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Microstructure evolution during laser surface cladding and remelting of Al-10wt%Bi-10wt%Cu

Amresh K. Gupta[1], Rolf Galun[2] and Gandham Phanikumar[1]
[1] Department of Metallurgical and Materials Engineering, Indian Institute of Technology Madras, Chennai, India
[2] Institut für Werkstoffkunde und Werkstofftechnik, TU-Clausthal, Clausthal Zellerfeld, Germany
E-Mail:gphani@iitm.ac.in
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ABSTRACT

Laser surface cladding and remelting provides a route to synthesize functional microstructures on the surface of structurally important materials. Alloys containing fine soft particles embedded uniformly in a hard matrix find applications as bearing materials with low friction coefficient. Elemental powder mixtures are used to clad Al + 10wt%Cu + 10wt%Bi on the surface of aluminium base metal in both single and multi-track mode at two different cladding speeds. The clad layers are remelted at speeds varying from 500 mm/min to 2500 mm/min to simulate different solidification speeds. Microstructure evolution during the process is studied by measuring particle size distribution and alignment to identify optimum processing conditions. Pin on disc experiments show a low friction coefficient of 0.22 for the samples remelted at 2500 mm/min.

1. Introduction

Hyper monotectic alloys undergo a liquid state phase separation up to the monotectic temperature as illustrated in the phase diagram in Fig. 1 [1]. Such a phase separation where one of the phases is soft and has a low melting point can be used to obtain dispersed microstructures with possible application as bearing materials. Al-Bi is a well studied monotectic system with the thermophysical data available. A hyper monotectic composition of this alloy is expected to undergo a liquid state phase change below 800 C and above the monotectic temperature leading to a two phase microstructure. Copper is chosen as an alloying element as it is immiscible with bismuth and strengthens the aluminium matrix.

Due to the large difference in densities between aluminium and bismuth, conventional manufacturing techniques such as casting lead to sedimentation and macro segregation. Laser surface remelting is a solidification technique that can simulate rapid growth rates at the surface and can be used to tailor the microstructure [2]. High cooling rates on the order of 10^{-4} K/s during laser remelting can prevent sedimentation as also demonstrated earlier [3,4]. In this study, the authors have used the laser surface cladding to obtain an alloy of desired composition and several mm in thickness on the surface of commercial pure aluminum. Processing parameters are optimized to obtain desired microstructure. Pin on disc experiments are performed to evaluate the friction coefficient of the alloy against steel substrate.

2. Experiments

Laser cladding is used to clad alloy of Al + 10wt% Cu + 10wt% Bi on the surface of commercial pure Al. Figure 1(a) shows a schematic of the experimental setup. Elemental powders are mixed to form the alloy composition. A rotating

Table 1
PROCESSING PARAMETERS

Laser	Rofin Sinar R10000
Laser Power	8 kW
Laser beam diameter at 30 mm defocus	3 mm
Protective gas	Ar + 30 v/v He
Elemental Powder Mixture	Al + 10wt% Bi + 10wt% Cu
Scanning speed for cladding	300 mm/min
Scanning speed for remelting	500 mm/min, 1000 mm/min, 1500 mm/min, 2000 mm/min and 2500 mm/min
Tracks	Single and Multiple
Overlap in case of multiple track clad	2 mm

