ICF1001056OR

FRACTURE OF THERMAL SPRAYED NANOSTRUCTURED COATINGS

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ABSTRACT

A nanostructured alumina-13 weight percent titania plasma sprayed coating has been developed with outstanding wear, toughness, adhesion and machinability properties. The optimized properties are associated with a bi-modal microstructure that consists of a fully melted region and a partially melted region. In contrast, a baseline, commercial Metco 130 coating of the same composition contains only the single-phase splat microstructure. The crack growth resistance or "toughness" of each of these materials was investigated using the cracks generated around Vicker's hardness indents.

In Metco 130, long, wide cracks initiate in and propagate along splat boundaries. In the nanostructured alumina-titania, the spherical particles in the bi-modal microstructure serve to trap and deflect the splat boundary cracks. This produces the approximately 100% improvement in the crack growth resistance of the nanostructured coating with the bi-modal microstructure.

The volume fraction of the partially melted regions can be systematically varied by changing the plasma flame temperature. It was found that the crack growth resistance of the nanostructured coatings was optimized when the microstructure contains 15-20% of the partially melted spherical particles.

KEYWORDS

Nanostructured coating, wear resistant coating, plasma sprayed coating, toughness, crack growth resistance.

INTRODUCTION

A nanostructured alumina-13 w/o titania plasma sprayed coating has been developed that has superior wear resistance, toughness, adhesion and machinability properties [1]. The composition, powder preparation procedure, plasma spray processing parameters, microstructure and properties have been described previously [1-4]. The technology for making this coating has been transferred to the U.S. Navy and an approved supplier. A military specification has been issued and this coating is being deposited on a number of ship and submarine components for service evaluation. This paper describes the microstructural features that give rise to the improved toughness of the coating.

EXPERIMENTAL RESULTS

Crack growth resistance, or pseudo-toughness, measurements were made using a Vickers hardness tester with a 3kg load, and measuring the crack length emerging from the indent corners. The crack growth resistance is defined as the reciprocal of the crack length.

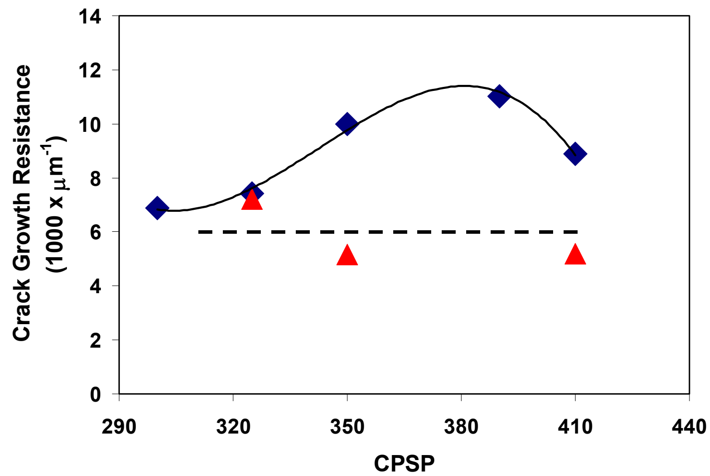

Figure 1. Crack growth resistance as a function of CPSP for Metco 130 coatings (▲) and nanocoatings (◆).

