The effects of tool workpiece relative position engineering essay

Engineering

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Abstract

High speed milling(HSM) is known as an advanced machining process increasingly used for modern materials such as nickel or cobalt based superalloys. In this paper, the effect of machining parameters including cutting velocity, feed rate and depth of cut on tool wear, material removal rate(MRR), cutting forces and power in symmetric and asymmetric face milling of cobalt-based superalloy with PVD coated and uncoated inserts has been studied. Aiming to achieve this objective, 180 milling experiments were carried out with different machining conditions. The settings of milling parameters were determined by using general full factorial design method. The analysis of variance (ANOVA) was employed to analyze the effect of machining parameters on the cutting forces. Cutting speeds’ effect on cutting forces hasn‘ t been observed. The depth of cut has greater influence on the resultant cutting forces. Experiments showed that the Fz component is the highest for symmetric face milling in the table system of cutting forces. The depth of cut and feed rate have greater influence on the resultant cutting forces in the symmetric and asymmetric face milling processes for PVD coated and uncoated inserts. It is found that if feedrate and depth of cut are increase then cutting power would increase and asymmetric milling strategy is superior as compare to symmetric milling for more cutting power. Additionally, the end of tool life is more frequently caused by chipping and breakage of the edge rather than regular tool wear

because face milling is an interrupted cutting operation. Keywords: Face milling, Cutting Forces, Specific Energy, Cutting Power, Wear, MRR, ANOVA

1. Introduction

Stellites are cobalt based super alloys. The cobalt-base superalloys have their origins in the Stellite® alloys patented in the early 1900's by Elwood Haynes. By virtue of their excellent physio-mechanical properties, stellites are highly regarded engineering materials. Stellites have high corrosion resistance and wear resistance properties. Cobalt-based casting alloys continue to be an important part of industrial processes and products. Today, cast cobalt alloys play an important role in the performance of aero- and land-based gas turbines[1](Cm-group). Cobalt-base superalloys are used extensively in applications requiring good wear resistance, corrosion resistance and heat resistance [2, 3]. Also this material is a preferred material to see in nuclear and aerospace industry [4-6]. Currently use of Stellite alloys has extended into various industrial sectors; pulp and paper processing, oil and gas processing, pharmaceuticals, chemical processing and medical application and the need for improving information regarding corrosion of Stellite alloys has increased. It has been recognised that processing changes, which affect the microstructure of Stellite alloy, will most probably affect the corrosion performance [7]. Co-based superalloys rely primarily on carbides formed in the Co matrix and at grain boundaries for their strength and the distribution, size and shape of carbides depends on processing condition. Solid solution strengthening of Co-base alloy is normally provided by tantalum, tungsten, molybdenum, chromium and columbium [8-10]. These alloys existing in a variety of more than 20 commercially available today, being used extensively in high temperature applications requiring superior wear resistance, corrosion resistance and heat resistance [11, 12]. The difficulty of machining cobalt-based superalloy brings forward two basic problems; (I) Short tool lives due to the work hardening and attrition properties of the superalloy, (II) Severe surface of machined workpiece due to the heat generation and the plastic deformation. In order to achieve adequate tool lives and surface integrity of the machined surface, the study of cutting forces, which are a criterion of selecting the reasonable machining conditions and parameters, is crucial. It is difficult to machine superalloys. Machinability of superalloys did not improve as much as cutting tools even new improvements of nowadays in cutting tools. Only by minimizing tool-chip connection area, providing sharp cutting edge and minimizing cutting depth, superalloys can be machined. Another method is to provide minimum heat extraction, slow cutting speed and feed rate in order to ease the machining of superalloys [5]. There are several studies on surface milling [13-15]. These studies show that the bigger feed rate and cutting depth, the bigger the cutting forces. Cutting forces are directly related to increase of cutting speed. Bhattacharyya et al. [16] examined the behaviour of three different carbide inserts during face milling tests of low alloy steel and martensitic stainless steels. Pekelharing [17] states that one of the reasons of the extreme chipping of the carbide inserts used in machining processes is a phenomenon he called " foot forming". Gu et. al. [18] have investigated the behaviour of 4140 preheat treated steel for face milling using uncoated and coated inserts. D'Errico et al. [19] tested four different types of cermets inserts during face milling of AISI 1045 steels.

