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Research article

# Impact toughness of laser alloyed aluminium AA1200 alloys

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## Abstract

Laser surface alloying of aluminium AA1200 was performed with a 4kW Nd:YAG laser and impact resistance of the alloys was investigated. The alloying powders were a mixture of Ni, Ti and SiC in different proportions. Surfaces reinforced with intermetallic phases and metal matrix composites were achieved during laser alloying. Brittle fracture of the SiC particles and transgranular cracking of the intermetallic phases was observed for the laser alloyed samples, while ductile fracture was observed for the bulk aluminium. Aluminium AA1200 metal absorbed high energy during fracture compared to laser alloyed samples due to its high ductility. Laser alloyed layers with a high Ti content had high absorbed energies which represent a reduction in brittleness, while alloyed layers with a high Ni content had low absorbed energies which indicate a preference for brittle fracture.


**Keywords:** Laser alloying; impact test; transgranular fracture; intermetallic phases

## 1. Introduction

Laser alloying involves modifying the composition and microstructure of the surface without affecting the bulk properties of the material [1,2]. Alloying materials are deposited as powders into a melt pool generated on the material surface by a focused laser beam. The beam is scanned over the part and the deposited material resolidifies resulting in a good bonding between the substrate and the alloyed layer. Process parameters such as laser power, laser beam spot size, laser scanning speed and powder feed rate have to be controlled to achieve the desired metallurgical bonding and alloyed surface properties. The aim of this work was to study fracture of aluminium AA1200 alloy by laser surface alloying with mixed Ni, Ti and SiC powders. Intermetallic phases are formed when aluminium is laser alloyed with metallic materials (e.g. Ni and Ti) while metal matrix composites are formed when alloying with ceramics (e.g. SiC) [3-4]. Laser alloying aluminium with mixed Ni, Ti and SiC has been shown to increase hardness [4] and O'Quigley et al. [5] showed that fracture toughness decreases with hardness of the materials. In this work, only the absorbed energies during fracture and the fractographs of the laser alloyed samples and the pure aluminium were studied.

## 2. Experimental Procedure

### 2.1 Materials and laser surface alloying

The chemical composition of the aluminium AA1200 was 0.12wt%Cu, 0.13wt%Si, 0.59wt%Fe and the balance was Al. Test pieces 100x100x6mm in dimension were prepared.. Prior to laser surface treatment, the samples were sand blasted to enhance the absorption of laser energy by the aluminium substrate. The laser processing used were, 4 kW laser power and 10 mm/s laser scan speed. A powder feed rate of 2.5g/min ensured a sufficient supply of powder during the alloying experiments. Argon was used as the carrier and shielding gas to prevent oxidation during the alloying process. Larger laser alloyed surfaces were produced by overlapping 10 tracks at 50% overlap ratio, i.e. the width of one track was overlapped by 50% when forming the following track. Table 1 shows powder ration used in experiments.

**Table 1:** Starting powder mixtures

| Sample | SiC | Ni | Ti |
|---|---|---|---|
| | 50 | 20 | 30 |
| | 40 | 20 | 40 |
| | 33.3 | 33.3 | 33.3 |
| | 30 | 50 | 20 |
| | 20 | 10 | 70 |
| | 10 | 60 | 30 |

The alloyed samples were ground and polished to 0.04 (colloidal silica OP-S suspension) surface finishes and etched with Keller's reagent (3ml HCl + 2ml HF + 5ml $HNO_3$ + 190ml $HO_2$) before analytical characterisation. The structural phases and microstructure of the alloyed samples was investigated by x-ray diffraction (XRD).and scanning electron microscopy (SEM) And the investigations were carried by and Metallurgical examination of the larger surface alloyed aluminium specimens were subjected to impact testing (Charpy V-notch) according to the ASTM G23-05 standard [9]. The impact test is a standardized strain-rate test which determines the amount of energy absorbed by a material during fracture. The tests were performed on a Tinius Olsen impact machine. Figure 1 shows a typical sample prepared for these tests. The specimens were machined to 55x10x6mm dimensions. A 2mm deep notch was machined at mid-length (27.5mm) at 45 degrees to the surface.

