

A Numerical Approach on the Design of a Sustainable Turning Insert

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Short title: **Novel Turing Insert Design**

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Abstract

To decrease the energy footprint of a machined product, a novel turning insert design has been reported in this work. Two geometrical models of the turning inserts: a commercially available design of insert and proposed design of insert have been used to numerically simulate the turning operation. FEM based coupled temperature displacement simulations for orthogonal turning operations for A2024-T351 are carried out. Reasonable associations of numerical results with the experimentally published result were found. Numerical simulation results show the efficacy of the new design of the insert in quantitative reduction of energy inefficient by product of machining named as “Burr”. Additionally an improved tool life has also been predicted.

Keywords:

Numerical simulation; Burr; Turning; chip morphology, Aluminum alloy 2024-T351

1. INTRODUCTION

Department of Commerce USA explicitly defines the Sustainable manufacturing as, “the creation of manufactured products that use processes that are non-polluting, conserve energy and natural resources, and are economically sound and safe for employees, communities and consumers”[1]. Developments of engineering products through smart sustainable manufacturing processes is the focus of manufacturing engineering related engineers and researchers for last some decades. These generic and specific product based processes and techniques encompass various methods (non polluting methods, energy efficient methods, fast production methods, etc) to achieve sustainable products. Amongst these methods cost effective and energy effective techniques have been more spotlighted and investigated in literature [2, 3]. In this continuation to get sustainable production through machining process a new design of an eco-friendly turning insert has been proposed. Some direct and indirect advantages attributed to the newly proposed design of the insert are:

- Reduced burr formation
- Less resource required for deburring process to get final product (including machines, man, money and time)
- Longer cutting insert life (with fewer chances of chipping and fracture)
- Less emission of CO₂ (Indirect advantage: less energy is required to get final finished product and less energy is required with longer tool life)

In the current study a FE-model for 3D- orthogonal turning operation has been developed. Initially FE model has been validated (with experimental data [4, 5] for turning of an Aluminum alloy 2024-T351 using the commercially available turning insert. Turning numerical model was exploited subsequently to perform cutting simulation using newly proposed design of insert.

2. FINITE ELEMENT MODEL FOR TURNING SIMULATION

Geometrical model for orthogonal turning operation realized in ABAQUS software is shown in Fig.1. During machining material plasticizes and onwards fracture occurs and chip is separated from the workpiece. During this cutting process high stress, strains, temperatures, damage and other associated multiphysical phenomenon occurs at tool-workpiece interaction regions. This promotes severe mesh distortions (based on Lagrangian formulation). Furthermore as chip detaches from workpiece a new surface (machined workpiece surface) is generated. In the present work to smooth the operation of chip formation and its detachment from workpiece an un-machined workpiece is geometrically modeled in three parts: predefined chip, machined part and chip separation zone. These parts are assembled through tie constraint algorithm, so that they behave like single identity “un-machined workpiece”. Thermally coupled continuum brick elements C3D8RT with an average size of 30 μ m have been used to mesh various parts of model. Tool and workpiece were constraints as shown in Fig1.

To model the friction between tool and workpiece Zorev's friction model was employed [6]. Whereas to model material elasto-plastic behavior, Johnson-cook thermo-elasto-visco-plastic model (Eq 1) is employed [4, 5]. Furthermore to simulate ductile damage for Al2014 Johnson-cook damage model (Eq 2) has been employed [4, 5].

$$\bar{\sigma}_{JC} = \underbrace{(A + B\bar{\epsilon}^n)}_{\text{Elasto-plastic term}} \underbrace{\left[1 + C \ln\left(\frac{\dot{\bar{\epsilon}}}{\dot{\bar{\epsilon}}_0}\right)\right]}_{\text{Viscosity term}} \underbrace{\left[1 - \left(\frac{T - T_r}{T_m - T_r}\right)^m\right]}_{\text{Softening term}} \quad (1)$$

$$\bar{\epsilon}_{0i} = \left[D_1 + D_2 \exp\left(D_3 \frac{P}{\bar{\sigma}}\right) \right] \times \left[1 + D_4 \ln\left(\frac{\dot{\bar{\epsilon}}}{\dot{\bar{\epsilon}}_0}\right) \right] \left[1 + D_5 \left(\frac{T - T_r}{T_m - T_r}\right) \right] \quad (2)$$

Further details on the numerical model are elaborated in [4]. Material Properties are shown in tables 1, 2.

