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Effect of MQL using Nanofluid on Turning of Austempered Ductile Iron : A Comparative Study

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Abstract

The paper describes the effect of minimum quantity lubrication (MQL) using nanofluid on turning of Austempered Ductile Iron (ADI) for enhancement of machinability. In this research a novel nanofluid, a mixture of palm oil (Base fluid) with 2% Al_2O_3 nano-particles (25-30 nm size) is employed. The experimental study is carried out under three different machining environments Dry, MQL-palm oil and MQL-Al_2O_3 Nanofluid. Two experimental strategies have been planned for comparative study. In the first set L9 Taguchi orthogonal array was selected. The first set of experiment clearly revealed that the machining using MQL- Al_2O_3 nanofluid reduces average surface roughness by 50% and chip thickness reduced significantly than dry machining. The second set of experiment was performed to estimate tool life and tool wear analysis. It is observed that the machining with MQL-Nano fluid increases tool life by 76% as compared to dry machining and by 2% than MQL- Palm oil machining.

Keywords: MQL- Al_2O_3 nanofluid, L_9 orthogonal array, surface roughness, chip thickness, tool life

1. INTRODUCTION

Cooling and lubrication has important role in rapid machining and production. A cutting fluid's effectiveness in cutting operations depends on a number of factors such as the method of application, temperature, cutting speed and type of machining operation. Temperature increases as cutting speed increases, therefore cooling of the cutting zone is of major importance at high cutting speeds. The conventional methods of enhancing the cooling rate are already stretched to their limits. Hence, there is need for new and innovative cutting fluids to achieve this high performance cooling [1]. In MQL operation MQL refers to the use of cutting fluids of only a minute amount-typically of a flow rate of 50–500 ml/h which is about three to four orders of magnitude lower than the amount commonly used in flood cooling condition [1]. MQL technique consists of atomizing a very small quantity of lubricant in an airflow directed towards the cutting zone. The aerosol can be sprayed by means of an external supply system, via one or more nozzles [5].
A new class of cutting fluids can be synthesized by mixing metallic, non-metallic, ceramics, or carbon nanoparticles in a conventional cutting fluid because as compared with suspended nano or micro-sized particles, nanofluid show better stability, rheological properties, extremely good thermal conductivity, and no negative effect on pressure drop[9]. Nanofluid may possess extremely good heat extraction capabilities (thermal conductivity) over conventional cutting fluids. Enhanced thermal conductivity may be an important factor for better performance in various applications [10].

In this work attempt has been made to use nanofluid as a cutting fluid through minimum quantity lubrication unit. A special type of nano-cutting fluid is developed by mixing self-synthesized Al_2O_3 nano particles into the conventional cutting fluid. The comparative study of surface roughness, chip thickness and tool wear has been done while machining with dry machining, MQL using palm oil and MQL using nanofluid on turning of austempered ductile iron to analyse effect of addition of nanoparticles in base oil.

2. EXPERIMENTAL PROCEDURE

2.1 Experimental theme

The experimentation is divided into 2 strategies. In first strategy the experimentation was carried out to analyze surface roughness and chip morphology where as in second strategy the no of passes were taken to estimate tool life. Experiments were performed under three cutting environments i.e Dry, MQL using palm oil and MQL using nanofluid.

2.2 Experimental Setup

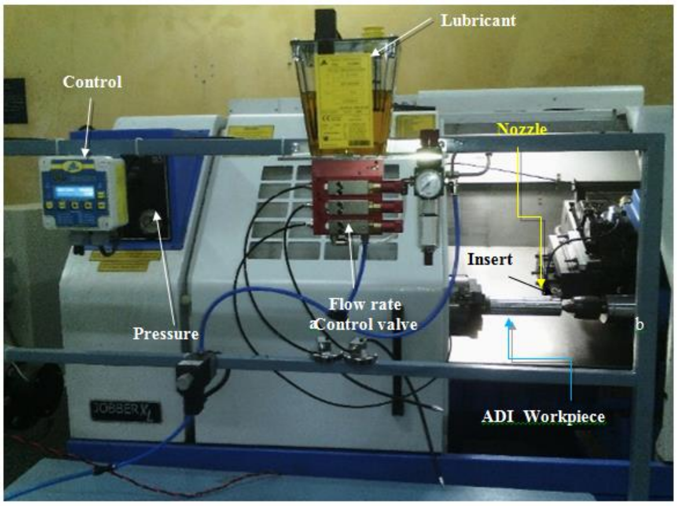

Fig. 1 Experimental setup

2.3 Experimental Conditions

Experiments have been carried out by plain turning of Austempered Ductile Iron on CNC lathe. The ranges of the cutting velocity, feed rate and depth of cut were selected based on the tool manufacturer’s recommendation.