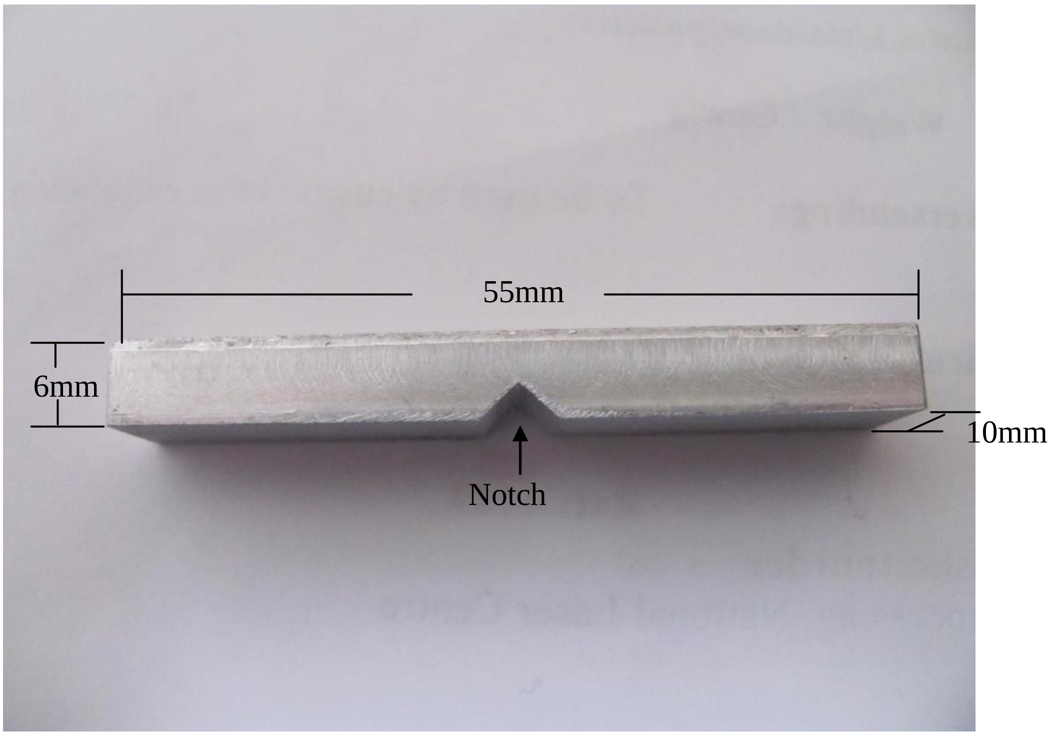


**Figure 1:** Specimen used for impact tests.

## 3. Results

### 3.1 XRD analysis

After laser treatment of Al with Ni, Ti and SiC, the alloyed layer exhibited hybrid metal matrix composite, reinforced with SiC particles and by inter-metallic phases. XRD analyses of the phases obtained in the alloyed layer are shown in Table 2. The reactions of Al with Ti resulted in the in-situ formation of the needle-like $Al_3Ti$ phase while the dendritic $Al_3Ni$ and the equiaxed dendritic $Al_3Ni_2$ phases were formed in-situ from the reactions of Al with Ni. Due to the high surface temperatures achieved during laser alloying, some of the SiC powder particles dissolved in the melt pool. The dissolved SiC particles dissociated to form Si and C. The C reacts with either Ti or Al to form TiC or $Al_4C_3$ or $Al_4SiC_4$ phases depending on the Gibbs free energy and the powder composition [4,10].

The interfacial TiC phases were formed around SiC particles due to adsorption of Ti on the SiC surface while the dendritic TiC phases were formed inside the melt pool from the reaction of the dissolved SiC particles and Ti. The needle-like $Al_4C_3$ phase is brittle and the $Al_4SiC_4$ phase has a platelet shape. The free Si (from SiC) reacted with Ti to form the thermodynamically stable $Ti_5Si_3$ [11].

