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Microstructural Features and Mechanical Behavior of Laser Welded Magnesium Alloy Sheet

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Magnesium Alloy is gaining momentum now a days as it is light in weight and possess moderate strength. Automotive and aerospace industries and electronics companies looking for light and strong and smart materials to save fuel and emission free environments, which magnesium alloy can meet. As Tailor welded magnesium alloy sheets are in demand, AZ31B -H24 magnesium alloy sheet with 2 mm thickness is selected in this research work. Laser welding is used to join magnesium alloy sheets in butt configuration. The samples are analyzed, and observations and challenges are addressed with help of micrographs for further scope of work. Effect of laser welding on grain or microstructure changes are also outlined. Thorough micro structural analysis is carried out with an objective to capture grain structure near parent metal, left and right-hand sides of heat affected zone and weld line. Impact and hardness tests are conducted to assess the mechanical behavior of laser welded samples.

Keywords: Microstructure, Laser welding, Magnesium alloy sheet, Automotive and aerospace industries, Heat affected zone

1 Introduction

In many automotive, aerospace and electronics related companies, magnesium alloys have potential applications as their attractive strength to weight ratio when compared to aluminum and to some extent to steel[1]. For extensive use of magnesium alloys, is obvious that the magnesium should be more ductile to be formable and weldable to suit structural and smart applications like electronics goods manufacturing. Though strength to weight ratio is impressive, due to hexa-closed-pack grain structure of magnesium, it is less ductile at room temperature. However, it has got excellent ductility or formability and are easily extruded at moderate to elevated temperatures[2], ranging from 150^0C to 350^0C. Other features like damping and recyclability made magnesium alloys more demanding in the automotive and aerospace industries. Though magnesium is richly available, cost of magnesium alloys are about 2 to 3 times higher than aluminum and about 6-7 times more than steel. Magnesium alloys possess good machinability and weldability. However, the welding process is lower and need of filler material arises due to evaporation and diffusion. Edge preparation is done with CNC wire cut EDM as essential and surface treatments before and after welding is also significant. For increased mass production and sound welds, Laser welding is preferred, as it overcomes many disadvantages associated with ordinary arc welding techniques. Rakshith M and Seenuvasaperumal P studied the effect of processing parameters on microstructural and mechanical behavior of materials[3].

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2 Materials and Methods

2.1 Experimentation

Laser welding Experiments are conducted on AZ31 B H24 magnesium alloy of 2±0.1mm thick sheets using Fiber Optic as Laser medium in butt configuration[4-6]. A total of 15 experiments are conducted on 15 sets of samples each of 300x150x2mm size. The edges of the samples are machined with CNC wire cut EDM for accurate butting of the edges. Laser butt welded specimen is shown in Fig. 1. As received AZ31 B -H24 magnesium ally sheet contains 3%Al and 1% Zn and balance as magnesium. The EDS chemical report of raw magnesium alloy sheet was shown is Table 1.

The material is partial annealed and tempered. The weld test parameters are listed in Table 2. The micrograph for different welded samples are shown in Figs 2-9. Selected samples and their micrographs are

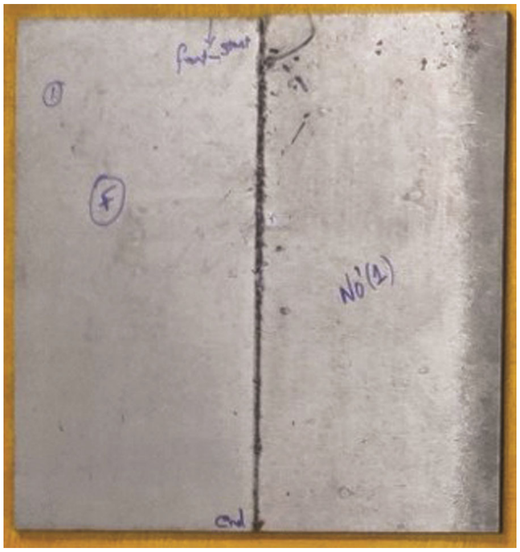

Fig. 1 — Laser welded AZ31B-Magnesium alloy sheets in Butt configuration.

Table 1 — EDS chemical report of AZ31 B magnesium sheet

Element	Weight %	Atomic %
Mg	58.98	70.05
Al	13.15	14.07
Si	8.65	8.89
P	5.32	4.96
Se	0.08	0.03
Mo	0.41	0.12
Au	1.78	0.26
Pb	11.63	1.62

Table 2 — Experimental design and welding parameters.

