



24th COBEM - 2017



24th ABCM International Congress of Mechanical Engineering  
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-2791

## ANALYSING THE EFFICIENCY OF THE COMPRESSED AIR CLEANING ALLIED TO THE ADDITION OF WATER TO THE MQL IN GRINDING THE AISI 4340 STEEL WITH CBN

**Bruno Kenta Sato**

**José Claudio Lopes**

jclaudio.lopes@hotmail.com

**Luiz Eduardo de Angelo Sanchez**

sanchez@feb.unesp.br

**Paulo Roberto Aguiar**

aguiarpr@feb.unesp.br

**Eduardo Carlos Bianchi**

Universidade Estadual Paulista Júlio de Mesquita Filho, Faculty of Engineering, Department of Mechanical Engineering, Bauru, Brazil

bianchi@feb.unesp.br

**Abstract.** *The implementation of the Minimum Quantity of Lubricant in the grinding process is not practicable for two reasons: the insufficient cooling effect and the intensification of the clogging phenomena. This research aim for adapt the MQL technique in the grinding process. Therefore, water is added to the lubricant to increase the technique refrigerating capacity, boosting the heat dissipation when it evaporates. In this research, the compressed air cleaning was adopted, its advantages were: no utilization of cutting fluid and the method does not present the hydraulic brake. The water influence in the MQL technique was evaluated conducting trials diluting the oil in water in different proportion: 1:1, 1:3, 1:5. To analyze the efficiency of the compressed air wheel cleaning method in expelling the chips from the grinding wheel pores, trials were done using the wheel cleaning allied to the MQL with water and were compared with the conventional cooling method. The output variables analyzed were: surface roughness, roundness deviation and consumed power. The obtained results showed that the addition of water to the cutting fluid used in the MQL technique had a positive effect on the output parameters. It was noticed the occurrence of the clogging phenomenon during the grinding trials. The results got better when the grinding wheel cleaning system with compressed air was used, demonstrating the efficiency of the method. The addition of water to MQL allied to the cleaning system provided results comparable to the results obtained when the conventional cooling method was used.*

**Keywords:** *Cylindrical external plunge grinding, MQL with water, compressed air wheel cleaning*

### 1. INTRODUCTION

The grinding process has high specific energy, i.e., it consumes a significant quantity of energy to remove a small quantity of material. Usually, the machining employs cooling and lubrication methods to avoid high temperatures. In most cases the cutting fluid is applied with high flow and low pressures, this technique consumes a huge amount of cutting fluid that causes serious problems in the environment and in the worker's health. An alternative to the conventional cooling method is the Minimum Quantity of Lubricant. In some cases, e.g. grinding, it's cooling ability is not adequate (Yoshimura et al., 2005). The MQL cooling effect is provided by the compressed air, despite the high forced convection, it is insufficient to remove all heat generated in the grinding process.

The addition of water to the MQL technique emerged to raise the cooling ability of the method. The added water evaporates during the process, draining the overage heat (Yoshimura et al., 2005).

The phenomenon of wheel clogging, or wheel loading, occurs when the chips generated by the grinding process does not get completely removed from the process (Cameron et al., 2010). This phenomenon is aggravated when the MQL technique is used. An alternative to solve this problem is the grinding wheel cleaning with compressed air. The air injected with high pressure impacts the wheel cutting surface and expel the impurities lodge in the porosity, improving the workpiece quality and reducing the grinding wheel wear (Oliveira et al., 2012).

### 1.1 Addition of water to the MQL technique

In order to increase the heat dissipation during the machining processes the technique addition of water to the MQL emerged. This technique improves the cooling effect of the MQL because of a large amount of energy absorbed during the water evaporation. Basically, the water evaporation absorbs the thermal energy in two steps. The first one is caused by a rise in the temperature of water droplets until the boiling point. In the second step, the water absorbs a large amount of energy in the phase transformation. Despite the improvement of the cooling effect, the addition of water decreases the adherence of the chips in the tool cutting surface (Yoshimura et al., 2005).

The tiny droplets dispersed in the compressed air are composed of water and lubricant when they strike the tool surface the lubricant spreads all over the surface (it produces an efficient lubrication effect) and the water evaporates in contact with the high temperatures (it removes the extra heat produced in the process). Figure 1 represents the mechanism behind the addition of water to the MQL.