Traces of $Ti_3SiC_2$ and $Al_4SiC_4$ were also observed for alloys with high Ti and SiC contents (viz. 20wt%Ni + 30wt%Ti + 50wt%SiC and 20wt%Ni + 40wt%Ti + 40wt%SiC). The α-Al mean free path decreased with increasing Ni content due to the formation of the highly dense equiaxed dendritc $Al_3Ni_2$ phase [4].

**Table 2:** Phases observed in the laser alloyed layers

| Powder composition | Phases |
|---|---|
| 10wt%Ni + 70wt%Ti + 20wt%SiC | α-Al, SiC, TiC, $Al_3Ni$, $Al_3Ti$ and $Ti_5Si_3$ |
| 20wt%Ni + 40wt%Ti + 40wt%SiC | α-Al, SiC, TiC, $Al_3Ni$, $Al_3Ti$, $Ti_5Si_3$, Si, $Al_3TiC_2$ and $Al_4SiC_4$ |
| 33.3wt%Ni + 33.3wt%Ti + 33.3wt%SiC | α-Al, SiC, TiC, $Al_3Ni$, $Al_3Ni_2$, $Al_3Ti$ and $Ti_5Si_3$ |
| 20wt%Ni + 30wt%Ti + 50wt%SiC | α-Al, SiC, TiC, $Al_3Ni$, $Al_3Ni_2$, $Al_3Ti$, $Ti_5Si_3$, Si, $Al_3TiC_2$ and $Al_4SiC_4$. |
| 50wt%Ni + 20wt%Ti + 30wt%SiC | α-Al, SiC, TiC, $Al_3Ni$, $Al_3Ni_2$, $Al_3Ti$, $Al_4C_3$ and $Ti_5Si_3$ |
| 60wt%Ni + 30wt%Ti + 10wt%SiC | α-Al, SiC, TiC, $Al_3Ni$, $Al_3Ni_2$, $Al_3Ti$ and $Ti_5Si_3$ |

## 3.2 Fracture analysis

The energy absorbed by aluminium and the laser alloyed samples during fracture was recorded and is listed in Table 3. The reported energy is the average of 4 measurements. The data shows that high energy was absorbed during fracture of the ductile aluminium AA1200 metal. The laser alloyed samples absorbed lower energies due to the increased hardness of the surface layers [4].

Figure 2 shows a macrograph of untreated aluminium after impact test. The untreated aluminium did not completely fracture but were plastically deformed and simply bent. This indicates that plastic deformations occurred in this surface and not fracture, Tthe absorbed energy listed in Table 3 for aluminium is due to this plastic deformation.

**Table 3:** Absorbed energy during fracture.

| **Sample** | **Average Energy (J)** |
|---|---|
| Aluminium | 14.8±0.2 |
| 50%wt SiC+20wt%Ni+30wt%Ti | 9.2±0.3 |
| 40wt%SiC+10wt%Ni+70wt%Ti | 10.0.0±0.0 |
| 33.3wt%Ni + 33.3wt%Ti + 33.3wt%SiC | 9.8±0.2 |
| 30wt%SiC+50wt%Ni +20wt%Ti | 8.5±0.4 |
| 20wt%SiC+ 10wt%Ni+70wtTi | 10.2±0.2 |
| 10wt%SiC+60wt%Ni+ 30wt%Ti | 7.3±0.2 |

