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Studies the Cold Cooling using Bio-Nanofluids, Characteristics and Applications in Milling Operations on High-Hardness Steels

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The cooling system has an important role in the quality of machining results, the cooling fluid (air/fluid) are developed to be able to reduce heat and friction arising from the formation of the product, but also environment-friendly. The use of natural oils has been tested in various machining conditions with a minimum quantity lubrications (MQL) method, including the addition of materials that can improve fluid convective properties. Cooling performance with natural materials results in surface roughness according to product smoothness requirements according to ASTM classification and is able to maintain a low tool temperature and reduce chatter/tools vibration. Improvement of the MQL process, temperature, and compressed air pressure conditions determine cooling performance, the lower the compressed air temperature will increase the fluid's ability to reduce tool temperature and increase durability and tool life. The process of forming steel with high hardness requires a cooling system with special conditions. The properties of natural oils will be enhanced by the convective thermophysical properties by the addition of Titanium Oxide (TiO_2), CuO and Aluminum Oxide (AL_2O_3). Natural oils used in the study are corn oil, sunflower oil, water with the addition of nanoparticles. The formation of nanofluids uses magnetic stirrer with varying time and rotation speed, and % weight ratio. The MQL System is equipped with cold air from the compressor which is cooled by utilizing the evaporation/refrigeration process which is kept constant at 10ºC. The cooling system is equipped with a microcontroller/interface to keep the air temperature/pressure constant. In this paper the data presented is a study of cooling in the hard milling process to determine the most nanofluid/dominant factors that affect the results. The results showed that the use of cutting fluids reinforced by nanoparticles in natural oils in a minimum amount increased lubrication properties. There is a significant effect on the use of cooling fluid types with surface roughness, fluids with high lubrication properties, significant to reduce surface roughness, cutting temperature and power consumption. The nanofluid prove was able to apply in an environment-friendly manufacturing process very promising.

Keywords: *Bionanofluid, Cooling, Temperature Tool, Cold Air, Surface Roughness.*

1. INTRODUCTION

Cooling in the machining process is industrial 4.0, demanding a cooling system that is able to reduce process temperature, save energy, and is environmentally friendly. The development of machining cooling technology using dry cutting, cryogenic and very small lubrication has been applied with various models [1]. In the MQL process the use of nanoparticles as additives has been investigated with various treatment and machining processes for materials with high hardness both hard milling, hard turning and other machining processes with satisfactory results. The parameters used are reference to surface indeks and temperature cutting zone, [2]. The basic media for the formation of nanofluid, for environment friendly, formation using non-fossil oils. Types of natural oils that have the potential to be nanofluid are the soybean oil, coconut oil,

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sun flower oil, and corn oil, has been carried out both directly and supplemented with AL_2O_3, CuO, MOS_2, and TiO_2 nanoparticles, [3]. The types of nanoparticles added as cooling media produce variations in results, from the research conducted, the same machining process and parameters adding AL_2O_3 and TiO2 to natural oils can produce better surface roughness compared to CuO, [2] [3]. The cooling of MQL uses natural oil, requires air pressure by adjusting the pressure and amount to produce the optimum spray / fogging profile to improve cooling fluid performance, [4] [5]. There are three types of air-cooled cooling systems, namely (1) vortex tube (VT), (2) The thermoelectric system (TEC), (3) The cryogenic cooling, (4) The cold air base Refrigrated Compressed Air (CCA) [6].

Mixing of nanoparticles in natural oils aims to improve the convective properties of the fluid, the mixing process is affected by rotation, time and process temperature, [7]. Use of a magnetic stirrer with parameter settings to increase nanofluid homogeneity and reduce sediment, [8]. The addition of solid nanoparticles will increase the ability of nanaofluid, the addition of nano graphite, 80 Nm improve cooling performance, reduce temperature, reduce the chisel force, [9]. The use of molybdenum disulfide (MoS2) powder with grain dimensions of 1.5 µm, improves cooling performance in the formation of high carbon steel workpieces, [10]. Tool life improvement reached 177% -230%, reduction in surface roughness decreased by 35% -60%, with the use of Al_2O_3 nanofluids, with the application of nanofluid this resulted in better contact / tribological properties, due to cooling and lubricating functions, [11], TiO_2 has good stability in dispersion conditions, does not require surfactants, [12], [13]. The use of TiO2 and AL_2O_3 nanoparticles with natural oil as the basic media will be tested in the milling process with cold air pressure from the refrigeration process. The use of refrigeration-based temperature-lowering devices is an energy-saving tool that is able to produce a constant temperature below 10ºC, which will be used as the MQL process compressed air in the formation of high hardness steel.

1.2 Literature Review

1.2.1. Air-Cooled Cooling Systems In Machining

Low process temperatures in the cooling process are needed to improve cooling performance, the fluid used is lowered using various methods. Cold air needed to suppress the liquid in the MQL process, the amount and temperature of cold air will affect to the shape of mist form to improv the effectiveness of cooling, [14]. The form of spray, temperature, duration of giving fluid at the site (tools) will affect the process conditions during cooling, [15]. Fluid-lowering technology for the machining process, have developed and applied, are three method, vortex tube (VT), Thermoelectric Cooling (TEC), and Compressed Chriogenic Air Cooling (CRA).