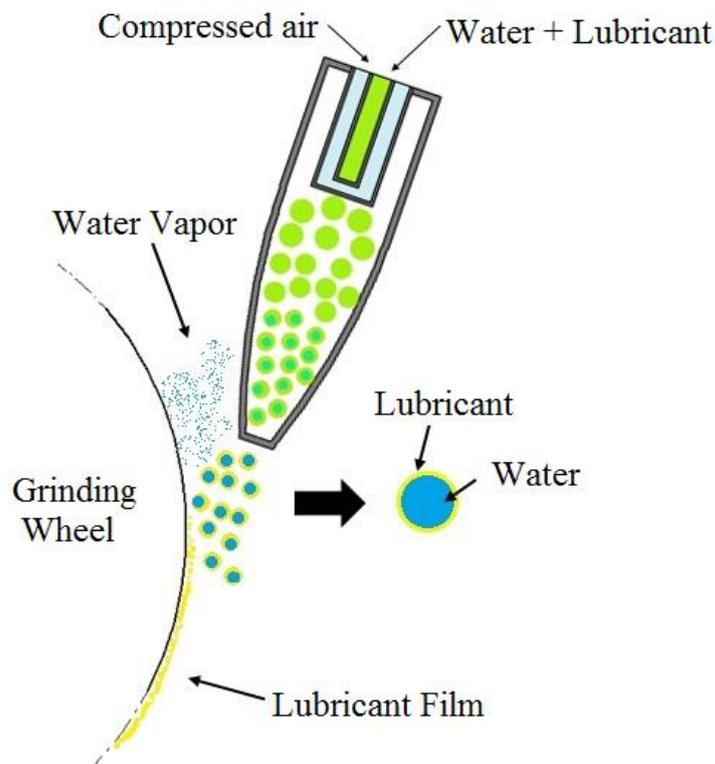


Figure 1. Representation of the addition of water performance.

### 1.2 Phenomenon of wheel clogging

The clogging phenomenon is intrinsic to grinding process, it occurs when the chips produced in the process lodge in the cutting surface porosity. The grinding chips are very small, they can fit in the grinding wheel porosity and this fact may impair the process efficiency.

Grinding process under conventional cooling tends to be more efficient, the cutting fluid flow is enough to clear away the majority of produced chips, consequently, the occurrence of clogging phenomenon is imperceptible. However, when the MQL is applied in the process, the clogging phenomenon becomes a problem, the MQL technique is not capable to take away sufficient chips to make the clogging phenomenon imperceptible. Instead of clear away the chips, the MQL cutting fluid intermingle with the chips, what creates kind of sludge and it is problematic for the process efficiency.

The chips lodge in the grinding wheel porosity together with the residual cutting fluid block the ingress of new cutting fluid in the contact zone and the egress of produced chips, these occurrences affect the grinding wheel cutting ability, what reduces the process efficiency. In addition, the clogging phenomenon increases the cutting efforts, raising the generation of thermal energy, what elevates the temperature and, consequently, the chances of thermal damage in the workpieces increases. Also, the surface quality gets worse and the grinding wheel wears early (Oliveira et al., 2012).

## 2. MATERIALS

### 2.1 Workpieces

The workpieces were ring-shaped with an external diameter of 54 mm, an internal diameter of 30 mm and thickness of 4 mm. The material of the workpieces was steel AISI 4340, which was quenched and tempered, resulting in the hardness of  $54 \pm 2$  HRc. The steel AISI 4340, high strength steel, is categorized as mechanical construction steel. It is widely used in the manufacture of mechanical components that have to be machined by grinding process, e. g. shafts, rods, and crankshafts.

### 2.2 Grinding Wheel

The vitrified Cubic Boron Nitride (CBN) grinding wheel was used, with the external diameter of 350 mm, the internal diameter of 127 mm, the width of 15 mm and abrasive thickness of 4 mm. The specification of the grinding wheel was SBN 151 Q12 VR2. The CBN is the superabrasive used in machining steels, because it does not react with the carbon of the steel, unlike the diamond. In addition, CBN is thermally stable at high temperatures and it is an excellent thermal conductor.

### 2.3 Cooling Conventional Method

The cutting fluid was the emulsion of semisynthetic oil in water at 3% concentration. The flow of the cutting fluid was 17 l/min ( $2,83 \times 10^{-4}$  m<sup>3</sup>/s) and the cutting fluid was stored in a tank of 80 liters to cool down and decant the chips.