Cutting speed is a parameter directly affecting tool life. In asymmetric milling is better than ones in symmetric milling [14]. Main aim of asymmetric milling is to use a cutting tool whose cutting diameter is bigger than milling width (¾ D recommended). In asymmetric milling turning axis and workpiece axis are eccentric. In other words, if while machining cutting tool's axis is not moving in the middle of workpiece, this process is called as asymmetric milling as shown in Figure 1 [14, 20]. Figure 1. Symmetric (a) and asymmetric face milling (b)Comparing the contact angle () between the symmetric and asymmetric positions (eqs. 1 and 2), we have:[14](1)(2)where the j parameter measures the distance between the end of the cutter diameter and the beginning of the workpiece, as can be seen in Figure 1. A first distinction is usually made between asymmetric and symmetric milling processes. The main group of asymmetric cuts is subdivided into down milling and up milling operations which characterized either by a smooth cutting edge entry or by a smooth exit. This type of milling strategy leads to force spectra without zeros. Symmetric cutting combines the disadvantages of both asymmetric cuts. Therefore the entry impact of down milling and the harmful exit of up milling give severe working conditions. In this paper, symmetric and asymmetric milling processes are compared from cutting forces, power, MRR, tool wear and chip formation perspective by using PVD coated tool and uncoated tool hard metal inserts which is obtained dependent on feed rate, cutting velocity and cutting depth.

2. Experimental Set-up and Force Measurements

These experiments are done on CNC milling machine (9 kW, ability to linear and circular interpolation on three axes, programmable in ISO format for SI and English units). Possible parameter values are selected among recommended ISO face milling standard values [21]. Cutting forces, power, MRR and tool wear are investigated by considering the some factors affecting cutting velocity, feed rate and cutting depth. Experimental setup is shown in Figure 2. Figure 2. Experimental setup

2. 1 Machining Conditions

Design of experiments is a powerful analysis tool for modeling and analyzing the effect of process variables over some specific variable which is an unknown function of these process variables [22]. In a factorial design, a variable range is divided into levels between the lowest and the highest values [23]. A general full factorial design method was used. In this study, three independent variables, such as depth of cut (a), cutting velocity (Vc) and feed rate (f) had total 180 experimental runs. Ranges for process parameters are shown in Table 1. Table 1. Levels of the variables (a) and cutting conditions (b) for milling processes

2. 2 Cutting Tools and Material Properties

In this work, Stellite 6 superalloy is machined. TiN/TiCN/TiAlC coated F40M tool and uncoated H25 tool are used[24]. They are preferred for rough milling, slow feed rate and slow cutting speed. Especially, it is preferred for machining of superalloys. Because it is difficult to machine superalloys, tool holder which cutting tools are connected (four inserts are connected to holder) is selected to be suitable to inclined machining. Cutting tools are connected to tool holder as the way positive cutting can be done. 0. 18 mm chamfered cutting tool having 20° angle is selected in order to prevent breaking of cutting tool on instant cutting process and cutting edge at the top of this tool are selected as knurled in order to distribute stresses formed on cutting process. Cutting tool has 26° angle toward backward. Also, cutting tools are designed as having 2° angle with contact length while cutting. PVD coated are well at fine medium rough milling. Among them, TiN/TiCN/TiAlC coated F40M is recommended for steels, aluminum, micro-grain materials and superalloys. The coating enhances the wear resistance of the cutter. The commercial coatings composed using PVD method are TiN, Ti (C, N) and (Ti, Al)N (İseco tools)-r. These coated tools are recommended for with low fed rate where high edge toughness and intermediate cutting speed is required [15]. Because heat extraction is inevitable in cutting process, cutting corner of contact edge causes thermal stresses and will become blink in a short time. This affect could be prevented by coating the surface of cutting tool. The heat comes from tool-chip contact will be reflected by coated tool to chip. Used cutting tools are PVD coated tools. Coating depth is 7-8 🕴m. SEM micrographs of microstructure of cutting tools are shown in Figure 3. Figure 3. Geometry and microstructure of cutting insertsCutting test was performed on precipitation with final dimensions 50x70x120 mm. Cobalt based superalloy Stellite 6 is selected as workpiece material in experiment. Chemical composition of material is given at Table 2. Cobalt is a soft material and easily worn. But, increasing alloy material’s content gives better mechanical properties. Change in carbon and tungsten contents is the main difference of Stellite 6 superalloy. Carbon content affects the ductility, resistance to corrosion and strength properties of material. Table 2. Chemical composition and mechanical properties of Stellite 6

