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EFFECT OF CUTTING PARAMETER INTERFACE TEMPERATURE & CHIP MORPHOLOGY ON SURFACE ROUGHNESS AND FLANK WEAR IN HARD TURNING – A REVIEW

KEYWORDS: Hard turning, Interface temperature, chip morphology, surface roughness, Flank wear

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ABSTRACT *Hard turning is a one kind of machining process which involves turning of hardened material (45-70 HRC) in to finish components in the industries. The main problem associated with hard turning is a generation of high interface temperature between tool and work piece, which affect the quality of product produced. The main objectives of this study investigate and evaluate the effect of different cutting parameters (cutting speed, feed rate and depth of cut)and interface temperature and chip morphology on surface roughness and flank wear during hard turning of alloy steel.*

INTRODUCTION

Hard turning is machining process performed on hardened materials with the aim of replacing grinding operation. Hard turning, which is the dominant machining operation performed on hardened materials. Recently hard cutting operations using tools with geometrically defined cutting edges have become increasingly capable of replacing grinding operations providing good surface finish [1-4].

Hard turning reduces both equipment cost and personal expenses, since it can be performed in one pass using one setup Thermal consideration of hard machining processes is very important for tool wear mechanisms and heat penetration into the subsurface layer, which leads to the formation of the white layer and determines the distribution of residual stresses. The cutting temperature in hard machining depends not only on the cutting conditions but also on the hardness of the work piece material. Flank wear is a major cause of thermal damage in the subsurface layer in finish hard machining [1, 5]. The cutting edge angle of the tool significantly affects the cutting process because, for a given feed and cutting depth, it defines the uncut chip thickness, width of cut, and thus tool life. Tool wear leads to tool failure. Wear of cutting tools depends on tool material and geometry, work piece materials, cutting parameters (cutting speed, feed rate and depth of cut), cutting fluids and machine-tool characteristics [1].

INTERFACE TEMPERATURE

Temperature on the chip-tool interface is important parameters in the analysis and control of machining process. Due to the high shear and friction energies dissipated during a machining operation the temperature in the primary and secondary shear zones are usually very high, hence affect the shear deformation and tool wear. In a single point cutting, heat is generated at three different zones i.e. primary shear zone, chip tool interface and the tool work-piece interface as shown in Figure. 2. The primary shear zone temperature affects the mechanical properties of the work piece-chip material and temperatures at the tool-chip and tool-work piece interfaces influence tool wear at tool face and flank respectively. Total tool wear rate and crater wear on the rake face are strongly influenced by the temperature at chip-tool interface. Therefore, it is desirable to determine the temperatures of the tool and chip interface to analyze or control the process.

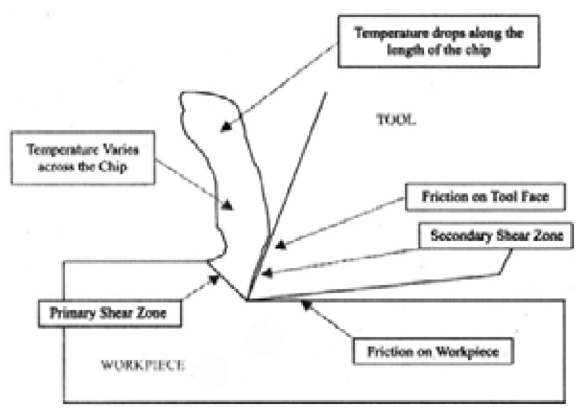

Figure. 2: Heat generated by chip formation [8]

There are number of methods for measuring the chip tool interface temperature: Tool work thermocouple, Radiation pyrometers, embedded thermocouples, temperature sensitive paints and indirect calorimetric technique. Of all these methods, the tool work thermocouple technique is the most widely used technique for the measurement of the average chip tool interface temperature. The other methods suffer from various disadvantages such as slow response, indirectness, and complications inmeasurement. [9, 10]

