Conduction Heat Rate Analysis of Tool in AISI 4340 TurningProcess

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Conduction Heat Rate Analysis of Tool in AISI 4340 TurningProcess

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Abstract. In the turning process a very high temperature is generated from the friction of cutting tool and workpiece. In the turning process there is also contain heat transfer reaction that occurs due to rising temperatures during the turning process. The high temperature in the cutting process has a very important influence on increasing the amount of heat that produce during the process of machining. Therefore it is necessary to analyze the effect of the rake angle and the use of LN2 and SCCO2 as a cooler to the heat transfer rate on the cutting tool using Autodesk simulation mechanical 2017 software. Based on the simulation results obtained temperature distribution values on the cutting tool during the AISI 4340 turning process using carbide tungsten as the cutting tool where the rake angle is 0°,5°, and 10°. Without using any coolant, the heat transfer rates are 30.613W, 28.386 W, and 26.160. By applying cooler such as SCCO2 and LN2 the rate of heat transfer decreases. With the application of the LN2 heat flow rate with rake angle 0°, 5°, and 10° decrease to 21.429 W, 19.191 W, and 16.965 W. The application of the SCCO2 heat flow rate on the tool with a rake angle 0°, 5°, and 10° will be 20.260 W, 18.479 W, and 16.252 W. Based on the result it is found that increased rake angle will cause a decrease in heat transfer rate. The application of SCCO2 and LN2 can reduce the heat transfer rate, therefore it can extend the cutting tool life.

1. Introduction

In today's machinery industry, AISI 4340 has been widely used in the aircraft industry. AISI 4340 is widely used because it has superior properties, namely a combination of a ratio between strength and weight that is good at high temperatures, has a fracture resistance, and corrosion-resistant properties at high temperatures. However, in addition to its superior properties AISI 4340 is categorized as a material that is difficult to process machining because of its low thermal conductivity which can cause damage to the material being cut. The main motivation for application of AISI 4340 alloys is their very good biocompatibility, superior resistance to corrosion, high levels of reliable performance and high specific strength. In addition, they indicate good fatigue resistance that comes in spite of its low density, quite unlike aluminum [1].

With the increasing cutting speed in modern machining processes, the thermal aspect of cutting is very important. The temperature of the cutting process will greatly affect the tool life. The higher the temperature it will accelerate damage to the tool.

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In the turning process, a very high temperature is coming as a result from friction between the cutting edges and the workpiece [2]. In the turning process there is also a heat transfer reaction that occurs because of the increase in temperature during the turning process. In the turning process there are 2 types of heat transfer, namely conduction and convection.

Conduction is one method of heat transfer. Conduction heat transfer is a form of energy transfer as heat through a stationary medium process, such as copper, water, or air. In solid objects, transfer energy arises because atoms at higher temperatures vibrate faster, so that atoms can move energy to the more sluggish atoms that are nearby by microscopic work, namely heat.

2. Literature Review

In turning, a cutting tool is fed into a rotating workpiece to generate an external orinternal surface concentric with the axis of rotation. Turning is carried out using a lathe, one of the most versatile conventional machine tools [3]. Lathe is a machine that is generally made of metal and is used to form workpieces by cutting, where the main motion rotates. Generally turning is used to form cylindrical objects. In figure 1[4] There are some basic elements you need to know; cutting speed, feeding rate, time

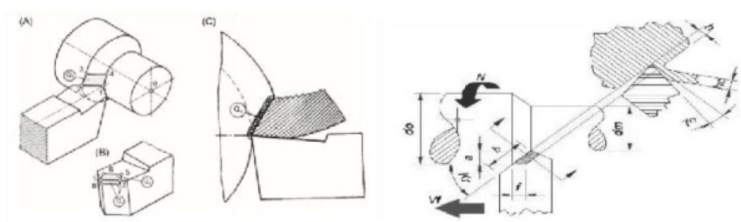

Figure 1. Mechanism of Turning Process

Cryogenic Machining is a cooling process where conventional cooling fluids are replaced with cryogenic coolers such as liquid nitrogen and CO2. In this method, the liquid gas is directly directed to the cutting temperature zone and cools the tool and workpiece [5]. Cryogenic medium absorbs the temperature from the cutting zone and evaporates into the atmosphere.

Tool is used to cut workpieces. Tool must be able to withstand certain conditions during the turning process, such as high temperatures and friction caused by the chip. Therefore, cutting tools or cutting edges must have certain properties depending on the type of machining operation.