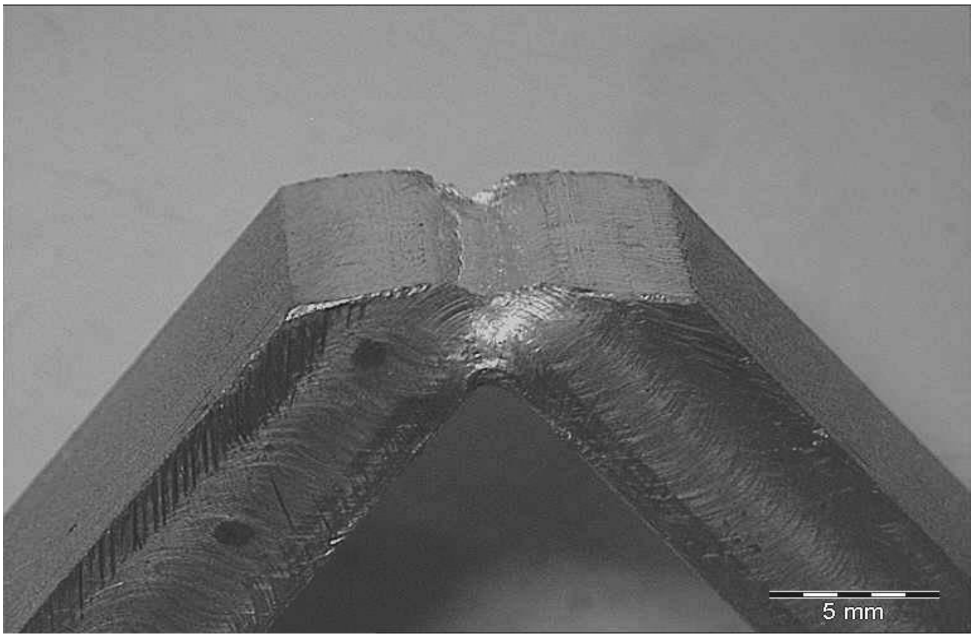


**Figure 2:** Untreated aluminium AA1200 after impact test.

Figure 3 shows a typical fractured surface for the laser alloyed samples. Three different regions are observed; the laser alloyed layer followed by the aluminium surface and then the notched aluminium. The fractured surface of the aluminium surface region is shown in Figure 4. Cuplets characteristic of ductile fracture were observed in this region.

