

# Investigation of Tool Temperature and Surface Quality in Hot Machining of Hard-to-Cut Materials

M.Davami, M.Zadshakoyan

**Abstract**—Production of hard-to-cut materials with uncoated carbide cutting tools in turning, not only cause tool life reduction but also, impairs the product surface roughness. In this paper, influence of hot machining method were studied and presented in two cases. Case 1-Workpiece surface roughness quality with constant cutting parameter and 300°C initial workpiece surface temperature. Case 2-Tool temperature variation when cutting with two speeds 78.5 (m/min) and 51 (m/min). The workpiece material and tool used in this study were AISI 1060 steel (45HRC) and uncoated carbide TNNM 120408-SP10(SANDVIK Coromant) respectively. A gas flam heating source was used to preheating of the workpiece surface up to 300 °C, causing reduction of yield stress about 15%. Results obtained experimentally, show that the method used can considerably improved surface quality of the workpiece.

**Keywords**—Hard-to-cut material, Hot machining, Surface roughness, Tool Temperature

## I. INTRODUCTION

DURING the two past decay, there has been significant industrial interest in machining hard-to-cut materials. These materials are being used in producing component for electrical, chemical, dental orthopedic, aerospace and nuclear industry, where high dimensional accuracy, tool life and satisfactory surface roughness quality is indeed. According to chemicals composition and mechanical characteristics of the materials four group of hard-to-cut material may be distinguished [1]. These are (1) Chilled cast iron, (2) Steel with hardness over 50 RC hard, (3) Steel that surface is hardened with cobalt, and (4) Steels hardened by alloy additions.

For machining of hard-to-cut steel to cut, the cutting tools materials must be harder than workpiece materials. Due to expensive cost of cutting such materials, the different machining methods are being used. Practical guides for the economic machining of hard-to-cut materials, aerospace, super alloys, were proposed [2]. Usually, formation of second phase particles makes the alloy both stronger and more abrasive and thus more difficult to machine. Advantage, therefore, lies in machining in the soft state. A positive rake cutting edge is recommended for semi – finishing and finishing operation wherever possible.

Authors are with the Tabriz University, Tabriz, Iran.  
e-mail: zadshakoyan@tabrizu.ac.ir, e-mail: modavami@gmail.com

Positive rake geometry minimizes work hardening of the machined surface by shearing the chip away from the workpiece in an efficient way in addition to minimizing build-up edge. Very light hones or even sharp insert edge are useful in preventing material build-up and improving surface finish during machining. Dull or improving build up edge increase cutting force during machining, causing metal build up, tearing and deflection of workpiece material.

The sharp tools are more fragile and susceptible to chipping during machining, thus honed edges are recommended for most roughing operation. Sharp edges are used for finishing operations. The other guides are:

- A large nose radius
- Use a rigid set up, preventing vibration and subsequent chatter
- Prevent part deflection
- Use a high rake angle
- Use of filler metals, special fixturing, to prevent movement during machining
- Vary the depth of cut, when more than one pass is required

Also machinability of hard-to-cut materials can be improved by employing ramping (taper turning) technique, high pressure coolant supply technology, cryogenic machining, use of self propelled rotary tooling and hot machining.

In hot machining, preheating of the workpiece can be performed before and/or during cutting. The workpiece temperature was chosen above the recrystallisation temperature, where the yield stress of the materials decreased rapidly [3]. The yield strength of the structural steel (C355) tend to decrease, when its temperature increasing. Fig. 1.

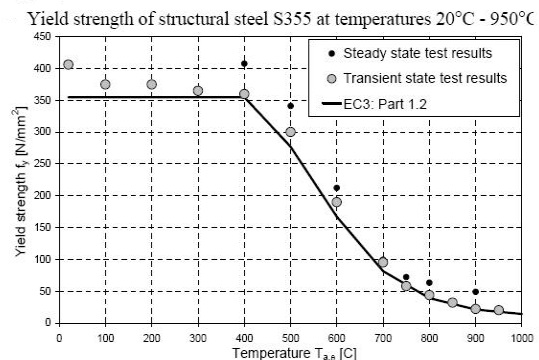


Fig. 1 Effect of Temperature on the yield Stress[3]

Consequently, cutting force or power consumption and tool wear rate decrease. In this condition high integrity of machined surface with low cost could be obtained.

