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# Experimental Characterization of Metal Matrix Composite with Aluminium Matrix and Molybdenum Powders as Reinforcement

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**Abstract**

This paper is on the successful fabrication of Metal Matrix Composite (MMC) using an Aluminium plate and Molybdenum powder by Friction Stir Process (FSP). The aim was to produce a superficial MMC layer on the Al plate in order to increase the mechanical properties of the as received Al plate. A uniform dispersion of Mo particles in the Al matrix was observed from SEM observations and EDX analyses and a significant improvement in the Vickers microhardness was also detected.


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*Keywords:* Metal Matrix Composite; Aluminum; Molybdenum; Friction Stir Pprocessing; Mechanical Properties

## 1. Introduction

Aluminium and its alloys are widely used in different engineering fields such as aerospace, automobile, and marine industries, due to their low density, high specific mechanical properties and good workability. It is known that in some of these applications the surface properties are crucial and dictate the performance and the life of a component. Therefore, material having a surface with high hardness and wear resistance together with a ductile core having high toughness may be required [1]. In this scenario the surface Metal Matrix Composites (MMCs) turn out to be one of the best examples of modern engineered materials that have clearly demonstrated their potential for different structural applications.

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The interest in the technologies concerning the production of surface engineered material has grown more and more in the past years [2]. There are different methods to produce surface MMCs modifying only the top surface without affecting the inner core of the material such as plasma spaying, diffusion bonding, laser assisted processes and centrifugal casting [2;3]. All of these methods involve matrix material transformation from solid to liquid or vapor during the process. On the other hand, by using the solid state processes for the production of a surface MMC, the material state transformation does not occur, offering many advantages over the conventional processes. In this context, the friction stir process (FSP) is the one of the best example for such solid state process used to modify the surfaces and to develop the surface composites [4;5]. The FSP, based on the basic principles of friction stir welding, consists of a rotating tool with a shoulder and a pin inserted and moved along the material. The friction developed between the tool and the work piece provides localized heating and plastic deformation [1;6]. As Mo has low solubility and diffusivity in aluminium [7;8] and a high melting point, it could be interesting to use this material as reinforcement in an aluminium matrix. On the basis of these considerations, this study has shown that the FSP can be effectively used to produce an Al-Mo surface layer on Al base plate.
Microstructural observations and microhardness measurements have been carried out both on the top surface and cross section surface of the MMC samples to study the dispersion of the molybdenum particles within aluminium matrix and in order to detect whether use of Mo as alloying element increase the microhardness value.

## 2. Experimental section

The materials used in this experiment were commercial Al as base plate and Mo powder (99.9% pure, Sigma Aldrich) as reinforcement element. The as-received molybdenum powder was measured using a Particle Size Analyzer and the average size of Mo particles was found to be 30.46 μm. The aluminium plate with a thickness of 6 mm was cut in a rectangular shape of dimension 150 x 100 mm and exactly in its centre a groove with 2 mm width and 0.5 mm depth was cut throughout the top surface of the aluminium plate. Molybdenum powder used as alloying element was filled inside the groove cut on the plate surface and then the FSP is carried out on these aluminium plates with Mo powder filled grooves. The Friction stir processing of Al-Mo system was carried out using a Friction Stir Welding machine (Fig.1). The used machine has 12 HP spindle motor having clockwise as well as anti-clockwise spindle rotation with a maximum of 3500 rpm rotational speed and 50 kN plunge load capacity. High speed steel (HSS) tool was used for the Friction stir processing to generate sufficient frictional heat required for the process as well as successful incorporation of Mo particles into the alloy system. The tool with shoulder diameter of 20 mm and tool pin length of 1mm with a diameter of 6 mm was used for processing. The experiments were performed with a tool rotational speed of 840 rpm, a traverse speeds of 40mm/min and a plunge speed of 3 mm/min.