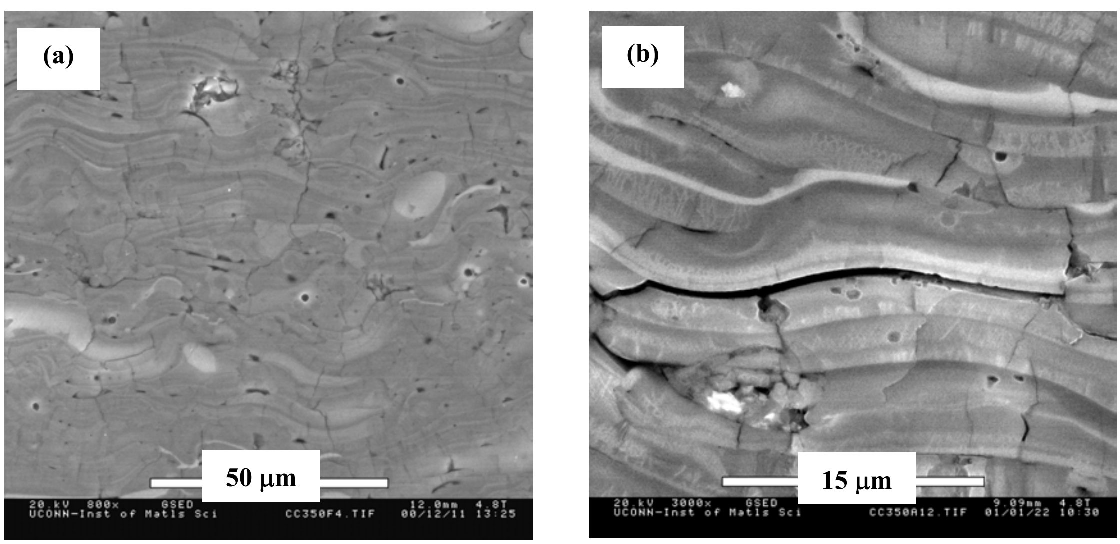

Figure 2. Microstructure and crack characteristics of Metco 130 coatings.

Figure 1 shows the crack growth resistance of the nanostructured alumina-13w/o titania coatings and that of the commercial Metco 130 coating of the same composition. The data is plotted against the critical plasma spray parameter, CPSP, that is a function of flame temperature, and was found to be the most important processing parameter that controlled the microstructure and properties of the nanostructured alumina-titania coatings [1-4]. The crack growth resistance of the nano-coating increases with increasing CPSP to a peak at CPSP of about 390. By contrast, the crack growth resistance of Metco 130 remains at a constant low value with CPSP. At its peak, the crack growth resistance of the nano-coating is twice that of the Metco 130.

Figure 2a shows the microstructure of the plasma sprayed Metco 130 coating, with its well-defined lamellae or splat structure, associated with deposition and rapid solidification of molten powder particles. Figure 2b shows that the cracks from the hardness indents propagate along splat boundaries.

