EFFECT OF CHILLED AIR COOLANT ON SURFACE ROUGHNESS AND TOOL WEAR WHEN MACHINING 2205 DUPLEX STAINLESS STEEL

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ABSTRACT: Cutting fluid is important to enhance machinability. However, conventional cutting fluid is uneconomical and hazardous to environment and health. This paper analyzed the effect of chilled air coolant on surface roughness and tool wear when machining 2205 duplex stainless steel. The compressed air was chilled using vortex tube. Cold air and hot air were produced by means of vortex tube from the source of compressed air. This study also investigated the comparison of machining performance between conventional flood coolant and chilled air coolant. The tests were conducted on a conventional turning machine with TiAlN coated carbide tools and the constant parameters like feed rate, cutting depth, and cutting speed. Surface roughness and tool wear were measured after each run and the results were analyzed. The results showed that chilled air coolant gave better surface finish compared to conventional flood coolant. However, tool life was better when using conventional flood coolant compared to chilled air coolant. For both coolant method, the result showed a decreasing trend for surface roughness and tool wear values when the temperature of chilled air coolant decreased.

KEYWORDS: *Vortex Tube, Chilled Air Coolant, Turning, Surface Roughness, and Tool Wear.*

1.0 INTRODUCTION

Turning is a process where the cutting tool is fed to a rotating workpiece to generate an external and internal surface concentric with the axis of rotation. When the metal is cut, energy is dissipated in overcoming friction between the tool and workpiece and in deformation of the chip. This energy is converted to heat, and this will cause high temperature in the deformation zone as well as the tool and workpiece. Therefore, a cutting fluid or coolant is needed to reduce the temperature [1].

Cutting fluid performance in the machining operation is important to enhance the effectiveness of the machining process. The main purpose of cutting fluid is for cooling and lubrication but it also helps in improving surface finish, increasing life span of the cutting tool, and increasing the dimensional accuracy of the workpiece. Other than that, cutting fluid is used to flush away the chips from the cutting zone, increase the corrosion resistance of the workpiece and machine, and prevent formation of build-up edge [2].

As an alternative to cutting fluids, various cooling methods have been carried out, such as minimum quantity lubrication (MQL), cryogenic cooling, flood cooling, solid coolants and others. Zhang et al. [3] stated that although MQL is often used but the low cooling capacity limits its application. Bermingham et al. [4] investigated the differences between high pressure coolant and cryogenic coolant on tool life and chip morphology in machining of Ti-6Al-4V alloy and they found that both liquid nitrogen and high pressure emulsion are effective to extend tool life significantly over dry cutting. Nandam et al. [5] also found that the cryogenic coolant has enhanced the machinability of tungsten heavy alloys, where the material removal rate and the surface finish of the machined surfaces are extremely good when compared with conventional coolant method. Although cryogenic coolant is very effective in enhancing machining performance, the process is very costly, which is the main hurdle in the wide implementation for the machining in the industry.

There is a scarce literature on the turning process using chilled air coolant. Hence, in this study, chilled air coolant was used and its effect on surface roughness and tool wear when machining 2205 duplex stainless steel was investigated.

2.0 METHODOLOGY

The experiment was performed using variable speed center lathe G410-TCV model. The workpiece for this experiment was 2205 duplex stainless steel measuring 100 mm in diameter and 300 mm in length. The cutting tool was TiAlN coated. For conventional flood coolant, the soluble oil was used. The turning process parameters were set constant for all experimental runs. The machining conditions are stated in Table 1. These values were selected by referring to the handbook from cutting tool supplier.

The machining was stopped after 120 seconds and the surface roughness was measured. The cutting tool was removed in order to measure the flank wear on the cutting tool. The new cutting tool was inserted for every run.

