LASER ALLOYING OF Al WITH MIXED Ni, Ti AND SiC POWDERS

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Abstract

Laser alloying of aluminium AA1200 was performed with a 4.4kW Rofin Sinar Nd:YAG laser to improve the surface hardness. Alloying was carried out by depositing Ni, Ti and SiC powders of different weight ratios on the aluminum substrate. The aim was to form surfaces on aluminium reinforced with metal matrix composites and intermetallic phases. The laser parameters used were 4kW power and 10mm/s laser scanning speed. The microstructures formed were examined using optical and scanning electron microscopes and the phases were identified with XRD and EDX analytical techniques. Preliminary results showed that the microstructure of the alloyed layer depends on the content of Ni, Ti and SiC in the deposited powder mixture. The distribution of the SiC particles was not homogeneous. 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.

Introduction

Aluminium is widely used in industry due to its low cost, light weight and excellent workability. However its low wear resistance and hardness are limiting factors in many applications. Laser alloying may be used to improve the aluminium surface properties such as hardness by modifying the composition and microstructure of the surface without affecting the bulk properties of the material [1,2,3]. This process involves melting the substrate surface and injecting powder of the alloying material into the melt pool. Process parameters such as laser power, beam spot size, laser scan speed and powder feed rate have to be controlled to achieve the desired surface properties [4].

The surface properties can be modified by adding elemental powders, thereby forming intermetallic compounds. An intermetallic compound is a solid phase consisting of two or more metallic elements in definite proportions. The intermetallic compounds generally have superior properties compared to the base aluminium such as high hardness and high wear and corrosion resistance [2,4,5]. Hard particles such as Al_3O_2, SiC, TiC and WC can also be injected into the surface of a metal matrix to improve surface properties [6-8]. In this way a surface metal matrix composite (MMC) is formed. The MMC layer has excellent hardness and wear resistance compared to the base alloy [9-13].

Man et al. [14] used a high power continuous wave Nd:YAG laser to alloy aluminium AA 6061 with preplaced NiTi (54 wt% Ni & 46 wt% Ti) powder to improve its hardness and wear resistance. A laser alloyed surface free of cracks and pores was achieved and SEM micrographs showed a dendritic microstructure. XRD patterns confirmed the intermetallics formed as $TiAl_3$ and Ni_3Al. The wear tests were performed on a pin on disc setup. A hardness increase of 200HV and wear resistance of about 5.5 times that of the virgin substrate was achieved for the modified layer. Ternary intermetallic phases and the wear mechanisms were not reported by the authors.

Ravi et al. [2] laser alloyed aluminium with preplaced Ni and Cr powders. The alloying was performed with a 3kW continuous wave CO_2 laser. The hardness of the laser alloyed surface increased with decreasing Ni and a maximum of 490HV was achieved with the composition of 20wt%Ni-80wt%Cr. The microstructure showed needle type structures for alloys with a high Ni composition which disappear as the Cr content is increased. The microstructure undergoes a phase transformation when the Cr concentration is increased. The intermetallic phases formed were AlNi, Al_3Ni_2, $AlNi_3$, $AlCr_2$, Cr_9Al_{17} and Cr_3Ni_2. The wear mechanisms of these alloys were not investigated.

Man et al. [15] synthesised TiC *in situ* on AA6061 aluminium surface by alloying with SiC and Ti powders. A Nd:YAG laser was used during the alloying at 1 to 1.5kW of power. The processing speed was between 5 and 25mm/s and the track overlap was 50%. The optimum powder composition for a high quality surface metal matrix composite was achieved with 40wt% SiC and 60wt%Ti. The average size of the TiC particles that formed after alloying was less than 3μm and these were uniformly dispersed in the matrix. XRD analysis of the alloyed layer revealed TiC, TiAl, Ti_3Al, SiC, Al and Si phases. The hardness increased from 75HV to 650HV due to the formation of the TiC particles and TiAl and Ti_3Al intermetallics.

Su and Lei [9] laser cladded Al-12wt%Si with a powder containing SiC and Al-12wt%Si in a 3:1 volume ratio. A CO_2 laser was used with 2-4kW laser power, 2-10mm/s laser scanning speed and a 3mm diameter laser beam. The aim of the study was to form a surface MMC layer on the aluminium matrix. It was reported that the laser melting of SiC particles onto an aluminium substrate produces aluminium carbides. The presence of the Al_4C_3 phase in MMC is not desirable as it is brittle and hydroscopic. The addition of Al-12wt%Si was found to suppress or eliminate the aluminium carbides in the MMC layer. A good distribution of injected SiC particles was achieved near the surface. The microhardness of the coating was between 220 and 280 $HV_{0.1}$.