Sample No	Welding Power (W)	Welding Speed (mm/sec)	Focal Length (mm)
1	1500	12.5	106
2	2000	15	105
3	2000	12.5	105
4	1750	10	106
5	1750	15	106
6	1500	12.5	105
7	1500	10	105
8	2000	12.5	106
9	1750	10	104
10	1750	15	104
11	1500	15	105
12	1750	12.5	105
13	1750	12.5	105
14	1400	9	104
15	1750	12.5	105

given explanation and other samples and their micrographs with similar features are not presented in this paper. Detailed observations are mentioned against each micrograph. Many observations along with necessary precautions and recommendations are emphasized for achieving good quality welds. The focus of this work is to outline micro and macro characteristic features of welded samples. Welding factors like power speed and focal length and corresponding responses like weld penetration, width and heat affected zone, are mainly controlled, and optimized by analyzing these micro or macrographs. Interpretation of these micrographs is also a challenging task.

2.2 Microstructure Analysis

For Sample No.1**,**the parent metal magnesium alloy used in the laser welding process is shown in Fig. 2(a). The microstructure of the parent metal shows fine uniform grains of primary magnesium. The grain size is measured as 20 to 25 microns. The grain boundary shows precipitation of Mg17Al12 eutectics. The microstructure shows uniform recrystallized grains by normalizing treatment.

The photomicrograph as shown in Fig. 2(b), is captured from the Left-hand side plate at the heat affected zone of the laser welding zone. The field is 1.0 mm away from the weld zone[7]. The microstructure shows negligible effect of the process heat. Very less change is observed at the primary grain size of magnesium. It shows the insufficient heat transmission at the heat affected zone. Probably the gravity of heat has not crossed the recrystallization temperature[8].

The interface zone of the two magnesium plates of left and right side is shown in Fig. 2(c). The laser welding process has not affected fusion of both the metals. The possible reason could be insufficient power to produce heat. Another reason could be due to air gap between the two plates which led lack of diffusion of constituents from one side to the other side. However, the transformation of grain size to finer size shows the effect of laser heat produced[9]. The crack zone width is 10 microns.

The right-side alloy heat affected zone 1.0 mm away from the laser weld zone interface is shown in Fig. 2(d). No change in the microstructure observed and the matrix retained the same microstructure of primary magnesium solid solution grains. Not seem to be affected by the heat of the weld process.

For Sample No.2**,** the microstructure of the parent metal shows fine uniform grains of primary magnesium is shown in Fig. 3(a). The grain size is measured as 20 to 25 microns. The grain boundary shows precipitation of Mg17Al12 eutectics. The microstructure shows uniform recrystallized grains by normalizing treatment.

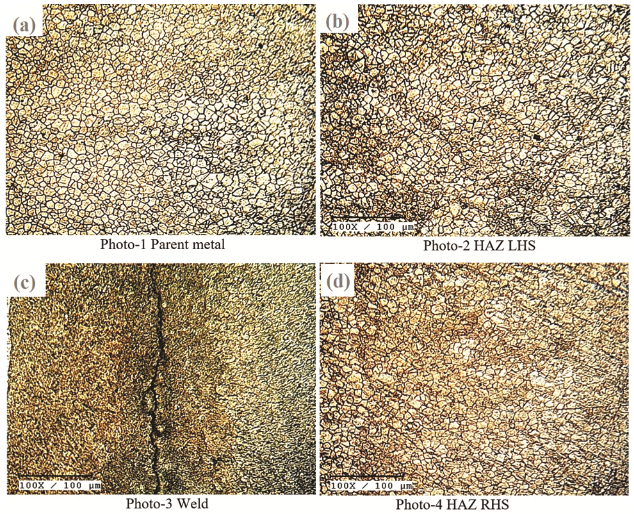

Fig. 2 — Micrographs for sample no.1 (a) Parent metal (b) HAZ LHS, (c) Weld line, and (d) HAZ RHS.