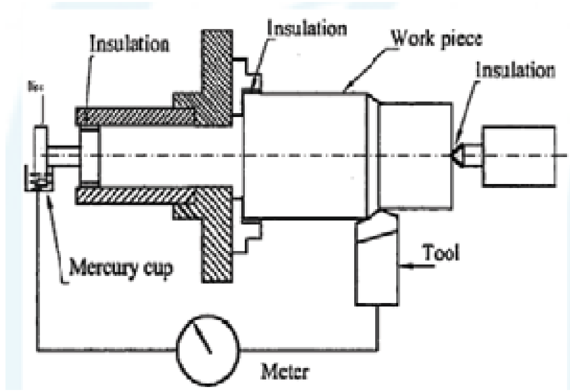

Figure. 3: Setup of tool work thermocouple

In this method Chip-tool interface temperature is the tool-

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work thermocouple as shown in figure.3,with due care to avoid generation of parasitic emf and electrical short circuit. This method uses the tool and work piece as the elements of a thermocouple. The hot junction is the interface between the tool and the work piece and cold junction is formed by the remote sections of the tool and work-piece which must be connected electrically and held at a constant reference temperature [10].

Cutting speed is main influencing factor on chip-tool interface temperature as compared to others. It has been shown that increasing cutting speed, feed rate and depth of cut lead to an increase in cutting temperature. However, increasing the tool nose radius decreases the cutting temperature. A good combination among the cutting speed, feed rate, depth of cut and tool nose radius can generate minimum cutting temperature during steel turning. Response surface methodology coupled with factorial design of experiments actually save a lot of time and cost of experiments.[8]

The possible detrimental effects of high cutting temperature on cutting tool (edges) are: Rapid tool wear, which reduces tool life, Plastic deformation of the cutting edges if the tool material is not enough hot-hard and hot-strong, Thermal flaking and fracturing of the cutting edges due to thermal shocks, Built-up-edge formation.[10]

The possible detrimental effects of cutting temperature on the produced jobs are: Dimensional inaccuracy of the job due to thermal distortion and expansion contraction during and after cutting, Surface damage by oxidation, rapid corrosion, burning etc and Induction of tensile residual stresses and micro cracks at the surface/subsurface.[10]

The relationship between the work piece tool interface temperature and flank wear at the cutting edge of the tool is analyzed to determine the effect of one parameter over another parameter. As the Inter-face temperature increases, the hardness of the cutting tool is lowered, favouring the wear at the cutting edge. From the experimental analysis, with increase in interface temperature the flank wear increases comparably. By varying the machining parameters and geometrical parameters, the interface temperature can be minimized, thus lowering the wear occurring at the flank wear. By minimizing the wear, the surface roughness of the machine surface will be lowered. Figure.4 show the relationship between the interface temperature and flank wear for various combinations of input parameters.[1]

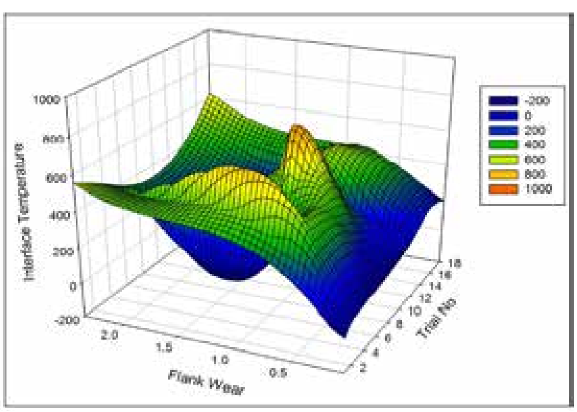

Figure. 4: Relationship between interface temperature and flank wear [1]

CHIP MORPHOLOGY

Two parameters influencing the chip morphology and segmentation in hard turning are the Feed rate and The microstructure of material. The lowest feed rate facilitates the formation of uniform chips (continuous chip). Higher feed rates results in segmentation of the chips (Discontinuous chip).For all tests, chips forms were examined and their microstructures were observed using scanning electron microscope. [6]