3. RESULTS & DISCUSSIONS

Generation of various types of burrs for various machining processes and material properties has been reported in literature [7-9]. Side burr also called Poisson burr is the main type of burr which produces during turning operations [7]. Schematic of side burr formation in orthogonal turning operation is shown in Fig. 2. In the present section numerical simulation work on qualitative and quantitative formation of side burr has been discussed. Initially numerical model results (chip morphology and cutting forces) for cutting speed = 800 m/min, feed rate = 0.3 and 0.5 mm/rev, depth of cut = 4 mm for Sandvik insert have been validated with experimental results [4, 5]. Onwards FE simulations have been reproduced with the new proposed geometry of cutting insert.

3.1 Simulation Results with Commercial Turning Insert

Fig. 3a shows the chip morphology produced for orthogonal turning operation for cutting speed = 800 m/min, feed rate = 0.3 and 0.5 mm/rev, depth of cut = 4 mm. The chip morphology has good corroboration with the experimentally produced [4] chip (Fig. 3b). In addition cutting forces shows good correlation (Table 3).

Insight observation of chip and machined surface shows that material mainly plastically flows along x axis and y axis (in the form of chip), however some material flows along Z-axis because out of plane deformation. In addition surface contact conditions (e.g contact pressure of tool and workpiece) are more severe at tool edges (Fig. 4) than at the central section of tool. This further enhances material flow towards edges. Consequently after machining one finds a non value added by product in the form of sharp burr. Quantitative prediction of side burr can be figured out in Fig. 5.

3.2 Simulation Results with New Design of Turning Insert

A new geometry of the insert has been proposed (Fig. 6). The purpose is to reduce the non value added by product "burr". Orthogonal turning Simulation for cutting speed = 800 m/min, feed rate = 0.3 and 0.5 mm/rev, depth of cut = 4 mm, were reproduced. Considerable decrease in side burr was noticed as shown in Fig.5. In addition, as geometry of the new insert requires less area of tool to contact with workpiece so less initial impact force is generated on tool. (Fig.7). This is very useful in decreasing early failure of tools because of chipping and fracture.

4. CONCLUSION

3D Orthogonal turning simulations shows that out of plane deformation and severer contact conditions at tool work piece edges produces and enhances side burr formation. New proposed design of turning insert is helpful in reducing burr formation. Therefore, less resource are required for deburring process to get final product. As lesser initial tool-workpiece contact is required to initiate cutting so longer cutting insert life (with fewer chances of chipping and fracture) has been predicted. Lesser emission of CO₂ would be produced to get final machined product. In future, further numerical and experimental tests shall be produced to realize the insert design for onward actual machining.