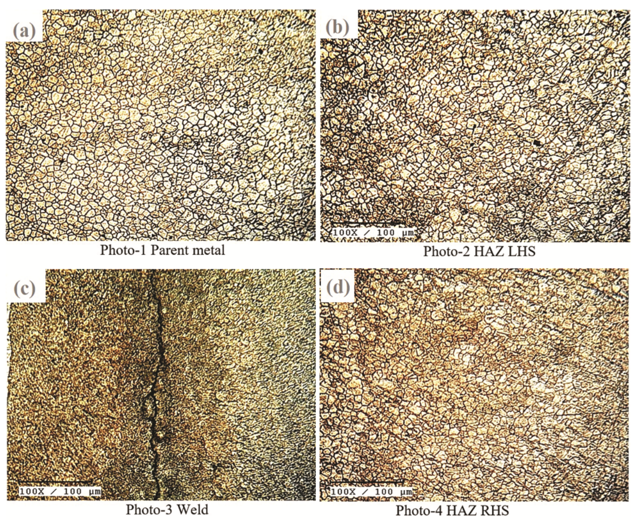

Fig. 3 — Micrographs for sample no.2 (a) Parent metal, (b) HAZ LHS, (c) Weld line, and (d) HAZ RHS.

The photomicrograph as shown in Fig. 3(b), is captured from the Left-hand side plate at the heat affected zone of the laser welding zone. The field is 0.5 mm away from the weld zone. The microstructure shows marginally effect of the process heat. Very less change is observed at the primary grain size of magnesium. It shows the insufficient heat transmission at the heat affected zone[10].

The interface zone of the two magnesium plates of left and right side is shown in Fig. 3(c). The laser welding process has not affected fusion of both the metals. The possible reason could be insufficient power to produce heat. Another reason could be due to air gap between the two plates which led lack of diffusion of constituents from one side to the other side. However, the transformation of grain size to finer size shows the effect of laser heat produced. The weld zone shows the crack formation during the welding process. The crack zone width is 15 microns.

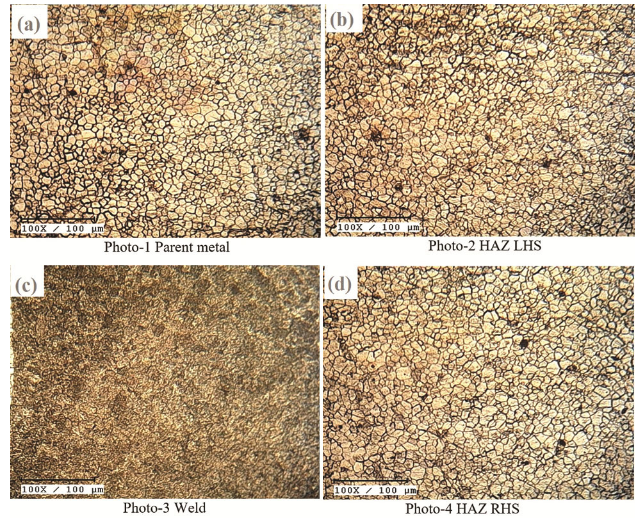

Fig. 4 — Micrographs for sample no.3 (a) Parent metal, (b) HAZ LHS, (c) Weld line, and (d) HAZ RHS.

The right-side alloy heat affected zone 1.0mm away from the laser weld zone interface is shown in Fig. 3(d). No change in the microstructure observed and the matrix retained the same microstructure of primary magnesium solid solution grains. Not seem to be affected by the heat of the weld process.

For Sample No. 3**,** the microstructure of the parent metal shows fine uniform grains of primary magnesium is shown in Fig. 4(a). The grain size is measured as 20 to 25 microns. The grain boundary shows precipitation of Mg17Al12 eutectics[11]. The microstructure shows uniform recrystallized grains by normalizing treatment.

The photomicrograph as shown in Fig. 4(b), is captured from the Left-hand side plate at the heat affected zone of the laser welding zone. The field is 0.5 mm away from the weld zone. The microstructure shows negligible effect of the process heat. Very less change is observed at the primary grain size of magnesium. It shows the adequate heat transmission at the heat affected zone.

The interface zone of the two magnesium plates of left and right side is shown in Fig. 4(c). The laser welding process has not affected fusion of both the metals. The transformation of grain size to finer size shows the effect of laser heat produced. The weld zone shows the complete fusion and orientation of the grains are equilibrium.

The right-side alloy heat affected zone 1.0 mm away from the laser weld zone interfaceis shown in Fig. 4(d). No change in the microstructure observed and the matrix retained the same microstructure of primary magnesium solid solution grains. Not seem to be affected by the heat of the weld process.

