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Novel nucleation mechanisms through satelliting in direct metal deposition of Ti-15Mo

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ABSTRACT

Control of microstructural formation in direct metal deposition (DMD) presents a significant current limitation to the technology. Researchers have attempted to overcome this by thermal management in the process and through the formulation of new alloys. A novel material preparation method "satelliting" was used in combination with DMD to improve the microstructure of the deposited alloys. Three feedstocks of Ti-15Mo, including a satellited feedstock, a blend of Ti/Mo (150 μm) and blended Ti/Mo (3 μm), were prepared and used for DMD of Ti-15Mo. Fine equiaxed grains and near-equiaxed grains distributed uniformly were found in the deposited sample from satellited feedstock, while the samples from blended Ti/Mo (150 μm) and Ti/Mo (3 μm) are dominated by larger near-equiaxed grains and epitaxial columnar grains, respectively. The effect of the nucleation was verified by combinatory analysis of unmelted Mo particles. This demonstrates a new route to the manufacture of components through DMD which produces applicable microstructures directly from the build.

1. Introduction

Direct metal deposition (DMD) is a form of additive manufacturing technology that can be used to fabricate near-net shape and high-performance metallic components. However, the melting and solidification dynamics during DMD process usually lead to the microstructures characterized by large columnar grains, which will cause mechanical anisotropy [1]. In contrast, the fine equiaxed microstructure is sought for improving the properties of the material. Recently, Martin et al. [2] reported that equiaxed fine-grained microstructures were achieved in the metal-based additive manufacturing of the aluminum alloy by using aluminum alloy powders coated with nano particles. This is related closely to developments reported by Clare and Kennedy [3].

DMD has been used to form alloys from blended elemental powders [4–6]. An elemental powder with higher melting point but the same crystal structure as the parent powder is often added. If such an elemental powder with small particle size can be delivered to the solid/liquid interface in the melt pool, it can not only play the role of an alloying agent but also as a nucleation point to promote equiaxed grain nucleation and growth. The aim of this study is to introduce a novel satelliting method to create a feedstock for DMD, performed by attaching fine elemental particles onto relatively large metal particles, and investigate the nucleation effect of such elemental particles. Since titanium alloys have been extensively used in additive manufacturing [7], titanium alloy Ti-15Mo, which demonstrates good properties consistent with biomedical applications [8], was investigated in this study. By comparing the microstructures of DMD Ti-15Mo samples from three different feedstocks, the nucleation role of Mo satellites is revealed.

2. Experimental method

Pure Ti powder with 100–150 μm size range, Mo powder with an equivalent diameter of ~3 μm and larger Mo powder with an equivalent diameter of ~150 μm were used as the elemental powders. Ti particles and Mo (3 μm) particles were "satellited" together to create a composite powder feedstock of Ti-15Mo. The satelliting process is described elsewhere [9]. The Ti/Mo (3 μm) particles and Ti/Mo (150 μm) particles were mixed separately according to the composition of Ti-15Mo as separate feedstocks. All three feedstocks were dried in a vacuum oven at 400 K for 12 h. The morphologies of the Ti, Mo powders and the feedstocks are shown in

