Optimizing MQCL Performance in Hard Turning of 90CrSi Steel Using Nanofluids

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ABSTRACT

The present work shows an experimental investigation on the effect of minimum quantity cooling lubrication (MQCL) during hard turning of 90CrSi steel (60-62 HRC). The cooling strategy created by Ranque-Hilsch vortex tube combined with MQL ideal to from MQCL technique. Moreover, Al_2O_3 nanoparticles are suspended in soybean-based fluid to improve the lubricating character and retain the environmental friendly character. The response parameters, including cutting force and surface roughness are studied. The results of this work show that cutting performance of coated carbide tools improves due to the better cooling and lubricating effect. In addition, MQCL using Al_2O_3 nanofluid reduces the cutting forces significantly and shows the worse surface roughness compared MQCL with pure fluid. The promising results when using MQCL technique in hard machining will be a big step toward green manufacturing

Keywords: Hard turning, MQCL, soybean oil, Al2O3 nanoparticles, nanofluid, machining.

INTRODUCTION

In recent years, hard turning has gained much attention due to the growing demand of high productivity, good surface quality, and manufacturing cost reduction. Also, the use of cutting fluids can be eliminated or minimized to give out the environmental friendly characteristics [1]. The inserts with geometrically defined cutting edges are used directly for machining hardened materials with the hardness of 45–70 HRC [2]. In the earliest type, hard turning processes were carried out under dry condition, which showed the obvious cost benefits from the usage elimination of cutting fluids. Due to the high hardness materials, the high-grade inserts such as coated cemented carbide, ceramics, (P)CBN (Polycrystalline Cubic Boron Nitride), PCD (Cubic Boron Nitride) tools are always required [3–7]. However, the very high cutting temperature causes rapid wear rate, which shortens the tool life as well as limits the cutting condition [4]. To remain the environmental friendly characteristics and overcome the drawbacks of dry turning, minimum quantity lubrication (MQL) was proposed and developed with the use of small amount of cutting fluid with oil mist form, directly sprayed to contact zone to bring out the high lubricating efficiency. The significant reduction of friction coefficient, cutting forces, cutting temperature, and tool wear, as well as the improvement of surface quality and tool life was proven by numerous studies [8-11], but low cooling effect is still the main drawback of MQL technology in machining hard materials. On the other hand, the use of vegetable oils as MQL base fluid to retain the environmental friendly character faces the difficulty because of the low ignition temperature [12]. To develop MQL technique assisted for hard cutting, minimum quantity cooling lubrication (MQCL) technique is developed to solve the low cooling problem. Some studies had been made to study the effects of MQCL performance on machining difficult-to-cut materials, but 2 the cooling effect is generated by the cooling property of the base fluid [13-16]. From the literature review, the combination of MQL method with Ranque-Hilsch vortex tube to form MQCL device used for hard cutting is a new topic, which brings out superior cooling and lubricating effects to improve machining performance [17]. The nano additives suspended in MQCL base fluid are also the new research trend, which is needed to study. Hence, the authors are motivated to make the study of MQCL performance in hard turning of 90CrSi steel. Moreover, the effects of Al_2O_3 nanofluid in MQCL technique on hard turning are also investigated.

MATERIAL AND METHODS

2.1. Experiment set up

2.1.1. Experiment devices

The CS-460x1000 Chu Shing lathe was used to conduct the experiments. Tungaloy CNMG120404-TM T9125 tungsten carbide inserts with coating layers of CVD Al_2O_3/TiCN were utilized. The PCLNR 2020 K-16 tool holder (KYOCERA Precision Tools, Inc.) was used.

