Laser Surface Alloying of Al with Mo for hardness improvement

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Abstract: Laser surface alloying (LSA) of aluminum AA1200 was accomplished with a 4.4 kW Rofin Sinar Nd:YAG laser. Alloying was carried out by depositing molybdenum metallic powder on the aluminum substrate. The aim was to improve the hardness property of the aluminum substrate. The micro-hardness measurement of the samples was performed through the cross section of the alloyed layers using a Vickers micro-hardness tester model FM700. Experimental results obtained show that the intermetallic phases formed brought a significant increase in the hardness property of Al. A maximum microhardness increase of over 54 times the hardness of the substrate was achieved. Cracking was experienced during the hardness testing process. Optimized laser surface alloying processing parameters are 4 kW power, scan speed of 1 m/min at a 75% overlap.

1. Introduction

The mechanical, physical and chemical properties of aluminum and its alloy depend greatly on its composition and microstructure [1]. These properties can be enhanced by application of a surface coating using laser surface alloying technique. Aluminum is widely used in many industries due to its attractive properties such as light weight, low cost, corrosion resistance and its excellent workability. However, its low hardness, that is inadequate resistance to plastic deformation, is a limiting factor in some applications. To overcome such anomaly, LSA may be used to improve the surface properties.

Laser alloying is a material processing method which utilizes the high power density available from a focus laser source to heat and melt the substrate surface while injecting the alloying elements/compounds powder(s) into the melt pool. Modification of metal surface properties can be well influenced by the addition reinforcement powder(s), thereby forming intermetallic compounds through chemical reactions between the substrate and powder(s). An intermetallic compound is a solid phase consisting of two or more metallic elements in definite proportions; these phases are generally characterized by very high hardness. A number of parameters such as laser power, beam diameter, laser scanning speed, powder feed rate during large area alloying significantly influences the microstructure and chemical composition of the laser alloyed layer. These parameters should be well controlled to achieve the desired enhanced surface properties.

Many researchers have performed different studies on the hardness improvement of aluminium. Popoola et al [2] used a high power Nd:YAG laser to alloy aluminum AA1200 with a combination of nickel and titanium diboride using different weight ratios to improve its hardness. The alloyed surfaces composed of the initial phase of Al-Ni dendrites and eutectics of TiB_2/Al and TiB_2/Ni distributed on the initial phase. Experimental results obtained showed that Al-Ni intermetallics brought about a significant increase in the hardness property of Al, however, these intermetallics are highly brittle and prone to fail by brittle fracture or stress corrosion cracking when put in service. A micro-hardness increase of over 10 times the hardness of the substrate was achieved.

Mabhali et al [3] laser alloyed aluminum AA1200 with Ni, Ti and SiC powders of different weight ratios using a 4.4 kW Rofin Sinar Nd: YAG laser to improve the surface hardness. Intermetallic phases were formed between Al-Ni-Ti-SiC during laser alloying. An increase in surface hardness was achieved after laser alloying. A surface hardness of approximately 356.8±43.4 $HV_{0.1}$ was achieved after alloying with a powder containing 70wt%Ni, 20wt%Ti and 10wt%SiC. The increase in hardness was attributed to the formation of the intermetallic phases.

Laser alloying of aluminum AA1200 with a metallic powder mixture of Ni and SiC in different ratios was performed by Mabhali et al [4]. An Nd: YAG laser was used with 4 kW laser power, 10 mm/s scanning speed and a 4 mm defocus laser beam spot size. Analysis of the alloyed layer revealed the presence of Al_4C_3, $AlNi_3$ and α-Al-Si eutectic phases. The SiC particles dissociated into Si and C elements. The dissociated C reacted with Al to form Al_4C_3. The addition of Ni resulted in the formation of the Al_3Ni phase. A hardness increase of approximately 4 times that of aluminum AA1200 was achieved in the alloyed layer.

The aim of the present research work is to improve the surface hardness property of aluminum AA1200 alloy. Molybdenum will be used as metallic reinforcement powder. The micro-hardness property will be investigated and reported.

2. Experimental

2.1 Material and laser treatment

Pure aluminum AA1200 plate which was cut and machined to dimensions 100 mm x 100 mm x 6 mm was used as substrate. The plate was prepared for laser alloying by sand blasting to increase the beam absorption. The chemical composition of the substrate used is shown in Table1. Metallic molybdenum powder was used as an alloying powder. All the samples were sectioned with a Corundum L205 cut-off wheel using a Struers Discotom-2 cutting machine. A Struers lubricant, which acts as a coolant, was used during cutting. After sectioning, the specimens were hot mounted in clear thermosetting Bakelite resin using a Struers Prestopress-2 heat and pressure mounting press. The specimen were then ground from 80 to 1200 grit of SiC paper and polished to a 0.04 micron followed by the oxide polishing (OP-S) with a Struers TegraForce-5 auto/manual polisher. Prior to optical evaluation, the samples were rinsed in water and subsequently in alcohol and dried.