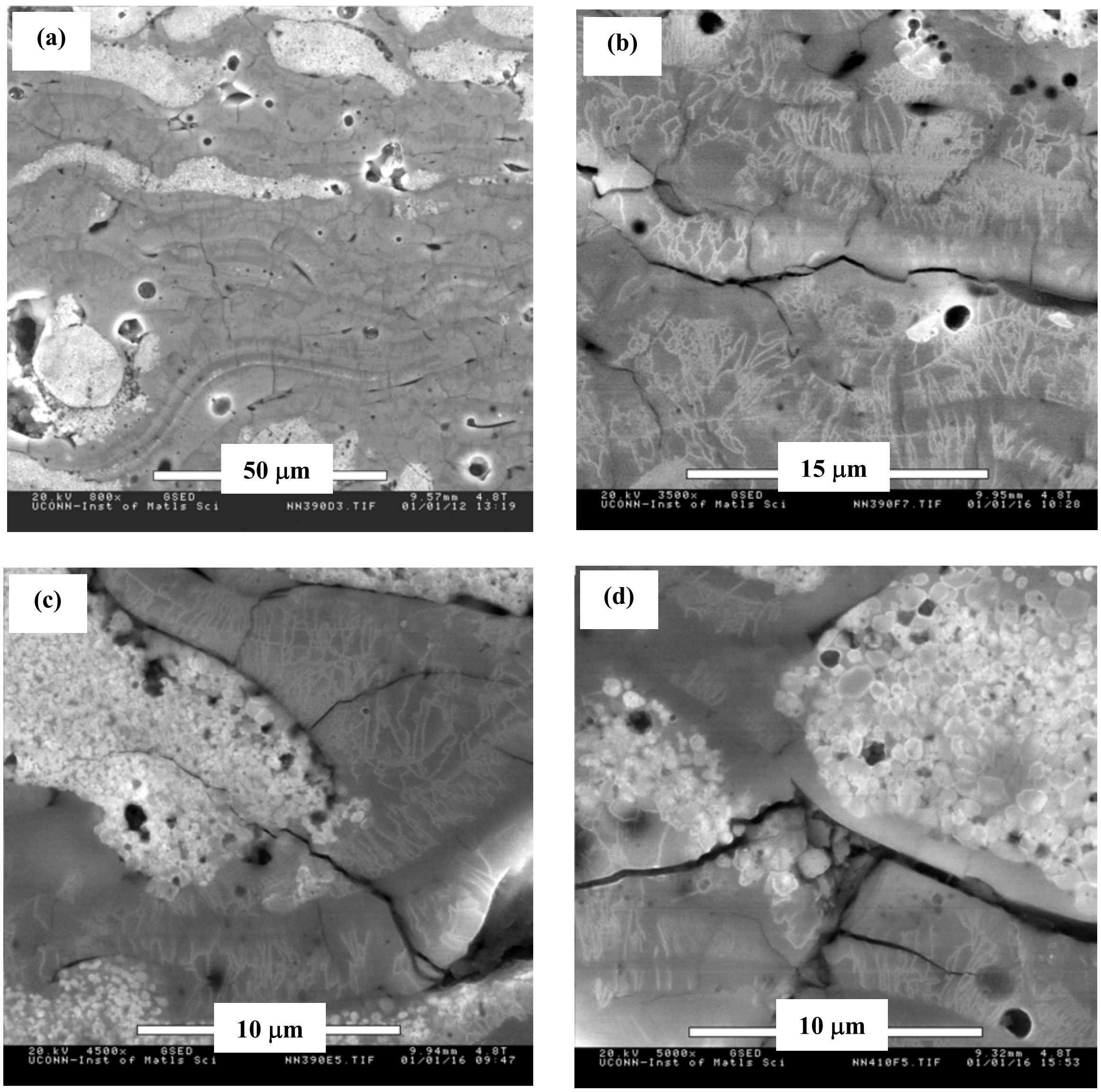

Figure 3. Microstructure and crack paths of nano alumina-titania coatings.

In contrast, Figure 3a shows the microstructure of the nano alumina-titania coating. In addition to the splat structure, there are particulate microstructures (partially melted regions) the shape of which varies from a splat like structure to a round, agglomerate structure depending on the amount of melting that occurred during the thermal spray process. As in the

Metco 130, some cracks also propagate along splat boundaries (Figure 3b). However, in the nanocoatings with the bi-modal microstructure, there are various microstructural features that serve to arrest or deflect cracks and provide toughening. Figure 3c shows a crack being stopped or trapped in the partially melted region. Figure 3d shows a crack being deflected at the interface between the fully melted splat region and the partially melted spherical particles. It is well established that toughening mechanisms such as crack deflection and crack trapping can improve the crack growth resistance of brittle materials [5-8]. Thus, based on these results, we can conclude that nanocoatings should have higher crack growth resistance than Metco 130 coatings because of the toughening mechanisms observed in the nanocoatings.

In order to provide a semi-quantitative determination of the effect of microstructure on crack growth resistance, the microstructural changes with CPSP were determined. Figure 4 shows that the volume fraction of the partially melted regions decreases with CPSP. Based on detailed examination of cracks around at least 10 hardness indentations in each nanocoating, the relative contributions made by various microstructural features, interface boundaries, porosity, partially melted and fully melted regions, to crack growth resistance was assessed. Figure 5 shows the results. By comparing Figures 4 and 5, it can be seen that at CPSP=410 where 90% of the microstructure is fully melted splats, the splats account for only 10% of the crack arrests. By contrast, 64% of the crack arrests in the CPSP=410 specimens are associated with crack arrests in the partially melted regions and by crack deflection at the boundary between partially and fully melted areas.