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Table 1 Experimental Conditions

Machine tool	CNC lathe Make -Micromatic Model – Jobber XL
Work Material	Austempered Ductile Iron (ADI) (C-3.6%, Si-2.6%, Mn-2.5%,P-0.01%,S-0.019%, Cr-0.03%, Mo-0.05%, Ni-0.26%,Al-0.01%,Cu-0.72%,Ti-0.03%, Sn 0.01%,Fe-93.22%)
Cutting tool insert	CNMG120408 – TiN2000
Working Tool Geometry	Inclination angle -6° Orthogonal rake angle -6° clearance angle 0 Nose Radius 0.8mm
Cutting Fluids	Palm oil Al_2O_3 Nanofluid
Cutting Fluid Supply	For MQL Air Pressure -7 bar Flow Rate- 90 ml/h
Surface Roughness Tester	MITUTOYO SJ-301, Japan
Measuring Microscope	Nikon Magnification – 75x

2.4 Preparation of Nano fluids

Fig.2 a) Ultrasonicator b) magnetic stirrer

100 ml palm oil (Base fluid) mixed with 2% Al_2O_3 nano-particles (25-30 nm size). The ultra-sonication process with magnetic stirrer is used for homogeneous dispersion of nano-particals in palm oil. The mixture is stirred for 8-9 hrs.

2.5 Selection of Cutting Parameters

In the first strategy of experiments Taguchi L_9 orthogonal array has been used for designing the experiments for statistical analysis of surface roughness and chip thickness in which 3 levels of cutting speed and 3 levels of feed is used. The depth of cut is considered as constant

In second strategy the experiments were performed on different diameter ADI rods. The highest feed (0.2mm/rev) and cutting speed (200m/min) were chosen for experiments.

3 EFFECT OF MQL USING NANOFLUID

3.1 Effect on Surface Roughness

The surface roughness increases with increase in feed and cutting speed.

3.1.1 Effect of feed on surface Roughness

From above graph it has been seen that surface roughness value is increases with increase in feed because time available is less to carry out the heat from cutting zone, high amount of material removal rate and accumulation of chip between tool workpiece zone. The MQL using nanofluid shows better surface finish as compared to MQL using palm oil and dry machining.

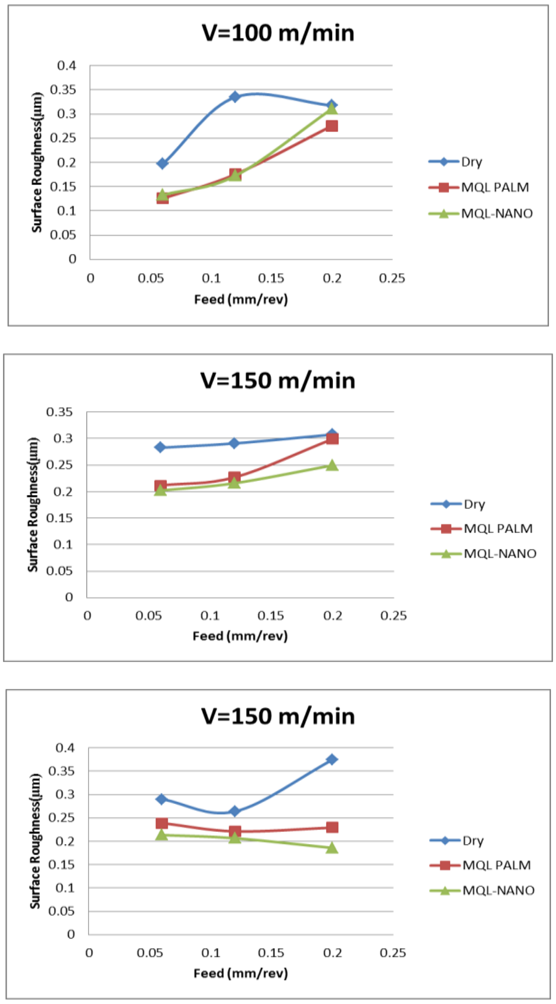

Fig. 3 Effect of feed on surface roughness at different cutting speed

3.1.2 Effect of speed on surface Roughness

As the cutting speed increases tool wear occurs rapidly hence the value of surface roughness increases with increase in speed. In case of dry machining process the surface roughness is more because in the absence of cutting fluid the tool wear occurs rapidly hence surface roughness increases more rapidly. When machining with MQL-Palm oil the presence of cutting fluid protects the cutting edge due to its lubricating and wetting properties so the process becomes smooth than dry machining and surface roughness reduces as compared to dry machining. In case of machining with MQL-Nanofluid the presence of nanoparticles greatly improves the wetting and lubricating properties in rake and flank region and also better heat dissipation in cutting zone hence the machining process becomes smoother which aids in retaining of hardness of cutting tool edge, this results in better surface finish as compared to MQL using palm oil and dry machining. Table 2 shows reduction in average surface roughness.