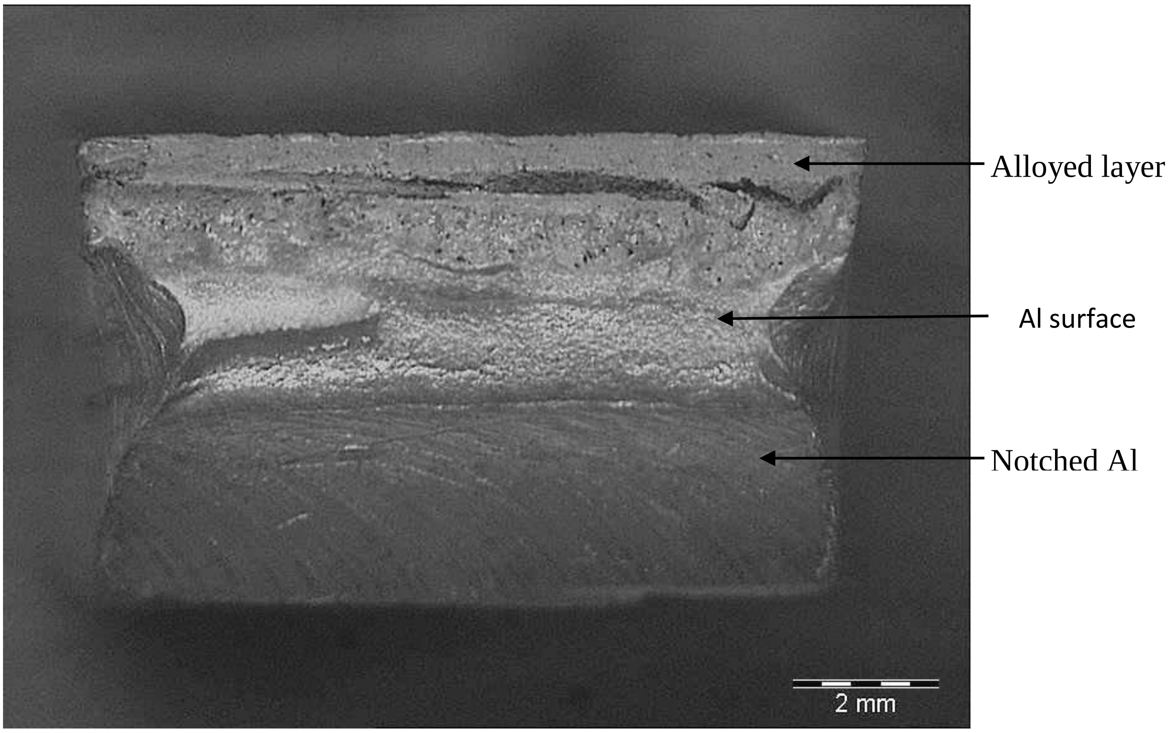


**Figure 3:** A typical fracture surface for the laser alloyed samples.

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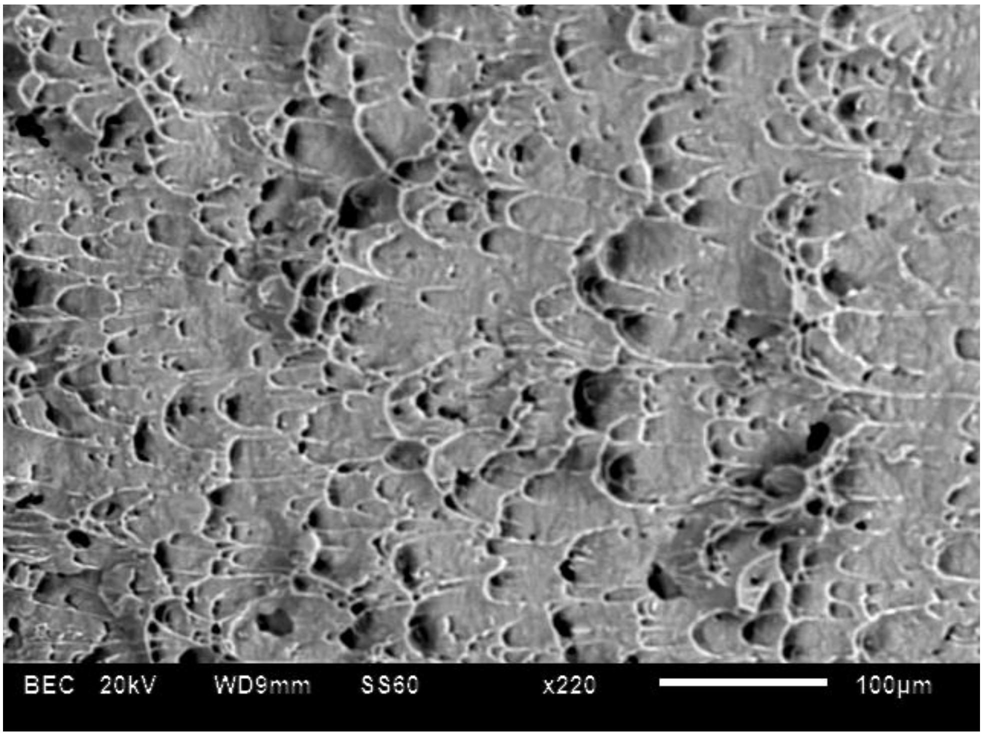
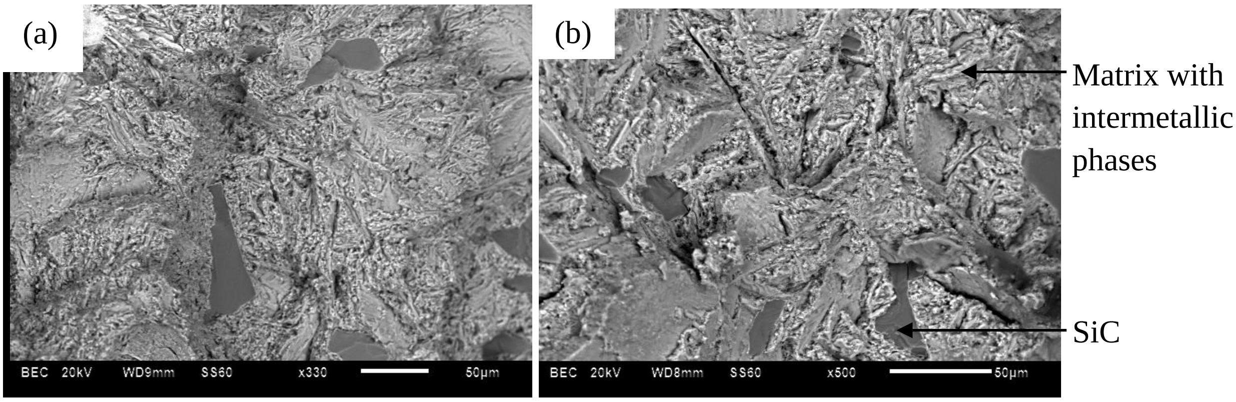



