ABSTRACT

The challenges facing machining industries today are high metal removal rate and better product quality. Grinding is vital to many manufacturing processes as it generates finer surfaces and closer dimensional tolerances. The selection of the machining parameters is crucial for a better performance in the grinding process. The grists are continuously abraded, fractured, and dislodged from the bond. New grists are exposed to combination of cutting, plowing and rubbing which is changing continuously. The grinding process generates large energy, and most of the energy is converted to heat. The intense heat affects the mechanical properties of the work material and the grists of the grinding wheel. The dullness of the grit affects the surface quality, and increases the grinding forces. New grists are exposed to frequent grit breakages, and wear of the wheel increased rapidly. The problems with the conventional coolant are the flow of the material around the grit and failure of the lubrication at higher removal rates. All these lead to poor quality surfaces and failure of the components.

The coolant which received the attention of researchers is liquid nitrogen (LN$_2$) used in cryogenic machining. The application of LN$_2$ as coolant in the different manufacturing processes like turning, and milling has desired beneficial improvements in the generation of defect free surfaces, and lower residual stresses due to effectiveness in control of grinding zone temperature. Cryogenic machining is an environmentally accepted clean technology.
In the present study, a cryogenic cooling system has been developed for supplying liquid nitrogen to the cutting zone of the work material and the grinding wheel interface of the surface grinding process. Grinding experiments were carried out with AISI 316 stainless steel, EN31 steel and AISI D3 steel, with Al₂O₃ (aluminum oxide) and sol-gel (SG) alumina grinding wheel at different depth of cut-work speed combinations under dry, wet and cryogenic cooling conditions. The experimental results of the grinding forces, grinding zone temperature, surface roughness, specific grinding energy, surface modifications and chip morphology of cryogenic grinding have been compared with those of dry and wet grinding.

Experiments were carried out on the surface grinding of AISI 316 stainless steel under dry, wet, and cryogenic cooling with the SG grinding wheel. The effective delivery pressure of the LN₂ on grinding performance was analysed. It is observed that the SG wheel produces better surface quality under cryogenic cooling, when grinding AISI 316 stainless steel. Cryogenic cooling produces a reduction in the range of 32-50%, and 23-41% in the tangential forces and 23-50%, and 11-26% in the surface roughness compared to dry and wet cooling, while grinding with the SG wheel. Cryogenic cooling produces a reduction of about 22-37%, 13-22% in the tangential forces and 47-59% and 19-24% in the surface roughness compared to dry and wet cooling, when grinding with Al₂O₃ wheel. Cryogenic grinding generates 37% and 29% less grinding energy compared to dry and wet grinding. The swarf produced by the cryogenic grinding shows that they are least affected by the grinding zone heat. The surfaces ground under cryogenic cooling produce
fewer defects like surface burns, grinding marks and pull out of material compared to dry and wet grinding. The increased delivery pressure of cryogenic cooling, results in a reduction of 7-12% in the surface roughness, and 7-9% tangential grinding force with the Al$_2$O$_3$ grinding wheel, and a reduction of 7-11% in the surface roughness and 5-12% in the tangential force with the SG wheel.

Cryogenic cooling produces a reduction of about 10-24% and 7-9% in the grinding forces, compared to dry and wet cooling, when grinding EN 31 steel with SG wheel. The reductions are 7-24% and 2-10% when grinding with the Al$_2$O$_3$ wheel. The surface roughness under cryogenic cooling is found to produce 16-38% and 4-24% lesser values compared to surfaces ground under dry and wet cooling, when grinding with the SG wheel. The reduction produced by the Al$_2$O$_3$ wheel is 18-43% and 7-26%. The cryogenic grinding produces 24% and 10 %less grinding energy compared to dry and wet grinding. The increased delivery pressure of cryogenic cooling results in a 3-8% improvement in the surface roughness and 5-12% reduction in the grinding forces, when grinding with SG wheel.

Cryogenic cooling produces a reduction in the range of 25-33% and 2-6% in the tangential grinding forces, compared to dry and wet cooling, while grinding AISI D3 steel with SG wheel. The reductions in the tangential forces are 24-32% and 3-8% when grinding with the Al$_2$O$_3$ wheel. The surface roughness under cryogenic cooling is found to produce 48-62% and 34-51% lesser values compared to surfaces ground under dry and wet cooling while grinding with the SG wheel. The reduction produced by the Al$_2$O$_3$
wheel is 48-51% and 27-36%. The increased delivery pressure of cryogenic cooling results in a maximum of 7% improvement in the surface roughness when, grinding with the Al₂O₃ wheel and 7-10% improvement with SG wheel.

The optimization study of the grinding parameters was conducted for the following materials, AISI 316 stainless steel, EN31 steel, AISI D3 steel by the Taguchi and Grey relational analysis under the three environments of dry, conventional cooling and cryogenic cooling. The performance characteristics considered are, the material removal rate (MRR), surface roughness (Rₐ), and grinding force (Fₜ). Experiments were conducted with the Al₂O₃ and SG grinding wheels under different cutting conditions, such as work speed, depth of cut (DOC), and cooling environments. An orthogonal array L₁₈ is used for the experimental design. From the optimization results, it is evident that, cryogenic cooling and SG wheel were found to be most effective parameters which affect the grinding performance.

Based on the experimental results, it was observed that cryogenic cooling has a substantial benefit of a reduction in the grinding force, surface roughness, effective control of grinding zone temperature and less adhesion between the work material-grinding wheel interfaces. Cryogenic grinding produces fewer surface defects even at high feeds and work speeds. The optimization results also suggest that cryogenic cooling provides better grinding performance compared to dry, wet grinding. Taguchi-Grey approach can be employed for improving the grinding performance and application of cryogenic cooling in the manufacturing industries.