# An experimental study on cutting temperature and burr in milling of ferritic stainless steel under MQL using nano graphene reinforced cutting fluid

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## Abstract

In this experimental study, cutting temperatures and burr forms were investigated during MQL (Minimum Quantity Lubrication) milling of AISI 430 ferritic stainless steel. In the experiments, uncoated and TiN (Titanium Nitride) coated WC (Tungsten Carbide) cutting tools were used and the experiments were performed under dry and MQL conditions. A commercial vegetable cutting fluid was chosen as cutting fluid and MQL flow rates were applied at 20 ml/h and 40 ml/h. Additionally, a nanofluid was prepared by adding nano graphene particles to the vegetable cutting fluid at 0,5%wt. Depending on the experimental results, low cutting temperature and small burr forms could have been obtained in the results of using TiN coated WC cutting tool and applying MQL method. In addition, the minimum cutting temperature and burr form were observed during MQL milling with nanofluid. Copyright © 2017 VBRI Press.

**Keywords:** Nano graphene, ferritic stainless steel, minimum quantity lubrication, cutting temperature, burr.

## Introduction

Stainless steel materials have been widely used in many industrial areas, but they are classified as hard-to-machine materials due to the tendency of work hardening and relatively low thermal conductivity. Several investigations were performed on the machining of these materials. Lin [**1**] reported the experimental results on the reliability and failure of face-milling tools in milling of stainless steel. In addition, researcher performed an experimental study of burr formation and tool chipping in the face milling of stainless steel [**2**]. According to the results, five different burr types were observed on the exit edge. Nordin *et al.* [**3**] aimed to compare the performance of three multilayered PVD (Physical Vapour Deposition) TiN/TaN (Titanium Nitride/Tantalum Nitride) coatings to single-layered TiN and TaN coatings in milling of stainless steel. It was found that a multilayered PVD TiN/TaN coating showed better performance than single-layered TiN and TaN due to its lower chip-tool interaction and superior toughness. Lin [**4**] performed some milling experiments of stainless steel with TiN coated WC (Tungsten Carbide) cutting tool to obtain the optimal cutting parameters for the minimum burr height. Researcher specified that the most effective parameter was the cutting speed following by the feed rate and the depth of cut, respectively. Shao *et al.* [**5**] investigated the wear and failure mechanism of TiCN/TiN (Titanium Carbo-nitride/Titanium Nitride) multilayer coated cemented carbide tool during milling of 3%Co-12%Cr (3%Cobalt-12%Chromium) stainless steel. Depending on their study, main failure modes of cutting tools were found as chipping and breakage. Liew and Ding [**6**] studied the wear of PVD TiAlN (Titanium Aluminum Nitride) coated WC and uncoated WC cutting tools during milling of modified AISI 420 stainless steel at low cutting speeds. It was found that the hardness of the workpiece had significant effect on the tool wear and the coating could enhance the abrasive resistance of the cutting tool and prevent edge chipping. Biermann and Steiner [**7**] analysed the micro-burr formation for slot milling of austenitic stainless steel and investigated the effects of the cutting speed, feed, and lubrication method on the bur formation. The burr height increased with increase of the cutting speed and feed. According to the researhers' study, the application of MQL (Minimum Quantity Lubrication) caused the height burr due to the fact that a constant supply of lubricant was difficult. However, many researchers proved in their studies that MQL method has many advantages compared to dry and flood cuttings and the problem of the constant supplying has been eliminated by innovative MQL system designs. In the MQL method, the flow penetrates in the cutting zone and it acts in three different ways which are cooling tool and workpiece, lubricating and removing the chips but the flood cooling in inefficient due to not able to reach the inner zones in between cutting tool and workpiece [**8**]. Additionally, EPA (Environmental Protection Agency) has implemented some sanctions concerned with the applying plenty of cutting fluid. For these reasons, there is a growing usage of MQL machining in which the coolant is supplied as a mixture of air and cutting fluid in the form of an aerosol known as the mist [**9**]. Rahman *et al.* [**10**] evaluated the MQL method with respect to flood cooling and the results indicated that the MQL method had advantages over the dry cutting and could be an alternative to flood cooling. Burr height and burr length for the MQL method were observed as the lowest within all conditions. Kishawy *et al.* [**11**] offered the use of MQL method to replace flood cooling in high speed machining and they also suggested that it had an economic advantage over completely. Liao *et al.* [**12**] investigated the feasibility of the MQL method in high speed end milling by TiAlN and TiN coated WC cutting tools and specified that the MQL method proved beneficial at high speed milling for improving the tool life and the surface finish. Fratila and Caizar [**13**] presented a study on the optimization of face milling parameters considering the cooling lubrication techniques (MQL method, dry milling, and flood cooling) as an influence factor on the surface quality. The study presented that the MQL method could be successfully applied without affecting the machining process results such as surface roughness and cutting power. Shahrom *et al.* [**14**] examined the effect of cutting parameters and lubrication techniques on the surface roughness. In their study, milling experiments were conducted under dry cutting, MQL condition, and flood cooling. It was found that the MQL method produced better surface finish as compared to wet machining.

