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# Effect of cutting parameters on tool life and cutting temperature in milling of AISI 1038 carbon steel

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***Abstract***

*During chip formation process of machining operations, thermo-mechanical loads are generated which can decrease life of cutting tool and quality of machined components. As a result, analysing the cutting temperatures and cutting tool life during milling operations can enhance productivity in process of part manufacturing using CNC machine tools. To predict the cutting tool life and cutting temperature during machining operations of AISI 1038 Carbon Steel, an application of the virtual machining system is developed. The impact of machining parameters such as cutting speed, feed rate and depth of cut on the cutting tool life and temperature are investigated in order to enhance productivity of milling operations. The modified Johnson–Cook model is used to investigate the combined influence of strain rate and deformation temperature on yield stress during alloy milling operations. Finite element analysis of milling operations is implemented to obtain the cutting temperature of the milling tool during the chip formation process. Then, cutting tool life during milling operations is predicted in order to be analyzed and maximized. The results of virtual machining system in prediction of cutting temperature as well as life of cutting tool are compared with the experimental results in order to validate the developed methodology in the study. So, an advanced virtual machining system is developed in the study in order to decrease cutting temperatures and increase cutting tool life in terms of efficiency enhancement of part production using milling operation.*

*Keywords: Cutting parameters; Cutting tool life; Cutting temperature; Virtual machining; AISI 1038 Carbon Steel*

## 1. Introduction

Material is removed from a component through metal cutting during the machining processes in order to produce the machined parts with the proper shape, size, and polish [1]. Heat generation during metal cutting is an essential physical phenomenon in machining operations which creates high temperatures in the local cutting zone, leading several issues such as excessive tool wear, short tool life, and poor machining accuracy. Tool wear occurs during cutting operation, resulting in the cutting tool's failure [2]. As a result, in order to provide the longest tool life and increase efficiency in machining operations, cutting tool temperatures should be analyzed in order to be minimized. Also, the cutting tool life should be analyzed and maximized in order to increase efficiency in machining operations.

The carbon steels alloys are used in different industries such as hot water pipes and radiators, blades, cutting tools and surgical devices due to higher corrosion and oxidation resistance of austenitic carbon steels alloys. However, carbon steels alloys are considered as difficult-to-cut materials due to unique features such as strong mechanical and microstructural responsiveness to strains and pressure rates [3]. So, in order to increase quality of machined carbon steels alloys, cutting temperatures as well as generated residual stress should be analyzed and minimized. Moreover, the life of cutting tool should be analyzed in order to be enhanced in terms of efficiency enhancement of part production using milling operation.

The impact of cutting speed, feed rate, and tool nose radius on forces, cutting power, and tool life are examined in order to extend the life of cutting tools during machining operations [4]. In order to extend tool life during machining operations, experimental research on the impact of high-pressure coolant with variable cutting speed and feed on surface roughness in cylindrical turning of AISI 1060 Steel is provided [5]. Machinability analysis in high-speed turning operations is investigated in order to extend cutting tool life by assessing and minimizing tool wear during machining operations of Ti-6Al-4V alloy [6]. Experimental research works on the impact of various micro-geometries on cutting edge and wiper edge of cutting tools are implemented in order to examine the surface roughness and cutting forces in face milling operations [7]. To determine the impact of the wiper facet's micro-geometry on the functionality of a milling insert, an experimental inquiry and validation utilizing numerical simulation was implemented [8].

To analyze and minimize the cutting forces and surface finish throughout milling operations of Al/SiC MMC alloys, effects of cutting parameters was studied [9]. Effects of cutting parameters on surface roughness and strain hardening is studied in order to improve the quality of machined components of NiTi shape memory alloy [10].

The optimized machining parameters using the Taguchi techniques was obtained to minimize the cutting force, temperature and roughness of surface in milling operations of Mg hybrid MMC [11]. Analytical and experimental methods are implemented in order to analyse the impact of milling conditions on cutting temperatures [12]. To minimize the cutting temperatures during milling operations of Al 7068 alloys, applications of the optimized machining parameters was investigated [13]. Cutting force and thermal simulation using a finite element method in AISI H13 Steel milling was presented in order to minimize the cutting temperature during milling operations [14]. The impacts of cutting parameters as cutting speed, feed rate and depth of cut by using the response surface methodology was investigated to decrease cutting temperature during carbon fiber-reinforced polymer composite milling [15]. To increase productivity during milling operations, influence of the process parameters to the cutting temperatures during milling operations of Al6082-T6 alloy are studied [16].

The effects of machining parameters to the chip formation and turning operations of carbon steel is experimentally investigated in order to increase surface quality of machined parts [17]. In order to predict and enhance cutting tool life in milling operations, the cutting temperature during chip formation process is predicted [18]. To enhance the surface quality and cutting tool life during turning operations of Inconel 625, the effects of hBN nanoparticles to nanofluid-MQL lubrications is experimentally investigated [19]. To enhance efficiency of part production using milling operations, chip morphology and cutting tool wear during milling operations of Inconel 718 are experimentally investigated [20]. Tool wear during high speed machining of NITi shape memory alloy is experimentally investigated in order to enhance cutting tool life during turning operations [21].

To enhance cutting tool life during machining of lightweight composite materials, optimized machining parameters using Adam – Gene Algorithm are obtained [22]. The optimized machining parameters using the genetic and PSO-based neural network models are obtained in order to increase cutting tool life during machining operations of GFRP composite materials [23]. In order to analyze and minimize tool wear during machining operations of GFRP composite materials and AISI D2 Steel alloys, the effects of cutting tool materials is studied [24]. The machinability of GFRP composite material using alumina cutting tools is studied in order to minimize cutting tool wear and enhance surface quality of machined parts [25].

To analyze the effect of sensorial data on tool wear during turning operations, a review of recent development in advanced cutting tool monitoring and decision making applications is presented [26]. Response surface methodology is used in order to describe cutting conditions and geometry of cutting tool in terms of productivity enhancement of turning operations using Multi-Criteria optimization process [27]. The Role of dry and MQL regimes to machining quality during the milling of structural Strenx 900 steel is investigated in order to enhance productivity during machining operations [28]. The erosion and tool lifetime of carbide and cubic boron nitride cutters during high-speed milling are investigated in order to extend the life of the cutting tool during milling [29]. Influence of cutting variables on life and wear of cutter during milling of hardened steel was studied in order to maximize cutting tool life during milling operations [30]. Optimal machining settings for milling Al alloy SiC particle compositions was developed in order to reduce power consumption and increase wear resistance [31].

Optimized machining parameters are obtained in order to maximize cutting tool life during machining operations of Inconel 718 [32]. The Taguchi optimization method is used in order to maximize the life of cutter during machining operations of medium carbon steel alloys [33]. To maximize productivity during milling operations, impacts of cutting parameters to the cutting temperature, wear rate, and life of cutter tool is studied [34]. Effects of machining parameters is investigated in order to increase cutting tool life and surface quality in milling of titanium alloy Ti-6Al-4V [35].

