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Experimental study on hard turning of 90CrSi steel under MQCL condition

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Abstract
The present work exhibits an experimental study on hard turning process of 90CrSi steel (60-62 HRC) under minimum quantity cooling lubrication (MQCL). Two types of cutting oils were used: soybean oil and soybean oil with Al_2O_3 nanoparticles. The influences of cutting speed and cutting oil type on cutting force components were investigated and evaluated by using the factorial experimental design. The obtained results show that nano cutting oil has improved lubricating and cooling efficiency compared to pure cutting oil, thus reducing cutting forces and improving machinability of carbide inserts. The cutting speed has a great influence on the cutting forces.When the cutting speed increases in the investigated range, the cutting force components go up. The study also provides the technical guides for choosing nanoparticle concentration and cutting speed.
Keywords: *Hard turning, MQCL, soybean oil, Al_2O_3nanoparticles, nanofluid, hard machining.*

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I. INTRODUCTION

In recent years, hard turning has gained much attention, is widely applied and used as a partial or complete replacement for grinding operations [1]. Direct cutting of hardened steels has become easier due to the advances in material technologyof cutting tools and machine tools [2]. Furthermore, the dimensional accuracy and surface quality in hard turning are equivalent to grinding operations, but productivity and flexibility are higher. Along with the trend of clean manufacturing, the studies and application of environmentally friendly machining technologies are increasingly interested, especially in the issue of using cutting oils in metal cutting field.

Hard machining processes using cutting tools with geometrically defined cutting edges have provided new solutions in finishing and allowed machining in the dry condition. The complete elimination of cutting oil has contributed to a reduction in cutting oil usage and disposal costs as well as a reduced negative impact on the environment [3]. However, for machining materials with high hardness, enormous heat and large cutting forces accelerate tool wear, adversely affecting the quality of the machined surface [1]. Also,the application of carbide inserts in dry cutting faces with early tool worn, thereby increasing tooling costs. Therefore, it is necessary to have suitable cooling lubrication solutions to overcome this problem but still ensure environmental friendliness [4].

In recent years, MQCL technology has been studied and applied in the machining field. There have been many studies that show high efficiency in lubrication and cooling with a very small amount of cutting oil used, so it is classified as environmentally friendly technology [5,6]. The application of MQCL technology in machining reveals that the efficiency of the cutting process is improved through the assessment of the cutting forces and the quality of the machined surface [7,8]. However, the study on applying this technology in machining hard materials is still limited [9]. Therefore, the authors made an experimental study to evaluate the influence of cutting speed and type of cutting oil in hard turning of 90CrSi steel (60-62 HRC) under minimum quantity cooling lubrication (MQCL).

II. MATERIAL AND METHODS

The cutting trials were conducted on CS-460x1000Chu Shing lathe.The tungsten carbide inserts with coating layers of CVD Al_2O_3/TiCN were utilized. The cooling and lubricating system includesMQCL nozzle, compressed air, pressure stabilization device, soybean oil, and Al_2O_3 nanoparticles. Cutting force components were measured by Kistler quartz three-component dynamometer (9257BA).The image of experimental set up is shown in Figure 1. The workpiece samples are90CrSi steel with the hardness of 60-62 HRC. The sample diameter is 40 mm with the chemical composition (Table 1).

