Chapter 7

Conclusion and Future Research Initiatives

7.1 Conclusion

This Dissertation study looked into alternatives to dry and traditional flood cooling in micromilling, such as coated tools, MQL, and MQL consisting of solid nanoparticles. Surface roughness, tool wear, cutting forces, and top burr width were among the performance characteristics that were evaluated. The following list includes the precise conclusions that may be taken from each section of this research.

7.1.1 External delivery using CuO-enhanced environmentally-benign water-based cutting fluids and utilization of different coated microtools

- Based on experimental research into the effectiveness of micro milling with AlTiN and TiAlN coated WC microtools and water-based CuO nanofluids MQL, minimized burr development on the top side of microchannels, reduced cutting forces, built-up edges, and tool wear. The characteristics of water-based CuO nanofluids, such as spherical size, dynamic viscosity, particle size in solution, XRD, and wettability over different cutting tools, were investigated. With increasing CuO nanoparticle volume fraction, contact angles of CuO nanofluids on uncoated, TiAlN-coated, and AlTiN-coated WC substrates reduce. Dynamic viscosity also rises with volume concentration, with base fluid showing a more significant increase at 1 vol% CuO nanofluids of 16.85%.
- Relative to dry machining and base liquid MQL, the inclusion of CuO nanoparticles in deionized water reduces cutting forces, surface roughness, and top burr width values. Compared to uncoated and TiAlN coated WC micro-mills, the AlTiN coated WC microtools show better machining performance

owing to higher hardness and lower coefficient of friction relative to Ti6Al4V alloy.

- The lowest resultant cutting forces are observed below 0.4 N in 0.25 vol% CuO nanofluid MQL conditions with AlTiN coated WC micro-mill owing to the ball-bearing capability of CuO nanofluids and higher hardness of the coating.
- With several cutting conditions and an AlTiN-coated WC micro-mill, surface roughness was decreased. Under a 0.25 vol% CuO NF-MQL cutting condition, lower surface roughness values also were attained below 50 nm.
- The top burr width was evaluated for both up and down milling in each cutting condition. It was discovered that the AlTiN coated tool with 0.25 vol% CuO NF-MQL performed better, resulting in burr widths that were reduced by 61.04% and 77.75% against dry conditions in up milling and down milling, respectively. Similarly, TiAlN coated tools reduced burr width by 36.52% and 82.53% while up and down milling, respectively.
- The most crucial component in lowering tool wear, edge chipping, and adhesion wear was the addition of CuO nanoparticles at a concentration of 1 vol%.
- MQL provided a uniform surface morphology with lesser flaws utilizing coated and uncoated tools.

7.1.2 External delivery using CuO and MoS_2-enhanced environmentally-benign vegetable oil-based cutting fluids

- This work sought to investigate the efficacy of soybean oil as a cutting fluid for micro-machining purposes by dispersing stable suspensions of CuO nanoparticles and MoS_2 nanoplatelets in vegetable oils, especially soybean oil. It also discussed micromilling performance in terms of tool wear, specific cutting force, burr formation, surface roughness, and surface topography. Before performing micromilling experiments, the physical property of nanofluids was measured in terms of dynamic viscosity, contact angle, and droplet size.

- It has been noted that introducing CuO nanoparticles and MoS_2 nanoplatelets increase wettability and dynamic viscosity. Applying CuO, MoS_2 and CuO-MoS_2 nanofluids increases the dynamic viscosity of vegetable oil by 6.12%, 10.17%, and 11.72%, respectively. While soybean oil (37.45°) was combined with CuO (23.48°), MoS_2 (26.57°), and CuO-MoS_2 (27.45°) nanoparticles, the contact angle of nanofluids on AlTiN coated WC substrate lowered.
- The areal surface roughness (S_a) at 0.3 μm/tooth was lessened by about 38.6%, 50.8%, 40.7%, and 52.9% using soybean oil MQL, CuO, MoS_2, and hybrid CuO-MoS_2 nanofluids MQL compared to dry conditions. Similarly, at 4 μm/tooth, areal surface roughness (S_a) reduce by about 32.12%, 47.3%, 38.8%, and 55.1% using soybean oil MQL, CuO, MoS_2, and hybrid CuO-MoS_2 nanofluids MQL than dry conditions.
- Because of the combined action of rolling and shearing by CuO nanoparticles and MoS_2 nanoplatelets, the areal surface roughness measured was minimum for hybrid CuO-MoS_2 nanofluids than other lubricating circumstances at 0.3 μm/tooth and 4 μm/tooth. Hybrid nanofluids' surface topography also showed evidence of being smoother, with fewer feed marks and surface flaws.
- For dry, CuO, MoS_2, and CuO- MoS_2 nanofluids MQL except for soybean oil, edge radius enlargement for 0.3 μm/tooth is attained higher than 4 μm/tooth, and the percentage enlargement for cutting edge radius was 12.37%, 29.99%, 23.18, and 54.23% accordingly. For dry, soybean oil, CuO, MoS_2, and CuO-MoS_2 nanofluids MQL conditions, the enlargement in edge radius due to 0.3 μm/tooth than 4 μm/tooth, results in larger size wavy and thicker burrs in down

milling, which causes percentage enlargement of equivalent burr width by 51.85%, 3.76%, 61.12%, 60.61%, and 47.54%, respectively.