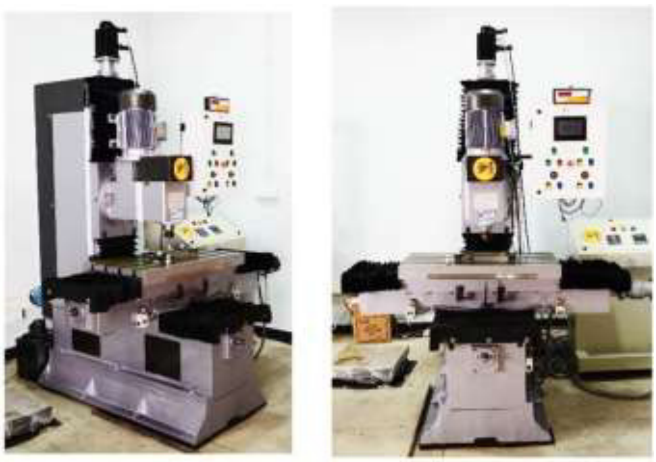

Fig. 1. Friction stir welding machine used for processing of aluminum plates.

Vickers microhardness tests were carried out by means of a DAT Instruments Microdurometer using 50 g load and 25 seconds dwell time. The samples were degreased with acetone and grinded with a proper abrasive paper to obtain a smoother surface before taking measurements on the top surface. In order to build a map of the microhardnesses on the top surface, a grid made of 560 indentations was build. The distance between two consecutive indentations was set at 500 µm. In order to measure the microhardness in the cross section of the sample, to evaluate the distribution of the Mo powders in the cross section, the samples were cut by a precision metallographic cutting machine. The samples were mounted in thermoset resin and then polished to a mirror-like finishing. Three different lines of indentations were made from the top to the bottom surface of the sample.
Metallographic observations and EDX microanalysis were carried out to evaluate the dispersion of the Molybdenum powders within the aluminium matrix. A Leica DCM3D confocal microscope was used for the low magnification macrographs and Hitachi TM3000 tabletop SEM equipped with a National Instruments micro probe was used for both the high magnification observations and the EDX analysis. The observations were performed both on the cross section and top surface of the sample.

## 3. Results and discussion

### *3.1. Tests on the top surface*

In Fig. 2 a macrograph of the top surface of the sample is reported. This macrograph is obtained through the merging of more than 30 different macrographs. It is possible to see the Mo powders dispersed due to the action of the FSP tool, the difference between zone B (where the particles were dispersed) and zone A (zone free from particles) is evident. The white arrow highlights a zone in which it is possible to appreciate the typical plastic flow induced by the FSP process. The dispersion of the particles appears quite asymmetric, such a result probably is because the FSP process itself is asymmetric, resulting in the formation of two zones: advancing side and retreating side. Moreover it is possible to observe that the particles are well dispersed on the surface and are coherent with the plastic flow induced by the FSP process (Fig.3a). From Fig. 3b it is possible to observe molybdenum particles of different dimensions which may be due to the crushing of some Mo particles by the tool during the process.

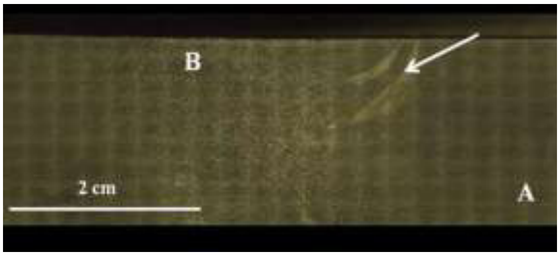


Fig. 2. Macrograph of the top surface of the sample.

Moreover several EDX analyses were carried out on the top surface of the sample in order to confirm the presence of Mo particles. In Fig. 4 the bigger particles observed in the EDX spectrum are Mo particles. To understand the dispersion of the powder better a composition map was carried out (Fig. 5).
It is possible to note that the dispersion of the particles occurs following the plastic flow induced by the stirring action of the tool during the FSP process.