Virtual machining methodologies are proposed in order to assess and improve CNC machining operations in virtual environments [36-39]. Virtual machining system is developed in order to reduce deflection error and residual stress throughout five-axis milling processes of turbine blade [40]. An improved virtual machining method was proposed to improve surface properties throughout five-axis milling operations of turbine blades [41]. To develop the applications of virtual machining systems in part production process using machining operations, Virtual machining systems in milling and turning CNC machine tools is reviewed [42] . To analyze and increase efficiency in process of part production using welding operation, a review in recent development of friction stir welding operations is presented [43]. To analyze the cutting temperate, material removal rate, workpiece deformation and residual stress during machining operations, mechanical behaviour of materials in metal cutting operations is reviewed [44]. To minimize the residual stress and deflection error during five axis milling operations of turbine blades, applications of virtual machining systems is developed [45]. In order to analyze and decrease the cutting temperature during milling operations of difficult to cut materials, applications of virtual machining system is developed [46]. To assess and decrease residual stress during machining processes a review in residual stress is presented [47]. To minimize surface integrity and residual stress during grinding operations of Inconel 718, optimized machining parameters using the Taguchi optimization approach is presented [48]. To increase cutting tool life during machining operations, different methods of tool wear prediction is studied [49]. Computer aided process planning is reviewed in order to enhance productivity in process of part manufacturing [50].

Cutting temperature and life of cutting tool during the chip generation process are experimentally investigated in many research works to improve productivity during machining operations. Most of the proposed research works in analysis of cutting parameters on cutting temperature and cutting tool life are investigated based on experimental works which can decrease the efficiency and flexibility of the studies in comparison to the virtual machining systems regrading to the time, cost of experiments and flexible conditions of workpiece materials and machining operations. The analysis of previous research indicates that utilizing a virtual machining system to predict the cutting temperature and cutting tool life in machining processes of carbon steel alloys has not been investigated. Also, the FEM methods are not applied to the virtual machining systems in order to predict and analyze the effects of cutting parameters to the cutting tool life and temperature. Thus, the research work is original and new methodology in order to increase cutting tool life as well as efficiency of component manufacturing utilizing the applications of virtual machining systems in milling operations.

A virtual machining methodology is proposed in the study in order to examine the effect of cutting parameters such spindle speed, depth of cut, feed rate, and material removal rate on cutting tool life and cutting temperature throughout milling operations of AISI 1038 Carbon Steel. Using a modified Johnson–Cook model, the combined effects of strain rate and deformation temperature on flow stress during milling operations of AISI 1038 Carbon Steel are investigated. Finite Element Method (FEM) simulation of milling operations is implemented in the study in order to determine the cutting temperature of the cutting tool throughout the chip formation process. So, the effects of different cutting parameters to the cutting tool life and cutting temperature during milling operations of AISI 1038 Carbon Steel can be investigated by using the developed virtual machining system in the study. The cutting tool life regarding the different cutting parameters can also be predicted using the developed virtual machining system in the study in order to be maximized. To validate the developed methodology in the research work, the experimental results are compared to the virtual machining system outputs of cutting temperatures and expected life of the cutting tool. As a consequence, the system can be used in decreasing the cutting temperature and increasing life of cutting tool in order to improve the productivity of component manufacture using milling operations.

The cutting force modelling methodology is explained in section 2. Section 3 presents the Johnson–Cook model and a modified Johnson–Cook model for AISI 1038 Carbon Steel. The equations of cutting tool life regarding the machining parameters is presented in section 4. The section 5 describes the developed virtual machining system for predicting cutting temperature and cutting tool life. Section 6 presents a finite element simulation and experimental method for simulating and validating the proposed method in the study. Finally, in section 7, the obtained results from the study are presented.

## 2. Cutting Force Model

In order to calculate cutting forces during milling operations, the mathematical model of cutting forces is presented [51]. The formulas of cutting force model can be mathematically specified for a range of helical end mills. Cutting force calculations for any type of cutting tool model can be generated by substituting the model parameters of cutting tool based on tool envelop shape. In a chip with differential format, $dz$ is the chip section's varying heights, $ds$ is the cutting edge's dimensions and $h_j$is tool nose to the cutting-edge elevation. So, Eq. (1) shows the tangential divergence $(dF_t)$, radial $(dF_r)$ and axial$(dF_a)$ cutting pressure which are exerted to a discrete tiny region of the cutting edge [51].

$$\begin{cases} dF_t = K_{te}ds + K_{tc}h(\phi_j, k)db \\ dF_r = K_{re}ds + K_{rc}h(\phi_j, k)db \\ dF_a = K_{ae}ds + K_{ac}h(\phi_j, k)db \end{cases} \quad (1)$$

Where $h(\phi_j, k)$ is thickness of an uncut chip measured normal on the cutting edge, which changes regarding to the cutting point's location and cutter rotations.

The Eq. (2) can be utilized in order to compute the undeformed chip thickness in flat end milling [52]

$$h(\phi_j, k) = S_{tj}Sin(\phi_j) \quad (2)$$

Where $S_{tj}$and $\phi_j$are feed per tooth and radial lag angle of tooth j respectively.

In the cutting velocity's orientation, $db$ is the a tiny cutting flute's predicted dimensions, which is as the Eq (3) [51]

$$db = \frac{dz}{SinK} \quad (3)$$

The edge cutting coefficients $K_{te}$,$K_{re}$and $K_{ae}$ are constants which are proportional to the cutting-edge length $ds$.

The sheer force coefficients $K_{tc}$, $K_{rc}$ and $K_{ac}$ are extracted by using the experiments [53]. To verify the current findings, an experiment was implemented in order to obtain cutting edge and sheer force coefficients. The geometric model is used in order to identify the cutting point positions along the flute. During the chip generation process, the kinematics of rigid body for the cutter and workpiece, and structural separations, are also considered in order to determine the same flute point on the cut surface. Thus, Eq. (4) can be presented in order to calculate the cutting forces in the Cartesian coordinate system [51].

$$\begin{bmatrix} dF_x \\ dF_y \\ dF_z \end{bmatrix} = \begin{bmatrix} -\sin\phi_j \sin\kappa & -\cos\phi_j & -\sin\phi_j \cos\kappa \\ -\cos\phi_j \sin\kappa & \sin\phi_j & -\cos\phi_j \cos\kappa \\ \cos\kappa & 0 & -\sin\kappa \end{bmatrix} \begin{bmatrix} dF_r \\ dF_t \\ dF_a \end{bmatrix} \quad (4)$$

As a consequence, the rotating location of the cutting conditions throughout milling $\phi_j$ can be explained by integrating as Eq. (5) [51]

$$F_x(\phi_j) = \sum_{j=1}^{N_f} F_{xj}[\phi_j(z)] = \sum_{j=1}^{N_f} \int_{Z_1}^{Z_2} [-dF_{rj} \sin\phi_j \sin\kappa_j - dF_{tj} \cos\varphi_j - dF_{aj} \sin\phi_j \cos\kappa_j]\, dz$$

$$F_y(\phi_j) = \sum_{j=1}^{N_f} F_{yj}[\phi_j(z)] = \sum_{j=1}^{N_f} \int_{Z_1}^{Z_2} [-dF_{rj} \cos\phi_j \sin\kappa_j + dF_{tj} \sin\phi_j - dF_{aj} \cos\phi_j \cos\kappa_j]\, dz$$

$$F_z(\phi_j) = \sum_{j=1}^{N_f} F_{zj}[\phi_j(z)] = \sum_{j=1}^{N_f} \int_{Z_1}^{Z_2} [dF_{rj} \cos\kappa_j - dF_{aj} \sin\kappa_j]\, dz \quad (5)$$

Where $N_f$ is the number of flutes on the cutter, $z_1$ and $z_2$ are the contact boundaries of the flute which is in the cut and $\kappa_j$ is axial immersion angle of flute j.