2. 3 Force Measurements

In face milling, more than one cutting tool is forming chip in the meantime. So, cutting forces acting on each tool is decreasing. Cutting width and chip formation is continuously changing in milling. Face milling is a highly efficient common process in machining. Figure 4. Variation of cutting force direction in symmetric and asymmetric milling [36]In symmetric milling, vibration can occur due to this variation of the direction of the force, as can be seen in Figure 4A. This is worse when only one edge is engaged in the cutting at a time. As can also be seen in Figure 4B, asymmetric cutting minimizes this variation of force and, thus, minimizes the vibration. Another aspect to be noted related to cutting forces and relative positions of tool and workpiece is that, for a certain feed per tooth, the symmetric position will result in a larger average chip thickness due to the smaller tool–workpiece contact angle. The experimental set-up consisted of Kistler three-component force measurement dynamometer platform , Kistler charge amplifier and data storage system (See Figure 2 for the schematic of the experimental set-up). The effect of these parameters on the maximum resultant cutting force, which was evaluated from the individually averaged XYZ signals. All experiments show that the Fz component is the highest for symmetric face milling in the table system of cutting forces. The reason is thought to be that cobalt-based super-alloy has high yield strength. Fz values shown in Figures 5 and 6 for PVD coated and uncoated inserts. Figure 5. Fz cutting forces for PVD coated inserts in the face milling processesFigure 6. Fz cutting forces for uncoated inserts in the face milling processes

3. Analysis of MRR using B-Rep Technique

In this section, solid modeler based cutter/workpiece engagement model and a model for the calculation of real MRR was presented in face milling process. The information about machining process can be obtained using developed approach based on B-rep solid modeling. Once the in-process workpiece is obtained for each CL point, the contact area and surface between the cutter and workpiece can be extracted by using CAM software API application. The MRR and machining type are closely relevant.(r) MRR value should be calculated via determining the intersection cutter swept volume and workpiece during the tooth passing period (tp). This requires finding the area of the cutting tool that is in contact with the workpiece and then sweeping that area in the direction of the tool movement a portion equal to the feed per teeth. This swept volume is the average MRR and then approximated through integrating the chip thickness over the engagement area. This volume is divided by the tooth passing frequency (tp) to determine the average material removal rate[28, 29]. Figure 7. Chip geometries for asymmetric milling (a) and symmetric milling (b)Figure 8. MRR values for asymmetric and symmetric millingThe Figure 8 show the chip volumes calculated for symmetric milling strategies was bigger than asymmetric milling strategies. Material removal rate in machining process is an important factor because of its vital effect on the industrial economy. Increasing the feedrate and depth of cut leads to an increase in the amount of MRR. The analysis of the experimental observations highlights that MRR in face milling process is greatly influenced by depth of cut. It is found that if feedrate and depth of cut are increase then MRR would increase and symmetric milling strategy is superior as compare to asymmetric milling for more MRR. It is observed from the direct effects, depth of cut plays more vital role on MRR than other two parameters. Figure 9. MRR values in function of feed rate for milling strategies

Effect of Milling Strategies on Spindle Power Consumption

Machining power is an essential parameter affecting the tool life, dimensional accuracy, and cutting efficiency. Although one may wish to describe the energy per unit volume needed to form the chip, machine tools are typically rated in terms of power. Unit (or specific) power values can be calculated by dividing the power input to the process. The specific power, Psp, is a measure of the difficulty involved in machining a particular material and can be used to estimate the total cutting power, Pavg. The specific power is the power required to remove a unit volume per unit time. The material removal rate can be computed as the uncut area multiplied by the rate at which the tool is moved perpendicular to the uncut area. There are many Standard sources for specific power values for a variety of materials. Given the value of specific power (Psp) for different material and cutter combinations from handbook[30] (MCSD, 1980) and MRR calculated by using CAM software in-house API application. , the average power (Pavg) consumed is given by: Pavg = Psp × MRR (MRR = Volume removed/time) (3)where MRR is the material removal rate, or volume of material removed per unit time. Unfortunately, machine tools are not completely efficient. Losses due to component wear, friction, and other sources prevent some power from reaching the tool. The machine tool efficiency is an indicator of losses from the motor which directly transmits the torque to the cutting tool.

