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Surface Grinding of BÖHLER K340 ISODUR- A Review

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ABSTRACT
Grinding is a finishing process, broadly used in manufacturing of components requiring fine tolerances, good surface finish and higher dimensional and geometrical accuracy. In this review study, studies focused optimal parameters of surface roughness, temperature and material removal rate (MRR) with dry, flood and minimum quantity lubrication (MQL). In floodcooling has removed the burning problems in the grinding process. After that, a new technique was developed which is known asminimum quantity lubrication (MQL).This technique is a recognized opportunity to eliminate environmental concerns. This paper reviews experimentation model developed on grinding and a case study on surface grinding recently conducted grinding experimentation on D2 die steel with Al_2O_3wheel under dry, wet, and MQL.After reading thisresearch paper, one can easily get an overview of the previously conducted research to find the output parameter trends in dry, flood, MQLcondition. The reader can infer from this paper in which direction the development trend in grinding is in the machining process.

Keywords: surface roughness, material removal rate (MRR), minimum quantity lubrication (MQL), K340 ISIODUR die steel

I. INTRODUCTION

Grinding is a finishing process, broadly used in manufacturing of components requiring fine tolerances, good surface finish and higher dimensional and geometrical accuracy. Compared with other material removal processes as an example of turning, milling and boring, the grinding process is more complex and more difficult to control. In addition to the static parameters of the grinding machine tool, there are many dynamic factors that contribute to resulting dimensional accuracy. Surface finish is very important for parts which will be in contact with other metal surfaces. The lower value of surface roughness causes less wear and friction. The lowest value of surface roughness gives the best surface finish. The surface quality produced in surface grinding is influenced by various parameters such as i. wheel parameters – abrasives, grain size, grade, structure, binder, shape and dimension; ii. Work piece parameters – fracture mode, mechanical properties and chemical composition; iii .process parameters – wheel speed, depth of cut, table speed and dressing condition; iv. Machine parameters – static and dynamic characteristics, spindle system, and table system.

BÖHLER K340 ISIODUR tool steel is regarded as a key material in high performance engineering applications such as in the mold-and-die industry; for use as industrial cutting tools, gauges, and machine parts exposed to wear and injection screws; in aerospace and automotive industries; medical appliances; heavy engineering; and tools in the manufacturing industry. This is due to its superior properties like high wear resistance, compressive strength, temperature resistance, and narrow tolerances as well as its high strength-to-weight ratio. However, the manufactured parts demand for high geometrical and dimensional intricacy—which raises the necessity of using a grinding operation.

II. LITERATURE SURVEY

The following section discusses the major contribution of the researchers with regard to the optimization of surface grinding process.

Aqib Mashood Khan et al. [6] investigated on surface grinding of AISI D2 steel and used Grey–Taguchi method and Response Surface Methodology (RSM) for the multi-objective optimization. Itwas found that the developed models are statistically significant, with optimum conditions of depth of cut of 15 m., table speed of 3 m/min, cutting speed 25 m/min, and MQL flow rate 250 mL/h.

Saraanan et al. [7] experimental studied on the enhancement of conventional flood cooling by adding nano droplets which about 5 Nm of average particle size for using surface grinding of EN-31 stee. Taguchi L36 orthogonal array used for Design the experiment. Here the control factors are feeds, in feeds and various cutting fluids when surface grinding EN31 steel were considered to observe the response of surface roughness and cutting zone temperature. The Scanning Electron Microscope analyses were carried out to validate the performances. The nano fluids out performs in case of reduction of cutting zone temperature and enhance surface qualities such as free from thermal defects and reduction of surface roughness under the designed experimental conditions.

M. Aravind et al. [8] used to Taguchi Method (L27 orthogonal array)And Response Surface Methodology(Box-Behnken method) to Optimization of Surface Grinding Process Parameters of AISI 1035 steelplates.

Bruno Kenta Sato et al. [9] evoked Novel comparisonconcept between CBN and Al_2O_3 grinding process for eco-friendly production. In this study, Minimal Quantity of Lubrication was developed to achieve green manufacturing in machining process and parameters of cutting fluid flow, grinding wheel type and wheel cleaning system were evaluated to achieve the maximum potential of this technique in grinding process.

Taghi Tawakoli et al. [10] conducted to study the influence of the abrasive and coolant lubricant types on the minimum quantity lubrication (MQL) grinding performance. One type of CBN and three types of conventional wheels (corundum) have been tested. The tests have been performed in presence of fluid, air jet and eleven types of coolant lubricants, as well as, in dry condition. The results indicate that the finest surface quality and lower grinding forces could be obtained while grinding with CBN wheel.

