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Experimental Analysis of chip-back temperature during machining depending on cutting parameters

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Abstract: *Thermally induced damage to the work piece can have a deleterious effect on strength-related properties. Consequently extensive research has been directed towards investigating temperatures and predicting thermal damage by experimentally analyzing the cutting zone temperatures from the energy input to the process and the operating conditions. Optimize value of parameters such as feed rate, depth of cut and speed for minimum thermal damage in work piece. In present study, measurement of the chip-back temperature developed during cutting was investigated using an embedded thermocouple into the cutting tool. AISI AISI 1010 steel was used as the workpiece material and a K type thermocouple was used for the temperature measurement. The cutting tests were carried out on a MTAB XL CNC turning center. In selecting the cutting parameters, the reference values indicated in ISO 3685 were used. In order to locate the thermocouple on the cutting tool, a Flir Systems Therma Cam thermal camera was used. The results showed that increasing cutting speed, feed rate and depth of cut resulted in increase in the temperature at the back rake surface. However, cutting speed had the most influence on the temperature.*

Keywords: *Cutting Parameters, Thermocouple*

I. Introduction

Heat generation is a cause of some of the most serious problems encountered in precision machining. It may affect the workpiece and/or cutting tool. Excessive temperatures at the workpiece surface reduce surface quality by causing thermal cracks or, in some cases, burning the surface. Thermal gradients introduce strength-reducing tensile residual stresses. Dimensional inaccuracies may result from these gradients. Temperature may also influence the cutting mechanism, either by softening the material or by introducing phase transformations and stock removal rate is often limited by thermal damage to the ground component. A significant portion of the energy used in removing stock transmits to the workpiece as the heat, which causes damage to the ground surface. In order to avoid thermal damage, the amount of heat entering the workpiece must be controlled. Because thermal damage is usually the limiting factor to grinding operations, controlling heat is important to good machining practices. The effects of excess heat in a workpiece appear in many different ways ranging from obvious workpiece burn, to changes in hardness, to changes in compressive stresses, to changes in metallurgical structure and composition. Controlling thermal damage can include changes in process parameters such as feed rate, tool characteristics such as, sharpening techniques. There are many variables that affect the flow of energy that creates undesirable metallurgical changes in the workpiece.

II. Heat Generation mechanism

The chip formation during metal cutting is a high shear strain process at very high strain rate involving very high hard contact condition between chip and tool. The work of plastic deformation as well as friction at the tool–chip interface is in a major part transformed into heat [1] and [2]. This heat contributes directly to increase the temperature of the chip and by conduction, of the tool. The rise of the temperature during the manufacturing determines thermo-mechanical behavior of the workpiece and so becomes one of important parameters in the definition of optimum conditions of cut (cutting speed, rake angle, depth of cut). Indeed the thermal softening following this increase in the temperature can have as a consequence to make the cut easier by decrease of the cutting forces. However, it should be noted that the field of temperature in the chip is far from being uniform and is often characterized by zones of high-temperature gradients. In fact, during the cutting process the heating is located mainly in three zones, as shown in Fig.1. The rise in temperature is initiated in the primary zone due to the high shear deformation. This local heating along a shear plane leads to a thermal softening of the workpiece material and tends to decrease the global cutting forces. Then, the heating initiated in the first zone increases during the contact with the tool. The heat generated in the secondary zone is consequent with the deformation of the chip along the rake face to which sliding friction is added. The temperature thus reached in the chip affects primarily the chip formation and by conduction the tool life and the tool wear. Under the tool tip, a tertiary zone is defined by elastic deformation and rubbing contact between the tool flank face and the machined surface. This heating controls also the tool life but mainly the quality, the tolerance and the integrity of the finished surface. Fig. Shows the heat distribution in the chip and workpiece material during orthogonal metal cutting. The material moving in X direction pass through the first deformation zone.

