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Analysis of Tool Wear using Machine Vision System

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Abstract: The research paper namely "Analysis of tool wear using machine vision system" is a study conducted to devise a fool proof method to detect the level of deterioration of tool and predict the rate of tool failure. Due to advancement of automatic manufacturing processes in the last thirty years, tool condition monitoring is gaining a significant development for improvement of product quality. The advances of digital image processing techniques used in tool condition monitoring are an important research interest due to the improvement of machine vision system, computing hardware and non-tactile application. In this paper, a review of development of digital image processing techniques in tool condition monitoring is discussed and finally a conclusion is drawn about required systematic research in this field.

Keywords: on-machine tool condition monitoring, image texture analyses. gray level co-occurrence matrix, flank wear, linear support vector machine based regression.

1. INTRODUCTION

Producing superior Quality of final product is the aim of any machining process. The trend towards automation in machining has been driven by the need to maintain high product quality with improving production rate and the potential economic benefits of automation in machining are significant as well. These process improvements can be possible by monitoring and control of machining process.

. The tool wear of cutting tools has a very strong impact on product quality as well as on the efficiency of machining processes overall. Despite the current high automation level in the machining industry, a few key issues prevent complete automation of the entire turning process. One of these issues is tool wear, which is usually measured off the machine tool and is still done by hand under a toolmaker's microscope. The conventional wear measurement requires stopping the automated turning, removing the tool, measuring the tool and putting the tool back to the holder, which is a considerable time loss relative to the tool's life. Therefore, the in-line characterization of cutting tool wear is crucial for cutting cycle times and costs, as well increasing the overall efficiency of the machining process. Machine vision system consists of an area scan cam-era, an illumination system, image processor and decision making tool. Area scan camera has an advantage to capture 2D information of machined surface image within lesser time than a contact type surface profiler. Since cutting tool creates an imprint on work-piece, machined surface image carries the information about the cutting tool condition as well as the machining condition. Thus, machined surface images carry the information about the cutting tool condition with progressive machining time.

1.1 CUTTING TOOL

In the contest of machining, a cutting tool or cutter is any tool that is used to remove material from the workpiece by means of shear deformation. Cutting may be accomplished by single-point or multipoint tools. Single-point tools are used in turning, shaping, planning and similar operations, and remove material by means of one cutting edge. Milling and drilling tools are often multipoint tools. Grinding tools are also multipoint tools. Each grain of abrasive functions as a microscopic single-point cutting edge (although of high negative rake angle), and shears a tiny chip.

Cutting tools must be made of a material harder than the material which is to be cut, and the tool must be able to withstand the heat generated in the metal-cutting process. Also, the tool must have a specific geometry, with clearance angles designed so that the cutting edge can contact the workpiece without the rest of the tool dragging on the workpiece surface. The angle of the cutting face is also important, as is the flute width, number of flutes or teeth, and margin size. In order to have a long working life, all of the above must be optimized, plus the speeds and feeds at which the tool is run.

1.2 MACHINE VISION

Machine vision (MV) is the technology and methods used to provide imaging-based automatic inspection and analysis for such applications as automatic inspection, process control, and robot guidance, usually in industry. Machine vision is a term encompassing a large number of technologies, software and hardware products, integrated systems, actions,

methods and expertise. Machine vision as a systems engineering discipline can be considered distinct from computer vision, a form of basic computer science. It attempts to integrate existing technologies in new ways and apply them to solve real world problems.
Definitions of the term "Machine vision" vary, but all include the technology and methods used to provide imaging-based automatic inspection and analysis for such applications as automatic inspection and robot and process guidance in industry. This field encompasses a large number of technologies, software and hardware products, integrated systems, actions, methods and expertise. Machine vision as a systems engineering discipline can be considered distinct from computer vision, a form of basic computer science; machine vision attempts to integrate existing technologies in new ways and apply them to solve real world problems in a way that meets the requirements of industrial automation and similar application areas. The term is also used in a broader sense by trade shows and trade groups such as the Automated Imaging Association and the European Machine Vision Association. This broader definition also encompasses products and applications most often associated with image processing. The primary uses for machine vision are automatic inspection and industrial robot/process guidance.