**Figure 4:** Fracture surface of the aluminium surface showing cuplets.

Figure 5 shows a series of fractured surfaces that were laser alloyed at different powder mixtures. In alloys with a high SiC content (Figure 5(a-d)), crack propagation was promoted by transgranular fracture of these hard SiC particles. Fracture of the SiC particles occurred by cleavage which is characteristic of brittle fracture while the matrix was dull and fibrous which is characteristic of ductile fracture. Cleavage is known to occur due to transgranular fracture [6]. Few cracks were observed in alloys with a low SiC content, but decohesion of the intermetallic phases was observed as shown in Figures 5(e-f). This was also observed by Vreeling et al. [7] while studying the failure mechanisms in an Al/SiC metal matrix composite. Cracking of the intermetallic phases was also observed in the fractographs. In general the overall fracture was ductile.




(d)

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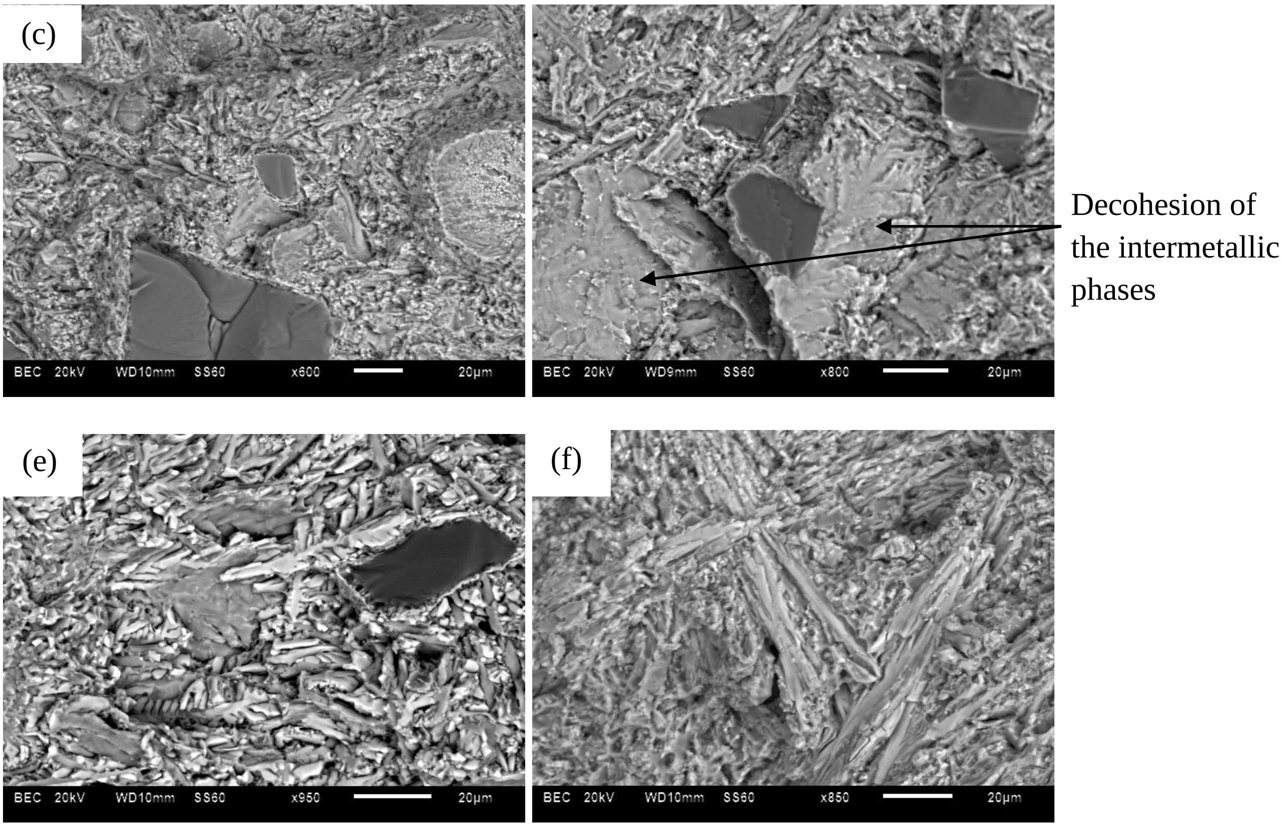