It is seen that the heat developed in this zone increases until it leaves this zone together with the chip. It is also seen that the same phenomenon takes place in the Y direction in the second deformation zone. Therefore, it is understood that the highest temperature is observed on the cutting tool surface a bit away from the cutting edge. InZdirection, some amount of the heat is observed on the workpiece as the result of heat developed in the first deformation zone. Also, some amount of heat transferred from the second deformation zone is concentrated on the cutting tool. The chip moves very fast as it is close to the cutting tool surface. Therefore, the chip has more heat carrying capacity than the cutting tool. For this reason, the heat gone into the cutting tool is generally constitutes only a small portion of the total heat developed and this can be neglected at very low cutting speeds [4]. In present study embedded thermocouple method is a difficult method to be implemented for temperature measurement, but the momentary changes in heat during machining can be determined. These changes occur mainly due to the friction. This method requires high accuracy and is time consuming. Also, placement of the thermocouples into the holes is another disadvantage of this method. In this study, the most widely used embedded thermocouple method was selected for measurement of the temperature during machining as this method is good at determining the temperature distribution on the cutting tool and the momentary changes in heat in a best way. This method is also useful and reliable. When protected by compacted mineral insulation and appropriate outer sheath, type K is useable from -36 to 1260°C, (-32 to 2300°F). If temperature range falls between 316 to 593°C, (600 to 1100°F),then using type J or N because of aging which can cause a drift rate of 1 to 2°C, (2 to 4°F) in a few hours time.

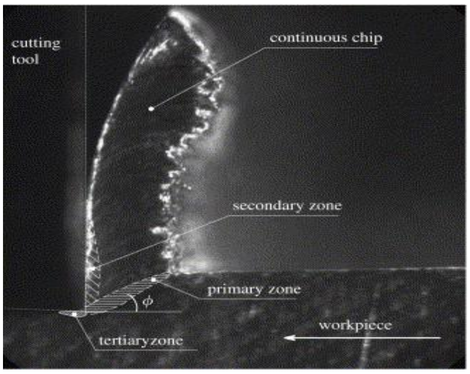


Fig.1 Different Zones of Heat Generation

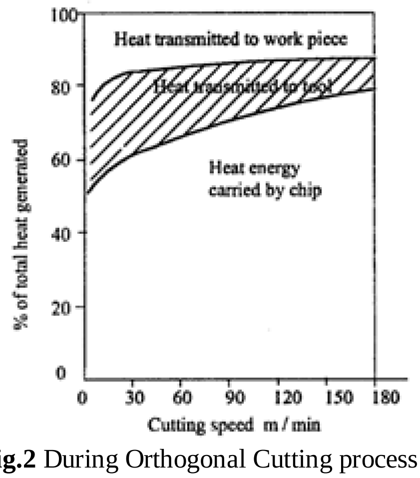


Fig.2 During Orthogonal Cutting process

It is clear that maximum heat is developed within the chip material, and hence it is the hottest portion of metal in the cutting process. Some heat from the tool interface. The distribution of heat generated between tool, chip and work piece may vary according to the conditions of the process.

The rise of temperature of work piece and tool give rise to:

i. Early wear of tool.
ii. Dimensional in-accuracy of machined surface.
iii. Damage of surface properties of machined component.

III. Experimental Set-up

In order to measure the chip-back surface temperature, a hole that is a bit away from the cutting edge should be formed on the cutting tool and a thermocouple should be inserted into this hole. The difficulty in determining the place of this hole is one of the most important disadvantages of embedded thermocouple method. That is because, the tool–chip contact point changes continuously during cutting as the results of changes in cutting speed, feed rate and depth of cut. Additionally, a Flir Systems Thermal Cam thermal camera was also used to verify this place during the tests (Fig. 2). The highest temperature value was observed for the tool, which had a hole 1.5 mm away from the cutting edge. Both of the methods were compared and it was decided that the thermocouples should be placed 1.5 mm away from the cutting edges. For this purpose, the cutting tools were drilled from side to side.