1.3 OBJECTIVE

To study tool wear analysis to predict tool failure in an automatic fashion using machine vision system to capture data and perform analysis using ANSYS software.
To identify tool wear parameters and methods to study the tool wear parameters by mathematical models.
The mathematical models developed to study tool wear must be implemented in ANSYS software to implement automatic system to study tool wear.

2. DIFFERENT MECHANISMS OF TOOL WEAR

2.1 END MILL WEAR MECHANISM

Recently, the carbide-coated end mill is widely used to machine high-hardness materials and resist the high heat generated in the cutting of high speed machining. The wear parameters of the carbide-coated end mill san be divided into two: the mechanical parameters like abrasion and adhesion that are the thermal-dynamic wear parameters influenced by the thermally loaded motion acting between the tool and the workpiece; and the chemical parameters such as diffusion and oxidation stemming from the activation of the chemical responses due to temperature rise.
The temperature of cutting edge goes up to 1000 °S in high speed machining therefore oxidation becomes one of the major causes of the end mill wear. And the wear process is caused due to the oxide between the workpiece and the coating layer of the end mill while the adhesion process is caused by the excessive wear of the flank face of the cutting edge. In particular, when the coating of the tool tip is separate it causes an abrupt increase in the temperature of the cutting edge, resulting in the sudden occurrence of shipping or breakage of the tool.
In terms of the wear pattern of the tool, the ball end mill mostly shows central wear and flank wear while the flat end mill displays flank wear. When the feed rate is low, below 1 m/min in particular, the central wear takes a form similar to the built-up-edge. The flank wear occurs when the feed rate is high and it takes place especially in the cutting edge.
categories of quality characteristic in the analysis of the S/N ratio, i.e. the lower- the-better, the-higher-the-better, and the-nominal-the-better. The S/N ratio for each level of process parameter is computed based on S/N analysis. Regardless of the category of the quality characteristic, a grater S/N ratio corresponds to better quality characteristics.

2.2 EXPERIENTAL EQUIPMENT

This study is used in the Makino V33 high speed machining center and flat end mill to generate the artificial wear of tool wear. The side of the wear. First, the traditional optical microscope was used. To minimize the error components occurring when measuring with the optical microscope, a system using an exclusive jig and a CCD camera was constructed to measure the tool wear and the shortcomings of the lighting part of the CCD camera and the exclusive jig were improved and a system that enables on the machine measuring was developed and employed.

2.3 EXPERIMENTAL METHOD

First of all, to generate the artificial wear of the tool, the side machining of the workpiece was conducted with a flat end mill and a high-speed machine. In particular, the experiment conducted in each system did not use the table of orthogonal arrays of Taguchi method but used a one-parameter experiment method in which an experiment is son-dusted on only one parameter to find an optimal condition while other parameters are fixed. Based on the optimal condition, a system with minimized error components was developed and the error component reducing effect was ascertained through repeated experiments.
The artificially generated tool wear was measured with the traditional measuring method using a optical microscope. The tool was detached from the tool holder and it was observed by a optical microscope. The shape was captured with an image grabber and it was measured on the monitor using a precision table. The flank wear of the clearance face was measured and the corner of the end mill was excluded. The size of the tool wear was calculated by subtracting the