Hoang Tie Dung et al. [11]studied on surface roughness of workpiece when grinding SKD11 and SUJ2 steels using Al2O3 and CBN wheels.

Jeffrey Badger et al. [12]studied on comparison of specific energy, wheel wear, surface-generation mechanisms and surface characteristics when grinding with Al2O3 and CBN to achieve a given surface roughness and new concept is developed, the nominal bond shear stress, which can be used to quantify the risk of grit fracture or bond fracture in a single grit. The fundamental relationships between grit size, grit sharpness and contact mechanisms are discussed and practical recommendations are given.

Konrad Wegener et al. [13] studied on recent developments in grinding machines.

Ch. N. V. Jaswanth et al. [14] experiment performed on Surface Grinding of HC-HCr Steel using Dry and MQL Techniques used Response Surface Methodology to optimization carried out for minimization of surface roughness and temperature. The desirability of surface roughness and temperature and composite desirability are found to be 1. That indicates that the optimization is valid for minimum values of responses. The optimal values of % of Nanoparticles, cutting speed, table feed and depth of cut are found to be 0.3636%,9.166m/s, 7.12m/min and 10µm respectively.

P.P.Pereverzev et al. [15]developed a mathematical model is for the grinding force in cylindrical plunge grinding that allows for the grinding conditions, the size of the flank wear land areas formed on the grinding wheel cutting grains, the properties of the work material, and the geometrical parameters of the grinding tool and work surfaceand obtained a formula for calculating the stock removal rate as a function of the degree of dulling (glazing) of the grinding wheel.

J. Vivancos et al. [16] experiment model developed for surface roughness in high-speed side milling with carbide end mill coated with (Al, Ti, Si)N cutter of hardened (61–62 HRC) Böhler K340 die steels. The influence of cutting speed, feed per tooth, axial depth and radial depth of cut is studied using a 2^{4-1} fractional factorial design of experiments. Finally, it has been determined the factors and interactions that are statistically more significant for modelling the surface roughnessR_a.

Todkar et al. [17]a vibration device has been designed and developed in which the workpiece is subjected to vibration up to a frequency of 1 kHz and amplitude of 2.5 µm.and investigated the feasibility of drilling deep microholes in difficult-tocut Tungsten carbide by means of low frequency workpiece vibration-assisted micro-Electro Discharge Machining (micro-EDM) of K340 Steel**.**

Roy R. et al. [18] carried out Multi-Response Optimization of Surface Grinding Process Parameters of AISI 4140 Alloy Steel Using Response Surface Methodology and Desirability Function under Dry and Wet Conditions.

Rajesh Choudhary et al. [19] have investigated of Machining Performance and Surface Integrity of AISI D2 Die Steel Machined Using Electrical Discharge Surface Grinding Process. They have used Taguchi method (L27 Taguchi orthogonal)was applied to identify the optimum levels of process parameters for each performance characteristics individually.

M. Janardhan [20] used Response surface methodology (RSM) for modeling and non-dominated sorting genetic algorithm-II (NSGA-II) for multi-objective optimization of a surface grinding process on AISI 4340 steel.

Alves et al. [21] developed water-based grindingfluids consists of sulfonate vegetable oil in water to meet CBN grinding needs and is of environmentally friendly. The quality of oil was evaluated by conducting various tests and proved that the proposed oil is readily biodegradable. The performance of new oil was evaluated and expressed regarding of G-ratio (volume of metal removed per unit volume of wheel wear). The results compared with semi-synthetic oil and mineral oil. The semi-synthetic oil acts as a good coolant but not a good lubricant and hence less G-ratio. The mineral oilacts as both lubricant and coolant hence high G-ratio. The proposed oils have G-ratio almost same that ofmineral oil.

Vasu et al. [22]investigated the effect on surface roughness, tool wear, and temperature dissipation of suspending Al2O3 nanoparticles in Coolube 2210EP eco-friendly vegetableMQL oil when machining Inconel 600 alloy at different cutting parameter combinations by coated carbide cutting tools on a precision engine lathe machine. Experimental results show that surface roughness, temperature, cutting force, and tool wear are reducedsignificantly by MQL with (6 vol. % of the Al2O3 particle) nanofluids than dry.