The aim of this work is to improve the surface properties of aluminium by forming metal matrix composites and intermetallic compounds on the surface during laser alloying. The alloying powder was a mixture of Ni, Ti and SiC particles. The microstructure, hardness and in situ products were studied.

Experimental Method

The aluminium AA1200 was cut into $100x100mm^2$ plates with a thickness of 6mm. These plates were sand blasted and cleaned with acetone prior to alloying. The chemical composition of aluminium AA1200 is shown in Table 1.

Table 1 Chemical composition of aluminium AA1200.

Element	Cu	Si	Fe	Al
Composition (wt%)	0.12	0.13	0.59	Balance

The laser surface alloying-particle injection was carried out using a 4.4kW Rofin Sinar Nd:YAG laser. The processing parameters used were 4kW laser power, 10mm/s laser scanning speed and 4mm beam spot size. An off-axis nozzle was used for powder injection. Argon was used as the shielding gas to prevent oxidation during the alloying process and the flow rate was 4L/min. The laser energy density of $100MJ/m^2$ was calculated from the following equation:

$$E\ (MJ/m^2) = q/(d_B v) \qquad (1)$$

where q is the laser power, d_B is the diameter of the laser beam and v is the laser scanning velocity.

The alloying powders used were Ni, Ti and SiC powder particles of different weight ratios. The powder compositions used were 33.3wt%Ni + 33.3wt%Ti + 33.3wt%SiC, 50wt%Ni + 20wt%Ti + 30wt%SiC and 70wt%Ni + 20wt%Ti + 10wt%SiC. The powder particle morphology and size distribution were analyzed using a scanning electron microscope (SEM) and Malvern Mastersizer 2000 image analyzer.

Cross-sections of the alloyed layers were cut, mounted and polished to a 1μm finish. The polished surfaces were etched using Keller's reagent. The microstructure and chemical composition of deposited layers were studied using optical and scanning electron microscopy with energy dispersive x-ray (EDX) analysis. X-ray diffraction (XRD) was used for identifying the phases formed.

The hardness measurements of the specimens were performed on polished cross sections using a Vickers microhardness tester with a load of 100g. Hardness profiles were constructed for each alloying composition depicting the hardness from the alloyed surface through to the base aluminium. For the profiles the spacing between two consecutive hardness indents was 100μm

Results and Discussion

The Ni, Ti and SiC powder particle morphology was investigated. The shape of the particles was determined from SEM micrographs and the size distribution was determined using a Malvern Mastersizer 2000 image analyzer. The results are given in Table 2.

Table 2 Sizes and shapes of the Ni, Ti and SiC powder particles.

Powder	Ni	Ti	SiC
Size (μm)	7-200	5-158	14-800
Shape	Spherical & irregular	Irregular agglomerates	Irregular

Figure 1 shows a laser alloyed surface with a 33.3wt%Ni, 33.3wt%Ti and 33.3wt%SiC powder. The thickness of the alloyed layer was 1.81mm. The SiC particles can be observed in the alloyed layer showing that a metal matrix composite was formed.

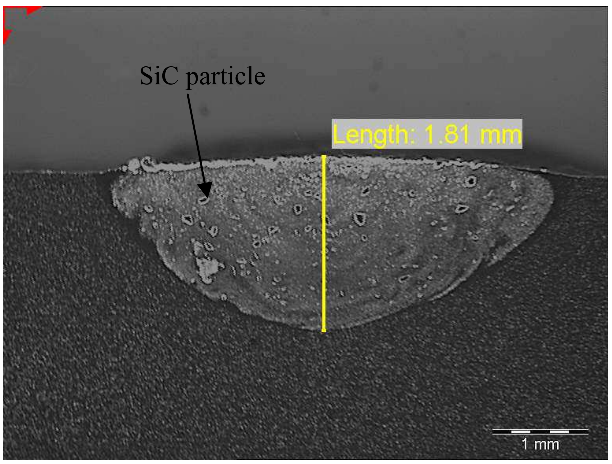

Figure 1: The alloyed layer formed after laser alloying with a powder containing 33.3wt%Ni, 33.3wt%Ti and 33.3wt%SiC.

Figure 2 shows a typical microstructure of this alloyed surface (33.3wt%Ni, 33.3wt%Ti and 33.3wt%SiC). The SiC particles are not homogeneously distributed within the alloyed layer. A large variation in size of the SiC particles is observed in the alloyed layer due to the wide particle size distribution of the SiC particles (Table 2).

