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Selective laser melting of boron carbide particles coated by a cobalt-based metal layer

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ABSTRACT

Selective laser melting (SLM) is an additive manufacturing technology widely applied for direct fabrication of functional parts from metal powders. In this paper, the feasibility of the fabrication of three-dimensional cermet objects by SLM using 5–35 μm boron carbide particles surrounded by ~2 μm cobalt-based layers was explored. Microstructure, composition, porosity, compressive strength and microhardness of the fabricated object were investigated. A highly porous (37%) homogeneous structure containing grains of boron carbides with 2900–3200 HV hardness embedded in the cobalt-based matrix was obtained. It was also found that new phases were formed during SLM as a result of the interaction of B_4C with the cobalt-based matrix.

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1. Introduction

Selective laser melting (SLM) of metal powders is an Additive Manufacturing technology with the ability of layer-by-layer building of complex-shape functional parts (Wohlers Report, 2007). The available literature reports successful results of SLM manufacturing of 3D objects and functional parts from steel (Murr et al., 2012), nickel (Jia and Gu, 2014), cobalt (Pupo et al., 2013) and titanium based alloys (Yadroitsev et al., 2014). However, materials with enhanced performance compared to metallic alloys typically applied in SLM are required to withstand harsh operating conditions such as elevated temperature, high abrasive wear, etc. For example, cutting tools materials must have strong characteristics of hardness, wear resistance and compressive strength. Applying different types of ceramic and cermet materials is now emerging as the only solution to achieve this goal. Cutting tools are typically manufactured by sintering ceramic and cermet powders containing tungsten carbide, titanium carbide, titanium carbonitrides or other types of hard phases. SLM of ceramics is a difficult task (Deckers et al., 2014). High temperature gradients during SLM process often lead to parts cracking (Shishkovsky et al., 2007) and high residual stress. Some successful results have been reported on SLM of yttria-stabilized zirconia (YSZ) (Bertrand et al., 2007) and alumina-zirconium (Shishkovsky et al., 2007) ceramics. However, the mechanical properties of the obtained materials are significantly lower compared to conventional ceramics. For example, YSZ fabricated by SLM has a very high porosity (44%) and a poor interlayer adhesion (Bertrand et al., 2007). SLM of cermet powders or mixtures of metal and ceramic powders where the metal phase acts as a binder material seems to be less challenging. In this case, the laser melts the metal phase creating the connection between separated particles of the layer whereas the ceramic particles could remain in solid state (Kumar, 2009) or be partially molten (Gu et al., 2006). However, composition inhomogeneity, phase segregation and high porosity of the resulting structures are common problems of SLM of conventional cermet powders (Kruth et al., 1996) and metal-ceramic powder mixtures (Krakhmalev and Yadroitsev, 2014). It can be caused by the initial inhomogeneity of the material in the powder bed, heat and mass transfer particularities in the molten pool, and melting-solidification process of a multimaterial system.

This paper proposes a method for SLM manufacturing of 3D objects from a cermet cladded powder in which the ceramic core is surrounded by a thin layer of metallic binder. The literature reports successful results of the use of this type of powder in cold spray of nickel-coated alumina (Li et al., 2008) and boron carbide particles (Feng et al., 2012) for coating deposition and, as a tentative experiment, for 3D parts building. Such metal-ceramic powders have never been applied in SLM.

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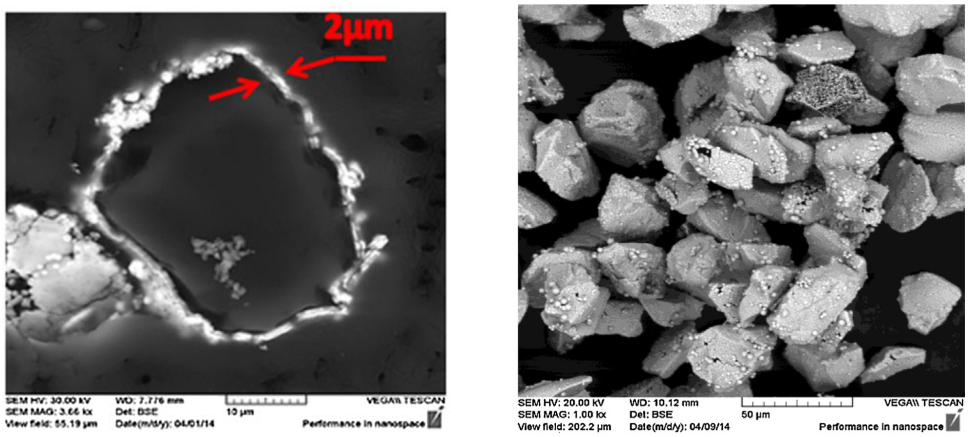

Fig. 1. SEM images of B_4C particles coated by a cobalt-based layer used in the experiments: (a) particle cross-section, (b) powder general view.