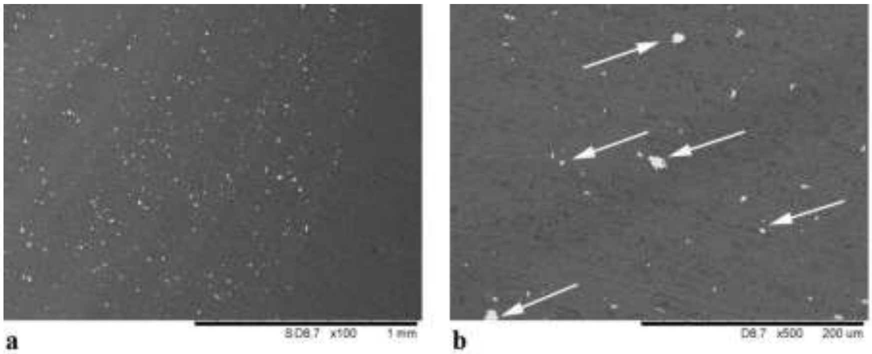


Fig. 3. (a) SEM image of the top surface of the sample; (b) High magnification SEM image of the top surface of the sample, some Mo particles are highlighted by means of white arrows.

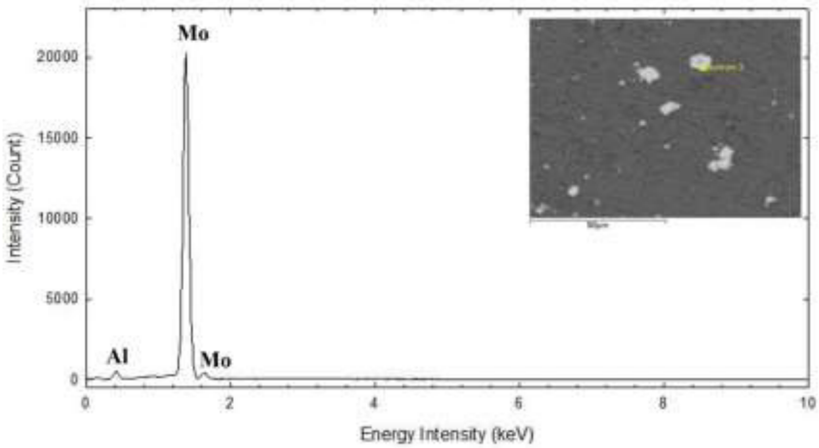


Fig. 4. EDX spectrum of a Mo particle.

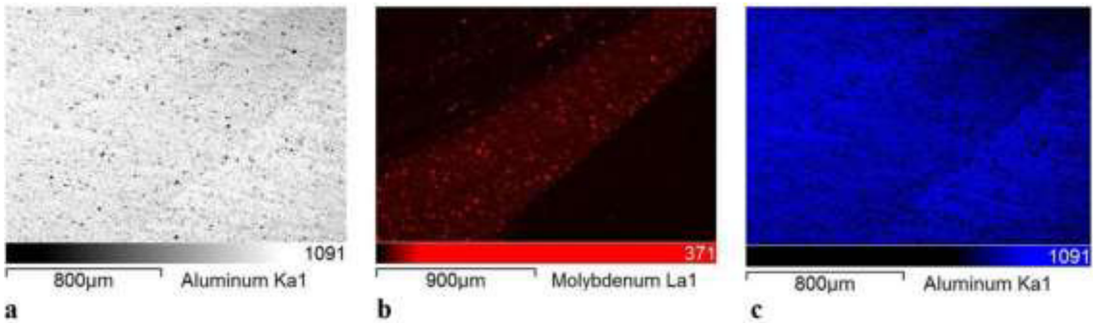


Fig. 5. Distribution map of Aluminium and Molybdenum on the top surface: (a) Macrograph of the area under investigation; (b) Molybdenum distribution; (c) Aluminium distribution.

