Heat Generation and temperature in Orthogonal Machining

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Abstract— Heat generation during metal cutting process is of particular importance as it governs machining mechanisam and thus the economy of machining. The high temperature adversely affects the strength, hardness and wears resistance of the cutting tool. Excessive heat generation in cutting zone causes dimensional changes in the part being machined and can induce thermal damage to the machined surface. Temperature at tool-chip and tool-workpiece interfaces influences tool wear, tool life and surface integrity. Tool–chip contact length can be a critical parameter in machining as it provides the path for heat flow from the secondary deformation zone into the tool. Therefore, reducing the amount of heat flowing into the cutting tool is of great significance. In all, it is very important to study the heat generation mechanisam, heat partition and temperature distribution in machining processes. The paper reviewed the heat generation and effects and control of temperature rise in metal machining.

Index Terms—Heat generation, High speed machining, Residual stresses, surface integrity, Temperature, Tool wear, Tool life.

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1 INTRODUCTION

THE higher productivity, quality and overall economy in manufacturing by machining insists high material removal rate. The material removal rate increases with increase in velocities and feed rates but it also raises the temperature considerably. High cutting temperatures strongly influence chip formation mechanism, tool wear, tool life and workpiece surface integrity [1]. Cutting force is also increased with tool wear which results the increase of power and specific energy consumption. The heat generated in cutting zone causes thermal deformation of the cutting tool and dimensional deviation of the workpiece. The cutting temperature is the cause of several problems restraining productivity, quality and hence machining economy. The study of effects of heat generation and temperature distribution has become crucial. Many researchers have studied and worked on various techniques to control the increased cutting temperature as well as cutting force, tool wear rates and surface integrity. The study of effects of cutting temperature in machining is becoming more significant as most of the research concentrated on effect of tool geometry and process parameters on machining responses. . Hence, in order to enhance the productivity and quality of the product, there is need and scope to study the effects of machining temperature and different methods to control it.

2 HEAT GENERATIONION

There are three main regions where heat is generated during the metal cutting process. In primary deformation zone the heat is generated due to plastic work done at the shear plane. In secondary deformation zone the heat is generated due to work done in deforming the chip and in overcoming the friction at the tool-chip interface. Finally, in tertiary deformation zone the heat is generated at the tool-workpiece interface due to work done to overcome friction which occurs at the rubbing contact between the tool flank face and the machined surface of the workpiece. The increasing temperature decreases the strength of the workpiece material and thus increases its ductility. It is assumed that nearly all of the work done by the tool and the energy input during the machining process are converted into heat [1, 2, 3]. 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. Heat generation in metal cutting process is depends on properties of tool and workpiece material, tool geometry, cutting conditions, cutting fluid and cutting fluid applications method [5].

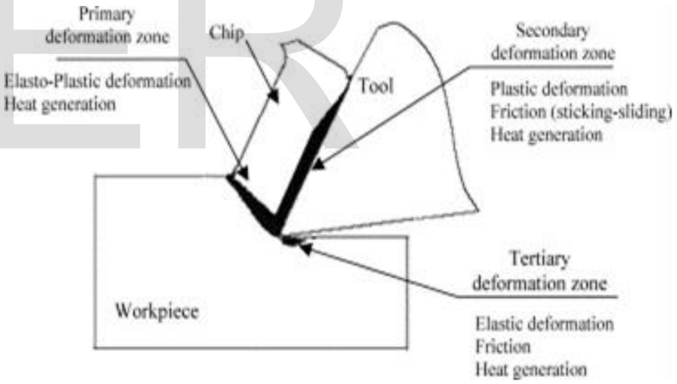

Fig.1 Sources of heat generation in the orthogonal cutting process [4]

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3 ESTIMATION OF HEAT GENERATION

Heat generated in metal cutting can be estimated either by calorimetric methods or by measuring the cutting forces. The rate of energy consumption in metal cutting is given by [6]:

$$W_C = F_V V$$

Where, F_V is the cutting force and V is the cutting speed.

Based on first law of thermodynamics, then heat generation in the primary deformation zone is given by:

$$Q_R = F_V V$$

Where, F_V is the tangential cutting force and V is the cutting velocity.

The amount of heat generated in the secondary deformation zone along the tool rake face is given by the following equation:

$$Q_S = F_{Fr} V/\mu$$

Where F_{Fr} is the total shear force acting on the rake face, and μ is the chip thickness ratio.

$$F_{Fr} = F_V \sin\alpha + Fs \cos\alpha$$

Where, F_S is the feed force and a is the rake angle.