A 4.4 kW Rofin Sinar Nd: YAG solid-state laser was used for laser surface alloying. An off-axes nozzle was used for powder feeding. The laser is delivered to the target material through Nd: YAG optical fibre. A Kuka robot is used to move the alloying head. Argon was used as a shielding gas to prevent oxidation during the alloying process. The powder was fed onto the substrate at 3 g/min through the laser spot of 3 mm. The laser scanning speed and the power were varied in order to get the optimum laser processing parameters as shown in Table 2.

Table 1: Aluminum AA120 substrate chemical composition.

Elements	**Cu**	**Si**	**Fe**	**Al**
Chemical composition (wt %)	0.12	0.13	0.59	Balance

Table 2: Parameters used during laser surface alloying experiment.

Sample no	Alloying element	Power (kW)	Beam diameter (mm)	Scan speed (m/min)	Powder feed rate (g/min)	Shielding gas	Shield gas flow (L/min)
AM1	Molybdenum	4	3	1	3	Argon	4
AM2	Molybdenum	4	3	1.2	3	Argon	4
AM3	Molybdenum	2	3	1	3	Argon	4
AM4	Molybdenum	2	3	1.2	3	Argon	4

2.2 Micro-hardness and microstructure analysis

The microstructures of the alloyed layer were analyzed using the optical microscopy and the scanning electron microscopy (SEM) equipped with energy dispersive spectrometer (EDS) used for elemental analysis of the alloyed layer. A PANalytical X'Pert Pro X-ray diffractometer (XRD) with a CuKα radiation source was used to analyze the phases formed. The micro-hardness measurement of the samples was performed on the surface as well as through cross section of the alloyed layers (from the top of the alloyed zone into the substrate). The Vickers hardness test of the polished specimens was determined using a Vickers micro-hardness tester model FM700. An indenting load of 100 g, (50 µm, 100 µm, 150 µm and 500 µm spacing and a 10 second dwell time was used. The average micro-hardness of all the samples was calculated using ten representative indent values from the obtained results.

3. Results

3.1 Characterization of the alloyed sample

Laser alloying of aluminium with Mo powder resulted in the formation of intermetallic phases. The scanning electron micrograph of the alloyed AM1 layer is shown in Figure 1. It can be seen from Figure 2 that the alloyed layer represents a homogenous surface free of cracks and porosity. This is however due to ample time spent on optimization during alloying. The alloyed layer consists of a few undissolved Mo particles, which can be the result of fast reaction rate. Due to the high melting point of Mo (2623 °C) some of its particles remained undissolved and this indicates that the reaction temperature was lower than 2623^{o}C especially at the heat affected zone. The undissolved Mo particles (white phases) that resulted during the reaction can be observed in Figure 1.

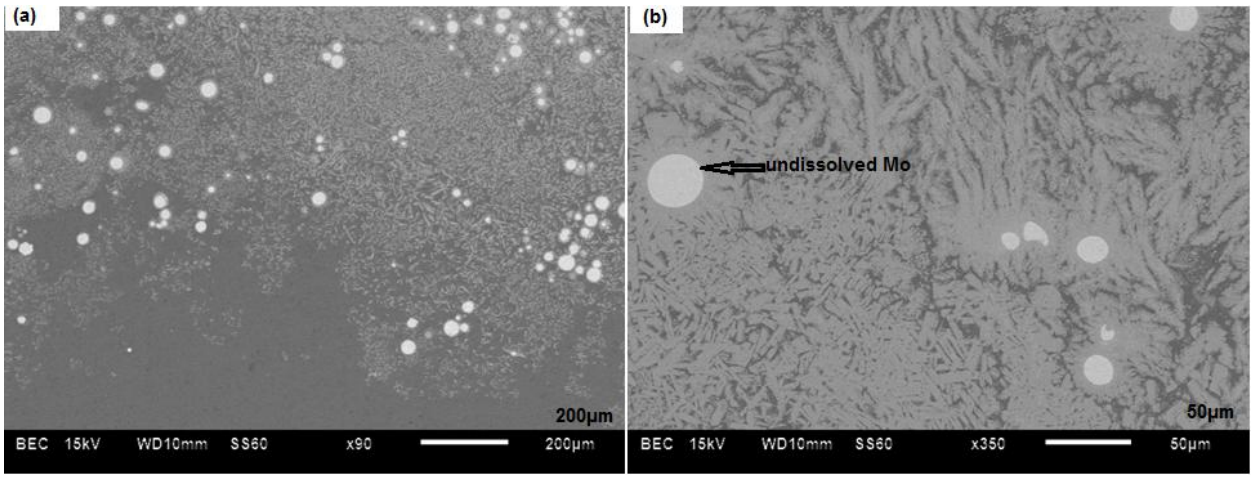

Figure 1: SEM for few undissolved Mo of sample AM1.

