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An experimental investigation on the effects of minimum quantity nano lubricant application in grinding process of Tungsten carbide

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ABSTRACT

Minimum quantity lubrication (MQL) technique is an efficient and eco-friendly method of lubricant application in machining processes. The lubricant type applied in this technique is not only important in relation to environmental aspects but also has a great effect on machining efficiency. Nanolubricant (nanofluid) is composed of nanoparticles suspended in base oil and shows prominent lubrication performance. In the present study, the effects of minimum quantity nano-lubrication (MQNL) in surface grinding of Tungsten carbide grade YG8 is experimentally investigated. The nanolubricants applied in the experiments include MoS_2, graphite, and Al_2O_3 nanoparticles (with varying concentration) dispersed in two different base oils- mineral oil (paraffin) and vegetable oil (sunflower). The grinding outputs such as specific energy, cutting force, and surface quality were used as measurands for determining the process efficiency. Furthermore, performance evaluation of MQNL in grinding process of WC material was performed by comparing the grinding outputs at different environment such as dry, wet, and MQL. The results show that, if nanoparticles are selected properly, MQNL technique is an effective method to improve the process efficiency by reducing the grinding force, specific energy, and increasing surface quality.

1. Introduction

Minimum quantity lubrication (MQL) is an environmentally friendly method of using cutting fluid in machining processes. In MQL machining, the high pressurized air sprays a minute amount of lubricant (10–200 ml/h) in the form of an aerosol onto the tool-workpiece contact zone [1]. MQL has been applied to different machining processes such as turning, milling, drilling, grinding, and etc. Also, promising results in MQL machining have been reported [2–5]. Grinding is a conventional machining process which is mainly applied for finishing work surface. However, it is inherently associated with high specific energy requirements, unlike other conventional machining processes such as turning, milling, drilling, etc., which result in a high grinding zone temperature and poor surface integrity [6]. The researches conducted on MQL in grinding have depicted that, MQL can considerably improve the grindability of work material. Hafenbraedl and Malkin [7] found that utilizing MQL technique in internal cylindrical grinding, reduces the grinding power as well as specific energy and grinding wheel wear due to efficient lubrication of the grinding zone. Silva et al. [8] investigated the effects of MQL in cylindrical plunge grinding of ABNT 4340 steel (60 HRC). They found that the MQL technique results in more effective lubrication, improve the surface roughness, wheel wear, grinding forces and residual stress. Tawakoli et al. [9] performed a comparative study of two steel grades namely, hardened steel 100Cr6 and soft steel 42CrMo4 in MQL surface grinding process. Their study showed that lower tangential grinding force and improved surface quality are obtained when MQL is applied to grinding 100Cr6 hardened steel. Furthermore, MQL grinding compared to flood cooling resulted in higher material removal rates with higher surface quality and lower grinding force. Barczak et al. [10] investigated three cooling methods: wet, dry and MQL on the grinding process of steel alloys EN8, M2, and EN31. Their research showed that MQL can perform comparably to flood delivery under the experimental conditions applied.

The media used as a lubricant in MQL plays an important role in improving the grinding efficiency and surface quality. Studies by Brinksmeier et al. [11] demonstrated that the type of lubricant applied in MQL grinding (ester oil or emulsion) can significantly affect the process results. Brunner [12] showed that ester oil, as compared to mineral oil, during MQL grinding of 16 MnCr5 (SAE-5115) reduces the tangential and normal grinding forces to one third, but increases the surface roughness by 50%. Sadeghi et al. [5] investigated the influences of two types of lubricants (vegetable oil and synthetic ester oil) on MQL

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grinding of Ti–6Al–4 V titanium alloy. Their results showed that synthetic ester oil outperforms vegetable oil in terms of higher surface quality (lower surface roughness, improved surface texture, no burned surface) and lower grinding force in the conditions investigated. Emami et al. [13] explored the performance of four types of lubricants, namely mineral, hydrocracked, synthetic, and vegetable oils, with regard to the reduction in cutting force, specific energy and surface roughness during near dry grinding (MQL grinding) of Al_2O_3 engineering ceramic. Their research depicted that synthetic and hydrocracked based oils show satisfactory environmental and technical performance in MQL grinding of Al_2O_3 ceramics. It is clear from the above literature that MQL-media is a key technical area that can enable the success of MQL grinding processes. Recently, nanolubricants due to their special tribological properties have been applied as MQL-media in machining processes. Nanolubricant is defined as an engineered material that consists of nanometer sized particles dispersed in base oil [14]. In minimum quantity nano-lubrication (MQNL) process the nanolubricant is atomized into droplets by an air atomizing nozzle. The oil droplets containing nanoparticles are carried by the air stream and impinge on the wheel surface. Then the wheel grains impregnated with both oil and nanoparticles come into the cutting zone and lubrication is performed. It has been shown that nanoparticles can improve the tribological properties of base oils by increasing the extreme-pressure and load-carrying capacity and decreasing the friction coefficient [15,16]. The effectiveness of the nanolubricants depends on the properties of the base oil and dispersed nanoparticles characteristics. Type, Morphology, crystal structure, size, and quantity of nanoparticles are important factors influencing the lubrication performance (tribological properties) of nanolubricants [17]. Shen et al. [15] applied water-based Al_2O_3 and diamond nanofluids (with varying concentration of nanoparticles) in the MQNL grinding of cast iron and compared the results with dry, wet, and MQL methods. Their study showed that lower grinding force, improved surface roughness, and higher G-ratio are obtained when high concentration nanofluids are used as media. Kalita et al. [18] experimentally investigated the influences of oil-based nanolubricants composed of MoS_2 nanoparticles (< 100 nm) dispersed in two different base oils -mineral oil (paraffin) and vegetable oil (soybean)- in MQNL grinding process. The experiments were carried out on cast iron and EN 24 steel under different lubrication conditions—MQNL (with varying concentration of nanoparticles), MQL with pure base oils, and flood grinding using water-based coolant. The authors concluded that the MQNL grinding increases process efficiency by reducing the specific energy, coefficient of friction, and tool wear. Moreover, the nanolubricant effectiveness is also found to increase with increasing nanoparticle concentration. Vegetable and mineral based-nanolubricant performed best for steel and cast iron, respectively. Furthermore, the formation of tribo-chemical films on work surface was identified as the mechanism responsible for process improvements.