(a) Vortex Tube (VT)

The vortex tube (VT) tool has been used and applied to the manufacturing process, using compressed air and is easy to use. VT can be used for cooling with dry cooling methods or to support MQL processes. The drop in air temperature, technically VT is easy to use but a high and constant air flow rate is needed, which can be done with a large air / compressor storage system, [6]. The VT image can be seen in Figure 1.

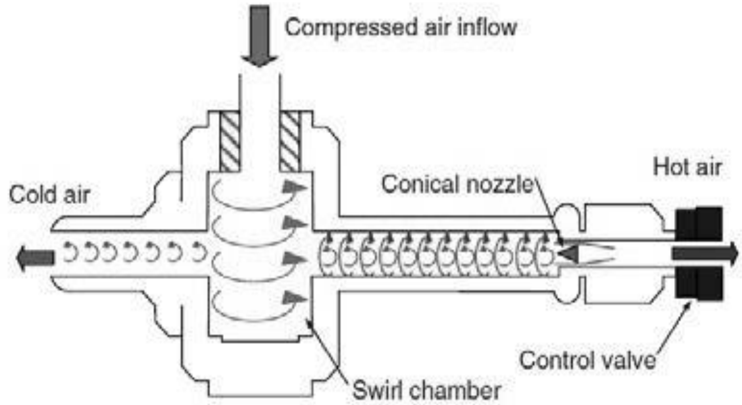

Figure 1. Working principle of vortex tube heat exchange with parallel flow direction, [16][17]

(b) Thermoelectric Cooling (TEC)

The use of cooling methods by utilizing a thermo-electric system (TEC) by making two hot and cold sides. The wall temperature TEC system is regulated by controls and electronic circuits. The working principle can be seen in Figure 2.

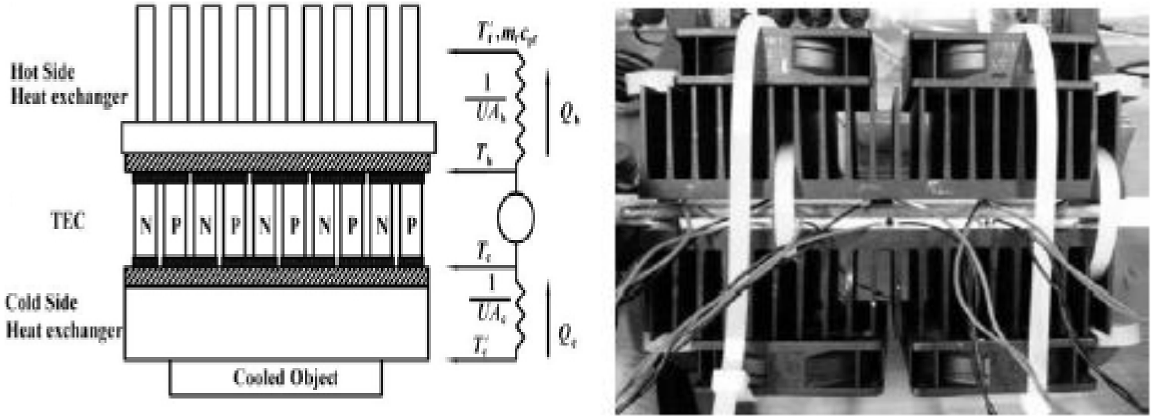

Figure 2. Typical TEC schematic diagram [18]

The cold air produced is flowed through a flexible pipe system and is used in the machining process. The main principle of this cooling system is that the temperature of the cold air produced has sufficient flow rates to cool the tool contact with the workpiece. The TEC tool does not produce gas and is easy to use, [18], Dimensions of temperature-lowering devices based on TEC/thermoelectric modules, using a length and width of about 2.5-50 mm, thickness/height of about 2.5-5mm, [18]. Advantages of TEC systems are in addition to immovable, lightweight and small TEC tools, easily applied to cooling the process of metal formation. This TEC system is in principle simple but the application and use in the field is constrained by the selection of components for heating and cooling parts.

(c) Compressed Chriogenic Air Cooling (CRA)

The CRA cooling method uses Liquid Nitrogen (LN2) to cool the machining process by spraying LN2 directly into the cutting zone. The CRA method can improve the machining process performance, but because the temperature is very low, making handling and LN2 applications dangerous, and to work safely, a protection system is needed. The CRA method is generally described as follows in Figure 3.

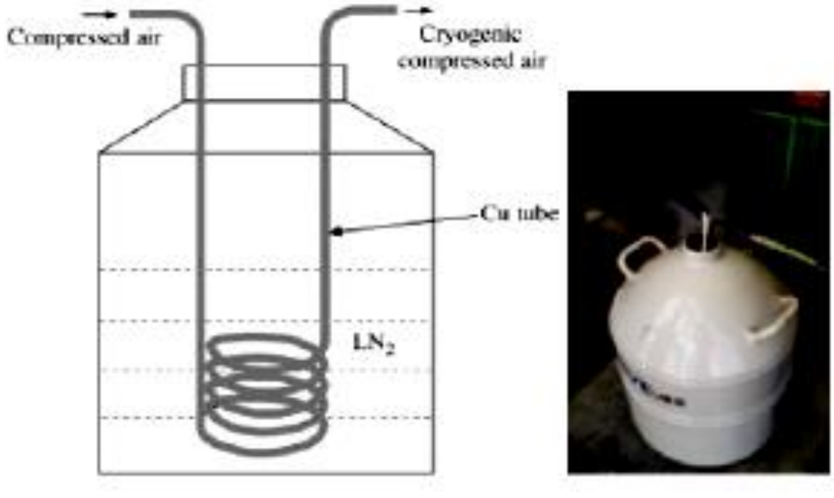

Figure 3. Compressed air cryogenic coolant, CRA, [19]

The Use of LN2 can produce cold air that can be used, as a cooling medium for machining processes. This CRC technology is easy to implement and is also capable of producing high air flow rates with very low temperatures [20].

