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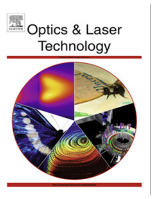

Full length article

# Formation of anomalous eutectic in Ni-Sn alloy by laser cladding

Zhitai Wang [a,b], Xin Lin [a,*], Yongqing Cao [a], Fencheng Liu [b], Weidong Huang [a]

[a] State Key Laboratory of Solidification Processing, Northwestern Polytechnical University, Xi'an 710072, China
[b] Light Alloy Processing Science and Defense Technology Key Laboratory, Nanchang Hangkong University, Nanchang 330063, China

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ABSTRACT

Ni-Sn anomalous eutectic is obtained by single track laser cladding with the scanning velocity from 1 mm/s to 10 mm/s using the Ni-32.5 wt.%Sn eutectic powders. The microstructure of the cladding layer and the grain orientations of anomalous eutectic were investigated. It is found that the microstructure is transformed from primary α-Ni dendrites and the interdendritic (α-Ni + $Ni_3Sn$) eutectic at the bottom of the cladding layer to α-Ni and β-$Ni_3Sn$ anomalous eutectic at the top of the cladding layer, whether for single layer or multilayer laser cladding. The EBSD maps and pole figures indicate that the spatially structure of α-Ni phase is discontinuous and the $Ni_3Sn$ phase is continuous in anomalous eutectic. The transformation from epitaxial growth columnar at bottom of cladding layer to free nucleation equiaxed at the top occurs, i.e., the columnar to equiaxed transition (CET) at the top of cladding layer during laser cladding processing leads to the generation of anomalous eutectic.

## 1. Introduction

Eutectic solidification has been widespread studied by researchers because of the universality engineering applications of eutectic alloys [1–3]. The microstructure of non-faceted/non-faceted eutectics were regular lamellar or rod in general solidification conditions, however, a transition from regular lamellar or rod eutectic to anomalous eutectic has been found under rapid non-equilibrium solidification conditions, such as Ag-Cu alloys, Co-Sn alloys and Ni-Sn alloys [4–7]. There are various explanations for the formation of anomalous eutectic. Kattamis and Flemings [8] proposed that the anomalous eutectic structure observed in undercooled Ni-Sn alloys originated from the dendritic growth of the supersaturated α-Ni phase. According to their interpretation, these α-Ni dendrites subsequently separate to α-Ni and β-$Ni_3Sn$. Jones [4] suggested that the anomalous eutectic structure in Ni-Sn and Ag-Cu alloys arises from an decoupled simultaneous growth of the two involved phases. Goetzinger [9] believed that incorporated the fragmentation model to account for the origin of anomalous eutectic microstructures in Ni–Si, Co–Sb and Ni–Al–Ti metallic alloys. Li [10], however, thought that both coupled eutectic growth and decoupled dendritic growth in the rapid solidification can result in the anomalous eutectic formation.

High undercooling solidification is one of the most popular methods to study the microstructure evolution and formation mechanism of anomalous eutectic under rapid non-equilibrium solidification in the previous studies. However, the melt undercooling can be only controlled in the initial solidification during high undercooling solidification process. Meanwhile, the recalescence during solidification process also influences the initial solidification structure, and it will reduce the analysis accuracy of the initial solidification behavior in the melt. The laser surface remelting technique also belongs to rapid solidification. Furthermore, the local growth rate ($V_s$) of molten pool interface can be accurately determined according to the laser scanning speed ($V_b$) and the orientation of the cladding layer. Hence, the laser surface remelting technique provides an important research path to systematically and exactly elucidate the anomalous eutectic structure formation mechanism during rapid solidification [11]. A new anomalous eutectic structure formation mechanism was found by the author by laser cladding Ni-Sn hypereutectic alloys, which is that the free nucleation and rapid growth of two eutectic phases should be a necessary condition for the formation of anomalous eutectic [12]. Compared to laser melting technology, laser cladding technology can examine the impact of varied solidification parameters on the solidification structure [13].

In order to further clarify the formation mechanism of anomalous eutectic in Ni-Sn eutectic alloy, the microstructure and orientation distribution of Ni-Sn alloy by laser cladding with different process parameters were revealed. Then, the formation mechanism of the anomalous eutectic by laser cladding was analysed.

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* Corresponding author at: State Key Laboratory of Solidification Processing, Northwestern Polytechnical University, Xi'an 710072, China.

*E-mail addresses:* wwwangzt@gmail.com (Z. Wang), xlin@nwpu.edu.cn (X. Lin).