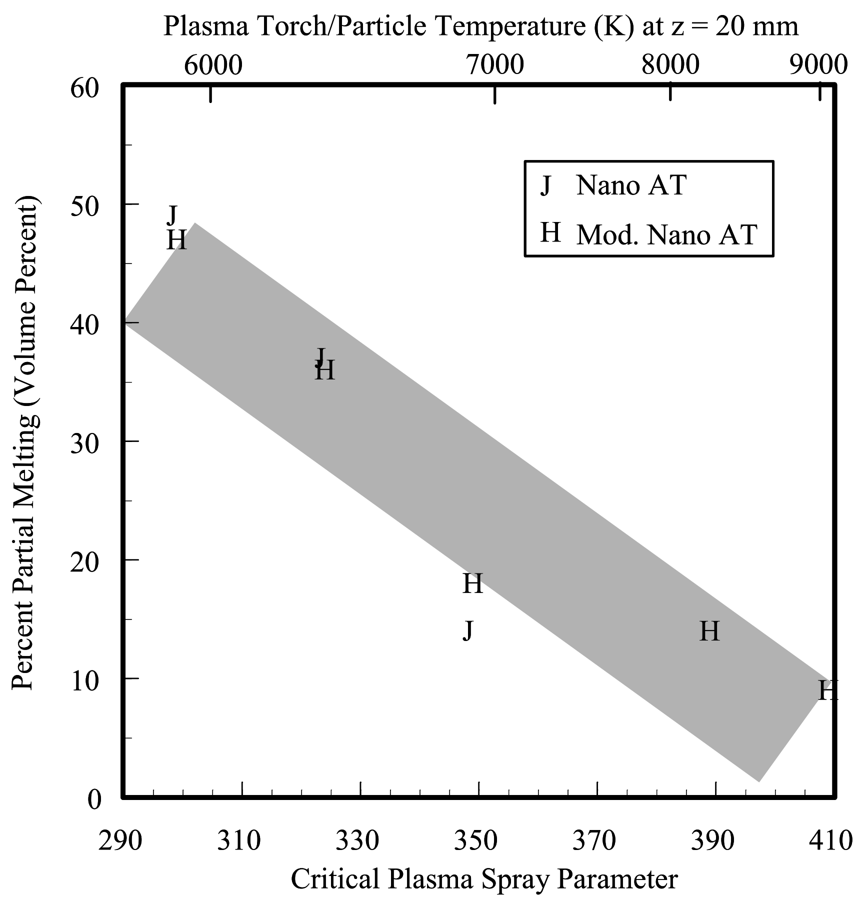

Figure 4. Percentage of coating that is partially melted, determined by quantitative image analysis as a function of CPSP or the plasma torch temperature at a spray distance of 20 mm.

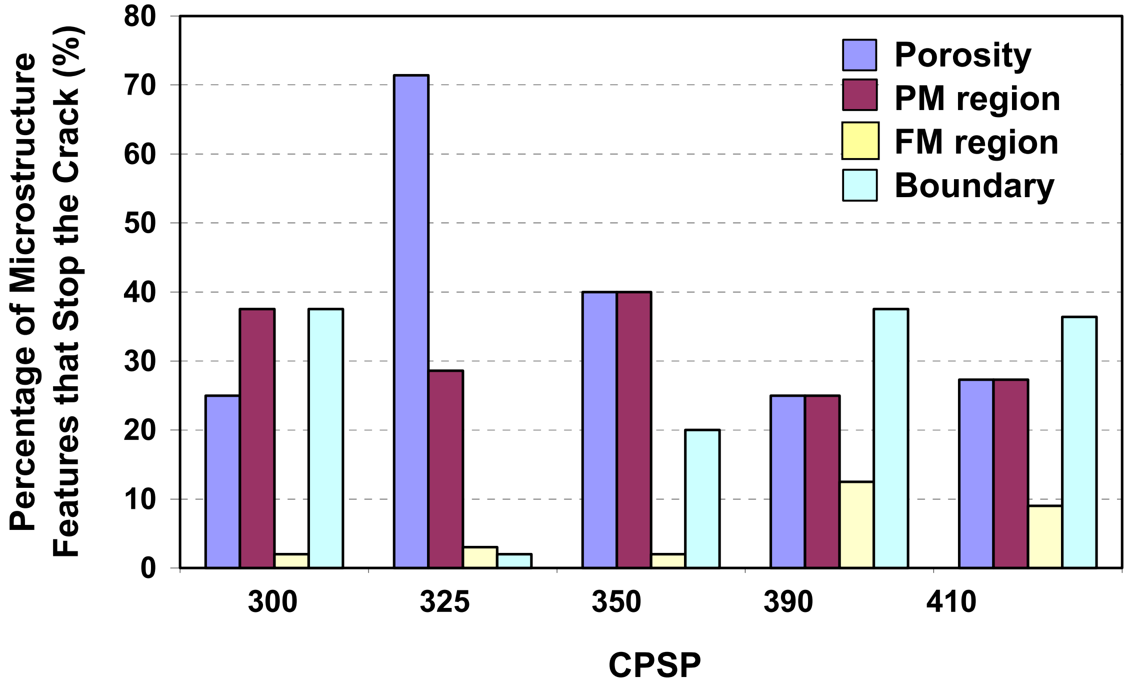

Figure 5. Percentage of microstructure features in the nano alumina-titania coatings that stop the crack as a function of CPSP.

Porosity in the microstructure plays a larger role as the CPSP is reduced. However, for CPSP's less than 350, the porosity level is high (about 10%) because of a high volume fraction of partially melted particles, and this lowers the overall crack growth resistance of these microstructures.

SUMMARY AND CONCLUSIONS

For the nanostructured alumina-titania coatings, optimized crack growth resistance and toughness were obtained for intermediate levels of CPSP. For these CPSP levels between 350 and 390, the partially melted regions represent 15 to 20% of the bi-modal microstructure and provide optimum toughening from a variety of crack arresting and deflection mechanisms. When CPSP is high; e.g., 410, there are insufficient partially melted regions to provide toughening. When CPSP is low; e.g., <350, the coating has sufficient porosity that the toughness of the microstructure is low.

ACKNOWLEDGEMENTS

This work was supported under ONR Contract No. N00014-98-C-0100. The vision and support of Dr. Lawrence Kabacoff, ONR Program Administrator, is greatly appreciated. The efforts of Inframat Corporation in plasma spraying the specimens is noteworthy.

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