2. MATERIALS AND METHODS

2.1 Material

Table 1. The high hardness Steel SS 304 Material

No	Material	density	Thermal Konduktifitas (W/m.^{o}k)	Hardness (Hra)	Dimensions of Workpiece
1	Stainless Steel 304L, Ni (8%);Cr 18%	7,93 kg/dm^3	At 100°C 16.3, At temperature 500°C, 21.5	63,33	length : 70 mm Width : 60 mm Thickness : 60 mm

Nanoparticles **:** Al_2O_3, TiO_2, CuO (30 nm),
Tools : 4 mill flute, HSS, 12 mm tool end mill.

2.2. MQL Using Natural Oil

The cooling technology using natural oil / neat oil, has been applied both pure and mixed with nanoparticles, mixing using a weight ratio (0.5%, 0.75%, 1%); (weight of natural oil). The formation process is carried out using magnetic stirrer, which regulates the mixing duration, electric time and temperature. The stages of making nanofluid can be seen in Figure 4.

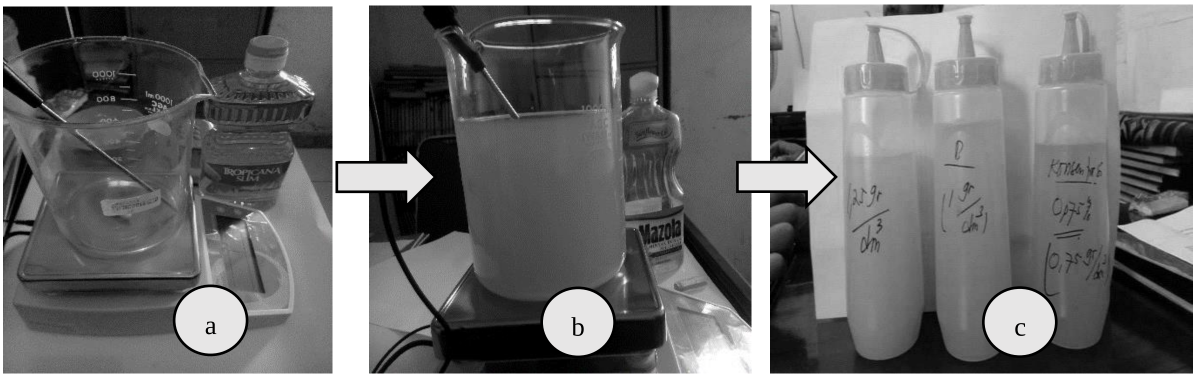

Figure 4. The process of making nanofluid with magnetic stirrer by controlling temperature, time and speed of rotation, (a) Preparation of the tool, set-up, weight ratio, (b) mixing process, (c) Nanofluid

2.3. Refrigrated Cold Air (RCA) Innovation With Interface/Microcontroller Atmega

The temperature-lowering methods that have been discussed above have advantages and disadvantages that are used as input in innovation and the development of a temperature-lowering system that is easy and economical. The refrigeration system is a system that is widely known by engineering personnel, the use of a temperature-lowering system with refrigeration is a development option for cooling, for work optimization is controlled by the ATMEGA microcontroller, to automatically adjust the work of the refrigeration system. Compressor pressure is regulated using a valve with a pressure gauge control, the temperature on the input and output sides is set with ATMEGA.The cooling scheme developed can be seen in Figure 5.

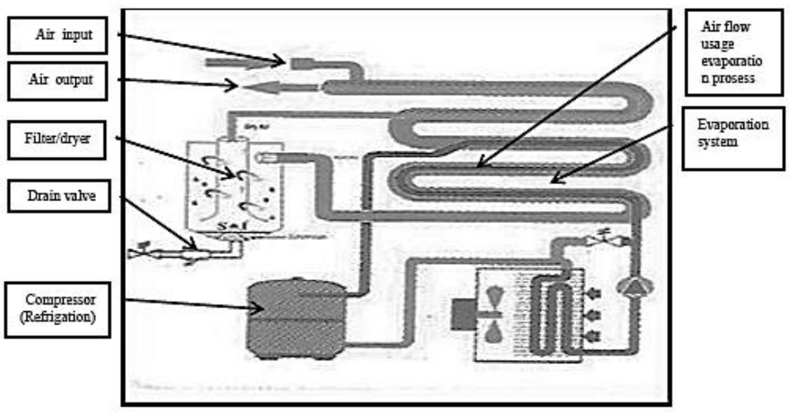

Figure 5. The air heat absorption system utilizes the refrigeration system for machining, [2][21]

