Selective Laser Sintering Preparation and Tribological Testing of Nanostructured Tungsten Carbide-Cobalt Composites

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Abstract

This paper describes the results to date of research done to compare and contrast the tribological properties of nanostructured tungsten carbide-cobalt composites consolidated by selective laser sintering (SLS) and conventional grain size composites of the same chemical composition consolidated by conventional commercial methods. The powder preprocessing and selective laser sintering methods will briefly be described. The tribological testing methods will be discussed, and the tribological properties of the selective laser sintered and commercially consolidated materials will be compared. It will be seen that the nanosized WC-Co composites have far superior harness and wear resistance compared to their microsized counterparts.

Introduction

It has long been known that by refining the grain size of polycrystalline materials you can greatly improve many of their mechanical properties. Nanostructuring seeks to carry this principle out to its ultimate extreme by producing polycrystalline materials with grains, say, one hundred atoms in diameter. The problem with these materials is that they are produced in powder form and conventional consolidations methods can't be used because they involve long exposure to high temperatures which cause rapid grain growth and destroy the nanostructuring. This is where SLS comes into play. The consolidation rate is so rapid with SLS that the nanocrystals don't have time to grow.

This paper will first describe the powder preprocessing steps to densify the nanostructured WC-15Co powder[*] prior to sintering. Next, the SLS parameters will briefly be discussed, and, finally, the microhardness and abrasive wear resistance of the SLS nanostructured WC-15Co will be compared to those of the commercial WC-15Co.

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[*] Supplied by Nanodyne Incorporated, New Brunswick, N. J.

Powder Preprocessing

The as received Nanodyne nanostructured WC-15Co powder is composed of **hollow** spherical particles up to around 100 microns in diameter, which contain millions of nanosize WC grains. Because the spheres are hollow, the initial density of the powder is quite low, around 12% of full theoretical density. In order to increase the density of the final SLS product, the powder has to be densified as much as possible prior to sintering.

Step 1: Ball Milling - The as received Nanodyne powder was ball milled for 45 minutes to increase the tap density of the powder from 12% to 32%. Particles from the broken hollow spheres formed semi-spherical agglomerates up to 100 microns in diameter. A pure WC vial and balls were used to prevent contamination.

Step 2: Vacuum Heat Treatment - Next, the ball milled powder was heat treated in a high-vacuum furnace (10^{-5}- 10^{-6} Torr) at 1050°C for 1 hour. This partially sintered the powder into a green body.

Step 3: Grinding and Sieving - The green body was then ground and passed through a 125 micron sieve. The resulting powder consisted of spherical agglomerates up to around 100 microns in diameter. The final powder tap density was 47% of full theoretical density.

Selective Laser Sintering

The densified nanostructured WC-15Co powder was then laser sintered to form specimens for tribological testing. The SLS parameters used were:

Vacuum Environment: 10-20 mTorr
Scanning Speed: 500 micron per second
Line Spacing: 250 microns
Layer Thickness: approx. 200 microns
Laser Power: 25 watts
Beam Diameter: 700 microns
Geometry of Rasher Pattern: 7 mmx 4 mm rectangle

Mono-directional scanning was found to be more reliable for such small specimens because it yielded (compared to bi-directional scanning):

1) better homogeneity in the scan lines
2) more accurate specimen geometry
3) reduced incidence of curling at the line ends

The density of the SLS nanostructured WC-15Co was around 60% of theoretical full density.

Tribological Testing

Microhardness - Vickers (DPH) microhardness values given here were averaged from 5 or 6 measurements. 500 gram load was used.

Nanostructured WC-15Co
WC grain size 20-50 nanometers: 1980

Commercial WC-15Co
average WC grain size ~1.3 microns: 1260

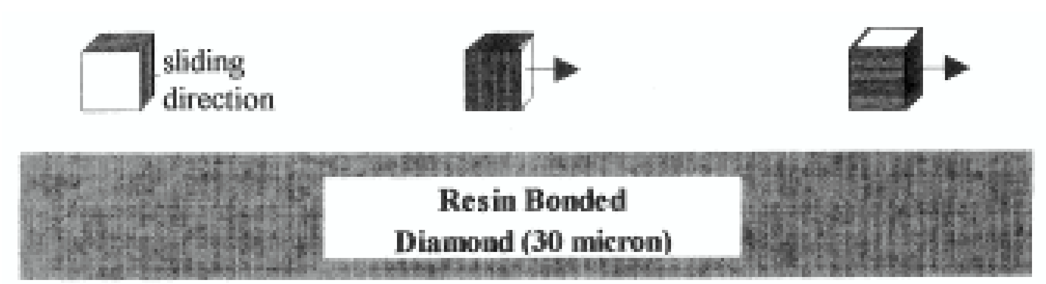
For a conventional grain sized material to be as hard as the nanostructured material it would have to have a much lower cobalt content, say, WC-3Co, which would be extremely difficult (if not impossible) to SLS.