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Figures

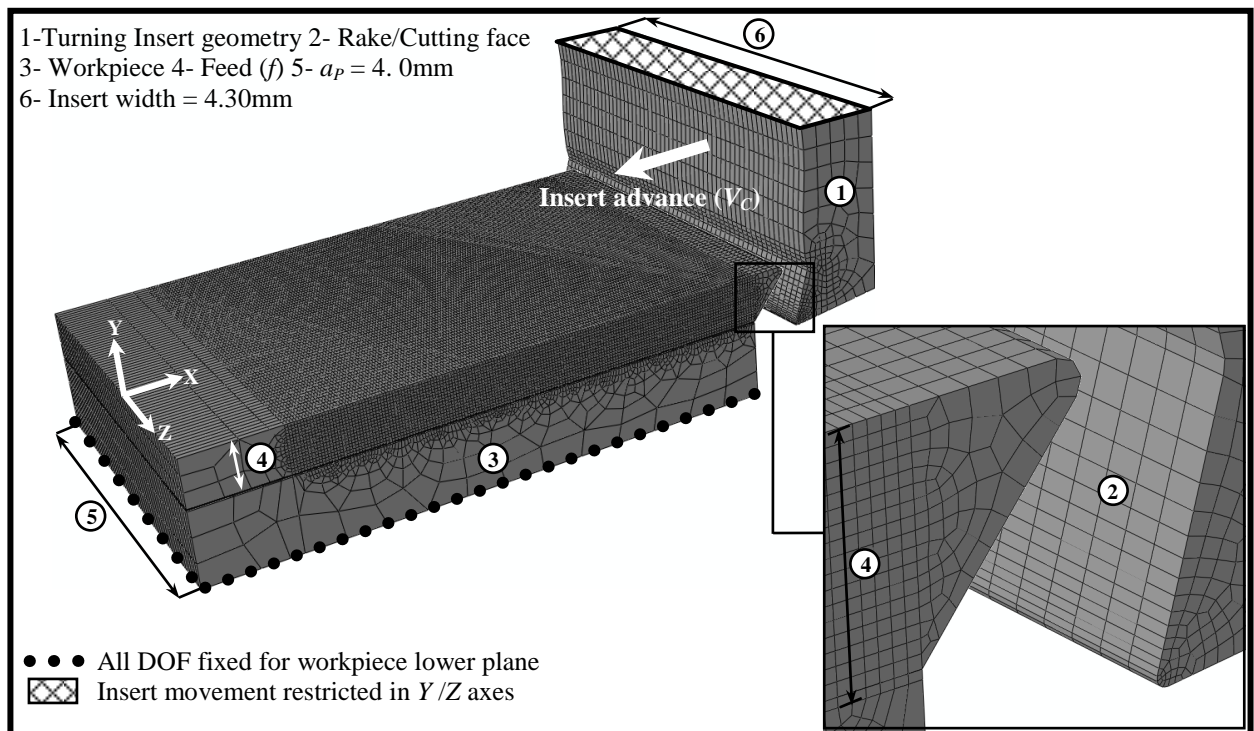


Figure 1. 3dimensional workpiece and turning insert model

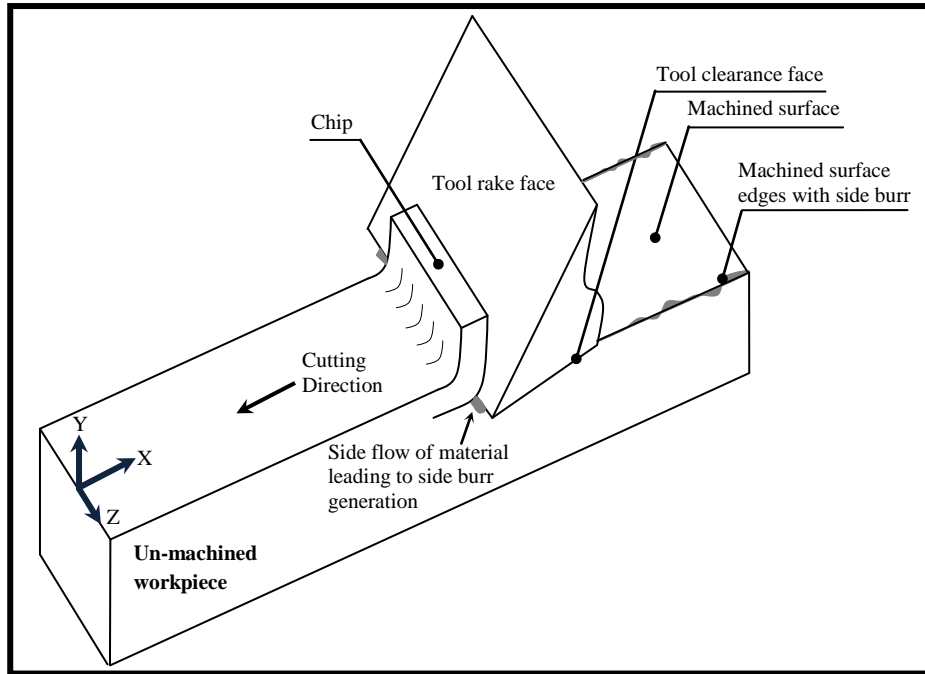


Figure 2. Side burr in turning operation

