UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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OPTIMIZATION OF CUTTING PARAMETERS TO REDUCE CUTTING TOOL TEMPERATURE IN A DRY TURNING PROCESS USING GENETIC ALGORITHM

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OPTIMIZATION OF CUTTING PARAMETERS TO REDUCE CUTTING TOOL TEMPERATURE IN A DRY TURNING PROCESS USING GENETIC ALGORITHM

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2014

DECLARATION

I declare that this thesis entitled "Optimization of cutting parameters to reduce cutting tool temperature in a dry turning process using Genetic Algorithm" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : MUHAMMAD WASEEM

Date : 11-07-2014

APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfillment of Master of Manufacturing Systems Engineering.

Signature : ....

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Date : 11 JUL 2014

ABSTRACT

High cutting temperatures in dry turning processes increase tool wear and affect the quality of the work piece. This project presents the optimization of cutting parameters in a dry turning process in order to reduce the cutting temperature using mild steel as the work piece and carbide insert cutting tool. The optimization has been carried out by manipulating the feed rate, depth of cut and cutting speed using Genetic Algorithm. GA was processed using MATLAB and the values of cutting speed, depth of cut and the feed rate were varied between constraints of 50 - 200 m/min, 0.5 – 2 mm and 0.05 to 0.25 mm/rev. respectively. The effects of varying cutting speed, depth of cut and feed rate on the cutting temperature were analyzed and the optimal parameters resulting in the lowest temperatures for different production volumes were then selected from the results.

ABSTRAK

Suhu pemotongan tinggi dalam proses perubahan kering meningkatkan penggunaan alat dan menjejaskan kualiti sekeping kerja. Projek ini membentangkan pengoptimuman pemotongan parameter dalam proses perubahan kering untuk mengurangkan suhu pemotongan menggunakan keluli lembut sebagai sekeping kerja dan memasukkan karbida alat memotong. Pengoptimuman ini telah dijalankan dengan memanipulasi kadar suapan, kedalaman pemotongan dan pemotongan kelajuan menggunakan Algorithm.GA genetik telah diproses menggunakan MATLAB dan nilai pemotongan kelajuan, kedalaman pemotongan dan kadar suapan telah diubah antara kekangan 50 - 200 m / min, 0,5-2 mm dan 0,05-0,25 mm / rev. masing-masing. Kesan yang berbeza-beza kelajuan memotong, kedalaman pemotongan dan makanan kadar kepada suhu pemotongan telah dianalisis dan parameter optimum menyebabkan suhu paling rendah untuk jumlah pengeluaran yang berbeza telah dipilih daripada hasil.

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CHAPTER 1

INTRODUCTION

Tool wear in a turning machine directly affects the outcome of the finished product. In order to get a finished work piece with precise measurements tool wear needs to be reduced as it is not feasible to constantly change the tool. The cutting temperature is a key factor which directly affects cutting tool wear, work piece surface integrity and machining precision (Sekulić et al., 2011). The cutting temperature can be lowered by using lubricants, however the consumption of cutting fluid used in metal machining for a variety of reasons such as improving tool life, surface finish and flushing away chips from the cutting zone, has become a health detriment to the operator as well as a contaminant into the environment (Bagheri et al., 2012).

Machining materials such as Titanium and Nickel based alloys, due to their low thermal conductivity, causes most of the heat generated during the machining to flow into the tool resulting in severe thermal stresses on the cutting tool, accelerating tool fatigue and failure due to fracture, wear or chipping (Augustine et al., 2013). Furthermore, if the temperature exceeds the crystal binding limits, the tool rapidly wears due to accelerated loss of bindings between the crystals in the tool material (Augustine et al., 2013). During a cutting process the mechanical energy due to the plastic deformation developed at the primary shear plane and at the chip - tool interface is converted into heat (Carvalho et al., 2006).

