MEASUREMENTS OF COATING THICKNESS OF DIAMOND-COATED TOOLS BY WHITE-LIGHT INTERFEROMETRY

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ABSTRACT
In this study, the coating thickness of diamond-coated tools was evaluated and investigated by non-contact measurements. Commercial cobalt-cemented tungsten carbide (WC-Co) cutting inserts (edge radii from 5 to 80 microns) were used as substrates for varying CVD-diamond depositions. A white-light interferometer (WLI) was used to acquire the surface profile data around cutting edges. MATLAB algorithms were generated to further analyze the tool geometry using the data cloud obtained from the WLI.

The characteristics of a cutting edge (the edge radius, the rake/flank surfaces, and the wedge angle) were then obtained by curve fitting. This methodology was applied to both uncoated and coated tools for the geometry characterizations. To evaluate the coating thickness, the fitted uncoated and coated profiles (from the same tool) were overlapped with the edge rounding centers kept at the same location. The coated profile was then rotated to have the rake face parallel to the uncoated one (as a reference). The normal distance between the two tool profiles (uncoated vs. coated) was used for coating thickness estimates. The combination of WLI and the developed algorithm is capable of efficient coating thickness measurements. Tools with large edge radii had high uncertainties in coating thickness.

INTRODUCTION
Chemical vapor deposition (CVD)-grown diamond films have been increasingly explored for cutting tool applications as an alternative to costly polycrystalline diamond (PCD) tools [7]. Coating attributes such as the coating thickness significantly affect the coating-substrate interface stresses resulted from the deposition process. Therefore, accurate estimates of coating thicknesses, especially around the tool tip is important for quality control and process modeling.

Presently, multiple options exist for coating thickness measurements. Many accurate methods, such as differential interferometry [5], stylus profilometry [10], scanning electron microscopy [11], involve scratching/cratering [1] or other destructive methods. Acoustic thickness measurements are non-destructive; however, the resolution may not be sufficient for the thicknesses used for diamond-coated tools [13]. Raman spectroscopy is a promising prospect, but presently, it is only used for ultra-thin coatings on the order of nanometers [14]. Optical pyrometry has also shown favorable results, but it can only offer an average coating thickness over a large surface [2].

WLI has been applied to coating thicknesses measurements before; however, most cases have only employed a single measurement after the deposition process. This approach is limited by the need to precisely know the refractive index of the tool materials (both coating and substrate) in order to calculate the difference in distances traveled by light reflected from the coating and substrate surfaces [3]. Also, the method has only been applied to ultra-thin coatings [8] and has proven largely ineffective on opaque coatings [6].

The objective of this study was to investigate the coating thickness of diamond-coated cutting tools by WLI. WLI data was processed using generated algorithms which objectively evaluate the tool geometry. These algorithms were applied to individual tools before and after the diamond coating process. The results from each tool were compared and used to calculate diamond coating thickness.
METHODOLOGY

Experimental Setup
A white light interferometer, NT1100 from Veeco Metrology, was used to collect surface data around cutting edges using the vertical scanning interferometry mode. An objective lens of 50X and a 0.5X field of view lens were used. Commercial WC-Co cutting inserts of square shape were used (SPG422): 12.7 mm width and 3.1 mm thickness. The nominal corner radius was 0.8 mm and the wedge angle was 79°. Four separate tool sets (coded A through D) of various edge radii (A: 18 μm, B: 39 μm, C: 80 μm and D: 4 μm), each including five individual samples was tested. Straight cutting edges were measured, 4 edges for each tool sample. A single scan mode was used. In addition, the tools were subsequently diamond coated with 3 different thicknesses, and then further measured by the WLI.

Edge Measurements
An example of a cutting edge surface acquired by the WLI is shown in Figure 1. The instrument software (Vision) was also used for initial data processing including a low pass filter and data restoration to interpolate and replace any missing data. Once finished, the data file can be processed using MATLAB.

![Figure 1](image1.png)

**FIGURE 1.** A cutting edge image from measurement.

An algorithm to characterize the straight cutting edge was developed in order to allow coating thickness measurements later. After importing the data matrix into MATLAB, an algorithm developed was applied to approximate the edge profile and returns the edge radius and the wedge angle [12]. Figure 2 conceptually shows an example of the results described above.