The main purpose of this study is to explore the feasibility of SLM of a cobalt-cladded boron carbide ceramic powder as a potential solution for additive manufacturing of cutting tools. The choice of boron carbide as a ceramic reinforcing phase was governed by its good mechanical properties, high hardness and high abrasion resistance. Cobalt is actually used as a matrix in cermet materials due to its high corrosion and wear resistance in a wide temperature range. From these considerations, it appears that a cobalt-cladded boron carbide powder may be a good choice to investigate the SLM potential for cutting tools manufacturing.

2. Experimental procedure

2.1. Feedstock material

Batches of composite metal-coated B_4C powders were produced using a chemical vapor deposition (CVD) facility for the industrial production of cladded powders (LIFCO Industrie, France). A patented CVD coating process (Bucher and Iacob, 2004) was applied using a fluidized bed furnace reactor. The use of a fluidized bed allowed the flow of gaseous reactive species to have a good contact with each particle to be cladded. CVD precursors served to synthesize a cobalt metallic layer reinforced by inclusions of pure boron and Co_3B phase deposited onto the surface of fine B_4C powder.

The particles have a strongly irregular shape; 95% of the particles have a size lying in the range between 5 and 35 μm with an average size of about 13 μm. SEM analysis of the powder revealed that the average thickness of the cobalt-based coating layer was near 2 μm (Fig. 1).

SEM images show that the metallic coating layer is homogenous in thickness but contains some spherical inclusions representing points of nucleation during CVD deposition of cobalt on the ceramic surface of the particles. Also, an amount of particles having visible gaps in the surrounding layer was detected. The percentage of the non-fully covered particles was not measured, but visual observation permitted to estimate their percentage as about 3–5 %. XRD analysis of the particles detected the presence of pure cobalt, pure boron and a Co_3B phase in the particle coating (Fig. 2).

2.2. Experimental set-up

Samples were fabricated using a PM100 (Phenix Systems) SLM machine. The radiation source was a continuous-wave Ytterbium fiber laser YLR-4 × 200-SM (IPG Photonics Corporation) with 1.075 μm wavelength and 200 W maximum laser power. The size of the laser spot on the surface was 70 μm. The process chamber was filled by argon as a protective gas. Stainless steel plates were used for the tests as a substrate for the powder bed. For a better bonding of the first layer, the substrate was laser cladded with cobalt-reach Stellite 6 powder. The deposited Stellite 6 layer was further on machined and grinded. The resulting coating thickness was ~100 μm.

2.3. Characterization of the samples

The samples were analyzed using an optical microscope Zeiss Axioscope and a SEM Tescan Vega 3 sSB with EDS function.

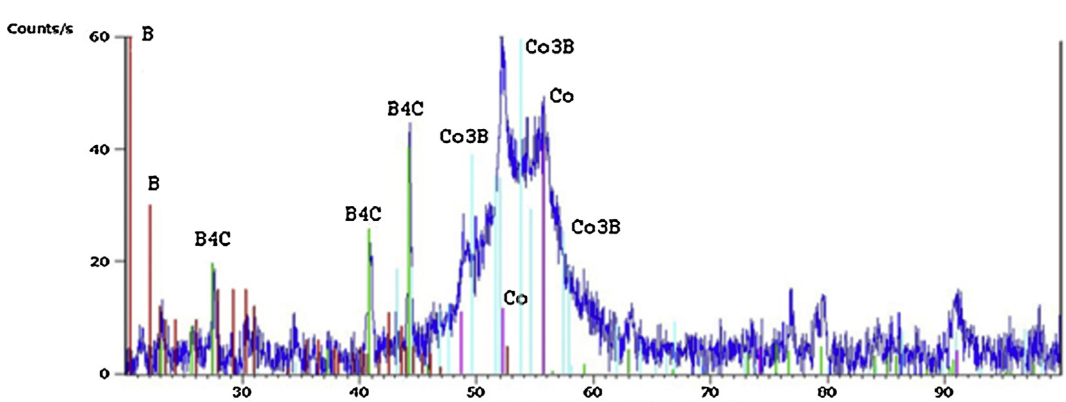

Fig. 2. Results of XRD analysis of B_4C powders covered by a cobalt-based layer.

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