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unworn size after machining from the size of the clearance face before machining. And measuring was performed using four tools that had different degrees of wear to ensure the reliability of the measurements. To observe the influences of the illumination intensity, which is one of the error components in measuring tool wear, measuring was conducted while adjusting the intensity of illumination by stages from 40 to 60 W. It was repeated five times and the results were compared to determine an optimal illumination condition.
A system using a CCD camera and an exclusive jig was created to enable on the machine measuring without detaching the tool under the optimal illumination condition selected in the optical microscope system. In this system, the experiment was first conducted by adjusting the angle of illumination up and down to observe the influences of the changes in the lighting angle, in addition to the experiment with the changes in the angle to the left and right. After obtaining the tool wear image through the CCD camera and image board, the standard line was defined on the PS monitor and the size of the tool wear was measured while moving the feed table. And under the optimal condition determined based on the experiment results, the experiments were conducted five times for the four end mills having different wear sizes to confirm the error reduction effect just like the optical microscope system.
Finally, a new exclusive system was constructed under the optimal condition determined in the above two experimental systems. In the new exclusive system, an image measuring program called 'image pro plus' was used to exclude subjective views of the measurer when measuring tool wear. And a light course was inserted to reduce error components from the lighting angle. In addition, the jig was made to rotate 90° so that the measuring of the base as well as the side of the end mill may be possible, enabling a wide range of applications. Also in this system, the experiments were carried out five times for the four end mills having different wear sizes to confirm the effect of reducing error components.

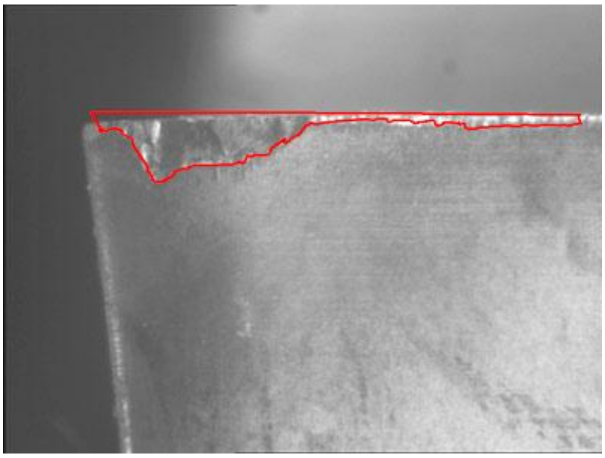

Fig2.1. Tool worn at the edge

A tool wear measuring system using a CCD camera and an exclusive jig was constructed to reduce the time delay caused by the detachment of the tool from the holder that is necessary in the case of the optical microscope system, to decrease the influences of the illumination intensity. To reduce the error components depending upon the position of the CCD camera that san occur in the measuring system using the traditional CCD camera and a magnetic jig. And that to make on the machine measuring possible. In this system, the intensity of illumination was fixed at 60 W that was selected as the optimal condition in the one-parameter experiment using a tool wear system. To reduce the measuring errors occurring in repeated measurement, the position was precisely designated so as to obtain a clearest image through a preliminary experiment with the operation of the sub-program of the machine after machining.

First of all, experiments by changing the lighting angle upward and downward were conducted but images could be obtained only between 30° and 40° due to the differences in the magnification and lens focus distance of the CCD camera. Following several times of trial and error, a clearest image could be obtained at the lighting angle of 36.3°. With the top and bottom lighting angles fixed at 36.3°, the tool wear image was obtained by changing the lighting angles to the left and right. As a result, as Fig. 2.2 shows, when the lighting comes from the front side, a definite image that enables the most precise tool wear could be obtained. This is because it becomes difficult to obtain an image due to the shade created by the characteristic of the end mill having a helix angle when the lighting angle gets deviated from the center.

When the lighting comes from the lower part of the center at an angle of 36.3°, the tool wear was measured and the value was converted into the S/N ratio. The error components occurring from repeated measuring was reduced to a great extent when the wear was measured with the tool wear system using a CCD camera and an exclusive jig compared with those measured with the optical microscope system.