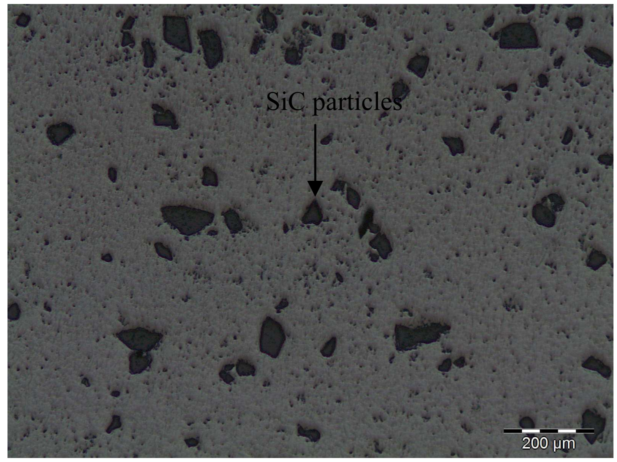

Figure 2: Optical micrograph of an alloyed layer showing SiC particles distributed within the alloyed layer.

A SEM micrograph of a surface laser alloyed with a powder containing 33.3wt%Ni, 33.3wt%Ti and 33.3wt%SiC is shown in Figure 3. The phases were identified using XRD and EDX. The reaction of Al with Ni resulted in the formation of Al_3Ni and Al_3Ni_2. The reaction of Al with Ti resulted in the formation of Al_3Ti. The SiC particles act as reinforcements resulting in the formation of an aluminium matrix composite. Some of the SiC particles dissociated to form Si and C. The C then reacted with Ti to form TiC dendrites. The SiC also reacted with Al to form Al_4SiC_4 intermetallic phases.

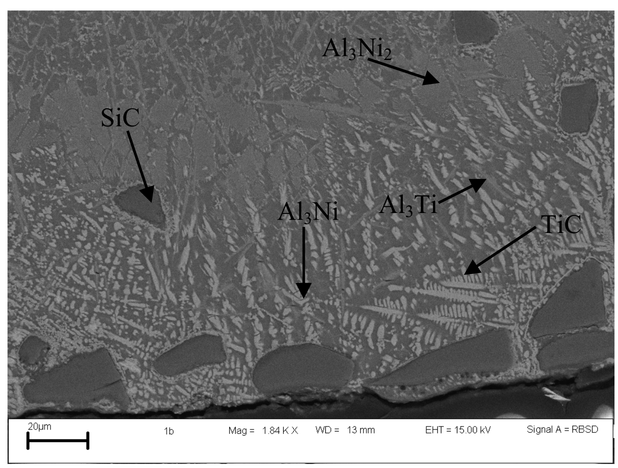

Figure 3: SEM cross-sectional micrograph (near surface region) of a surface alloyed with a powder containing 33.3wt%Ni, 33.3wt%Ti and 33.3wt%SiC.

The XRD diffractograph of the surface laser alloyed with a powder containing 33.3wt%Ni, 33.3wt%Ti and 33.3wt%SiC at 10mm/s laser scanning speed is shown in Figure 4. The phases observed were Al, SiC, TiC,

Al_3Ni, Al_3Ni_2, Al_3Ti and Al_4SiC_4. The XRD results together with the results from the EDX were used to identify the phases in the microstructure.

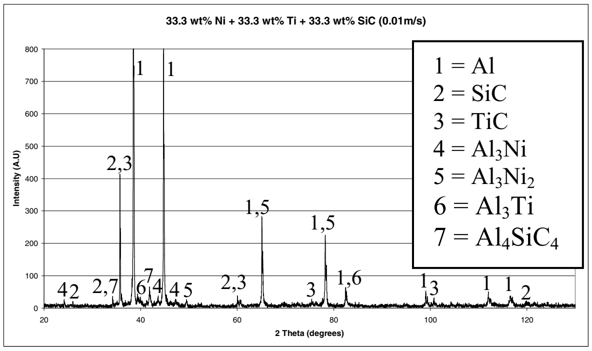

Figure 4: XRD diffractograph of surface laser alloyed with a powder containing 33.3wt%Ni, 33.3wt%Ti and 33.3wt%SiC at 10mm/s laser scanning speed.

Figure 5 shows a microstructure of an aluminium surface alloyed with a powder containing 50wt%Ni, 20wt%Ti and 30wt%SiC. The brittle Al_4C_3 phase was observed in the microstructure.