In MQL machining operations, petroleum semi-synthetic emulsion, soybean oil, mineral oil, ester oil, biodegradable oil, vegetable oil etc. can be used as cutting fluid [**15-19**]. In recent years, nanofluids consisting of nanometer sized particles dispersed in base fluid have been also used as cutting fluid to improve the cooling and the lubricating. Hwang et al. [**20**] used various nanoparticles such as MWCNT (Multi Walled Carbon Nanotube), fullerene, copper oxide, silicon dioxide, and silver to produce nanofluids for enhancing thermal conductivity and lubrication. Shen et al. [**21**] investigated the effect of $MoS_2$ (Molybdenum Disulphide) nanoparticles based nanofluid in MQL grinding. The result showed that the nanofluid reduced friction and improved the grinding performance. Lee et al. [**22**] carried out MQL grinding experiments by using nano-diamond particles reinforced paraffin oil. The results showed that the nanofluid MQL grinding reduced the grinding forces and surface roughness when compared with dry and pure MQL conditions. Nam et al. [**23**] examined the micro drilling process with the nano diamond based nanofluid MQL. The nanofluid MQL increased the number of drilled holes and eliminated remaining chips and burrs to enhance the quality of drilled holes. Park *et al.* [**24**] performed MQL ball milling experiments with nano graphene enhanced vegetable cutting fluid to reduce tool wear as well as edge chipping at cutting edge and the MQL milling provided well performance. The surface morphology of the machined workpiece was investigated in MQL milling with $MoS_2$ and $SiO_2$ nanoparticles reinforced nanofluids. The presence of $MoS_2$ and $SiO_2$ nanoparticles in the tool-workpiece interfaces improved the surface quality [**25,26**].

In literature, there is not much study about milling of ferritic stainless steels. Therefore, in this experimental study, the cutting temperatures and the burr forms were investigated in MQL milling of AISI 430 ferritic stainless steel with uncoated and TiN coated cutting tools. A commercial vegetable cutting fluid and a nanofluid prepared by adding nano graphene to the vegetable cutting fluid were used in MQL system. The milling experiments were also conducted in dry condition to compare the results.

## Experiment

Experimental studies were carried out on a vertical CNC machining center. AISI 430 ferritic stainless steel was selected as workpiece material and its chemical composition is given in **Table 1**. The dimensions of specimens were 400x250x6 mm.

**Table 1**. Chemical Composition of AISI 430 Ferritic Stainless Steel.

| C% | Mn% | S% | P% | Si% | Ni% | Cr% |
|---|---|---|---|---|---|---|
| 0,052 | 0,69 | 0,002 | 0,029 | 0,67 | 0,26 | 16,54 |

In milling operations, uncoated and TiN coated WC cutting tools (SPHN 120404) were used and mounted on a 32 mm diameter end mill. The milling operations under dry cutting and MQL conditions were performed. Eraoil KT/2000 commercial vegetable cutting fluid (12 cst at 40°C) was used for MQL milling. The MQL oil mists were supplied with Werte DKN 25 micro lubrication system. Milling parameters and MQL conditions are given in **Table 2**.

**Table 2**. Milling Parameters and MQL Conditions.

| | |
|---|---|
| Milling conditions | Dry, MQL, and MQL + 0,5%wt. nano graphene |
| MQL flow rate | 20 ml/h and 40 ml/h |
| MQL pressure | 5 bar |
| Nozzle angle | 10° (in parallel to the workpiece surface) |
| Nozzle distance | 50 mm |
| Cutting Tool | uncoated WC and TiN coated WC |
| Spindle speed | 995 rpm |
| Feed rate | 180 mm/min |
| Depth of cut | 0,5 mm |

Nano graphene seen in **Fig. 1** were added to the vegetable cutting fluid at weight fraction of 0,5. Firstly, nano graphene particles were dried at a drying oven for 2 hours and then the mixture of cutting fluid and nano graphene was prepared by Daihan WiseTis HG-15D digital homogenizer. During preparation of the nanofluid, sodium dodecyl sulfate was added to the mixture as dispersant to improve the homogeneity.