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

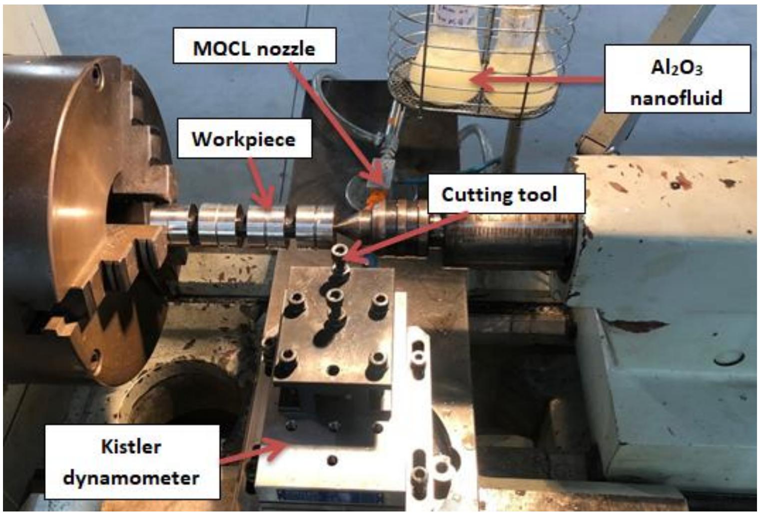

Figure 1. The experimental set up

The factorial design of two factors and their levels 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 MQCL parameters are air pressure of 0.6 MPa, flow rate of 30 ml/h, and the base oil ofsoybean oil with/without Al_2O_3 nanoparticles. Each experimental trialiscarried out be following the factorial design and is repeated by three times under the same cutting parameters and takes the average values for cutting forces.

Table 1. Factorial design of two factors and their levels

Input machining parameters	**Low level**	**High level**
Cutting speed, V (*rev/min*)	950	1400
Nanoparticle concentration, NC (*%*)	0	3

III. RESULTS AND DISCUSSION

Carrying out the experiments according to the factorial design, the experimental data was collected and processed. The graphs of main effects of the input parameters on the cutting force components (Figures 2-4). It can be seen that for increasing the cutting speed from 900 rev/min to 1400 rev/min, all three cutting force components increase sharply due to the increased area of the cross-section of a cut layer [9]. In case of using Al_2O_3 nano-cutting oil with the soybean-based oil, the cutting forces F_x, F_y, F_z were reduced, which proves that the nano-cutting oil contributes todecrease the friction in the cutting zone [10] and improve the lubricating performance compared to pure soybean oil.