### 2.4 MQL System

The cutting fluid was the solution of synthetic oil diluted with water in the proportions (oil : water): 1:1, 1:3 and 1:5, also the synthetic oil are tested. The flow of cutting fluid was 100 ml/h ( $1,67 \times 10^{-6}$  m<sup>3</sup>/s) and the pressure of compressed air was  $6,0 \times 10^5$  Pa, they were conducted separately and the atomization process occurs in the nozzle by the Venturi Effect.

### 2.5 Cleaning System

The cleaning system has been developed to remove impurities from the wheel porosity to avoid the phenomenon of wheel clogging and to improve the process efficiency. The system uses air jet to expel the chips and residual lubricant. The pressure of air jet was  $7,0 \times 10^5$  Pa and it was injected by the nozzle placed with 1 mm from the cutting surface with the incidence angle of 30° from the normal, that according to Oliveira's work *et al.* [3] provided the best efficiency.

## 3. EXPERIMENTAL PROCEDURE

To analyze the influence of addition of water to the MQL four conditions were tested (pure oil, 1 part of oil and 1 part of water, 1 part of oil and 3 parts of water and 1 part of oil and 5 parts of water). These conditions were done with the cleaning system and without the cleaning system to verify the efficiency of the wheel cleaning system. Also, tests were done under the conventional condition. Three repetitions were done for each condition, resulting in twenty-seven machined workpieces.

All the input parameters were kept constant during the machining process, with the exception of the cooling method. The input parameters are present in table 1.

Table 1: Input parameters of the grinding process.

Input parameters	
Grinding mode	External cylindrical plunge grinding - up-grinding
Cutting speed ( $v_s$ )	30 m/s
Radial feed rate ( $v_f$ )	0,5 mm/min
Workpiece speed ( $v_w$ )	0,58 m/s
Effective depth of cut ( $a_e$ )	$2,5 \times 10^{-3}$ mm/ver
Spark out time ( $t_s$ )	1,78 s in the grinding cycles 3,76 s at the end
Dresser type	conglomerate type dresser
Dressing depth ( $a_d$ )	0,02 mm
Dressing speed ( $v_d$ )	600 mm/min

The grinding cycle were two feeds of 100  $\mu\text{m}$  and two spark outs, i.e. the wheel feeds 100  $\mu\text{m}$ , remain static for the spark out time (1,78 s), it feeds 100  $\mu\text{m}$  again and remains static (1,78 s). For each workpiece, forty-two cycles were applied.

The surface roughness was measured perpendicularly to the grinding marks. The equipment was the Surtronic 3+, of Taylor Hobson company, and the parameter was the arithmetic average of roughness profile (Ra). Five measurements were done in each workpiece, resulting in fifteen measurements for each condition.

The roundness deviation was measured using the Talyrond 31C equipment, of Taylor Hobson company. For each workpiece three initial contacts were done, resulting in nine measurements for each condition.

The electric power consumed by the motor was measured using the data acquisition board A/D and the LabVIEW 7.1 software, of National Instruments.

## 4. RESULTS AND DISCUSSION

### 4.1 Surface Roughness

The results of surface roughness are shown in figure 2.