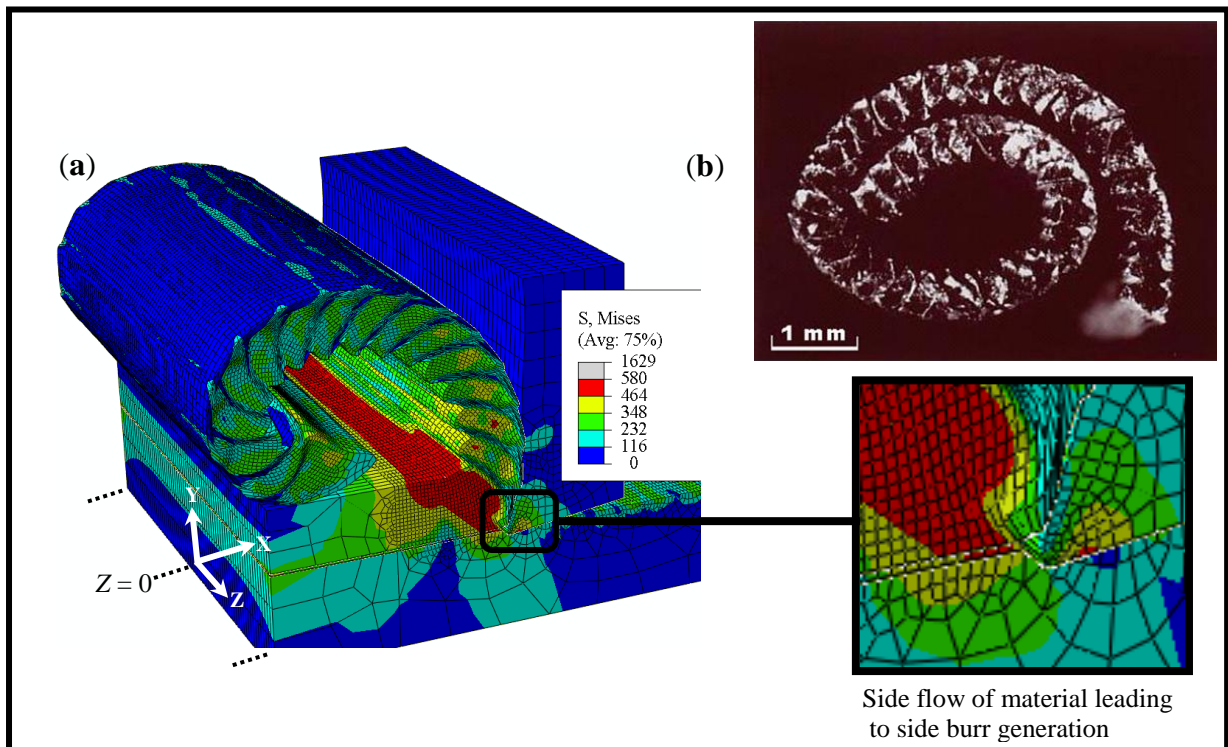


Figure 3. Chip evolution (a) Numerical (b) Experimental [4]

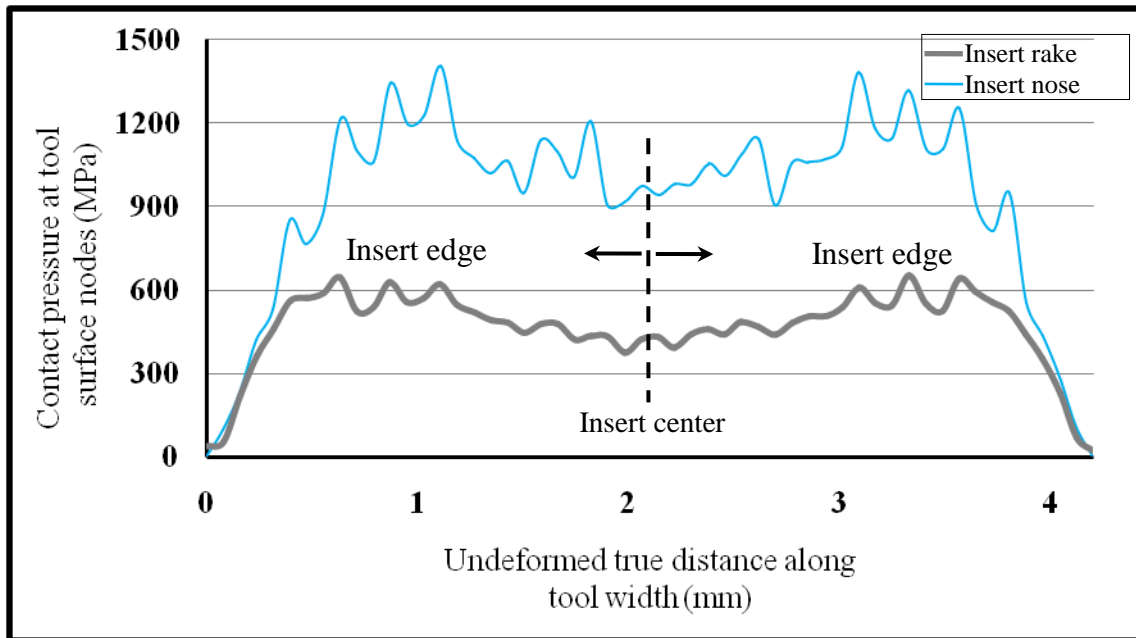


Figure 4. Profiles of contact pressure at various contact sections of cutting insert

