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Al_2O_3 Nanofluids: An Experimental Study for MQL Grinding

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Abstract

In the course of grinding, conventional grinding fluid is frequently utilised, which leads to excessive consumption and negative environmental effects. MQL, or minimum quantity lubrication, is a possible replacement for traditional dry and fluid coolant application. It is well known that the MQL grinding process's effectiveness depends on the lubricating and cooling capabilities of fluid. A water-based Al_2O_3 nanofluid was used in this work to grind materials due to its outstanding convective heat transfer and thermal conductivity qualities. Hardened steel's grinding properties are examined and contrasted with those of MQL grinding done in wet, dry, and pure water. Al_2O_3 nanofluid MQL grinding using water dramatically lower the grinding temperatures, minimise grinding forces, and enhance the ground surface finish.

Keywords: *Al_2O_3 G Ratio, MQL Grinding, Nanofluids, Surface Finish*

1.0 Introduction

Abrasive material removal techniques like grinding are frequently utilised in the production of components with precise tolerances and smooth finish. Extreme heat and strong cutting forces are produced during the grinding process at the wheel to work-piece contact. Cooling and lubrication are essential to avoid work-piece burn, phase transitions, undesired residual loads, fractures, lower fatigue strength and thermal distortion. Grinding fluids are utilised to improve lubrication, remove chips, and reduce heat damage to work-pieces, and provide a superior surface finish. A huge volume of cutting solution (6400ml/min) is pumped into the grinding area during a traditional surface grinding operation. The nucleate boiling that occurs when the cutting fluid is first supplied to the grinding zone accelerates the rate at which heat is transferred from the workpiece to cutting fluid[1,2]. When temperature rises, vapour coating forms in between workpiece and cutting fluid, acting thermal barrier and preventing heat transmission. Due to this the temperature of the workpiece increases fast, burning material's surface. The traditional grinding process has a detrimental impact on the environment, the cost of recycling, and the health of the machine operator. Grinding fluid reduction is accomplished by the use of MQL, dry grinding, use of solid lubricants, and dry grinding with workpiece precooling. Thermal damage occurs on the work surface during dry grinding[3].

Ibrahim *et al.*,[4] advocated chilling the workpiece prior to grinding. They discovered that precooling is achievable for certain workpiece features when the stock removal is smaller than 0.150mm. A simulation must be done for each application to assess the feasibility of operation. MQL is a

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superior option for dry grinding[4]. MQL ensures cooling and lubricating benefits. The benefits of dry grinding and flood grinding are included into the MQL process. The MQL technique's fluid flow rate while grinding is 30-300ml/hour. As a cooling fluid, a combination of compressed air and nanoparticles with water is employed. Nanoparticles provide lubrication in MQL technology, while compressed air keeps the grinding zone cold. Nanoparticles have a spherical form and work similarly to ball bearings. Contact between the workpiece and the abrasive changes from sliding to rolling friction. Improved lubrication ability reduces damage to the work-piece. De Paiva *et al.,*[5] investigated nanofluid as a metalworking fluid for low-volume lubrication in surface grinding operations. They discovered that adding nanoparticles to the base fluid altered the lubricating characteristics, resulting in a decrease in friction[5]. The concentration of nanoparticles, the kind of nanoparticles, and the flow rate of MQL all played important roles in friction reduction. During the grinding process, a layer was generated on the ground surface, lowering the coefficient of friction. Water-based Al_2O_3 nanofluid increases grind ability by lowering temperature, friction, promoting optimum chip formation, efficiently grain fracturing, and effectively flushing chips out of the grinding zone. The rolling movement of billions of nanoparticles at the tool chip contact minimises friction and generates substantially superior surface quality[6]. Hübner *et al.,*[7] conducted an experimental evaluation for delivery parameters and spray atomization of the MQL grinding process. They discovered that in MQL, the size of the liquid droplet was regulated by gas flow rate, lubricant flow rate, and lubricant physical parameters. In their investigation, the optimal settings are 15^0 nozzle angles, 30mm nozzle distance, 150 ml/hr rate of lubricant flow, and 30 lit/min. rate of gas flow[7]. Nanoparticles boost thermal conductivity and heat carrying capability of lubricating oil, preventing work piece damage. The optimal speed of the grinding wheel results in a smooth and uniform surface. MQL reduces wheel rate of wear and reduces tangential force of cutting as compared with conventional cooling[8,9].

