Chapter 8
Experimental Research on Heat Transfer Performance in MQL Grinding With Different Nanofluids

ABSTRACT

An investigation into the effect of nanofluid minimum quantity lubrication (MQL) on the temperatures in surface grinding is presented and discussed. Six types of nanoparticles, namely molybdenum disulfide (MoS2), zirconium dioxide (ZrO2), carbon nanotube (CNT), polycrystalline diamond, aluminum oxide (Al2O3), and silica dioxide (SiO2), are considered to mix individually with a pollution-free palm oil in preparing the nanofluids. A commonly used Ni-based alloy was chosen as the workpiece material. It is shown that CNT nanofluid results in the lowest grinding temperature of 110.7°C and the associated energy proportionality coefficient of 40.1%. The relevant physical properties of the nanofluids such as the coefficient of thermal conductivity, viscosity, surface tension, and the contact state between the droplets and workpiece surface (contact angle) were discussed to shine a light on their effect on the cooling performance. A mathematical model for convective heat transfer coefficient was then developed based on the boundary layer theories.

8.1 INTRODUCTION

The grinding process to remove a unit volume of metal materials has a large energy input. Almost all energy transformations occur in the grinding zone. Most of the energies are converted into heat, so the temperature of the grinding zone increases. Grinding temperature influences the surface quality of the processed workpiece and the cutting performance of abrasive particles on the grinding wheel. A high grinding temperature will change the metallographic structure of the surface and cause grinding burn (Hadad, Tawakoli, Sadeghi, & Sadeghi, 2012). A high transient temperature will result in thermal stress during grinding and cooling; this thermal stress will in turn cause considerable residual stress and even

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cracks on the processed surface. This problem is aggravated in metallic materials with low thermal conductivity (e.g., titanium alloy). A high grinding temperature will also affect the dimensional and shape accuracies of parts. Additionally, the hardness of abrasive particles declines significantly at a high temperature. The bond wear and diffusion wear between abrasive particles and grinding materials passivate abrasive particles so fast that they lose their cutting capability (Chen, Rowe, & McCormack, 2000). Therefore, studying grinding temperature is important.

According to the requirements of sustainable development and environmental protection, traditional pouring grinding is unfit for the development in this new century. Existing green processing technologies, such as minimum quantity lubrication (MQL) and nanofluid MQL, can replace traditional pouring cooling lubrication and have shown significant advantages and development prospects (Malkin & Guo, 2007). Hadad et al. (2012) investigated 100Cr6 grinding through MQL and used an overhead thermocouple to measure the grinding temperature. They found that MQL consumes 7%–10% less energy than dry grinding. Barczak et al. (2010) compared the grinding power, grinding force, grinding temperature, and surface roughness of MQL grinding with those of pouring grinding and dry grinding. Their results revealed that MQL grinding is superior to pouring grinding in terms of grinding force and grinding power but inferior in terms of workpiece surface roughness and residual stress at an appropriate material removal rate. Although MQL grinding has more technological advantages than dry grinding and pouring grinding, the research indicated that it has insufficient heat transfer capability.

Researchers have explored nanofluid MQL machines according to the heat transfer enhancement of nanofluids. Shen et al. (2011) prepared nanofluids by adding Al2O3 and diamond nanoparticles to water to grind cast irons. They found that nanofluid MQL significantly reduces grinding force and surface roughness and effectively eliminates workpiece burning. A high nanoparticle concentration leads to a high G ratio. Lee et al. (2011) prepared nanofluids by adding diamond nanoparticles to liquid paraffin and studied the grinding performances of dry grinding, liquid paraffin MQL, and nanofluid MQL. The results showed that nanofluid MQL has a much lower grinding force and surface roughness than the others. Moreover, a small nanoparticle size leads to good surface quality. Kalita et al. (2012) conducted an experimental study on nanofluid grinding of cast iron and EN24 alloy steel by adding MoS2 nanoparticles to paraffin and soybean oils. They found that MoS2 nanofluids can reduce grinding force, grinding force ratio, and specific grinding energy and increase the G ratio of MQL grinding significantly. Kalita et al. (2012) also conducted an experimental study on spheroidal graphite cast iron 100-70-30 grinding by using different concentrations of MoS2 nanofluids and found that 8% MoS2 nanofluids has the lowest grinding temperature. Furthermore, they reported that nanofluid MQL grinding has good wear resistance. Mao et al. (2012) tested dry grinding, pouring grinding, MQL grinding, and Al2O3 nanofluid MQL grinding and discovered that nanofluid MQL has a lower grinding force and grinding temperature than the others and excellent workpiece surface quality. The researchers also discussed the effect of nanofluid MQL parameters and concluded that the lowest grinding temperature is achieved at 15° nozzle angle, 20 mm distance between the nozzle and the grinding zone, and 0.6 MPa air pressure (Mao et al., 2013). Zhang et al. (2015) ground quenching 45 steel with different nanofluids, including soybean oil, ZrO2, and CNT. The volume fraction of all nanofluids was 1%. They analyzed the energy proportionality coefficient and specific grinding energy during the grinding process and reported that CNT nanofluids contribute lower grinding temperature and energy proportionality coefficient than the other two nanofluids. According to the thermal conductivity of CNT nanoparticles, CNT nanofluids possess excellent heat conduction and reduce the temperature of the grinding zone dramatically.
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