Abrasive Wear Resistance - Pin-on-disk abrasive wear resistance tests were conducted to compare the performance of the nanostructured material to the commercial materials and to evaluate the anisotropy resulting from the layered structure of the SLS specimens.

For all tests the cross-sectional area of the pins was 3mm x 3mm squares and the counterface (disk) material was resin bonded 30 micron diamond particles. Each specimen was subject to one, two, three, and four pound loads for thirty minutes each at a sliding rate of 16.8 inches per second.

To test for anisotropy, with respect to abrasive wear resistance, three orthogonal layer orientations were used in the pin specimens.

Layer Orientation 1 **Layer Orientation 2** **Layer Orientation 3**



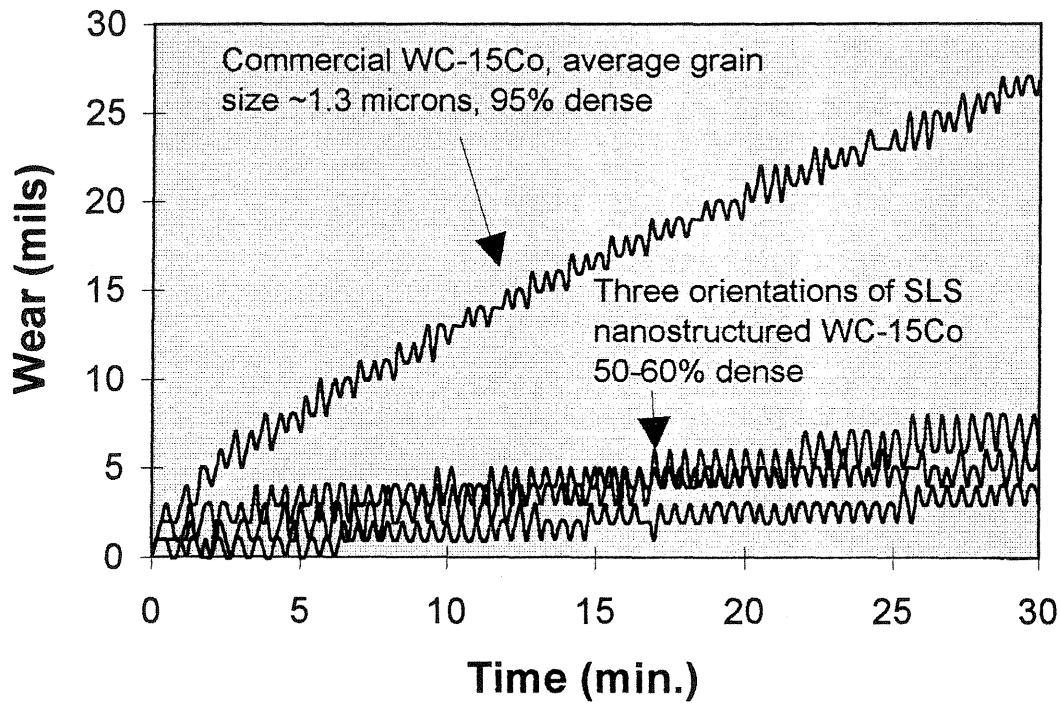
No significant anisotropy effect was observed in the abrasive wear values.

The pin-on-disk abrasive wear tests showed that the SLS nanostructured WC-15Co had approximately five times better wear resistance than the coarser grained commercial material. These results are even more impressive if one considers:

1) The SLS specimens were only around 60% dense compared to 95% for the commercial material.

2) The wear recorded for the nanostructured specimens is partially due to wear of the diamond counterface, whereas, the commercial materials did not wear the counterfaces at all.

The following graph compares the wear of the commercial material to the three orientations of SLS nanostructured specimens (the orientations are not labeled because there was no significant difference between them).



Conclusions

SLS proved to be a viable method for consolidating nanostructured powders without causing unwanted grain growth. Though the nanocrystalline microstructure has not been verified by TEM, yet, the nanostructuring must be present as nothing else could account for the superb properties measured.

What does this mean to the future of rapid prototyping (RP)? If one wanted to RP a superhard, wear resistant part (tool bits, wire drawing dies, wear pad, etc.) by SLS, a conventional grained material would have to have such a low binder composition, like WC-3Co, that there wouldn't be enough binder to hold the carbide grains together and the specimen would crumble. Now, with the advent of nanostructured WC, we can increase the binder content without losing the hardness and wear resistance we need. As an added bonus, the increased binder content should provide much greater fracture toughness and impact strength (properties which are normally improved by sacrificing wear resistance and hardness).

Future work is planned to verify the extent of grain growth, if any, during SLS, evaluate the corrosive characteristics of the nanostructured materials, increase the density of the SLS parts by bleeding binder into the pores, and to study the small scale deformation characteristics of the nanostructured materials by scratch testing.

Acknowledgments

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