Chip serration causes the formation of microwaves on the machined surface, and this increases surface roughness. At different serration stages the influences of chip serration on wave amplitude are different, resulting in different surface roughness at different cutting speeds. The maximum value of machined surface roughness appears at about the middle rather than beginning or ending of serration range. The minimum surface roughness is at chip serration stage corresponding to separated segments. This hints the machining with higher cutting speed at separated segments chip is feasible under the permission of tool wear. Chip segmentation degree has no effects on the chip serration caused surface roughness. The principal factor influencing the machined surface roughness is the thickness of sawed segment of saw-tooth chip. The width of the sawed segment has weak effect on the machined surface roughness. [7]

Mean saw-tooth segmentation spacing (a1) and tooth height (a2) decrease as flank wear progresses while the chip height of continuous portion (a3) increases;

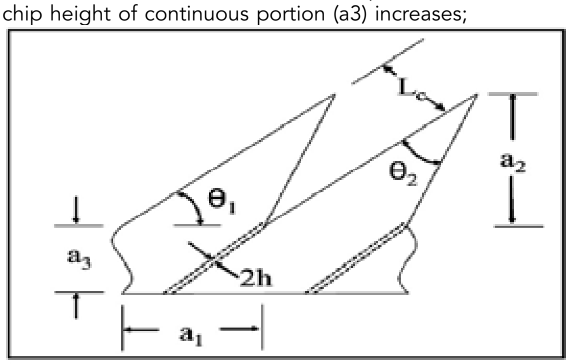

Figure. 5: SEM image of a saw-toothed chip cross-section [8]

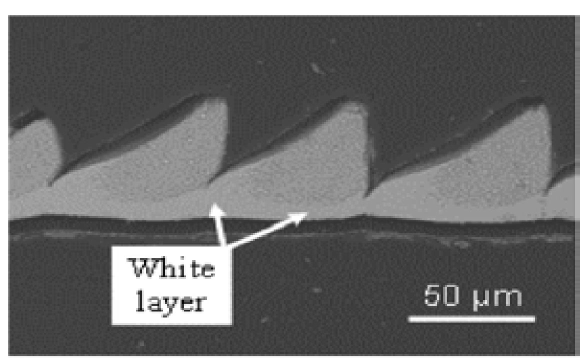

Figure. 6: Segmentation dimensions for saw-toothed chips.[8]

Segmentation spacing a1 always increases with cutting speed, feed rate, and=or depth of cut. The tooth height a2 is always larger than the continuous portion height a3 for the investigated cases when the tool was new. However, there are no monotonic relationships among cutting conditions and other chip dimensional values except a1; Both crack initiation angle (Θ1) and included angle of saw-toothed chip (Θ2) remain approximately constant as

35^0 and 45^0, respectively, under different tool wear and cutting conditions; Segmentation frequency increases with tool wear and cutting speed, decreases with feed, and oscillates with depth of cut; and Shear band spacing (Lc) of the saw-toothed chip can be reasonably estimated based on cutting configuration and work pieces' mechanical and thermal properties.

REVIEW OF WORK CARRIED OUT

Adeel H. Suhail et al.[11] predicted surface roughness using the work piece surface temperature of a turning work piece with the aid of an infrared temperature sensor. Relationship between the work piece surface temperature and the cutting parameters and also between the surface rough-ness and cutting parameters were found out for indirect measurement of surface roughness through the surface temperature of the workpiece. A 33 full factorial design was used in order to get the output data uniformly distributed all over the ranges of the input parameters. Response Surface Method (RSM) and analysis of variance (ANOVA) were used to get the relation between different response variables (Surface roughness and work piece surface temperature) and the input parameters (speed, feed and depth of cut). Based on variance analysis for the second order RSM model, most influential design variable is feed rate and depth of cut on surface roughness and work piece surface temperature respectively and the experimental results show that the work piece surface temperature can be sensed and used effectively as an indicator of the cutting performance. Depth of cut has a much greater influence on the work piece surface temperature and when feed rate increase surface roughness increase and work piece surface temperature decrease. Thus higher work piece surface temperature means better surface roughness.