2.3 Factor and level for Experiment

Table 2. Factors and levels

Faktor	Level I	Level II	Level III
Power (3 Kw), Spindle Speed regulated	625 rpm	925 rpm	1225 rpm
Depth of Cut	0.5 mm	0.75 mm	1.0 mm
Feed rate average	22 mm/rev	42 mm/rev	62 mm/rev
Nanofluids (natural oil)	0.50 % wt	0.75 % wt	1.0 % wt

Table 3. Nanoparticle Characteristics

Type of nanoperticle /nanofluid	Nanoparticle morphology	Color	Heat transfer coefficient (W/m.°C)
Al_2O_3	Nearly spherical	white	36.15
TiO_2	pure anatase phase/ Tetragonal	white	11.7
CuO	Monoclinic /cubic	Black	48.4

Factors (Control variable)

Milling machine (3 axis)	: Milling, 3 KW spindle Power, rotation (regulated)
Pressure regulated	: 1 Bar
Cooling temperature (cold air)	: 10-12 °C
Dimensions of nanaoparticle	: (30 nm)
Weight % of nanoparticle	: 0,5% wt; 0,75% wt ; 1,0% wt
Natural oil base nanofluid	: nanoparticle (corn oil, sunflower, water, drycutting)

2.4. Experiment Set-Up

Data retrieval of MQL application with refrigeration based pressure can be seen in Figure 6.

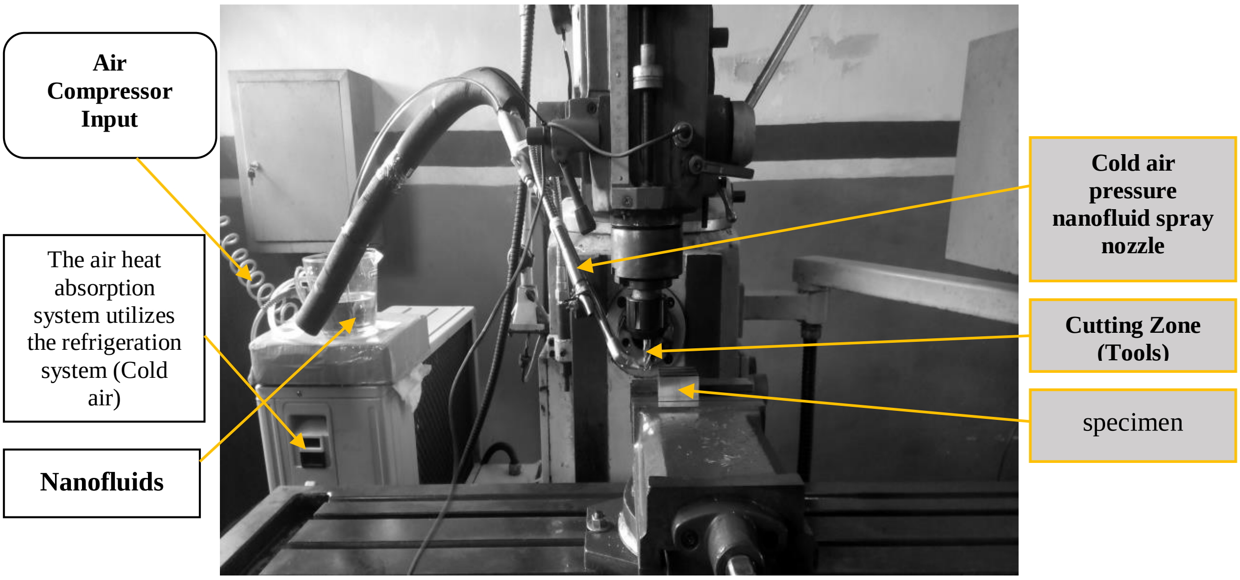

Figure 6. Experiment MQL cold set up on high hardness steel

3. RESULTS AND DISCUSSION

From the experiment using the taguchi distribution, the optimum results were obtained for each MQL system, especially on the surface roughness and temperature of the cut zone as presented in the table. 4, 5, and 6.

Table 4. SS304 testing uses sunflower oil with added ingredients (Al_2O_3)

Experiment	Surface Rouhgness (μm)	Cutting Zone Temperature (°C)	Power comsumption (Watt)
1	1,2650	28,53	332,20
2	1,6363	27,03	334,40
3	2,5750	29,90	352,00
4	1,6803	26,73	352,00
5	1,6063	31,70	346,13
6	1,1437	28,47	332,20
7	1,7297	31,00	352,00
8	1,3037	26,57	352,00
9	1,5617	30,50	339,53

Data from testing corn oil with TiO_2 in the machining process on high-hardness steel (HHS), shown in table 5.

Table 5. Data from testing the use of nanofluid with corn oil with TiO_2

Experiment	Surface Rouhgness (μm)	Cutting Zone Temperature (°C)	Power comsumption (Watt)
1	1,2780	27,50	330,00
2	5,0380	27,13	330,00
3	9,8730	32,20	330,00
4	3,0287	28,87	330,00
5	2,5517	30,50	330,00
6	5,0847	27,37	337,33
7	3,6473	29,47	337,33
8	1,6327	27,57	337,33
9	6,3497	29,73	337,33

Data from testing the use of nanofluid with water with CuO in the machining process shown in table 6.