This value is supposed via the suppliers to be at least 85%(ή).(IJENS-tangential forces-r-kaynak göster) Therefore, the gross power, Pg, needed by the motor can be defined as: Pg = P/ή (4)Sivarao, Fairuz Dimin, T. J. S. Anand, A. Kamely, Kamil, Investigation of Tangential Force, Horsepower and Material Removal Rate Associating HAAS CNC Milling, Al6061-T6511 Work Material & TiAlN Coated End Mill Tool, International Journal of Basic & Applied Sciences IJBAS-IJENS Vol: 10 No: 04where is the efficiency of the machine tool. The variation of cutting power and feedrate with depth of cut has been shown in Figure 10 for symmetric and asymmetric milling with 85% MTE. The results of cutting power for various depths of cut and MTE are compared as can be seen in Figure 10. From Figure 10, it is observed that increase in depth of cut and feedrate(or MRR) tends to increase the cutting power. It is found that if feedrate and depth of cut are increase then cutting power would increase and asymmetric milling strategy is superior as compare to symmetric milling for more cutting power. Figure 10. Machining power in function of feed rate for different cutting conditionsThe variation of cutting power and feedrate with various MTEs has been shown in Figure 11 for symmetric milling with constant DoC(2. 5 mm). From Figure 11, it is observed that increase in MTE value tends to decrease the machining power. Figure 11. Machining power in function of feed rate for different MTE valuesThe specific energy model can be used to estimate the total energy consumed while cutting. Diaz, et al. [31, 32] and Kara, et al. [33] developed a method for modeling the specific energy of milling centers. Since parts are inherently complex, the goal of this research was to assess the accuracy of a machine tool energy characterization model in estimating the energy consumed to manufacture a part with varied material removal rate. The optimal MRR can be determined using standard process parameters based on the work piece material and the appropriate cutting tool for the feature creation. Therefore, the total energy consumption while cutting can be calculated by multiplying the specific energy estimate by the volume of material removed. The total specific energy, which accounts for cutting and air cutting power demand, was indeed found to have an inverse relationship with the MRR. The impact of the cutting power demand on the specific energy was minimal since at high loads (i. e. at high MRR's) the machining time decreased significantly. Figure 12. Average specific energy demands as a function of MRRThe specific energy decreases rapidly until a MRR of approximately 57mm3/s and 40 mm3/s is reached for symmetric and asymmetric milling, respectively. For MRR's lower than 57 mm3/s and 40 mm3/s, a slight increase in the material removal rate causes a sharp drop in the specific energy because machining time improves dramatically for symmetric and asymmetric milling, respectively.

Analysis of variance (ANOVA)

ANOVA helps in formally testing the significance of all main factors and their interactions by comparing the mean square against an estimate of the experimental errors at specific confidence levels. The percentage contribution P can be calculated as below:(5)where SSd is the sum of squared deviations. ANOVA results are illustrated in Table 3-4. Statistically, there is a tool called an F test named after Fisher [25] to see which design parameters have a significant effect on the quality characteristic. In the analysis, F- ratio is a ratio of mean square error to residual, and is traditionally used to determine significance of a factor.

5. 1 ANOVA for symmetric face milling

P value reports the significance level (suitable and unsuitable) in Table 3. Percent (%) is defined as the significance rate of process parameters on cutting forces. The percent numbers depicts that depth of cut and feed rate have significant effects on cutting forces. It can observed from Table 3 that depth of cut (DoC) and feed rate (f), affect cutting forces by 37, 48%, 34, 26% in the symmetric face milling of the Stellite 6 material for PVD coated inserts, consecutively. Cutting speeds’ effect on cutting forces hasn‘ t been observed for PVD coated and uncoated inserts. Table 3. ANOVA for cutting force using coated insert in the symmetric face millingFigure 13. Main effects plot- data means for symmetric face milling using coated insertIt can observed from Table 4 that depth of cut (DoC) and feed rate (f) affect cutting forces by 39, 84%, 10, 3% in the symmetric face milling of Stellite 6 material for uncoated inserts, consecutively. Cutting speeds’ effect on cutting forces hasn‘ t been observed for PVD coated and uncoated inserts. Table 4. ANOVA for cutting force using uncoated insert in the symmetric face millingFigure 14. Main effects plot- data means for symmetric face milling using uncoated insert

5. 2 ANOVA for asymmetric face milling

It can observed from Table 5 that depth of cut (DoC) and feed rate (f) affect cutting forces by 60, 66%, 12, 23% in the asymmetric face milling of Stellite 6 material for uncoated inserts, consecutively. Cutting speeds’ effect on cutting forces hasn‘ t been observed for PVD coated and uncoated inserts. Table 5. ANOVA for cutting force using uncoated insert in the asymmetric face millingFigure 15. Main effects plot- data means for asymmetric face milling using uncoated insertIt can observed from Table 6 that depth of cut (DoC) and feed rate (f) affect cutting forces by 48, 58%, 21, 41% in the asymmetric face milling of Stellite 6 material for PVD coated inserts, consecutively. Table 6. ANOVA for cutting force using coated insert in the asymmetric face millingFigure 16. Main effects plot- data means for asymmetric milling using coated insert