Table 1: Machining Conditions

Parameter	Value
Cutting Speed	210 m/min
Feed rate	0.10 mm/rev
Depth of Cut	1.00 mm

The procedure was repeated for chilled air coolant at 12°C, 14°C and 16°C using Frigid-X Tool Cooling System. The compressed air was chilled using vortex tube due to its simplicity and ability to generate separated cold and hot streams from a single injection [6]. Figure 1 shows the structure of the flow inside a counter flow vortex tube. Injected into the vortex tube tangentially, the compressed gas was then divided into two parts and exhausted from the exits at temperatures lower and higher than the inlet gas, respectively. In this way, cold and hot streams were generated by only the vortex tube without any additional components. As the vortex tube contains no other part inside the tube, the separation of two streams at different temperature by the vortex tube can only be attributed by the effects of fluid dynamics [7].

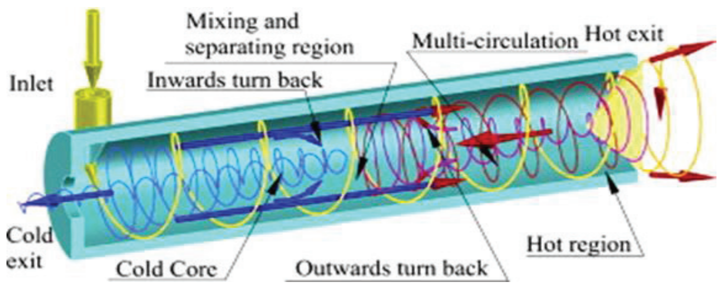

Figure 1: The structure of the flow inside a counter flow vortex tube [7]

The temperature of the chilled air coolant was controlled by controlling the pressure of the air. The pressure of the compressed air was controlled by the air compressor filter regulator and the temperature of the compressed air was measured using thermocouple thermometer. After each run, the surface roughness and tool wear were measured using Mitutoyo Profilometer SJ-301 and scanning electron microscope (SEM), respectively. The measurement of the flank wear was done at 500x magnification with the scale of 10 μm. All the experiments were repeated three times and average data were taken.

3.0 RESULTS AND DISCUSSION

3.1 Surface Roughness

Surface finish is one of the crucial factors that determines the effectiveness of the machining process. The surface roughness was measured at five different locations and the mean values were calculated. The temperature of the chilled air coolant varied from 12°C to 16°C. Figure 2 shows the surface roughness under different cutting conditions.

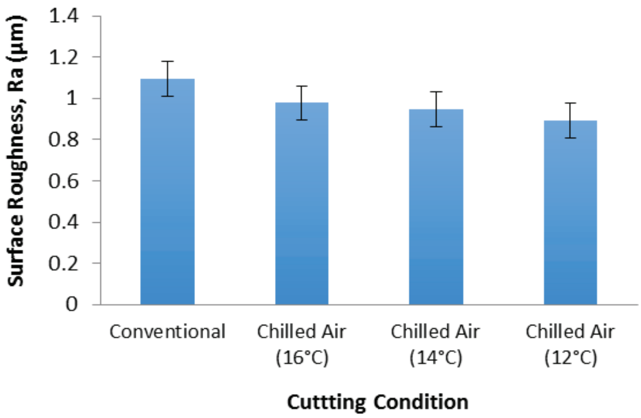

Figure 2: Surface roughness for all cutting conditions

The results yielded that the surface finish was slightly better with the application of the chilled air coolant compared to conventional coolant. The highest surface roughness value, 1.092 µm, was obtained with the use of conventional coolant method. The surface roughness value obtained with chilled air coolant method showed a decreasing trend which were 0.9767 µm, 0.9447 µm and 0.8920 µm at 16°C, 14°C and 12°C, respectively.

This is due to the fact that chilled air with lower temperature could remove the accumulated heat at the cutting zone [8]. Although the surface roughness for chilled air coolant was only slightly lower than conventional coolant, this cooling method was still better compared to the conventional coolant.

These findings are in agreement with those obtained by Tosun et al. [9] which discovered that the surface roughness values with the use of air cooling method are better than that of conventional cooling method. The cooling capability increased when air was compressed and cooled because high pressure air was capable to penetrate the interface between workpiece and cutting tool. Other than that, high pressure air could blow the chip away so that the chip would not scratch the surface of the workpiece. Chilled air coolant reduced the formation of built up edge. Therefore, the surface finish improved.