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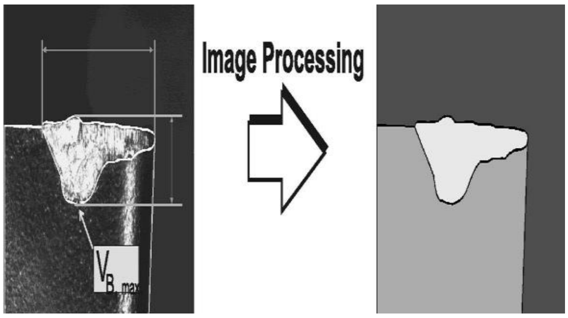

Fig 2.2.Optimized adjustment of illumination is a prerequisite to extract flank wear contours reliably

In addition, considerable time saving was possible because the on the machine measuring became possible without detaching the tool. Some examples of different types of tool wear are shown in the Fig 2.3.

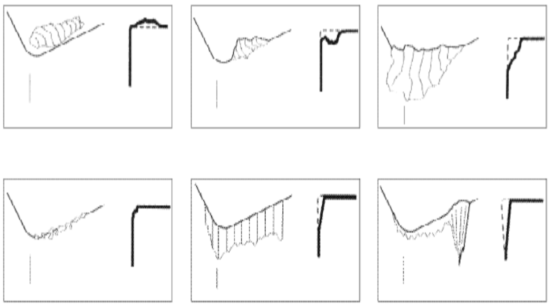

Fig 2.3. Some examples of different types of tool wear

Fig.2.3 shows as an example the image series of a cutting tool, consisting out of six images. The images of this series vary in quality considerably, although the illumination has changed only a little bit. This series shows all the undesired effects and artifacts, which make the automized analysis of images of worn cutting tools so difficult. Because of these artifacts there are 'false' contours in the image, by which dimensional measurements are mislead. As a consequence, in many cases the derived results, for example the extension of the flank wear area, are wrong. Also, standard image processing algorithms like thresholding are not adequate solutions.

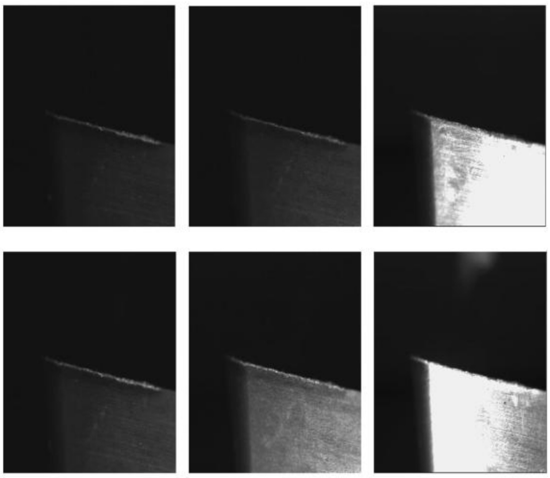

Fig 2.4. Images of worn tool with slightly varied illumination.

2.4 FLANK WEAR AND NOTCH WEAR

The product quality is principally dependent on the machined surface. The surface quality is mainly dependent on the cutting tool wear. Cutting tool wear is dependent upon cutting conditions, work and tool material, tool geometry. There are four modes of cutting tool wears, such as, adhesive wear due to shear plane deformation, abrasive wear due to hard particles cutting, diffusion wear due to high temperature and fracture wear due to fatigue. Four principal types of wear occur in cutting tool and they are nose wear, flank wear, crater wear and notch wear. Flank wear occurs due to rubbing between tool flank surface and work piece. Flank wear is specified by maximum flank wear width (VBmax) or mean

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flank wear width (VBmean). Tool life criterion is mainly dependent on the VBmean. Cutting tools are experiencing three stages of wear viz. initial wear (during first few minutes), steady-state (cutting tool quality slowly deteriorates) and severe wear (rapid deterioration as the tool reaches the end of its life). Crater wear are produced at the due the high temperature for chip-tool interaction. This wear is characterized by the crater depth and crater area.