Cutting temperatures (T) were measured by Optris® CTlaser 3MH1 two-wire infrared thermometer. The measurement range and response time of the device are 150°C - 1000°C and 1 ms, respectively. The laser of the infrared thermometer was focused on the cutting edge of the tool and the measurements were carried out during milling operation. The burr forms were photographed by SOIF XLB45-B3 digital stereo microscope.

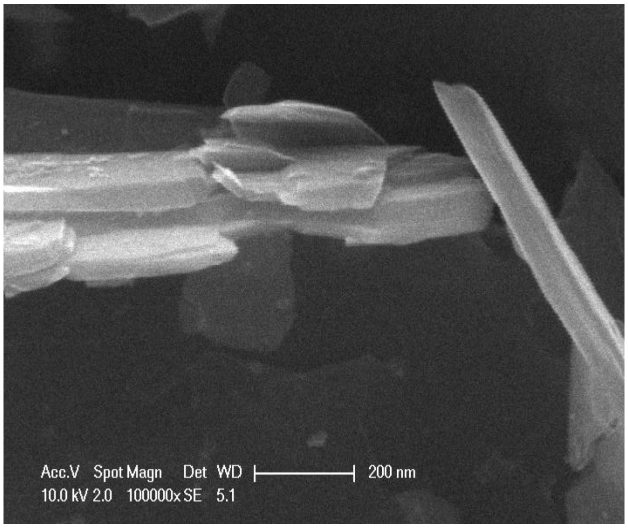


**Fig. 1**. SEM images of nano graphene

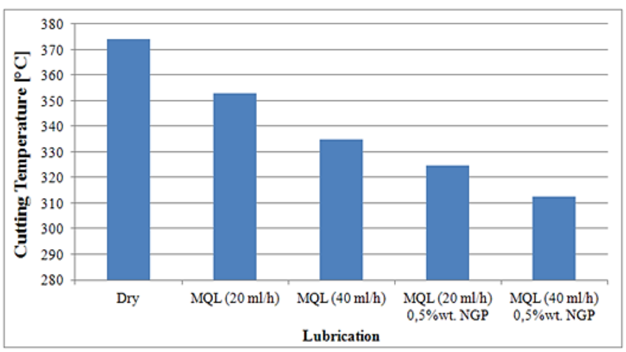


**Fig. 2.** The variation of cutting temperature with lubrication for uncoated WC cutting tool.

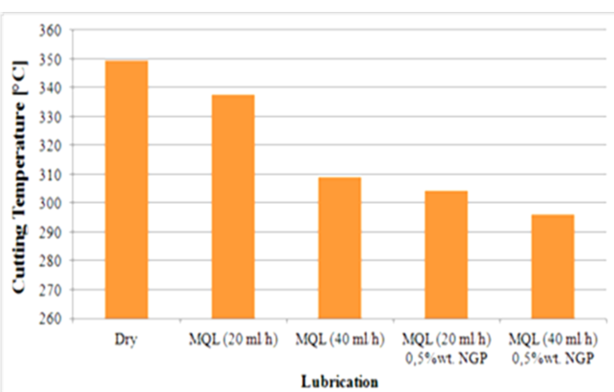


**Fig. 3.** The variation of cutting temperature with lubrication for TiN coated WC cutting tool.

## Results and discussion

According to the experimental results, the maximum cutting temperatures were obtained in milling under dry condition seen in **Fig. 2** and **3**. The cutting tools coated TiN caused lower friction between tool and workpiece than uncoated cutting tools and so lower cutting temperatures were occurred. For instance, the cutting temperature decreased by 6,6% as using the TiN coated WC cutting tool under dry condition. When MQL method was applied, the cutting temperatures decreased for both cutting tools due to the cooling effect. This reducing was obtained as 5,6% and 3,4% in MQL flow rate of 20 ml/h for uncoated and TiN coated WC cutting tools, respectively. In the case of applying nano graphene based nanofluid in MQL milling with uncoated WC cutting tool at MQL flow rate of 20 ml/h, the cutting temperatures could be reduced in the ratio of 13% and 8% compared to dry and MQL conditions, respectively. Because, the nano graphene have high thermal conductivity and well lubrication effect and these characteristics led to decrease of the cutting temperature. In addition, high MQL flow rate caused low cutting temperature due to improve the cooling as seen **Fig. 2** and **Fig. 3**. When the MQL flow rate was increased from 20 ml/h to 40 ml/h, the cutting temperatures decreased by 3,8% and 2,7% in MQL with nanofluid for uncoated WC and TiN coated WC cutting tools, respectively. Depending on the experimental results, TiN coating, MQL with vegetable cutting fluid, MQL with nanofluid, and increasing of MQL flow rate were beneficial to reduce the cutting temperature. However, the most effective method was found as MQL with nanofluid due to providing both cooling and lubrication.