The use of hot machining as a technique for improving machining operation, has been under consideration since the late 19<sup>th</sup> century. This was informed by understanding that metals, tend to deform more easily when heated, thus enhancing machining.

The principle behind hot machining is the reduction of the large difference in hardness of workpiece leading to reduction in the component force, improving surface finish and longer tool life [4].

Tighes use machining with heating workpiece in 1888. In early stages, materials difficult to machine under normal conditions such as Stainless Steel, S-816alloy, X-alloy, Inconel-X, Timken 16-25-6 and Navy Grade V, a nickel-Chromium Steel have been hot machined by Tour and Fletcher, Armastrong, Krabacher and Merchant, Schmidt and Roubik, Krabacher and Merchant observed that at an optimum temperature the tool life raises to a maximum value and after that it reduces. Another important observation made by Shaw is that the strain-harden ability and flow stress of material reduces with increase in temperature in hot machining.

Heating source is important in this process and selecting non ideal heating may induce unwanted structural changes or making more dimensions inaccuracy. The heating techniques include electric current, high frequency induction(Fig 2), plasma jet, gas flam [1].

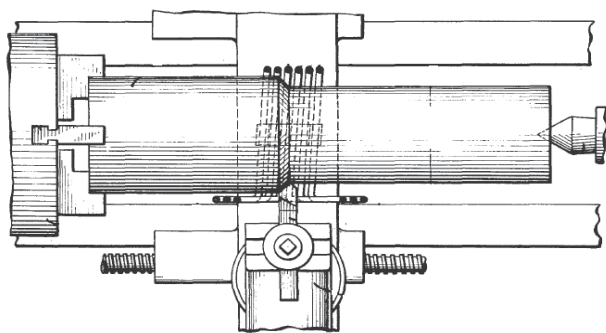


Fig. 2 Induction Heating in the Hot Machining [5]

Barrow studied the wear of carbide tools during hot machining of alloy steels. He used electric current heating. Ghosh and Basu carried out temperature distribution in a rotating cylinder with steady point heat source at the surface. Dutta carried out hot machining by friction heating. Mukherjee and Basu carried out statistical evaluation of metal cutting parameters in hot machining. They used Nickel-Chromium Steel as the workpiece material with hardness of 440 BHN. He measured tool life and surface finish. They also observed that surface roughness decreases more considerably with increase in temperature than that of cutting velocity.

They concluded that the influence of workpiece temperature on surface roughness is much more pronounced than on tool life. Meakawa and Kubo performed plasma hot machining for high hardness metal and new engineering materials.

Roughuram and Mujo carried out hot machining by magnetization field in hot machining. Ozler et al.[1] carried out hot machining operation using austenitic manganese steel as workpiece material and using gas flam heating. They show experimentally the effectiveness of hot machining technique under condition where the workpiece temperature set to 200<sup>oC</sup>,400<sup>oC</sup> and 600<sup>oC</sup>.They were obtained that tool life increasing 3 times, when the workpiece surface temperature is set to 400 <sup>oC</sup>. High manganese steel was machined in their study.

Wang et al [6] have been reported the benefits of hybrid machining of Nickel base Inconel 718 alloys.

N.Tosun and Ozler [7, 8] were used hot machining technique in turning operation. The optimization of the turning operation with multiple performance characteristics, tool life and workpiece surface roughness, was studied using weighted factor to improve the tool life and the workpiece surface roughness. The parameter design method proposed by Taguchi was adopted. Experimental results obtained, when cutting high manganese steel heated with the liquid petroleum gas (LPG) flam, were presented. They improved the approach proposed.

Maity et al [9] invested hot-machining operation of high manganese steel using flam heating. A tool life equation has been founded from their statistical analysis. Fig 3.

