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Microstructure evolution in laser surface remelting of Ni–33 wt.%Sn alloy

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

[a] State Key Laboratory of Solidification Processing, Northwestern Polytechnical University, Xi'an 710072, PR China
[b] Engineering Training Center, Nanchang Hangkong University, Nanchang 330063, PR China

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ABSTRACT

Laser surface remelting experiments have been performed on a Ni–33 wt.%Sn hypereutectic alloy. The microstructure characteristic, grain orientation and microhardness were investigated. The lamellar eutectic spacing decreased with increasing the scanning velocity, and the lamellar eutectic spacing is reduced significantly after laser rapid solidification. The anomalous eutectic was obtained in the bottom of the molten pool when the sample was melted thoroughly with the low scanning velocity of 0.1 mm/s. It is found that the free nucleation and rapid growth of two eutectic phases should be a necessary condition for the formation of anomalous eutectic. The EBSD maps and pole figures indicated that the grain orientations of anomalous eutectic obtained by laser remelting are analogous to that obtained by high undercooling solidification. The microhardness of anomalous eutectic is lower than that of regular lamellar eutectic.

1. Introduction

Eutectic solidification is an important liquid–solid phase transformation process which is involved in many important metallic and non-metallic materials. The performance of eutectic materials largely depends on the characteristic scale of the regular or irregular eutectic structure and the orientation of eutectic phases, which makes the regularity of eutectic structure become an important content of the eutectic researchers [1–4]. In general solidification conditions, the microstructure of non-faceted/non-faceted eutectics were regular lamellar or rod, however, some researchers showed that there should exist a transition from regular lamellar or rod eutectic to anomalous eutectic under rapid non-equilibrium solidification conditions [5–9].

Several theories have been developed to explain the formation of anomalous eutectic. Kattamis and Flemings [10] 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 et al. [11] suggested that the anomalous eutectic structure in Ni–Sn and Ag–Cu alloys arises from an decoupled simultaneous growth of the two involved phases. Wei et al. [12] suggested that a cooperative dendritic growth of the independently nucleating phases is responsible for the development of the anomalous eutectic microstructures in Co–Sb and Ni–Si alloys. Li et al. [8] proposed that the formation of anomalous eutectic is attributed to the fragmentation of primary α-Ni phase dendrite during the dendritic growth of α-Ni and β-Ni_3Sn colonies in undercooled Ni–Sn alloys based on the electron backscatter diffraction pattern (EBSP) mapping analysis. Li et al. [13], however, thought that both coupled eutectic growth and decoupled dendritic growth in the rapid solidification can result in the anomalous eutectic formation.

It should be indicated that the high undercooling solidification is the most popular method to study the microstructure evolution and formation mechanism of anomalous eutectic under rapid non-equilibrium solidification in previous studies. However, it is difficult to measure the growth velocity of the primary solidified phase or eutectic phases in high undercooling solidification. Actually, the growth velocity of the primary solidified phase or eutectic phases is generally reckoned as an important processing parameter to determine the transition between regular lamellar or rod eutectic and anomalous eutectic. As one knows, the laser surface remelting technique also permits rapid solidification [14,15]. Furthermore, the local growth rate can be accurately determined according to the laser scanning speed and the orientation of the microstructure and the molten pool interface [16]. Hence, the laser surface remelting technique provides an important research path to systematically and exactly clarify the anomalous eutectic structure formation mechanism during rapid solidification.

In the present paper, a series of laser surface remelting experiments were performed to investigate the microstructure evolution of Ni–33 wt.%Sn hypereutectic alloy during rapid solidification. The

* Corresponding authors. Tel.: +86 29 88494510; fax: +86 29 88494001.
E-mail addresses: xlin@nwpu.edu.cn (X. Lin), huang@nwpu.edu.cn (W. Huang).

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phase selection mechanism of Ni–33 wt.%Sn during rapid solidification was studied, and the formation mechanism of the anomalous eutectic was analyzed.

2. Experimental procedure

Ni–33 wt.%Sn alloys were prepared from high purity Ni (>99.99 wt.%) and Sn (>99.999 wt.%) by the electric arc melting process. The specimens with the thickness of 2 mm were cut from the ingot. All specimens were polished and cleaned thoroughly in the acetone to ensure a similar surface quality before laser surface remelting.

The experiments were carried out using a continuous wave CO_2 1aser with a nominal power of 2000 W. The laser beam was focused to a spot with the diameter of 2 mm and the scanning speed varied between 0.1 and 10 mm/s. In order to enhance the cooling effect, the specimens were stuck on a copper plate. Ni–Sn alloys were laser remelted in an argon shielded glove box to prevent heavy oxidation during the laser treatment.

The remelted specimens were cut along the traverse direction of the laser trace respectively. 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). The microhardness of the different regions in the specimens was tested by a Duramin-A300 microhardness tester.