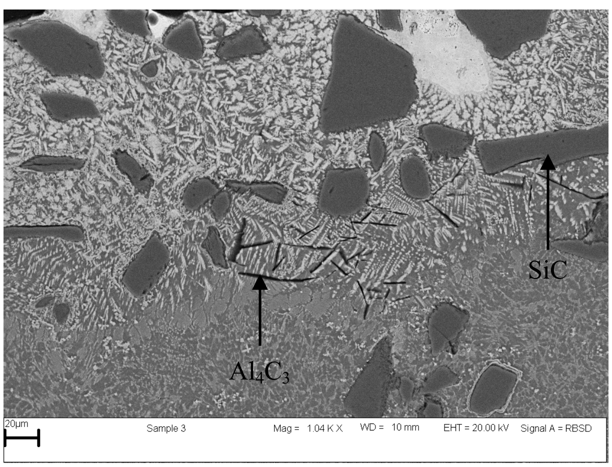

Figure 5: SEM cross-sectional micrograph (near surface region) of a surface alloyed with a powder containing 50wt%Ni, 20wt%Ti and 30wt%SiC.

Figure 6 shows a microstructure of an aluminium surface alloyed with a powder containing 70wt%Ni, 20wt%Ti and 10wt%SiC. Since Ni was dominant in the alloying powder, Al_3Ni phase dominated the microstructure of the alloyed layer. This phase is known to increase the hardness of aluminium alloys [1,2].

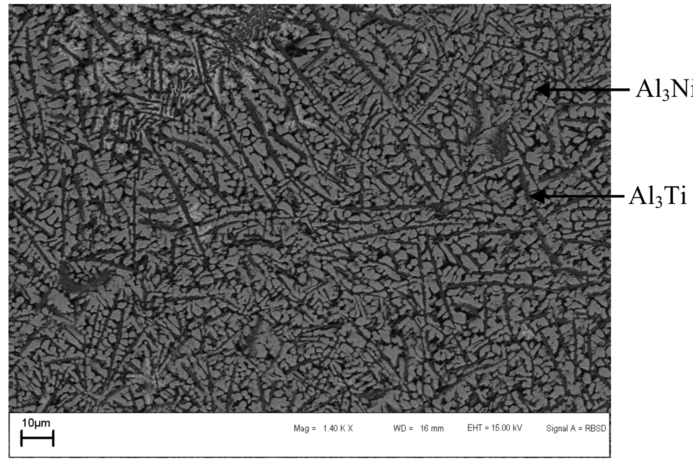

Figure 6: SEM cross-sectional micrograph of a surface alloyed with a powder containing 70wt%Ni, 20wt%Ti and 10wt%SiC.

Hardness

The hardness profiles of the alloyed surfaces are shown in Figure 7. The average hardness values are given in Table 3. The high hardness achieved when alloying with 70wt%Ni + 20wt%Ti + 30wt%SiC was attributed to the dominance of the Al_3Ni phase in the microstructure. Laser alloying with 33.3wt%Ni+ 33.3wt%Ti + 33.3wt%SiC and 50wt%Ni+ 20wt%Ti + 30wt%SiC powders results in a similar hardness profiles.

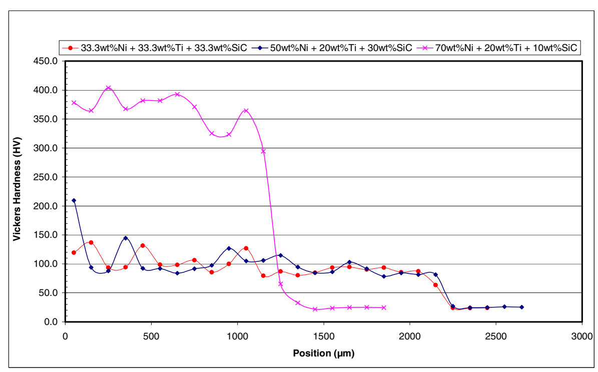

Figure 7: Hardness profile of the alloyed layers.

Table 3 Average hardness of the alloyed surfaces.

Powder content	Hardness ($HV_{0.1}$)
33.3wt%Ni + 33.3wt%Ti + 33.3wt%SiC	95.5±16.9
50wt%Ni + 20wt%Ti + 30wt%SiC	94.4 ± 16.0
70wt%Ni + 20wt%Ti + 30wt%SiC	362.5 ± 31.9

Conclusion

Laser surface alloying of aluminium AA1200 with powders containing Ni, Ti and SiC result in an increase in hardness. The increase is 4 times when alloying with 33.3wt%Ni + 33.3wt%Ti + 33.3wt%SiC and 50wt%Ni + 20wt%Ti + 30wt%SiC and 14 times when alloying with 70wt%Ni + 20wt%Ti + 30wt%SiC. The increase in hardness is attributed to the formation of the Al_3Ni, Al_3Ni_2, Al_3Ti intermetallic phases. The retained SiC particles were not homogeneously distributed in the alloyed layers. The TiC was formed in situ during the alloying.

Acknowledgements

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