The MQL system includes: The MQCL system includes Frigid-X Sub-Zero Vortex Tool Cooling Mist System (made by Nex Flow™, Richmond Hill, Canada), compressed air, pressure stabilization device, soybean oil, and Al2O3 nanoparticles. Measuring equipment consists of Kistler quartz three-component dynamometer (9257BA), SJ-210 Mitutoyo (made by Japan) for surface roughness, data acquisition system A/D DQA N16210 (made by National instruments, USA), and DASYlab 10.0 software. The experimental set up is shown in Fig.1. Al_2O_3 nanoparticles with the average size of 30 nm were made by Soochow Hengqiu Graphene Technology Co., Ltd (Fig.2). In this study, 90CrSi steel with the hardness of 60-62 HRC was used. The workpiece diameter is 40 mm with the chemical composition (Table 1). To ensure uniform suspension of Al2O3 nanoparticles in soybean oil, the prepared nanofluids are kept in Ultrasons-HD ultrasonicator (JP SELECTA in SPAIN), generating 600W ultrasonic pulses at 40 kHz, and the time for the concentration 3.0wt% in 6 hours.

Table 1 – Chemical composition in % of 90CrSi steel

Element	C	Si	Mn	Ni	S	P	Cr	Mo	W	V	Ti	Cu
Weight (%)	0.85-0.95	1.20-1.60	0.30-0.60	Max 0.40	Max 0.03	Max 0.03	0.95-1.25	Max 0.20	Max 0.20	Max 0.15	Max 0.03	Max 0.3

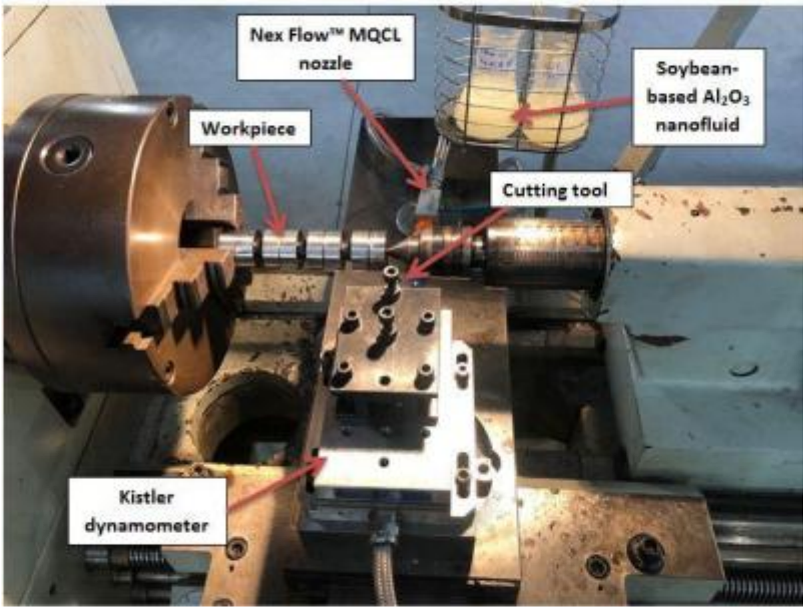

Figure 1. The experimental set up

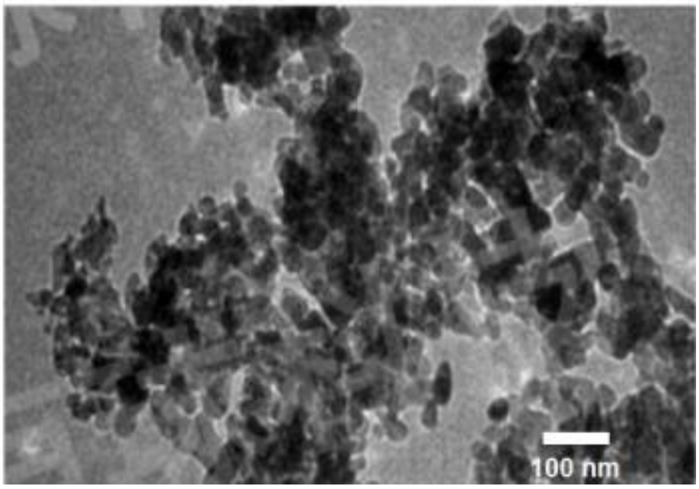

Figure 2. TEM image of Al2O3 nanoparticles [18]

2.1.2 Experiment design

The cutting condition is given by Table 1. The depth of cut and the feed rate are fixed at 0.15 mm and 0.1 mm/rev. The parameters of MQCL system are air pressure of 6 Bar, flow rate of 30 ml/h, and the temperature of output cool air 4–8 °C with the room temperature 24–27 °C. Each experimental trial is repeated by three times under the same cutting parameters and takes the average values for cutting forces and surface roughness. Hard turning process is conducted under MQCL condition with soybean-based fluid and soybean-based nanofluid.