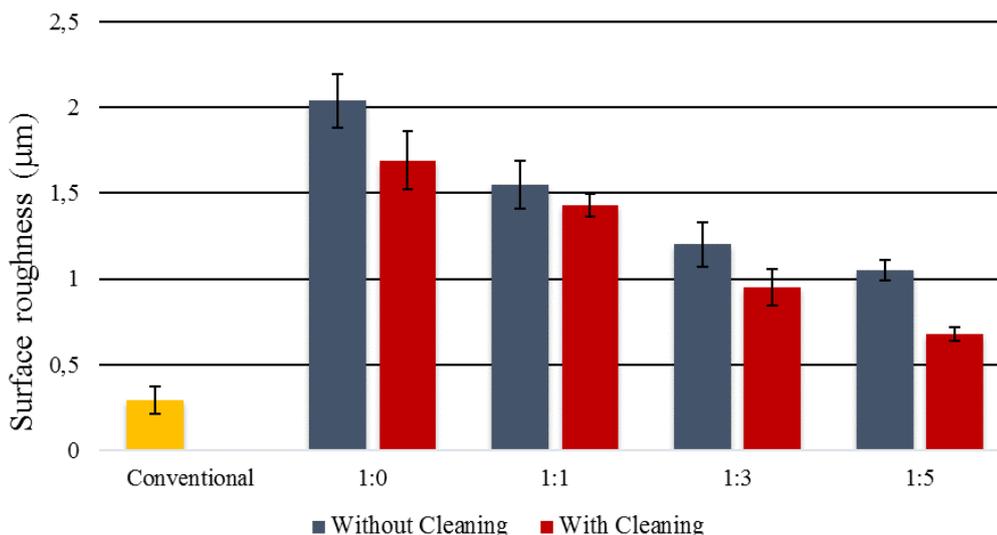


Figure 2. The arithmetic average of surface roughness (Ra) of each cooling condition.

The lowest roughness was provided by conventional cooling, as observed in figure 2. It is interesting to note in figure 2 that the surface roughness improved as far as the water is added in the MQL. Also, analyzing the MQL conditions, in all cases, the surface roughness got better with cleaning system. According to Sinot *et al.*, (2005) surface

roughness is influenced by the cutting ability of grinding wheel, which, in turn, reduces with the phenomenon of clogging. Figure 4 shows the occurrence of the phenomenon of clogging in three conditions.

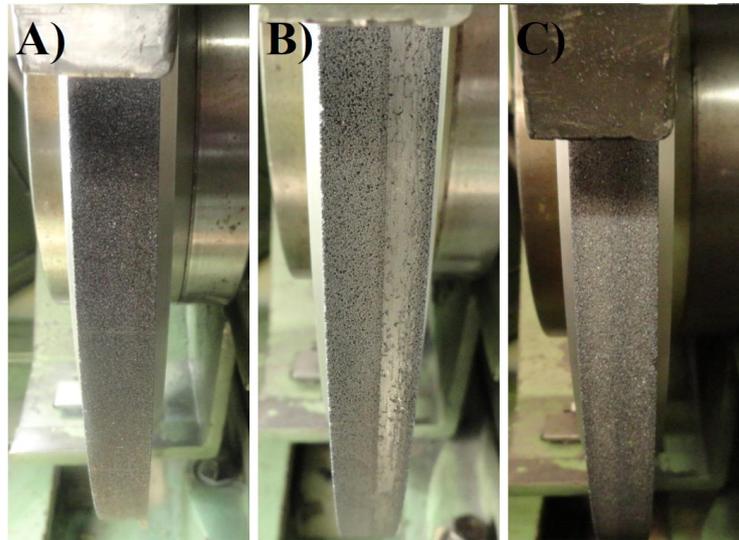


Figure 3. Grinding wheel after the grinding process under: A) conventional cooling, B) MQL without cleaning and C) MQL with cleaning.

It is seen from figure 3 that grinding under conventional condition results in the least phenomenon of clogging occurrence, followed by MQL with cleaning condition and MQL without cleaning condition. It is consistent with the results shown in figure 2 and the Sinot *et al.* (2005) comment. In this case the phenomenon of clogging occurrence impaired surface roughness. Based on figures 2 and 3, the cleaning system with compressed air proves its efficiency in expelling impurities lodged in the cutting surface grinding wheel porosity, thus, the cleaning system kept the grinding wheel cutting ability.

As observed in figure 2, the addition of water improved the surface roughness. The dissipation of heat increases, when the water is added to MQL, it avoids the material softening. With the rise of material ductility, the tendency of the phenomenon of clogging increases (Sinot *et al.*, 2005). Thus, the addition of water ameliorates the occurrence of clogging phenomenon.

#### 4.2 Roundness Deviation

Figure 4 shows the arithmetic average of roundness deviation.

