Microstructure and Wear Behaviour of Al/TiB$_2$ Metal Matrix Composite

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Abstract. Al/TiB$_2$ metal matrix composite (MMCs) was fabricated on aluminium AA1200 with the aim of improving the wear resistance property of the substrate. The characterization of the MMCs was carried out by Optical Microscopy (OM), Scanning Electron Microscopy (SEM/EDS) and X-ray Difffraction (XRD). The microhardness and wear resisance tests were carried out. Results showed that the microhardness property of the AA1200 was increased by three times the original value and the wear resistance was also significantly improved.

Introduction

The demand for lightweight metals is continually increasing and because of this aluminium based alloys have found applications in automobile industries primarily due to the high strength to weight ratios they exhibit. Poor tribological properties and load bearing capacity are the major reasons that limit the applications of aluminium based alloys especially in specific areas where failure due to wear is of major concern. This stems from the fact that aluminium possesses weak interatomic bonding, low hardness and low melting point. Wear resistance is a surface phenomenon and it is primarily determined by the surface properties of a material rather than by the bulk properties. Surface-dependent degradation may be improved by surface treatment that adequately modifies the microstructure while consuming only a small amount of reinforcement material(s) to effect the modification. The surface properties of metals can be tailored using laser surface alloying (LSA) to obtain a higher and better mechanical and chemical properties, while maintaining the bulk properties unaltered. In LSA the very high solidification/cooling rates results into refined microstructure in the deposition area and hence considerable improvements in properties like wear, impact and corrosion resistances are obtainable [1-4].

In this investigation, LSA is employed to form metal metal composite (MMC) on aluminium alloy. TiB$_2$ is chosen as reinforcement material due to its high hardness, low density, good oxidation resistance and thermodynamic stability in aluminium. Optical and Scanning electron microscopy, X-ray diffraction analysis, microhardness and sliding wear testing were carried out in this work.

Experimental

Materials and Laser Surface Alloying. Substrate material is aluminium AA1200 which is a pure form of aluminium. The aluminium plates were cut and machined to dimensions 100 x 100 x 6 mm. The chemical composition of the substrate is 0.59% Fe, 0.12% Cu, 0.13% Si and Al balance. The pure Al -plates were sand blasted to achieve a uniform rough surface which in turn enhances laser energy absorption at the surface of the Al –plates and also the removal of the oxide scale.

A Rofin Sinar continuous wave Nd: YAG solid-state laser was used to carry out laser surface alloying of the substrate. The Nd:YAG laser is fitted with off-axes nozzle used for powder feeding. The laser is delivered to the target material through fibre optics while a Kuka robot is used to move the alloying head. The shielding gas used was Argon, this prevent oxidation during the alloying process. The process was then optimized by continuously running series of tests. The laser parameters used are shown in Table 1. Multiple track lines were made on the substrate with a 75% overlap in this experiment.

Table 1: Laser processing parameters and sample composition

Sample No	System	Power (kW)	Beam diameter (mm)	Scan speed (m/min)	Powder feed rate (rpm)	Shielding gas	Shielding gas flow (l/min)
1	Al-TiB_2	4	3	0.6	4	Argon	4
2	Al-TiB_2	4	3	0.8	4	Argon	4
3	Al-TiB_2	4	3	1.0	4	Argon	4
4	Al-TiB_2	4	3	1.2	4	Argon	4

Materials Characterisation. The reinforcement powder used was TiB_2. The powder particle sizes ranges from -100 to 45 µm. The powder particle morphology and size distribution were analyzed using a scanning electron microscope SEM and Malvern Mastersizer 2000 image analyzer. A Philips PW 1713 X-ray diffractometer fitted with a monochromatic Cu Kα radiation set at 40 kV and 20 mA was used to determine the phase composition of powder. The scan was taken between 10^o and 80^o two theta (2Θ) with a step size of 0.02 degree. Phase identification was done using Philips Analytical X'Pert HighScore® software with an in-built International Centre for Diffraction Data (ICSD) database. All starting materials (the substrate and reinforcement powder) were characterized. Metallographic analysis started by cutting, grinding, polishing and etching the surfaces MMCs using Keller's reagent. In the current investigation, the chemical reaction between molten aluminium and the TiB_2 alloying powder tend to lead to the formation new phases in the matrix. The new phases formed were studied.