Atzeni et al. [23] developed mathematical model for surface roughness and kinematic parameters using regression analysis. The developed model shows that the roughness is mainly influenced by the feed per grain and cutting speed. A smoother surface is produced by decreasing the feed per grain, through the spacing between successive peaks along the work piece and depth of engagement decreases.

Bhushan et al. [24] usedthe response surface method and desirability analysis to examine the impact of cutting parameters during the turning of 7075 Al alloy SiC composite in order to minimize machine power consumption and enhance tool life.

Buranska et al. [25]demonstrated multi-criterial optimization with desirability function analysis (DFA) of input factors cutting environment, feed for two defined target functions roughness, and cylindricity for drilling of aluminum alloys.

III. CASE STUDY

3.1 Author Name: Aqib Mashood Khan, Muhammad Jamil, Mozammel Mia, Danil Yurievich Pimenov, Vadim Rashitovich Gasiyarov, Munish Kumar Gupta, Ning He.

3.2 Title: Multi-Objective Optimization for Grinding of AISI D2 Steel with Al2O3 Wheel under MQL.

3.3 Objectives: Investigation the effects of the cutting parameter and the cooling mode on the grinding zone temperature, normal forces, and ground surface quality of AISI D2 steel.

3.4 Methodology:
Experimental setup

The surface grinding was performed on AISI D2 steel having 1.56% carbon and 12% chromium by weight. The chemical composition of the workpiece material is verified through optical emission spectrometer before experiments. Alumina oxide grinding wheel manufactured by NORTON (Shanghai, China) was used. The grinding process was performed on a surface grinding machine with Model (WAZAA415X-NC) with motor driving having a capacity of 6 kW. Surface grinding was employed on AISI D2 steel. Alumina oxide grinding wheel (FE 38A60KV) manufactured by NORTON was used in present work according to the cutting condition, hardness and tool manufactures recommendation. Alumina Oxide vitrified grinding wheel of size (250 mm x 72.5 mm x 31.8 mm) was used as abrasive cutting material.

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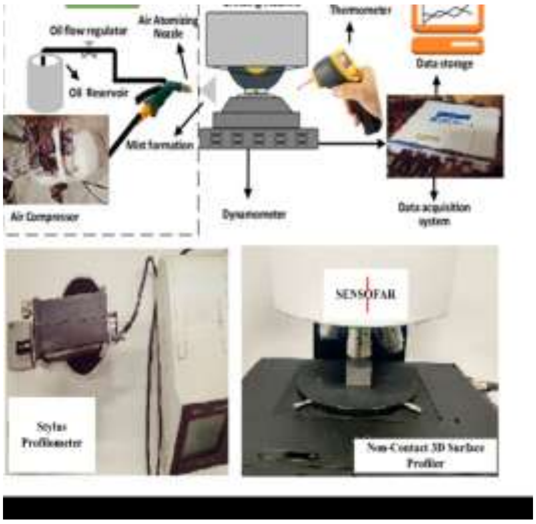

Figure 1. Schematic diagram showing minimum quality lubrication (MQL) working principle and response measurements.

The experiments were performed under three conditions namely dry, wet, and MQL grinding. Under the dry condition, grinding was performed without coolant. Castrol Syntilo 9954 (Shangai, China) with density 1066 kg/m3 was used as the coolant for conventional wet grinding. A flow rate of 6 L/min was maintained throughout wet grinding. For experiments involving grinding under MQL condition Accu-Lube 6000 with specific gravity 0.92, flash point 214 _C, and density 8.9 CSt special cutting oil was used at variable flow rates between 50 and 50 mL/h. During the whole process the air pressure was 6 bar, with a nozzle angle of 15_, and nozzle distance of 30 mm, which were kept constant. The schematic diagram for surface grinding process along with responses measurement has been shown in Figure 1.

Design of experiment (DOE)

Response surface methodology (RSM) with central composite design (CCD) has been consideredfor the modeling and analysis of the performance measures of the ground workpiece. In CCD, if some process parameters are represented by k and number of central points by m, the total number of experimentation can be calculated by Equation (1) process parameters and their levels for Dry, Wet, and MQL

Number of Experiments = $2k + 2^k + m$ (1)

A total of 30 experiments have been performed for different process parameter combinations(depth of cut, table speed, cutting speed, and lubricant flow rate) in MQL-grinding and 18 experiments have been performed with process parameter (depth of cut, table speed, and cutting speed) for the dry and wet grinding processes.

3.5 Result and discussion

In this section,the normal force, grinding temperature, and surface roughness were analyzed bythe experimental investigation, statistical analysis, mathematical modeling, and graphical plots.