Studies have shown that the chip and the environment dissipate a great deal of this heat while the reminiscent is conducted both into the work piece and into the cutting tool (Carvalho et al., 2006). However, this small quantity of heat conducted into the tool (8–10% of the total heat rate) is enough to create high temperatures near the cutting edges, which can reach the level of 1100°C (Carvalho et al., 2006). As a result of the high temperatures developed at the tool surfaces critical tool wear, short tool life and poor work piece surface integrity will generally impair productivity (Carvalho et al., 2006).

There are 3 heat generation zones, the Shear zone representing 60% of the total heat generation, the Chip-tool interface zone representing 30% of the total heat generation and the tool-interface zone representing 10% of the total heat generation. Figure 1.1 shows the different heat zones during cutting.

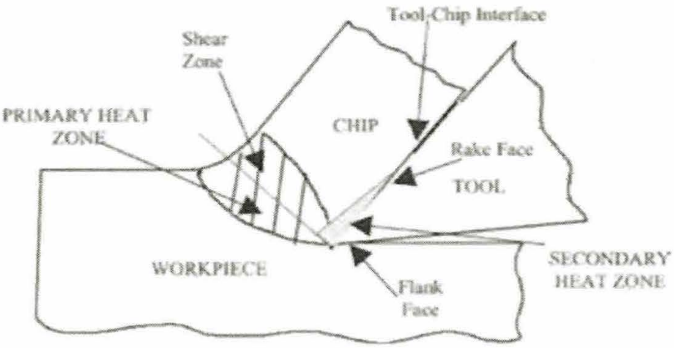

Figure 1.1: Heat Generation Zones (Adnan et al., 2013).

The selection of optimal cutting parameters, like the number of passes, depth of cut for each pass, feed and speed, is important in a turning process and in workshop practice, cutting parameters are selected from machining databases or specialized handbooks, but the range given in these sources are actually starting values not the optimal values (Quiza et al., 2006). It has been observed from previous studies that three important decision variables that affect the chip-tool interface temperature are, cutting speed, depth of cut and feed rate.

The process of modeling the temperature of the tool is hard because the relation between the large numbers of experimental data is very complex. Therefore, several researchers proposed applying different approaches based on empirical models for modeling this complex problem. Among all modeling approaches applied in engineering applications, heuristic approaches such as genetic algorithms, genetic programming, neural networks and swarm intelligence have proved their competence in terms of accuracy, efficiency and performance (Faris, 2013).

Genetic Algorithms (GA's) are heuristic search algorithms premised on the evolutionary ideas of natural selection and genetic. The basic concept of GA is designed to simulate the processes in natural system necessary for evolution, specifically for those that follow the principle of survival of the fittest (Faris, 2013). Hence, GA will be used as an optimization tool in the proposal report.

1.1 OBJECTIVE

The main objective of this project is to optimize the cutting parameters, cutting speed, feed rate and depth of cut, using Genetic Algorithm in order to reduce the cutting temperature resulting in enhanced tool life and the best quality product. It can be achieved by the specific objectives as follow:-

- Analyzing the effect of cutting speed on the shear zone temperature.

- Analyzing the effect of depth of cut on the shear zone temperature.

- Analyzing the effect of feed rate on the shear zone temperature.

- Analyzing the effect of cutting force on the shear zone temperature.

1.2 PROBLEM STATEMENT

High cutting temperatures lead to increased tool wear and a low quality product hence lowering the cutting temperature is necessary to counter the negative effects. Cutting speed, feed rate and depth of cut are important factors that contribute towards the cutting temperatures hence the optimal values for cutting speed, feed rate and depth of cut are required to reduce the cutting temperatures.

1.3 SCOPE OF THE STUDY

This study can pave the way for further research into ways to reduce the cutting tool temperature and can assist in experimenting with a diverse range of cutting tools and work piece materials leading to enhanced tool lives and the best quality products.

CHAPTER 2

LITERATURE REVIEW

2.1 CUTTING TOOL TEMPERATURE

Cutting metals at high speeds is associated with high temperatures and hence the thermal aspects of the cutting process strongly affect the accuracy of the machining process. The high temperatures generated in the deformation zones have serious consequences for both the tool and the work piece. Cutting temperatures strongly influence tool wear, tool life, work piece surface integrity, chip formation mechanism and contribute to the thermal deformation of the cutting tool. In HSM, where the process is nearly adiabatic, the aspects of cutting temperature become even more important (Abukhshim et al., 2005).