For Sample No. 4, the microstructure of the parent metal shows fine uniform grains of primary magnesium is shown in Fig. 5(a). The grain size is measured as 20 to 25 microns. The grain boundary shows precipitation of Mg17Al12 eutectics. The microstructure shows uniform recrystallized grains by normalizing treatment.

The photomicrograph as shown in Fig. 5(b), is captured from the Left-hand side plate at the heat affected zone of the laser welding zone. The field is 0.5 mm away from the weld zone. The microstructure shows marginally effect of the process heat. Very less change is observed at the primary grain size of magnesium. It shows the insufficient heat transmission at the heat affected zone.

The interface zone of the two magnesium plates of left and right side is shown in Fig. 5(c). The laser welding process has not affected fusion of both the metals. The possible reason could be insufficient power to produce heat. Another reason could be due to air gap between the two plates which led lack of diffusion of constituents from one side to the other side. However, the transformation of grain size to finer size shows the effect of laser heat produced. The weld zone shows the crack formation during the welding process. Due to the rapid heat solidify, the shrinkage of the crack zone. The crack zone width is 20 microns.

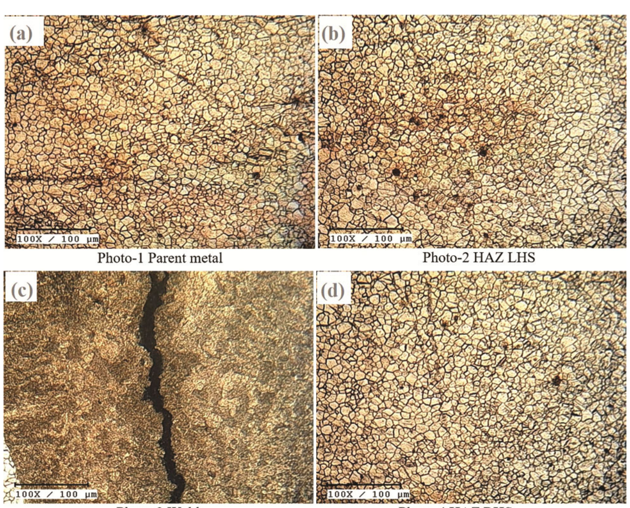

Fig. 5 — Micrographs for sample no.4 (a) Parent metal, (b) HAZ LHS, (c) Weld line, and (d) HAZ RHS.

The right-side alloy heat affected zone 1.0mm away from the laser weld zone interface is shown in Fig. 5(d). No change in the microstructure observed and the matrix retained the same microstructure of primary magnesium solid solution grains[12]. Not seem to be affected by the heat of the weld process.

For Sample No.5, the microstructure of the parent metal shows fine uniform grains of primary magnesium is shown in Fig. 6(a). The grain size is measured as 20 to 25 microns. The grain boundary shows precipitation of Mg17Al12 eutectics. The microstructure shows uniform recrystallized grains by normalizing treatment.

The photomicrograph as shown in Fig. 6(b), is captured from the Left-hand side plate at the heat affected zone of the laser welding zone. The field is 0.5 mm away from the weld zone. The microstructure shows marginally effect of the process heat. Very less change is observed at the primary grain size of magnesium. It shows the insufficient heat transmission at the heat affected zone.

The interface zone of the two magnesium plates of left and right side is shown in Fig. 6 (c). The weld zone is coarse grain morphology and transformations of the grains are transformed. The possible reason could be insufficient power to produce heat. Another reason could be due to air gap between the two plates which led lack of diffusion of constituents from one side to the other side. However, the transformation of

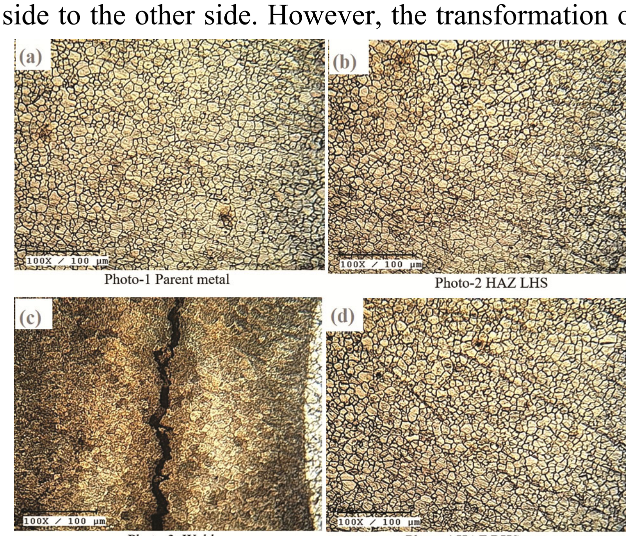

Fig. 6 — Micrographs for sample no.5 (a) Parent metal, (b) HAZ LHS, (c) Weld line, and (d) HAZ RHS.

grain size to finer size shows the effect of laser heat produced.