L.B.Abhang et. al [9] have performed some experiments on the tool-chip interface temperature is measured experiment-tally during turning of EN-31 steel alloy with tungsten carbide inserts using a tool work thermo-couple technique and the results were found that cutting temperature increases as cutting speed, feed rate and depth of cut increases. However, increasing the tool nose radius decreases the cutting temperature. A good combination among the cutting speed, feed rate, depth of cut and tool nose radius can generate minimum cutting temperature during steel turning. Response surface methodology coupled with factorial design of experiments actually save a lot of time and cost of experiments. The tool-work thermocouple technique is the best method for measuring the average chip-tool interface

temperature during metal cutting.

N. Senthil Kumar et .al have investigated the inter relationship between work piece tool interface temperature and wear at the flank face of the cutting tool during machining hardened alloy steels using carbide cutting tools. The temperature developed during machining is critical for analysis since it effects wear of the cutting tool and increases the surface roughness of the machined surface. Experiments were designed based on Taguchi's Design of Experiment, for seven input parameters varied through three levels, an L18 Orthogonal array is chosen. The output responses are analyzed based on Signal-to-Noise ratio and statistical tool like Analysis of Variance. The relationship between the responses is analyzed and the optimum input parameters determined will reduce the interface temperature and flank wear to a considerable amount and the outcomes are, 1) As the interface temperature increases the hardness of cutting tool is lowered, Favouring the wear at the cutting edge means as the temperature increase flank wear increase. By minimizing the wear, surface roughness of the machine surface will be lowered. It means as the interface temperature increase surface roughness increase and vice a versa

Mason D. Morehead et. al [8] investigated the effect of tool wear and cutting conditions on the saw-toothed chip morphology in machining 52100 hardened 52100 bearing steel and the results shows

Chip morphology research in hard machining is believed to help unveil the segmentation chip formation mechanisms as well as promote hard machining to be a viable technology.

Samir Khamel et.al [3] investigated the effects of process parameters (cutting speed, feed rate and depth of cut) on performance characteristics (tool life, surface roughness and cutting forces) in finish hard turning of AISI 52100 bearing steel with CBN tool. The cutting forces and surface roughness are measured at the end of useful tool life. The combined effects of the process parameters on performance characteristics are investigated using ANOVA. The composite desirability optimization technique associated with the RSM quadratic models is used as multi-objective optimization approach. The results show that feed rate and cutting speed strongly influence surface roughness and tool life. However, the depth of cut exhibits maximum influence on cutting forces. The experimental and statistical approaches bring reliable methodologies to model, to optimize and to improve the hard turning process. They can be extended efficiently to study other machining processes.

Sudhansu Ranjan Das et.al [13] have investigated the effect of cutting parameters on the performance characteristics in finish hard turning of AISI 52100 bearing steel with CBN tool. The combined effects of the process parameters on two performance characteristics are investigated employing Taguchi's L9 orthogonal array and analysis of variance (ANOVA). The results show that feed rate and cutting speed strongly influence surface roughness. However, the depth of cut is the principal factor affecting cutting force, followed by feed.