Normal Forces

The cutting forces largely influence the performance of grinding. The grinding mechanics are, inturn, altered by the lubrication effects prevailing between the wheel and work surface. The normal forces were measured during the grinding process using dynamometer. To check the influence of dry, wet, and MQL conditions on the normal forces, a comparison has been drawn in Figure 2.

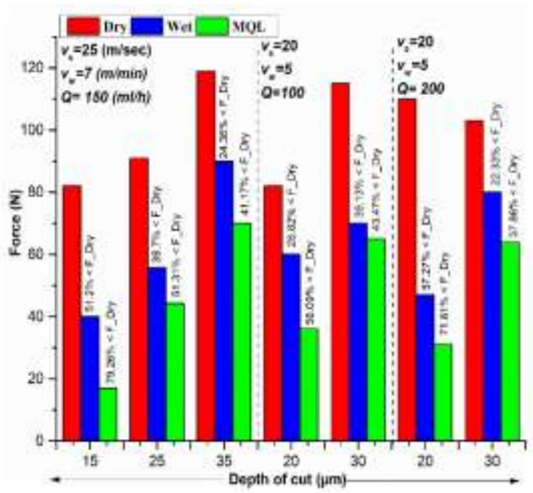

Figure 2. Comparison of force measurements in different cooling environments.

It can be seen that a reduction of 37.86 to 79.26% in normal forces was found for MQL grinding; however, a reduction of only 22.33 to 57.27% in forces was achieved for wet grinding. It can be concluded from the results that the MQL environment has generated lower forces than the dry and wet environment.

Figure 3 a–c demonstrates the contribution of the depth of cut and table speed on the normalforce found in dry, wet, and MQL grinding.

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By comparing the response surface plots for dry, wet and MQL, it is evident that the behavior of force is nearly similar at varying depth of cut and table speed conditions. The force is more sensitive to variation in depth of cut compared to table speed. The similar results are also claimed in a previous paper. The force increases with the increase in table speed in dry grinding; however, in wet MQL grinding table speed has a negligible effect

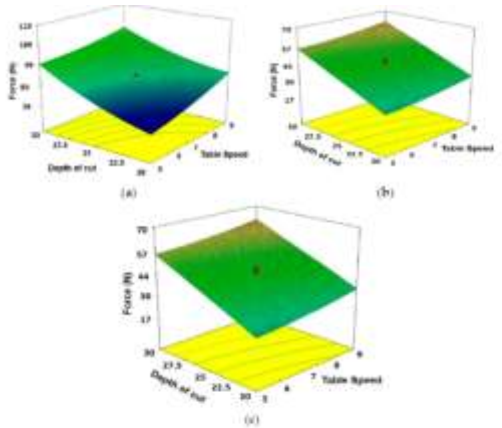

Figure 3. 3D Surface plots showing the effects of depth of cut and table speed on forces for (**a**) Dry,(**b**) Wet, and (**c**) MQL conditions. Units of table speed and depth of cut are 'm/min' and 'μm', respectively.

Temperature

Temperature is produced due to the interaction of the grinding wheel with the workpiece. Datafor temperatures were recorded using an Infrared thermometer (Raytek-Raynger MX4 (Guangdong, China)). Comparison of temperatures allowed us an assessment of the thermal performance of the MQL-assisted grinding compared to dry and wet cases. It gives an insightful analysis of lubrication in wet and MQL techniques. As the depth of cut was found the most significant parameter for temperature (discussed later), therefore, it is plotted on the x-axis in the comparison graph in Figure 4. It is depicted in Figure 4that the temperature reduction in wet grinding is between 65.83% and 72.44% and in MQL grinding is between 55.18% and 67.4%. It is further noticeable that the temperature achieved in MQL environment is much lower than dry and close to the wet temperature; it is even lower than the flash point of oil used which recommends its usage during grinding.