Garcia *et al.,*[10] investigated the grinding for CI under various lubrication methods and discovered a significant improvement in force of grinding, surface quality and G ratio. Many studies have investigated and reported on the good effects of various process parameters for MQL technology in grinding applications[10-12]. However, the combined influence of nanoparticle size, grinding wheel speed, nanoparticle concentration in base fluid, and nanofluid coolant amount has not been well studied for surface grinding operations by previous researchers[13-15]. The current research is concentrating on the combined influence of process factors on surface grinding operations. Lubricant type, grinding cut depth, coolant rate of flow, speed of grinding wheel, nanoparticle size and nanoparticle concentration all regulated in a grinding process. G ratio, grinding force, grinding surface temperature, and surface quality are all used to assess grinding performance. We're looking at how controllable parameters affect grinding performance.

2.0 Experimental Configuration

An instrumented surface grinding machine was used for the grinding trials. Figures 1 and 2 depict the grinding experiment's setup. Two sample Al_2O_3 dry powders were made available from the market, having mean diameters of 30 and 40 nm. These dry Al_2O_3 granules are mixed with water without the need of a surfactant. Al_2O_3 nanofluids were created with volume proportion ranging from 2% to 6%, and every mixes remained stable for an extended length of time.

The lubricant is delivered via a MQL fluid delivery system. To get liquid and air to the site of application separately, a biaxial hose is employed. The nanofluid liquid is encircled by compressed air and driven the workpiece by compressed air pulses at varied flow rates (5, 15, and 30 ml/min). It employs a grinding disc using a medium abrasive

Figure 1. Grinding machine setup.

Figure 2. MQL fluid delivery Device.

size. The wheel that is used for grinding is 16 mm wide and 160 mm in diameter. Iron bar has been created as the work material. The workpiece was ground by moving the wheel over it at a table speed of 2400 mm per minute in one direction. Using a dynamometer, tangential and normal forces were quantified. The integrated thermocouple was used to measure the grinding temperatures. The workpiece is cooled to its starting temperature after each grinding pass. For ensuring the precision of G-ratio, 6 μm of feed is given to the grinding wheel. A profilometer is utilised to determine the roughness of the ground surface. Three measurement that were perpendicular and parallel to the direction of grinding were taken. The roughness was represented by the mean value of surface roughness across and along grinding direction.

3.0 Experimental Studies

3.1 Surface Roughness

A surface roughness tester measures surface roughness. Figure 3 depicts the workpiece's surface roughness. Flood grinding offers the highest surface polish, whereas dry grinding has the lowest. Additionally, the flood cooling offers effective chip cleansing. The decrease in friction and grinding forces makes nanofluids perform better than dry grinding. Surface roughness for Al_2O_3 nanofluids is improved by 2.0 vol% in comparison with dry grinding. There was a substantial variety in the outcomes when compared to all grinding surface finishes. As shown in the above comparison with Al_2O_3, the results keep getting better as the concentration of nanoparticles rises from 2% to 6%. As the concentration of nanoparticles rises, the surface finish is improved. Figure 3 shows the surface roughness for various coolants.

3.2 Temperature for Grinding

At the same grinding condition, measurements of the temperature are taken, and the average results are utilised for analysis. The comparison of temperature distribution for grinding area under various cooling settings is shown in Figure 4. The temperature of flood cooling is the smallest, while the temperature of dry grinding is the greatest, as would be predicted. For both wet and dry grinding, the typical high temperatures are 196^{0}c and 604^{0}c, respectively. Positively, highest temperature of