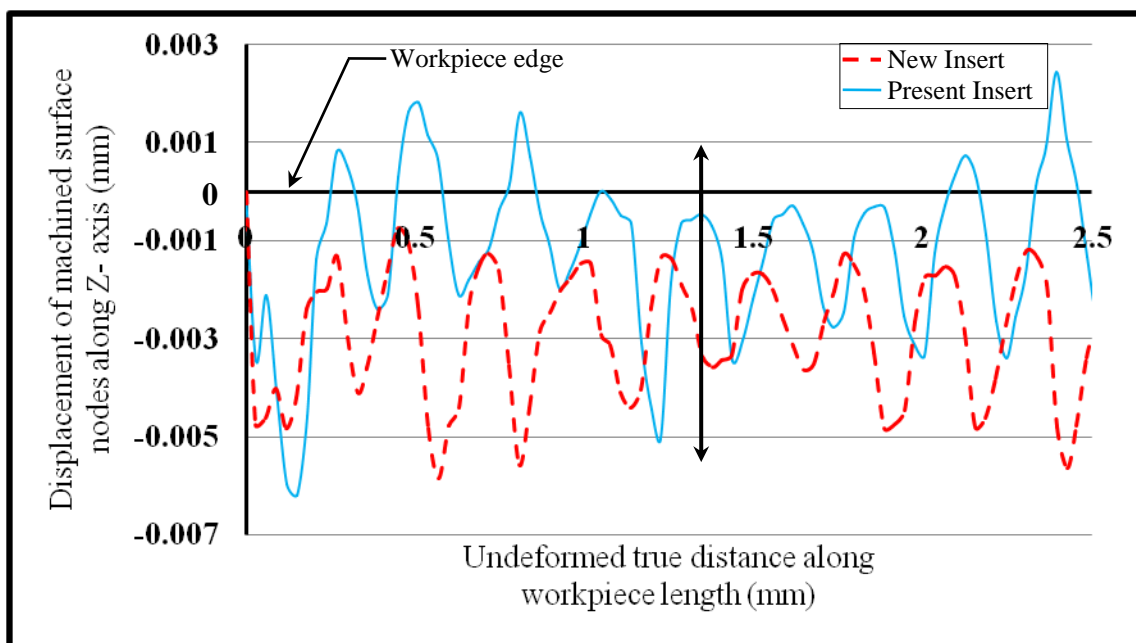


Figure 5. Quantitative prediction of side burr

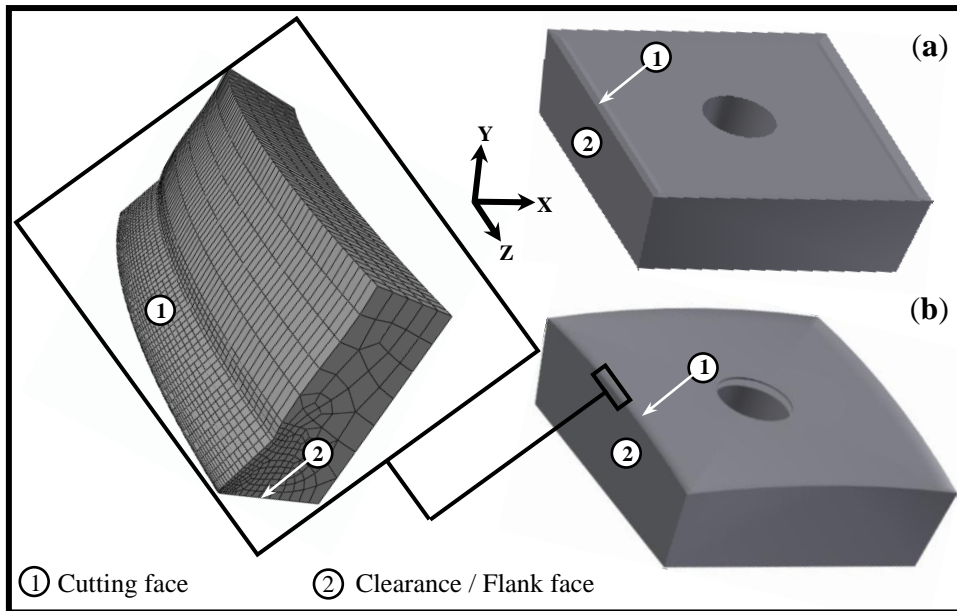


Figure 6. Geometrical representation of (a) Original industrial Insert (b) New design of insert

