

PREFACE

AISI D2 tool steel is a challenging material to machine due to its high hardness, rapid work hardening, and low thermal conductivity. Grinding has emerged as a more cost-effective solution than conventional machining, but it generates significant heat due to the high specific energy involved. This necessitates flood mode lubrication with petroleum-based cutting fluids, which pose environmental, health, and energy concerns. To address these concerns, this research explores the use of sustainable techniques like ultrasonic vibration assisted grinding (UVAG) and ultrasonic vibration assisted minimum quantity lubrication (UVAMQL) grinding to eliminate or minimize the use of cutting fluids. These techniques combine conventional grinding with ultrasonic vibration or a small amount of cutting fluid mixed with pressurized air, offering a more cost-effective, environmentally friendly, and socially viable grinding process. To investigate the surface integrity of AISI D2 tool steel under these sustainable grinding conditions, we employed indigenously developed UVAG and UVAMQL systems. Before conducting actual experiments, we calibrated the ultrasonic vibration-assisted grinding setup for grinding force measurement using the standard procedure.

Due to the rapid action of abrasive grits and the small affected region, experimental investigation of real-time multiphysics domains in conventional and ultrasonic assisted grinding is impractical. Therefore, an experimental study of single alumina abrasive grit grinding is combined with finite element analysis (FEA) simulation to model the grinding processes and compare the results with experimental findings.

To optimize our developed UVAG and UVAMQL systems, preliminary tests were conducted to determine the optimal parameters for ultrasonic vibration amplitude, frequency, grinding wheel speed, worktable feed rate, downfeed, stand-off distance, nozzle

angle, and UVAMQL flow rate and air pressure. These parameters significantly impact the cooling and lubrication performance of dry, wet, UVAG, and UVAMQL grinding systems. The UVADG mode was evaluated in terms of grinding force, force ratio, specific grinding energy, surface roughness, bearing area curve (BAC), BAC ratio, ground surface morphology and topography, grinding temperature, grinding chip morphology, microstructure, and microhardness analysis. Optimized amplitude and frequency in UVADG mode resulted in reduced grinding forces and superior surface integrity compared to CDG and CWG modes. Small, thin chips generated in UVADG mode indicate the ease of grinding AISI D2 tool steel.

During UVAMQL grinding, four sustainable cutting fluids were tested: soybean oil (SO), soybean oil-deionized water (SO + DW) emulsion, and aluminum oxide nanofluids (Al_2O_3 NFs) at concentrations of 0.5 and 1.0 wt%. Their thermal conductivity, viscosity, and wettability were characterized before use. Highly concentrated Al_2O_3 NFs proved to be the best substitute for conventional cutting fluids due to their excellent lubrication and heat transfer performance. Grinding force, surface roughness, surface functional parameters, surface topography, chip morphology, and grinding temperature were evaluated as response variables.

The last section of this research explores the potential of novel non-destructive techniques, magnetic Barkhausen noise (MBN) and hysteresis loop (HL), for qualitative assessment of surface integrity and thermal damage under various environmental conditions. Experiments were conducted at an extreme downfeed of 40 μm in six environments: dry, flood, SO, SO+DW emulsion, Al_2O_3 NFs (0.5% wt.), and Al_2O_3 NFs (1% wt.). The machining heat's impact on the ground surface was examined in terms of the ground surface, grinding temperature, and microhardness. Additionally, MBN and HL

outcomes such as root mean square (RMS), Peak, permeability, coercivity, and MBN and HL envelopes were correlated with microhardness under different environments.

Keywords: ultrasonic vibration assisted grinding; minimum quantity lubrication; finite element analysis; magnetic Barkhausen noise; hysteresis loop