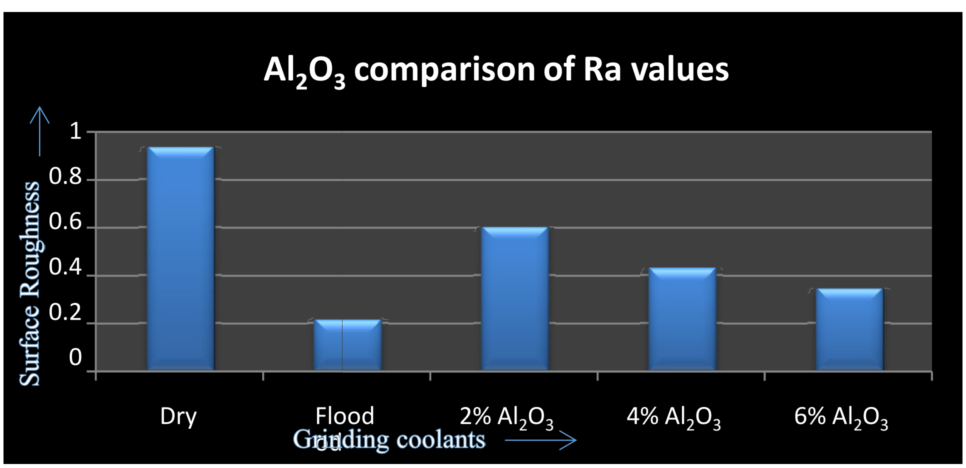

Figure 3. For different coolants.

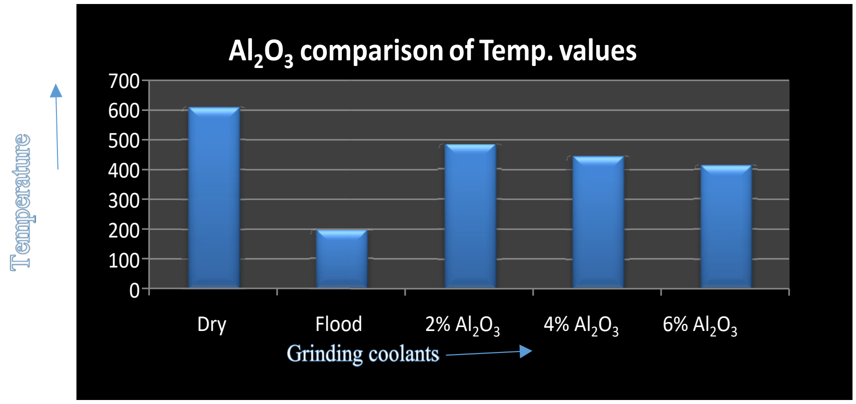

Figure 4. Peak grinding temperatures for different coolants.

MQL grinding is around 125°C to 160°C smaller than dry grinding. The level of temperature in dry grinding is much greater than that of MQL grinding. This is because dry grinding requires no lubrication or cooling. Lubrication improves chip disposal, decreases loading, and results in improved grinding. The grinding temperature is lower with flood grinding. However, for water soluble grinding solutions, boiling occurs at around 140°C. When the fluid boils, the gas phase forms a partial barrier between the grinding fluid and the work-piece surface. As a result, the impact of cooling and lubrication in the grinding zone is considerably diminished, causing the grinding temperature to rise.

3.3 Grinding Forces

The Figure 5 depicts the relation between tangential grinding force and number of runs. Force divided by the

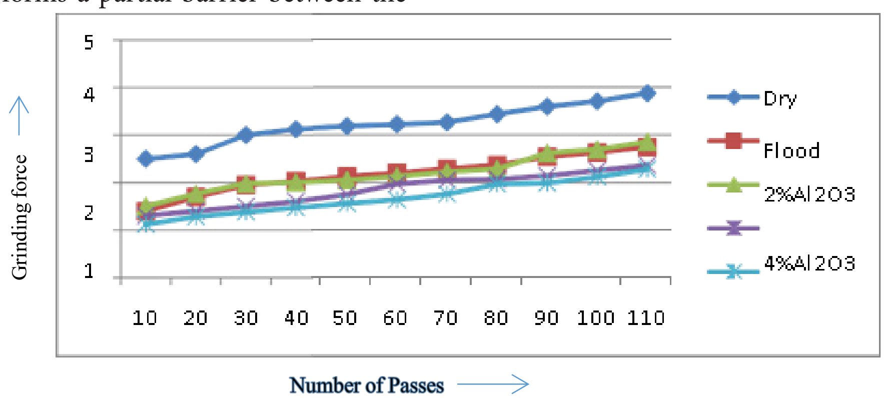

Figure 5. Specific Tangential grinding force vs number of passes.