Tool work Piece Thermocouple

This Method makes use of the emf produced between hot contact of tool and work piece and their cold ends. if the cold ends of the two are joined, a small current will flow which can be measured by a voltmeter. The general arrangement of the apparatus is shown in fig. The work piece is insulated from the chuck and tail stock center. The end of work piece in the chuck is connected a copper wire which is connected to a slip ring fixed at the far end of the spindle dipped in a mercury cup.

The external connection is made with the mercury through a galvanometer to tail end or cold end of the tool. The magnitude of the current depends on the temperature difference between the hot and cold junctions and the nature of the tool and work piece.

The introduction of a copper wire in the circuit does not affect the output as long as the temperatures at its junctions with the tool and work piece are the same. The measure values of emf or current are converted into temperature with the help of a calibration curve. Calibration is carried out by dipping the tool tip on which the chip is attached Tied in a molten lead bath.

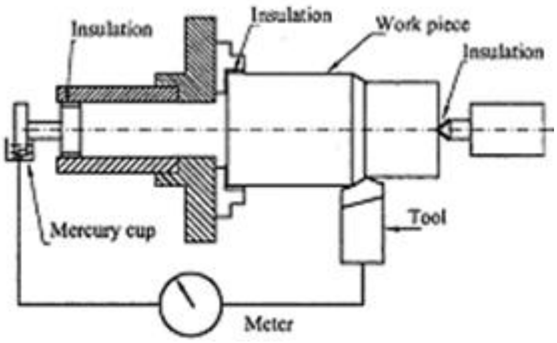


Fig.3 Tool work piece thermocouple

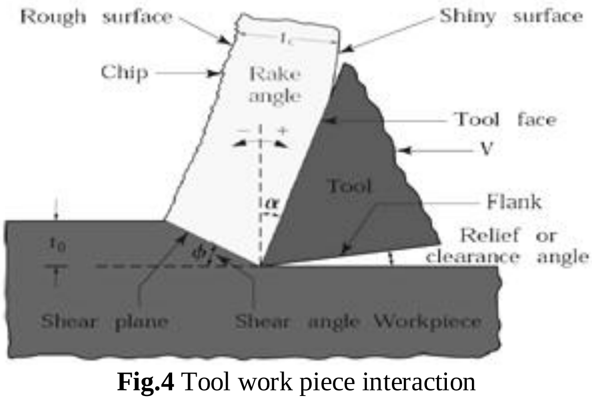


Fig.4 Tool work piece interaction

IV. Results

Feed rate: 0.5 mm/pass		
Sr.No.	Depth of cut in	Temperature in ° C
1.	0.01	248
2.	0.02	271
3.	0.03	284
4.	0.04	298
5.	0.05	312
6.	0.06	321
7.	0.07	331
8.	0.08	341
9.	0.09	349
10.	0.1	359
11.	0.11	373
12.	0.12	383
13.	0.13	393
14.	0.14	399
15.	0.15	410

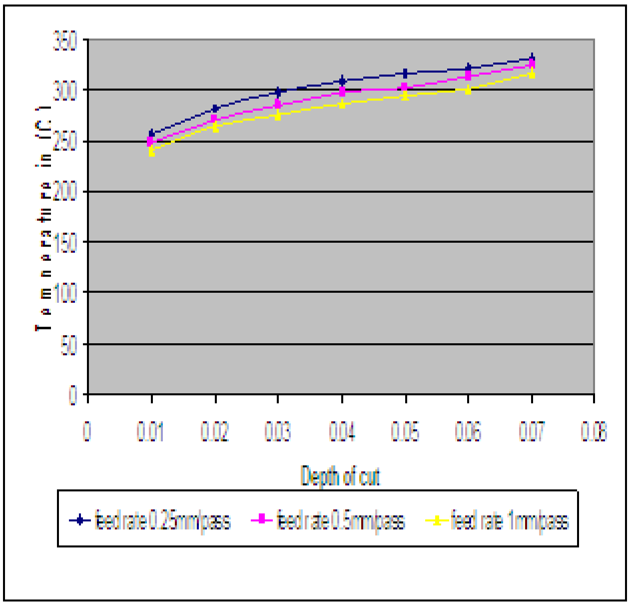
Table 7.1 Temperature at Feed rate: 0.5 mm/pass