Carbide is a tool made by sintering carbide powder with a binder which is generally from cobalt (Co). The greater the percentage of the Co binder, the hardness decreases and the tenacity improves conversely. Carbide has a half expansion coefficient rather than steel and its thermal conductivity is about two or three times the thermal conductivity of HSS. Carbide is divided into 3 types, namely1. Tungsten carbide (WC + Co), is a type of carbide tool used to cut cast iron,2. Alloy Tungsten Carbide, is a type of carbide tool used for cutting steel, 3. Layer Carbide, is a type of tungsten carbide coated with carbides, nitrides, or other oxides that have high hot hardness but are more brittle [6].

The characteristics of AISI 4340 alloy materials is that they also have easy properties to form austentite during the machining process so it tends to apply heat treatment. Another characteristic is that it is easy to react with tool material under atmospheric conditions so that it tends to form a build up edge and attach to the cutting tool surface. Low thermal conductivity of AISI 4340 causes surface damage to the material being cut. In addition, the low thermal conductivity of AISI 4340 can also damage the cutting edges because of the heat produced during the turning process [1].

Table 1. Advantages and Disadvantages of AISI 4340

Advantages	Disadvantages
A good Combination ratio between strength and weight at high temperatures	Easily react with cutting tool material
Has broken resistance	Low thermal conductivitiy
Has Corrosion resistance at high temperatures	Low modulus of elasticity

During metal cutting a large amount of heat and high temperature is generated because the power used for plastic deformation and friction is changed to heat at the cutting edge [7].

Work or mechanical energy in the cutting process, which is vibration free, is entirely converted to . The heat will be partially carried away by chip, some will flow towards the tool and workpiece, which can be written into the equation below [6].

$$Q = Q_c + Q_w + Q_t \quad (1)$$

As in equation (1) where Qc : The heat carried by chip with a percentage of about 75% ; Qt :Heat through tool with a percentage of about 20% Qw ; heat through a workpiece with a percentage of about 5%

Chip formation in this area experience plastic deformation and broken / broken metal. This area covers all surface flows, underlying the first heat source (Q1) The friction area between chip a the cutting surface, underlies the second heat source (Q2) The friction area between the surface of the cutting tool and the workpiece machined with cutting speed, underlies the third heat source (Q3), see figure 2 [8].

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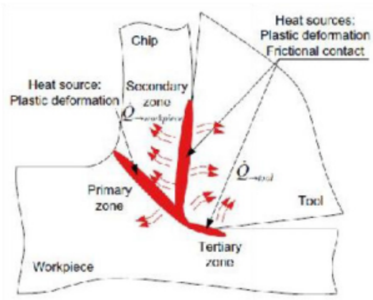

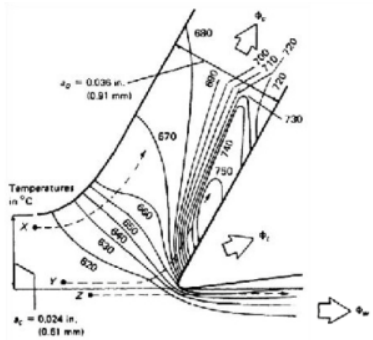

Figure 2. Heat flow & distribution in Figure 3. Heat distribution in metal cutting cutting metal process

The heat flux flow to chip (qc), to the tool (qt), and to the workpiece (qw) can be schematically shown as above [9]. The figure 3 shows the heat distribution that occurs on the workpiece and chip during orthogonal metal cutting in mild steel with a cutting speed of 0.38 m / s. heat at point X, moves towards the tool and passes through the primary deformation zone and is carried away by chip [10].

2.1. Heat transfer

Heat transfer (heat transfer) is the science to determine the energy transfer because of the temperature difference between objects or material. heat transfer process is divided into three, namely, conduction convection, and radiation.

Conduction is the transfer of energy from the more energetic particles of a substance to the adjacent, less energetic ones as a result of interactions between the particles [11]. Conduction heat transfer is the process of heat transfer in which heat flows from high-temperature areas to lowtemperature areas in a medium (solid, liquid, gas) or between different mediums which are directly in contact. Conduction heat transfer is divided into two types, namely conduction of steady and nonsteady states.

In general, the heat flow rate can be calculated using the following formula:

$$q = kA\frac{dT}{dX} \quad (2)$$

As in equation (2) where: q : Heat flux(W) ; k : conductivity (W/m.°C) ; A : Crosssectional area (m2) ; dT/dx : temperature gradient to the cross section.