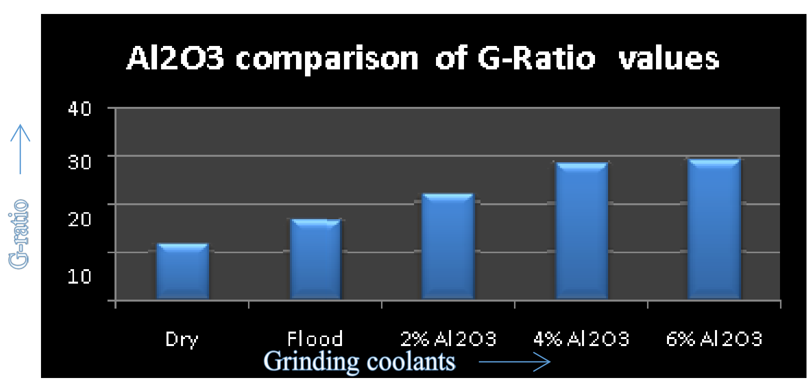

Figure 6. G-ratio for different coolants.

grinding breadth is specific tangential force. Graph clearly shows that dry grinding without lubrication produces the greatest specific tangential force. MQL grinding has the least amount of grinding force. This clearly shows that the MQL in technology lubrication penetrate into the contact zone between the work-piece and the wheel and lubricate it. The force rises as the number of grinding passes increases owing to grinding wheel wear.

3.4 Grinding Ratio (G-ratio)

The amount of material extracted to the grinding wheel wear is given as the grinding ratio. High G-ratio wheels outperform wheels with lower G-ratios in terms of durability. According to Figure 6, nanofluid operation displays a higher G-ratio, 17 to 34. The lowest G-ratio is for dry grinding, has the most wheel wear and is around 12.

The G-ratio rises as the volume percentage for Al_2O_3 nanoparticles increases. Two greatest G-ratio findings were found while using 4 and 6.0 vol % of Al_2O_3 nanofluids. This is explained by the development of a slurry layer, which can guard against grain/bond fracture and protect the grinding wheel. Higher G ratios and greater protection are also benefits of high concentration nanofluid.

4.0 Conclusion

Based on the current research on the Minimum Quantity Lubrication for Grinding application, the following conclusions may be made.

1. Surface roughness rises with both an increase in feed rate and cut depth. The flood cooling offers effective chip cleansing. The surface finish is lowest in dry grinding. The surface roughness values are continuously increasing from 2% to 6% nanoparticle concentration.

2. Positively, highest temperature for MQL grinding was around 90^0–130^0c smaller than dry grinding. However, it has been discovered that for water soluble grinding solutions, boiling occurs at roughly 140°C. The partial barrier created by the gas phase between the workpiece surface and the grinding fluid when the fluid boils. As a result, the grinding zone's cooling and lubricating effects are considerably diminished, which will raise the grinding temperature.

3. MQL grinding produces the least amount of grinding force, whereas dry grinding without lubrication produces the maximum specific tangential force. This illustrates the ability of the MQL system that lubricates contact area between workpiece and wheel. Grinding force rises with quantity of passes, which was result of wear of grinding wheel.

4. Grinding ratio, is a unit used to represent wheel life in grinding process. G-ratio of nanofluid MQL grinding typically ranges from 16 to 33. The lowest G-ratio is for dry grinding and has the most wheels wear and are around 12. The G-ratio for Al_2O_3 nanofluids rises as volume percentage of Al_2O_3 nanoparticles increases. This is explained by the development of a slurry layer, which can guard against grain/bond fracture and protect the grinding wheel.

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