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MQL MACHINING OF DIFFICULT TO CUT MATERIALS

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ABSTRACT
Metal working fluids (MWFs) are widely used as their benefit to machining process is evident. But nowadays MWF-s has become huge liability and the economic use of them has become questionable. Most promising alternative of using MWF-s in a classical way (flooding of cutting zone) is use of minimum quantity of lubricant or/and coolant. This paper gives comparison of MQL machining (type: OoW: Oil on Water) of widely used construction steel St52-3 and nickel based super alloy Nimonic 263 which belongs to category of difficult to cut materials. Main purpose is to present how common steel behave in situation with and without MWF-s and compare it to difficult to cut material like super alloy Nimonic 263. The results show that common material like St52-3 react as expected (lover forces and better quality) on MWFs and super alloy on the other hand quite opposite
Keywords: MQL machining; Oil-on-water droplet; super alloy; cutting forces; surface roughness.

1. INTRODUCTION
The basic function of a metal working (cutting) fluid is to provide cooling and lubrication and thus reducing the severity of the contact processes at the cutting tool–chip and cutting tool–workpiece interfaces. A metal working fluid may significantly affect the tribological conditions at these interfaces by changing the contact temperature, normal and shear stresses and their distributions along the interfaces, the type and/or mechanism of tool wear, machined surface integrity and machining residual stresses induced in the machined parts, etc.[6,2]. In some applications, it is expected that metal working fluid should also provide secondary service actions, for example, washing of the machined part or chip transportation in deep-hole drilling, in which the metal working fluid transports the chip over significant distances [7].
Although the significance of metal working fluids in machining is widely recognized, cooling lubricants are often regarded as supporting media that are necessary but not important. In many cases, the design or selection of the metal working fluid supply system is based on the assumption that, the greater the amount of lubricant used, the better the support for the cutting process. As a result, the machining zone is often flooded with metal working fluid without taking into account the requirements and specifics of an operation [3].
According to the manufacturing statistics the total cost for acquiring, maintaining and disposing of coolants represents between 8% to 20% (approximately 15%) of total production cost depending on the workpiece, the production structure and the production location [4]. In contrast, tooling cost is within single digits (usually about 4%). Cost, as well as health and environmental issues, mandate manufacturing enterprises to drastically reduce coolant consumption and, if possible, eliminate it altogether. As a result, these trends tend to two more economically and environmentally friendly conceptions of machining, termed, dry machining and MQL machining or near-dry machining.
Ecological and health aspects of metalworking fluids’ manufacture, use and disposal have become very important due to new stricter legislation, notably in Europe [3].
It is estimated that metal working fluid consumption is more than 100 million gallons per year in the USA [1], in Germany .500 tons a year [5] and in Japan 100,000 kilolitres of water-immiscible, 50,000 kilolitres of water-soluble coolant without chlorine and 10,000 kilolitres of water-soluble coolant with chlorine [1]. A typical large automobile metal processing facility utilizes more than 2.28 million liters of metal working fluid concentrates per year and more than 1.14 million liters of straight oil per year.

2. EXPERIMENTAL WORK

During the last ten years, a lot of research studies in area of MQL machining have been performed. Much of the results of various studies are available in the periodical literature. For example, Tai et al, 2011, reported on lubricant properties in MQL machining, than Kalita & Malshe, 2010, reported on nano lubricant in advanced MQL machining, and Hiroshi, 2004, made study on oil on water drop cutting fluid.

The experiments, which results are presented in this paper were conducted at the Laboratory for metal cutting and machine tools (LORAM) at Faculty of Mechanical Engineering University of Zenica. Machining tests were carried out on a lathe. Experiment is performed on two work piece materials. First work piece material is a high strength structural low-carbon steel St52-3 used for machinery parts, mobile equipment, crane, booms, chassis, anchor bolts, connecting bolts and most other structural activities. Mechanical properties are as follows:

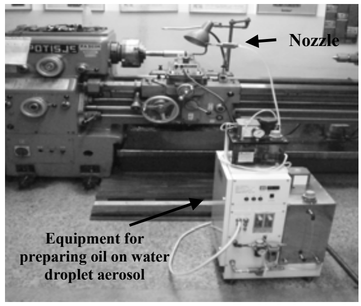

Figure 1. Experimental setup

Table 1 Mechanical properties of low-carbon steel St52-3.