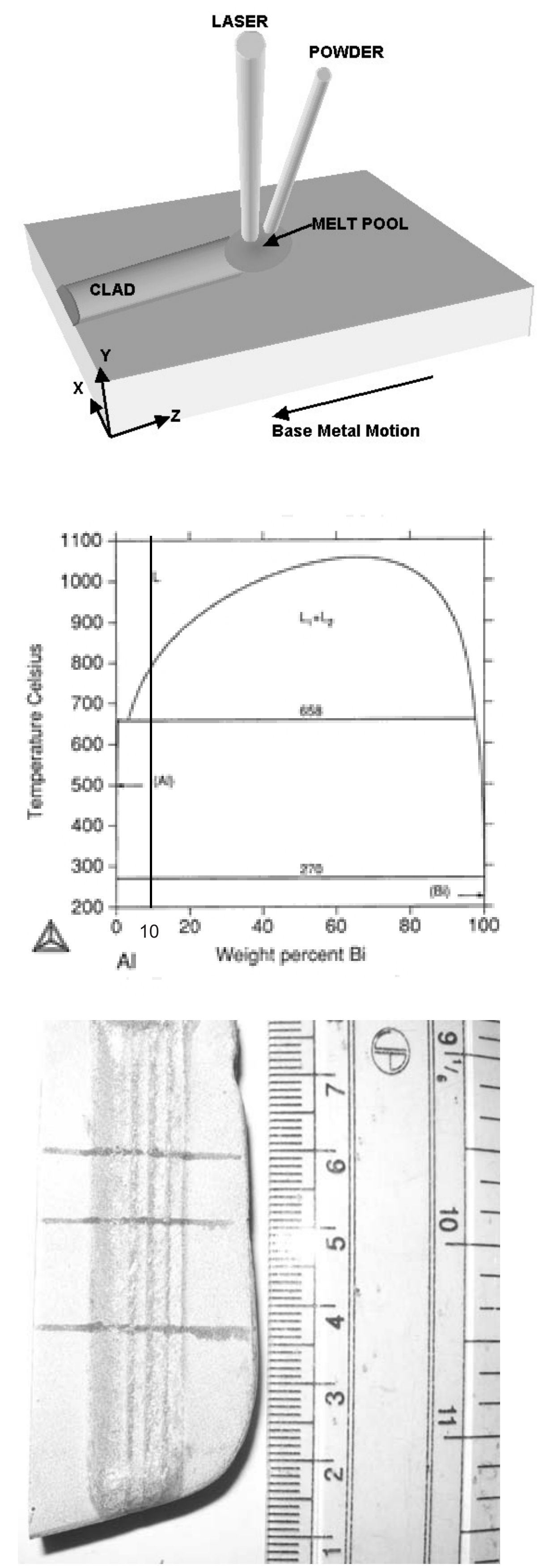

Fig. 1 : (a) Schematic of laser cladding and surface remelting setup. (b) Phase diagrams of Al-Bi [1]. (c) Top view of a multi-track sample. The marks show where transverse sections are taken.

wheel based METKO powder feeder is used to feed the powder into the laser melt pool. The cladding experiments are done by focusing the powder feeder at the same location as the laser and translating the base at pre-determined speed. The carrier gas for powder is same as that of protective shroud around the laser melt pool. Multi track samples are prepared by depositing single tracks side by side with an overlap. The clad layers can be seen in the Fig. 1(c). All clad tracks are with identical processing conditions. Several trial experiments are performed before determining the optimal processing conditions to obtain a smooth, continuous track of about 2.2 mm thickness and without any porosity. Using the same setup, the tracks are then remelted at different speeds to simulate different growth rates. The processing parameters used are listed in Table 1.

Microstructure analysis is performed on both single track and multi track samples. Both transverse and longitudinal sections are taken. Detailed microstructure analysis is done on transverse sections of single track samples whereas the multi-track samples are used to perform friction coefficient experiments. Longitudinal sections are used to estimate the growth rate as a function of the depth of the remelt pool as illustrated by the geometrical relation between the growth rate and the laser scanning speed [2]. Bulk composition analysis is performed on clad layers dissolved in aqua regia using inductively coupled plasma (ICP) technique and the individual particles of bismuth are confirmed using energy dispersive analysis of X-rays (EDAX) attachment to the scanning electron microscope (SEM). Microstructure analysis is performed using optical microscopy and SEM. Image analysis software has been used to quantify the size distribution of the bismuth particles.

3. Results and Discussion

Composition analysis performed using ICP confirmed that the ratio of bismuth to copper added in the alloy is close to unity. However, the composition is about 7 wt% for each, indicating loss of powder during deposition. EDAX analysis confirmed that the bright second phase particles seen in the BSE images are nearly pure bismuth.

As the laser scanning speed is increased, the depth of remelted layer decreased from 1.9 mm for a 500 mm/min scanning speed to 1.26 mm for a 2500 mm/min speed. This is expected from the decreasing heat input with increasing scanning speed. Typical microstructure of the remelted layer is shown in Fig. 2. The cellular microstructure in the optical micrograph of etched sample can be seen. Average cell spacing is around 6 ìm and is found to decrease slightly with increasing scanning speed. The microstructure contains uniformly distributed spherical particles of bismuth as can be seen in the back scattered electron image shown in Fig. 2(b). The average particle size is around 1 ìm.