Figure 2 shows the concentration profile of various elements along the alloyed layer from the EDS analysis. In area 1 of the alloyed layer, the aluminium and Mo content was analyzed to be 75 wt% and 25wt% respectively. The phase present in this area is Al_3Mo. Area 2 consists of 100wt% Mo which represents the undissolved Mo particles. Area 3 contained 70 wt% and 30 wt% of Mo and Al respectively. The undissolved Mo particles can also be seen form Figure 2 which represents the EDS analysis of sample AM1.

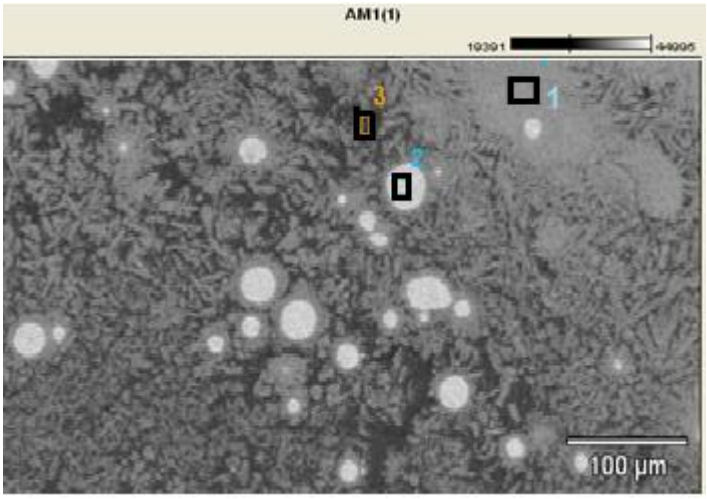

Figure 2: EDX Map area micrograph

Figure 3 shows the scanning electron micrographs of the cross section of sample AM3 laser alloyed with Mo powder. The micrographs from the SEM results consist of Mo particles dispersed in the Al-matrix with some undissolved Mo particles. Sample AM3 contained a number of cracks which can be seen from Figure 3. These cracks are probably induced by the internal stresses generated during solidification of the alloyed layer. Figure 3 shows the depth of the alloyed layer which was measured to be 875µm. The Figure also indicates spherical particles at the bottom of the alloyed layer which is undissolved Mo. The Mo particles are not homogeneously distributed within the alloyed layer. This greatly dominates and can be reason for the low hardness achieved as compared to sample AM1.

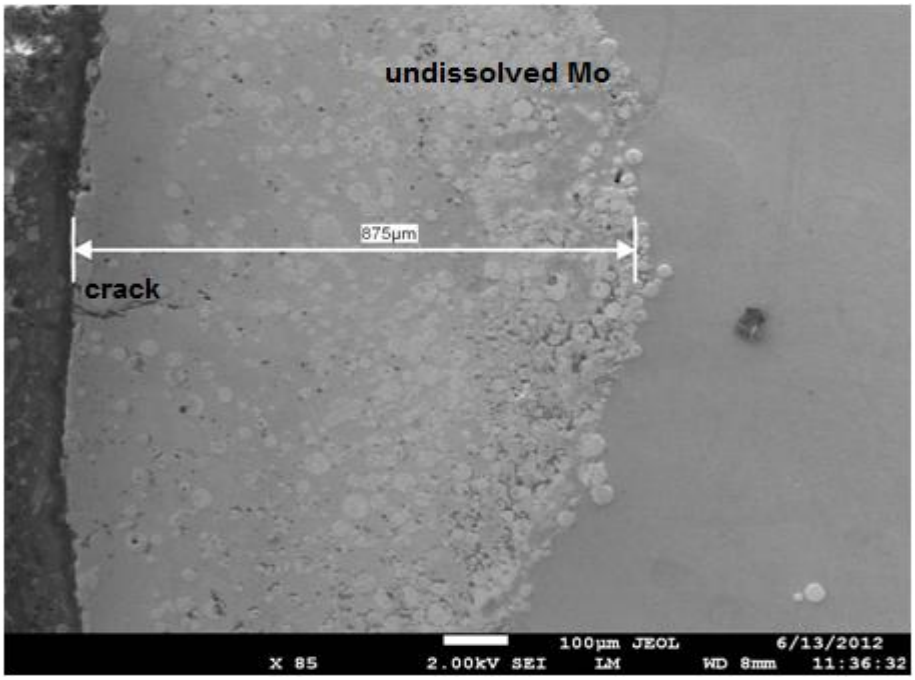

Figure 3: Scanning electron micrograph of sample AM3 laser alloyed surface of Al with Mo.