The weld zone shows the crack formation during the welding process. Due to the rapid heat solidify, the shrinkage of the crack zone. The crack zone width is 18 microns.

The right-side alloy heat affected zone 1.0mm away from the laser weld zone interface is shown in Fig. 6(d). No change in the microstructure observed and the matrix retained the same microstructure of primary magnesium solid solution grains. Not seem to be affected by the heat of the weld process.

For Sample No.6,the microstructure of the parent metal shows fine uniform grains of primary magnesium is shown in Fig. 7(a). The grain size is measured as 20 to 25 microns. The grain boundary shows precipitation of Mg17Al12 eutectics. The microstructure shows uniform recrystallized grains by normalizing treatment.

The photomicrograp has shown in Fig. 7(b), is captured from the Left-hand side plate at the heat affected zone of the laser welding zone. The field is 0.5 mm away from the weld zone. The microstructure shows marginally effect of the process heat. Very less change is observed at the primary grain size of magnesium. It shows the insufficient heat transmission at the heat affected zone. The heat affected zone has increasing the heat grain growth in the microstructure.

The interface zone of the two magnesium plates of left and right side is shown in Fig. 7(c). The weld zone is coarse grain morphology and transformations of the grains are transformed[13]. The possible reason could be insufficient power to produce heat. Another reason could be due to air gap between the two plates which led lack of diffusion of constituents from one side to the other side. However, the transformation of grain size to finer size shows the effect of laser heat produced. The weld zone shows the crack formation during the welding process. Due to the rapid heat solidify, the shrinkage of the crack zone. The crack zone width is 12 microns.

The right-side alloy heat affected zone 1.0 mm away from the laser weld zone interface is shown in Fig. 7(d). No change in the microstructure observed and the matrix retained the same microstructure of primary magnesium solid solution grains. Not seem to be affected by the heat of the weld process. It shows the insufficient heat transmission at the heat affected zone[14]. The heat affected zone has increasing the heat grain growth in the microstructure.

For Sample No.7, the microstructure of the parent metal shows fine uniform grains of primary magnesium is shown in Fig. 8(a). The grain size is measured as 20 to 25 microns. The grain boundary shows precipitation of Mg17Al12 eutectics. The microstructure shows uniform recrystallized grains by normalizing treatment.

The photomicrograph as shown in Fig.8(b), is captured from the Left-hand side plate at the heat affected zone of the laser welding zone. The field is 0.5 mm away from the weld zone. The microstructure shows negligible effect of the process heat. Very less change is observed at the primary grain size of magnesium. It shows the adequate heat transmission at the heat affected zone.

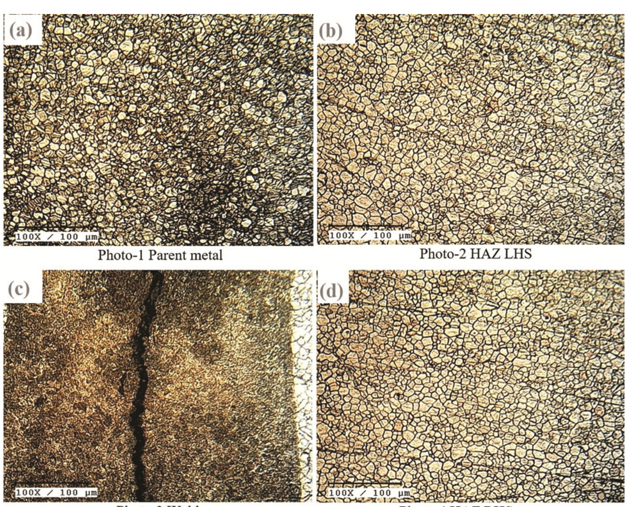

Fig. 7 — Micrographs for sample no.6 (a) Parent metal, (b) HAZ LHS, (c) Weld line, and (d) HAZ RHS.

