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Influence of processing parameters on particulate dispersion in direct laser sintered WC–Co_p/Cu MMCs

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Abstract

Homogenizing the particulate dispersion in the matrix is an important consideration in obtaining high-quality particulate reinforced metal matrix composites (MMCs) using direct metal laser sintering (DMLS). In this paper, the effects of processing parameters in terms of laser power, scan speed, and powder layer thickness on the particulate dispersion in the DMLS-processed submicron WC–Co_p/Cu[1] MMCs were investigated. It shows that for a given scan speed larger than 0.04 m/s, a proper increase in the laser power between ∼650 W and ∼750 W leads to a uniform dispersion of smooth and fine WC particulates, due to a sufficient liquid formation and an improved wettability. Whereas, an excessive increase in the laser power results in a severe particulate aggregation, because of the balling effect. There exists a critical scan speed of 0.04 m/s, above which the particulates can be well engulfed by the advancing dendritic front, thereby homogenizing the particulate dispersion in the matrix. A proper decrease in the powder layer thickness to 0.20 mm can alleviate the particulate aggregation, due to the elevated Marangoni convection and liquid capillary forces.

Keywords: Metal matrix composites (MMCs); Particulate reinforcement; Rapid prototyping (RP); Direct metal laser sintering (DMLS); WC–Co

1. Introduction

Particulate reinforced metal matrix composites (MMCs) exhibit a favorable combination of metallic matrix and stiffer and stronger reinforcements [1,2]. Depending on the nature of the final product desired, the selection of types of metallic matrix and reinforcement is performed [3]. WC–Co, as a well-known hard metal, has excellent properties such as high strength, high hardness, wear resistance, and reasonable fracture toughness [4]. Copper is characterized by excellent electrical and thermal conductivity and outstanding resistance to fatigue and corrosion [5,6]. In order to combine their superior properties, the development of WC–Co particulate reinforced Cu matrix composites is of significance.

Direct metal laser sintering (DMLS), as a typical rapid prototyping (RP) technique, enables the quick production of complex shaped three-dimensional (3D) parts directly from metal powder [7–11]. The DMLS process creates parts in a layer-by-layer fashion by selectively fusing thin layers of loose powder with a scanning laser beam. Each scanned layer represents a cross-section of the object's mathematically sliced CAD model. After consolidation of one cross-section, a fresh layer of powder is deposited and the process is repeated until a 3D part is finished. This technique competes effectively with other conventional manufacturing processes when the part geometry is complex and the production run is not large [12]. Our recent research efforts reveal that DMLS process, due to its flexibility in materials and shapes, exhibits a great potential for net-shape fabrication of complex shaped WC–Co particulate reinforced Cu matrix composites that cannot be easily developed by other conventional methods [13].

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[1] All the subscript "p" indicates powder form.

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However, as is evident from our previous work [14], the aggregation of the reinforcing particulates and the resultant crack formation between the reinforcement and the matrix occurs frequently in the laser processed MMCs, due to the complex metallurgical nature of DMLS involving multiple modes of heat, mass, and momentum transfer [15,16]. Thus, in order to obtain high-quality MMCs by DMLS, it is important to establish the process conditions under which laser fabrication is able to generate a uniform distribution of particulates in such composites. These conditions include both powder characteristics (e.g., particle shape, particle size and its distribution, component ratio) and processing parameters (e.g., laser power, scan speed, powder layer thickness). Besides the optimization of powder characteristics [14], the capability of defining the processing window in improving the particulate dispersion homogeneity is becoming another important consideration.

As a further step in obtaining high performance MMCs with controllable microstructures, the present work employed DMLS to prepare a series of WC–Co_p/Cu MMCs under different processing parameters. The effects of laser power, scan speed, and powder layer thickness on microstructural features of the laser processed MMCs, especially the dispersion states of the reinforcing particulates (e.g., the degree of dispersion, particle shape, and particle size), were investigated.

2. Experimental

2.1. Materials

Electrolytic 99% purity Cu powder with an irregular shape and a mean particle size of 15 μm (Fig. 1a) and WC–10 wt.% Co composite powder with an irregular structure and an average equivalent spherical diameter of 0.6 μm (Fig. 1b) were used in this experiment. The WC–Co composite powder was synthesized using a novel "spray drying and fixed bed" technique, which involved spray drying a precursor solution containing ammonium metatungstate (AMT) and $Co(NO_3)_2$, followed by roasting, ball milling, reduction, and carbonization [17]. The two components (i.e., Cu and WC–Co) were mixed according to the Cu:WC–Co weight ratio of 70:30 (the equivalent volume fraction of the WC–Co constituent of 20.4 vol.% and the WC constituent of 17.5 vol.%, respectively) in a vacuum ball mill at a rotation speed of 150 rpm for 60 min, with balls to powders weight ratio of 5:1.

