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# Hardfacing of aluminium alloys by means of Metal Matrix Composites produced by laser surface alloying

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## Abstract

Metal matrix composite layers were formed on an aluminium substrate by means of laser surface alloying method. Aluminium 1200 was used as a host material and TiC particles were used as the reinforcement. The microstructure of the modified layer consisted of the hard particles uniformly distributed in the host metal matrix. A strong bond between the particles and matrix was formed in the modified layer. A Rofin Nd: YAG laser was used for injecting the ceramic powder into the substrate. In these experiments the laser power was varied from 3 to 4.0 kW, the laser scan speed was varied from 0.8 to 2.0 m/min. The powder feed rate was varied from 2 to 5 g/min. The structural characterisation of the metal matrix composite included X-ray diffraction (XRD), optical and scanning electron microscope (SEM) as well as microhardness measurements. The micro-hardness of the layers increased from 20 HV to 350 HV. This represented a significant improvement of the surface properties compared to the base metal.

**Keywords:** Laser surface alloying, TiC, MMC

## 1 Introduction

Aluminium is a very important material which is used in many industries. The choice of aluminium is based on its excellent physical properties such as low density and high specific strength. However, its application is limited by its low surface hardness and surface wear resistance. The surface wear can be improved by hard-facing. A number of researchers have studied deposition of hard particles onto the aluminium surface by laser surface alloying, laser melt injection and cladding. In laser melt injection, hard particles are incorporated into the surface resulting in considerable improvement of the surface especially its wear resistance [1-5].

The laser surface alloying and melt injection generally involve melting the target surface and simultaneously injecting hard particles into the melt pool [6]. The parameters of importance are the laser beam power (*P*), the beam radius (*r*) and the scan speed (*v*). The combination of these parameters give the energy density as $E = P/(rv)$ in $MJ/m^2$ [7]. Also of importance is the powder flow rate. The distribution of the injected particles in the melt is governed by convection flow in the melt pool [8]. The movement of the liquid in the melt pool is influenced by the surface tension gradient which is dependent on the temperature difference between the centre and the edge of melt pool.

The surface reinforced by the incorporation of hard particles such as SiC, TiC and $Al_2O_3$ is called a metal matrix composite (MMC). The MMCs exhibit very high hardness and improved wear resistance compared to the base alloy [9-10]. When fabricating MMCs especially for abrasive wear applications, it is essential to consider the volume fraction, distribution and interfacial bonding of the particles with the metallic host matrix [11]. If the bonding is strong the MMC is expected to offer higher resistance even in cases where severe wear conditions prevail.

In the present study surface metal matrix composites were formed on an aluminium substrate by means of laser surface alloying. The aim was to investigate the feasibility of creating a high volume fraction and uniformly distributed TiC particles in the alloyed layer and furthermore to characterise the surface hardness of such layers.

## 2 Experimental Details

### 2.1 Laser surface alloying

The substrates used in the experiments were commercially pure AA1200 aluminium. Its chemical composition is shown in **Tab. 1**. The surface of the aluminium substrate was sandblasted prior to laser surface alloying. This enhances the absorption of the laser energy by the aluminium substrate. The powder material used for alloying was pure Titanium carbide (TiC) with particle sizes ranging from 40 to 100 µm.

The alloying powder was fed into the melt pool by means of an argon gas stream. A commercial powder feed instrument equipped with flow balance was used to control the powder feed rate. The gas flow rate was set a 2 L/min and the powder feed rate varied from 1 to 5 g/min.

A 4.4 kW Rofin Sinar continous wave Nd:YAG laser equipped with a fiber optic beam delivery system was used in the experimental investigations. The laser power was varied from 3 to 4 kW and the beam size was fixed to 3 mm in diameter. A KUKA robot was used to deliver the laser beam through a 600 μm optical fiber to the targert surface. The scan speed of the laser beam was varied 0.8 to 1.2 m/min.

***Tabl. 1** Composition of AA 1200 alloy, wt-%*

| Si | Fe | Cu | Mn | Zn | Ti | Al |
|---|---|---|---|---|---|---|
| 1.0 | 1.0 | 0.05 | 0.05 | 0.1 | 0.05 | Bal |

### 2.2 Material Characterisation

Transverse sections of the alloyed specimens were prepared for structural, microstructural and micro-hardness investigations. The X-ray diffraction (XRD) patterns of the alloyed surface were obtained from polished sections using a PANalytical X' Pert Pro powder diffractometer with X' Celerator detector. The radiation source used was $CuK_{\alpha}$ . The phases were identified using X'Pert High-score plus software.