The literature review shows that the MQL using nanolubricants have a great potential to be applied in grinding processes. Therefore, more investigations are required to elucidate the effects of nanolubricants on grinding process of engineering materials. On the other hand difficult to grind materials such as carbides, superalloys, ceramics, and etc have poor grindability and there is an urgent need to improve their grinding efficiency and surface quality. Tungsten carbides due to high hardness, toughness, and wear resistance are extremely difficult to grind. These materials have been used extensively for various wear-resistant applications, such as cutting bits for machining, coal mining and well boring as well as wear resistance parts in dies, machinery, and ore crushing equipment. Therefore applying nanolubricants in MQL grinding of Tungsten carbide material is an interesting case to be explored. In the present study nanolubricants with different types of nanoparticles such as Al_2O_3, MoS_2, and graphite at two concentrations (1 wt% and 3 wt%) dispersed in two different base oils—mineral oil (paraffin) and vegetable oil (sunflower)— are applied in MQL grinding of tungsten carbide (WC) grade YG8. For comparing purposes, other lubrication techniques such as dry, wet and pure MQL are also tested. Cutting force and surface quality (including surface roughness and surface texture) are used as measurands for determining the efficiency of the process. The morphology and of chemical analysis of the ground specimens are studied using field emission scanning electron microscopy (FE-SEM) and energy dispersive spectroscopy (EDS).

Table 1
Workpiece Material Specification.

Tungsten Carbide Grade	Density [g/cm3]	Elastic modulus [GPa]	TRS[MPa]	HardnessHRA
YG8	14.80	698	2200	89.5

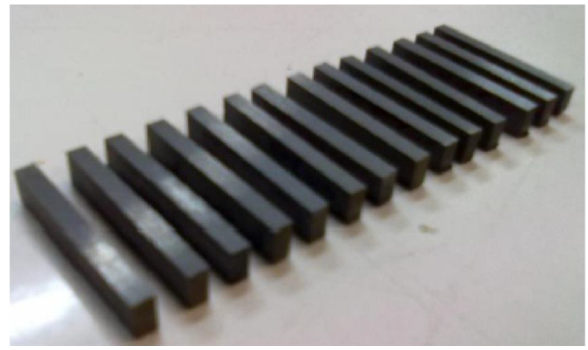

Fig. 1. Grinding workpiece specimens (rectangular bars of 42 × 8 × 4 mm).

2. Experimental setup and procedure

The work material used in this study is tungsten carbide (WC) grade YG8. The physical and mechanical properties of the workpiece material are shown in Table 1. Grinding workpiece specimens were cut to rectangular bars of 42 × 8 × 4 mm (Fig. 1) using wirecut Electro Discharge Machining (EDM). The experimental setup and grinding parameters used in this study are shown in Fig. 2 and Table 2 respectively. The grinding machine used for the tests is JUNG F 50 horizontal surface grinder. A resin bonded diamond grinding wheel with grit size D181 and a 75% diamond concentration was used with a constant peripheral speed of 30 m/s. A brake-controlled truing device (Norton 4597) with a vitrified silicon carbide wheel GC60 L at a speed 1250s.f.p.m, depth 10 μm and transverse feed rate 150 mm/min was used for wheel truing. Prior to each test, wheel dressing was carried out with an alumina stick Norton 38A150-I8VBE so that the wheel topography consistency could be maintained. Each grinding experiment was done on the 42 mm × 4 mm specimen surface in up-cut plunge mode. The nanolubricants were prepared for the experiments by addition of nanoparticles, such as MoS_2, graphite, and Al_2O_3 (with 1 wt% and 3 wt% concentration) in two different base oils: mineral oil (paraffin) and vegetable oil (sunflower) as shown in Fig. 3. Moreover, a sonicator (Hielscher UP4OOS, probe tip diameter 3 mm) was used at 80% amplitude for 15 min to disperse the nanoparticles in the base oils. An MQL system equipped to separately control the oil and air flow rates with a gas-assisted atomization nozzle sprays the nanolubricants to the grinding zone. The MQL jet spray was targeted at an angle a = 15°, distance L = 30 mm toward a point on the wheel surface and at a height H = 15 mm from the work surface. Furthermore, the nanolubricants at a flow rate of 1.5 ml/min with gas at a flow rate of 30 l/min were applied via the MQL nozzle to the lubrication target point. Fig. 4 illustrates the schematic of the nanolubricant spray impinges on the grinding wheel. Additionally, pure MQL, flood cooling as well as dry tests were conducted for comparison purpose with the nanolubrication tests. The pure MQL tests were carried out using neat base oils: mineral oil or vegetable oil with the same