The cutting force of Eq. (5) can be simplified as Eq. (6) while the $\kappa$ = 90° in flat end mill operations [51].

$$h(\phi_j, k) = S_{tj} Sin(\phi_j) Sin(k_j) \quad (6)$$

Where $S_{tj}$, $\phi_j$ and $\kappa_j$ are feed per tooth, radial lag angle and axial immersion angle of tooth j respectively [51]. As a result, the cutting forces in differential format can be presented as [51],

$$\begin{cases} dF_x(\phi_j) = -dF_t \cos\phi_j - dF_r \sin\phi_j \\ dF_y(\phi_j) = +dF_t \sin\phi_j - dF_r \cos\phi_j \\ dF_z(\phi_j) = +dF_a \end{cases} \quad (7)$$

## 3. Johnson-Cook model

The Johnson-Cook model is used to calculate the stress distribution of a material as a result of several strain effects, impacts of cutting temperature and rate of strain due to great accuracy and theoretical simplicity. The three variables explain the impact of hardening via strain, rate of hardening via strain, and heat relaxation on the stress of the flow of the component during deformation. As a result of adaptability of the method in FEM analysis, the method is applied to evaluate the different materials' deformation propensities. The Johnson-Cook model is [54].

$$\sigma = (A + B\varepsilon^n)(1 + Cln\frac{\dot{\varepsilon}}{\dot{\varepsilon}0})\left[1 - \left(\frac{T-T_0}{T_m-T_0}\right)^m\right] \quad (8)$$

where ε is the equivalent plastic strain˙ andε˙0 are the equivalent and reference plastic strain rates, $T$, $T_m$, and $T_0$ are the material's cutting zone, melting, and room temperature, respectively. N is the strain hardening index and m is the thermal softening index. Also, A, B, and C represent the yield strength, strain, and strain rate sensitivities of the material, respectively.

The Johnson-Cook model implies that the three affecting factors of tension, strain severity, and heat are completely unrelated, eliminating the accumulating effect of any influence component. Using the standard J-C constitutive model, such strain rate dependency is difficult to predict. The modified Johnson-Cook model investigates the linked impacts of cutting temperature of deformation and strain rate on flow stress, considerably enhancing the model's prediction accuracy over the original Johnson-Cook model [55].

Lin et al. [56] explained an updated Johnson-Cook model to remove the Johnson-Cook model's restrictions as Eq. (9) [56].

$$\sigma = (A_1 + B_1\varepsilon + B_2\varepsilon^2)(1 + C_1 ln\dot{\varepsilon}) exp[(\lambda_1 + \lambda_2 ln\dot{\varepsilon})(T - T_{ref})] \quad (9)$$

where $A_1$, $B_1$, $B_2$, $C_1$, $\lambda_1$ and $\lambda_2$ are material constants, and the meanings of the other parameters are the same as that in the Johnson-Cook model.

The modified Johnson-Cook model for the steel alloys is obtained as Eq. (10) [57].

$$\sigma = (32.76109 + 270.75562\varepsilon - 452.38228\varepsilon^2)(1 + 0.14759\, ln\frac{\dot{\varepsilon}}{\dot{\varepsilon_0}}) \times exp\left[\left(-0.0051 + 0.0091\, ln\frac{\dot{\varepsilon}}{\dot{\varepsilon_0}}\right)(T - 1173)\right] \quad (10)$$

## 4. Cutting tool life

Taylor discusses the relationship between tool life and cutting parameters in metal cutting processes as Eq. (11) [58],

$$V.T^n = C \quad (11)$$

Where V is speed of cutting, T is life of cutting tool, n and C are constants of Taylor (empirical) which are mostly determined by the materials used in tooling and the cutting conditions (cutting fluid application). Consequently, this basic connection was expanded to a more comprehensive form known as Eq (12) [58].

$$\sigma = T = \frac{C_T}{V_C^x.f^y.a^z} \quad (12)$$

Where $C_T$ is constant of Taylor. The cutting tool life is then analytically calculated by using Taylors algebraic structure for different cutting speed and feed rates as Eq. (13) [59].

$$T = C_T.V_C^x.f^y.a^z \quad (13)$$

Where T is the tool life in (s), V is cutting speed in m/s, f is feed rate in mm/rev, and a is depth of cut in mm. Also, x, y and z are constants and $C_T$ is constants of Taylor. The model of cutter life for the Carbon Steel alloys is obtained as Eq. (14) [60].

$$T = 1774.598.V^{-0.804}.f^{-0.724}.a^{-0.267} \quad (14)$$

Where T is the life of cutting tool in (s), V is speed of cutting in m/s, f is rate of feed in mm/rev, and a is depth of cut in mm.

## 5. Virtual machining system

A virtual machining system is developed utilizing the Visual Basic programming language in order to calculate cutting tool forces and determine cutting tool life and cutting temperatures during milling operations of Carbon Steel Alloy. The theoretical cutting tool pathway, the shape and material parameters of the milling cutting tool, and the CAD file of the workpiece are entered as input of the system. in order to analyze the impacts of machining parameters such as speed of cutting, feed rate, depth of cut and material removal rate on the cutting tool life and cutting temperature, the proposed virtual machining system can determine cutting forces at each location of cutter along machining pathways based on cutting tool information and machining process parameters. Cutting tool life is calculated regrading to the machining parameters as well as cutting tool geometry by utilizing the proposed method of cutting tool life prediction. Then, based on cutting tool data and machining process variables, cutting forces along machining paths can be determined using the developed virtual machining system. By using the calculated cutting forces along machining paths, the amounts of ε as equivalent plastic strain, ε˙ and ε˙0 as the equivalent and basis plastic strain rates are calculated. As a result, the modified model of Johnson–Cook for the steel alloy as Eq. (10) is used to obtain the information of cutting temperature (T) during milling operations. To calculate the cutting temperature during the chip generation process, the developed virtual machining system is coupled to the FEM analysis software of Abaqus R2016X. The CAD model of the workpiece is then mesh-generated, allowing finite element methods can be employed in order to analyze it. To determine the cutting temperature in milling tool during metal cutting operations using finite element analysis, the modified Johnson–Cook model for the AISI 1038 Carbon Steel is employed. Figure 1 depicts the procedures for a virtual machining system for computing cutting force, evaluating cutting tool life, and calculating cutting temperature.