4 EFFECTS AND CONTROL OF CUTTING TEMPERATURE

The cutting temperature has great influence on both the tool and the workpiece. The increase in temperature at tool-chip interface will cause tool wear, thermal flaking of cutting edge and built up-edge formation. And also it causes dimensional inaccuracy of the job due to thermal distortion and residual stresses at the surface. The amount of heat generated in secondary deformation zone depends on contact phenomenon at tool-chip interface. Contact length is parameter which governs the heat transfer to cutting tool. A considerable amount of heat generated during machining is transferred into the cutting tool and work piece, thus the contact length between the tool and the chip affects cutting conditions and performance of the tool. Also the contact phenomenon at the tool-workpiece surface is important to understand tool flank wear and surface characteristics. The heat generated at this interface increases flank wear and affects surface integrity of the machined surface. [7].

High temperatures at the tool–chip interface result in an increase of diffusion and chemical wear [8]. The high specific energy required in machining under high cutting velocity and unfavorable condition of machining results in very high temperature At High temperature the cutting edge deforms plastically, which lead to dimensional inaccuracy and results in increased in cutting forces and premature tool failure [9]. Tool wear and excessive heat can induce thermal damage and metallurgical changes in the machined surface. The tool wear is an important factor affecting the values of induced residual stress, strain, subsurface energy and the quality of the machined surface. Increase in notching occurs on carbide tools at higher cutting speed which usually leads to the premature fracture of the entire insert edge. Tool wear causes an increase in the cutting force and the cutting temperature leads to dimensional inaccuracy in the work pieces machined [10]. High speed machining is inherently generated high cutting zone temperature. Uncoated carbide insert creates more cutting temperature than coated insert when turning different steels [11]. Turning hard to cut materials using existing conventional techniques is not economical as the turning process results in high tool wear and high cutting force [12]. The heat generation is very high while turning difficult to cut materials due to strong adhesion between the tool and work material and low thermal conductivity. The cutting temperature is optimum when the work piece material hardness is HRC 50 [13]. With further increase in the work piece hardness, the cutting temperature shows a descending tendency. Under different cutting parameters, the role of cutting force changes with work piece hardness. The cutting temperature and force can be controlled or reduced to some extent by appropriate selection of process parameters, cutting tool geometry and cutting fluids application [14].

Appropriate selection of the process parameters can provide better machinability without sacrificing productivity. Increase in cutting velocity reduces tool life but it also reduces cutting forces and improves surface finish. Therefore proper increase in cutting velocity, even at the expense of feed rate often can improve machinability quite significantly [15]. The feed rate and cutting speed are the most influential factors on the surface roughness and tool life, respectively. The surface roughness is related to the cutting speed, whereas the depth of cut has the greatest effect on tool life. The geometrical parameters such as; tool rake angles, clearance angle, cutting angles and nose radius of cutting tools significantly affect the machinability aspect. Increase in tool rake angles reduces main cutting force through reduction in cutting strain, chip reduction coefficient. The variation in the principal cutting edge angle influences feed force and the cutting temperature quite significantly. The increase in feed force may impair the product quality by dimensional deviation. Inadequate clearance angle reduces tool life and surface finish by tool-work rubbing and again too large clearance reduces the tool strength and hence tool life. Proper tool nose radius improves machinability to some extent through increasing in tool life by increasing mechanical strength and reducing temperature at the tool tip. The elevation of feed rate and reduction of the nose radius increases surface roughness. The use of large nose radius together with low depths of cut lead to low true side cutting edge angle values, thus resulting in high thrust forces [16].

In machining processes, the main objective of employing cutting fluid is to improve machinability characteristics of work-tool pair through improving tool life, surface integrity and dimensional accuracy by cooling and lubricating action. Cutting fluids also make chip-breaking and chip-transport easier. For reducing the cutting zone temperature cutting fluid is impinged into the cutting zone to facilitate heat transfer from the cutting zone. Lubricants reduce friction and coolants effectively reduce high cutting temperature of tools/work pieces. It can flush chips away from the cutting zone, protect the machined surface from environmental corrosion and these factors improve tool life and surface roughness. But some conditions like machining steels by carbide tools, the use of coolant may increase tool wear though it can reduce temperature [17]. In case of high speed-feed machining, which inherently generated high cutting zone temperature, cutting fluid can't reduce the temperature because fluid can't reach to the chip-tool interface [18]. The favorable roles of cutting fluid application depend not only on its proper selection based on the work and tool materials and the type of the machining process but also on its rate of flow, direction and location of application. Proper selection and application of cutting fluid generally improves tool life and surface roughness.

5 CONCLUSION

On the basis of the research findings reported in the available literature reviewed and presented in this paper, conclusions can be drawn as discussed below:

High productivity with high cutting velocity, feed and depth of cut is inherently associated with generation of large amount of heat and high cutting temperature. High cutting temperature reduces tool wear, tool life and also impairs the surface integrity of the product by inducing residual stresses. Heat generation and temperature can be control by proper selection of the process parameters (cutting velocity, feed rate and depth of cut) tool geometry and cutting fluid and its application methods. The better machinability characteristics of a given work-tool pair even without sacrificing productivity can be obtained by analyzing and optimizing various process, product and flow parameters.

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