In-Process Cutting Temperature Monitoring Method Based on Impedance Model of Dielectric Coating Layer at Tool-Chip Interface

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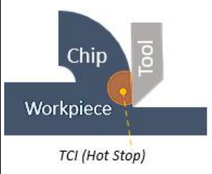
Journal of Manufacturing and Materials Processing

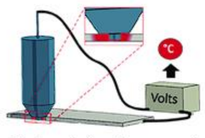
Published @ J. Manuf. Mater. Process. 2022, Volume 6, Issue 5, 97

Abstract & Motivation

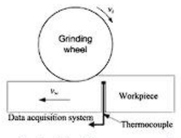
- Controlling and monitoring the machining process are critical for manufacturing efficiency.
- However, monitoring the region of the tool-chip interface (TCI) is challenging due to the physical inaccessibility.
- Currently, there are no tools available in the commercial market for measuring and monitoring cutting processes at the TCI region.
- The proposed method measures the real-time cutting temperature by directly probing the localized TCI using a cutting tool coated with dielectric material.
- The application and expectation of this study is to provide real-time machining data to help end users in manufacturing industry to improve product quality, productivity, and prolonged lifespan of cutting tools.



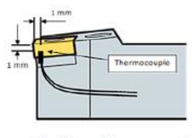
TCI (Hot Stop)



Tool-workpiece thermocouple



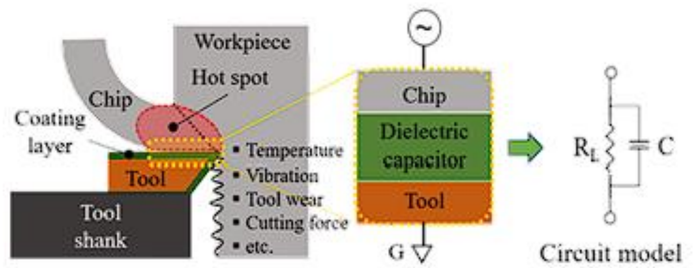
Embedded thermocouple



Tool-insert thermocouple

Methodology

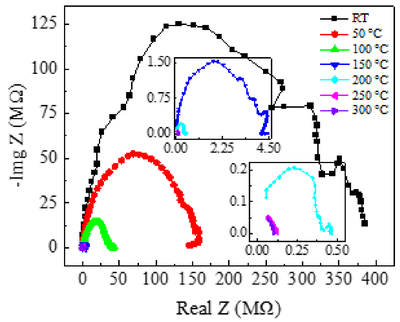
- Thin (<100μm) layer of coating are applied to the cutting tools to prevent tool wear and prolong the lifespan.
- Sandwiched tool structure is constructed while machining as shown in the below figure.
- Workpiece and base material (tool) » Electrodes
- Diamond coating » Dielectric capacitor
- Equivalent impedance is subject to change under varying temperature, contact area, and thickness of the dielectric material.
- Therefore, cutting temperature, vibration, tool wear, cutting force at the local TCI may be monitored.

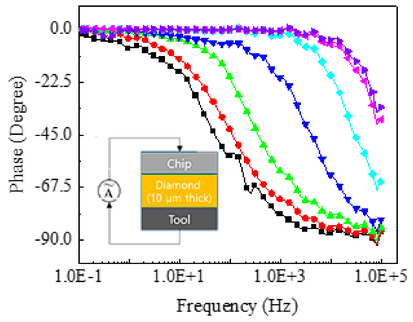


Schematic of Tool-Chip Impedance Model

Impedance Analysis

- Impedance Spectroscopy (EIS): Diamond layer (contact area: ~3.14mm²)
- Impedance decreased as temperature increased.
- Exhibited 1st order system response and natural frequency increased.
- Thus, the temperature-dependent impedance characteristic of dielectric could be utilized for the machining monitoring method to monitor the cutting temperature at the local TCI region.