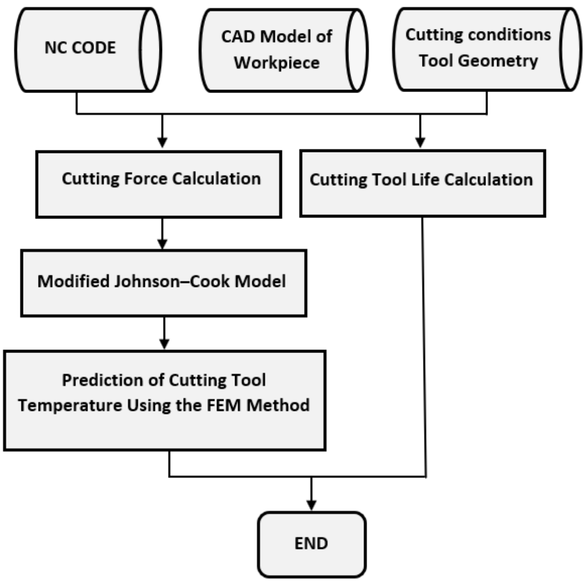


Figure 1. Procedures for a virtual machining system for computing cutting force, evaluating life of cutter, and calculating cutting temperature.

As a result, developed virtual machining system in the study can explore the impacts of process parameter including speed of cutting operations, feed rate, depth of cut, and rate of material removal on cutting tool life and cutting temperature during milling operations. As a result, the developed virtual machining system can be used in terms of cutting temperature reduction and cutting tool life enhancement using virtual simulation and modifications of CNC machining operations.

## 6. Simulation and validation

To experimentally validate the proposed methodology in the study, 5-axis Kondia HM 1060 CNC machine tool is utilized. The coefficients of cutting for the AISI 1038 Carbon Steel is are experimentally obtained to predict the cutting forces in virtual environments. Cutting forces averaged over twenty slot milling experiments with 1.5 mm axial depth of cut are measured using Kistler 9139AA dynamometer in order to determine the cutting coefficients as

$$K_{tc} = 1527.26, K_{te} = 21.4$$
$$K_{rc} = 315.39, K_{re} = 34.8$$
$$K_{ac} = 612.1, K_{ae} = 4.1 \quad (15)$$

The used insert of cutting tool in the experiment is Pramet triangular milling insert with i=16.1 mm, d=9.53 mm, s=3.18, m=2.45, a=1.2 which is shown in the figure 2. The experiments are repeated for 10 times in order to reduce the effect of errors in the obtained results. The used holder of cutting tool is ISCAR H690 F90AX-16 with triangular inserts and 6 helical cutting edges as is shown in the figure 3.

Finite element analysis of tool insert is implemented by using the Abaqus R2016X FEM analysis software. A configurable mesh density is employed in the simulations, with an element size of at least 1 µm. Mesh is applied to a workpiece having chip geometry with 110,000 tetrahedral elements, while the end mill of a cutting tool is meshed with 150,000 tetrahedral elements, both of which are employed in milling simulations for total immersion cutting. When the model was divided into mesh elements, grid independence test is implemented in order to choose the best partition of the meshed part. The specific heat capacity of the AISI 1038 Carbon Steel is 470 J/kg-K in the FEM simulation. The figure 4 shows the finite element simulation of milling operation.

Figure 5 depicts the influence of the cutting settings on the simulated insert's cutting temperatures using the FEM approach.

The FLIR E5-XT infrared camera with -20°C to 400°C temperature range and an accuracy of 0.1°C is used to obtain the cutter temperature during the milling. The experiments were carried out with a temperature of reference of 23 ± 1°C. The distance between the camera and the point of measurement is 40 cm. As a result, the thermal image of the milling operations is described in the figure 6.

The effects of cutting speed on the temperature of cutting tool which are obtained by using the simulation and experiment are shown in the figure 7. The machining parameters are spindle speed 10,000 rpm, depth of cut 1.2 mm and feed rate 0.14 mm/rev.

As is shown in the figure 8, cutting temperature rises when cutting speed increases. This is due to less time for heat to be dispersed during chip removal from the surface of machined parts [61].

Also, the figure 8 shows the depth of cut impacts on the temperature of cutting tool which are obtained by using the simulation and experiment. The machining parameters are speed of spindle 10,000 rpm and rate of feed 0.14 mm/rev.

By increasing the depth of cut, the maximum temperature increase as is shown in the figure 8. When depth of the cut increases, the cross section of chip also grows, which raises friction and ultimately cutting temperature during chip formation process. Also, the critical value of the equivalent plastic strain is increased in terms of depth of cut enhancement. So, the generated heat at the cutting zone is increased [62].

The impacts of feed rate on the cutting tool temperature which are obtained by using the simulation and experiment are shown in the figure 9. The machining parameters are spindle speed 10,000 rpm and depth of cut 1.2 mm.

By increasing the feed rate, the cutting temperature in cutting tool is also increased as is shown in the figure 9. With an increase in feed rate, chip section grows, friction rises as a result, and more heat is produced in the shear zone [60].

The material removal rate ($cm^3/mm$) during milling operations cab be obtained by using the Eq. (16)

$$Q = \frac{A_P \times a_e \times V}{1000} \quad (16)$$

Where, $A_P$ is axial depth of cut, $a_e$- depth of cut in a radial direction in mm and $V$ is speed of cutting in m/s respectively. So, the effects of material removal rate on the cutting tool temperature which are obtained by using the simulation and experiment are shown in the figure 10. The spindle speed is 10,000 rpm.

The chip section areas are increased due to enhancement of material removal rate which can increase the friction as well as generated heat in the cutting zone during milling operations [63].

The impact of cutting speed on the tool life which are obtained by using the simulation and experiment are shown in the figure 11. The machining parameters are spindle speed 10,000 rpm, depth of cut 1.2 mm and feed rate 0.14 mm/rev.

The tool life decreases when the cutting speed increase as is shown in the figure 11. The reason is that as cutting speed increases, tool wear increases as well, and cutting tool life also decreases [63].

The effects of feed rate on the cutting tool life which are obtained by using the simulation and experiment are shown in the figure 12. The machining parameters are speed of spindle 10,000 rpm and depth of cut 1.2 mm.

The tool life decreases when the feed rate increases as is shown in the figure 12. When feed rates increase, more heat is generated in the cutting zone and the cutting tool is subjected to rapid collapse, which reduces the cutting tool life [63].

The effects of depth of cut on the tool life which are obtained by using the simulation and experiment are shown in the figure 13. The machining parameters are spindle speed 10,000 rpm and feed rate 0.14 mm/rev.

The tool life decreases when the depth of cut increases as is shown in the figure 13. More heat is generated in the cutting zone by increasing the depth of cut which can increase the tool wear and reduce the cutting tool life during milling operations [63].