Table 1. Cutting condition

Control factor	
Cutting speed (V_c), *m/min*	120; 170
Nanoparticle	Al_2O_3
Nano concentration (*wt%*)	0; 3
Base fluid	Soybean oil
Cooling and lubricating condition	MQCL

RESULTS AND DISCUSSION

The cutting force components F_x, F_y, F_z in MQCL hard turning with different cutting speeds are given by Figs. 3-5. The surface roughness R_a, R_z are shown in Figs. 6-7.

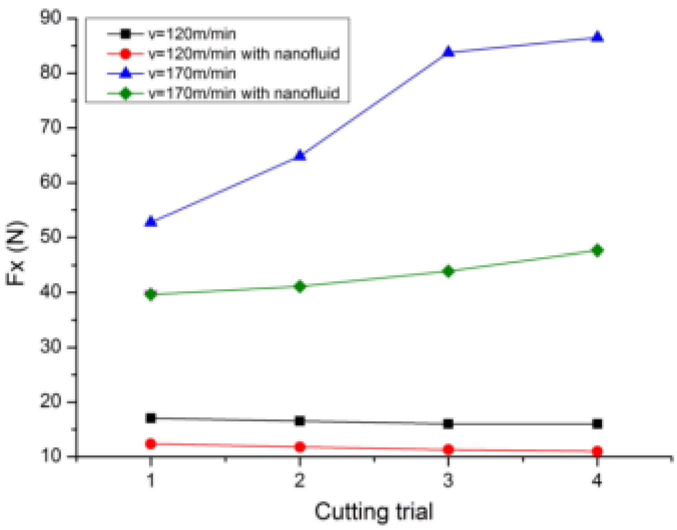

Figure 3. Cutting force F_x in MQCL hard turning

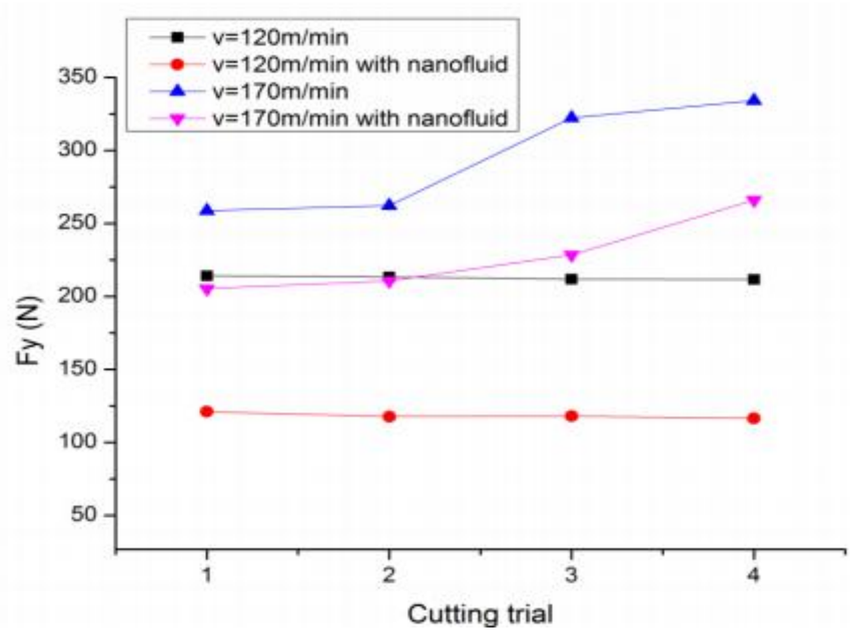

Figure 4. Cutting force Fy in MQCL hard turning

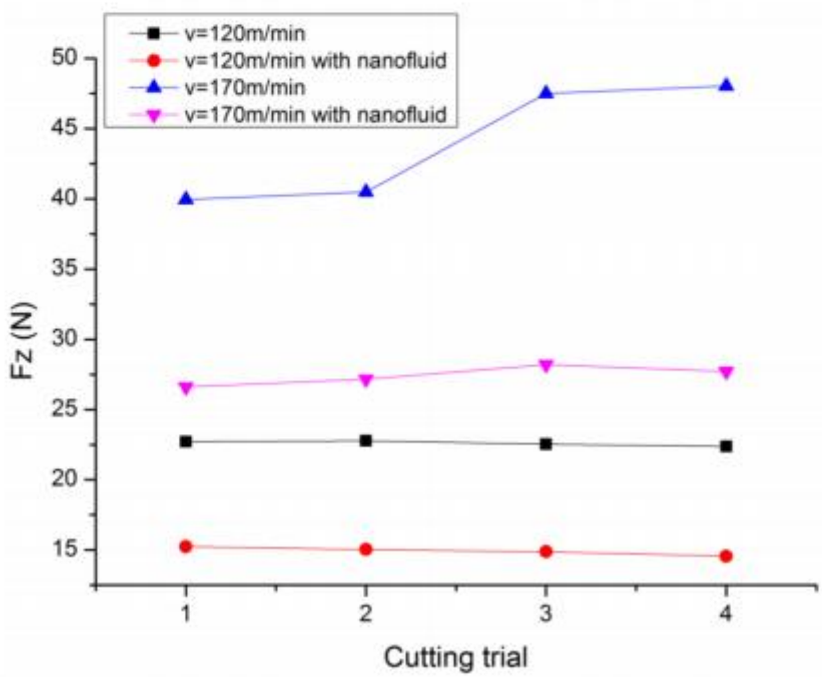

Figure 5. Cutting force F_z in MQCL hard turning

From the obtained results, it clearly indicates that the cutting forces increase with the rise of cutting speed from 120 m/min to 170 m/min. Also, the cutting force components F_x, F_y, F_z under MQCL condition using Al_2O_3 soybean-based nanofluid significantly reduce when compared to MQCL condition using soybean-based fluid. The main reason is the better lubricating performance of Al2O3 nanofluid caused by the "rolling effect" of Al2O3nanoparicles. The rolling contact instead of sliding one in cutting zone contributes to decrease the friction coefficient much [12]. Furthermore, at cutting speed of 170 m/min, the high rate of rising cutting forces is observed from MQCL using soybean-based fluid (Figs. 3-5), which is contrary to the case of MQCL with nanofluid. Accordingly, Al_2O_3 nanoparticles suspended in soybean-based fluid used in MQCL strongly influence on cutting forces and they show the effectiveness in stabilizing cutting force components [19-20].