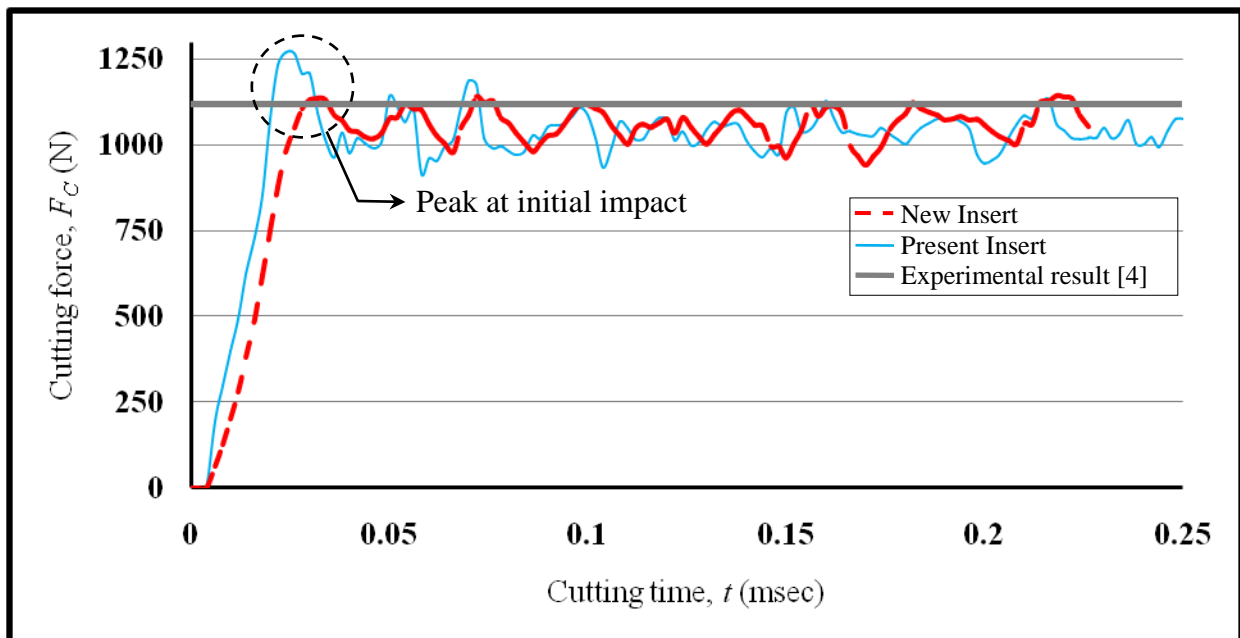


Figure 7. Plots of cutting forces for $V_c = 800$ m/min, $f = 0.5$ mm/rev, $a_p = 4$ mm

Tables

Table 1 Physical properties of various materials [4]

Parameters	Workpiece (A2024-T351)	Insert (tungsten carbide)
Density, ρ	2700	11900
Young`s Modulus, E	73000	534000
Poisson`s ratio, ν	0.33	0.22
Fracture energy, G_f	20E3	x
Specific heat, C_p	$0.557 T + 877.6$	400
Expansion Coefficient, α_d	$8.910^{-3} T + 22.2$	x
Thermal conductivity, λ	$25 \leq T \leq 300: \lambda = 0.247T + 114.4$	50
	$300 \leq T \leq T_m: \lambda = -0.125T + 226$	
Meting temperature, T_m	520	x
room temperature, T_r	25	25

Table 2 Constitutive model parameters for A2024-T351 [4]

A	B	n	C	m	D_1	D_2	D_3	D_4	D_5
352	440	0.42	0.0083	1	0.13	0.13	-1.5	0.011	0

Table 3 Cutting forces results for $V_c = 800$ m/min, $a_p = 4$ mm

	Feed rate f (mm/rev)	
	0.3	0.5
Experimental measurement (data)	738	1110
Numerically obtained	686	1090