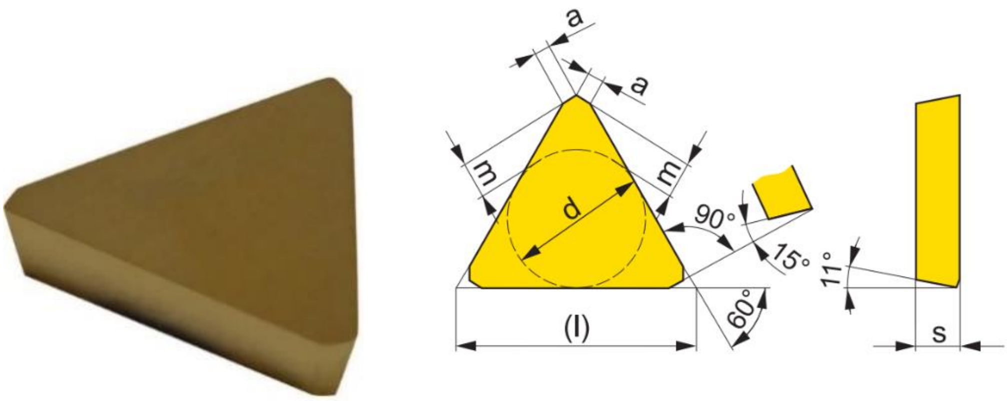


Figure 2. The specification of the cutting tool insert.

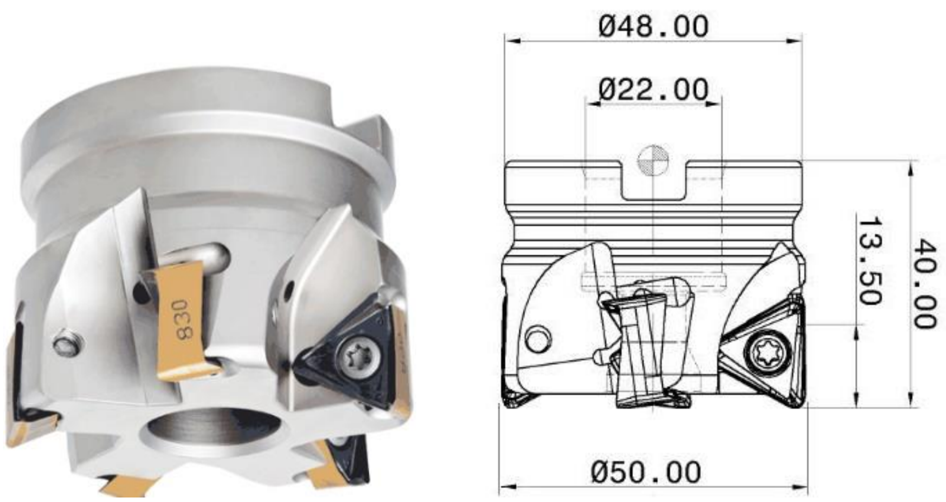


Figure 3. The specification of cutting tool holder.

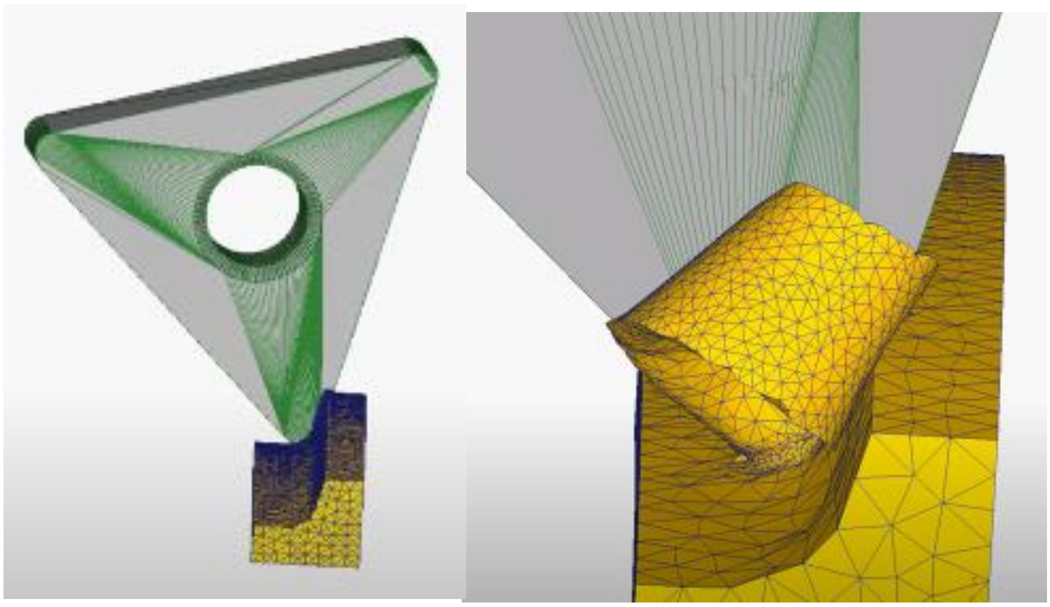

Figure 4. The finite element simulation of milling operation.