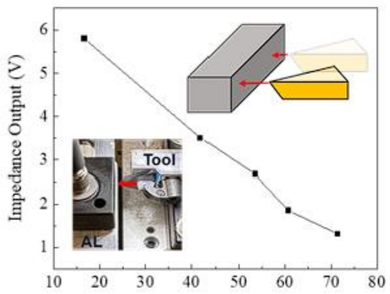


Impedance spectroscopy of dielectric coating layer under varying temperature

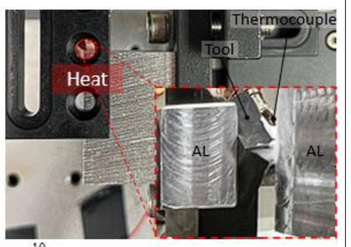
Indentation & Heat Effects

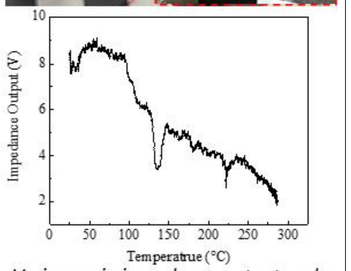
- Impedance Output vs. Depth of Contact
- Tool was contacted under varying depth conditions and the output voltage was monitored. As the depth of contact increased, the output impedance decreased.

- Impedance of dielectric layer was monitored while increasing temperature. As temperature raised, output impedance dropped significantly.



Impedance output under varying depth of contact

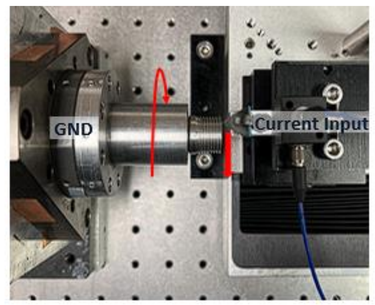


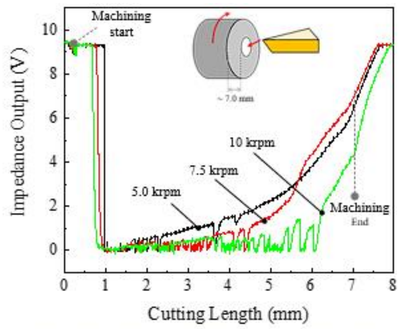


Variances in impedance output under elevated temperature

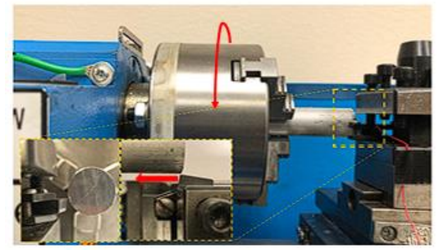
Machining Experiment

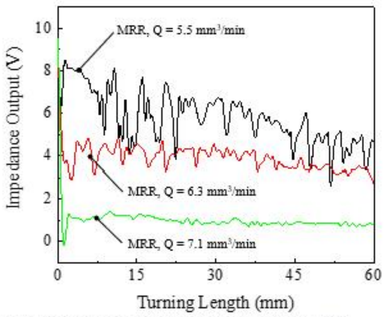
- Facing & Turning Operations performed
- Impedance at the TCI dropped drastically as machining started during facing operations and showed different temperature profiles for turning operations.





Facing machining experimental setup for impedance measurement and results





Turning machining experimental setup for impedance measurement and results

Conclusion

- Preliminary study of the impedance model based in-process machining process monitoring method was introduced
- Impedance spectroscopy showed that the impedance of the dielectric coating layer was dependent on temperature
- Machining experiments were conducted, and the method exhibited the capability of monitoring the machining process
- Impedance of the dielectric layer was also dependent on the contact area
- Preliminary study results showed that the method can be applied to the machining process monitoring method

Future Works

- Relationship among impedance, temperature, contact area will be numerically and quantitatively analyzed throughout calibrations and characterization process
- Various cutting mechanics and machining processes will be assessed and monitored
- Other dielectric coating materials and different workpiece materials will also be considered after characterizing the impedance model.

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