The Leo 1525 scanning electron microscope (SEM) equipped with energy disperive spectrometer (EDS) was used for the microstructure and the elemental composition analysis. An optical microscope was also used for microstructure analysis. The hardness profiles of the alloyed amples were measured using a Matsuzawa hardness tester with a load of 100g. A minimum of five indents were made in each location in order to obtaina good statistical representation of the dataset. In each case, the average of all the measurements was used to get the hardness profile of the alloyed track.

## 3 Results and discussion

### 3.1 TiC particle characterisation

**Fig. 1** shows a SEM micrograph of the as received TiC particles which were used in these experiments. The morphologies of the TiC particles were granular and irregular in shape. The average particle size was measured and found to range from 45 to 100 μm. It has been reported that the relative size of the particles plays an important role in the abrassive wear mechanism [12]. If the particle size is smaller than the groove produced by the abrasive, then the reinforcing agents provide no protection to the surface.

The purity of the powder was determined by the XRD and EDS. The XRD diffractograph is shown in **Fig. 2.** This shows that the powder was free from any contamination.

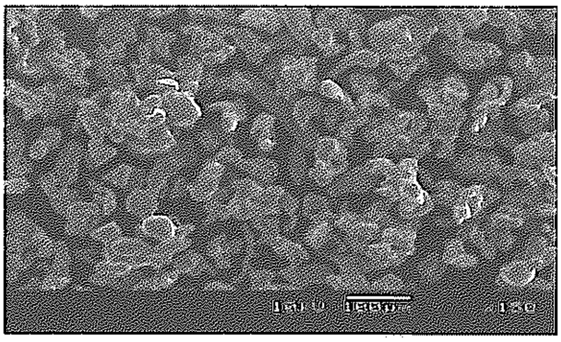

***Fig. 1**: Morphology of TiC particles*

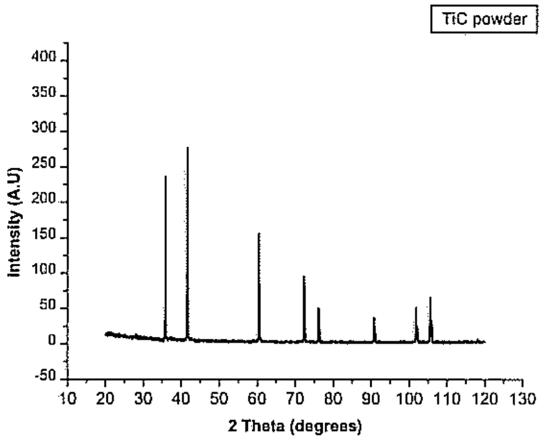


***Fig. 2**: XRD diffractograph of TiC particles*

### 3.2 Laser melt injection

In the present study single laser tracks were made on the target surface using laser power ranging from 3 to 4 kW and scan speeds from 0.8 to 1.2 m/min. Poor particle injection was observed when a low power and high scan speeds were used. In **Fig. 3** a SEM micrograph of a cross-section of a polished sample is shown after the laser melt injection process. The laser power delivered onto the sample was 3 kW and the scan speed was 0.9 m/min.

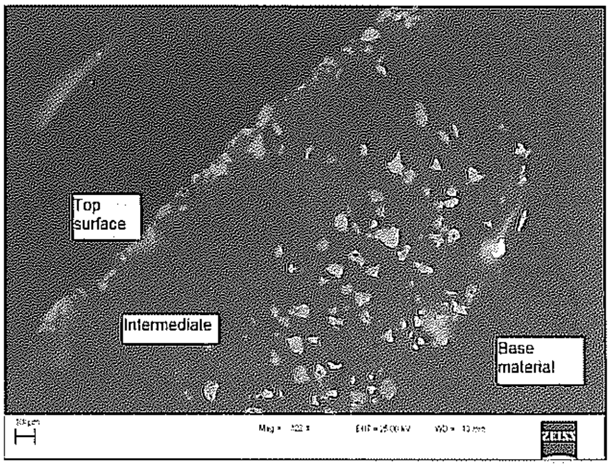


***Fig. 3**: SEM image of a laser composite surface of Al with TiC particles treated with 3 kW and 0.9 m/min scan speed*

The width of the laser track is approximately equal to that of the laser beam of ~3 mm. It is observed that the TiC particles penetrate as far as ~2 mm below the surface. A high number of the injected particles are seen to be settling near the botton of the melt. In the intermediate region, (**Fig. 2**) there are almost no TiC partcles present. This is due to a number of factors; the short lifetime of the aluminium melt pool caused by the low energy density ~66.6 MJ/m$^2$ resulting in low heat input; the high density of TiC (4900 kg/m$^3$). The melt pool solidifies before a sufficent number of particles could be injected, whilest the few particles that enter the melt sink to the bottom of the pool due to high density.