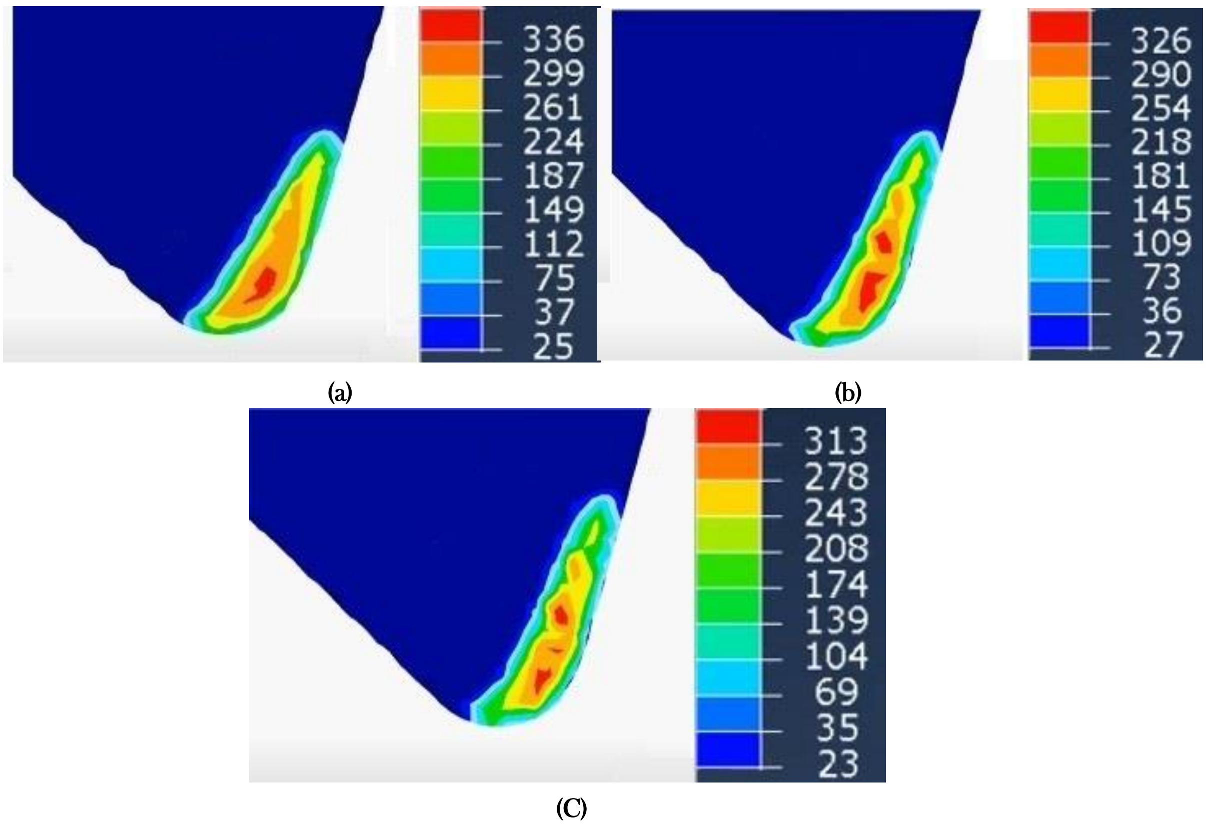


Figure 5. The effects of cutting variables to the temperatures of cutter inserts, (a) The effects of cutting speed while the speed of spindle 10,000 rpm, depth of cut 1.2 mm and rate of feed 0.14 mm/rev, (b) The effects of depth of cut while the speed of spindle 10,000 rpm and rate of feed 0.14 mm/rev, (c) The effects of feed rate while the speed of spindle 10,000 rpm and depth of cut 1.2 mm.

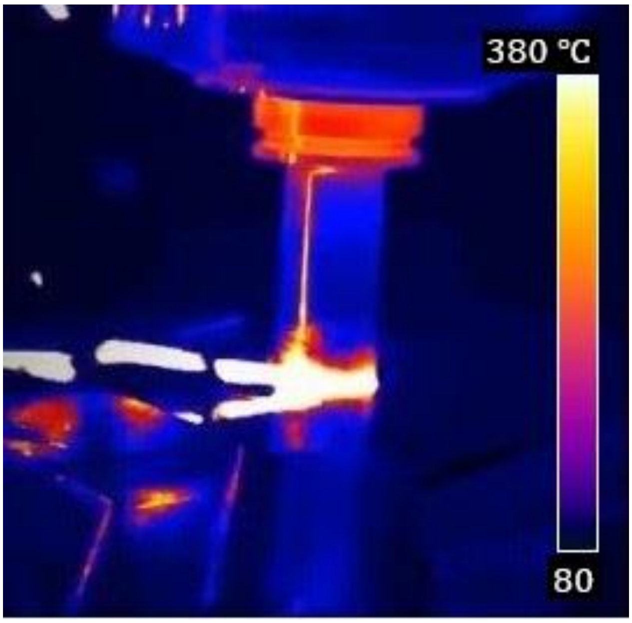


Figure 6. Thermal image of the milling operation.

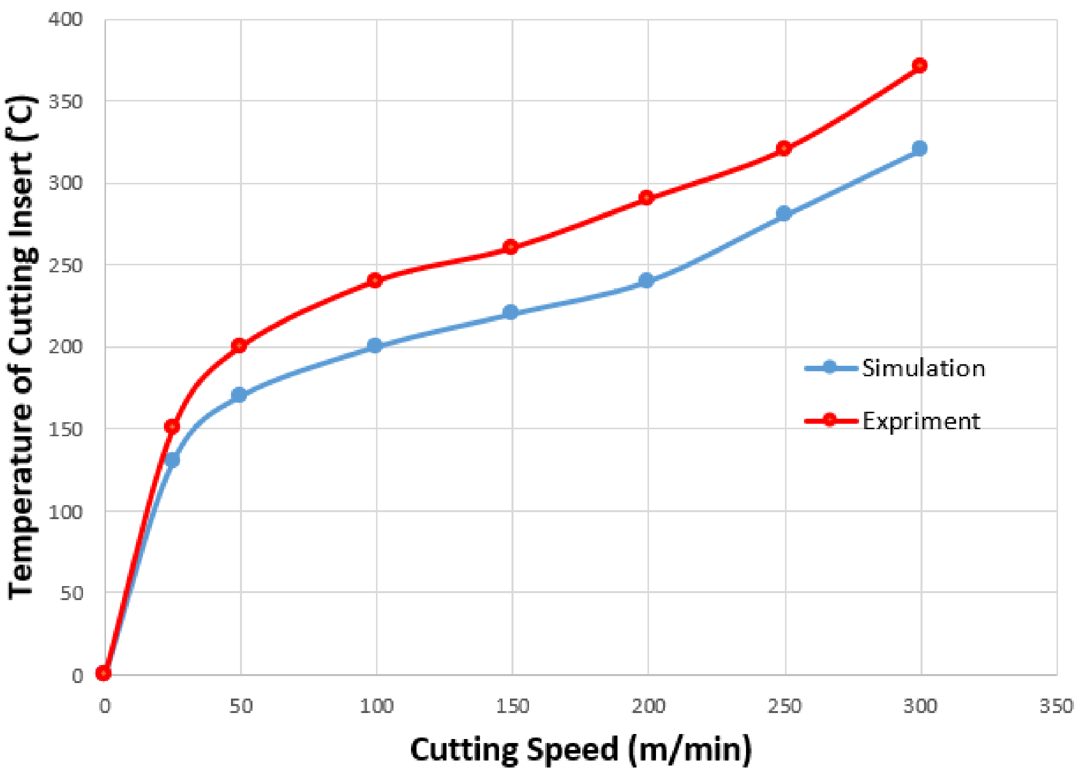


Figure 7. The effects of cutting speed on the temperature of cutting tool.