3.2 Tool Wear

The results of the flank wear are shown in Figure 3. It is clearly seen that conventional coolant acted as better coolant compared to chilled air coolant. The flank wear increased dramatically at 39.81% when using chilled air coolant at 16°C. These findings are consistent with the studies of [8,10] which discovered that conventional coolants are more effective in reducing flank wear compared to compressed cold air. The absence of lubricant in compressed cold air caused high generation of heat between cutting tool and workpiece. The heat caused the tool worn out aggressively. However, the tool wear was seen to be decreasing when the temperature of chilled air coolant decreased at 14°C and 12°C. This might attribute to lower temperature of chilled air coolant which reduced the cutting temperature, thus promoting a better tool life compared to higher temperature of chilled air coolant.

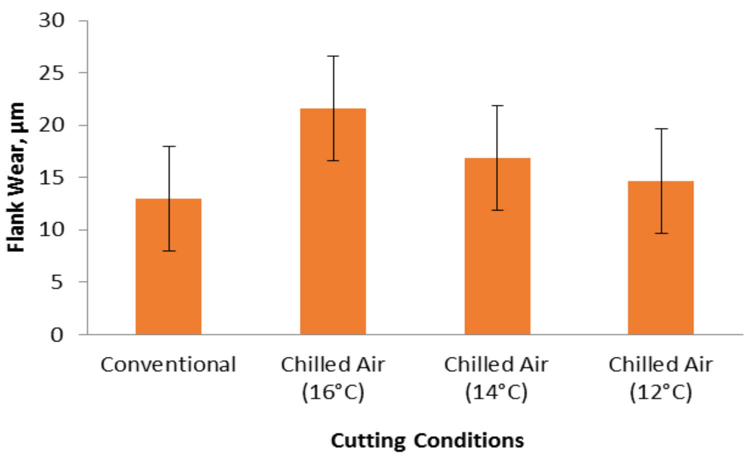

Figure 3: Flank wear values for all cutting conditions

The images of the tool wear were also captured using the scanning electron microscope (SEM) with the magnification of 500x after every run, as shown in Figure 4. The formation of grooves on the tool surface was an evidence of the abrasion wear. The grooves were obvious when using chilled air coolant at 16°C and they were not seen when using conventional coolant.

This is because conventional coolant reduced the abrasion on the tool flank. The presence of lubricant in conventional coolant reduced the friction when hard rough surface slides across a softer surface, thus, reducing the abrasive wear. According to Wang et al. [11], flank wear is mainly caused by abrasive wear. Abrasive wear occurs when the debris from the hard particles penetrated into the softer surface under normal pressure.