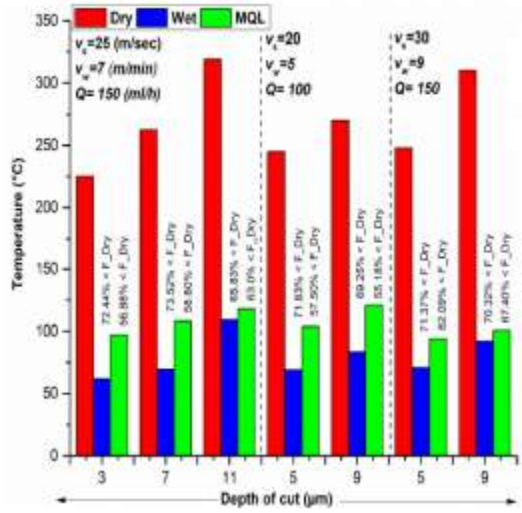

Figure 4. Comparison of temperature measurements in different cooling environments

3D response surface graphs in Figure 5a–c highlights the effects of depth of cutand table speed on temperature for dry, wet, and MQL environments. It is noted that the interaction effect of depth of cut and table speed is not similar for all given environment. In the case of dry environment (Figure 5a), the temperature increases as the depth of cut increases; also the depth of cut has a direct and significant effect on temperature. However, the table speed has a less significant effect on temperature compared to the effect of depth of cut; therefore, the temperature slightly increases with an increase in table speed. Figure 5b depicts that in wet grinding the temperature increases rapidly at a higher level of table speed.

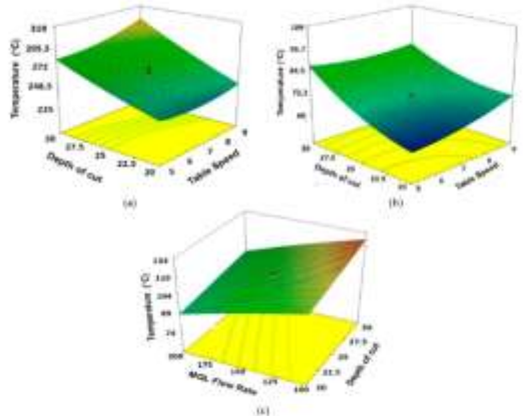

Figure 5. Surface plots showing the effects of depth of cut and table speed on temperature for (**a**) Dry,(**b**)Wet, (**c**) and MQL conditions. Units of table speed, depth of cut, and MQL flow rate are 'm/min', μm'and 'mL/h', respectively.

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Surface Roughness

Surface roughness is an important parameter to analyze the quality of the surface of the workpiece.The surface finish largely influences the dimensional accuracy and product life. Surface roughness values were measured by using portable stylus profilometer Surftest SJ-410 (Mitutoyo, Tokyo, Japan). To elaborate the effectiveness of MQL over the wet and dry environment, a comparison of surfaceroughness in three different environments has been made and presented in Figure6.Since the tablespeed was found as the most significant parameter for surface roughness (discussed later), therefore, the comparison has been drawn by varying the table speed and keeping the other process parameters at a constant level. During comparison, the dry grinding process was set as a reference point. It can be noted from Figure 6that wet grinding resulted in a 42 to 69.7% reduction in surface roughness, whereas MQL grinding was only able to reduce roughness by 32 to 66.1% when compared with the dry grinding process. From these results, it is clear that MQL provides better results than dry and almost similar result with wet grinding.

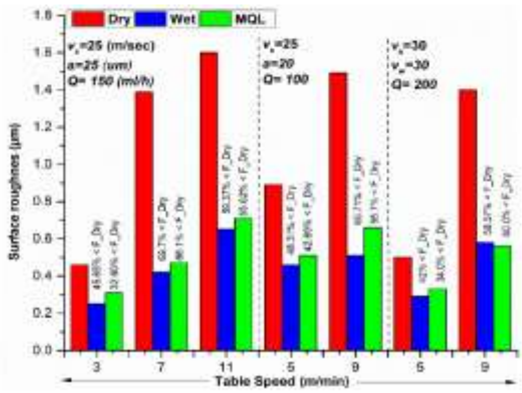

Figure 6. Comparison of surface roughness in different cooling environments.

It is significant to know that Figure 7a–c shows the effect of two process parameters(simultaneously) on the output parameters while other process parameters are fixed at their middle levels. The effects of table speed and cutting speed on surface roughness (Ra) for dry, wet, and MQL grinding environments are presented in Figure 7a–c, it is evident from these figures that the surface roughness has a direct relation to table speed and cutting speed, i.e., an increase in speed also increases surface roughness. The impact of changing table speed is more at a low level of cutting speed as compared to the high level of cutting speed. Similarly, the impact of table speed on surface roughness is higher at a low level of table speed as compared to the high level of table speed.