Near the surface of the remelted layer, the bismuth particles are found to be aligned. Such an aligned nature of particle distribution in monotectic systems is usually attributed to break up of rod like formation of the second phase growing co-operatively with the primary phase. Such a break up is often justified due to Rayleigh instability [5]. However such a

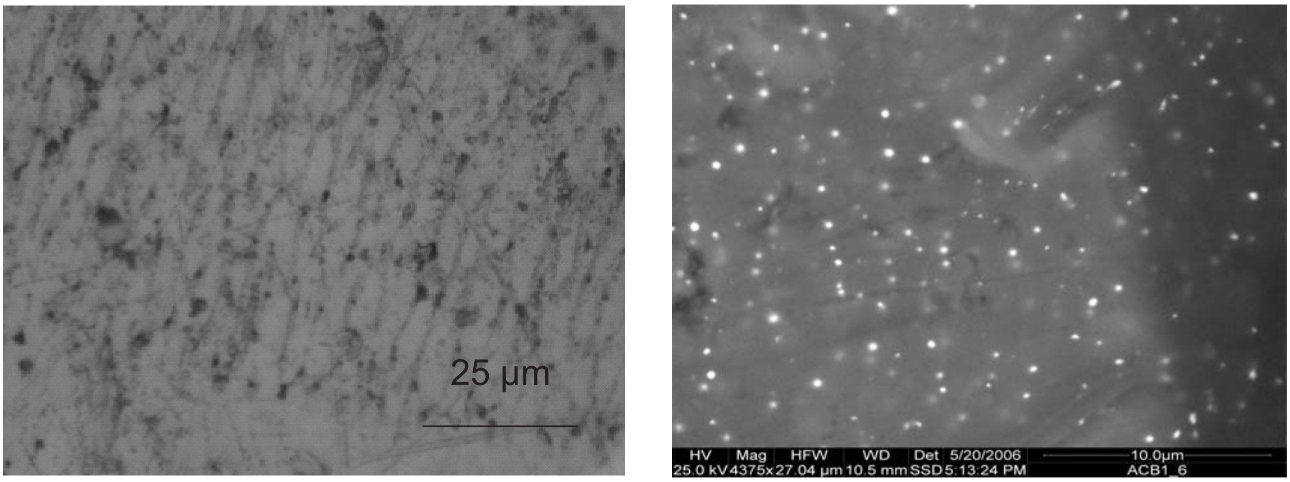

Fig. 2 : (a) Cellular microstructure as seen in optical microscope (b) dispersion of Bi (bright) particles in the Al(Cu) in back scattered electron image.

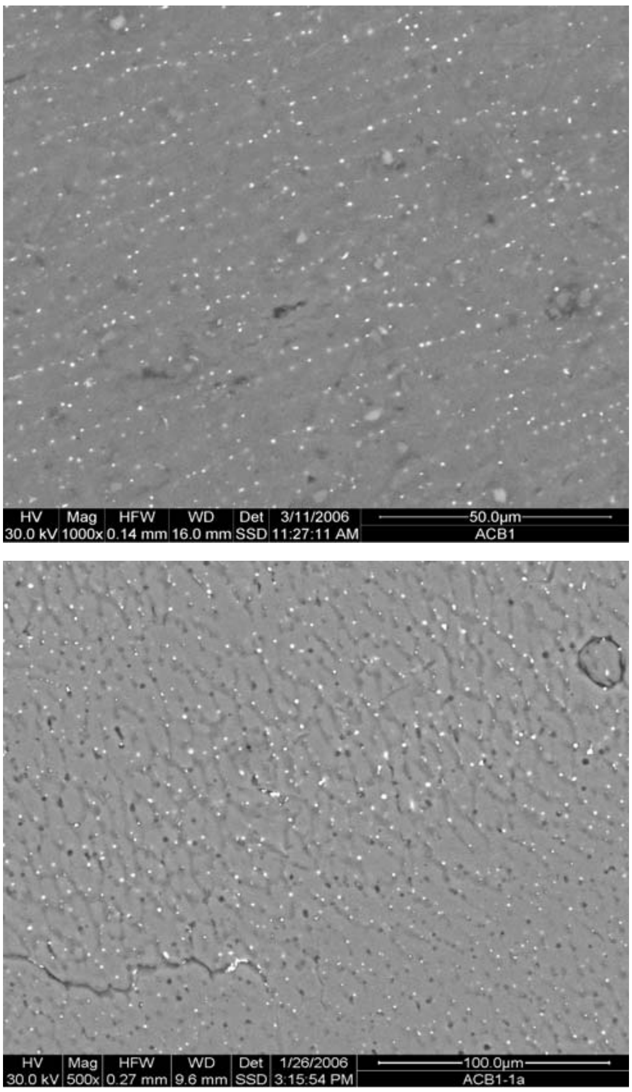

Fig. 3 : BSE images showing (a) aligned bismuth particles in the remelted layer and (b) presence of bismuth particles along the cell boundaries.