3. Results

3.1. Solidification microstructure

Fig. 1 shows the SEM backscattered electron images of the microstructure in the molten pool with the different scanning speed. It can be seen from Fig. 1a–d that the molten pools are composed of regular lamellar eutectic entirely with the scanning speed between 0.5 mm/s and 20 mm/s. The depth of the molten pool decreased with increasing the scanning speed. The lamellar eutectic spacing after laser rapid solidification reduced significantly with increasing the scanning speed. According to the previous rapid solidification eutectic [17], it is generally thought that the anomalous eutectic could be formed at a high solidification velocity which makes a cooperative eutectic growth not be realized. However, when the scanning speed further increased to 400 mm/s, the molten pool was still composed of the remarkable refined regular lamellar eutectic. On the contrary, when the scanning speed decreased to 0.1 mm/s, anomalous eutectic can be found at the bottom of the molten pool.

Fig. 2 illustrates the macrostructure and the corresponding microstructure from the top to the bottom of molten pool of Ni–33 wt.%Sn hypereutectic alloy with the scanning speed of 0.1 mm/s. It should be indicated that, the re-molten sample with the scanning speed of 0.1 mm/s is different from others. There was a clear convex at the bottom of the sample, which indicates the thoroughly melting of the sample during laser remelting (Fig. 2a). Both the fine primary Ni_3Sn equiaxed dendrites and regular lamellar eutectic can be observed clearly at the top of the molten pool. On comparison with the microstructure in the substrate, the microstructure refinement occurs due to the rapid solidification in laser remelting processing (Fig. 2b). Fig. 2c shows the microstructure in the center of the molten pool. The microstructure at these position consisted of a mixture of regular lamellar and band structure. Fig. 2d shows the microstructure at the bottom of the molten pool. It can be seen that, there exist two kinds of microstructure: the primary Ni_3Sn equiaxed dendrites and the regular lamellar eutectic at the upper region and anomalous eutectic at the lower region (the boundary as shown by the arrow in Fig. 2d).

Fig. 3 illustrates the high magnification images of the anomalous eutectic morphologies at the bottom of the molten pool of the Ni–33 wt.%Sn hypereutectic alloy after laser remelting. From the top to the bottom of the molten pool, there is an obvious boundary between the fine regular lamellar/rod eutectic and the coarse anomalous eutectic as shown in Fig. 3a and b, where a few primary Ni_3Sn particles in lamellar/rod eutectic region also can be found. Moreover, the anomalous eutectic microstructure formed at the bottom of the regular lamellar/rod eutectic region. At the anomalous eutectic region, the scale of bright Ni_3Sn particles is similar to the primary Ni_3Sn particles in the substrate (Fig. 3b). It can be speculated that the larger Ni_3Sn particles of this region could be attributed to the incomplete melting in the original substrate under rapid solidification. The larger Ni_3Sn particles were surrounded by anomalous eutectic, with the disappearance of the

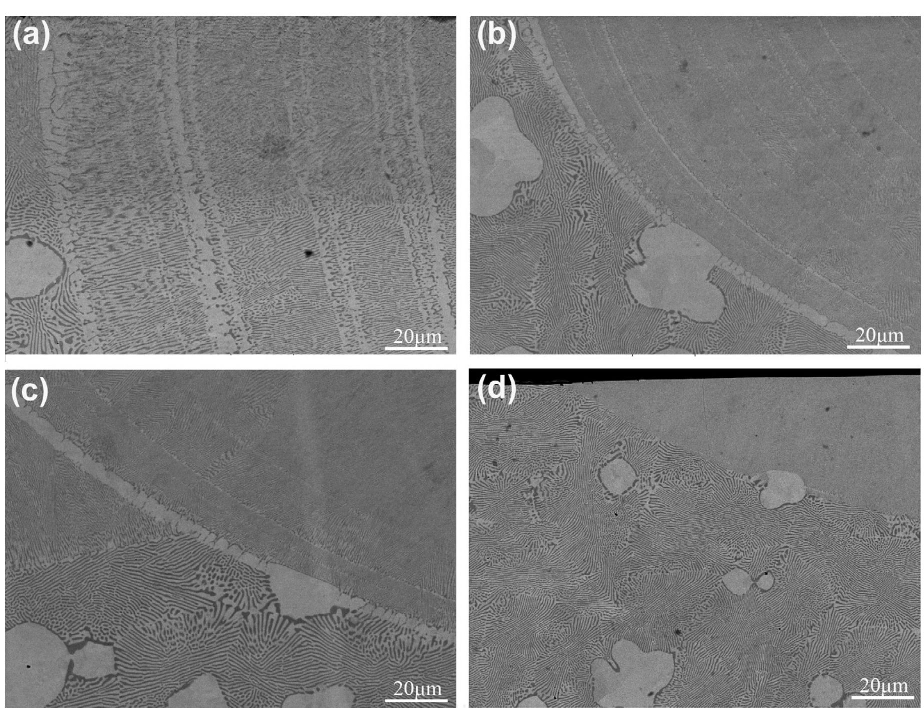

Fig. 1. Microstructure in the molten pool of Ni–33 wt.%Sn alloy with different laser scanning speed. (a) V = 0.5 mm/s, (b) V = 2 mm/s, (c) V = 5 mm/s, and (d) V = 20 mm/s.