The main regions where heat is generated during the orthogonal cutting process are shown in Figure 2.1 (Wallbank et al., 1999). Firstly, heat is generated in the primary deformation zone due to plastic work done at the shear plane. Secondly, heat is generated in the secondary deformation zone due to work done in deforming the chip and in overcoming the sliding friction at the tool-chip interface zone. Finally, the heat generated in the tertiary deformation zone, at the tool-work piece interface, is due to the work done to overcome friction, which occurs at the rubbing contact between the tool flank face and the newly machined surface of the work piece. Heat generation in this zone is a function of the tool flank wear (Abukhshim et al., 2005).

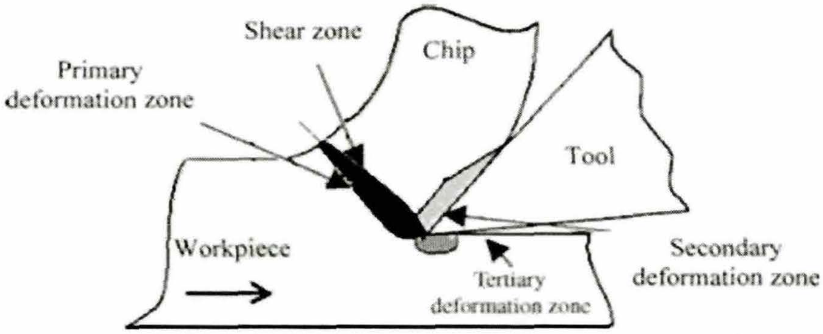

Figure 2.1:Sources of heat generation in the orthogonal cutting process (Abukhshim et al., 2005).

Heat is removed from the primary, secondary and tertiary zones by the chip, the tool and the work piece. Figure 2.2 schematically shows this dissipation of heat. The temperature rise in the cutting tool is mainly due to the secondary heat source, but the primary heat source also contributes towards the temperature rise of the cutting tool and indirectly affects the temperature distribution on the tool rake face. During the process, part of the heat generated at the shear plane flows by convection into the chip and then through the interface zone into the cutting tool. Therefore, the heat generated at the shear zone affects the temperature distributions of both the tool and the chip sides of the tool-chip interface, and the temperature rise on the tool rake face is due to the combined effect of the heat generated in the primary and secondary zones.

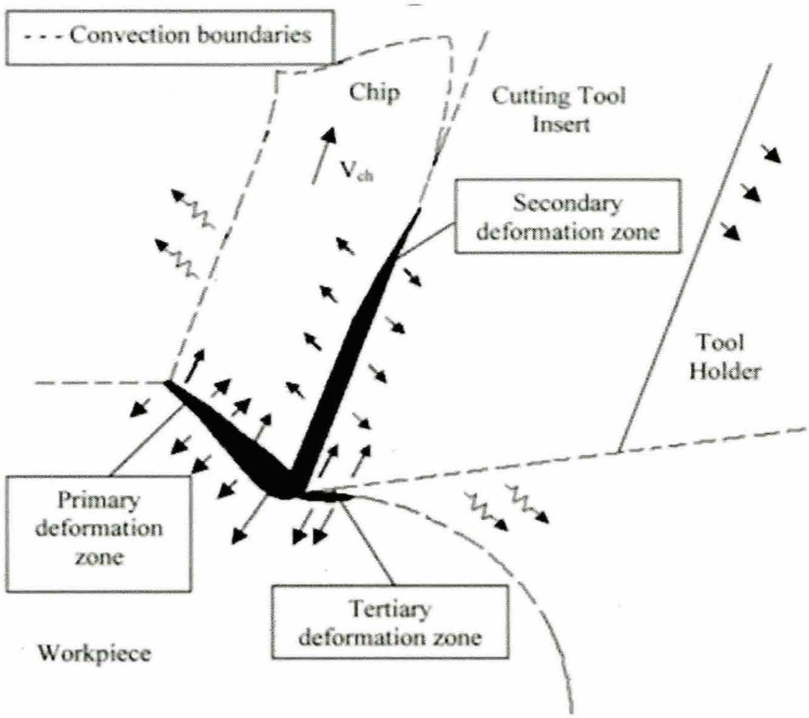

Figure 2.2: Schematic representation of a heat transfer model in orthogonal metal cutting considering the combined effect of the three heat sources (Abukhshim et al., 2005).