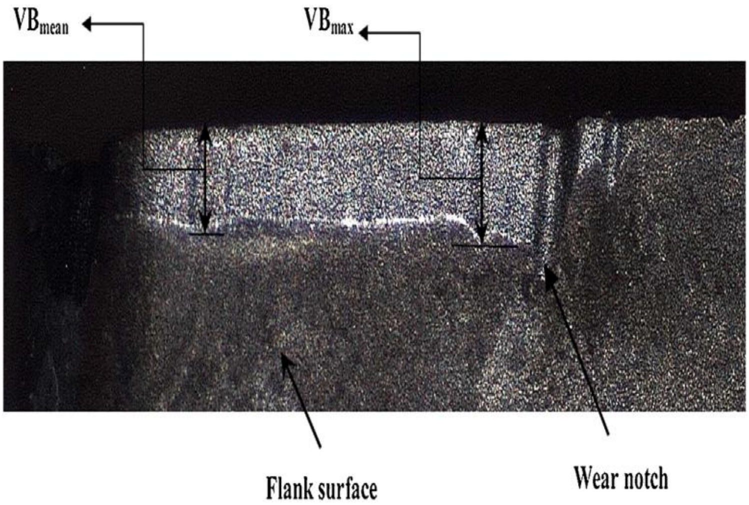

Fig 2.5. Flank wear and notch wear from the microscopic image of a tool insert.

3. RESULTS

3.1 PROPERTIES

Table 4.1. Thermal and mechanical properties cutting insert and tool holder

Property	Cutting Insert and Shim Seat	Tool Holder
Material	Tungsten Carbide	AISI 1045 Steel
Density(kg/m3)	15000	7850
Yang module (Gpa)	800	207
Poisson's ratio	0.2	0.3
Specific heat (J/kg.deg C)	203	452
Thermal Conductivity (W/ m.deg C)	33+0.015T	45-0.0225T

3.2 WEAR AREA

Table 3.1. Measured features of the wear area

No. of pass	Flank wear			Nose wear		
	Area(mm2)	Equivalent Diameter	Centroid	Area(mm2)	Equivalent Diameter	Centroid
1	0.2777	0.5922	0.0333	0.2667	0.5803	0.0667
2	0.3669	0.6807	0.1000	0.4176	0.7262	0.1333
3	0.5465	0.8308	0.1333	0.5344	0.8215	0.1389
4	0.6523	0.9077	0.1667	0.6247	0.8883	0.1667
5	0.7625	0.9813	0.1791	0.633	0.8883	0.2000
6	0.8595	0.9813	0.2195	0.8485	1.0352	0.2333

Table 3.2. Average temperature in the tool and chip in tool-chip contact area

Cutting speed (m/min)	Chip	Tool	Heat Flux (FEM)
105	734	585	20.9 MW/m2
150	753	619	24.7 MW/m2
210	785	672	29.4 MW/m2

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3.3 TEMPERATURE DISTRIBUTION (ANSYS)