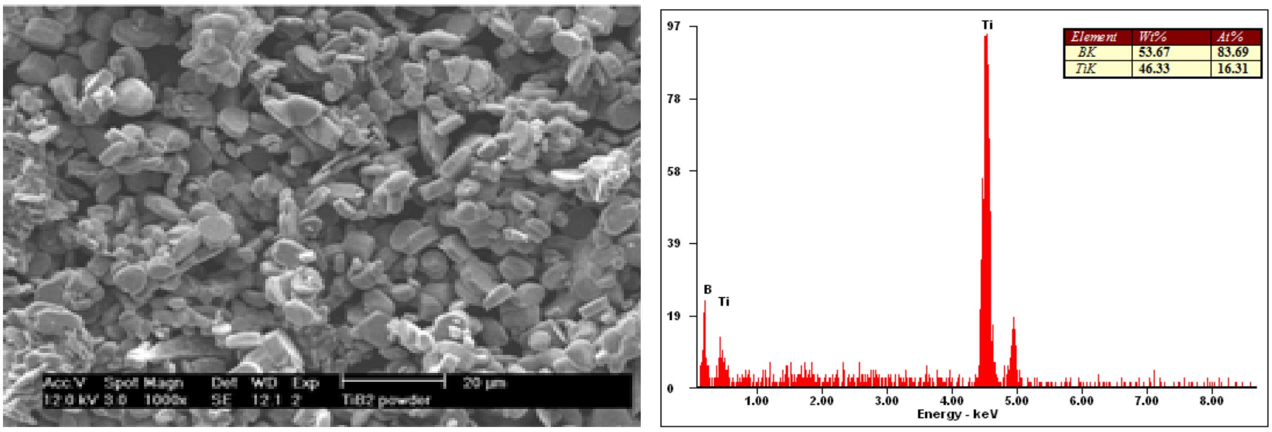
Microhardness Test. The Vickers hardness of the MMCs cross sections was determined according to the ISO standard 3878 using a Matsuzawa Seiki micro hardness tester. Indentations started from the surface of the alloyed layer through to the base, microhardness of samples were determined with a 150 µm spacing between corresponding indentations using a load of 100 g for 15s.

Wear Resistance Test. All MMCs were polished lightly with 1200 µm SiC paper to ensure a common reference roughness. The wear test was evaluated by a two-body wear testing machine with the sample sliding against SiC paper. The sliding tests were carried out at room temperature, with a load of 217.597 g, using 80 µm SiC paper, on a rotating disc with a fixed speed of 262.7 rpm for a spiral length of 2.53 m in a time cycle of 2.4 s. All the samples used for the test were made to undergo an oscillating motion. In order to avoid inclusion of a third body, the SiC paper was changed for each experiment. The wear rates for the different samples were calculated from mass loss, and the average wear rates were plotted against time.

Results and Discussion

Starting materials characterisation. The powder purity was determined by XRD and EDS. The peaks shown on the XRD spectrum were that of Ti and TiB_2. This shows that the powder used was pure and free from any contaminant. Figure 1 shows a SEM micrograph and EDS of the reinforcement TiB_2 powder particles which were used for the fabrication of the MMCs. The morphologies of the TiB_2 particles were irregular in shape and clustered together.