Fig. 6 shows the results of the microhardness measurements, in particular both the microhardness map and the anisotropy of the indentations are reported. From Fig.6a it is possible to appreciate that the hardness in the top surface is higher than the one of the parent material due to the presence of Mo powders, considering that the microhardness of the parent aluminium used as matrix was close to 50 HV.

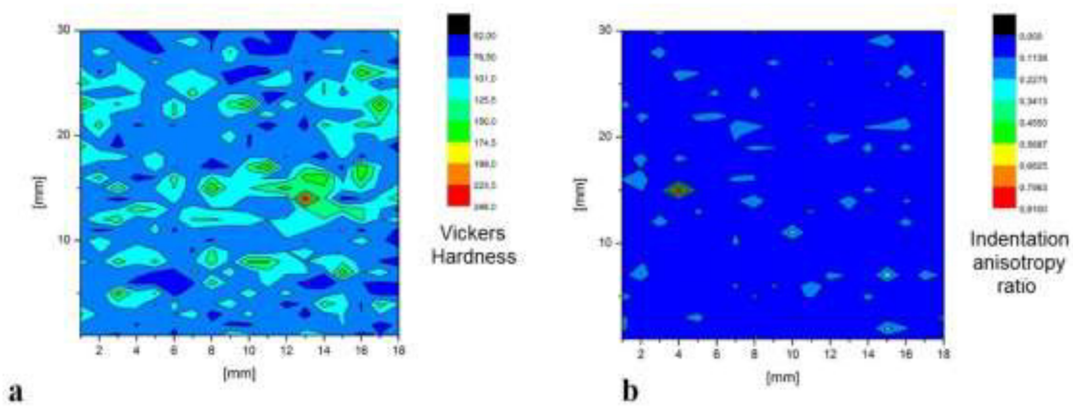


Fig. 6. (a) Microhardness map on the top surface of the sample; (b) map of the anisotropy ratio of the indentations..

The hardness is not constant across the surface, observing some peaks in correspondence of the bigger Mo particles. However, a preliminary result is that the Mo powders induced a noticeable increase in the superficial microhardness. Moreover, in Fig.6b the map of the anisotropy ratio (A.R.) calculated according to equation (1) is shown. From the anisotropy ratio, it is possible to highlight that the indentations are quite regular across the surface and the material can be considered as isotropic.

$$A.R. = \left| 1 - \frac{d_1}{d_2} \right| \tag{1}$$

### 3.2. Tests on the cross section

In Fig 7, two SEM micrographs of the sample cross section of the sample are reported. In particular, Fig.7a is taken in proximity of the top surface while Fig.7b is taken in the bulk material. The two figures are quite different, in the zone close to the top surface there is an high amount of Molybdenum while in the bulk there is no presence of Molybdenum.

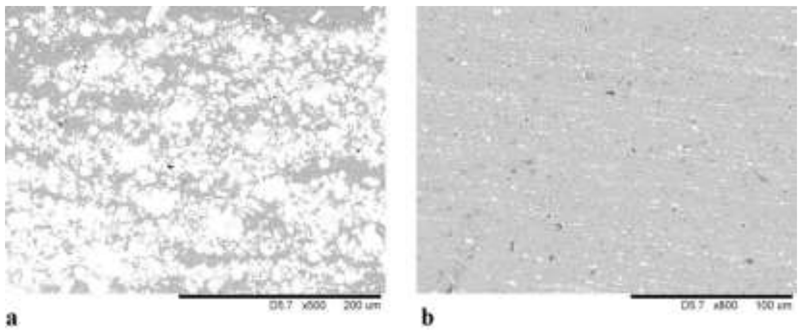


Fig. 7. (a) Cross section SEM micrograph taken close to the top surface; (b) Cross section SEM micrograph taken in the bulk material.

These assumptions are also proved by the EDX analysis reported in Fig.8 that proved the presence of the Mo powders only in a superficial region of the cross section. Therefore the FSP process was able to disperse the powders limited to a superficial region of the sample.

