# BURR FORMATION IN MICRO-MACHINING AND ULTRASONIC-ASSISTED ABRASIVE MICRO-DEBURRING

**Abstract – A V S S H Sravan Kumar (15ME91R07)**

The present thesis deals with (i) the investigation of micro-milling using water-based nanofluids as cutting fluids in minimum quantity lubrication (MQL) mode, (ii) the development of ultrasonic-assisted abrasive micro-deburring technique and (iii) the study of micro-deburring of micro-milled channels and pillars using the ultrasonic-assisted abrasive micro-deburring technique.

Four different nanoparticles were used for the preparation of nanofluids, namely alumina ($Al_2O_3$), hexagonal boron nitride (hBN), molybdenum disulphide ($MoS_2$), and tungsten disulphide ($WS_2$), with deionised water as the base fluid. Nanofluids were prepared using ultrasonic dispersion and characterised by measuring the stability (by visual inspection, zeta potential, and dynamic light scattering), wettability (contact angle), and viscosity. Tribological characterisation of the nanofluids was undertaken on a ball-on-disc tribometer where the performance of the nanofluids in MQL mode was evaluated by the coefficient of friction, wear depth, and specific wear measurements and comparing them with dry sliding and pure MQL environment using a commercially available cutting fluid (UNILUB 2032). Among the prepared nanofluids, alumina has performed the best. The spherical shape of the alumina nanoparticles has helped in reducing the coefficient of friction and wear due to the ball-bearing effect and the entrapment of the alumina nanoparticles in the asperities of the work surface. The commercial cutting fluid has performed slightly better than the alumina nanofluids due to the formation of a stable tribo-film. Micro-milling experiments were conducted on Ti-6Al-4V using two-flute TiAlN coated tungsten carbide end-milling cutters of 500 μm diameter. Machining environments used were dry, pure MQL using the commercial cutting fluid (UNILUB 2032), and nanofluid MQL using the prepared nanofluids. The effect of the machining parameters (cutting speed and feed per flute) and the machining environment on the machining forces, burr formation, and surface roughness was evaluated. The effect of the cutting environment during machining was found to follow a similar trend as that of the tribological performance with the commercial cutting fluid performing the best in terms of cutting force reduction, burr formation minimisation, and surface finish improvement, closely followed by the alumina nanofluids. An increase in the MQL flow rate has resulted in a better performance of the nanofluids due to a more stable tribo-film formation and the increased availability of the nanoparticles in the machining zone. Solid lubricant based nanofluids (hBN, $MoS_2$, and $WS_2$) have performed better than dry machining, but their performance was not as good as the alumina nanofluids. An ultrasonic-assisted abrasive micro-deburring process was developed employing a probe sonicator to remove micro-burrs from micro-machined components of metallic alloys with a focus on burr removal, preservation of dimensional accuracy of the channels, minimisation of surface damage, and improvement in surface finish. The process was tested to remove burrs from micro-channels and micro-pillars on a variety of soft and hard materials like aluminium 6061, copper, Ti-6Al-4V, and bearing steel. The mechanism of deburring was mainly by the impact of the abrasive particles accelerated by the shockwaves generated by the collapsing cavitation bubbles. Burr reduction by as much as 92% has been achieved in a very short time of ten seconds for soft materials like Al 6061 and copper, and three to six minutes for Ti-6Al-4V and bearing steel, without damaging the components or deteriorating the dimensional accuracy. Surface roughness has decreased from 8.97 nm to as low as 6.63 nm post deburring, resulting in a 26% improvement in surface finish. Visualisation of the deburring process using a high-speed camera and estimation of the energy of the abrasive particles at impact has shown a good correlation between the trend in the extent of burr removal and the process parameters. Further, trends between the impact energy for different materials and the time-based kinetic energy of the abrasive particles at impact have also matched, establishing feasibility of the analysis.

**Keywords:** micro-milling, nanofluids, minimum quantity lubrication, Ti-6Al-4V, burr formation, micro-deburring, ultrasonic, abrasive.