2.2. Processing

The DMLS apparatus mainly consisted of a continuous wave Gaussian CO_2 laser with a maximum output power of 2000 W, an automatic powder delivery system, and a computer system for the process control. Prior to the laser sintering process, a steel substrate was placed on the building platform and leveled. Afterwards, a thin layer of the loose powder was spread on the substrate by the roller. Subsequently, a laser beam scanned the powder bed surface to form a layer-wise profile according to the CAD data of the part. The process was repeated and the part was produced in a layer-by-layer fashion until completion. The entire sintering process was performed in ambient atmosphere at room temperature. The following processing parameters were used: spot size 0.30 mm, scan line spacing 0.15 mm, laser power 550–800 W, scan speed 0.01–0.07 m/s, and powder layer thickness 0.20–0.40 mm.

2.3. Characterization

Samples for metallographic examinations were cut, ground, and polished according to standard procedures. A solution consisting of $FeCl_3$ (5 g), HCl (10 mL), and dis-

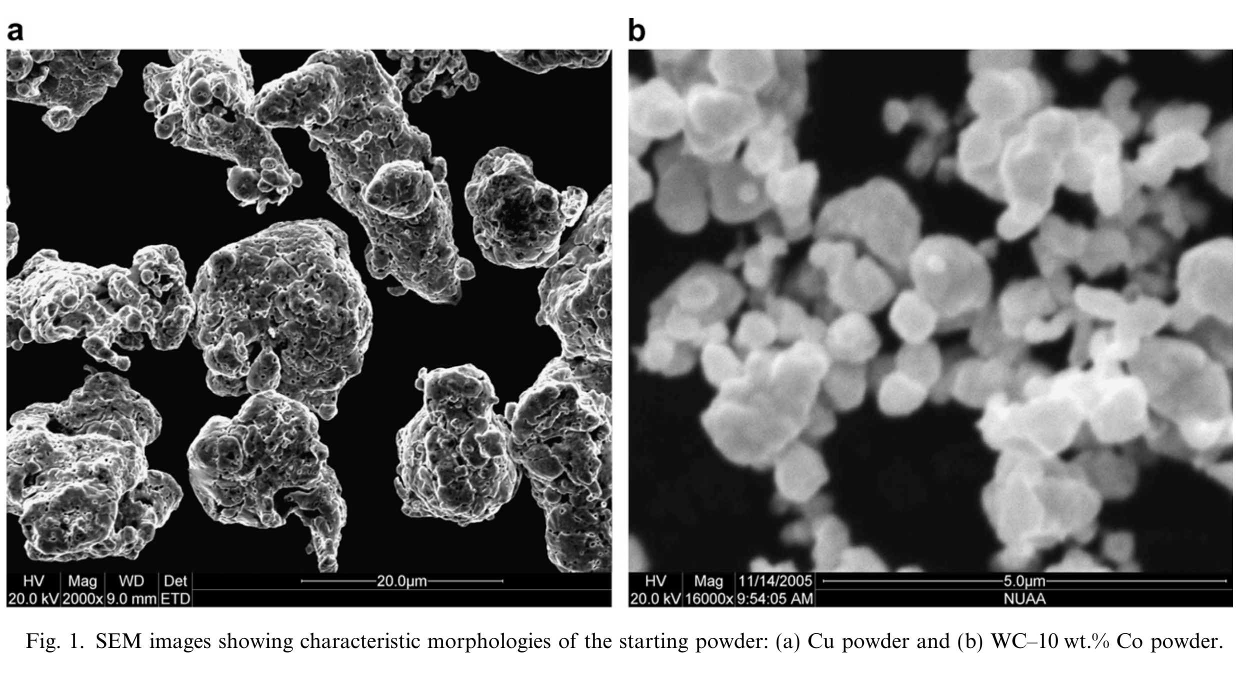

Fig. 1. SEM images showing characteristic morphologies of the starting powder: (a) Cu powder and (b) WC–10 wt.% Co powder.