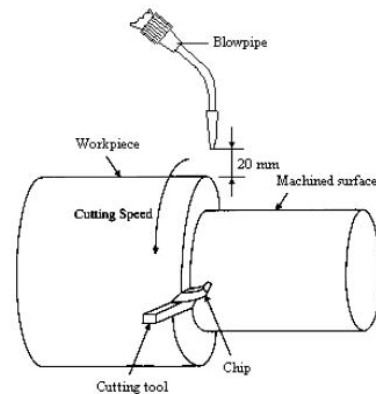


Fig. 3 Hot Machining Setup [9]

In this paper, hard-to-cut steel AISI 1060(45HRC) heated by flam, and machined under constant cutting parameter, cutting speed, feed rate, depth of cut and workpiece temperature, on a lathe.

The results obtained for surface roughness of workpiece compared by two workpiece temperature (room temperature and 300 °C). At the next section, the temperature variations of a point situated under the insert were investigated with tow cutting speeds 78.5,51 (m/min)

At the final section conclusion and discussion were performed

## II. EXPERIMENTAL PROCEDURE

Experimental setup is shown in Fig4. A heating torch was mounted on tool carriage, in opposite of tool holder, to provide moving heat source, while machining. Fig4 shows setup of the investigation.

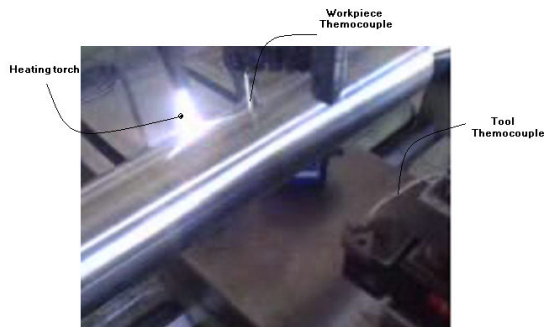


Fig. 4 Experiment setup (Tool thermocouple, Workpiece thermocouple, and Heating torch)

The torch burned a mixture of acetylene gas and oxygen. The distance of the tip of the torch from the workpiece can be varied to control the surface temperature. A K model thermocouple with digital indicator was used to measure the temperature.

AISI 1060 steel used in the experiments. The mean hardness of steel was 45(HRC) and its chemical composition was as shown in Fig 5.

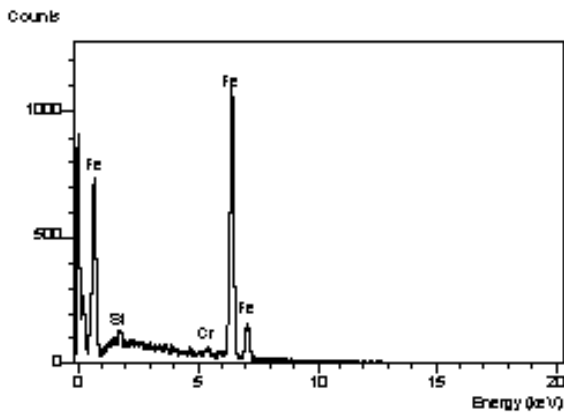


Fig. 5 Workpiece Chemical Composition

In this study the experimental studied, were performed in two cases:

- Case 1: Workpiece surface roughness quality
- Case 2: Tool temperature variations

*Case 1: Surface roughness quality*

The workpiece in this case machined under constant cutting parameter and with two workpiece surface temperature ( 20 °C and 300 °C). The cutting parameters were set to : cutting speed 35 ( m/min), feed rate 0.08 (mm/rev), depth of cut 1.5 (mm). The cutting length were chosen 11,22,32,45,67 and 110 (mm), where the tool insert were changed before the cutting of the each new length.

Experimental setup used in this study submerged in Table1.