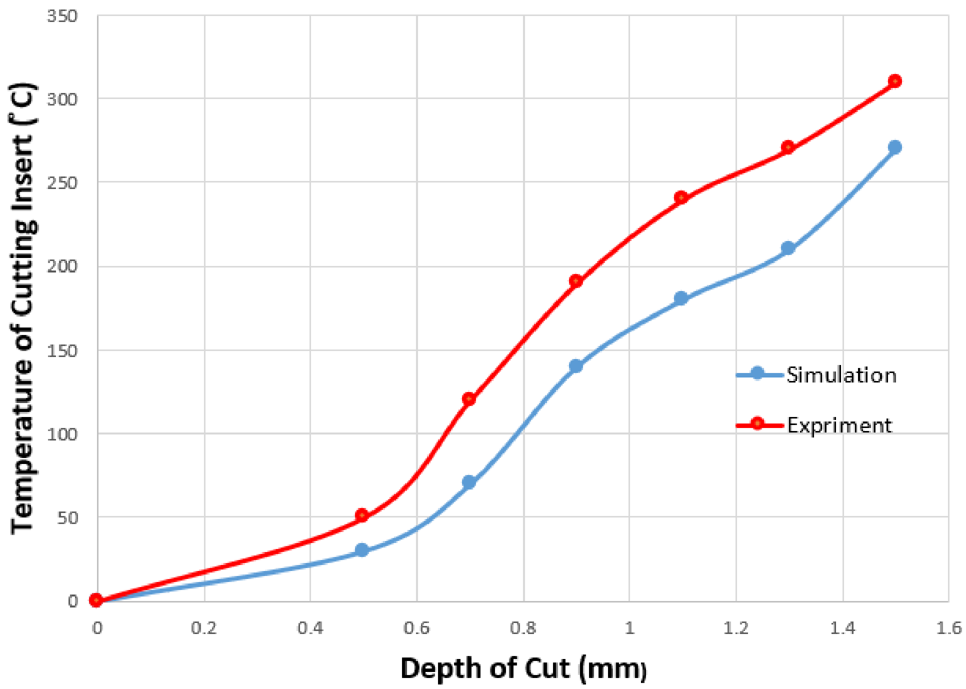


Figure 8. The effects of depth of cut on the temperature of cutting tool.

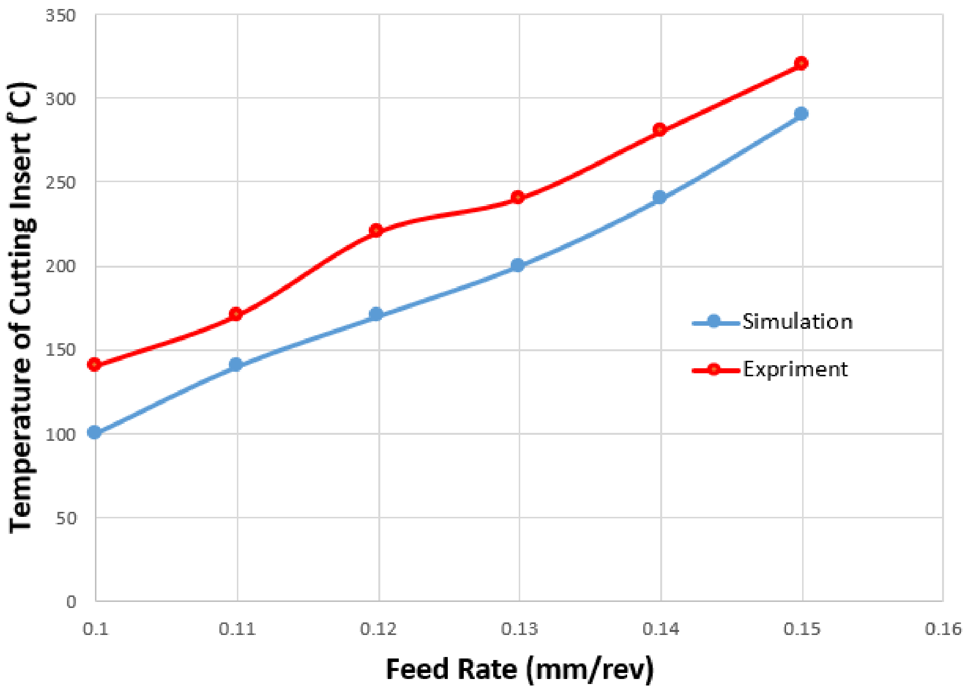


Figure 9. The effects of feed rate on the temperature of cutting tool.

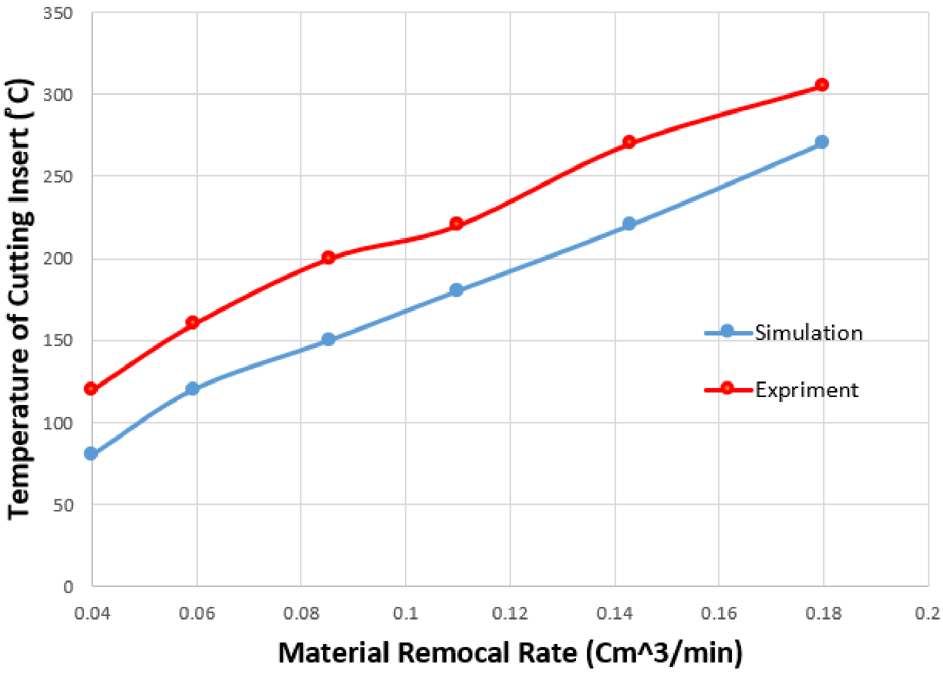


Figure 10. The effects of material removal rate on the temperature of cutting tool.

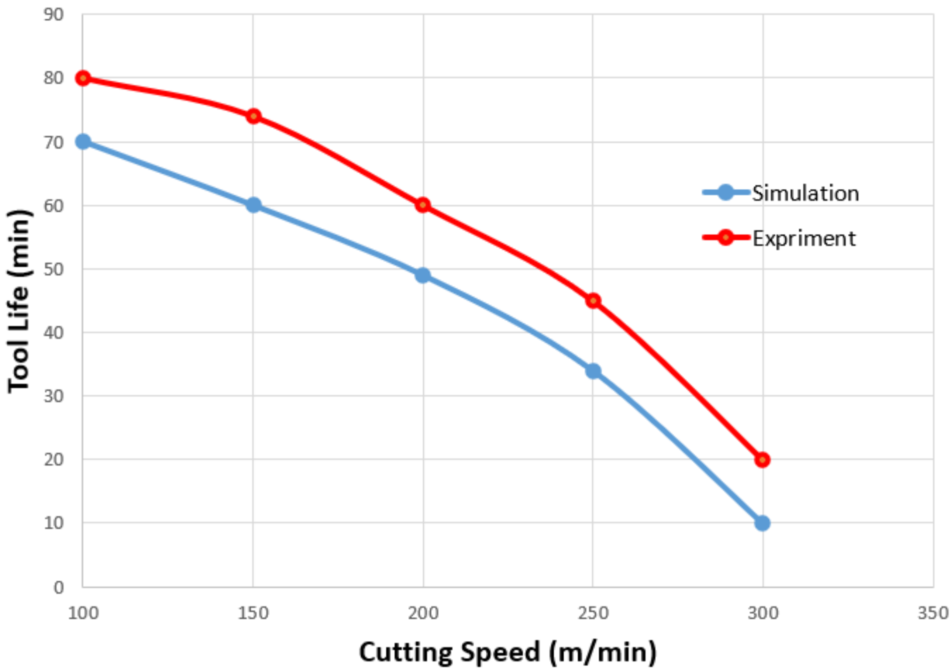


Figure 11. The impact of cutting speed on the life of cutting tool.

