CHAPTER 7

CONCLUSION

7.1 GRINDING PERFORMANCE UNDER CRYOGENIC COOLING

Grinding experiments were carried out on AISI 316 stainless steel, EN31 steel and AISI D3 steel with Al₂O₃ (aluminum oxide) and sol-gel (SG) alumina wheels at different depth of cut(DOC)-work speed combinations under dry, wet and cryogenic cooling conditions. The experimental results of the grinding zone temperature, grinding forces, specific grinding energy, surface roughness, surface modifications and chip morphology obtained under cryogenic grinding have been compared with those of dry and wet grinding. The effect of the delivery pressure of the liquid nitrogen for the cryogenic cooling was analyzed in terms of the grinding forces and surface roughness. Optimum parameters and conditions were predicted using Taguchi-Grey relational analysis for grinding AISI 316 stainless steel, EN 31 steel and AISI D3 steel with Al₂O₃ and SG grinding wheel under wet and cryogenic conditions. In this chapter, the conclusions of the grinding studies conducted on AISI 316 stainless steel, EN31 steel and AISI D3 steel with Al₂O₃ and SG wheels under dry, wet and cryogenic cooling conditions are presented.

1. The cryogenic cooling approach is an alternative method for controlling in the grinding zone temperature effective for different work-grinding wheel combinations.

2. Cryogenic cooling provides substantial improvement in the surface finish over dry and wet machining.
3. Grinding forces decreases with the cryogenic cooling approach for all the work material-grinding wheel combinations.

4. Cryogenic cooling with the SG grinding wheel produces maximum reduction in the grinding forces and surface roughness.

5. Cryogenic cooling produces lesser defects like material re-deposition, surface burns, pullout of material and grinding marks compared to dry and wet grinding for both SG and Al₂O₃ grinding wheels.

6. The swarfs produced by the cryogenic grinding are found to be smaller in sizes, lamellar and are not affected thermally, where as swarfs produced by the dry and wet grinding were shrink at the edges due to elevated temperature and found vary in sizes.

7. The increase in the delivery pressure of the liquid nitrogen at the work material-wheel interface enhances the effectiveness of the cooling abilities.

8. Grey relational analysis and the Taguchi method are useful tools for the optimization of multi response problems.

7.2 GRINDING PERFORMANCE OF AISI 316 STAINLESS STEEL UNDER CRYOGENIC COOLING

Experiments were carried out on the grinding of AISI 316 stainless steel under dry, wet cooling, cryogenic cooling with the SG grinding wheel. The conclusions from the investigation are as follows;
1. Cryogenic cooling with SG the wheel produces a reduction of grinding forces in the range of 32-50% and 23-41% compared to dry and wet cooling.

2. The surface roughness reduction for cryogenic cooling is found to be in the range of 23-50%, and 11-26% compared to dry and wet cooling conditions, while grinding with SG wheel.

3. Cryogenic cooling with Al$_2$O$_3$ grinding wheel produces a reduction in the grinding forces in the range of 22-37%, and 12-22% compared to dry and wet cooling.

4. The surface roughness under cryogenic cooling is found to be 47-59% and 19-24% lesser compared to that of surfaces ground with dry and wet cooling, while the Al$_2$O$_3$ grinding wheel is used.

5. Cryogenic grinding generates 37% and 29% lesser grinding energy compared to dry and wet grinding.

6. The swarf produced by the cryogenic grinding is less affected by the grinding zone heat.

7. The increased delivery pressure of cryogenic cooling improves surface roughness to a maximum of 12%.

7.3 GRINDING PERFORMANCE OF EN 31 STEEL UNDER CRYOGENIC COOLING

Experiments were carried out on the grinding of EN 31 steel under dry, wet, and cryogenic cooling, with Al$_2$O$_3$ and SG grinding wheels. The conclusions from the investigation are as follows
1. A reduction in the tangential force for the cryogenic cooling in the range of 10-24% and 7-9% respectively compared to dry and wet cooling with SG wheel.

2. The reductions of tangential force are in the range of 7-24% and 2-10% with the Al$_2$O$_3$ wheel.

3. The reductions in the surface roughness under cryogenic cooling is in the range of 16-38% and 4-27% compared to that of dry and wet cooling while grinding with SG wheel.

4. The reductions in the surface roughness produced by the Al$_2$O$_3$ wheel are in the range of 18-43% and 7-26% respectively compared to dry and wet cooling.

5. Cryogenic grinding produces about 24% and 10% less grinding energy compared to dry and wet grinding with SG wheel.

6. The cryogenic grinding produce favourable action for the chip production in grinding process for both the wheels.

7. The increased delivery pressure of cryogenic cooling results in a maximum of 8% improvement in the surface roughness.

### 7.4 GRINDING PERFORMANCE OF AISI D3 STEEL UNDER CRYOGENIC COOLING

Experiments were carried out on the grinding of AISI D3 steel under dry, wet, and cryogenic cooling, with Al$_2$O$_3$ and SG grinding wheels.

The conclusions from the investigation are as follows;

1. A reduction in the tangential force for the cryogenic cooling in the range of 25-33% and 2-6% respectively compared to dry and wet cooling with SG wheel.
2. The reductions in the tangential force are in the range of 24-32% and 3-8% with the Al₂O₃ wheel.

3. The reduction in the surface roughness under cryogenic cooling is in the range of 48-62% and 34-51% compared to that of dry and wet cooling while grinding with SG wheel.

4. The reductions in the surface roughness produced by the Al₂O₃ wheel are in the range of 48-51% and 27-36%.

5. Cryogenic grinding produces about 25% and 8% less grinding energy compared to dry and wet grinding.

6. The increase in delivery pressure of cryogenic cooling results in a maximum of 7% improvement in the surface roughness.

7.5 OPTIMIZATION OF THE GRINDING PARAMETERS UNDER CRYOGENIC COOLING USING TAGUCHI-GREY RELATIONAL ANALYSIS

The present study investigated the optimization of the grinding of 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 and cryogenic cooling. The performance characteristics considered are, the material removal rate (MRR), surface roughness (Rₐ), and grinding force (Fₜ). Experiments were conducted with Al₂O₃(Aluminum Oxide) and Sol-Gel(SG) grinding wheels under different cutting conditions, such as work speed, depth of cut, and cooling environments. An orthogonal array L₁₈ was used for the experimental design. The following conclusions are derived from the optimization of grinding parameters.
1. From the ANOVA it is evident that, environments, DOC, and work speed are significant factors, which affect the grinding of AISI 316 stainless steel. The contributions of environments, work speed and DOC are 27.64%, 27.55% and 28.97% respectively.

2. The contribution of environment of 50.28% was found to have more influence on the grinding performance of EN 31 steel and followed by work speed at 18.56% and DOC at 17.53%.

3. From the ANOVA it is evident that, environments, and grinding wheel are significant factors, which affect the grinding of AISI D3 stainless steel. The contributions of environments, grinding wheel and DOC are 52.32%, 13.02% and 8.47% respectively.

4. The optimal results from the Taguchi-Grey analysis suggest that cryogenic cooling can be employed for improving the grinding performance.

### 7.6 SUGGESTIONS FOR FURTHER STUDY

1. Machining parameters like speed, feed and depth of cut can be further optimized for a maximum material removal rate and minimum cost for machining.

2. Modifications in the experimental setup for cryogenic cooling may be attempted for delivering LN\textsubscript{2} at high pressure in the grinding zone.

3. The standoff distance and the nozzle diameter of the cryogenic coolant delivery may be optimized.
4. Modifications in the grinding wheel periphery may be attempted for effective use of cryogenic coolant in the grinding zone.