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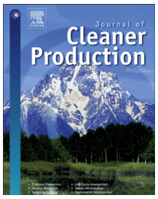

# Comparison among different vegetable fluids used in minimum quantity lubrication systems in the tapping process of cast aluminum alloy

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## ABSTRACT

Nowadays, cooling fluids are the great environmental issue, because they consume a considerable amount of water and can pollute natural water sources for decades when they are discarded and disposed of irregularly. Based on this, the Minimum Quantity Lubrication technique, that uses low amounts of fluids, has been used in drilling processes since 1990 and is a major breakthrough in reducing the use of cutting fluids. In this study, three different Minimum Quantity Lubrication cutting fluids were tested and compared with emulsions in cut and form tapping processes. A Full factorial design was performed to identify the significant effect of the type of oil, cooling/lubrication system and cutting/forming speed on the torque value of the tapping processes. A steering system carcass manufactured by A306 cast aluminum alloy was used as a workpiece in the tapping operations. The results showed that fluid A (ECOCUT) in the Minimum Quantity Lubrication system has a high potential to reduce torque value while minimizing the friction and can avoid that tools break, in some situations. Furthermore, form tapping was found to be a suitable alternative, since it does not generate chips, which reduces costs with recycling, storage, and waste disposal.

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## 1. Introduction

Modern industries are always looking for new production technologies in order to minimize costs and increase quality. This has been the strategy of all manufacturing industries over the last two decades. However, in recent years, a new factor has changed the culture on the shop floor, which is the minimization of environmental impact (Pusavec et al., 2010a,b). Nowadays, cooling fluids are the great enemy of the environment, because they consume a considerable amount of water and can pollute natural water sources for decades when they are discarded and disposed of irregularly. The focus of industries is not only the use of minimal quantity of fluids but also the application of fewer fluids that are aggressive to the environment.

Several studies have been developed on machine processes such as turning, milling, drilling and grinding, aiming to increase the use of MQL in these processes. MQL systems can be used in all machine processes with a defined and undefined cutting edge. However, some manufacturing processes, such as grinding, are more difficult to be implemented due to their cutting dynamic. According to Sanchez et al. (2010), the application of $CO_2$ together with MQL in grinding processes resulted in lesser wear of the grinding wheels than when using traditional coolants. Furthermore, there was absence of thermal damage and the temperatures in the process were lower when the water-cooling was available, showing a promising future for this technique.

The first applications of the MQL technique in manufacturing processes were in the drilling of aluminum alloys. This situation occurred because the drills have a complex geometry and during the drilling process the actuation of cooling fluids is difficult. These studies have been conducted to raise awareness about the use of MQL in drilling processes. Biermann and Iovkov (2015) studied deep drilling in cast aluminum using the MQL system. According to the authors, the use of MQL and high feed rates ($f = 1, \ldots, 4$ mm/rev)

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**Table 1**
Chemical composition of the A306 cast aluminum alloy.

| Chemical composition [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Elem. | Si | Fe | Cu | Mn | Mg | Ni | Zn | Sn | others | Al |
| Max. | 9.5 | 1.2 | 4.0 | 0.5 | 0.1 | 0.5 | 2.0 | 0.35 | 0.5 | Bal. |
| Min. | 7.5 | – | 3.0 | – | – | – | – | – | – | – |

decreased the temperature and the heat flux, simultaneously. In addition, this strategy generated a large amount of heat that was accumulated on the chips avoiding thermal damage to the workpieces.

Hardened steels are difficult-to-cut materials due to their high mechanical and thermal resistance, which increases the heat during the machine processes. They have a wide range of application in industries of moulds and dies because they are used to manufacture other products such as forging components, laminated sheets, injected polymers, among others. Chinchanikar and Choudhury (2015) performed a study which carefully reviewed the machining of hardened steels. The authors observed that the studies about MQL in machining of hardened steels showed that the new generation of coated tools has high strength in wear and improved tool life in almost 20–25%.

Simunovic et al. (2015) studied the use of MQL in face milling processes by applying different cooling systems. The study was based on the methodology of surface response, with focus on process optimization. The results showed that dry cutting was a good condition for face milling, which is the opposite of what was presented by other authors who prioritized the use of MQL. The authors affirm that dry cutting can be applied in some milling processes to avoid the use of fluids that pollute the environment and increase costs.