In previous studies cutting tests were conducted at 200, 400, 600, 800,1000 and 1200 m/min cutting speeds (Abukhshim et al., 2005). Cemented Carbide Inserts were used for one cutting speed and for four cutting passes of 200 mm each. The work piece was prepared by removing about 2 mm from the outside surface to eliminate any effect of work piece surface inhomogeneities on the experimental results (Abukhshim et al., 2005). A chamfer was also created at the end of the work piece prior to the actual turning tests to prevent any entry damage to the cutting tool edge at the beginning of the cut. The end of the tool-cutting pass was into free air to avoid detrimental exit conditions (Abukhshim et al., 2005). The temperature signals were measured by a stationary, fully digital and fast compact pyrometer for a calibrated temperature range of 250°C–2000°C (Abukhshim et al., 2005). The results discussed in the topics below.

2.2 EFFECT OF CUTTING FORCES

The cutting and feed forces versus cutting speed relationship for the various conducted cutting tests are shown in Figure2.3 (Abukhshim et al., 2005). It has been observed that the cutting force increased when the cutting speed increased from low to medium, 200–400 m/min, and decreased with cutting speed within the high-speed region (Abukhshim et al., 2005). The feed force also decreased gradually when the cutting speed was increased during all the cutting tests (Abukhshim et al., 2005).

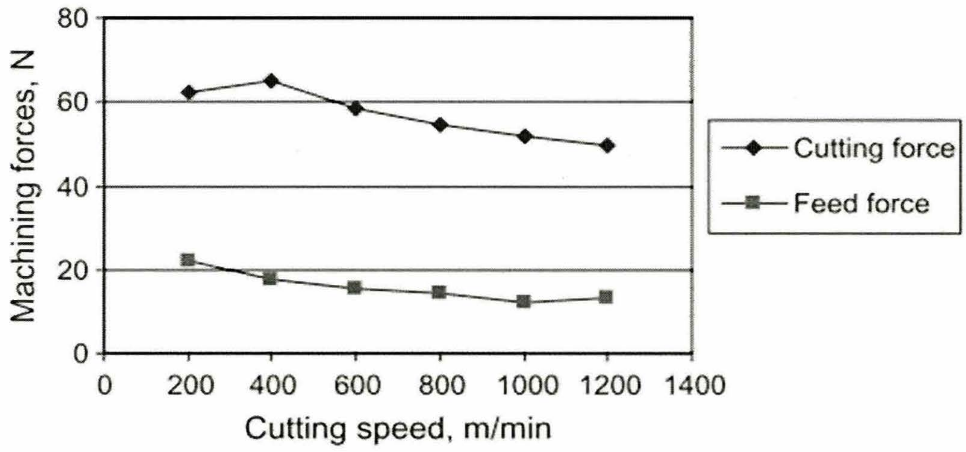

Figure 2.3: Measured machining forces versus cutting speed (Abukhshim et al., 2005).

Among the Cutting force, Thrust force and Feed force the former prominently influences power consumption and the most common equation available for the estimation of cutting force is given by,

$$Fc = kc \times DOC \times f \qquad \text{(Eq-1)}$$

Where,

DOC = Depth of cut (mm),

f = feed (mm/rev),

kc =Specific cutting energy coefficient (N/ mm2) (Murthy et al., 2012)

According to equation 1, cutting force is influenced by the depth of cut, feed, and specific cutting energy coefficient. A lot of work is in progress to study this influence and construct the models for different tool and work force material so as to optimize the power consumption.