Table 6. Testing SS 304 using water with CuO added ingredients

Experiment	Surface Rouhgness (μm)	Cutting Zone Temperature (°C)	Power comsumption (Watt)
1	6,1234	28,772	388,912
2	6,6367	29,512	396,497
3	4,6387	30,243	418,743
4	2,3891	28,011	414,577
5	5,3763	29,501	405,543
6	5,2210	29,302	390,623
7	3,1230	30,901	409,902
8	2,4188	28,102	416,045
9	3,4220	28,076	411,401

All MQL processes in each method use cold air to suppress fluid (nanofluid), cold air from the RCA system is applied with temperature control, and pressure using ATMEGA. Manual system of cooling level can be adjusted automatically set-up of the level of pressure and temperature output before machining process. The dry cutting using cold air applied in milling on SS 304. Data from testing the use of cold air in milling process on SS 304, shown in table 7 below.

Table 7. Test Result Data SS 304 uses cold air (cold air / dry cutting)

Experiment	Surface Rouhgness (μm)	Cutting Zone Temperature (^oC)	Power comsumption (Watt)
1	5,3820	60,00	465,91
2	7,6540	73,33	476,91
3	5,7840	65,00	490,11
4	1,9563	50,00	470,80
5	11,183	83,33	487,67
6	28,782	86,67	485,96
7	2,4949	46,67	496,71
8	2,8312	46,67	488,64
9	15,6011	74,00	531,67

3.1. Disscusion

From experimental data the use of cooling systems with the results of testing the surface roughness, process temperature and power (enegy consumption), the use of fluid types is very influential on the machining process conditions. The use of nanofluid with cold air suppressants also showed different results, although factors and levels used the same parameters, following the comparison of the data machining four cooling types above, were clarified with Figure 7.

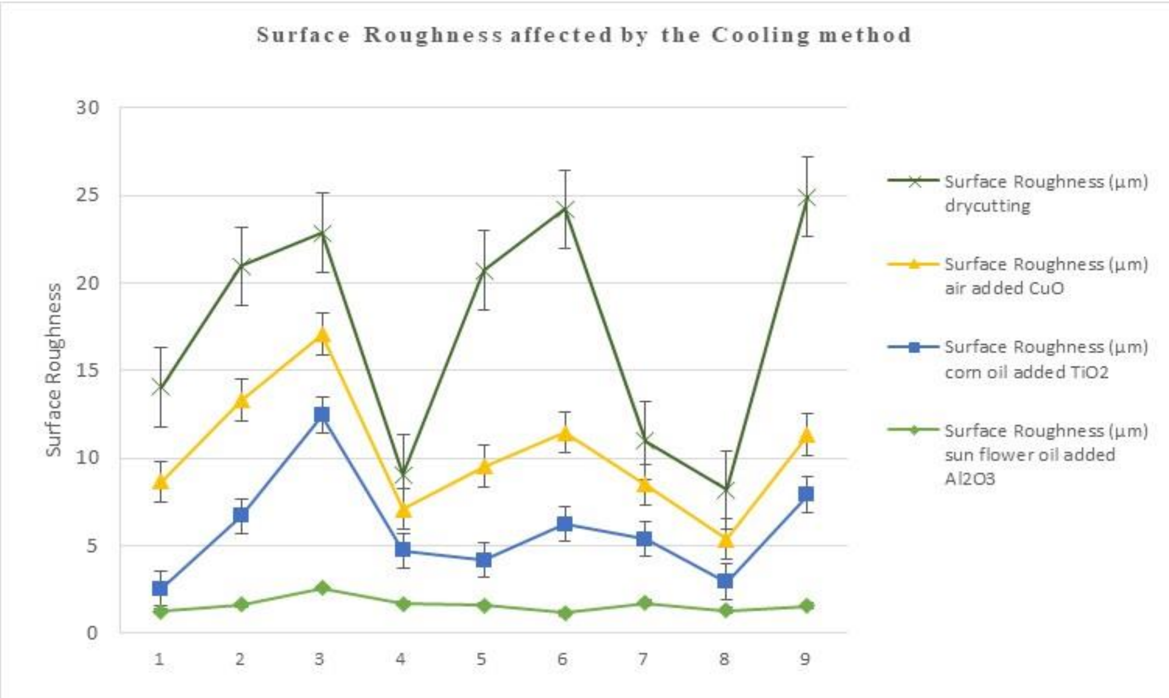

Figure 7. Relation an influence faktor between the type of coolant and the surface roughness of the workpiece

The graph 7 shown, that the use of coolant (nanofluid) used as shown above influenced to the surface indexes, the use of cold air on the formation of high hardness steel, the result is above the value of surface roughness produced using natural oil-based nanofluid. Taguchi process optimization shows the factors and experiment levels to 4 and 8 show the best results, while factors and levels with the highest criteria are factored and level (3) and (9). The phenomenon shown, the type of fluid and the cooling method greatly affect the results of the type of nanoparticles used affect surface roughness, Al_2O_3 nanoparticles with sunflower oil can produce the lowest roughness, followed by corn oil with TiO_2 nanoparticles added, CuO with water showed roughness the highest. The use of cold dry cutting method, with a temperature of 10-12^oC, has not been able to reduce and replace liquid lubrication with the MQL system, especially in materials with high hardness, the high temperature of cutting and without lubrication causes a rough surface. Roughness with index below 2 μm, generally can be grouped for finishing process, The results of this study if compared with other studies shown as the research of nanofluids base natural oil [11]. The surface of the workpiece as the formation target requires ASTM classifications achieved, the roughness indeks for finishing average at

