Journal of Cleaner Production xxx (2014) 1–11

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Experimental evaluation of MoS_2 nanoparticles in jet MQL grinding with different types of vegetable oil as base oil

Yanbin Zhang, Changhe Li*, Dongzhou Jia, Dongkun Zhang, Xiaowei Zhang

School of Mechanical Engineering, Qingdao Technological University, 266033 Qingdao, China

A R T I C L E I N F O

Article history:
Received 16 May 2014
Received in revised form
13 September 2014
Accepted 11 October 2014
Available online xxx

Keywords:
Nanoparticle
MQL grinding
Vegetable oil
Lubricating property
Specific grinding energy
Coefficient of friction

A B S T R A C T

In consideration of the combined present research situation of vegetable oil as minimum quantity lubrication (MQL) base oil domestically and abroad, the lubricating property of soybean oil, palm oil, and rapeseed oil as base oil in comparison with liquid paraffin was explored. In the experiment, a numerical control precision surface grinder was used for plain grinding on a 45 steel workpiece. The effect of adding MoS_2 nanoparticle with a particle size of 50 nm was studied. Four types of grinding working conditions were applied: dry grinding, flood lubrication (5% water-soluble grinding fluid), MQL (base oil, including three types of vegetable oils and liquid paraffin), and nanoparticle jet MQL (containing nanoparticles at different concentrations). Grinding force, particle size, viscosity of nanofluids, and workpiece surface roughness were measured. The experimental results indicate that palm oil-based nanofluids added with MoS_2 nanoparticles produce the best lubricating property in the nanoparticle jet MQL condition because of the high saturated fatty acid and high film-forming property of carboxyl groups in palm oil. As viscosity has a different effect on lubricating performance and heat transfer performance, high viscosity of nanofluids significantly reduced heat transfer performance while enhancing lubrication performance. In consideration of the lubricating property and heat transfer performance, the best choice of base oil is soybean oil, which has the lowest viscosity. With the improvement of MoS_2 mass fraction in soybean oil-based nanofluids, the increase in nanofluid viscosity leads to improved lubricating property. However, excessive mass fraction will result in nanoparticle agglomeration and will break the lubricating property. In the experiment, 6% mass fraction was identified to be the optimal addition concentration for molybdenum disulfide nanoparticles.

1. Introduction

To address the current environmental and health problems in industrial production and sustainable development strategy for energy, attempts have been made to replace traditional flood cooling lubrication with dry grinding and MQL, which meet the environmental protection requirement as an important grinding processing technique in finish machining. Dry machining is the earliest proposed processing technology by researchers considering green and environmental protection (Pusavec et al., 2014). This technology originated from the mobile industry and is widely used at present in many machining forms. Dry machining does not use cutting fluid under the premise of guaranteeing cutter service life and part processing precision (Sharma and Sidhu, 2014). However, only a small proportion of heat generated in the grinding zone is removed through chips in the grinding process (Jin and Stephenson, 2008). The majority of the generated heat is transferred to the grinding wheel and workpieces (Li et al., 2013a), resulting in an overly high-energy concentration on the workpiece surface that could burn it and deteriorate its surface (Malkin and Guo, 2007).

Minimum quantity lubrication (MQL) grinding technology is another green processing technology in which, after mixing and atomizing, a small quantity of lubricants and gas with certain pressure is jetted to the grinding zone as cooling lubrication (Tawakoli et al., 2010). The cooling and chip removal effect is mainly achieved by high-pressure gas. The flow of lubricants per unit wheel width of MQL is 30 mL–100 mL, and that of flood grinding is 60 L/h. However, the lubrication effect of MQL exceeds that of flood, and the quantity of lubricants obviously decreases (Tawakoli et al., 2011). To decrease lubricant pollution to the environment and handling cost, degradable vegetable oil is typically used as base oil

* Corresponding author. Tel.: +86 532 85071757; fax: +86 532 85071286.
E-mail addresses: zhangyanbin1_qdlg@163.com (Y. Zhang), sy_lichanghe@163.com (C. Li), jia_dongzhou@163.com (D. Jia), zhangdongkun1988@163.com (D. Zhang), xiaovzhang@126.com (X. Zhang).

http://dx.doi.org/10.1016/j.jclepro.2014.10.027
0959-6526/

in nanoparticle jet MQL grinding (Cetin et al., 2011). Sadeghi et al. (2009) conducted an MQL grinding experimental research for GB 20CrNiMo structural alloy steel. The results indicate that the high-pressure gas imported to the grinding zone did not have a good cooling effect and that the heat generated in the grinding process was limitedly removed through high-pressure gas. This result may lead to heat accumulation on the workpiece surface, which deteriorates the surface integrity of the grinding workpiece as well as shortens the service life of the grinding wheel or even scraps it. Considerable experimental research (Li et al., 2008; Wang et al., 2013) demonstrates that dry grinding and MQL grinding both have poor cooling effects, thus making obtaining higher surface quality of the workpiece difficult and resulting in burns on the workpiece surface. The new nanoparticle jet MQL technology better resolves heat transfer in the grinding zone while enhancing the lubricating property in the zone. Li et al. (2008) performed experiments to evaluate the performance of MQL technology compared with conventional flood cooling. Experimental data indicate that the proposed method did not negatively affect surface integrity and that process validity was verified.