S.Ben Salem et.al [6] has investigated the chip formation to obtain the optimal cutting conditions and to observe the different chip formation mechanisms. Analysis of machining of a hardened alloy, cold work steel: AISI D2 showed that there are relationships between the chip geometry, cutting conditions and the different micrographs under different metallurgical states. The results shows the microstructure reveal that the process of the chip formation gives a continuous form (shearing) in case of annealing and it occurs by crack propagation in case of quenched structure. Thus, the type and the shape of chip depend directly on the physical and mechanical properties of machined material. White layer is very brittle: cracks can easily nucleate and propagate within. At high cutting speeds, a considerable amount of fresh martensite are found within the microstructure of the chip that results in lower micro hardness values. As the cutting speed increases, the chips become relatively ductile. Thus, more the cutting speed increases more the chips are segmented microscopically. However, in a macroscopic state, the chips are increasingly in continuous form; this is probably, due to their ductility, and less effect of edge is observed. We have remarkably noticed that at a cutting speed of 50 m/min, there is a part of chip which is continuous, and the other part has relatively different forms. The method ANOVA permitted us to conclude that the cutting speed and the feed influence significantly the cutting force, whereas, their interactions do not influence this, Ft effort significantly. For the same cutting speed, Vc, the cutting pressure increases considerably when the removal rate of chips increases. The cutting force necessary to machining is decreased when machining is carried out with a higher cutting speed. All the heat sources produce maximum temperature at the chip-tool interface which substantially influences the chip formation mode, cutting forces and tool life. The heat generated was carried away by the chips rather than maintenance by work pieces. Heat was kept by the tool tip. Increase in the feed rate increases the cutting force. The removal of material take place in a short time for a given length required high cutting forces. The removal of material increased the plastic deformation and also generated more heat generation. In summary, some useful results was obtained in the present work, but more experiments are needed in order to develop the metallurgical aspects as a results understand the influence of various process parameters on surface and subsurface microstructural changes by using the detail operational parameters. As mentioned in the present work, other important metallurgical aspects, such as the grain size, grain elongation, etc., should be considered. Moreover, the main reason of the thermal effect under the worn tool condition should be studied for higher regularity segmentation as observed, primary to continuous-like chips. The chip segmentation mechanism needs clear identification since the effect of cutting conditions on machining process information depends on the chip segmentation mechanism. The shear band spacing model should be improved such as considering the work hardening effect to increase its predictive qualifications.

K.Senthil Kumar et.al[12] have performed some experiments to investigate the influence of turning parameters on the flank wear and chip morphology during a turning of Super duplex stainless steel SAF 2507 with uncoated carbide tool. Liquid CO2 which acts as a coolant, forms a gas cooled environment. The gas cooled machining in turn was compared with the dry and wet machining. Totally 18 experiments were conducted in order to measure the flank wear (Vb) with a tool makers microscope. The experiments were performed with the same cutting conditions and tool characteristics on the three methods of cooling. During the experimental procedure the removed chips were collected and evaluated together with the various cutting conditions. Using MINITAB 15 software, the optimized values of machining parameters were predicted using response surface methodology. Confirmation tests were carried out to compare the results of predicted values with the experimental value. The flank wear and the chips produced at the optimized values are analysed by scanning electron microscope from the experimental results, it was found that flank wear gets reduced in case of gas cooled machining. The cutting zone temperature and force acted during turning operation were also considerably reduced in case of gas cooled machining. Gas cooled machining (using liquid CO2 as coolant) was found to be an excellent alternative to conventional dry machining and wet machining

CONCLUSIONS

The tool-work thermocouple technique is the best method for measuring the average chip-tool interface temperature during metal cutting. Better Surface roughness is achieved as workpiece surface temperature increases.

Surface roughness influenced by feed rate, followed by depth of cut, interface temperature and lastly by cutting speed while the flanks wear influenced by cutting speed.

Depth of cut plays a minor role for both the surface roughness and flank wear especially at low feed rate and cutting speed.

With increase in interface temperature the flank wear increases. By varying the machining parameters and geometrical parameters, the interface temperature can be minimized, thus lowering the wear occurring at the flank wear. By minimizing the wear, the surface roughness of the machine surface will be lowered hence as interface temperature decrease surface roughness decrease and vice versa.

Minimum flank wear is obtained for higher depth of cut, moderate feed rate, with the increase in cutting speed, the flank wear of the tool also increases.

Segmentation frequency increases with tool wear and cutting speed, decreases with feed, and oscillates with depth of cut. When cutting at low cutting speed, the chip obtained is discontinuous, while at high cutting speed the chip obtained is serrated. Mean saw tooth segmentation spacing and tooth height decrease as flank wear progresses while the chip height of continuous portion increases;

The lowest feed rate facilitates the formation of uniform chips higher feed rates results in segmentation of the chips. Chip serration causes the formation of microwaves on the machined surface, and this increases surface roughness.

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