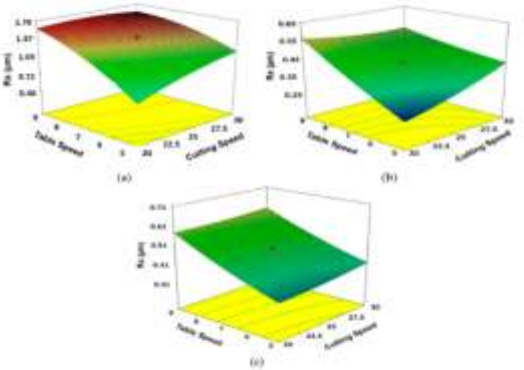

Figure 7. 3D Surface plots showing the effects of cutting speed and table speed on surface roughnessfor (**a**) Dry, (**b**) Wet, and (**c**) MQL conditions. Units of table speed and cutting speed are 'm/min' and'm/s'

Surface Topography for MQL-Assisted Grinding

Appropriate analysis of surface components, in terms of waviness, form, and roughness andmulti-scalar feature topographical features, is very important. Surface topography was studied using noncontact 3D surface profilometer (S NEOX) with magnification _1000 for AISI D2 steel in the MQL-assisted grinding process (Figure 8a). Figure 8b,c highlights 2D and 3D topography. The surface topography area was considered for 2mm along the grinding width direction and 1.5 mm along the grinding direction. From the experimental data, it was found that the table speed has a significant influence on ground surface roughness and topography. Figure 8shows the machined surface topography of the ground surface at depth of cut of 15 µm, table speed of 3 m/min, cutting speed of 25 m/s, and MQL flow rate of 250 mL/h; this was obtained using SENSOFAR with magnification _1000 for AISI D2 steel in the MQL-assisted grinding process. Figure 8indicates that in the MQL-assisted grinding process the plastic deformation by the mechanical load, distortion of the surface layer, and pull-out of grains are not present on the ground surfaces. MQL technique has fewer defects, especially no plastic deformation, due to higher lubrication conditions. It was noted that in MQL-assisted grinding a minimum of 0.31 _m surface roughness was achieved.

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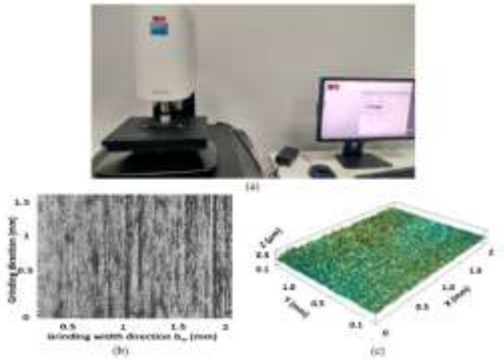

Figure 8. (**a**) General view of 3D optical profilometer S neox (Sensofar, Barcelona, Spain), (**b**)micrography of the ground surface, and (**c**) surface topography of the ground surface.

3.6 Conclusions

The influence of process parameter on three different responses has been analyzed based on the developed mathematical model. A mathematical model for each response in each cooling mode has been developed to correlate the process parameter. Finally, multi-objective optimization was performed for MQL cooling mode. Based on the results of the experimental investigation, the following comparative conclusions for MQL grinding can be drawn.

1. In all grinding conditions, the surface roughness is profoundly affected by the table speed, andthe surface roughness values achieved in wet and MQL conditions are comparable.
2. Depth of cut has been found as the critical process parameter for temperature in all cutting conditions. Comparison results for temperatures show that overall minimum temperature wasachieved in wet grinding followed by MQL-assisted grinding. Moreover, it was noted that MQL grinding results in a temperature reduction of 55.18 to 67.4% as compared to dry grinding.
3. Cutting forces were found increasing as the depth of cut was increased. Comparative resultsfor forces have shown that minimum cutting forces were achieved in MQL environment.

IV. CONCLUSIONAND FUTURE SCOPE

In this study introduce investigation and experimentation have been done on grinding by various investigators in literature. Review study helpful for researchers what have done on grinding in previously whether material, experimentation methodology and parameters. Case study explain a methodology process of experimentation for grinding of D2 because D2 also die steel.

In literature review “An Investigation of Vibration-Assisted Micro-Electro Discharge Machining of K340 Steel” and “Analysis of factors affecting the high-speed side milling of hardened die steels” both of experiments describes surface roughness, material removal rate and tool wear by using micro EDM and CNC milling respectively but not found investigation on surface grinding of BÖHLER K340 ISIODUR.

As we knows K340 used in manufacturing of high precision tools and dies but machining of cold die steel K340 by using of grinding method is not available in survey while grinding also important for tools that’s why we want perform experiment on K340 by surface grinding process.

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