Yield strength Reh min	**Tensile strength Rm min**	**Elongation A5 min**	**Impact strength (Charpy)**	**Hardness (Brinell)**
N/mm^2	N/mm^2	%	Joul	**HB**
355 min	**490 min**	**20 min**	**27 min na 20°C**	**160**

Second work piece material is nickel based super alloy Nimonic 263 used for jet engines and now days in turbines for internal combustion engines with following mechanical properties:

Table 2 Mechanical properties of Nimonic 263

0,2% Proof Stres	**Tensile strength Rm min**	**Elongation on 5,65 √So**	**Impact strength (Charpy)**	**Hardness (Brinell)**
N/mm^2	N/mm^2	%	Joul	**HB**
585	**1004**	**45**	**111 on 20°C**	**280**

This super alloy is designed to work on elevated temperatures up to 1050°C, it keeps mechanical properties till the 600°C (Tensile strength at 600°C is about 819 N/mm^2). Machining tests were carried out by turning in two ways: without the use of metal working fluid, and by use of MQL machining (oil on water droplet with following composition: Oil: 10 - 50 ml/h, Water: 300 -1700 ml/h, Air 6000 Nl/h (100 Nl/min). MQL used in machining of Nimonic 263 was of following composition: Oil: 10 ml/h, Water: 300 ml/h, Air 6000 Nl/h (100 Nl/min). Turning conditions are given in table 3.

Table 3. Machining conditions.

OoW (Oil on Water)	Supply volume	Oil: 10-50 ml/h, Water: 250-1700 ml/h, Air 6000 Nl/h (100 Nl/min 2 bar)
	Particle diameter	100 – 200 µm
Type of oil		Rapeseed oil
Dry machining		No MWFs used
Work piece material		St52-3 and Nimonic 263
Tool		Hard metal with titanium PVD coating designated SNMG 120408-SM from Mitsubishi Co Japan
Cutting forces		Kistler 5070
Surface roughness		Perthometer M1
Cutting zone temp.		Thermal imaginer Fluke Ti32
Work piece diameter		Nimonic 263: ø60 mm St52-3: ø54 mm
Depth		In the range of 0,04 to 2 mm
Feed rate		In the range of 0,05 to 0,25 mm/rev
Cutting speed		In the range of 20 to 100 m/min

Experimental setup is shown in Fig. 1. MQL machining conditions were as follows: the amount of oil 50 mlph, the amount of water 250 mlph, and the pressure of compressed air p=2 bar (100 nlpm). Vegetable (biodegradable) rapeseed oil is used. By using appropriate measuring equipment, cutting forces are measured (dynamometer KISTLER 5070), cutting zone temperatures (thermo imaginer Fluke Ti32) and also surface roughness parameters are measured (Perthometer M1). Table 4 and 5 shows the results of measuring cutting forces, cutting zone temperatures and surface roughness parameters. Corresponding graphical interpretation of hese results are given in Fig. 2, Fig. 3. and Fig 4. indicated wrong MQL settings (Figure 3). So another experiment is performed in which parameters of MQL are wearied and cutting forces and surface roughness are measured (Figure 4) Experiment showed that difference between MQL and DRY machining goes up to 25% depending on MQL settings.

Table 4. Cutting forces and cutting zone temperatures when machining Nimonic 263

No	**Machining parameters**			**Cutting forces**		**Surface roughness**	
	Cutting speed	Feed rate	Depth of cut	MQL	DRY	MQL	DRY
Unit	m/min	mm/rev	mm	Fm (N)	Fd(N)	Ram(°C)	Rad(°C)
1	105	0,05	1	382	277	1,03	5,57
2	105	0,25	2	1540	1442	4,53	8,49
3	45	0,25	1	1130	900	4,33	3,36
4	45	0,05	2	728	764	1,08	4,36
6	105	0,25	1	480	953	4,04	4,60
8	105	0,05	2	602	571	2,23	6,25
9	75	0,15	1,5	981	976	1,32	6,60
10	75	0,15	1,5	945	980	1,88	4,31