**Figure 5:** SEM fractographs of the samples laser alloyed with (a) 20wt%Ni + 30wt%Ti + 50wt%SiC, (b) 20wt%Ni + 40wt%Ti + 40wt%SiC, (c) 33.3wt%Ni + 33.3wt%Ti + 33.3wt%SiC (d) 50wt%Ni + 20wt%Ti + 30wt%SiC, (e) 60wt%Ni + 30wt%Ti + 10wt%SiC, (e) 10wt%Ni + 70wt%Ti + 20wt%SiC. (a-d) are alloys with high SiC content (≥ 30wt%) while (e-f) are alloys with low SiC content (< 30wt%).

## 4. Discussion

Laser surface alloying the Al AA1200 metal led to a 31-50% decrease in the impact resistance of the pure metal. This is predominantly due to the increased hardness achieved by the laser alloying process [4]. Ozden et al. [12] also observed an increase in impact resistance for untreated aluminium alloys (AA2124, AA5083 and AA6063) compared to the aluminium MMCs. The high impact resistance of the pure aluminium was noted by the high degree of plastic deformation experienced by the samples during impact testing. The pure aluminium samples did not fracture; they simply bent. All the laser alloyed samples fractured and displayed similar fracture characteristics. Cleavage occurred in the SiC particles and transgranular cracking occurred in the intermetallic phases. Alloyed surfaces with large α-Al mean free paths resulted in high absorbed energies being recorded during fracture. This was observed in microstructures which had high volumes of dendritic $Al_3Ti$, needle-like $Al_4C_3$ or platelet $Al_4SiC_4$ phases, i.e. alloys with high Ti and SiC content. Cuplets characteristic of ductile fracture were observed in the bulk aluminium.

The intermetallic phases assist in anchoring the SiC particles to the Al matrix by preventing decohesion of the SiC particles. Vreeling et al. [7] reported that when the matrix is deformed, the intermetallic phases transfer the stress to the SiC particle surface which leads to fracture of the SiC particles. The brittle fracture of the SiC particles is initiated by cleavage mechanisms. Vreeling et al. [7] concluded that suppressing the formation of intermetallic phases would postpone the fracture initiation process. For alloys with a low SiC content, decohesion and cracking of the intermetallic phases resulted in fracture of the alloys. Ozden et al. [12] reported that when the distribution of SiC particles in the matrix is heterogeneous, formation of clusters occur which decreases the matrix-reinforcement bonding and reduces the impact strength of the composite as the clustered particles are easily separated during impact loading. Interfacial debonding occurs and voids nucleate around the SiC particles. In regions of clustering and decohesion of the interface, a low Al mean free path facilitates linkage between neighbouring voids and cracks as a direct result of a decreased propagation distance between cracked SiC particles. This behaviour was observed in several alloyed surface layers in the current project. The impact strength has been shown to increase with SiC particle size [12] but in this work the SiC particle size distribution was wide (14-800µm) and this effect was not observed.

## 5. Conclusions

Brittle fracture of the SiC particles and transgranular cracking of the intermetallic phases was observed for the laser alloyed samples, while ductile fracture was observed for the bulk aluminium. Alloyed layers with a high Ti content had high absorbed energies which represent a reduction in brittleness, while alloyed layers with a high Ni content had low absorbed energies which indicate a preference for brittle fracture.

## 6. Acknowledgements

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