The bonding between the TiC particles and the solidified aluminium is shown by the SEM micrograph presented in **Fig. 4** at 500X magnification. There are no discernable secondary phase that can be identified. This indicates that the TiC was not disolved or melted during the injection process, therefore the brittle aluminium carbide phases were not formed. **Fig. 5** is the XRD phase analysis of the this layer. It shows that only TiC and Al phases are present in this layer.

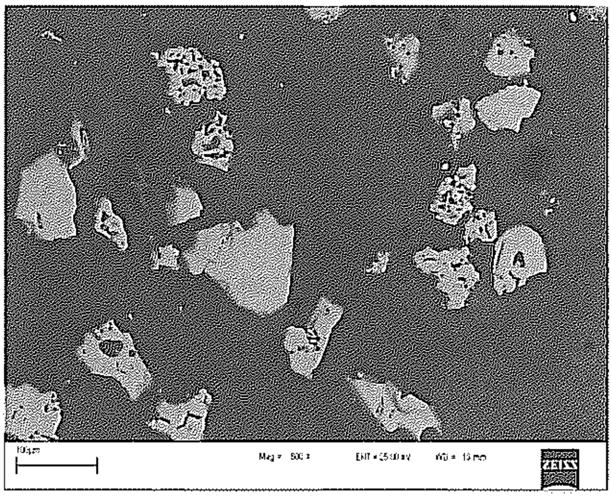

*Fig. 4: SEM micrograph at 500 X magnification, laser composite surface of Al with TiC particles treated with 3 kW and 0.9 m/min scan speed. The white phases are TiC in the solidified Al matrix*

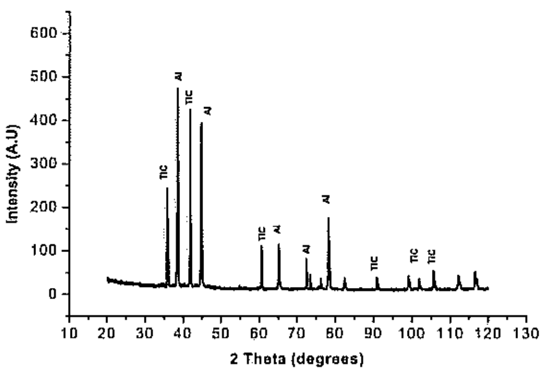


*Fig. 5: XRD of the layer shown in Fig. 3.*

When the laser power was increased to 4 kW and scan speed decreased to 0.8 m/min, this resulted in a higher volume fraction of the injected TiC particles in the melt pool. **Fig. 6** shows a SEM micrograph of a cross-section of the injected particles. The width of the melt is ~ 3 mm and its depth is ~ 2 mm. The particles are fairly homogeneously distributed throughout the whole melt-pool. The slightly longer lifetime of the aluminium melt pool caused by higher energy density ~ 100 MJ/m$^2$ leading to higher heat-input allows for more TiC particles to be injected into the melt. This makes it possible for more TiC particles to enter the melt pool before solidification takes place. The distribution of the TiC particles in the melt pool is due to convective flows taking place in the melt pool due to surface tension gradients in the liquid.