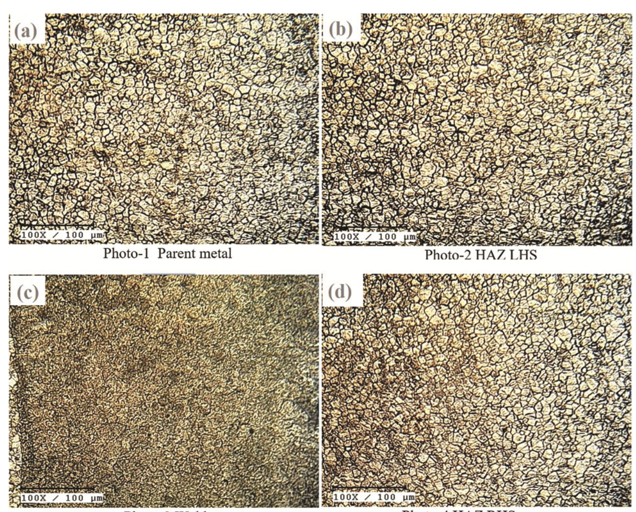

Fig. 8 — Micrographs for sample no.7 (a) Parent metal, (b) HAZ LHS, (c) Weld line, and (d) HAZ RHS.

The interface zone of the two magnesium plates of left and right side is shown in Fig. 8(c). The laser welding process has not affected fusion of both the metals. The transformation of grain size to finer size shows the effect of laser heat produced. The weld zone shows the complete fusion and orientation of the grains are equilibrium[15]. The grains are interconnected with fine grain morphology at the weld zone.

The right-side alloy heat affected zone 1.0mm away from the laser weld zone interfaceis shown in Fig. 8(d). No change in the microstructure observed and the matrix retained the same microstructure of primary magnesium solid solution grains. Not seem to be affected by the heat of the weld process.

For Sample No.8,the microstructure of the parent metal shows fine uniform grains of primary magnesium is shown in Fig. 9 (a). The grain size is measured as 20 to 25 microns. The grain boundary shows precipitation of Mg17Al12 eutectics. The microstructure shows uniform recrystallized grains by normalizing treatment. The photomicrograph is captured from the Left-hand side plate at the heat affected zone of the laser welding zone is shown in Fig. 9 (b). The field is 0.5 mm away from the weld zone. The microstructure shows marginally effect of the process heat. Very less change is observed at the primary grain size of magnesium. It shows the insufficient heat transmission at the heat affected zone.

The interface zone of the two magnesium plates of left and right side is shown in Fig. 9 (c). The laser welding process has not affected fusion of both the metals. The possible reason could be insufficient power to produce heat. Another reason could be due to air gap between the two plates which led lack of diffusion of constituents from one side to the other side. However, the transformation of grain size to finer size shows the effect of laser heat produced[16]. The weld zone shows the crack formation during the welding process. The crack zone width is 20 microns.

The right-side alloy heat affected zone 1.0mm away from the laser weld zone interface is shown in Fig. 9 (d). No change in the microstructure observed and the matrix retained the same microstructure of primary magnesium solid solution grains. Not seem to be affected by the heat of the weld process.

Fracture analysis also carried out on few samples to study the whether the failure is ductile fracture or brittle. Thermal cracking and undercut are observed and shown in Fig. 10. However ductile fracture is generally most favorable condition.

Further mechanical behavior of welded samples are studied by measuring the grain size and values are compared in Fig. 11. As the finer grain size forms more grain boundaries and resist plastic deformation, hence material loses its ductility. On the other hand, coarse grain size improves material's ductility[17]. Ductility play vital role in deep drawing and formability of sheet metals. Welded samples can be deep drawn and stretch formed. One of the methods to measure the strength of materials is by measuring impact strength or impact toughness. Shock loads and collision between two solid bodies is common in automotive and aerospace industry, hence measure of