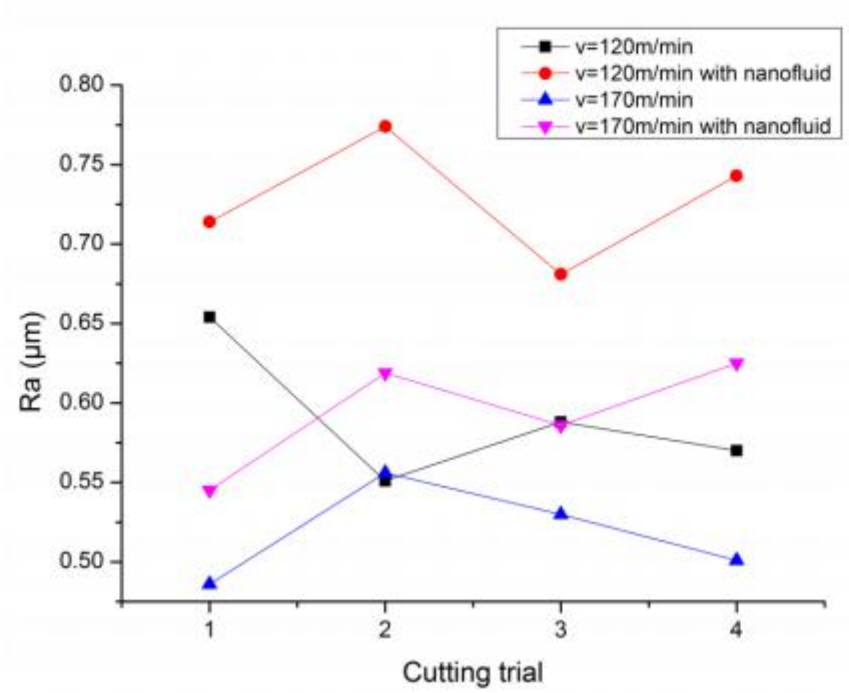

Figure 6. Surface roughness R_a in MQCL hard turning

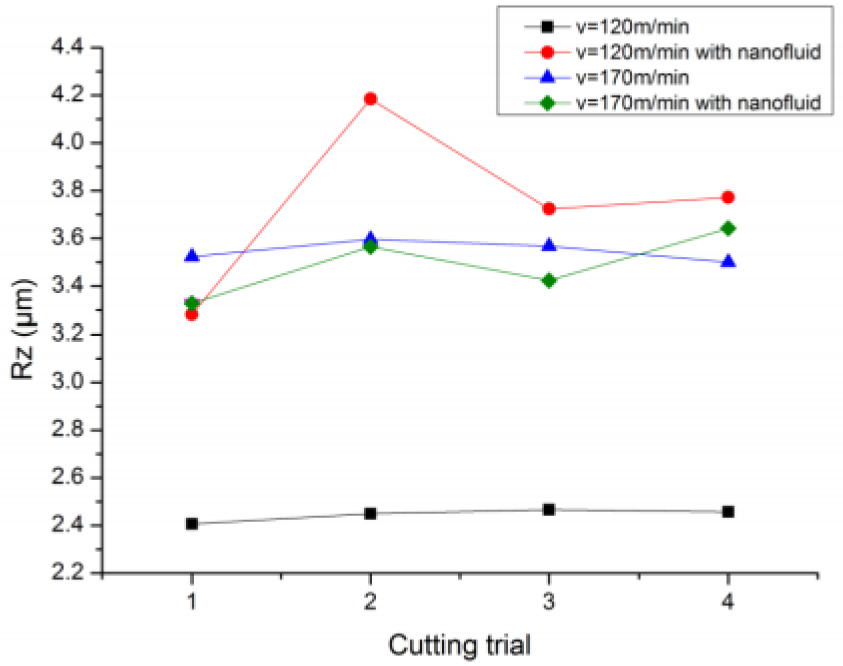

Figure 7. Surface roughness R_z in MQCL hard turning

From Figs. 6-7, surface roughness R_a, R_z in MQCL with soybean-based fluid is better than that with Al_2O_3 soybean-based nanofluid, especially at cutting speed of 120 m/min. It can be explained that the presence of large amounts of nanoparticles suspended in cutting fluid increases collision and impedance among the particles and asperities, which in turn results in worse surface quality [20]. Therefore, the use of large concentration of nanoparticles exhibits the effect on the reduction of cutting forces but causes the negative effect on surface roughness.

CONCLUSION

The application of MQCL technique using soybean oil as the base fluid contributes to improve the cutting performance of carbide inserts in hard turning due to the significant enhancement of thermal conductivity and lubricating effects. The performance of Al_2O_3 nanofluid in MQCL method is studied. From the experimental results, it could be concluded that MQCL method with Al2O3 nanofluid exhibits the better lubricating effect as well as the reduction of friction coefficient than that with pure fluid, from which the cutting forces much reduce. This comes from the rolling effect of Al_2O_3 nanoparticles in soybean oil. The large nano concentration of 3.0 wt% in MQCL fluid indicates the worse surface roughness than that of pure fluid due to collision and impedance among the particles and asperities. Moreover, the use of ordinary air based on Ranque-Hilsch vortex tube rather than CO_2 or nitrogen to create the cooling air, which combines with MQL to from MQCL technique. It is the novelty of the paper that the manufacturing cost is reduced and the device requirements assisted to hard machining can be simplified. In addition, the soybean oil, a vegetable oil, is successfully applied to hard turning as the based fluid of MQCL technique, which will be a big step toward sustainable production.

In further research, more investigations will be concentrated on optimizing nanoparticle concentration and its effect on surface quality. In addition, more focus will be given to investigate the influence other variables like feed rate, depth of cut and the parameters of MQCL using nanofluid.

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