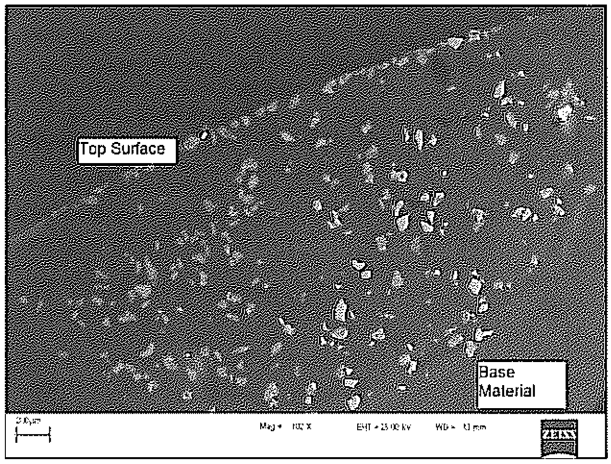


*Fig. 6 : SEM image of a laser formed composite surface of Al with TiC particle streated with 4 kW and 0.8 m/min scan speed*

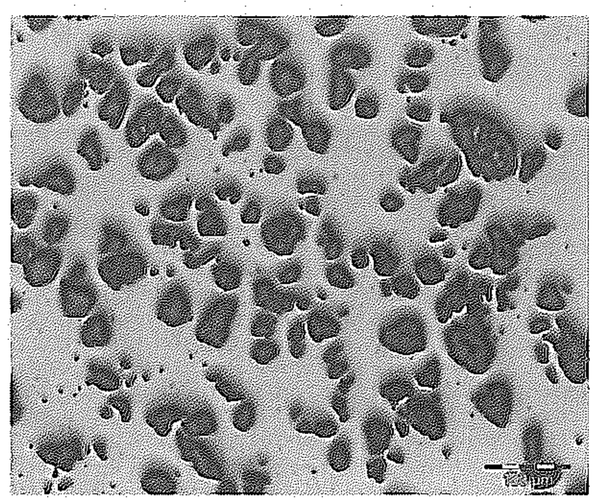

*Fig. 7: Optical micrograph of a laser formed composite surface of Al with TiC particles treated with 4 kW and 0.8 m/min scan speed*

**Fig. 7** shows an optical micrograph of this MMC layer. It shows that the TiC particles are well embedded in a smooth surface of aluminium. Small dark sports are clearlly visible on the micrograph which be an indication that some TiC particles may have melted during the laser melt injection process. However, the EDS analysis showed only the TiC and aluminium elements.

The XRD phase analyis of the injected area is shown in **Fig. 8**. The detected phases in the laser treated area correspond to those of TiC and aluminium. The were no others phases present in MMC layer.

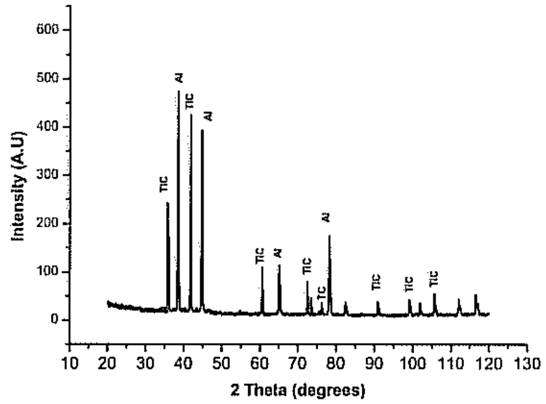


*Fig. 8 : XRD of the layer shown in Fig. 7*

A SEM micrograph of a cross-section obtained when laser melt injection was carried out using laser power of 4 kW and scan speed of 1.1 m/min ( E~ 72.7 $MJ/m^2$) is shown in **Fig. 9**. The shape and the depth of treated areas are the same as in the previous cases. However, the particle volume fraction is slightly lower than when laser power of 4 kW and scan speed of 0.8 m/min (100 $MJ/m^2$) was used, but lower than for the 3 kW and scan speed of 0.9 m/min (66.7 $MJ/m^2$). This illustrates that a higher number of particles are injected when higher energy density is used. The incorporation of the TiC requires a certain amout of liquid and sufficient liquid lifetime during the injection process.

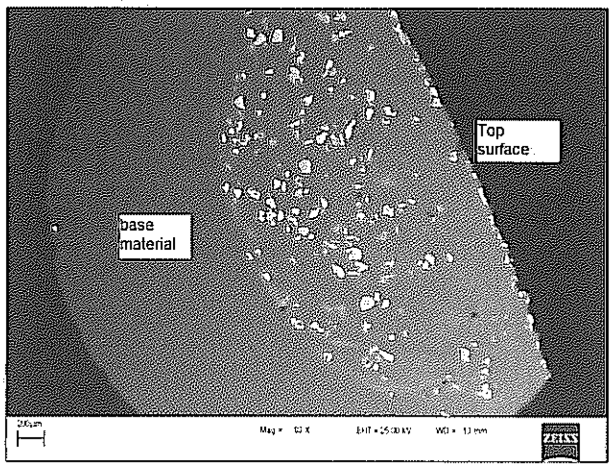


**Fig. 9** : *SEM image of a laser formed composite surface of Al with TiC particlestreated with 4 kW and 1.1 m/min scan speed*