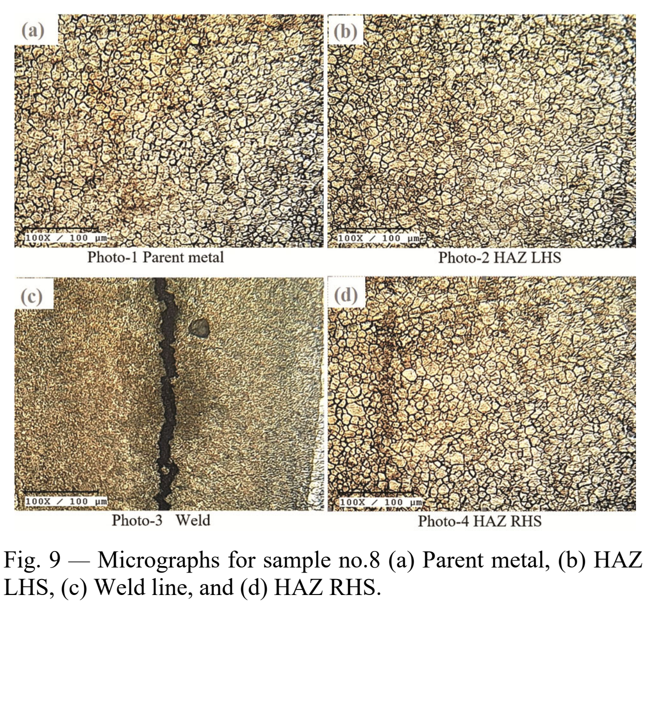

Fig. 9 — Micrographs for sample no.8 (a) Parent metal, (b) HAZ LHS, (c) Weld line, and (d) HAZ RHS.

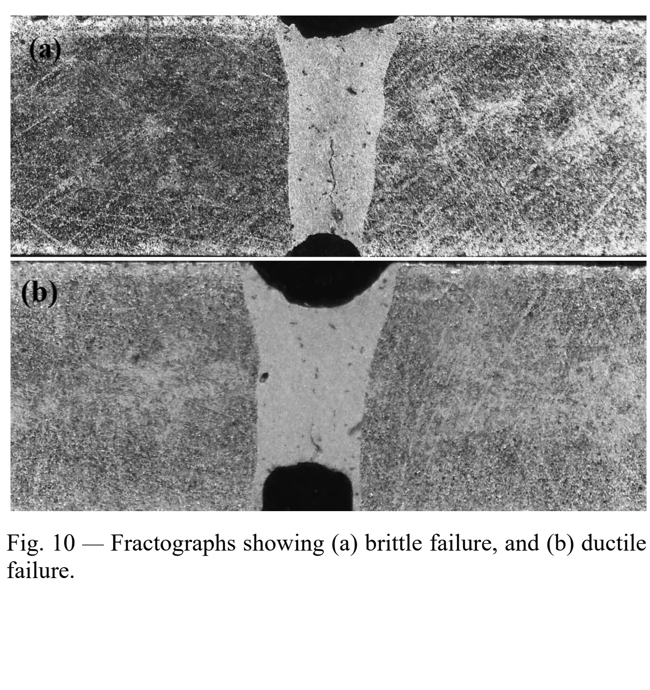

Fig. 10 — Fractographs showing (a) brittle failure, and (b) ductile failure.

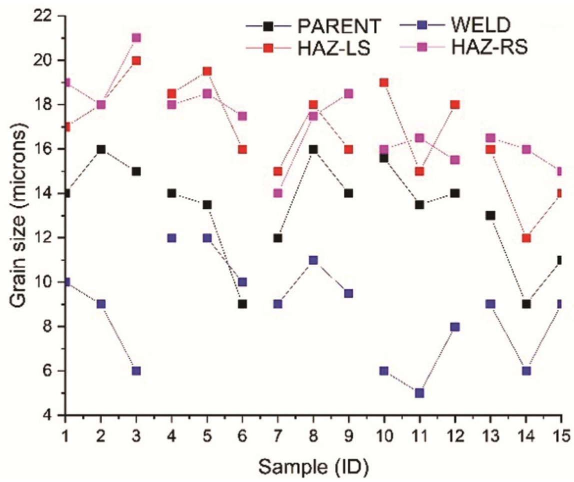

Fig. 11 — Grain size values of welded samples

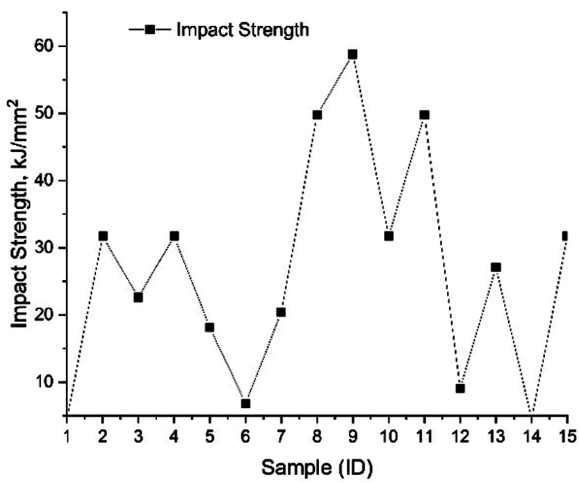

Fig. 12 — Impact strength values -welded samples

impact energy is essential[18].The tested results of impact strength values are illustrated in Fig. 12.