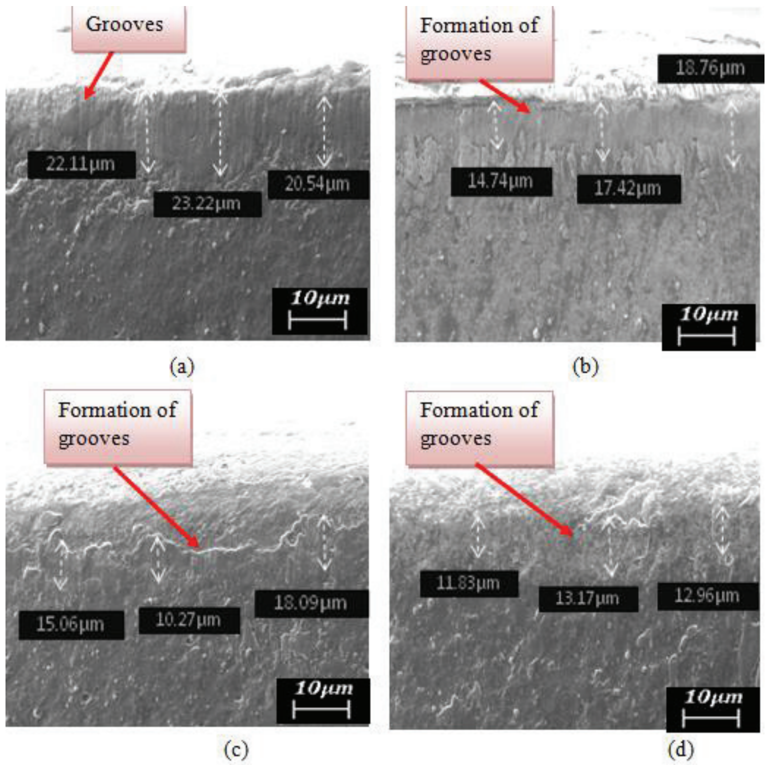

Figure 4: SEM images of flank wear after machining with (a) chilled air coolant at 16°C, (b) chilled air coolant at 14°C, (c) chilled air coolant at 12°C, and (d) conventional coolant

4.0 CONCLUSION

In conclusion, the effect of chilled air coolant on surface roughness and tool wear when machining 2205 duplex stainless steel has been investigated. Based on the experimental results, surface roughness is lower when using chilled air coolant compared to conventional coolant. The surface roughness values also decrease when the temperature of chilled air coolant decreases. However, tool wear is lower when utilizing conventional coolant method.

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REFERENCES

[1] D. A. Stephenson and J. S. Agapiou, *Metal Cutting Theory and Practice, Second Edition*. New York: CRS Press, 2006.

[2] R. D. J. Johnson, K. L. D. Wins, A. Raj, and B. A. Beatrice, "Optimization of cutting parameters and fluid application parameters during turning of OHNS steel," Procedia Eng., vol. 97, pp. 172–177, 2014.

[3] S. Zhang, J. F. Li, and Y. W. Wang, "Tool life and cutting forces in end milling Inconel 718 under dry and minimum quantity cooling lubrication cutting conditions," J. Clean. Prod., vol. 32, pp. 81-87, 2012.

[4] M. J. Bermingham, S. Palanisamy, D. Kent, and M. S. Dargusch, "A comparison of cryogenic and high pressure emulsion cooling technologies on tool life and chip morphology in Ti–6Al–4V cutting," J. Mater. Process. Technol., vol. 212 (4), pp. 752-765, 2012.

[5] S. R. Nandam, U. Ravikiran, and A. Anand Rao, "Machining of tungsten heavy alloy under cryogenic environment," 3rd International Conference on Materials Processing and Characterization (ICMPC 2014), pp. 296-303, 2014.

[6] Y. Xue, M. Arjomandi, and R. Kelso, "Energy analysis within a vortex tube," Exp. Therm Fluid Sci., vol. 52, pp.139–145, 2014.

[7] Y. Xue, M. Arjomandi, and R. Kelso, “The working principle of a vortex tube,” Int. J. Refri, vol. 36 (6), pp. 1730–1740, 2013.

[8] D. Fernandez, I. Bengoetxea, V. Garcia Navas, and A. Sanda, "Comparison of machining Inconel 718 with conventional and sustainable coolant," MM Sci. J., pp. 506–510, Dec. 2014.

[9] N. Tosun, and M. Huseyinoglu, “Effect of MQL on surface roughness in milling of AA7075-T6,” Mater. Manuf. Process., vol. 25 (8), pp. 793–798, 2010.

[10] P. Chockalingam and L. H. Wee, "Surface roughness and tool wear study on milling of AISI 304 stainless steel using different cooling conditions," Int. J. of Eng. Tech., vol. 2, no. 8, pp. 1386–1391, Aug. 2012.

[11] C. Y. Wang, Y. X. Xie, Z. Qin, H. S. Lin, Y. H. Yuan, and Q. M. Wang, "Wear and breakage of TiAlN- and TiSiN-coated carbide tools during high-speed milling of hardened steel," Wear, vol. 336-337, pp. 29–42, 2015.