- The bottom of the WC microtool surface and the cutting edges showed chip adherence while dry micromilling at 0.3 µm/tooth. Despite proper lubrication, soybean oil MQL minimizes tool adhesion for the ploughing regime at 0.3 µm/tooth. CuO NF-MQL and MoS2 NF-MQL were proven more efficient for adhesion wear for the shearing regime at 4 m/tooth than vegetable oil MQL and dry environments.
- At a feed rate of 0.3 µm/tooth, MoS_2 nanofluids produced a lower specific cutting force. In contrast, at a 4 µm/tooth rate, CuO nanofluids significantly reduced specific cutting force.

7.1.3 Variation of emulsions supply at different rotational speeds to enhance machining performance

The impacts of several MQL flow rates of 60, 125, and 250 ml/h of soybean oil-water and paraffin oil-water emulsions, along with two distinct spindle speeds—10,000 and 35,000 RPM—on machining performance indicators such as cutting forces, surface roughness, surface topography, and burr formation are demonstrated in this section.

- The largest magnitude of cutting forces is obtained in dry conditions, although increased spindle speed reduces cutting forces due to thermal softening from high heat generation.
- At 10000 rpm spindle speed, 125 ml/h and 60 ml/h flow rates are sufficient for cutting force reduction and tribofilm stability by paraffin oil water-emulsion (PO+ DIW) and soybean oil water-emulsion (SO+DIW), respectively. At 35000

RPM spindle speed, 250 ml/h MQL flow rate of paraffin oil-water and soybean oil-water emulsion is more effective for cutting force reduction.

- Since soybean oil-water emulsion has a higher viscosity and a more stable lubricant film than paraffin oil-water emulsion at 10000 rpm spindle speed, it performs better for surface roughness reduction; however, at 35000 rpm spindle speed, paraffin oil-water emulsion with a lower viscosity allows for quick penetration into the cutting zone.
- It has been observed that significant burr reduction occurs using paraffin oil-water emulsion and soybean oil-water emulsion at different flow rates. At 10000 rpm spindle speed, PO+DIW-60, PO+DIW-125, and PO+DIW-250 reduce the top burr width by 76.04%, 76.87%, and 65.08%, respectively, on up milling side while 78.84%, 87.04%, and 61.44% respectively in down milling compared to dry conditions. Similarly, SO+DIW-60, SO+DIW-125, and SO+DIW-250 reduce the top burr width by 71.25%, 66.03%, and 62.72% for up milling operations while 86.78%, 82.01%, and 84.77% respectively in down milling compared to dry conditions. At 35000 rpm spindle speed, PO+DIW-60, PO+DIW-125, and PO+DIW-250 reduce the top burr width by 47.56%, 83.11%, and 84.18%, respectively, on the up milling side while 79.08%, 84.90 and 73.56% respectively in down milling compared to dry conditions. Similarly, SO+DIW-60, SO+DIW-125, and SO+DIW-250 reduce the top burr width by 58.17%,70.77%, and 69.92% for up milling operations while 86.36%, 86.47%, and 88.53% respectively in down milling compared to dry conditions.

7.1.4 Future Research Initiatives

The results of eco-friendly techniques as alternatives to traditional cutting fluids are still ambiguous and urge additional study. Future work suggestions include the following:

- Other superalloys like Inconel 718, Nimonic etc. can benefit from copper oxide and molybdenum disulphide nanofluid application to reduce burr, improve the surface finish, and reduce cutting forces and tool wear.
- The use of dry lubricant coatings of solid lubricant like Diamond like carbon (DLC), nanocrystalline diamond (NCD), WS_2 and MoS_2 on the tool could be used in micromilling for sustainable and environment friendly manufacturing.
- The integration of micro-milling processes like laser-assisted micro-milling, nano-MQL assisted micro-milling, and vibration-assisted micro-milling processes should be investigated to improve the machinability performance.
- Research work can be broadened through application-based micro feature fabrication on hard ceramics, bio-glasses, and soft elastomers using cryogenic cooling techniques.
- Developing custom microtools with various geometries using the proper production system, such as wire electrical discharge grinding (WEDG), wire electrical discharge machining (WEDM), and pulse laser ablation (PLA) to test and improve the cutting effectiveness of microtools.