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Technical Note

Multimodal Coatings: A New Concept in Thermal Spraying

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Recently, considerable emphasis has been placed on HVOF thermal spraying of nanostructured WC/Co with the intention of achieving high hardness combined with excellent wear resistance. However, depositing dense coatings and simultaneously preventing decarburization has remained a challenge. We have approached the problem by developing a novel feedstock material that consists of a mixture of coarse and fine particles of WC/Co. Particles of different sizes have a different response in the combustion flame. The resultant coating is dense and has no decarburized phases. The abrasion wear resistance is at least 50% better than that of a pure coarse-grained WC/Co coating.

Keywords decarburization, multimodal, nanostructured, thermal spraying, wear resistance

1. Introduction

Traditional practice[1,2,3] in thermal spraying of hard metal coatings, such as WC/Co, calls for agglomerating micron size WC and Co particles into larger feedable particles that are in the 20 to 50 micron size range. An HVOF thermal spray gun is preferred over a plasma system because of the lower particle temperature and shorter residence time, which diminish the tendency for decarburization. While a low flame temperature preserves the desirable WC phase, it compromises on the bond strength and density of coating, resulting in a less than optimized coating. In order to improve the wear properties of WC/Co coatings, recent efforts have been directed at using *nanoparticle* agglomerates as feed materials.[2,4] However, the enhanced properties that were observed in *bulk* nanocrystalline WC/Co materials[5] have remained elusive in the *coatings,* because of extensive decarburization under different thermal spraying conditions.[2,4]

We have developed a new class of WC/Co feedstock material wherein the agglomerated particles consist of a mixture of *micro-* and *nano*particles of WC/Co. The agglomerated structure is designed so as to minimize the amount of material that goes through a high-temperature cycle, thus limiting the amount of decarburization. In fact, the extent of decarburization, if any, is too small to be detected by x-ray diffraction. The coatings are dense and display moderate hardness, but exceptional abrasive and sliding wear resistance.

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2. Background to Multimodal Feedstock Powders

Figure 1 shows two different types of mixed micro- and nanoparticles of WC/Co, in the form of sprayable agglomerates. The structure of such a multimodal material is reminiscent of that of concrete, which is a well-known composite material in the engineering field. Concrete consists of large particles (such as gravel), fine particles (such as sand), and a binder phase (cement). Likewise, our multimodal agglomerated material in both cases shown in Fig. 1 consists of coarse WC, nano-WC, and a Co binder phase. However, the two structures behave differently when passed through the flame in an HVOF thermal spray gun. In the case of structure 1, the entire agglomerate needs to be heated to a suitable temperature to generate a sufficient amount of liquid phase to form a dense coating. In contrast, in the case of structure 2, the nanoparticles adhering to the surface undergoes melting faster, leaving the coarse particles largely unmelted, but softened by heating. This is because the thermal mass that needs to be heated is very small. The semisolid nanoparticles, after quenching on the substrate, provide a matrix in which the coarser particles remain embedded. As shown below, the resulting multimodal coating combines the benefits of coarse and fine grains, leading to a more abrasive resistant material than what can be accomplished by either coarse or fine grains alone.

3. Experimentation

Sprayable powders of WC/12 Co were obtained from a commercial vendor. The powder consisted of agglomerates in the range 15 to 40 μm with a carbide grain size of 2 to 5 μm. Nanocarb® with a composition, WC/5Co, was obtained from Nanodyne Inc. and processed to form particles in the range 0.1 to 0.5 μm. Each particle is composed of many WC nanocrystals, ~30 nm in diameter. The two powders were homogeneously mixed so that the coarse grains constituted about 70 vol.% of the mixture. A paraffin binder was used. The average Co content was less than 10%. The mixed powders were heat treated to form sprayable powders, such as those shown schematically in Fig. 1 (structure 2). The powders were sprayed using a standard DJ

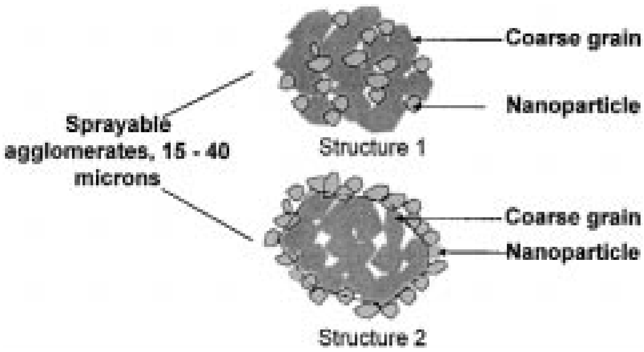


Fig. 1 Schematic showing two types of multimodal agglomerated powder feeds for thermal spraying