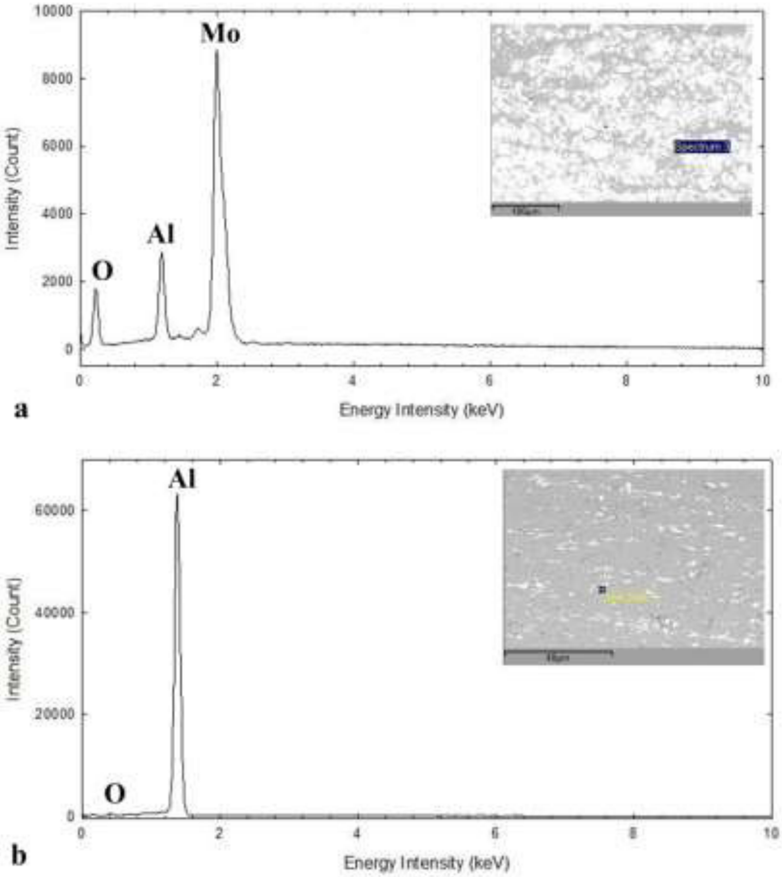


Fig. 8. (a) EDX analysis in the cross section close to the surface; (b) EDX analysis in the cross section in the bulk material.

The map of the microhardnesses measured in the cross section shown in Fig.9 confirms that the Mo particles are dispersed only in a superficial layer of the material. In fact the increase of the microhardness is appreciable only in the superficial layer, whilst in the bulk its value is the same of the aluminium parent material.

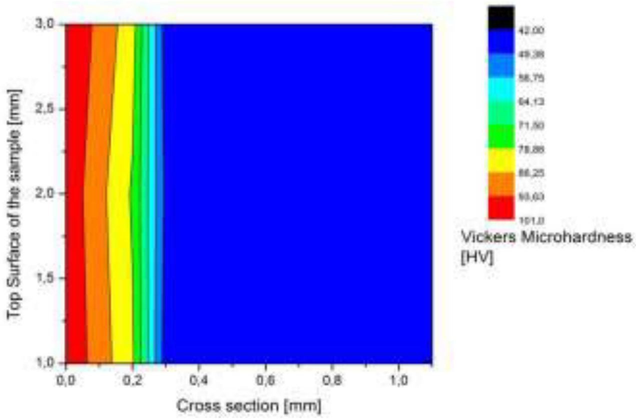


Fig. 9. Microhardness map in the cross section of the sample.

## 4. Conclusions

Superficial Al-Mo MMC was produced by means of FSP. The method under investigation appears to be suitable to produce a dispersion of Mo particles in a superficial layer on the top surface of the Al sample. The results obtained showed a good dispersion of the Mo powders on the top surface of the samples, conversely in the cross section no molybdenum powders were observed. Concluding it seems that the studied technique is useful to produce a superficial layer with improved performances due to the dispersion of the powders to surface metal matrix composite.

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