Feed rate: 1 mm/pass		
Sr.No	Depth of cut in mm	Temperature in ° C
1.	0.01	241
2.	0.02	264
3.	0.03	276
4.	0.04	287
5.	0.05	301
6.	0.06	314
7.	0.07	324
8.	0.08	337
9.	0.09	345
10.	0.1	353
11.	0.11	366
12.	0.12	377
13.	0.13	388
14.	0.14	398
15.	0.15	406

Table 7.2 Temperature at Feed rate: 0.25 mm/pass

Feed rate: 0.25 mm/pass		
Sr.No.	Depth of cut in	Temperature in ° C
1.	0.01	256
2.	0.02	282
3.	0.03	297
4.	0.04	309
5.	0.05	319
6.	0.06	328
7.	0.07	339
8.	0.08	347
9.	0.09	356
10.	0.1	369
11.	0.11	379
12.	0.12	389
13.	0.13	397
14.	0.14	408
15.	0.15	417

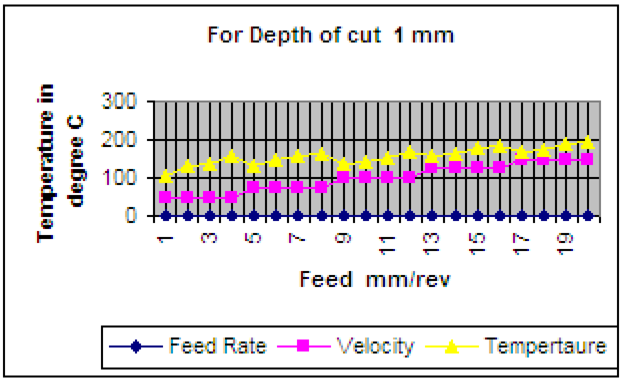
Table 7.3 Temperature at Feed rate: 1.0 mm/pass



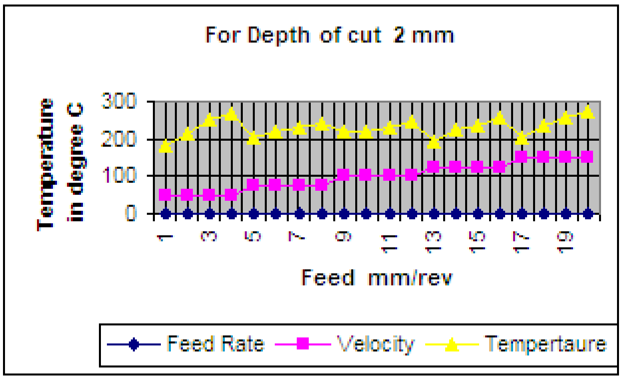
Graph-4.1

Sr. No.	F mm/rev	V m/mm	D mm	T^0 C
	0.10	50	1	107
	0.15	50	1	130
	0.20	50	1	138
	0.25	50	1	158
	0.10	75	1	130
	0.15	75	1	148
	0.20	75	1	160
	0.25	75	1	165
	0.10	100	1	135
	0.15	100	1	140
	0.20	100	1	155
	0.25	100	1	166
	0.10	125	1	160
	0.15	125	1	165
	0.20	125	1	178
	0.25	125	1	185
	0.10	150	1	169
	0.15	150	1	176
	0.20	150	1	187
	0.25	150	1	196

Sr. No.	F mm/rev	V m/mm	D mm	T^0 C
1.	0.10	50	2	180
2.	0.15	50	2	215
3.	0.20	50	2	250
4.	0.25	50	2	268
5.	0.10	75	2	205
6.	0.15	75	2	217
7.	0.20	75	2	228
8.	0.25	75	2	240
9.	0.10	100	2	218
10.	0.15	100	2	220
11.	0.20	100	2	231
12.	0.25	100	2	244
13.	0.10	125	2	194
14.	0.15	125	2	226
15.	0.20	125	2	236
16.	0.25	125	2	258
17.	0.10	150	2	205
18.	0.15	150	2	238
19.	0.20	150	2	256
20.	0.25	150	2	271