In the milling of AISI 430 ferritic stainless steel for the given cutting conditions, the burrs were observed as breakage form seen in **Fig. 4**, **Fig. 5** and **Fig. 6**. In **Fig. 4**, it was observed that the TiN coating caused less burr

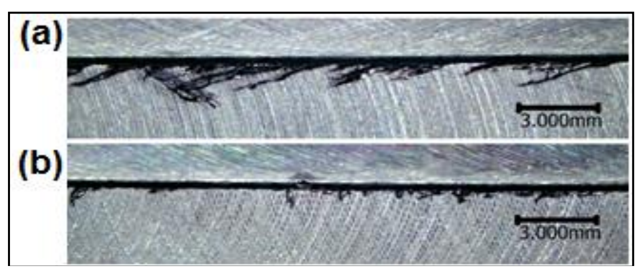


**Fig. 4**. Burr forms a) uncoated WC and b) TiN coated WC.

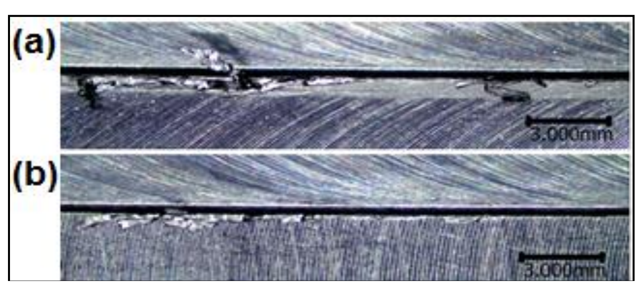


**Fig. 5**. The variation of burr forms according to MQL flow rate in MQL milling with uncoated WC cutting tool a) 20 ml/h b) 40 ml/h.

 

forms owing to occurring low cutting temperature and facilitating the cutting. As seen in **Fig. 4(a)** and **Fig. 5**, less and small burrs were observed in MQL milling compared to dry cutting due to the fact that the MQL made easier the cutting and reduced the cutting temperature. As investigated the effect of MQL flow rate on burr forms, high flow rate decreased the size of the burrs and led to occur less burr (**Fig. 5**). In MQL milling, less burr forms were occurred by using the vegetable cutting fluid reinforced by 0,5%wt. nano graphene and near burr-free operation could be carried out (**Fig. 6**).

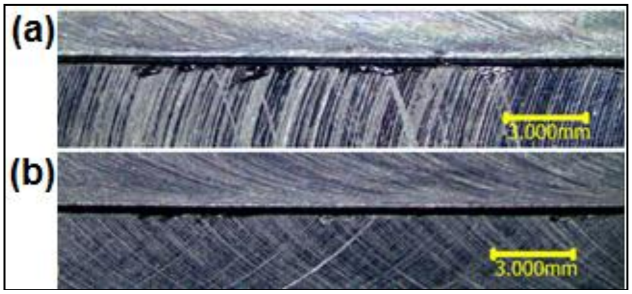


**Fig. 6**. The effect of nanofluid on burr forms for TiN coated WC cutting tool at MQL flow rate of 40 ml/h a) vegetable cutting fluid b) vegetable cutting fluid reinforced by 0,5%wt. nano graphene.

## Conclusion

In this study, the effects of the TiN coating, MQL method, and MQL flow rate on the cutting temperature and the burr forms were investigated in milling of AISI 430 ferritic stainless steel. A commercial vegetable cutting fluid and a nanofluid prepared by reinforcing 0,5 wt.% nano graphene to the vegetable cutting fluid were used as the cutting fluids. Depending on the experimental results, dry cutting caused the maximum cutting temperature and burr forms. Low cutting temperature and less burr forms were obtained by using MQL method. The effect of the MQL method was increased with increase of MQL flow rate. In addition, the TiN coating showed a positive effect in reducing the cutting temperature and occurring less burrs. The minimum cutting temperatures and the least and smallest burr forms were obtained in MQL milling with nanofluid due to the fact that nano graphene particles caused increasing the thermal conductivity and lubrication properties of the cutting fluid.

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### Supporting information

Supporting informations are available from VBRI Press.

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