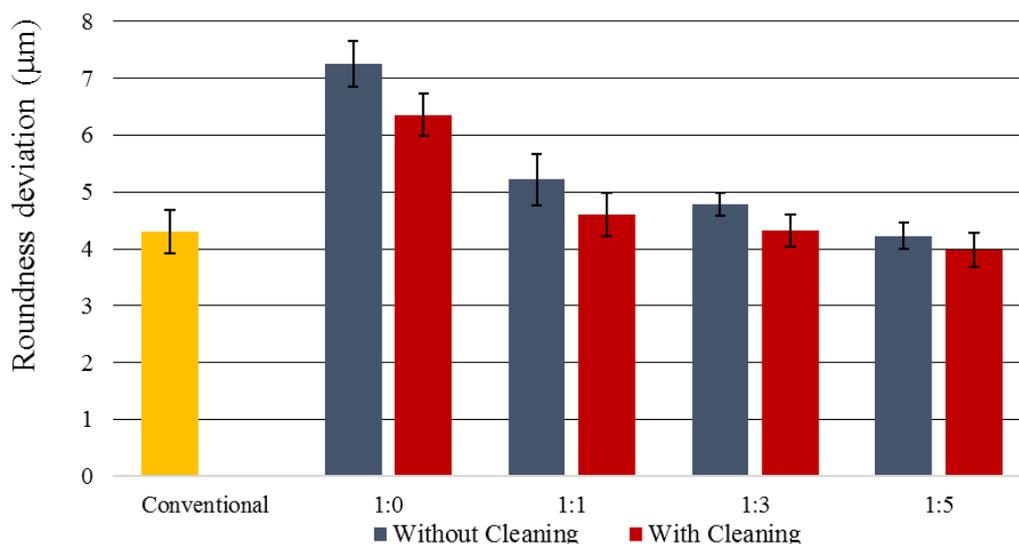


Figure 4. The arithmetic average of roundness deviation of each cooling condition.

According to Silva (2013), the process accuracy gets worse with temperature increase, thus, inefficient cooling methods leads to geometric errors. Yoshimura *et al.* (2005) conclude in their search that the addition of water to the MQL increased the heat dissipation of the cutting zone. Similar to figure 2, the roundness deviation declines with the addition of water, which is consistent with the statements of Silva *et al.* (2013) and Yoshimura *et al.* (2005). The addition of water improved the cooling effect of MQL technique, avoiding thermal expansions, which reduces the geometric errors.

In tested conditions, the use of cleaning system improved the roundness deviation. Oliveira *et al.* (2012) reported that phenomenon of clogging affects the process efficiency, it increases the specific energy of the process and leads to increase of generated heat. As depicted in figure 3, the cleaning system is an effective way to expel lodge chips and mitigate the phenomenon of clogging, with that the cleaning system reduces heat generation, as consequence, the roundness deviation is improved.

It can be observed from figure 4 that the MQL technique is capable to provide satisfactory roundness results when it is allied to the cleaning system and the addition of water.

### 4.3 Consumed Power

Figure 5 shows the arithmetic average of consumed power.

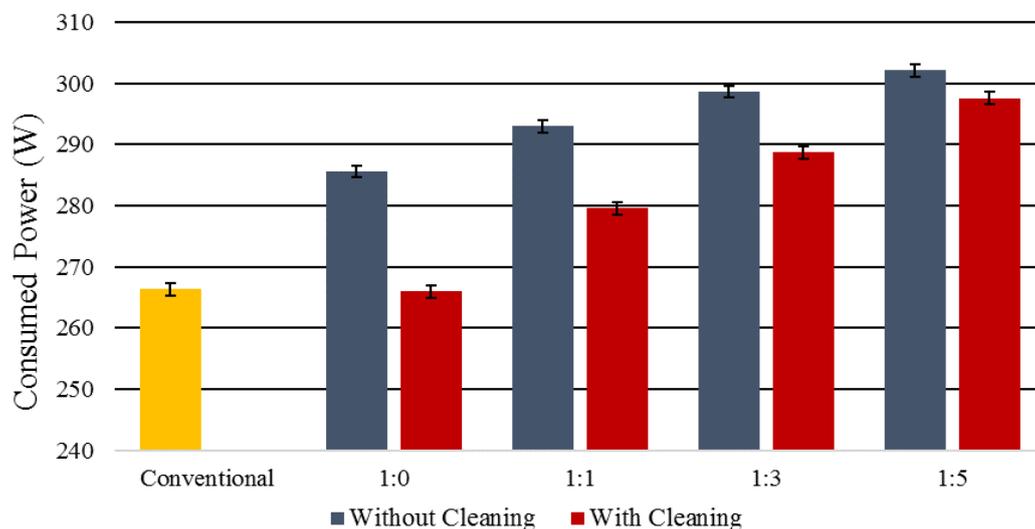


Figure 5. The arithmetic average of consumed power of each cooling condition.