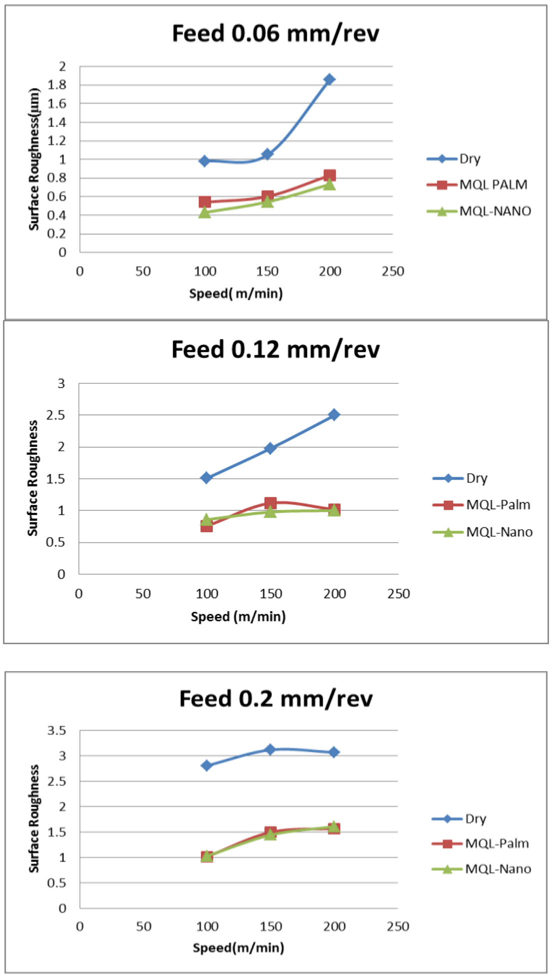

Fig.4 Effect of Speed on surface roughness at different feed

Table 2 Surface Roughness Reduction

Cutting Environment	Range of Surface roughness	% of reduction in surface roughness
Dry	0.98-1.98	-
MQL with palm oil	0.54-1.572	48
MQL with Nanofluid	0.43-1.611	50

3.2 Effect on Chip thickness

In dry machining the temperature is quite high at shear zone leading to thermal expansion of workpiece material causes to higher chip thickness. In case of MQL-palm oil machining hydrodynamic cutting fluid layer forms between tool rake surface and workpiece, the hydrodynamic cutting fluid layer tries to push away chips from rake surface hence helix angle of chip increases and chip breaks into small segments. The presence of palm oil provides better cooling and lubrication hence chip thickness reduces as compared to dry machining. In MQL-nanofluid cutting environment Al_2O_3 nanoparticles impinges on chips and forms tiny discontinues chips. The presence of nanoparticals also improves wettability, convective heat transfer coefficient and lubrication which will cause lesser rake wear and less thermal expansion of workpiece hence chip thickness is minimum as compared to dry and MQL-palm oil machining.

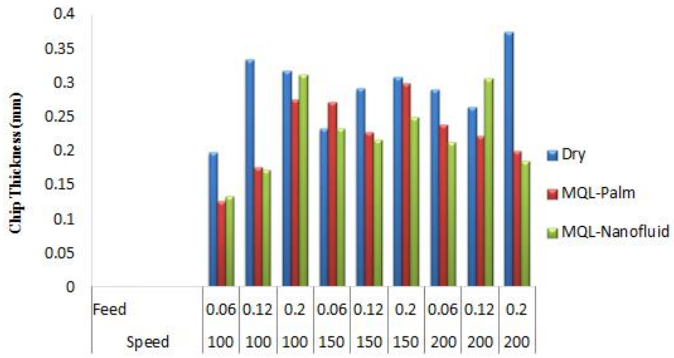

Fig.5 Effect of speed and feed on chip thickness

4. TOOL LIFE ESTIMATION

In this study the tool wear criteria used to estimate tool life to estimate tool life is when the flank wear land width reached 0.3 mm uniform wear land width (V_B). For each condition tool wear was measured after every pass of 180 mm. The highest feed (0.2 mm) and highest cutting speed (200mm/min) were chosen for experimentation because wear rate is very less. Tool wear was measured after every pass.