Graph-4.2



Graph-4.3

V. Discussion

The average temperatures for each cutting speed, feed rate and depth of cut were determined by taking into consideration the values which were between the starting and ending points of time dependent cutting tool temperatures. Changes in the temperature of the cutting tool were examined depending on the cutting speed, feed rate and depth of cut. When the five different cutting speeds were taken into consideration, the cutting speed increases by 25% and 33% at each step. However, the increase in the cutting temperatures with increasing cutting speed is not stable and was found to change between 3% and 35%. This situation indicates that the cutting speed has an important influence on the cutting temperatures developed during machining. At the low cutting speeds (50 and 75 m/min), increases in the cutting speed resulted in 9–24% increases in the temperatures while at high cutting speeds (125 and 150 m/min), increases in the cutting speed resulted in only little changes (3–10%) in the temperatures.

This situation indicates that the energy required for the plastic deformation of the work piece reaches to a sufficient level at the higher cutting. Therefore, the required energy for the further plastic deformation decreases with the further increase in the cutting speed and the heat developed in the deformation zone decreases. When the cutting speed was increased to 100 m/min from 75 m/min, a reduction of about 3–10% in the temperatures was observed at the different feed rates. This can be attributed to the decrease in the tool–chip contact length and this situation, in turn, results in less friction forces. This makes the flow of the chip easy. However, increases in the chip-back surface temperatures with increasing feed rate were not steady and are between 1% and 10%. This situation indicates that feed rate has a less influence on the temperatures developed during machining and also indicates that increasing feed rate leads to a stable trend in the temperature. When the cutting speed was increased to 75 m/min from 50 m/min at 2 mm depth of cut, the temperatures were decreased by between about 10% and 15% for 0.2, 0.25 and 0.3 mm/rev feed rates. These reductions can be explained by the elimination of BUE and easy deformation with increasing cutting speed. In metal cutting operations, the heat which effectively causes to increase the heat at the area close to the cutting edge is among the important factors for an acceptable tool wear process and predetermined tool life. Conversion of almost all the power used in machining into heat energy is a factor limiting the performance of the cutting tool. The temperature reaching very high values at the tool–chip interface as the result of the heat adversely affects the hot hardness of the cutting tool and at the same time activates wear mechanisms (adhesion, diffusion, thermal fatigue, etc.).

VI. Conclusion

Moreover on the other hand thermal damage can be minimized to meet accepted standards of quality of a ground part must retain good wear resistance while preserving its expected life. The heat generated depends upon the time of contact between the wheel and work piece. Hence by increasing the work speed the contact time can be reduced. So an effective remedy to avoid thermal damage is proper utilization of parameters. In present study the authors emphasizing on the chip-back surface temperature variations depending on the cutting parameters were examined and based on the findings the following conclusions can be drawn. When the changes in the temperatures are interpreted depending on the changes in the cutting speed and depth of cut, it is seen that the increase in the cutting speed and the feed rate caused an increase in the temperature and the cutting speed was found to be an effective parameter in temperature rise. When the cutting parameters (cutting speed, feed rate and depth of cut) are considered, the cutting speed and depth of cut were found to be more effective than the feed rate in the chip-back surface temperature. Especially, a twofold increase in the depth of cut resulted in about 40–60% increase in the chip-back surface temperature. A 25% and 50% increases in the cutting speed led to the increases of between 8% and 35% in the temperatures developed on the cutting tool while 33% and 50% increases in the feed rate 1–10%. – At 50 m/min cutting speed and 0.2, 0.25 and 0.3 mm/rev depths of cuts, built-up edge (BUE) was found to be effective.

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