MODELING AND EXPERIMENTAL STUDY OF THERMAL/WEAR BEHAVIOR IN CAST IRON TURNING OPERATION

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ABSTRACT

The present works involves the study of thermal and wear behaviour of tool and work interface. Experiments were conducted on a precision centre lathe and cutting forces, temperature at tool tip, thickness and weight of Chips formed during machining along with tool wear data were recorded. The influence of cutting parameters was studied. Based on the main effects plots obtained. Finite element analysis was done using ANSYS software tool and was used to find the tool tip deflection, counterplots. Thermal analysis was done to determine the temperature distribution over machining interface.

Keywords: Cutting Force, Finite Element Analysis, Machining, Tool Deflection, Tool Wear.

I. INTRODUCTION

Details Machining of metals is still not completely understood because of the highly non-linear nature of the process and the complex coupling between deformation and temperature fields [1]. Metal cutting can be associated with high temperatures in the tool-chip interface zone and hence, the thermal aspects of the cutting process strongly affect the accuracy of the machining process [2]. The deformation process is highly concentrated in a very small zone and the temperatures generated in the deformation zones affect both the tool and the workpiece. High cutting temperatures strongly influence tool wear, tool life, workpiece surface integrity, chip formation mechanism and contribute to the thermal deformation of the cutting tool, which is considered, amongst others, as the largest source of error in the machining process [1]. Measuring temperature and the prediction of heat distribution in metal cutting is extremely difficult due to a narrow shear band, chip obstacles, and the nature of the contact phenomena where the two bodies, tool and chip, are in continuous contact and moving with respect to each other. The ever-increasing demand on cost reduction and improving quality of final products are driving metal cutting research into new areas. As for high speed machining (HSM) [3], it has become a key technology of particular relevance to the aerospace, mould and die and automotive industries.

In HSM, cutting speed has a predominant effect on the cutting temperature and the heat transfer mechanism. As cutting speed increases, the cutting process becomes more adiabatic and the heat generated in the shear deformation zone cannot be conducted away during the very short contact time in which the metal passes through this zone. Consequently, highly localized temperatures in the chip occur. Therefore, it appears that in HSM, where the process is nearly adiabatic, the effect of the thermal phenomenon should become more important. The metal cutting is a coupled of thermo-mechanical process. During the process, the heat generation occurs as a result of plastic deformation and friction along the tool–chip and tool–work piece interface [4]. The maximum temperature occurs at the tool–chip interface. The tool–wear and fracture or tool failure considerably increases at higher temperatures. Temperature rise in machining has a
controlling influence on the cutting parameters. Many parameters depend on the temperature field during cutting tool life, mechanics of chip formation, surface quality, cutting forces, cutting speed, process efficiency etc. A lot of efforts have been made to measure the temperatures at the tool-chip interface zone, chip, cutting tool and the work piece [4]. A review of the common experimental techniques designed for temperature measurement in metal cutting processes reveals that these techniques can be classified as direct conduction, indirect radiation, and metallographic.

In the metal cutting process, the tool performs the cutting action by overcoming the shear strength of the workpiece material. This generates a large amount of heat in the workpiece resulting in a highly localized thermo mechanically coupled deformation in the shear zone. Temperatures in the cutting zone considerably affect the stress–strain relationship, fracture and the flow of the workpiece material. [4] Generally, increasing temperature decreases the strength of the workpiece material and thus increases its ductility. It is now assumed that nearly all of the work done by the tool and the energy input during the machining process are converted into heat.

Fig. 1: Sources of heat generation in the orthogonal cutting process [5]

The main regions where heat is generated during the orthogonal cutting process are shown in Fig. 1 [5]. Firstly, heat is generated in the primary deformation zone due to plastic work done at the shear plane. The local heating in this zone results in very high temperatures, thus softening the material and allowing greater deformation. 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 workpiece 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 workpiece. Heat generation and temperatures in the primary and secondary zones are highly dependent on the cutting conditions while heat generation in the tertiary zone is strongly influenced by tool flank wear.