While turning of Austempered Ductile Iron in Dry cutting environment the total turning length required to reach 0.3 mm flank wear land width is 3420 mm and total time is 8.58 min. The sudden wear occurs at the start but after 500 mm cutting length uniform wear prevailed as shown in fig.6

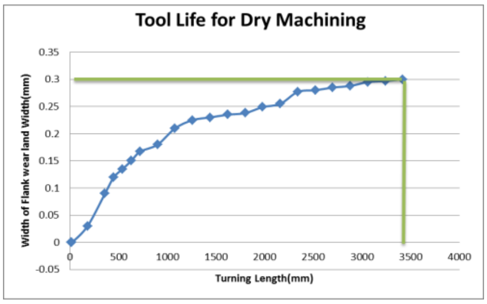

Fig.6 Tool life for dry machining

In the case of MQL-palm oil cutting environment sever wear occurs at the start but after 1000 mm turning length there is a formation of uniform wear. The time required to reach 0.3 mm uniform flank wear land width is 11.65 min. and turning length is 5040 mm. MQL-nanofluid machining environment needs 32 passes of 180 mm and 14.64 min to reach 0.3mm flank wear land width criteria which shows similar effect of tool wear pattern as like MQL-palm oil machining environment. In dry machining due to continuous rubbing of the machined work surface on the thermally softened flank face and absence of cutting fluid leads to severe flank wear and hence tool life in case of dry machining is found minimum (8 min).

The MQL-palm oil machining the presence of palm oil protects the cutting edge partially due to its cooling and lubrication properties hence machining process becomes partially smooth and tool wear is found minimum than dry machining process.

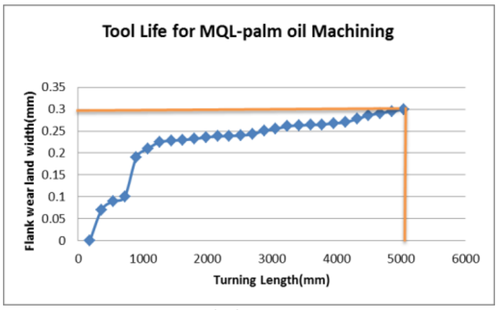

Fig.7 Tool life for dry machining

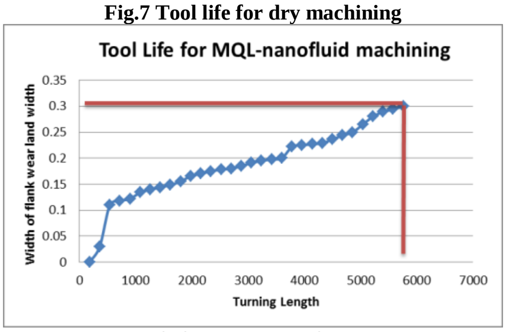

Fig.8 Tool life for MQL nanofluid machining

In MQL-nanofluid machining, due to better cooling and lubrication properties of nanofluid, the tool retains its original hardness for longer times. Thus the flank wear is minimum compared to the other two cutting environments. So the MQL-nanofluid takes maximum time (14.64 min) to reach 0.3 mm uniform flank wear land width tool failure criteria. Table 3 shows improvement in tool life while MQL using nanofluid machining as compared to MQL using palm oil and dry machining.

Table 3 Improvement in Tool Life

Cutting Environment	Tool Life (min)	% improvement in tool life
Dry	8.58	-
MQL with palm oil	11.65	51
MQL with Nanofluid	14.64	76

5. CONCLUSIONS

- Turning with MQL using nanofluid shows 50% reduction in surface roughness over dry machining as well as 2% over MQL using palm oil machining because in case of MQL using nanofluid the presence of nanoparticles greatly improves the wetting and lubricating properties in rake and flank region hence the machining process becomes smoother.
- The chip thickness after machining in case of dry machining is found higher than MQL by using nanofluid and MQL using palm oil due to effect of thermal softening which ease the material removal.
- The MQL using nanofluid increases tool life by 76% over dry machining as well as 25% over MQL using palm oil machining. In MQL-nanofluid machining, due to better cooling and lubrication properties of nanofluid, the tool retains its original hardness for longer times hence the flank wear is minimum.

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