0.50-2 µm, this result of milling process of SS 304 in accordance with the trend produced in the previous study [22]. The formation of products with high hardness, resulting in a high increase in process temperature, the use of cooling methods with low temperatures below 10-15 C and minimal lubrication (MQL) with corn oil with the addition of TiO2 proved to have good lubrication, low cutting temperature and power the smallest. The high cut zone temperature will quickly reduce the sharpness of the tool, will result in metallurgical changes and will eventually affect the machining results, [23]. The use of nanofluid sun flower and corn oil with cold air pressure, with nanoparticle used, keep the temperature tools of the cutting zone below 40^{o}C, while dry cooling used, using the same level increase the temperature of the cut zone. The cut temperature conditions in the research carried out are clearly illustrated in Figure 8.

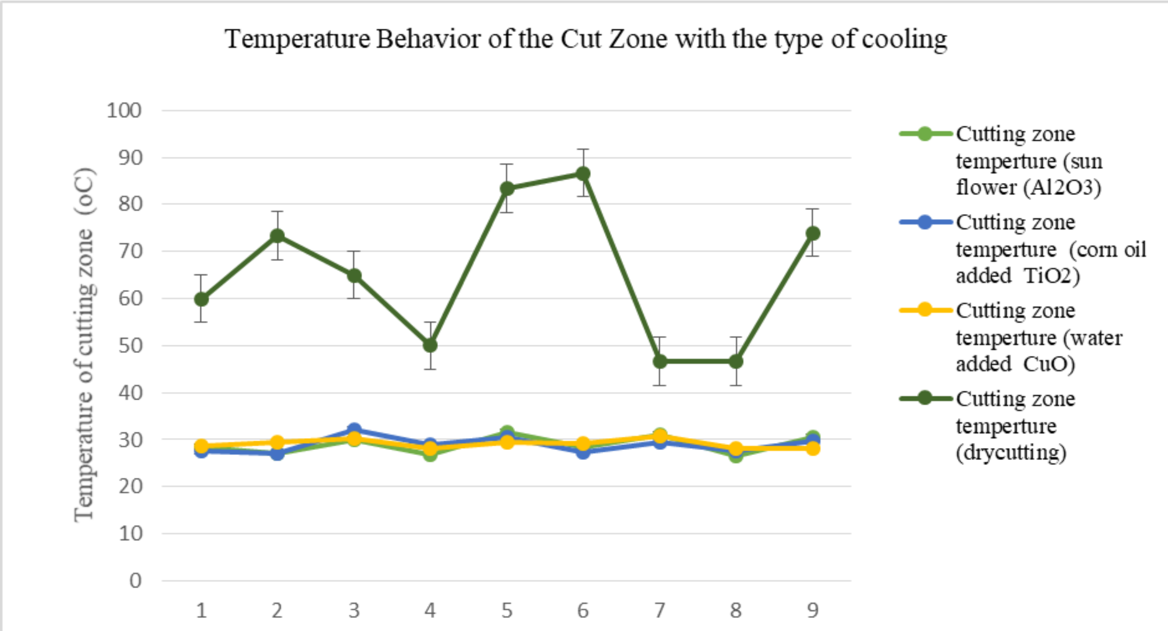

Figure 8. Temperature Behavior of the Cut Zone with the type of cooling

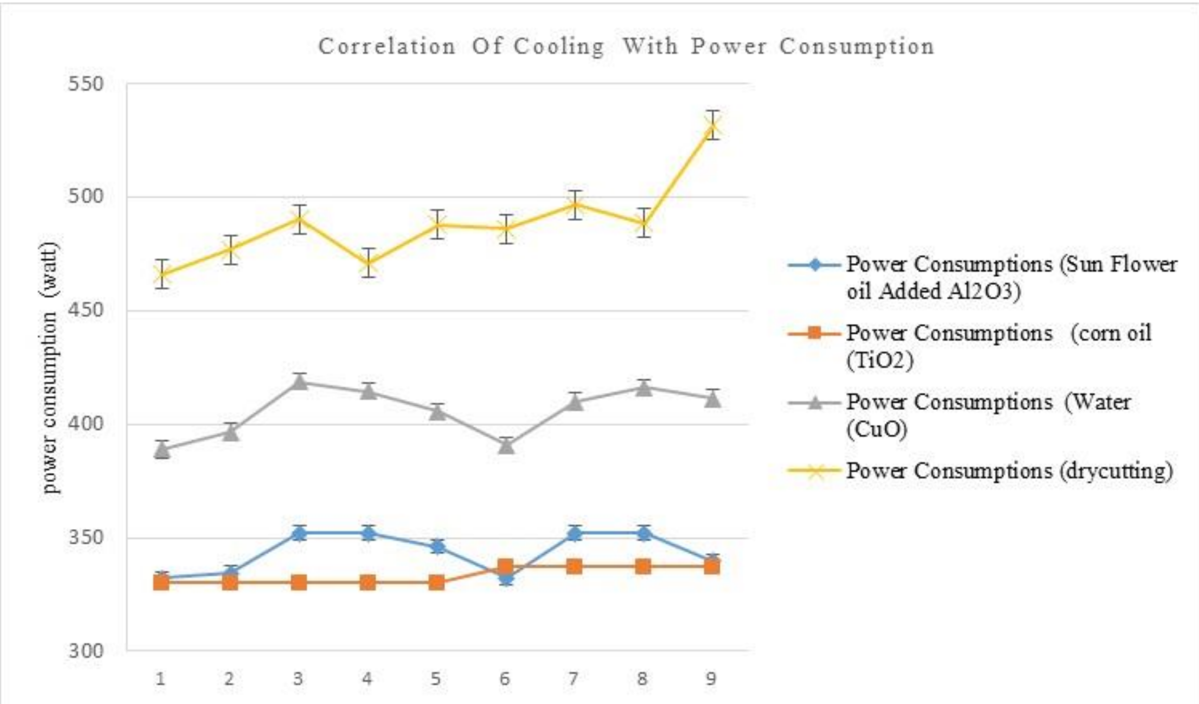

Figure 9. Correlation Of Cooling With Power Consumption with the type of cooling

Based on cutting zone temperature conditions, and energy of motor consumpted in Figures 8 and 9, there are interrelated relationships between the temperature of the cut zone and motor power. Increased heat in the cutting zone is caused by a large force so that it will increase the motor power needed for formation. In the formation of using nanofluid corn oil (TiO2) and sunflower oil (Al2O3), the motor power is almost the same as the power range of 300-350 watts, with a voltage of 220 V, then the current ranges from 1.4 to 1.6 A, while in water use and CuO shows lower lubrication properties, resulting in greater friction and energy consumption, [1][4][7]. The greatest power consumption occurs during dry cooling, motor power increases according to temperature rise and friction force.[21][24].

4. CONCLUSION AND FUTURE WORK

4.1. Conclusion

From the comparison of the type of cooling and its correlation with surface roughness, cut temperature and energy consumption it can be concluded;

a. There is a significant effect on the use of cooling fluid types with surface roughness, fluids with high lubrication properties will reduce surface roughness, cutting temperature and motor power.
b. Increasing the cutting temperature is directly proportional to the increase in energy consumption, the occurrence of high friction forces on the tool and workpiece will increase motor temperature and power, while cooling with dry cutting shows that lubrication is a very important factor for overall machining conditions, if the ability low lubrication, high temperature and power increase.