3. Research methodology

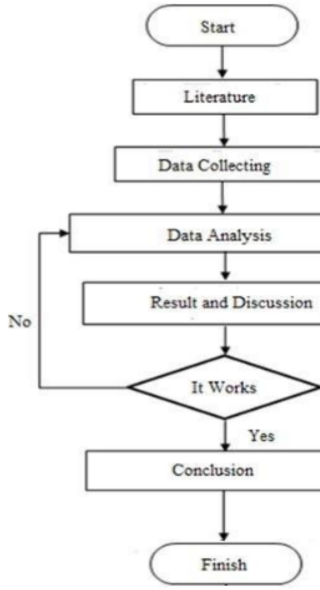

Figure 3. Research flowchart

In this research, there will be several stages of activities aiming to make the research work well and smoothly. It starts from the literature study stage to learn the aims and objectives of this study so that in the next stage there will be no more confusion when analyzing by utilizing studies that have been carried out before. Furthermore, the stage to be carried out is data collection related to heat transfer in cutting edges with simulation, the data needed includes determining the type of workpiece material, heat distribution of the tool and machining conditions. After all the data has been collected, the data is evaluated before the simulation process is carried out so that the heat flow rate can be seen in the cutting edge.

3.1. Machining boundary condition

Table 2. Machining boundary condition

Boundary Condition Research	Description
Machining Parameter	Cutting Speed, V_c (m/min) = 300 Feed Rate, F_r (mm/rev) = 0.2 Dept of Cut, d (mm) = 1
Tool	Tools = T Carbide Rake Angle, kr = 0°, 5°, 10°

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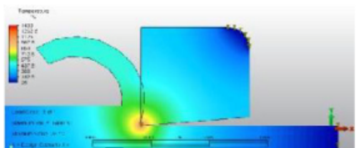
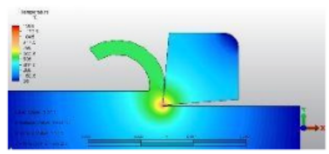
3.2. Simulation process

After the modelling in Autodesk Inventor 2016 completed, the simulation process will be conducted to determine the temperature distribution in the cutting edge during the process of turning take place using Autodesk Simulation Mechanical 2017 software simulation process is done with a couple of stages that will be carried out as shown in picture below.

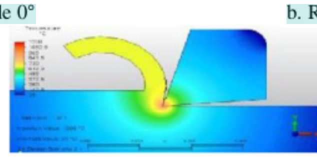
4. Result and discussion



a.Rake angle 0°

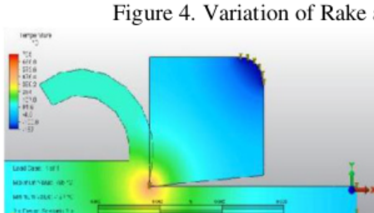


b. Rake angle 5°

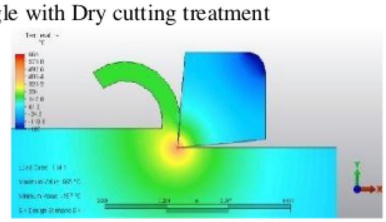


c. Rake angle 10°

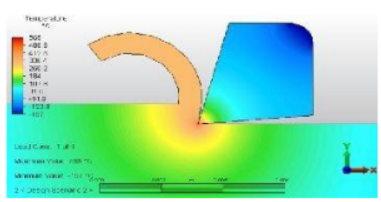
Figure 4. Variation of Rake angle with Dry cutting treatment



a.Rake angle 0°

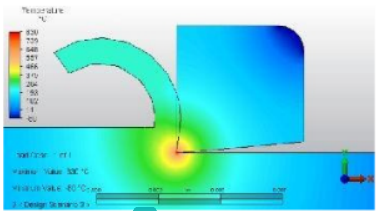


b. Rake angle 5°

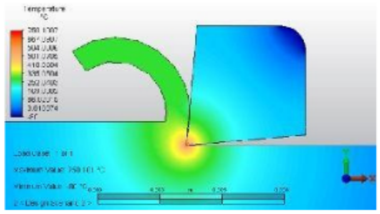


c. Rake angle 10°

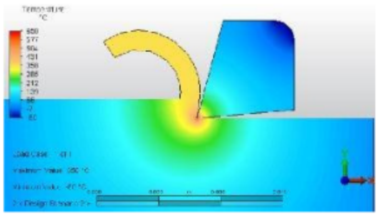
Figure 5. Variation of Rake angle with cooling LN



a.Rake angle 0°



b.Rake angle 5°



c. Rake angle 10°

Figure 6. Variation of Rake angle with cooling of SCCO2

After simulating using Autodesk mechanical simulation 2017 software, the heat transfer rate can be calculated and the results shown in the table below are calculated.