TABLE I EXPERIMENTAL CONDITIONS

Machine Tool	TN-50 Lathe (5hp),Iran
Workpiece	AISI 1060 Ø60(mm) × 600(mm) 45RC Harded
Tool	Uncoated , TNNM 120608 SP10 Sandvik Coromant
Cutting Speed	35 (m/min)
Feed Rate	0.08 (mm/rev)
Depth of Cut	1.5 (mm)
Cutting length	11,22,32,45,67,110 (mm)

*Case 2: Tool Temperature variation*

The variation of the tool temperature were measured, with thermocouple placed exactly on the opposite edge of tool tip. Fig 6 show thermocouple placement under the tool face.

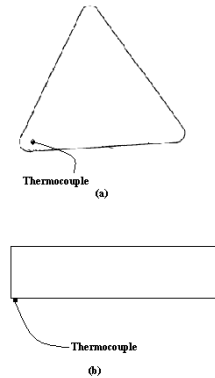


Fig. 6 Thermocouple placement under the cutting tool. (a:Rake face, b:Flank face)

This point has an advantage, providing no any constraint for cutting process.

The results obtained from measurement at tow workpiece temperature (20 °C,300 °C) and with tow cutting speed 78.5, 51.5 (m/min) are shown in Fig7, Fig 8.

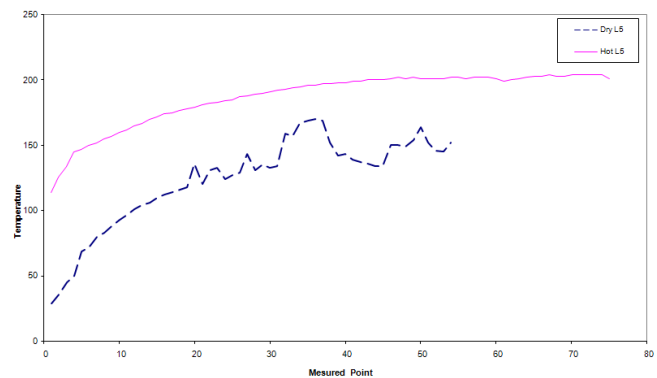


Fig. 7 Tool temperature in 78.5 (m/min) in 110 (mm) cutting length

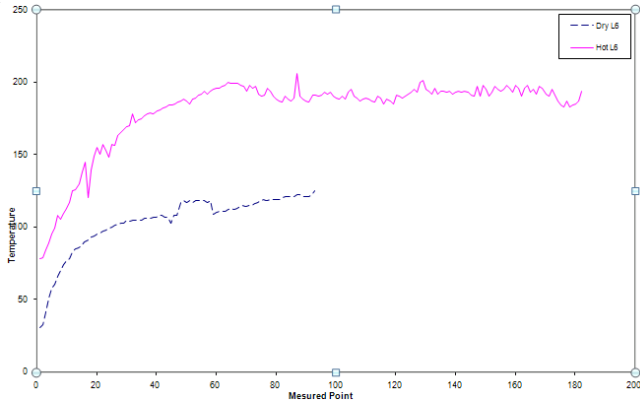


Fig. 8 Tool temperature in 51 (m/min) in 110 (mm) cutting length

The temperature in each cutting speed increase exponentially with time at the begging of machining, and then it reaches to steady state value. The temperature values, measured on steady state in each cutting speed for hot machining and machining at room temperature are as shown in Table 2.

TABLE II TOOL TEMPERATURE AT STEADY STATE

Cutting Speed \ Steady State Temperature	Vc=78.5 (m/min)	Vc=51.5 (m/min)
	Hot machining	200 °C
Room temperature machining	130 °C	100 °C

### III. RESULT AND CONCLUSION

The surface roughness of the workpiece was measured for each length as indicated above. A MAHR type roughness meter was used to the measurement.

The result obtained for machined surface roughness from measurement, was presented graphically in Fig 9.

