HEXRD measurements of strain in plasma-sprayed coatings

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Introduction

Plasma spraying is a widely used technique for production of various protective metal and ceramics coatings that find applications as thermal barriers and wear- and corrosion-resistant surface layers. As a result of the deposition process, the coatings have properties quite different from bulk materials of the same composition, among them being porosity, anisotropy, and residual stress [1, 2]. Residual stress as an important life-limiting factor is preferably measured nondestructively by diffraction techniques. Among these, high-energy x-ray diffraction (HEXRD) offers the advantage of stress/strain depth profiling on thin coatings (<1 mm) while keeping high spatial resolution with small gauge volumes [3, 4].

Methods and Materials

Several thermally deposited coatings of molybdenum, nickel, and one FGM (functionally graded material) having thicknesses ranging from 0.3 mm to 1 mm were investigated with respect to both the effect of applied strain and to their intrinsic strain states. All specimens were prepared at the Thermal Spray Lab at the State University of New York, Stony Brook, NY. Aperture sizes on both the incident and reflected beam sides were between 0.05 mm and 0.10 mm. Additionally, the divergence on the reflected beam side was limited by means of a second pair of slits to 0.013º (0.05 mm opening) and 0.026º (0.10 mm opening), respectively (Figure 1).

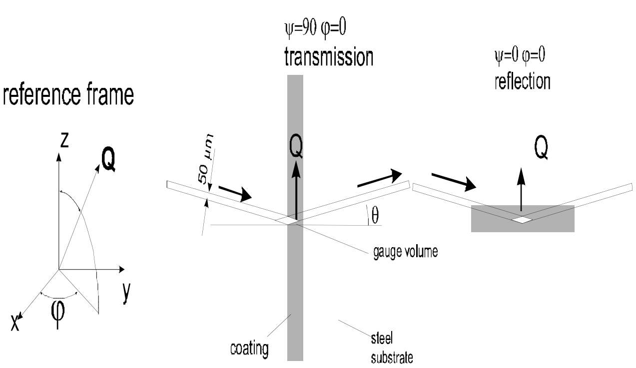

Figure 1: Schematic of beam dimensions and sample orientations.

The four-point bending experiments were conducted in a setup as shown in Figure 2. The transmission geometry was used because only in-plane strains were applied. The depth distribution of the in-plane strains was probed by moving the specimen stepwise through the sampling volume.

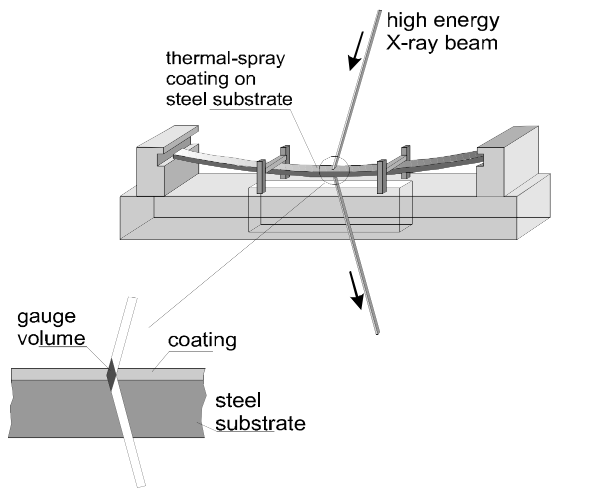

Figure 2: Experimental setup of the bending experiments. The actual scattering plane was horizontal.

Depth profiling as conducted here is strongly influenced by the shift of the center of gravity of the gauge volume due to partial immersion. The effect can be corrected for by using geometrical considerations if all values for thickness, slit width, and distances are precisely known. These corrections were applied but carry some uncertainties in the values for the slit distances.

Results

Figure 3 shows that the results are still affected by partial illumination effects in the near-surface region as indicated by the steep slope of the strain distribution within the first 100 μm. However, partial-illumination effects are symmetric on both sides of the coating. Thus, the nonsymmetric behavior of the strains at the surface side and the substrate side of the coating suggests a depth-dependent residual strain distribution in the coating (≈ 0.4 mm thickness) under applied strain.

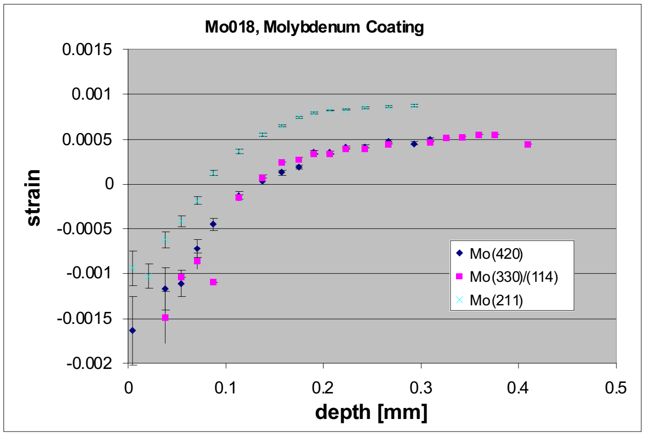

Figure 3: In-plane strain measured in transmission on a Mo coating.

The results are different for each reflection (hkl). Each reflection (hkl) originates from a different energy with a different penetration. Thus, each (hkl) suffers differently from partial-illumination effects and may show a different strain profile (Figure 4).

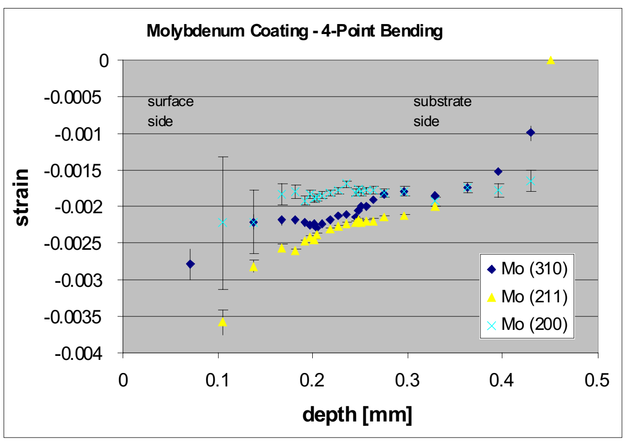

Figure 4: Molybdenum coating in a four-point bending experiment. The measurement was conducted in transmission geometry.

Discussion

These results indicate that HEXRD has a high potential for depth profiling of thin coatings. The spatial resolution used here can be further improved both by increasing the scattering angle and using smaller slit apertures and distances without sacrificing the high intensities that are necessary for sufficient strain resolution.

Acknowledgments

The authors thank Ali Mashayekhi and Adam Pyzyna for their valuable help as well as the Advanced Photon Source synchrotron and the Experimental Facilities Division for granting beam time (Argonne National Laboratory, Argonne, IL). This work was supported by the U.S. Department of Energy, Federal Energy Technology Center and Basic Energy Science – Material Sciences, under contract W-31-109-Eng-38.

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