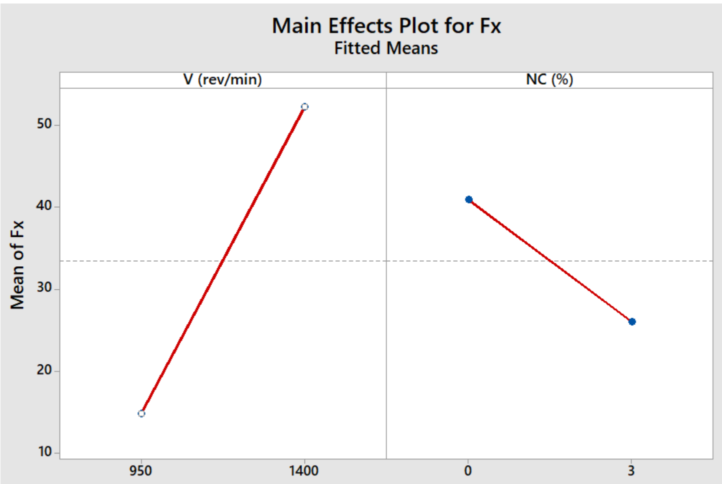

Figure 2. Main effects of input variables on cutting force F_x

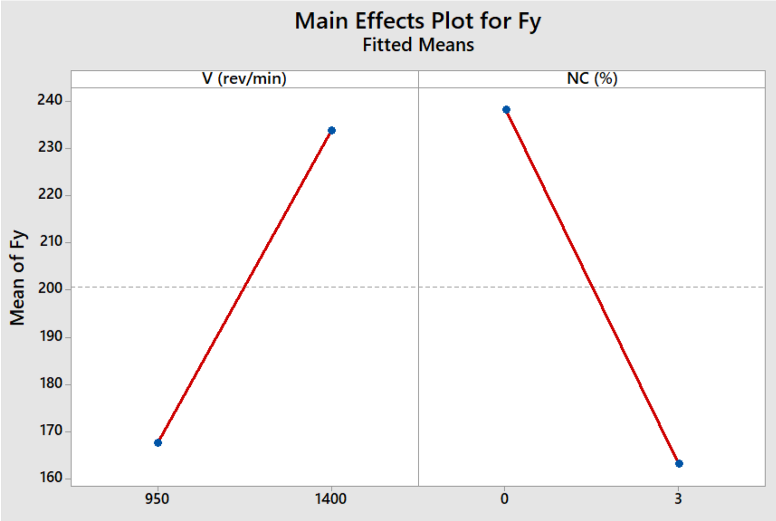

Figure 3. Main effects of input variables on cutting force F_y

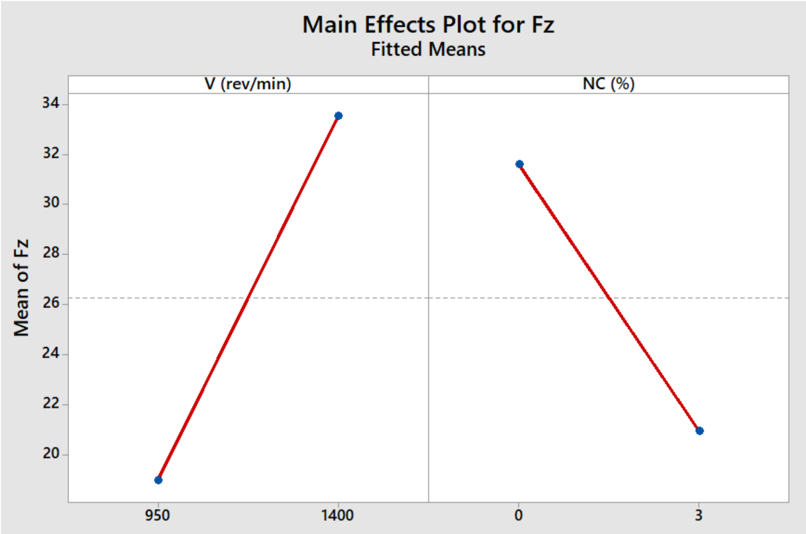

Figure 4. Main effects of input variables on cutting force F_z

From the contour plots showing the interaction effects between the nanoparticle concentration and the cutting speed on the cutting force components F_x, F_y, F_z. For F_x< 20N, NC =0÷3.0% and V = 950÷1150 rev/min should be selected (Figure 5). For F_y< 140N, it is recommended to choose NC = 2.4÷3.0% and V = 950÷1150 rev/min (Figure 6). For F_z < 20N, NC = 1.1÷3.0% and V = 950÷1120 rev/min should be selected (Figure 7). Therefore, for smaller cutting forces, it is possible to choose nanoparticle concentration from 2.4÷3.0% and V = 950÷1120 rev/min. Among the three cutting force components, the thrust component F_y has a great influence on the machining dimensional accuracy and flank wear of the tool. Accorsingly, when choosing the input parameter, more attention should be paid to this component [9].

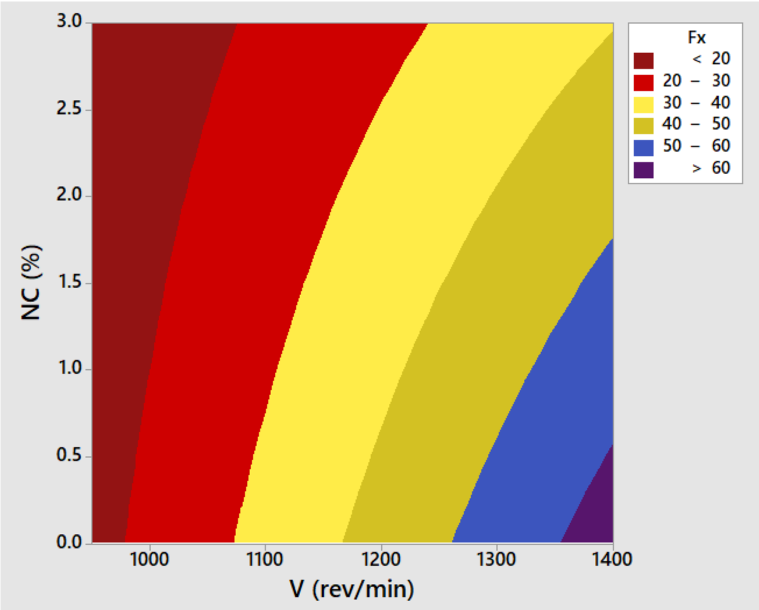

Figure 5. Contour plot of nanoparticle concentration and cutting speed on cutting force F_x