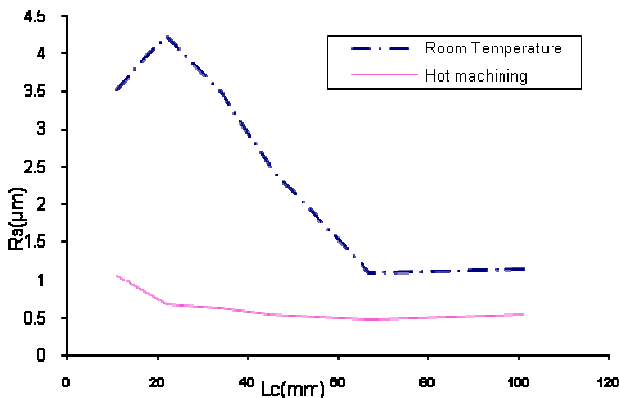


Fig. 9 measured surface roughness in Vc = 35 ( m/min )

The result, shows that the heating workpiece material can improve the surface quality of machined surface.

Also in heating conditions, the surface roughness is very uniform,  $Ra \approx 0.60(\mu m)$  measured, at the end of each machining length, when comparing with case where the workpiece were machined at room temperature ( $20^\circ C$ ). In two temperatures ( $20^\circ C, 300^\circ C$ ) and at shorter cutting length the observed tool wear were negligible.

One be noted that the improvement of roughness surface in short length when machining at room temperature can be explained by the increasing workpiece surface temperature, until 45(mm). Increasing surface roughness for longer machined length can be explained by the effect of increasing tool wear.

In hot machining , the change of the workpiece surface was also observed. Fig 10.

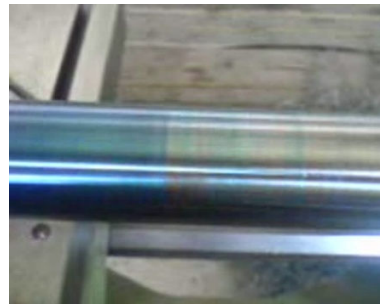


Fig. 10 Workpiece color changed after hot machining

### IV. CONCLUSION

From the experimental investigation can be conclude that :

- Surface roughness in hot machining got better when the workpiece surface temperature is  $300^\circ C$  with less variation,  $Ra \approx 0.6\mu m$  with  $Vc = 35$  (m/min).
- Hot machining is not only a very useful method for machining of hard-to-cut materials on the rough conditions but also it may used for finishing operation too, when the change of workpiece surface color is not very important.
- In low cutting speeds, the discontinuous form chips produced in machining may be changed to continuous form.

In hot machining tool life may be increase due to decreasing of the yield stress of the workpiece. But the high workpiece temperature may be cause, the increasing of tool wear rate.

Consequently, for obtaining better surface roughness and optimum tool wear rate, it is necessary to perform additional experiment to find the optimum workpiece temperature.

### REFERENCES

- [1] Ozler, L., Inan, A., Ozel, C., 2000. Theoretical and experimental determination of tool life in hot machining of austenitic manganese steel. *Int. J. Mach. Tool & Manuf.* 41,163-172.
- [2] E.O. Ezugwa, 2005, Improvement in the machining of difficult aerospace super alloy, *Int. J. Mach. Tool& Manuf.*45,1353-1367.
- [3] Outinen J., Mechanical properties of structural steels at elevated temperatures and after cooling down, Fire and Materials Conference, San Francisco, USA, Proceedings, Interscience Communications Limited, UK, 2006.
- [4] R.J.Karbacher,M.E.Merchant,1951, Basic factors in Hot-machining of metals, *Transactions ASME*73,761-776.

- [5] J.R.Macy, 1952, US PATENT, Heating device for hot machining apparatus.
- [6] Z.Y.Wang ,K.P. Pajurkar,J.Fan,S.lei, Y.C.Shin, G.Perfrescu, 2003,Hybrid machining of Inconel 718, Int. J. of Mach. Tools& Manuf.43 ,1391-1396.
- [7] N.Tosun,L.Ozler,2002,A study of tool life in hot-machining using artificial neural networks and regression analysis method,J. Material processing technology 124,99-104.
- [8] N. Tosun ,L. Ozler, 2004, Optimization for hot turning operations with multiple Performance characteristics, Int J Adv Manuf Technol 23, 777–782.
- [9] K.P. Maity, P.K. Swain, An experimental investigation of hot-machining to predict tool life, Int. J. of Materials processing technology 19 8 (2008) 344–349.