Table 3. Heat transfer rate (W)

Cutting Speed	Rake Angle	SCCO2	LN2	Dry Cutting
300m/min	0	20.260	21.4291	30.613
300m/min	5	18.479	19.1915	28.3866
300m/min	10	16.252	16.965	26.1602

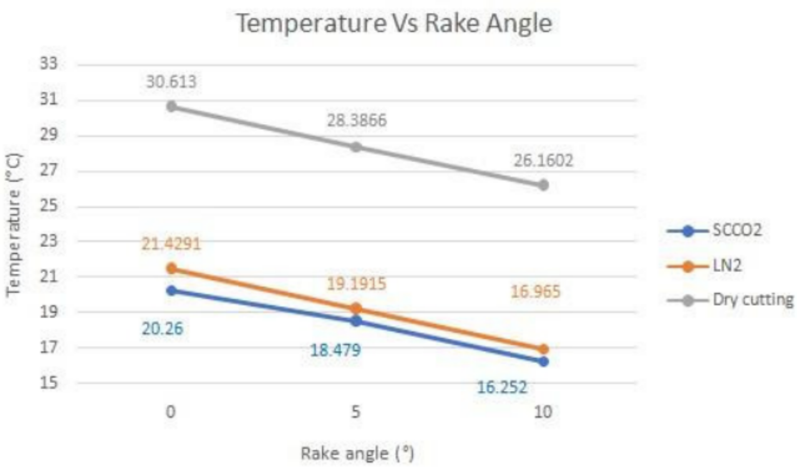


Figure 7. Heat transfer rate (W) in different rake angle

Based on the simulation and theoretical calculations, the results of variations in rake angle and variations in cooling conditions on temperature and heat flow rates in cutting edges are obtained. For the rake angle of 0 ° with the dry cutting method, the maximum temperature of 1400 ° C is obtained and the heat transfer rate in the cutting eye is 30,613 W. The rake angle of 0 ° with the cooling method using LN2 has a maximum temperature of 765 ° C and a heat transfer rate 21,491 W. The rake angle of 0 ° with the cooling method using SCCO2 obtained a maximum temperature of 830 ° C and the heat transfer rate in the cutting edge was 20,260 W

For the rake angle of 5 ° with the dry cutting method, the maximum temperature is 1300 ° C and the heat transfer rate in the cutting edge is 28,386 W. The rake angle of 5 ° with the cooling method using LN2 has a maximum temperature of 665 ° C and the heat transfer rate in the tool is 19.1915 W. The rake angle of 0 ° with the cooling method using SCCO2 obtained the maximum temperature of 830 ° C and the heat transfer rate in the cutting edge was 18,479W

For the rake angle of 10 ° with the dry cutting method, the maximum temperature of 1200 ° C is obtained and the heat transfer rate in the cutting edge is 26.1602 W. The rake angle of 10 ° with the cooling method using LN2 has a maximum temperature of 565 ° C and the heat transfer rate in the tool is 16,965 W. The rake angle of 10 ° with the cooling method using SCCO2 shows that the maximum temperature is 650 ° C and the heat transfer rate in the cutting edge is 16.25 W.

5. Conclusion

Based on the results of calculations and discussion of research, it can be concluded that:

1. The greater rake angle in the turning process, the cutting temperature will decrease.
2. The use of LN2 as a tool cooler can reduce the cutting temperature to approximately 500 ° C
3. Based on the results of this study, the heat transfer rate for rake angle was 0.5.10 ° with dry cutting cooling conditions including 30.613W, 28.386W, and 26.160W. For cooling conditions using LN2, the heat transfer rate is 21,429W, 19,191W and 16,965W. For cooling conditions using SCCO2, the heat transfer rate is 20.260W, 18.479W, and 16.252W.

4.From the data that has been obtained shows that by using LN2 and SCCO2 can reduce the heat transfer rate so that it can increase the life of the cutting edge.

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