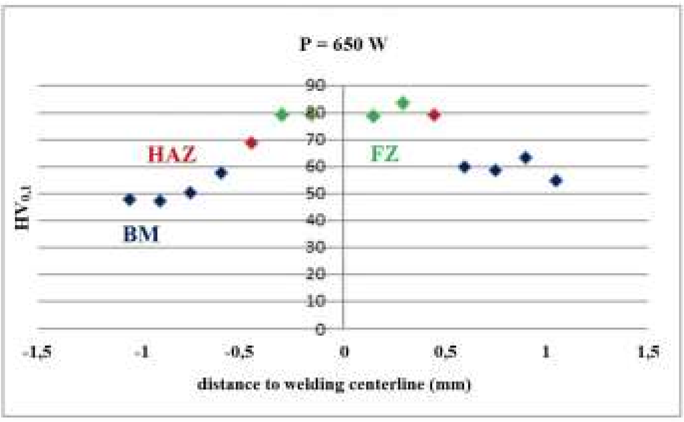


Fig. 9 Microhardness across the butt joint, P = 650 W, v = 80 mm.s^{-1}

Tensile and shear test

Static tensile test was used to evaluate mechanical properties. For the butt welds with edge milled under angle 45, 70° all samples fractured at the WM, for inner defects (lack of penetration) were present,. Butt joint with perpendicular edges fractured in BM at R_m = 263 MPa, for P = 650 W, v = 80 mm.s^{-1}.

For lap joints, the values of shear stress at fracture were in range 123 – 154 MPa depending on laser power. The fracture occurred in WM for every joint. Direct comparison of strength of tensile test of butt welds and shear test for lap welds is not possible.

CONCLUSION

Laser welding of AZ61 1 mm thick sheet was done. The results can be applied to automotive and aerospace industries. The varied parameters were P = 650 - 1000 W, v = 80 $mm.s^{-1}$, Ar = 12 $l.min^{-1}$, f = 0, +5 mm, butt welds and lap welds were tried in PA position.

It was found that joint edge quality is important for butt weld. The mechanical shearing does not reach necessary edge quality, as the sheared edge roughness led to too high weld gap and weld burn through. Further edges processing was thus necessary. Edge milling was applied. Different angle of milling, 90, 70, 45° were tried. Angles 45, 70° enabled easy pre-welding setup, yet the welds had lack of fusion, lack of penetration. The Mg alloy weld are susceptible to porosity, weld sagging and burn through especially for higher weld power. EDX analysis did not prove important change in chemical composition due to evaporation during welding. Hardness increase was noticed in WM. Best results were obtained for butt welds with perpendicular edge, i.e. milled to 90°, at parameters 650 W, 80 $mm.s^{-1}$, when tensile strength reached R_m = 263 MPa. The weld window for Mg alloy is very narrow, yet good weld quality can be reached.

ACKNOWLEDGEMENT

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