The challenges in modern industry can be summarized as the minimization of pollution and generation of wastes. Another problem in manufacturing processes is waste in the form of chips. Chips and fluids can be recycled after manufacturing processes, but to clean fluids and bring forth new raw materials, the energy expenditure is high and uses a finite resource: natural water. Thus, to create a new philosophy based on an environmentally friendly manufacturing, each special characteristic of the processes should be carefully studied. Tapping is the least researched process among several manufacturing processes, when compared, for example, with turning. However, tapping has great importance, since it provides an accurate and durable fixture in mechanical components.

Over the last decade, several researchers have been studying tapping processes, with focus on form tapping. Authors such as Fromentin et al. (2005, 2006, 2010) have been pioneers in the studies on form tapping and, according to them, the great advantage of form tapping is the fact that it does not generate chips. Carvalho et al. (2012) and Dias et al. (2014) also studied form tapping using taps with five lobes and proposed a new tapping process to form internal threads with a special tool, respectively. The studies demonstrated that form tapping, despite the incomplete profiles in the crest, provides internal threads with high quality at the bottom of profiles.

Form tapping not only improves the quality of thread profiles but also increases their strength. Stéphan et al. (2011) studied the torque in form tapping, which is an important parameter in the automotive industry. The results showed a similar resistance between the form and machine threads. Furthermore, the use of the MQL system was applied and the results demonstrated that thread profiles had better reliability and cleaning. In the studies developed by Carvalho et al. (2012), the variation of initial diameter had a strong influence on the thread profile. Small initial diameters filled the crest of the threads better than larger diameters.

Ductile materials such as brass, magnesium, and aluminum and its alloys are the main materials to which form tapping process can be applied. Aluminum and its alloys are used in great scale in the automotive and aeronautical industries. Machine processes mostly manufacture the mechanical components of these industry sectors. Laminated aluminum has a great capacity to accept deformation and is well indicated in form tapping, as was said before.

Therefore, considering that some automotive components are manufactured by casting, in this study a carcass of the steering system of an A306 cast aluminum alloy was used as the workpiece. Thereby, as the internal threaded holes in this carcass are machined, this work proposed the use of form tapping and the MQL system to improve the quality of threaded profiles.

## 2. Methodology

### 2.1. Experimental setup

Internal tapping tests were performed in a vertical machining center with a spindle speed of 10,000 rpm and 15 kW of power in the main spindle. The A306 cast aluminum alloy was used in the experimental tests. A specific region of the steering system carcass was used as the workpiece. In this region are located the threaded holes where the hydraulic connections of the steering system are assembled. The initial hole diameter was 9.3 mm according to the tool's supplier.

Table 1 shows the chemical composition of the A306 cast aluminum alloy. A piezoelectric dynamometer was used to measure the thrust force and the torque, and the sample rate was set at 500 Hz. The signal was captured using a dynamometer model 9272 for measuring of Mz torque (−200 to 200 N.m) and the Fz force (−5 to 20 N) and stabilized through a signal amplifier model 5070.

A MQL system with a flow rate of 20 ml/h and 8 bar of pressure was used to provide the cooling and lubrication in the process, simultaneously. Three specific oils used in MQL systems were applied and compared with the dry and emulsion conditions, namely fluid A (ECOCUT), fluid B (Vascomill MMS SE-1), and fluid C (PLANTOCUT). According to ASTM D5619-00 (2000) the tapping operation can be used as pattern for comparison and evaluation of cutting fluids, because it is highly sensitive to lubrication or cooling. Based on this, Table 2 shows the physical-chemical properties of the MQL oils used in the form and cut tapping operations. The forming and cutting taps supplied by EMUGE-Franken were coated

**Table 2**
Physical and chemical properties of the MQL oils.

| Physical-chemical properties | Fluid A (ECOCUT) | MMS SE-1 (Fluid B) | Fluid C (PLANTOCUT) |
|---|---|---|---|
| Boiling Point | >250 °C (ASTM D86) | >250 °C (ASTM D86) | >280 °C (ASTM D86) |
| Flash Point | 188 °C (ASTM D92) | >175 °C (ASTM D92) | 220 °C (ASTM D92) |
| Density at 20 °C | 0.84 g/cm$^3$ (ASTM D1217) | 0.85 g/cm$^3$ (ASTM D1217) | 0.92 g/cm$^3$ (ASTM D1217) |
| Solubility | Insoluble | Insoluble | Insoluble |
| Viscosity at 40 °C | 27 mm$^2$/s (ASTM D445) | 20 mm$^2$/s (ASTM D445) | 40 mm$^2$/s (ASTM D445) |

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