The radiation techniques are non-contact thermographic methods designed to measure the surface temperature of a body based on its emitted thermal energy [4]. It is available for temperature field measurement (infrared thermography), including photo camera with films sensitive to infrared radiation and infrared camera, and for temperature point measurement (infrared pyrometer) [5]. The development of new kinds of tools and new materials has expanded the experimental field. This has resulted in a renewed interest in the study of the phenomena of wear. This renewed interest is highlighted by examples of tool wear investigations in different application fields: It is clear that, in a given field, the wear criteria chosen alone should be used to judge reliably when the tool must be removed from service for renewal of the cutting edge [7]. The wear can be defined as the loss of material from the cutting edge due to mechanical or chemical factors associated with the cutting process [8]. Wear minimization has been pursued by different means. An ideal cutting material has to combine high hardness and wear resistance with good toughness and chemical stability, but no material has ever shown all these properties together at their best combination.

II. MATERIALS AND METHODS

In the present work Cast iron is used as a work material to estimate the HSS single point cutting tool wear. Cast iron is iron or a ferrous alloy which has been heated until it liquefies, and is then poured into a mould to solidify. It is usually made from pig iron. The alloy constituents affect its colour when fractured: white cast iron has carbide impurities...
which allow cracks to pass straight through. Grey cast iron has graphite flakes which deflect a passing crack and initiate countless new cracks as the material breaks. Carbon (C) and silicon (Si) are the main alloying elements, with the amount ranging from 2.1–4 wt% and 1–3 wt%, respectively. Iron alloys with less carbon content are known as steel. While this technically makes these base alloys ternary Fe–C–Si alloys, the principle of cast iron solidification is understood from the binary iron–carbon phase diagram. Since the compositions of most cast irons are around the eutectic point of the iron–carbon system, the melting temperatures closely correlate, usually ranging from 1,150 to 1,200 °C (2,100 to 2,190 °F), which is about 300 °C (572 °F) lower than the melting point of pure iron.

III. EXPERIMENTAL WORK

The cutting tests were performed using a Turn master 35 lathe. A strain gauge dynamometer was used to measure the cutting forces. Cutting conditions were feed rate 0.24 mm/rev, 4 different values for depth of cut (0.5, 1.0, 1.5, 2.0) and 4 different cutting speeds (180rpm, 280rpm, 450rpm, 710rpm). Tool geometry are nose angle 60°, End relief angle 30°, Face angle 0°. Cast iron rod of 32mm diameter was taken as work materials for experiment.
A lathe was utilized, fitted with a HSS tool. The other parameters were selected in order to obtain prompt treatment and to identify the most appropriate method to analyze the forces. One single sample was prepared and fixed on the Dynamometer for the force acquisitions are shown in Fig 3.

A Lathe tool Dynamometer was used to measure the cutting forces. The cutting forces were measured according to the three principal directions, cutting force, tangential and normal respectively. An Infrared thermometer is used to measure the Cutting temperatures at tool tip and work surface. Tool wear measurements were made by the loss of the material from the active cutting edge due to the factors associated with the cutting process. Tool wear or tool material loss was measured using Electronic balance of least count .0001gms. Tool material loss was measured after turning every 150mm length of work material for different speeds and depth of cut values. All measured parameters are summarized and relations between them are plotted.

**IV. RESULTS AND DISCUSSIONS**

The relation between the tool wear & cutting forces with cutting speed, depth of cut shown in the below graph, along with other cutting parameters the variation of temperature developed at tool tip also plotted.