Based on theory of heat transfer enhancement (Zhang et al., 2013), the heat exchange capability of solid exceeds that of liquid, which is better than that of gas. Based on this feature, a certain quantity of nanolevel solid particles is added to degradable MQL oil to form a nanofluid. Nanofluid is atomized with high-pressure gas and sent to the grinding zone in the form of jet flow. High-pressure gas performs the functions of cooling, chip removal, and liquid transfer. The MQL oil functions as a lubricant, and the nanoparticles increase the liquid's heat exchange capability in the grinding zone and imparts a cooling effect. Choi et al. (2011) conducted a tribology performance research on nanofluids prepared by metal and carbon nanoparticles as the lubricating oil base, and Hwang et al. (2006) conducted an experimental research on the thermal conductivity and lubricating property of nanofluids. Results indicate that nanoparticles had excellent anti-wear and antifriction performance as well as a high carrying capacity. Therefore, the particles are expected to further improve the lubrication effect in the grinding zone. Nanoparticle jet MQL grinding has all the advantages of MQL grinding while also enhancing heat exchange in the grinding zone to evidently improve workpiece surface quality and burn situation (Zhang et al., 2012a). The technology also prolongs the service life of the grinding wheel and improves the working environment. Therefore, the technology presents an effective grinding method with low consumption and environmental protection.

As a nanoparticle jet MQL grinding fluid, nanofluids have the functions of cooling, lubricating, chip removal, and rust protection that can prolong the service life of cutters, improve part processing quality, and enhance machining efficiency (Li et al., 2013b). Frequently used base grinding fluids include mineral oil, synthetic lipids, and polyethylene glycol, among others. The threat of these grinding fluids on health primarily lies in their toxicity. Grinding fluid produces smog under the grinding condition of the wheel's high-speed rotation, which releases harmful gas and oil mist, thus generating haze pollution. The gas spray can enter into the respiratory tract and stimulate respiratory system mucosa to cause inflammation. In addition, close contact with the gas spray may cause many types of skin diseases that may damage workers' health.

Compared with flood grinding, nanoparticle jet considerably decreases the required grinding fluid and the subsequent pollution on the environment. However, nanofluid atomization causes considerable damage to the health of the workers, results in certain pollution to the environment, and increases processing cost (Shen et al., 2008). Therefore, developing and promoting a new base of MQL liquid (environmental protection type) has become one of research directions of nanofluid jet MQL technology to decrease the environmental pollution index, improve the working environment of cleaning workers, and reduce processing cost, among others (Shaji and Radhakrishnan, 2002). Zhang et al. (2012b) demonstrated in their experiment that excellent lubricating property could be achieved with vegetable oil as a lubricant base oil and that the addition of nanoparticles could reduce the coefficient of friction and enhance the anti-wear capability of friction auxiliary materials. Vegetable oil has good biodegradability (Luna et al., 2011), no toxicity, high yield, and abundant resources. Compared with mineral oil, vegetable oil has a higher boiling point and molecule weight, which relevantly decreases loss during atomizing and gasifying. According to Steigerwald (2005), the glyceride base of vegetable oil is liable to hydrolyze. The unsaturated double bond in the ester group chain is easily attacked by microorganisms for β oxidation so vegetable oil has good biodegradability. The natural fatty acids in vegetable oil perform a driving function in the degradation process, and its biodegradation rate is above 90% in the CEC test.

Experimental research has been conducted on the attempts to use vegetable oil as metal machining liquid. Jain and Bisht (2008), scholars from India, tried to replace mineral oil with non-edible vegetable oil (i.e., rapeseed oil and Karanja oil), which has renewability, biodegradability, and lower price than synthetic ester oil and grease. In the experiment, 5% oil–water mixed liquors composed of many types of non-edible vegetable oil and mineral oil were compared with the standard oil to measure their stability, load capacity, size distribution, and frictional wear. Rahim and Sasahara (2011a, 2011b, and 2011c) conducted a series of experimental research. Palm oil and synthetic ester were used in a drilling experiment as MQL base oil to compare various properties in the drilling process. Rahim and Sasahara (2011a) considered GH169 alloy as the processing material in the first group of experiment and compared its surface quality after processing with palm oil and synthetic ester as MQL base oil. The researchers found better microhardness, surface roughness, surface defect, sub-surface deformation, and other properties of the workpiece after processing with palm oil as the MQL base oil than with synthetic ester. Rahim and Sasahara (2011b) also considered titanium alloy Ti–6Al–4V as the processing material in the second group of experiments to compare drilling force, torque, temperature, and cutter life in dry drilling and MQL drilling with two types of grease. The experimental results indicate that MQL drilling has considerable advantage over dry drilling in the above aspects. Given the formation of a lubricating oil film in the drilling process, palm oil presents certain advantages in the aspects of microhardness, surface roughness, and subsurface deformation, among others. Rahim and Sasahara (2011c) considered titanium alloy Ti–6Al–4V as the workpiece in the third group of experiments to compare the experimental results of dry drilling, flood drilling, and two types of grease. The advantages of palm oil as the MQL base oil were demonstrated using cutter life, drilling force, torque, temperature, and other indexes. Rahim concluded from this series of three experimental research that palm oil meets the standard of cutting fluid and can replace synthetic ester as the MQL base oil. With its unique properties, vegetable oil technology has been demonstrated to improve production efficiency and prolong cutter life. The use of vegetable oil base cutting liquid in machining can yield better workpiece surface quality and accurate tolerance to shorten downtime and improve production efficiency.

Researchers (Shashidhara and Jayaram, 2010; Nguyen and Kwon, 2012; Lawal et al., 2013) have demonstrated in previous research efforts that vegetable oil can be used as the cutting fluid and MQL base oil in turning, drilling, and other machining methods of metals and achieve good cooling and lubrication effect. The

Please cite this article in press as: Zhang, Y., et al., Experimental evaluation of MoS_2 nanoparticles in jet MQL grinding with different types of vegetable oil as base oil, Journal of Cleaner Production (2014), http://dx.doi.org/10.1016/j.jclepro.2014.10.027