Table 1 Hardness and wear data on WC/Co coatings

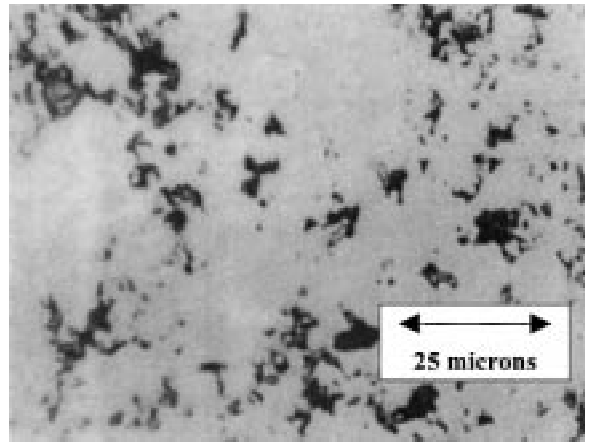
	Hardness (VHN)	Abrasive wear resistance (Nm/mm^3)	Sliding wear resistance	Amount of decarburization
Multimodal 1 Coarse WC/12 Co-Nano-WC/5Co Average Co: ~10 %	820	2.5×10^2	6.7×10^6	1.7%
Multimodal 2 Coarse WC/8 Co-Nano-WC/5Co Average Co: ~7%	470	0.76×10^2	10×10^6	3.8%
Coarse-grained WC/12 Co	1080	1.5×10^2	5.9×10^6	10%
Nanograined WC/12 Co	1020	0.68×10^2	1.75×10^6	83%

thermal spray gun. Thick coatings in excess of 0.2 in. were easily sprayed. A similar experiment was performed starting with WC/8Co coarse-grained powders mixed with nanopowders of WC/5Co. The average Co content in this case was about 7%.

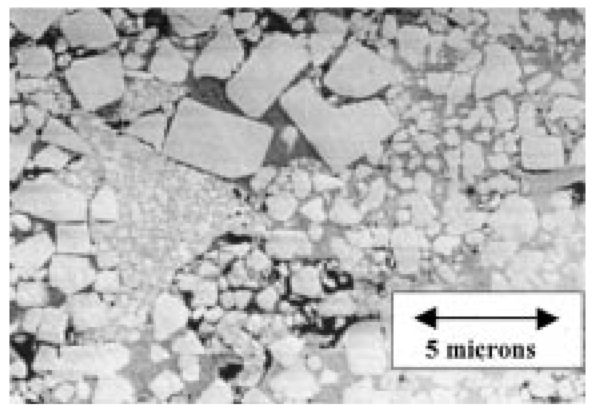
The hardness was measured on the surface by Knoop indentation at loads up to 1000 g. The sliding wear tests were conducted on a ball-on-disk tribometer at sliding speeds of 18 to 30 mm/s, load 9.8 N, and sliding distance from 24 to 12,000 m, at room temperature in laboratory atmosphere at unlubricated conditions, where WC-Co coatings work as the disk against Si_3N_4 ball. Friction coefficients were measured. Wear volume of both the coating disks and ball was determined. Abrasion tests were conducted on an ML-100 pin-on-disk tribometer in ambient temperature and humidity. WC/Co samples were cut into pins with 8×8 mm^2 cross section. The pins were applied with 2 N load, and slid against silicon carbide abrasive disk for 38 min. The abrasive disk was a LECO 120 GRIT (106 mm) plain back abrasive disk with the hardness of H_v 2600 (LECO Corporation, St. Joseph, MI). The abrasion rate was calculated from the weight loss before and after abrasion. The oxidized layers were removed by diamond grinding before abrasion.

4. Results and Discussion

Table 1 shows the hardness, abrasive wear resistance, and sliding wear resistance for the two types of multimodal coatings. Also shown are the corresponding data for conventional "single-mode" coatings of exclusively coarse-grained and nanograined WC/Co materials.



(a)



(b)

Fig. 2 (**a**) Optical micrograph of a polished surface of coating labeled Multimodal 1 in Table 1, and (**b**) SEM micrograph of the same, showing coarse and fine grains

Figure 2(a) shows an optical micrograph of the surface of coating labeled Multimodal 1 in Table 1. Figure 2(b) shows a scanning electron microscopy (SEM) image of a cross section of the same coating. The inhomogeneous distribution of the coarse and fine grains can be attributed to improper mixing of the powders and fragmentation of the agglomerates during spray deposition. Processing improvements are likely to further improve properties. Although part of the improved abrasive wear resistance in the multimodal coatings can be attributed to a tough matrix and the absence of any decarburized phases, it is likely that nanocrystalline phases act as "sand" and "cement" that hold the "gravel" together (analogy with concrete). Another contributing factor is the reduction in average Co content and, hence, an increase in the volume fraction of hard, wear-resistant WC phase.

Perhaps the most notable feature of our approach to forming hardmetal coatings is the realization of improved coating performance at reduced cost, compared to a single-mode nanophase coating. This is because the relatively more expensive nanopowder component of the multimodal feedstock powder is the minor constituent, about 30 vol.%. Thus, at a marginally increased cost (estimated to be no more than 8 to 10% increment in cost) for the feedstock powder, greater than 50% improvement in abrasive wear properties has been achieved. In addition, the deposition efficiency of these powders is better by about 20%, as compared to pure coarse-grained powders. A less apparent advantage of this new class of WC/Co powders is the lower amount of Co content in the powders. This further reduces the cost, as Co is the more expensive of the two phases in a WC/Co hardmetal.

5. Conclusions

We have developed a new class of thermal spray feedstock powders consisting of coarse- and nanoparticles. Hard metal coatings deposited using these powders, called multimodal coatings, have exceptionally high abrasion and sliding wear resistance.

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