2.3 TOOL-CHIP CONTACT AREA

The nature of contact between chip and tool rake face has a major influence on the mechanics of machining, heat generation and heat partition into the cutting tool. Previous experimental studies of the chip–tool interface, when machining at high cutting speeds, have shown that the nature of the contact conditions at the interface is composed of sticking/seizure over the whole contact area (Abukhshim et al., 2005).

The effect of the cutting speed on the actual tool-chip contact area was examined. Optical images of the worn inserts used in this study are presented in Figure 2.4, and clearly indicate that the contact length changes according to the contact phenomena in the tool–chip interface zone, which is predominantly affected by the cutting speed. Moreover, the influence of the cutting speed on the contact length, and hence on the contact area, changes significantly from conventional to high-speed cutting environments (Abukhshim et al., 2005).

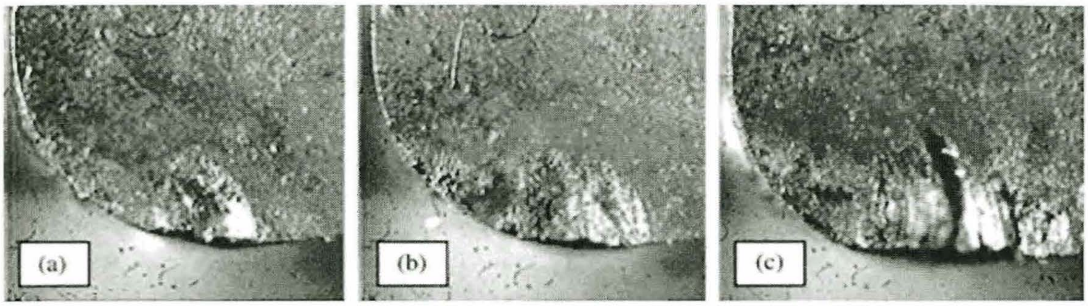

Figure 2.4: Optical microscope images of the rake face of uncoated carbide inserts after cutting for 200 mm at (a) VZ600 m/min, (b) VZ1000 m/min and (c) VZ1200 m/min (Abukhshim et al., 2005).

2.4 HEAT GENERATION IN THE PRIMARY AND SECONDARY DEFORMATION ZONES

Table 2.1 presents the rate of heat generation in the primary and secondary deformation zones and the frictional heat flux at the tool–chip contact area (Abukhshim et al., 2005). From Table 1, it can be seen that the tool-chip real contact area significantly affects the frictional heat flux. The contact area decreased as the cutting speed increased within the conventional region and consequently the heat flux increased substantially until the cutting speed of 600 m/min where the contact area reached a minimum (Abukhshim et al., 2005). In this case, the heat flux reached a peak value of 1015.5 W/mm2. This heat flux decreased as the cutting speed increased further within the high-speed region as the tool-chip contact length and the real area of contact increased (Abukhshim et al., 2005). This clearly indicates that within the high speed region the amount of heat flowing into the cutting tool was significantly high.

Table 2.1: The rate of heat generation in the primary and secondary deformation zones and the frictional heat flux at different cutting speeds.

Cutting Speed (m/min)	**200**	**400**	**600**	**800**	**1000**	**1200**
Q_p (W)	207.5	434.3	580.6	729.95	865.2	987.6
Q_s (W)	39.05	106.5	126.23	151.51	185.6	232.1
q_{fr}(W/mm^2)	260.3	777.4	1015.5	814.6	536.4	427.44

2.5 HEAT ENTERING THE TOOL

Figure 2.5 reveals that the partition of the heat flowing into the tool increased gradually with the cutting speed and reached 65% at 1200 m/min (Abukhshim et al., 2005). This can be explained as follows: at the engagement of the cutting tool for speeds of 600 m/min and above, a further reduction in the contact length and the contact area occurs and as a result the sticking region moves to its limiting position towards the cutting edge. This, in turn, results in a shift of the maximum temperature area on the tool rake face towards the cutting edge.

Due to a relatively small contact area; the intensive heat generation in the primary zone; especially near the cutting edge, localized contact stress is generated as a result of the very high strain rate and the high temperature nonlinear plastic deformation involved in the chip formation process, increases rapidly enlarging the contact area over the time of machining.