As shown in figure 5, the lowest value of consumed power occurred in the MQL 1:0 with cleaning condition. The MQL application with high pressures enables an efficient penetration of aerosol in the cutting zone, it creates a layer of lubricant that reduces the cutting efforts (Marinescu *et al.*, 2007). The elevated lubricity provided by MQL 1:0 condition allied with the cleaning system results in lower grinding power.

Differently to figure 2 and 4, the addition of water impacted negatively on the analyzed parameter, as shown in figure 5. According to Funes *et al.* (2014), the addition of water to MQL increases the consumed power due to two factors. The cooling effect is improved with the addition of water, it keeps the process temperature in lower levels, avoiding the material from softening, consequently, the cutting efforts are higher. Once the addition of water reduces the use of oil, the lubrication effect decreases as the proportion of water increases, it leads to the increase of cutting forces.

The occurrence of the phenomenon of clogging during the machining under MQL is heavy enough to increase significantly the contact area. Oliveira *et al.* (2012) state that in the phenomenon of clogging the chips filled the major part of available porosity. It can be seen from figure 3 that the phenomenon of clogging presents different magnitudes and the higher one is with the utilization of the MQL without cleaning system (Figure 3 B). Due to the higher contact area in the machining under MQL, the friction forces increase and it increases the consumed power. As shown in figure 5, the consumed power using the MQL conditions is higher than the consumed power using the conventional method. The use of cleaning system demonstrated efficiency in expelling lodged chips, improving the grinding wheel cutting ability and reducing the contact area (workpiece – tool), consequently the grinding power was reduced, as shown in figure 5.

## 5. CONCLUSIONS

From the results obtained in this study the following conclusions may be drawn:

- The cooling capability of MQL technique improves with the addition of water, providing a balance between the cooling and the lubricating effect. Also, the addition of water reduces oil consumption, i.e. comparing the MQL1:5 with MQL 1:0 condition, the reduction of oil utilization was around 83,33%.
- The surface roughness and the roundness deviation are influenced positively by the addition of water, once, these workpiece parameters get worse in high temperatures.
- The clogging phenomenon is intensified with the MQL utilization, impairing the output parameters.
- The wheel cleaning system with compressed air is an efficient method of expelling the lodge chips from the wheel porosity.

## 6. ACKNOWLEDGEMENTS

The authors sincerely thank to FAPESP (State of São Paulo Research Foundation - Process Number 2015/09868-9) for the supporting financially this work and the companies ITW Chemical Products, Quimatic Tapmatic and Nikkon Ferramentas de Corte Ltda by the material support given this research.

## 7. REFERENCES

- H. Yoshimura, F. Itogawa, T. Nakamura, K. Niwa, 2005. "Development of nozzle system for Oil-on-Water droplet metalworking fluid and its application to practical production line". *JSME International Journal*, Vol. 48, n. 4, p. 723-729.
- A. Cameron, R. Bauer, A. Warkentin, 2010. "An investigation of the effects of wheel cleaning parameters in creep-feed grinding". *International Journal of Machine Tools & Manufacture*, Vol. 50, p. 126-130.
- D. J. Oliveira, L. G. Guermandi, E. C. Bianchi, A. E. Diniz, P. R. Aguiar, R. C. Canarim, 2012. "Improving minimum quantity lubrication in CBN grinding using compressed air wheel cleaning". *Journal of Materials Processing Technology*, Vol. 212, p. 2559-2568.
- SILVA, L. R., CORRÊA, E. C. S., BRANDÃO, J. R., ÁLIVA, R. F., 2013. "Environmentally friendly manufacturing: behavior analysis of minimum quantity of lubricant – MQL in grinding process". *Journal of Cleaner Production*, doi: 10.1016/j.jclepro.2013.01.033.
- MARINESCU, I. D.; HITCHNER M.; UHLMANN E.; ROWE, W. B.; INASAKI, I., 2007. *Handbook of Machining with Grinding Wheels*. CRC Press, Taylor & Francis Group, 2007.
- FUNES, H. Jr., BELLENTANI, R. M., GONÇALVES, L. M. N., BIANCHI, E. C., AGUIAR, P. R., DINIZ, A. E., 2004. "Utilização da técnica de mínima quantidade de lubrificante (MQL) com adição de água no processo de retificação cilíndrica de mergulha de aços endurecidos com rebolos de CBN". Congresso Brasileiro de Engenharia de Fabricação.

## 8. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.