c. The effectiveness of cold air on machining does not have a large effect on the yield surface, the need for fluida with high lubrication is still needed especially in the formation of high hardness material such as SS 304.

4.2. Future Work

a. The use of nanocutting fluid, especially corn oil and sun flower with additional nanoparticles, is needed to be tested in high speed machining conditions. The use of different chisels needs to be applied to complete the data on the use of nanofluids in various machining processes.
b. Analysis of morphology and crystalline form of nanoparticles need to be studied more specifically to connect cooling performance with the shape and dimensions of added ingredients

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] ELMUNIFI MHS, KURNIAWAN D, NOORDIN M,. *Use of castor oil as cutting fluid in machining of hardened stainless steel with minimum quantity of lubricant*, 2015, Proced CIRP 2015; 20: 408–411.

[2] B SUGIANTORO, SAKURI, SUTARNO, *Performance evaluation of using water and bio oil-based nanocutting fluids under minimum quantity lubrication with compressed cold air during milling operations of steel*, 2018**,** International Conference on Engineering and Applied Technology (ICEAT), IOP Conf. Series: Materials Science and Engineering, Vol. 403.

[3] M M S PRASAD, R.R.SRIKANT, *Performance Evaluation Of Nano Graphite Inclusions In Cutting Fluids With Mql Technique In Turning Of Aisi 1040 Steel*, 2013, IJRET: International Journal of Research in Engineering and Technology eISSN: 2319-1163 | pISSN: 2321-7308, Volume: 02 Issue: 11 | Nov-2013.

[4] ZHANG X, LI C, ZHANG Y, *Performances of Al2O3/SiC hybrid nanofluids in minimum-quantity lubrication grinding*., 2016, Int J Adv Manuf Tech Vol 86: page 3427–3441.

[5] MARUDA RW, KROLCZYK GM, NIESLONY P, *The influence of the cooling conditions on the cutting tool wear and the chip formation mechanism*., 2016, J Manuf Process, vol 24: page 107–115.

[6] YOGIE RINALDY GINTINGA, BRIAN BOSWELLA, WAHIDUL K. BISWASB, MOHAMMAD NAZRUL ISLAM, *Environmental Generation of Cold Air for Machining*, 2016, The International Scientific Committee of the 13th Global Conference on Sustainable Manufacturing.

[7] XIANG-QI WANG AND ARUN S. MUJUMDAR, *A Review On Nanofluids - Part I: Theoretical And Numerical Investigations*, 2016, Brazilian Journal of Chemical Engineering, ISSN 0104-6632.