### 3.3 Hardness measurements

A microhardness depth profile of a cross-section of the composite formed when a 4 kW laser beam power and 0.9 m/min scan speed was used is shown in **Fig. 10**. Surface hardness values ranging from of 100 to 400 HV were obtained. The hardness profile shows a significant fluctuation in the measured values. A minimum of five readings were made and the average was taken as a representative hardness values. The scatter on the data points observed on the graph was caused by the incorporated TiC particles in the soft aluminium matrix. The hardness profiles for the low volume fraction injected TiC particles had hardness values as low as 100 HV, showing that a high number of particles is required for improving the surface properties.

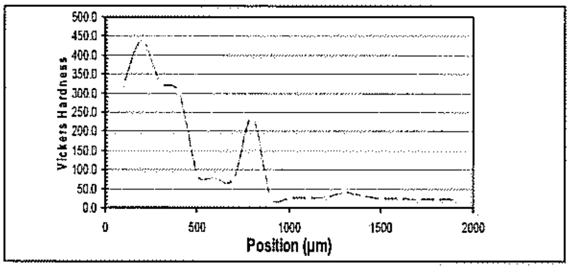


***Fig. 10:*** *Micro-hardness along the depth of the layer shown in Fig. 6*

## 4 Conclusions

In the present study metal matrix composite layers consisting of TiC and Al were formed on the aluminium substrate by laser melt injection. The volume fraction of the injected particles into the melt pool is dependent on the processing parameters such as laser power, laser beam size and laser scan speed. In order to obtain a high volume fraction a melt pool with a long lifetime is essential. A homogenous zone with well dispersed TiC particles was obtained at relatively high energy densities. A good metallurgical interfacial bond between the particles and the metal matrix host was achieved. The hardness of the MMC layer ranged from ~100 to 400 HV.

## Bibliography

[1] Majumdar, D. J., Chander, R. B., Manna, I.: Friction and wear behaviour of laser composite surfaced aluminium with silicon carbides. Wear 262 (2007), 641-648

[2] Pei, Y. T., Ocelik, V., De Hosson, J. Th. M.: $SiC_p$/Ti6Al4 fuctionally graded materials produced by laser melt injection. Acta Materialia 50 (2002), 2035-2051

[3] Anandkumar, R., Almedia, A. et. al.: Microstructure and wear studies of laser clad Al-Si/SiCp composite coatings. Surface & Coating technology 201 (2007), 9497-9505

[5] Verezub, O. N., Kalazi, Z. et. al.: Surface metal matrix composite Fe-Ti-C/$TiC_p$ layers produced

by laser melt injection technology. International Conference "ADVACED METALLIC MATERIALS', 5-7 November, 2003, Smolenice, Slovakia
[6] Hugon, A., Galerie, A., Pons,. Bonnetain, L. : Principle of constitution of surface alloys under laser beam. Journal De Physique, Colloque C7, supplement au no 12, Tome 48 (1987) c7-1987
[7] Hu, C., Baker, T. N.: A new aluminium silicon carbide formed in laser processing. J Mater. Sci., 32 (1997), 5047-5051
[8] Raj, P. M., Sarkar, S. et. al.: Modelling of transport phenomena in laser surface alloying with distributed species mass source. Int. J. Heat and Flow 23, (2002), 298-307
[9] Man, H. C., Zhang, S., Cheng, F. T., Yue, T. M.: In situ syntheis of TiC reinforced surface MMC on Al6061 by laser surface alloying. Sripta Materialia 46 (2002), 229-234
[10] Hu, C., Baker, T.N.: Laser processing to create in-situ Al-$SiC_p$ surface metal matrix composites. J. Mater, Sci. 30 (1995) 891-897
[11] Chen, Y., Wang, H. M.: Microstructure and wear resistance of laser-melted TiC reinforced nockel aluminide dual phase matrix in situ composite: Intermetallics 14 (2006) 325-331
[12] Mondal, D. P., Das, S.: High stress abrasive wear behaviour of aluminium hard particle composites : Effect of experimental parameters, particle sizes and volume fraction. Tribology International 39, (2006) 470-478

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