The Fig 6, 7, 8 shows Variation in Cutting force, Tangential force, Natural force on lathe tool while machining with four set of cutting speeds & different depth of cut combinations for cast iron turning.
Fig. 7: Tangential force (Fy) Values

Fig. 8: Natural force (Fz) Values.
The Fig. 9 shows the variations in temperature developed at tool tip while machining with different cutting speed & depth of cut combination for cast iron rod. From the graph it is clear that temperature developed at tool tip increases with the increase in machining speed and depth of cut values. The temperature developed at tool tip is maximum for 2.0 mm depth of cut and 710 rpm combination.

Fig. 10: Tool Wear values for turning
The Fig 10 and 11 shows values of tool wear while machining with different cutting speed & depth of cut combination for cast iron turning. From the graph it is clear that tool wear is increases with temperature developed at tool tip with the increase in cutting speed. Tool wear is minimum for 0.5mm depth of cut and it increases as we machine with higher depth of cut values.
Fig. 12 and 13 shows that tool wear value is minimum for cutting speed range of (300-350) rpm for Cast iron turning. To avoid high tool wear while machining cast iron, it is advised to run machine in the range of (180-300) rpm by giving moderate depth of cut and feed values. From the experiment on machining it is found that cutting Speed has significant effect on the temperature developed as well as the tool wear also depth of cut plays an influence on cutting force, and an insignificant influence on tool wear.

Fig. 14 shows relation between tool wear and Tool re-grind weight loss, this is tool weight loss while regrinding the worn-out tool. Graph shows linear relation between tool tip wear and tool weight loss while tool regrind. The focus should be on choosing an appropriate combination of feed rate and depth of cut will be helpful in machining, and to save tool re-grind time and tool replacements cost contributing to the cost reduction in the overall production process.
V. MODELING AND ASSUMPTIONS

In this present work a practical high speed lathe tool taken as a case study. A 2D lathe tool model was plotted and the keypoints are developed for lathe tool. The modeling is done on Solid 3D modeling & ANSYS 10.0 software tool. Fem element taken for the Thermal analysis is, 3D Brick 8 node 45, Thermal analysis is done by taking some of basic assumptions. Temperature at tool tip =2010C, Room temperature =290C, Air as convection medium and thermal properties of HSS lathe tool and Cast iron are considered for analysis.

![Fig. 15: Tool work Model meshed Elements](image1)

![Fig. 16: Temp Distribution Tool-Work](image2)

Fig 15 and 16 Shows meshed finite element model of tool work interface and temperature distribution counter plots respectively. The model is created using solid 3D modeling software then exported on to ANSYS environment and meshed with optimum number of elements. Fig 16 shows distribution of temperature over tool-workpiece interface. The counterplots shows temperature is maximum at tool tip and tool work interface and it decreases with distance from the tool work interface.

![Fig. 17: Temperature Distribution at Machining interface](image3)
Fig. 18: Temperature Distribution at tool

Fig 17 and 18 shows temperature distribution graphs for machining interface and tool tip region. From the fig. it is seen that maximum temperature region (0.088mm-0.0352 mm) is at tool work interface and the work piece is at its maximum temperature (0.3mm). From the graph the temperature developed is clearly seen for tool surface as well as Tool-Machining interface.

VI. CONCLUSIONS

Prediction and measurement of tool wear and cutting temperatures is a major challenge in metal cutting. This is due to numerous practical difficulties involved in the process. However, for temperature measurements of the high speed cutting process is the most promising. Therefore, more research is needed to develop numerical models to predict the contact geometry and separating contours between the sticking and sliding zones. Furthermore, ongoing research on the investigation of the relationship between the tool-chip contact phenomena and geometry with other process parameters should be incorporated into machining simulation researches. These models tend to minimise the uncertainties associated with the FE models for HSM simulations.

The Cast iron turning operation provided some useful results in relation to machining parameters, which will be useful in developing turning process optimization with respect to power consumption and tool life. The focus should be on choosing an appropriate combination of feed rate and depth of cut will be helpful in manufacturing automobile and other structural parts contributing to the cost reduction in the overall production process.

VII. REFERENCES