[8] K. S. CHAUDHARI, P. V. WALKE, U. S. WANKHEDE, R. S. SHELKE, *An Experimental Investigation of a Nanofluid (Al2O3+H2O) Based Parabolic Trough Solar Collectors*, 2015., Article *in* Current Journal of Applied Science and Technology.

[9] CHRISTOPHER JAMES TYLER, *The effect of cooling prior to and during exercise on exercise performance and capacity in the heat: A meta-analysis*, Department of Life Sciences, University of Roehampton, Danebury Avenue, London, SW15 4JD, England, UK.

[10] DEVESH KUMAR SINGH, MANISH KUMAR SINGH, DHARMENDRA DUBEY, *Performance of MoS_2 based cutting fluid Lubricants during Maching of AISI 316Ti Austenitic Stainless Steel*, 2016,

Vol-2 Issue-2, *IJARIIE-ISSN(O)-2395-4396*.

[11] DUC TRAN MINH, LONG TRAN THE, NGOC TRAN BAO, *Performance of Al2O3 nanofluids in minimum quantity lubrication in hard milling of 60Si2Mn steel using cemented carbide tools*, 2017, Advances in Mechanical Engineering, Vol. 9 (7)1–9, The Author(s).

[12] A. GRASSIAN, V.H. O'SHAUGHNESSY, P.T., ADAMCAKOVA-DODD, *Inhalation exposure study of titanium dioxide nanoparticles with a primary particle size of 2 to 5 nm*, 2007 Environ. Health Perspect., vol. 115, pp. 397–402.

[13] H. HE, Y. JIN, Y. CHEN, H. DING, Y. CANG, D., DAN LU, *Heat transfer and flow behaviour of aqueous suspensions of TiO2 nanoparticles (nanofluids) flowing upward through a vertical pip*e, 2007, *Int. J. Heat Mass Transf.*, vol. 50, pp. 2272–2281.

[14] CHANGFA TAO, XIN CAI, XINSHI WANG, *Experimental Study On The Effects Of Ambient Pressure Conditions On Spray Characteristics Of Water Mist*, 2011 Second International Conference On Mechanic Automation And Control Engineering, 15-17 July 2011.

[15] J.E. CAMPORREDONDO S., A.H. CASTILLEJOS E., F.A. ACOSTA G., E.P. GUTIÉRREZ M., AND M.A. HERRERA G., "*Analysis of Thin Slab Casting by the Compact Strip Process: Part I. Heat Extraction and Solidification*'', 2004, Metall. Mat. Trans. B, Vol. 35B, pp. 541-560.

[16] W. CONG, Z. J. PEI, T. DEINES, C. TREADWELL, *Rotary ultrasonic machining of CFRP using cold air as coolant: feasible regions,*, 2011, Journal of Reinforced Plastics and Composites, vol. 30, pp. 899-906.

[17] YOGIE RINALDY GINTINGA,C, BRIAN BOSWELLA, WAHIDUL K. BISWASB, MOHAMMAD NAZRUL ISLAM, *Environmental Generation of Cold Air for Machining*, 2016, 13th Global Conference on Sustainable Manufacturing - Decoupling Growth from Resource Use, Procedia CIRP 40 (2016) 649 – 653, The Authors. Published by Elsevier B.V.

[18] X. WANG, J. YU, AND M. MA, *Optimization of heat sink configuration for thermoelectric cooling system based on entropy generation analysis*, 2013, International Journal of Heat and Mass Transfer, vol. 63, pp. 361-365, 2013

[19] S. SUN, M. BRANDT, AND M. DARGUSCH, *Machining Ti–6Al–4V alloy with cryogenic compressed air cooling*, 2010, International Journal of Machine Tools and Manufacture, vol. 50, pp. 933-942, 2010

[20] E. RAHIM, M. IBRAHIM, A. RAHIM, S. AZIZ, Z. MOHID, *Experimental Investigation of Minimum Quantity Lubrication (MQL) as a Sustainable Cooling Technique*, 2015. Procedia *CIRP*, vol. 26, pp. 351-354.

[21] T SUGIARTO, B SUGIANTORO, N SUPRIYANA, K SETYAWAN, Y PRAHARTO, *Application of cold dry cutting and coated carbide tool on high speed turning process against tool wear and surface roughness of Brass MS58*, 2017, 1st International Conference on Engineering and Applied Technology (ICEAT), IOP Publishing, IOP Conf. Series: Materials Science and Engineering 403

[22] DING H, SHIN Y., *Laser -assisted machining of hardened steel parts with surface integrity analysis*., 2010, International Journal of Machine Tools & Manufacture, 50:106-114.

[23] ALI, S.M., DHAR, N.R, DEY, S.K., *Effect Of Minimum Quantity Lubrication (Mql) On Cutting Performance In Turning Medium Carbon Steel By Uncoated Carbide Insert At Different Speed-Feed Combinations*, 2011, Advances in Production Engineering and Management, ISSN 1854-6250.

[24] TD. NGUYEN, J. SUKUMARAN, J. DE PAUW, P. DE BAETS, *Tribological Behaviour Of Polymer Bearings Under Dry And Water Lubrication*, Ghent University, Laboratory Soete, Belgium, https://core.ac.uk/download/pdf/55735238.pdf, accessed, October 2018.