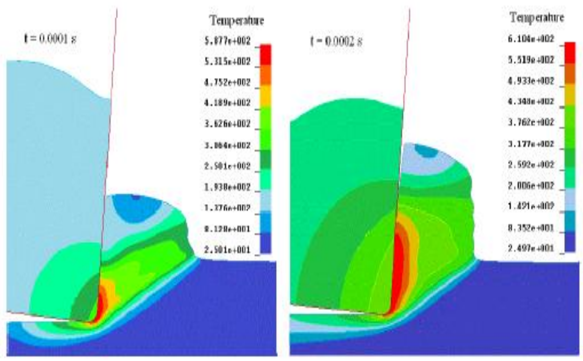

Fig 3.1.a Temperature at t =0.0002s Fig 3.1.bTemperature at t = 0.0001s

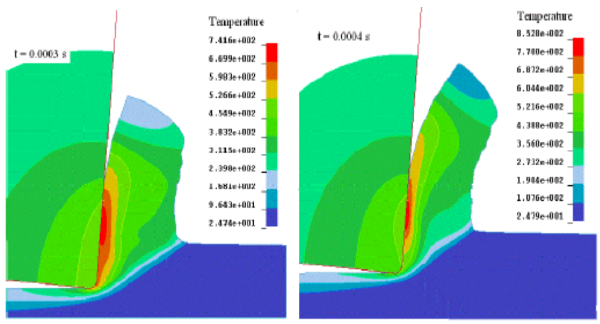

Fig 3.1.c Temperature at t = 0.0004s Fig3.1.dTemperature at t=0.0003s

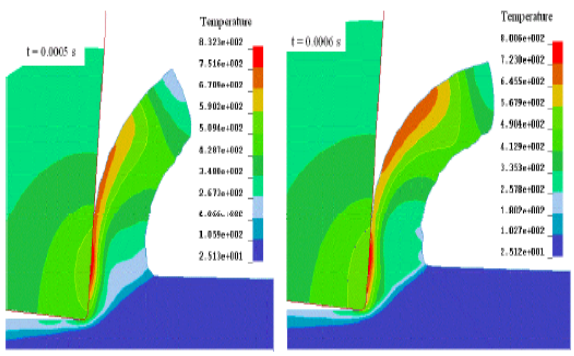

Fig 3.1.e Temperature at t = 0.0006s Fig 3.1.f Temperature t= 0.0005s
Fig 3.1 Temperature counters in various simulation times

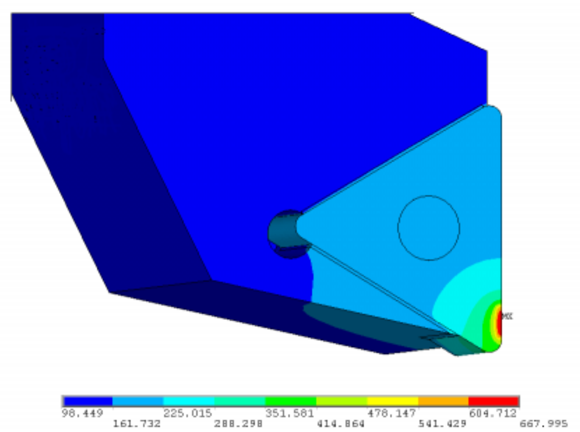

Fig 3.2 Temperature distribution in three dimensional cutting tool

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Table 3.3. Thermal analysis results

Cutting speed (m/min)	**Average temperature in interface (FEM)**	**Tool Chip contact length**	**Thermal contact conductance**
105	653	0.67	137KW/m2.°C
150	684	0.60	182KW/m2.°C
210	725	0.52	260KW/m2.°C

Table 3.4 Temperature distribution for different speeds at regular intervals

Cutting Speed	**105**	**150**	**210**
Time(sec)	**Temperature(deg C)**		
0	25.64889	32.75556	85.74902
30	25.71722	32.82389	86.73709
60	25.78556	32.89222	87.72515
90	25.85389	32.96056	88.71322
120	25.92222	33.02889	89.70129
150	25.99056	33.09722	90.68936
180	26.05889	33.16556	91.67743
210	26.12722	34.23356	92.6655
240	26.19556	36.44367	93.65357
270	26.26389	47.23365	94.64163
300	26.33222	40.29785	95.6297
330	26.40056	41.28592	96.61777
360	26.46889	42.27399	97.60584
390	26.53722	43.26206	98.59391
420	26.60556	44.25013	99.58198
450	26.67389	45.2382	100.57
480	26.74222	46.22627	101.5581
510	26.81056	47.21434	102.5462
540	26.87889	48.2024	103.5343
570	26.94722	49.19047	104.5223
600	27.01556	50.17854	105.5104
630	27.08389	51.16661	106.4985
660	27.15222	52.15468	107.4865
690	27.22056	53.14275	108.4746
720	27.28889	54.13082	109.4627