Characterization of the MMCs. Figure 2 shows the surface morphology of a typical MMC before tribological property testing. From the SEM results, uniform particle dispersion which is crack and pore free was achieved. The maximum depth of alloyed layer achieved was 1.24 mm representing approximately 21% of aluminium substrate thickness. Micrographs consisted of the TiB_2 powder well dispersed in the Al-matrix. XRD analysis of the MMCs indicated the presence of: TiB_2, AlTi, AlB_2, Al, Ti, B. The Al and Ti belong to the same crystal system and the same space group, and as such their peaks are overlapping. The same for TiB_2 and AlB_2 – they belong to the same space group and peaks are overlapping.



Element	Wt%	At%
BK	53.67	83.69
TiK	46.33	16.31

Fig. 1: Scanning electron micrograph and EDS of TiB_2 powder

The distribution of the TiB_2 particles in the melt is by convection flow. The gray phases are TiB_2 in the solidified Al-matrix.

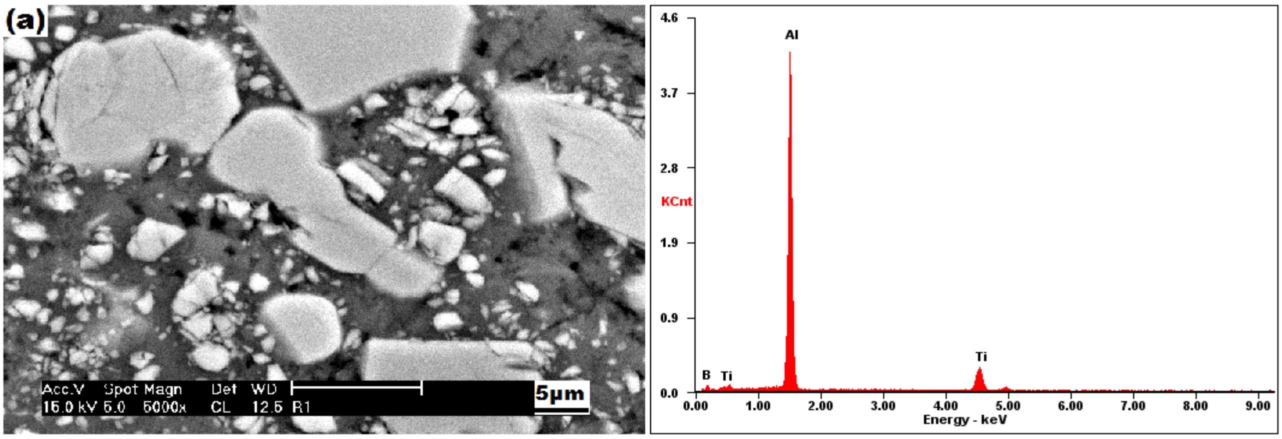


Fig. 2: SEM surface morphology of a typical formed MMC and EDS

Microhardness Evaluation. Laser alloying of AA1200 with TiB_2 powder resulted in microhardness increase from 24.0 ± 0.4 HV for pure aluminium AA 1200 to approximately 89.07 HV average highest microhardness value displayed. The microhardness profile data for all the samples shows significant fluctuation. The average microhardness values for all the samples were calculated, sample 2 has the highest value of microhardness, this can be seen in Table 2. This improvement in hardness (over three times the microhardness of substrate) was attributed to the formation of MMC during alloying. The optimum laser processing parameter for the highest average microhardness is laser power 4 kW, scan speed 8.0 m/min, powder feed rate 4 rpm.

Table 2: Properties of the Metal Matrix Composites

Sample label	1	2	3	4	AA1200
Average microhardness value displayed by MMC (HV)	37.32	88.07	41.91	34.00	24.04
Average wear rate (m^3/sec)	0.509	0.525	0.618	0.600	0.867
Depth of alloyed layer (mm)	1.24	1.23	1.21	1.09	-
Scan speed (m/min)	0.60	8.00	1.00	1.20	-

