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Synthesis of Nanostructured Wc-Co Hardmetal by Selective Laser Melting

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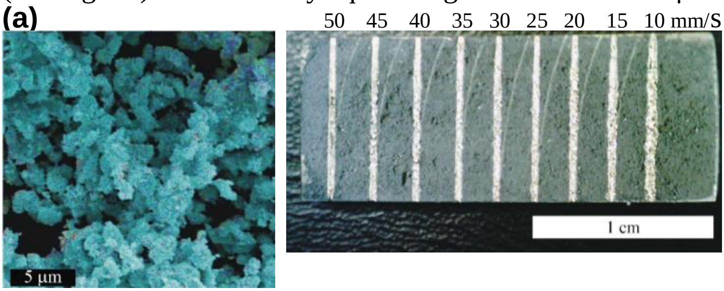
Nanostructured metal matrix composites often attain better mechanical properties than micron-sized structures of the same composition. They can be obtained from nanopowders. The principal difficulty is that the conventional powder metallurgy technologies require long-time treatment at high temperatures, which is favorable for grain growth. Therefore, novel techniques for powder consolidation are applied [1] to preserve the initial nanostructure of the powder. A promising method to avoid grain growth at consolidation is to shorten the thermal cycle. The shortest thermal cycle of 1 ms and less can be attained at selective laser melting (SLM). This is a layer-by-layer growth technique where the scanning laser beam locally melts and consolidates powder. SLM does not require any tool specific for a given shape of the growing part and is suitable for rapid prototyping of complex shapes directly from their computer models. This is very important for hardmetals because the existing methods of their shaping are complicated.

The WC-Co system is chosen for this study because micron-sized powders of this composition were successively treated by laser [2]. The known drawback of SLM is cracking of growing parts due to high thermal stresses. The preliminary tests on laser scanning of WC-20Co substrates indicated that this material does not crack at the laser parameters typical for SLM.

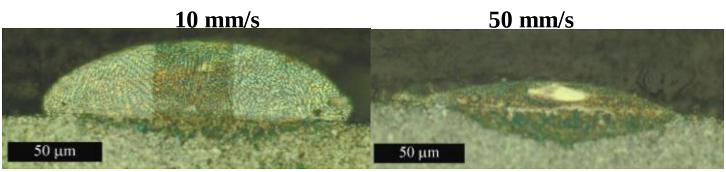
The powder mixture was prepared from 75 wt.% 1-2 μm Co powder and 25 wt.% 50-80 nm WC powder. To obtain uniform distribution of components, the mixture was treated for 2 hours in a ball mill at 200 r.p.m. The electron-microscopic image (see Fig. 1a) shows a uniform distribution of WC nanoparticles over the surface of the initial Co particles. No micron-size agglomerates of WC are detected as characteristic for the initial WC nanopowder. The obtained powder mixture was deposited from a water suspension on the surface of a WC-20Co substrate. The powder layer thickness was about 100 μm. The powder layer was scanned with a laser beam of 1.07 μm wavelength focused on a spot of 100 μm diameter to obtained separated beads of remelted powder shown in Fig. 1b. The incident laser power was 80 W and the scanning velocity varied from 10 to 50 mm/s.

The cross-sections of the obtained beads were polished and electrochemically etched to visualize the microstructure. Their optical microscopic images are shown in Figs. 2a and 2c. Perfect adhesion to the substrate, no cracks, and no pores are observed. The heat affected zone of the substrate is clearly visible by its darker contrast. The optical micrograph of 50 mm/s-sample does not reveal any microstructure in the zone of the remelted powder. At the scanning velocity of 10 mm/s, the microanalysis by electron-beam excitation of X-ray spectrum shown in Fig 2b indicates that tungsten is concentrated near grain boundaries while the centers of grains are occupied by cobalt. The most of grains are nearly equiaxial with size about 2-5 μm, while several columnar vertical grains are observed in the center of the bead with diameter about 2-3 μm and length about 15 μm. At a scanning velocity of 50 mm/s, the electron microscopy (see Fig. 2d) reveals nearly equiaxial grains less than 0.5 μm in size.

(a)


(b)

Figure 1: Composite powder (a) and remelted beads on the substrate (b). The scanning velocity (mm/s) is indicated on the top of the beads



(a) (c)

Figure 2: Cross-sections of the beads at 10 mm/s (left column) and 50 mm/s (right column): (a), (b), general view; element microanalysis (c) and microctructure (d) in the zone of the remelted powder

The duration of the thermal cycle at SLM can be estimated as the laser spot diameter divided by the scanning velocity. It equals 10 ms at 10 mm/s and 2 ms at 50 mm/s. The shorter thermal cycle means the higher cooling rate. This explains the finer microstructure at 50 mm/s. No grains containing W are resolved in Fig. 2b. Therefore, one can suppose that tungsten is still distributed in nano-sized carbides after laser remelting. Such a small size of the carbides is favorable for dispersion strengthening. According to the microanalysis, the characteristic scale of nonuniformity for strengthening carbide phase distribution is the grain size. The grain size decreases with increasing scanning velocity, so that the distribution of carbides becomes more uniform. This should increase the quality of the material. Figure 1b reveals the defects of powder deposition on the substrate. They can contribute to the linear nonuniformity of the beads and produce macrodefects in fabrication of 3D parts by SLM. The uniform deposition of uniform layers of submicron powders is still a serious technical problem for SLM. Small balls are visible on the surface of the beads in Fig. 1b. Their concentration generally decreases with increasing scanning velocity. This is the known decrease of the balling-effect.

In conclusion, a nanostructured WC-Co hardmetal containing nanosized tungsten carbide particles distributed in Co matrix with the nonuniformity scale less than 0.5 μm is obtained by selective laser melting (SLM) of composite powder prepared in a ball mill. The remelted beads do not contain pores and cracks and are well attached to the WC-Co substrate. The use of the WC-Co substrate for SLM of separated beads proves by induction the possibility of synthesis of coatings and 3D parts of the same high-quality material. Increasing the scanning velocity is favorable because of refining the microstructure and decreasing the balling-effect. A more uniform deposition of the powder is desirable.

References

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