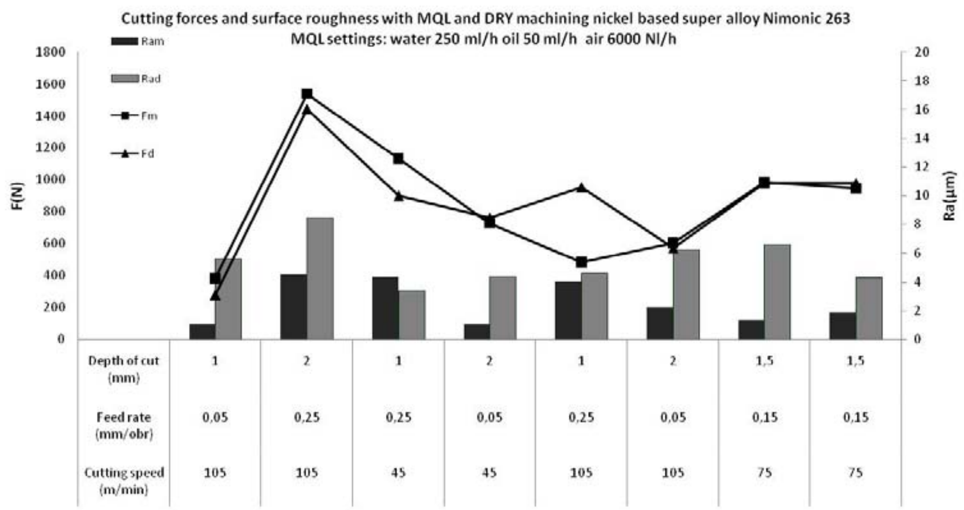

Figure 2. Graphical interpretations of cutting forces and surface roughness

Table 5. Results of measuring cutting forces and cutting zone temperatures when machining St52-3

No	**Machining parameters**			**Cutting forces**		**Cutting zone temperatures**	
	Cutting speed	Feed rate	Depth of cut	MQL	DRY	MQL	DRY
Unit	m/min	mm/rev	mm	Fm (N)	Fd(N)	Tm(°C)	Td(°C)
1	40	0,05	1	240	229	103	130
2	100	0,05	2	264	260	110	144
3	40	0,05	2	381	368	104	180
4	100	0,1	2	448	455	192	226
5	100	0,25	1	934	949	121	183
6	100	0,25	2	1277	1295	192	231
7	40	0,25	1	1429	1586	122	215
8	40	0,25	2	1989	2134	171	202

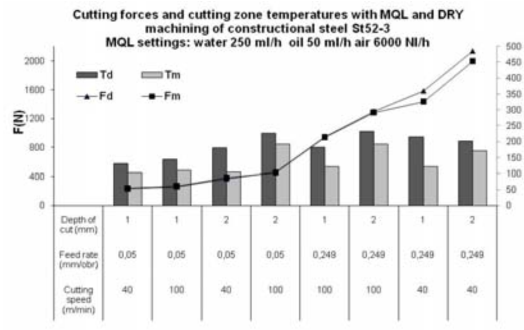

Figure 3. Graphical interpretations of cutting forces and cutting zone temperatures

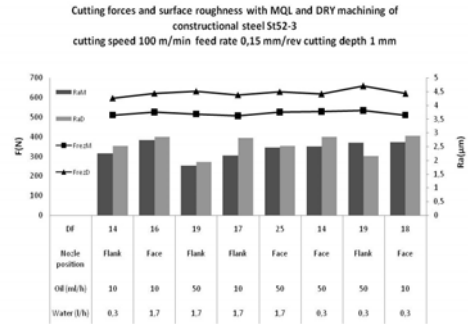

Figure 4. Graphical interpretation of cutting forces and surface roughness

3. CONCLUSION

When analyzing the results of measuring the cutting force following conclusions can be drawn. In MQL machining of common steels like St52-3 are measured less cutting force and cutting zone temperatures. The difference between MQL and DRY machining goes up to 25% in favor of MQL. Cutting zone temperatures are less from 15 to 40%. But, when machining super alloys this difference is not evident, the forces are slightly higher than in dry machining which can be explained by absence of embrittlement effect when cooling this austenitic steel. Effort must be taken to determine right amount of MWFs on these difficult to cut materials to gain effect of cooling and lubrication. Also, when considering the measured values of the surface roughness parameters, it is seen that the lower values are measured in MQL machining. Therefore, a better quality of the machined surface is achieved by the MQL machining.

Finally, as a general conclusion, it can be concluding the following:

- Application of MQL machining is much more acceptable from an environmental standpoint because the processing used vegetable oil that does not pollute the environment,
- Less cutting force up to 25% for MQL processing depending on settings of MQL parameters actually mean less power consumption which is very important in terms of energy savings (sustainability), and
- Better quality of the machined surface is achieved by the MQL machining in comparison with machining without metal working fluid.
- The temperatures of cutting zone are considerably smaller in MQL machining what actually means less tool wear and better stability of the cutting process.

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