In addition, a reduction in the rake angle, which is brought about by tool edge wear, also promotes a longer contact length and hence a larger contact area with more heat conducting into the tool (Abukhshim et al., 2005).

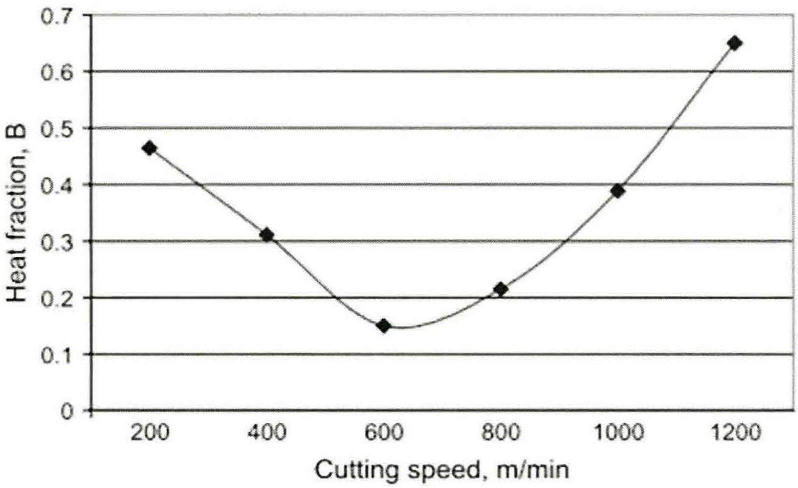

Figure 2.5: Effect of cutting speed on heat partition due to the secondary heat source (Abukhshim et al., 2005).

2.6 EFFECT OF CUTTING SPEED ON TOOL TEMPERATURE

Figure 2.6 shows the effect of the cutting speed on the maximum interface temperature at the tool-chip contact (Abukhshim et al., 2005). It shows that the rake face temperature, taken as the average temperature over the contact area, increases gradually with the cutting speed but not in a strictly linear fashion due to the increase in the contact area. The maximum steady-state temperatures were about 743°C and 1209°C for the cutting speeds of 200 and 1200 m/min, respectively. The tool-chip contact is greatly influenced by the cutting speed in the high-speed region. With increasing cutting speed, the contact area increases and as a consequence the fraction of the heat flowing into the cutting tool due to the secondary heat source increases (Abukhshim et al., 2005).

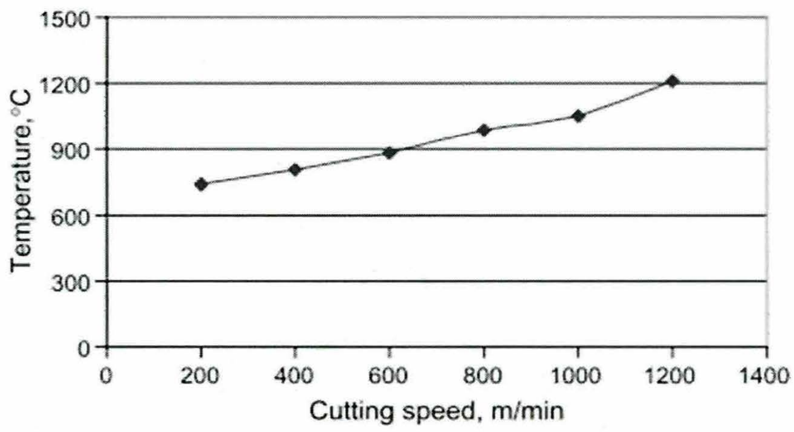

Figure 2.6: Effect of cutting speed on the maximum temperature at the tool- chip contact (Abukhshim et al., 2005).

2.7 GENETIC ALGORITHM

Genetic Programming (GP) is an evolutionary algorithm for automatically solving problems and is also known as Genetic Algorithm (GA). It. is inspired by biological evolution Darwin's theories (Faris, 2013) and has been applied successfully to a large number of complex problems like feature selection and classification industrial processes and robots, engineering optimization and modeling (Brezocnik et al, 2011).