![Figure 2](image2.png)

**FIGURE 2.** (a) 2D projection of raw data, (b) linear and circular fits of the edge profile.

Coating Thickness Algorithm
After performing the above algorithm for the uncoated and coated datasets for each tool, the 2D profile results were then used to calculate each tool’s coating thickness. To begin, the uncoated and coated datasets were plotted, directly using the results of the previous algorithm. Next, the coated data was translated such that its approximated tool edge center point lied concentric with that of the uncoated dataset. Because of the positioning of the tools during diamond coating and the coating process’s “line-of-sight” method, it was known that the uncoated and coated rake faces should be referenced as parallel. Thus, the coated tool data needed to be rotated in order to accurately represent the associated coated tool. This was accomplished by rotating the coated tool data about its edge center point until the rake face lied parallel with the uncoated rake face.

After the translation and rotation, the varying sizes of the coated and uncoated tool matrices necessitated the removal of overlying edges of each dataset. In particular, the data edges...
needed to be cut on a line perpendicular to the tool face in order to simplify the coating thickness calculation process. This was obtained by using the previously calculated tool face slopes and a simple point-slope calculation. Once the data edges were removed, the thickness calculation process began. The uncoated and coated data matrices were input into a separate inter-point distance matrix (IPDM) algorithm [4]. This allowed quick calculations of the distances between all points of the two datasets.

Due to the large number of data points, the minimum values were used as approximates of the perpendicular distance between the coated and uncoated tool faces at each data point. Finally, the diamond coating thickness along the tool edge was calculated using the difference of the coated and uncoated edge radii measurements.

RESULTS AND DISCUSSION

Result Example

Specimens with different edge radii and coating thicknesses were thoroughly tested using the developed methodology. Even with these large deviations in tool geometry, the developed algorithm proved effective on most cases. Figure 3 and Table 1 show a typical result output from an uncoated and a coated tool samples.

![FIGURE 3. Final plot of coated and uncoated fits prior to measurement.](image)

It should also be noted that the methodology employed displays some limitations when viewing extremely large radii tools (~70 µm or larger such as C case). A single WLI scan did not have enough data to provide a robust fit. Thus, multiple scans with the stitching function are needed to acquire more data.

<table>
<thead>
<tr>
<th>TABLE 1. Sample results from Figure 3.</th>
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</thead>
<tbody>
<tr>
<td>Radius Std. Dev</td>
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<tr>
<td>[µm]</td>
</tr>
<tr>
<td>16.1230</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Coated Tool Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius Std. Dev</td>
</tr>
<tr>
<td>[µm]</td>
</tr>
<tr>
<td>29.8457</td>
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</table>

<table>
<thead>
<tr>
<th>Coating Thickness Data</th>
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<tbody>
<tr>
<td>Rake Face Flank Face Tool Edge</td>
</tr>
<tr>
<td>Thickness Min. Thickness Avg. Thickness Max. Thickness Thickness</td>
</tr>
<tr>
<td>[µm]</td>
</tr>
</tbody>
</table>

Tool samples with varying edge radii and coating thicknesses were analyzed using the algorithms described above. The results showed that the rake face coating thickness was typically thicker than the flank coating thickness. Further, it was observed that thin coating tools resulted in more uniform thickness over the measured regions. Conversely, thick coatings resulted in a tapered coating thickness on the flank tool face. This was expected, due to the "line-of-sight" diamond coating process and the inward tilt of the flank face during that process. Example plots of thin and thick tool coatings are demonstrated in Figure 4: (a) a medium edge radius with a thin coating and (b) a sharp edge with a thick coating. Coating thicknesses were analyzed for tools which underwent the CVD coating process for varying amounts of time. Tools with three different edge radii (A, B, and D) were tested for each coating time type. Table 2 below shows the averaged results from the three cases for each of the coating processes.

![Coating Thickness Data](image)
FIGURE 4. (a) Plot of thin coating edge, (b) plot of thick coating edge.

TABLE 2. Coating thickness results.

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Average Coating Thickness (um)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Short&lt;-----Coating Time------&gt;Long</td>
</tr>
<tr>
<td>A</td>
<td>5.93  16.71  32.58</td>
</tr>
<tr>
<td>B</td>
<td>5.11  10.98  22.13</td>
</tr>
<tr>
<td>D</td>
<td>11.12 16.27  33.95</td>
</tr>
</tbody>
</table>

CONCLUSIONS
This study investigated and analyzed the coating thicknesses of diamond coated cutting tools using WLI. Algorithms were developed to filter and process the WLI data before estimating tool geometry and coating thickness. The major findings are summarized as follows:

(1) The combination of WLI and the developed algorithm is capable of efficient coating thickness measurements. Tools with large edge radii had high uncertainties in coating thickness.

(2) Coating thickness can be slightly thicker at the tool edge than at the rake/flank faces.

(3) Coating thickness is uniform at the rake face, but shows a linearly decreasing trend along the flank face. This feature became more prevalent with increased coating thicknesses.

ACKNOWLEDGEMENTS
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REFERENCES