3.4 SHEAR DISTRIBUTION (ANSYS)

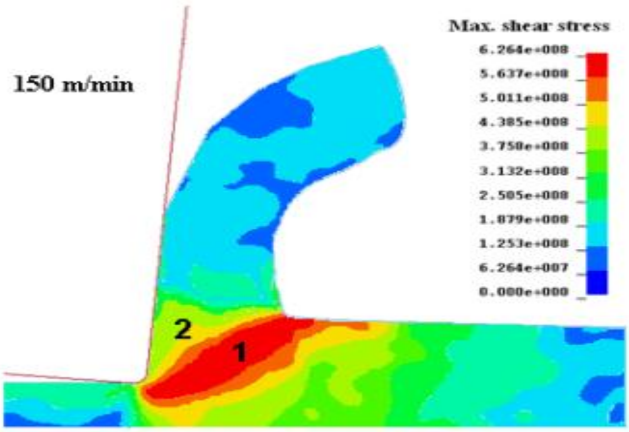

Fig 3.4. Shear distribution at speed of 150 m/min

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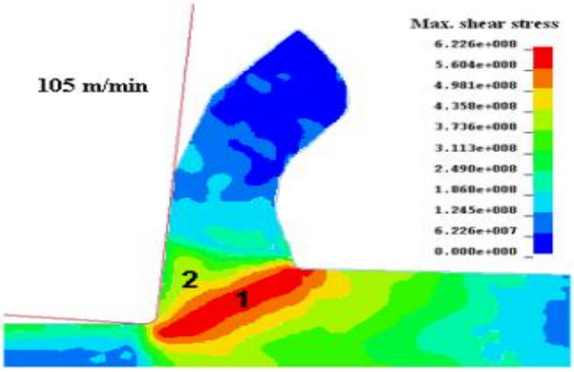

Fig 3.5. Shear distribution at speed of 105 m/min

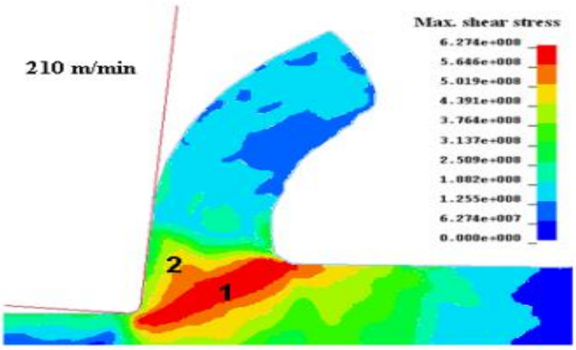

Fig 3.6. Shear distribution at speed of 210m/min

3.5 GRAPH

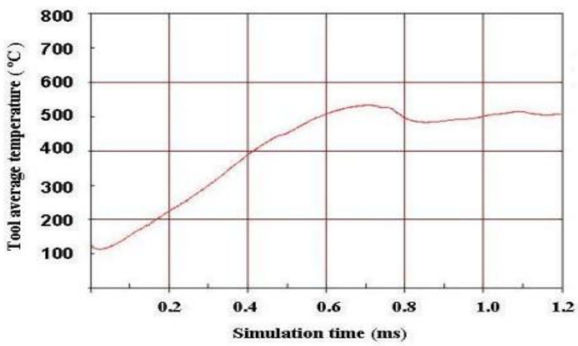

Fig 3.7. Tool average Temperature vs Simulation time

4. CONCLUSION

Machined surfaces are recitation the change in tool put on with machining time through the changes of its waviness, feed mark information and roughness. In this work, Con, Dis and SDM are extracted from GLCM-based texture analysis of machined surface images to obtain the waviness related information through spatial correlation of pixels. TAP and NzeroCM are the features extracted from VT-based texture analysis of machined surface images for extracting the changes of feed mark related information through detailed geometrical analysis. DWT-based texture analysis is also applied on machined surface images to obtain the information of change in roughness due to an increase in tool flank wear through Ga, GRMS and Energy in space–frequency localization, which can-not be possible using other methods. All these three information is utilized to predict tool flank wear successfully. Also a comparison of prediction performance using each single texture analysis technique and using all three texture analyses together are performed in this study. Enhancement of prediction performance using all three texture analyses together can be depicted from this comparison. These eight features can successfully predict tool flank wear using ε -SVR technique. Thus, a complete machine vision based approach for monitoring of cutting tool condition is proposed in this work.

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