Intermolecular bonds are affected by heat of welding, leads to changes in surface hardness[19]. Surface hardness is significantas it decides shape changes under force. Vickers hardness test was conducted at 0.5kgf with dwell period of 5 sec. Micro and macro hardness values are mainly important in tribological studies of metallic materials[20,21]. It is observed that the magnesium sheet has initial coating to protect from atmosphere may be the reason for lesser hardness values.

As hardness is also an indication of local plastic deformation as hardness is dependent on elastic modulus stain and ductility an plasticity and toughness[22,23].It is so significant to measure the surface hardness. Vickers scale has been used in these experiments and the results are shown graphically in Fig. 13.

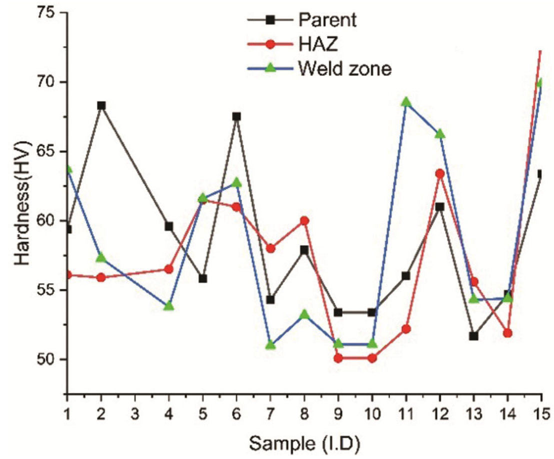

Fig. 13 — Hardness values of Laser welded samples (Units in HV@0.5kgf)

3 Results and Discussion

The overall microstructures of the parent material, weld zone as well as the region around weld zone reveal the presence of equiaxed grain although the average grain size reflects variations depending on the location within the sample. The microstructure within the weld zone shows very fine grain while the regions away from the weld zone exhibit relatively coarser grains. Accordingly, the Vickers hardness values also follows. This behaviour can therefore be attributed to both the starting microstructure along with the subsequent heating and cooling effect during welding process.

- Optimal hardness values about 59.4 HV are achieved at laser power 1500W, welding speed 12.5mm/s, focal length 106mm
- Higher values of impact strength is attained at laser power 1750W, welding speed 10 mm/s and focal length of 104mm
- Full weld depthis achieved, however thermal cracking is noticed
- Finer grains are observed in the HAZ from fractographs and micrographsthereby improved strength of the weld.
- Thermal cracks and weld defects can be reduced with increased rate of shielding gas supply
- Filler rod can be used for minimal undercut, as it has been observed in the weld zone.
- The grain size is measured as 20 to 25 microns. The grain boundary shows precipitation of $Mg_{17}Al_{12}$ eutectics
- No significant change is observed at the primary grain size of magnesium with increase in laser power and speed.

- The weld zone shows the complete fusion and orientation of the grains are equiaxed when increased focal length from 104 mm to 106 mm.
- No change in the overall nature of the micro structures is observed and the matrix retained the same microstructure of primary magnesium with equiaxed grains when welding speed increases form 10mm/s to 12.5mm/s.
- Due to the rapid heat solidification, the shrinkage of the crack zone is observed, and the crack zone width is measured as ~2 microns.

4 Conclusion

Micro and macro structure analysis have been carried out on AZ31B magnesium sheet of 2mm thickness in laser welded butt configuration. Mechanical behavior of welded samples has also been studied.

- The hardness and grain size values are uniform throughout the weld zones.
- The microstructure shows marginally effect of the process heat.
- Ductile fracture has been a favorable condition for formability and draw ability of selected laser welded sheets are possible.
- The photomicrographs showing favorable conditions for using the magnesium alloys in formability studies.
- Grain size and hardness values of laser welded samples are indicative of moderate strength applications.

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