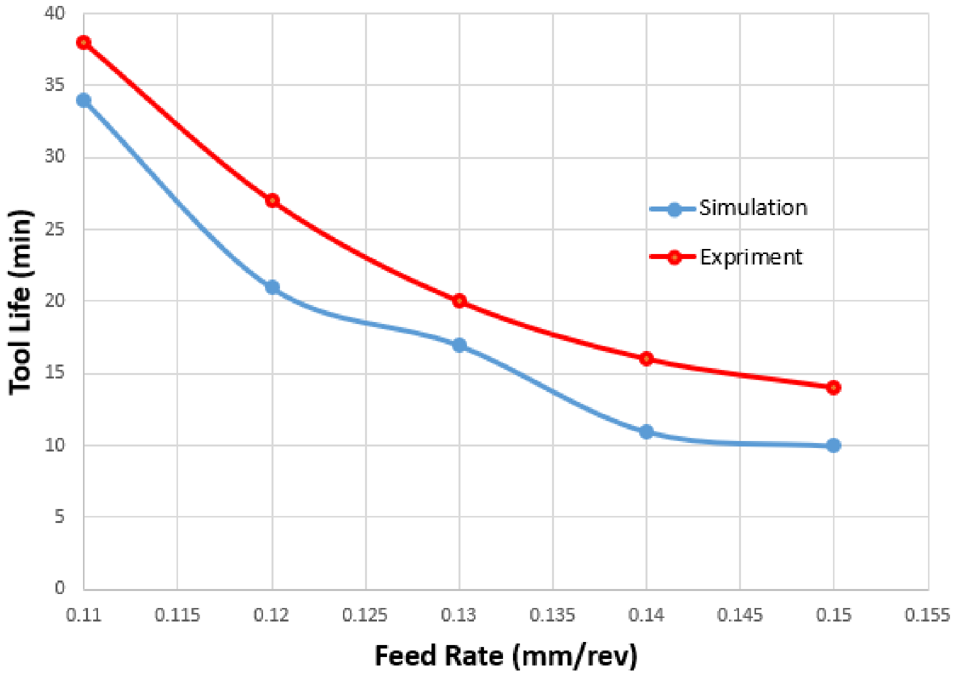


Figure 12. The impact of feed rate on the life of cutting tool.

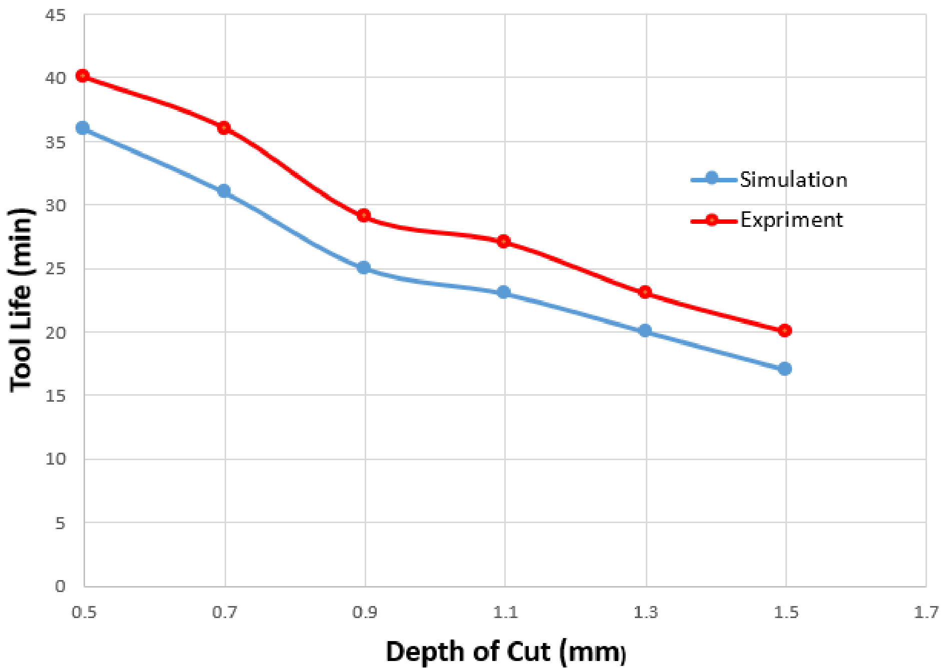


Figure 13. The impacts of depth of cut on the life of cutting tool.

## 7. Conclusion

Large amounts of thermal energy are generated during chip formation of machining operations, which can reduce cutting tool life and quality of machined part. As a consequence, monitoring cutting temperatures and cutting tool life during milling operations can improve precision and productivity of component manufacture using milling operations.

A virtual machining model is created in the study to explore the impact of cutting parameters such as speed of cutting, feed rate, depth of cut, and rate of material removal on cutting tool life and cutting temperature. In comparison to the experimental and virtual machining system results, a 87.8% compatibility is obtained. As a result, the generated heat in the cutter as well as cutter life due to different machining parameters can be accurately predicted.

1- The cutting temperature is enhanced by increasing the cutting speed during the milling operations of AISI 1038 Carbon Steel.
2- By increasing the speed of cutting during milling operations, less time for the generated heat in the cutting tool is provided in order to be conducted to the machined workpieces. As a consequence, heat energy is forced to stay in the milling cutter, raising its cutting temperature while lowering contact friction of machined surfaces.
3- By increasing the depth of cut, feed rate and rate of material removal during milling operations, the cutting temperature of cutter is increased. The cross section of chips in the cutting zone is increased by increasing the feed rate and depth of cut during milling operations, which can lead to enhance friction and a rise in the cutting tool's maximum temperature.
4- The cutting cycles with more depth of cut, feed rate and rate of material removal require more material to be removed. This is related to the increased plastic deformation that happens during the chip generation process at the primary and secondary deformation zones. As a result, more energy is used and converted to heat in the cutting area during machining operations.
5- The cutting tool life is decreased as a result of increasing feed rate, depths of cut and cutting speed. Because, the tool wear is increased due to increasing the generated heat in the cutting tool due to higher feed rate, depths of cut and cutting speed during process of chip generation.

In order to improve productivity in the machining, the impacts of cooling and wear of cutter conditions during machining operations can be analyzed. This can be future research work of the authors.

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