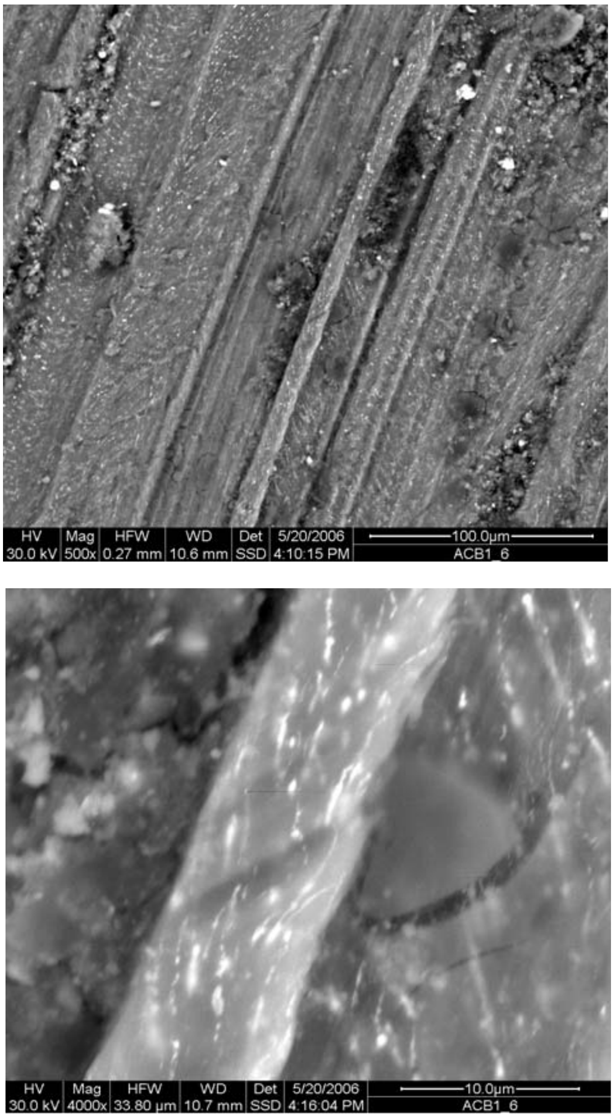

Fig. 4 : (a) Wear track of sample remelted at 2500 mm/min (b) BSE image showing bright smeared particles of bismuth

co-operative growth is not stable at growth rates above few tens of ìm/s. In the present study, the growth rate, comparable to the laser scanning speed, is on the order of several cm/s. Also, the spacing between the rows of such aligned particles is the same as that between cells in the microstructure. BSE images shown in Fig. 3 also show that the particles are present at the cell boundaries. Thus, the appearance of aligned bismuth particles, though similar to directionally solidified monotectic alloys, is due to geometrical entrapment of the bismuth particles at the cell boundaries.

Friction coefficient measurements are performed on multi-track samples using pin on disc setup with mild steel as base using the standard ASTMG99. The parameters used are: pin size of 10.5 mm, disc size of 160 mm dia and 8 mm thickness, normal load of 10 N and sliding distance of 1000 m. The average friction coefficient is noted to decrease with decreasing particle size achieved by increasing scanning speed during remelting. The lowest friction coefficient achieved was 0.22 for the sample remelted at 2500 mm/min where the average size of the bismuth particle is less than 1 ìm. SEM study of worn surface shows that smearing of bismuth particles is noticeable as in Fig. 4. As the size and thus, the inter-particle distance of bismuth particles decreases, the higher possibility of a soft bismuth phase available at a surface asperity is more. Thus, the decrease in friction coefficient can be rationalized.

Conclusions

1. Laser cladding and surface remelting has been shown to produce Al-Cu alloy with uniformly distributed bismuth particles on the surface of commercially pure aluminium
2. With increasing laser scanning speed, finer bismuth particles, finer cellular microstucture and harder matrix are obtained.
3. Friction coefficient has been observed to be low for the samples with finest bismuth particles.

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