Tool Wear in the Face Milling of Stellite 6

Tool wear is the result of load, friction, and high temperature between the rake face of tool and the workpiece. Several wear mechanisms can occur during machining processes: adhesive wear, abrasive wear, diffusion wear, oxidation wear, and fatigue wear [18]. In the face milling, the end of cutter life is often produced via frittering, mechanical and thermal cracks and fracture of the edge because milling is an non-continuous cutting operation, where cutter edge recurrently enters and exits the milled part in a short span of time[14-r]. If the cutting edge appears jagged or there are cavities, it means that chipping has occurred. Small chips breaks off from the tool cutting edge on account of mechanical impact, transient thermal stresses due to cycled heating and cooling in intermittent machining operations, chatter and excessive cratering and flank wear[26]. The mechanical impacts are also frequent in milling, due to the interrupted cutting inherent to it, and this may also generate cracks, chipping and cutting edge breakage. This is why it is necessary to choose a cutting tool with sufficient toughness and a rigid cutting edge, and to place the tool in a suitable position relative to the workpiece, in order to make the impacts less harmful to the tool [34, 35]. Chipping may also occur when the insert is leaving the cut in each revolution. The patterns of tool wear were showed in Figure 17 for PVD coated and uncoated tools in the symmetric and asymmetric face milling processes, respectively. Figure 17. Tool failures for symmetric and asymmetric milling

Conclusions

In this work, the effect of machining parameters including cutting velocity, feed rate and depth of cut on tool wear, MRR, cutting forces and power in symmetric and asymmetric face milling of stellite 6 with PVD coated and uncoated inserts has been studied. Aiming to achieve this objective, 180 milling test were carried out with different machining conditions. The settings of milling parameters were determined by using factorial design method. The level of importance of the milling parameters, tool coating and milling strategies on the resultant cutting force is determined by using ANOVA. For the experimental results presented on the influence of machining parameters, coating and milling strategies on resultant cutting forces, tool wear and chip morphology in the face milling of Stellite 6 material, the following conclusions can be mentioned: The depth of cut has greater influence on the resultant cutting forces in the symmetric and asymmetric face milling processes for coated and uncoated inserts. From Tables 3-6 it can be realized that the depth of cut (37, 48 %, 39, 84 %, 60, 66 %, 48, 58 %) and feed rate (34, 26 %, 10, 3 %, 12, 23 %, 21, 41 %) factors have statistical and physical significance on the obtained resultant cutting forces, respectively. All experiments show that the Fz component is the highest for symmetric face milling in the table system of cutting forces. The reason is thought to be that cobalt-based super-alloy has high yield strength. Cutting speeds’ effect on cutting forces hasn‘ t been observed. The cutting speed does not present statistical and physical significance on cutting forces. Cutting speed is a factor accelerating tool wear. Cutting forces are sometimes increasing with cutting speed and sometimes decreasing. In the face milling processes, the end of cutter life is often created via frittering, mechanical and thermal cracks and fracture of the edge rather than uniform wear(Brasil-r). It is noted that on symmetric milling, tool wear and chipping more than asymmetric milling. Because, exiting from the workpiece with a thick chip can cause a drastic reduction in tool life when using carbide. The chip being formed lacks support at the final point of cut. It will try to bend rather than be cut and as it changes direction, the force applied (compressive to tensile) on the carbide geometry fractures the last point of the edge to leave. Additionally, the higher the arc of engagement the greater the heat transferred into the cutting edge. On the contrary, in case of low arc of engagement, the chip thickness is normally lower and the sharper edge on PVD coated grades generate less heat and cutting pressure. Entering chip thickness does not much affect the carbide tool in asymmetric milling. Because, carbide copes well with the compressive stresses on impact of entering with a thicker chip(Sandvik). www2. coromant. sandvik. com/coromant/pdf/.../C-1120-5_14-19. pdfhttp://www. sandvik. coromant. com/en-us/knowledge/milling/getting_started/general_guidelines/chip_formation/pages/default. aspxhttp://www2. coromant. sandvik.

com/coromant/pdf/Milling/ENG/C-1120-5_14-19. pdfIt is found that if feedrate and depth of cut are increase then MRR would increase and symmetric milling strategy is superior as compare to asymmetric milling for more MRR. It is found that if feedrate and depth of cut are increase then cutting power would increase and asymmetric milling strategy is superior as compare to symmetric milling for more cutting power. The total specific energy, which accounts for cutting and air cutting power demand, was indeed found to have an inverse relationship with the MRR. The impact of the cutting power demand on the specific energy was minimal since at high loads the machining time decreased significantly.