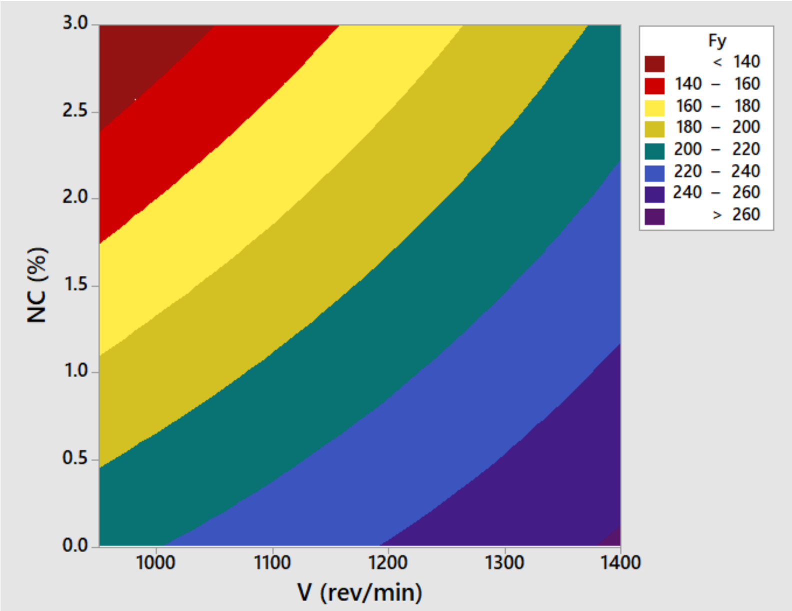

Figure 6. Contour plot of nanoparticle concentration and cutting speed on cutting force F_y

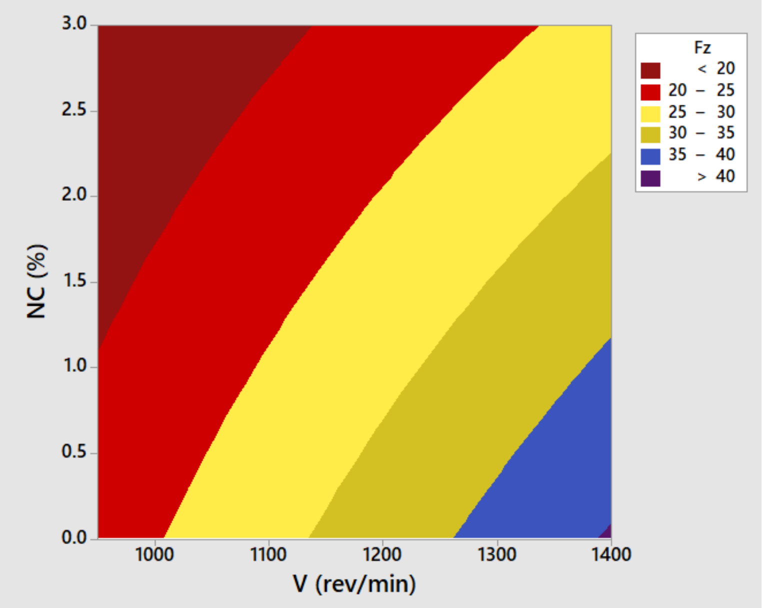

Figure 7. Contour plot of nanoparticle concentration and cutting speed on cutting force F_z

IV. CONCLUSION

In this paper, MQCL technology using vegetable oil has been successfully applied to hard turning of 90CrSi steel(60-62 HRC). Two input parameters including nanoparticle concentration and cutting speed were studied and evaluated for their influence on the cutting force components. Besides, the interaction effects of these two parameters are also studied to determine the optimal value domain. The growing cutting speed has a great influence on the cutting forces and increases their values, while using cutting oil with Al_2O_3 nanoparticles, it contributes to reduce the cutting forces. The main reason is that Al_2O_3 nanoparticles have contributed to improve the cooling lubricating efficiency of the base cutting oil. Moreover, Al_2O_3 nanoparticles have high hardness and good thermal conductivity, thus contributing to decrease the friction coefficient in the cutting zone, which is the difference ofmachining with nano-cutting oil.

In further research, more studiesshould be focused on optimizing nanoparticle concentration and its effect on cutting force.

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