Wear Rate Evaluation. The wear rates of the pure Al substrate and the alloyed layers are shown in Table 2. Fig. 3 shows the SEM images of the worn surfaces of pure aluminium substrate and the MMCs. It is seen that the worn surface of the pure aluminium substrate shows signs of wear debris, pits and shallow grooves, indicating that the wear mechanism is adhesion and abrasive wear (Fig. 3a). In addition, severe degree of deformation is also visible on its worn surface, especially on the two edges of the wear scars (Fig. 3a). Contrary to the above, lesser degree of deformation was observed on the worn surface of the MMCs, with debris and grooves emerging on the worn surfaces (Figs. 3b & 3c). This indicates that the wear mechanisms of the coatings are majorly abrasive and adhesion wears. Similar characteristics were observed on all the MMCs. In addition, it is seen that the width and depth of the wear scars on the MMCs are smaller than that of the Al substrate under the same wear conditions. This indicates that the MMCs exhibits mild abrasive wear while the substrate exhibits severe wear. From Fig. 3 it is seen that the alloyed layers exhibited higher wear resistance than the pure Al sample as a result of the formation of the MMC.

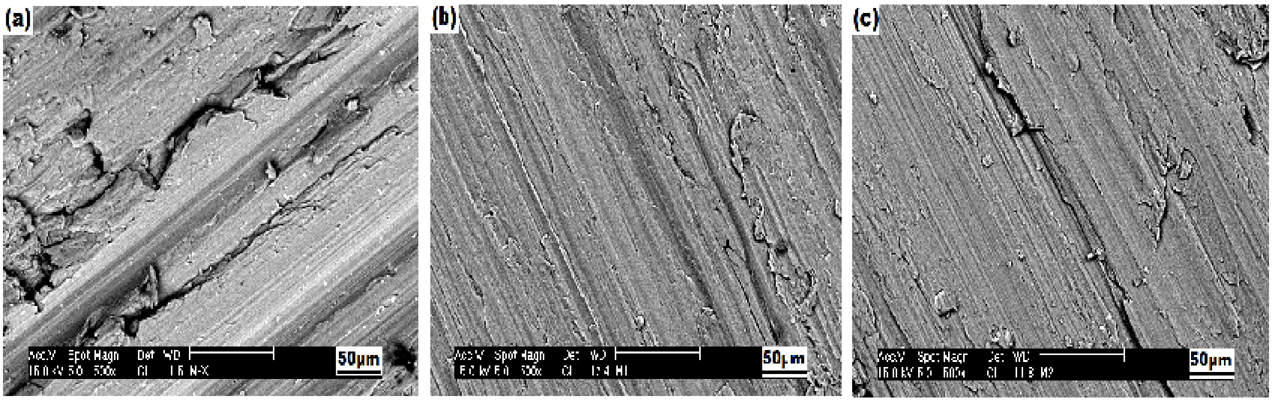


Fig. 3: SEM images of the wear scar on (a) the pure Al; (b) sample 1 and (c) sample 2

Conclusions

Successful laser surface alloying of AA1200 using TiB_2 reinforecment was carried out. The microhardness and wear behaviour of the resultant MMCs were investigated with the following conclusions:

- The increase in microhardness from that of Al-substrate 24±0.4 $HV_{0.1}$ to that of the alloy formed 88.07 $HV_{0.1}$ is over three times that of the substrate. TiB_2 reinforcement in Al-matrix does not give significant increase in microhardness of the substrate.
- Laser surface alloying with TiB_2 particles greatly improved the wear resistance of the AA1200. All the MMCs formed exhibited a better wear resistance than the pure Al substrate. The wear mechanism of pure Al is adhesion, severe abrasive and severe plastic deformation; while the MMCs experienced adhesion, mild abrasive wear and lesser degree of deformation.
- The wear resistance increased as the volume fraction of the TiB_2 particles in the matrix of AA1200 increased; wear resistance decreased with increased scan speed.
- The enhancement of microhardness and wear resistance of AA1200 by dispersion of TiB_2 hard particles is partly due to refinement in microstructure and precipitation of hard particles of TiB_2 in the Al-matrix.

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