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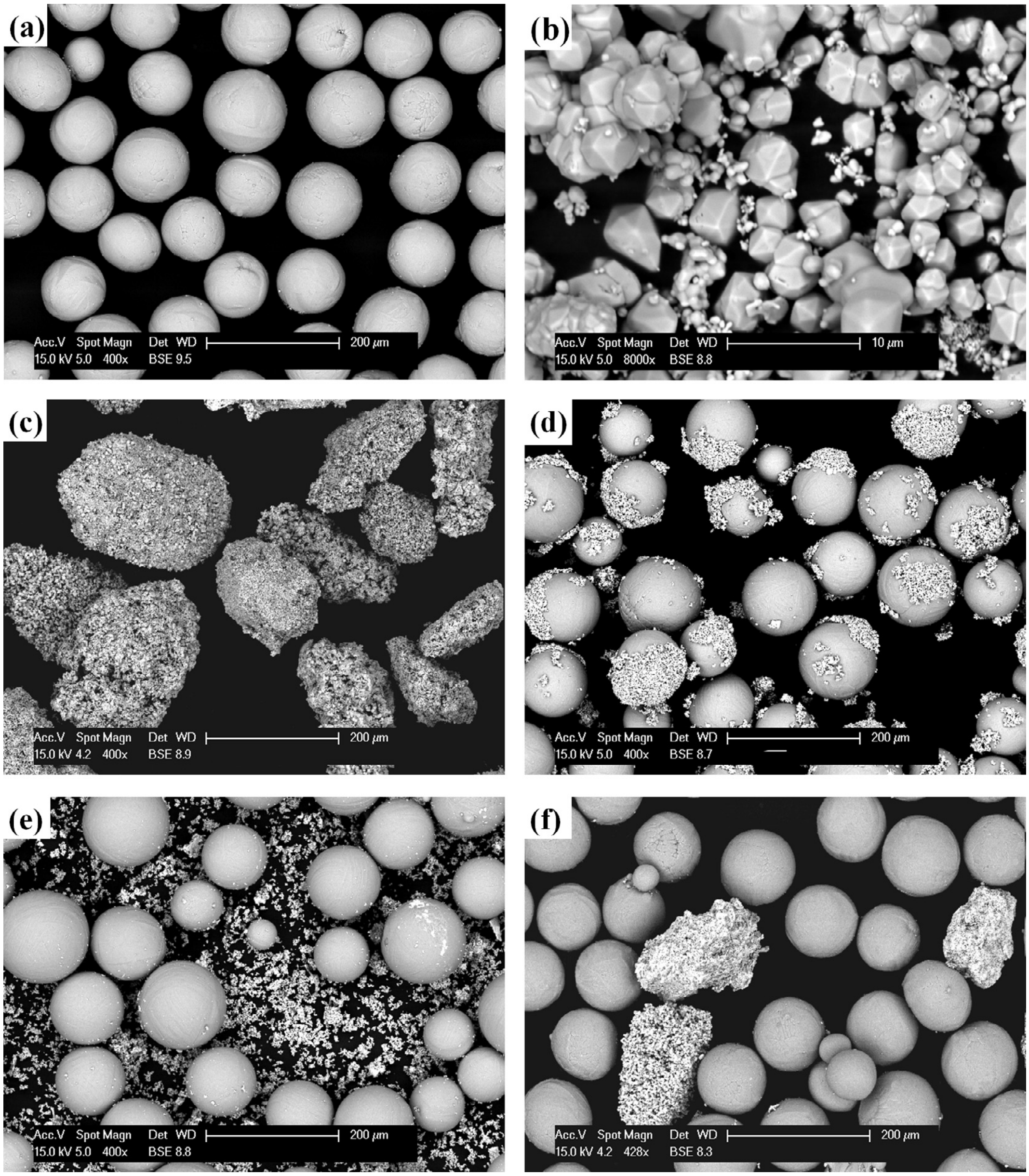

Fig. 1. BSE showing the morphologies of the elemental powders and feedstocks: (a) Ti; (b) Mo (3 μm) particles; (c) Mo (150 μm) particles; (d) satellited Ti-15Mo; (e) blended Ti/Mo (3 μm); (f) blended Ti/ Mo (150 μm).

Fig. 1 under an FEI XL30 SEM (scanning electron microscope) using BSE (backscattered electron). The substrate was a Ti-6Al-4V plate of 17 mm thickness.

Ti-15Mo alloy samples were deposited using a DMD system, the details of which are described elsewhere [10]. Thin wall samples of $50 \times (7–8) \times 4\ mm^3$ were deposited using a single line scanning strategy with principle processing parameters shown in Table 1.

The samples were cross-sectioned parallel to the laser scanning direction and the metallographic specimens were prepared. The microstructures of the samples were investigated using a Nikon ECLIPSE LV100ND optical microscope (OM) and an FEI XL30 SEM. Quantitative measurements of the microstructure were conducted using the Image-Pro Plus software.

3. Results and discussion

Fig. 2 shows the microstructures of DMD Ti-15Mo alloy from the three feedstocks. Fig. 2(a)–(c) present the microstructures obtained by using the satellited feedstock, in which Fig. 2(b) reveals the microstructure near the top surface and Fig. 2(c) shows the microstructure in a typical layer in the middle region of the

Table 1
The processing parameters used in DMD Ti-15Mo.

Laser spot size (mm)	Laser power (W)	Scanning speed (mm s^{-1})	Powder feed rate (g min^{-1})	ΔZ (mm)	Carrier gas flow rate (L min^{-1})
4	1500	8	20	0.8	10