3.2 Hardness results

With the use of the Vickers hardness tester, the micro-hardness/depth profile of the samples tested were plotted. Table III below represents the average microhardness of the samples with the scan speed used. An increase in the microhardness values was observed in the alloyed layers. However this increase was dependent on the laser processing parameters. AM2 and AM4 did not show much improvement of hardness compared to AM1 and AM3. Figure 4 display the micro-hardness/depth profile of the alloyed samples.

Table 3: Micro-hardness results for laser alloyed samples.

Sample no	Alloying element	Average Hardness through thickness ($HV_{0.1}$)	Scan speed (m/min)
AM1	Molybdenum	1298.72	1
AM2	Molybdenum	253.33	1.2
AM3	Molybdenum	701.41	1
AM4	Molybdenum	479.39	1.2

Figure 4 below clearly indicates that sample AM1 has the highest average hardness value, followed by sample AM3. Laser surface alloying of aluminum AA1200 using 4 kW power and a scan speed of 1 m/min resulted in a micro-hardness increase from 24.0 ± 0.4 HV to a maximum value of 1299.0 ± 0.2 HV; also LSA with 2 kW and scan speed of 1 m/min resulted to a micro-hardness value of 701 ± 0.4 HV. This increase attributed to the intermetallic compounds formed.

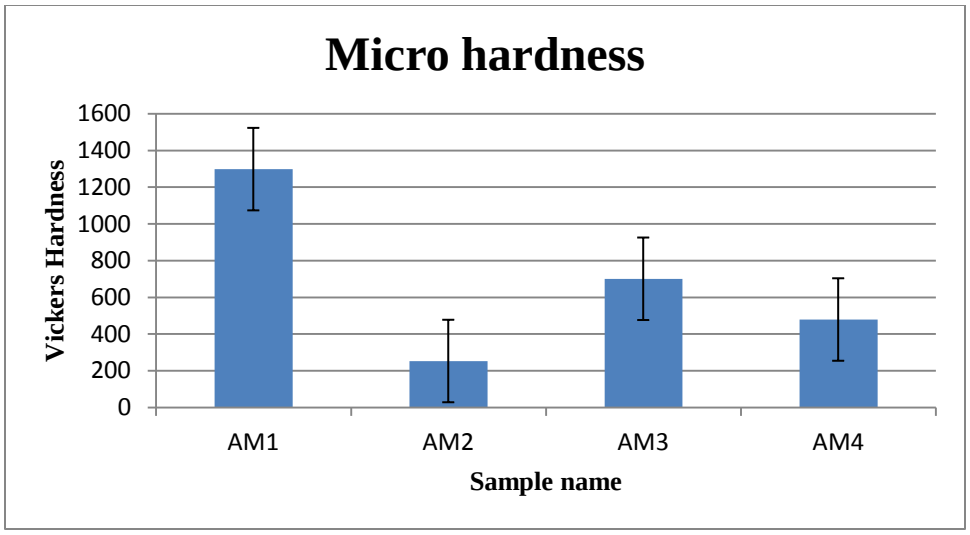

Figure 4: Variation of micro-hardness through thickness

The improvement in hardness is over 54 times and 29 times the hardness of the Al substrate. Sample AM2 and AM4 indicate diminutive improvement in hardness compared to sample AM1 and AM3. The average hardness improvement of these samples is 10 times and 20 times the hardness of the substrate respectively. This may be the cause of the chosen processing parameters. The optimum processing parameters that led to this high increase of the materials hardness were 4 kW power and 2 kW with a common scan speed of 1 m/min for sample 1 and 3 respectively.

4. Conclusion

Laser surface alloying of pure aluminum (AA1200) with molybdenum was successfully achieved. Good metallurgical bonding with the substrate was achieved with different intermetallic phases formed. The highest hardness attained is 1298 HV, which is due to the formation of the intermetallic phases. The hardness increase was 54 times higher than that of the substrate. The optimized laser processing parameter for hardness enhancement is 4 kW laser power and a scan speed of 1 m/min.

5. References

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Acknowledgments
This material is based upon work supported financially by the National Research Foundation. The National Laser Centre, CSIR, Pretoria is appreciated for laser facility.