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Obtaining crack-free WC-Co alloys by selective laser melting

R. S. Khmyrov[a], V. A. Safronov[a], A. V. Gusarov[a,b,]*

[a]Moscow State University of Technology "STANKIN", Vadkovsky per. 3a, 127055 Moscow, Russia
[b]Institute of Photonic Technologies (LPT), Friedrich-Alexander-Universität Erlangen-Nürnberg, Konrad-Zuse-Str.3-5, 91052 Erlangen, Germany

Abstract

Standard hardmetals of WC-Co system are brittle and often crack at selective laser melting (SLM). The objective of this study is to estimate the range of WC/Co ratio where cracking can be avoided. Micron-sized Co powder was mixed with WC nanopowder in a ball mill to obtain uniform distribution of WC over the surface of Co particles. Continuous layers of remelted material on the surface of a hardmetal plate were obtained from this composite powder by SLM at 1.07 μm wavelength. The layers have satisfactory porosity and are well bound to the substrate. The chemical composition of the layers matches the composition of the initial powder mixtures. The powder mixture with 25wt.%WC can be used for SLM to obtain materials without cracks. The powder mixture with 50wt.%WC cracks because of formation of brittle W_3Co_3C phase. Cracking can considerably reduce the mechanical strength, so that the use of this composition is not advised.

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1. Introduction

Cemented carbides WC-Co are known by their excellent mechanical properties and corrosion resistance. They are generally produced by liquid-phase sintering from the mixture of the component powders. Recent advances in the sintering process were reviewed byAl-Aqeeli et al. (2014). Shaping the compacted powder before sintering has well-known restrictions in geometry and precision of the sintered parts described by Kingery (1960).The machining of cemented carbides is difficult because of its high hardness. Thus, the essential drawback of the existing technology is

* Corresponding author. Tel.: +49-9131-85-23241 .
*E-mail address:*av.goussarov@gmail.com

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difficult shaping. Shaping by selective laser melting (SLM) could solve the problem. This is a layer-by layer process, where powder is consolidated at melting by scanning with a narrow laser beam. Indeed, SLM is useful for metals, as proved by numerous authors, for example by Yadriotsev et al. (2010). However, early attempts to apply SLM to the cemented carbide were not successful. Thus, Wang et al. (2002) could not eliminate the excessive porosity.

It seemed that increasing laser power would improve the material. However, this led to a strong cracking. Cracking is typical for SLM of ceramic materials. Deckers et al. (2014), Li et al. (2014) and many others could not optimize SLM process parameters to exclude cracking completely. The fundamental cause for cracking appears to be considerable thermal shocks at laser treatment. Hard materials are generally brittle and not resistant to the thermal shocks. Modeling of residual stresses at SLM by Gusarov et al. (2011) indicated that thermal stresses at laser treatment are essentially determined by a high temperature difference between the molten pool and the rest of the laser-treated body. This is consistent with the experimentally found trends to choose materials with higher plasticity and elasticity and lower thermal expansion along with the use of the preheating technique to reduce the thermal shocks.

Commercially available SLM machines do not allow the necessary preheating. It is difficult to modify significantly the elasticity and the thermal expansion of a structural material. Though, the plasticity of WC-Co hardmetals is known to increase with increasing the content of Co binder. At a high fraction of the binder, the SLM was successfully applied to metal-matrix composites TiB-Tiby Attar et al. (2014) and SiC-Ti by Gu et al. (2011) and by Krakhmalev and Yadroitsev (2014). It was found that the mechanical strength of the obtained materials is excellent but cracking may arise if the fraction of the hardening phase is greater than 10%. Similar works are not known for the system WC-Co. However, the thermodynamics of this system is well known, and the perfect compatibility of the components is proved. The objective of this work is to study SLM of WC-Co composites with the content of the carbide less than in the standard hard alloys, and to estimate the maximum possible carbide concentration to avoid cracking.

2. Materials and methods

Commercially available powders of 1-2 μm Co and 50-80 nm WC were used to prepare non-standard mixtures of 75wt.%Co-25wt.%WC and 50wt.%Co-50wt.%WC. The mixtures were treated for 2 hours in a ball mill at 200 r.p.m. to destroy agglomerates of WC nanoparticles and to attain more uniform distribution of the components. Figure 1 shows composite WC-Co powder after milling. No micron-size agglomerates of WC are detected after milling. The nanoparticles of WC are distributed over the surface of micron-sized Co particles.

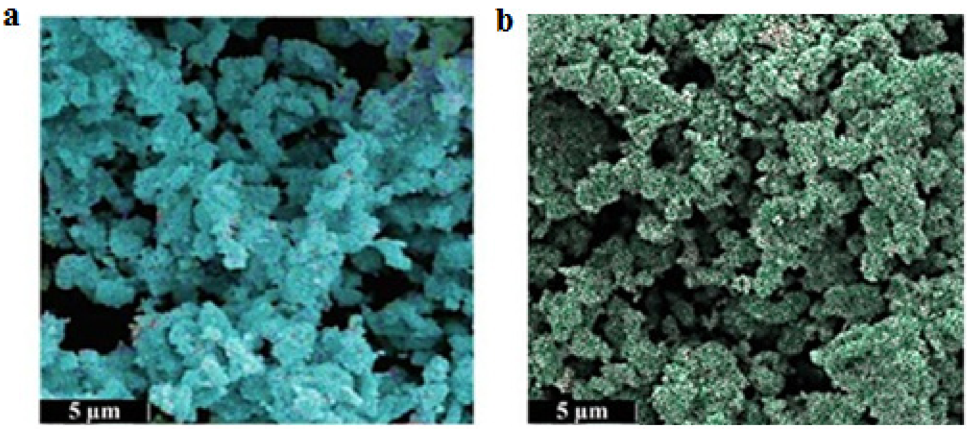

Fig. 1. Composite WC-Co powder after milling: (a) 25%WC-75%Co; (b) 50%WC-50%Co.

A water suspension of the obtained powder mixture was prepared. The suspension was deposited on the substrate surface. The substrates were plates of BK20 hard alloy of thickness 5 mm produced at Kirovgrad hard alloys plant.