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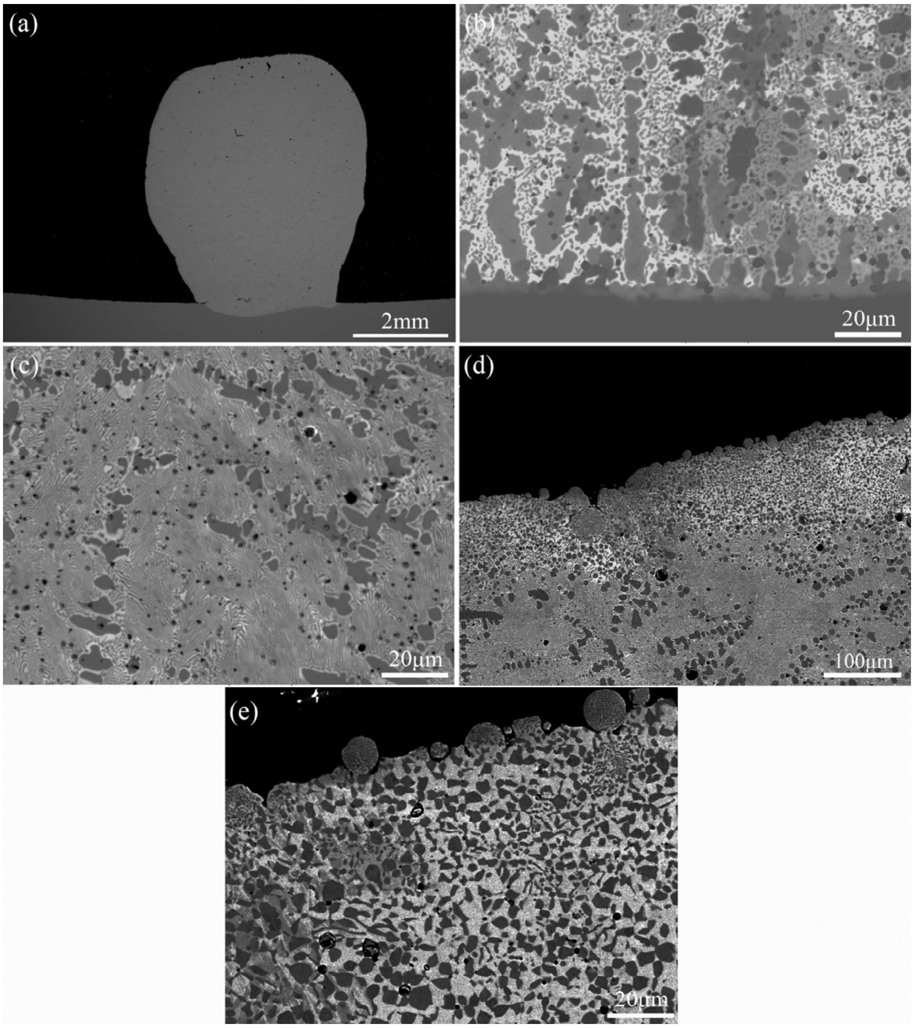

**Fig. 1.** Microstructure of different areas of cladding layer perpendicular to the scanning direction after laser cladding (laser scanning velocity $V_b$ = 1 mm/s, single track, 20 layers). (a) Overall appearance of cladding layer. (b) The bottom of cladding layer. (c) The middle of cladding layer. (d) The top of cladding layer. (e) Enlargement of top.

## 2. Experimental procedure

The laser cladding of Ni-Sn eutectic alloy was carried out via a LRF-II laser solid forming and remanufacturing system, which consists of a PRC2000 continuous wave $CO_2$ laser, a controlled atmosphere chamber and a powder feeding system with a coaxial nozzle. The Ni-32.5 wt.%Sn eutectic alloy powders with diameter of 20–100 μm, prepared by argon gas atomization were laser cladding on Nickel plate (99.99%) which was polished and cleaned thoroughly in the acetone. The single track laser cladding process were carried out using a continuous wave $CO_2$ 1aser with a nominal power of 2500 W. The feeding rate of powder was 8 g/min. The laser beam was focused to a spot with the diameter of 2 mm and the scanning speed was varied between 1 and 10 mm/s, and the increment of Z was 0.2 mm.

The laser cladded specimens were cut along the traverse direction of the laser trace. The microstructures of the samples were observed with a TESCAN VEGAII LMH scanning electron microscopy (SEM). The grain orientation of anomalous eutectic was measured by Electron backscattered diffraction (EBSD).

## 3. Results and discussion

### 3.1. Microstructure evolution at different region of cladding layer

Fig. 1 shows the SEM backscattered electron images of the cross-sectional structure after laser cladding (laser scan velocity was 1 mm/s, 20 layers). As seen from the overall morphology of the cladding layer, the cladding height was about 5 mm (Fig. 1a). Fig. 1b shows the microstructure at the bottom of the cladding layers, where the primary α-Ni columnar dendrites and regular lamellar eutectic can be observed. During the laser cladding process, the heat is mainly dissipated from the Ni substrate and the heat flow direction during the solidification of molten pool is nearly perpendicular to the surface of substrate. Consequently, the upward growth of directional columnar dendrites develops. According to the EDS measurement, the concentration of Sn is 28.05 wt% in this area. As increasing height to the middle of the cladding layer, the α-Ni columnar dendrites and regular lamellar eutectic still existed in this area (Fig. 1c). It should be noted that the α-Ni dendrites herein appears finely in comparison to that at

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