

ROLE OF CUTTING TOOL PARAMETERS ON RESIDUAL STRESSES IN UNCONVENTIONAL TURNING

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Abstract. Residual stresses carry a vital role in determining the quality of the turned workpieces. Numerical modelling of residual stresses provides a deep insight of the process mechanism and increases the productivity by conserving time, material and manpower. In simultaneous turning process, two tools are engaged simultaneously to perform the turning process. This research work focuses on numerical investigation to estimate the impact of chamfer angle and width for various feed on surface residual stresses. The numerical simulation was done by commercially available finite element code. The work and tool material are AISI 4340 steel and carbide. CPE4RT four node plane strain element was used for the analysis. A widely used damage criterion was employed for the chip removal. The coefficient of friction in between the sliding surfaces was based on penalty approach. The friction coefficient was taken as 0.3. With the increase in chamfer angle and chamfer width, the surface residual stresses increase. This is caused by the rise in cutting forces and inelastic strain. At constant chamfer angle, with increase in cutting speed the cutting forces remain constant for both the cutting tools. The same trend was also observed for the chamfer width. On the whole, the usage of chamfered cutting tools proved to be beneficial in imparting higher compressive residual stresses in the simultaneous turning process.

Keywords: Chamfer angle, Chamfer width, Residual stress, simultaneous turning, cutting speed, feed.

1 Introduction

Metal cutting technologies are witnessing a rapid development in various fields such as computational modelling, tool materials, high material removal rate and better surface finish. These factors lead to higher productivity and superior product quality. Fatigue life of the turned components is one of the important quality parameter for rotational shafts, gears, axles and other parts that are subjected to fluctuating reversal loads. A method of increasing the fatigue life of rotary components is by inducing higher compressive residual stresses during the turning process. Fatigue life and productivity can be increased by turning with two tools simultaneously. The machining variables such as cutting velocity, feed, rake angle, edge radius, chamfer angle, chamfer width plays an important role in inducing the residual stresses on the turned component. Several researchers had investigated this aspect. Hirao et al. [1] determined the impact of tool cutting edge chamfer angle and chamfer length of on tangential and feed forces. The tool and workpiece materials used were carbide and 4340 and 1045 steel. Cutting and thrust forces were measured for chamfer angles of 22°, 41° and 60° for different chamfer lengths. It was found that the chamfer angle has significant influence on thrust force and negligible effect on cutting force. Fuh & Chang [2] developed a three dimensional model of the chamfered tool. The cutting forces were determined by certain laws applying the principle of minimum energy. Ren & Altintas [3] proposed an analytical model to examine the role of tool angle and other process variables on tangential force. Workpiece material used was P20 mold steel and two different chamfered cutting tool materials of carbide and CBN were used. It was observed that the optimum conditions obtained during machining was chamfer angle of -15° and the cutting speed 240m/min for the carbide tools. For CBN tools, the cutting speed can be increased up to 600m/min. Movaheddy et al. [4] performed the computational simulation of the machining process with pointed, blunt and chamfered edges for carbide and CBN tools. ALE approach was used to examine the tool geometric features on chip generation mechanics. It was found that the tangential forces increase with the increase in chamfer angle. Zhou et al. [5] studied the influence of tool angle on wear of PCBN material in chip generation process. It was found that the tangential forces increase with the increase in chamfer angle. The tool life was found highest for the chamfer angle 15° and minimum for the chamfer angle 30°. Ozel et al. [6] revealed the impact of various factors such as cutting tool geometry, cutting velocity, feed and workpiece hardness on the forces in turning of AISI H13 steel. The results obtained shows that the cutting and feed force components were affected by cutting speed, cutting edge geometry and workpiece hardness. Small edge radius and lower workpiece hardness resulted in lower tangential and radial forces. Choudhury and Zuhairi [7] performed the interrupted and continuous turning on traditional lathe machine. The tangential and thrust forces elevated with the rise in both chamfer width and chamfer angle. Kurt and Seker [8] analysed the effect of chamfer angle on the cutting forces and stresses during turning process using the finite element software ANSYS. The material used was bearing steel and the cutting tool was polycrystalline cubic boron nitride. It was found that the cutting forces and stresses raised with the raise in chamfer angle. Klocke and Kratz [9] studied the influence of PCBN cutting tool geometry both experimentally and by numerical simulation for hard turning. It was monitored that the cutting tool edges failed abruptly due to excessive crater wear which decreases the cutting tool strength. Karpal and Ozel [10] performed the finite element simulation to analyse the cutting process using round and oval-shape tools. Also, the influence of edge geometric features and cutting parameters on the tribology and tool temperatures were studied. Khalili and Safaei [11] performed the finite element simulation using the Johnson-Cook model based on pure deformation method. The workpiece and tool material used was AISI 1045 steel and the tungsten carbide. It was found that the chamfer angle and chamfer width has significant influence on thrust force and negligible effect on cutting force. For a constant chamfer width, as the cutting speed increases, the

tool temperature is elevated. Sahoo and Sahoo [12] investigated the various aspects of hard turning of AISI 4340 steel like cutting forces, chip morphology and machining using both uncoated and coated carbide tools. The results showed that the tool life for multilayer coated carbides was higher than the uncoated carbides. Also, the forces generated using uncoated carbide were higher than the multilayered and single coated tools. Li et al. [13] performed the hard-turning of bearing steel with PCBN tools for negative chamfered and strengthened edges. It was noticed that the tangential forces of the cutting edge were lesser than the negative chamfered edges. Chen et al [14] studied the performance of bearing steel in hard turning process using chamfered tool. The tools with varying chamfer edges produce less axial and radial forces as compared to uniform chamfered edge. The chips formed by variable chamfered edge tools remained wavy while as those of uniform chamfered edge tools were curvilinear. Gao et al [15] investigated the influence of micro mill with varying lengths of chamfer edges. The results obtained showed that with the elevation in chamfer length, the life of tool rises. But the width of flank wear also increases because of high stresses generated in the cutting zone. Liu et al. [16] investigated the influence of tool wear and cutting speed on the machined surface of bearing steel using the PCBN cutting inserts with chamfer. The tools with varying chamfer edges produce less cutting forces as compared to uniform chamfered edge. Yadav [17] developed a neoteric turning process called as duplex turning in which two cutting tools are used instead of a single cutting tool. The influence of this new process on various cutting variables was studied using AISI 1040 steel. This process minimised the requirement of secondary cut succeeding the turning process.

It can be seen from the above literature that substantial amount of work was done on conventional and un-conventional turning process in the aspect of experimentation, numerical modelling and optimisation. In the case of chamfered tools, the work reported in the above literature is limited to single tool turning process. The work done on the chamfered tools in case of simultaneous turning is not done up to now. The purpose of the current research is to computationally study the influence of chamfer angle and chamfer width on the surface retained stresses imparted on machined surface for various feeds in simultaneous turning process. Fig.1 shows the schematic of simultaneous turning with chamfered cutting tool.

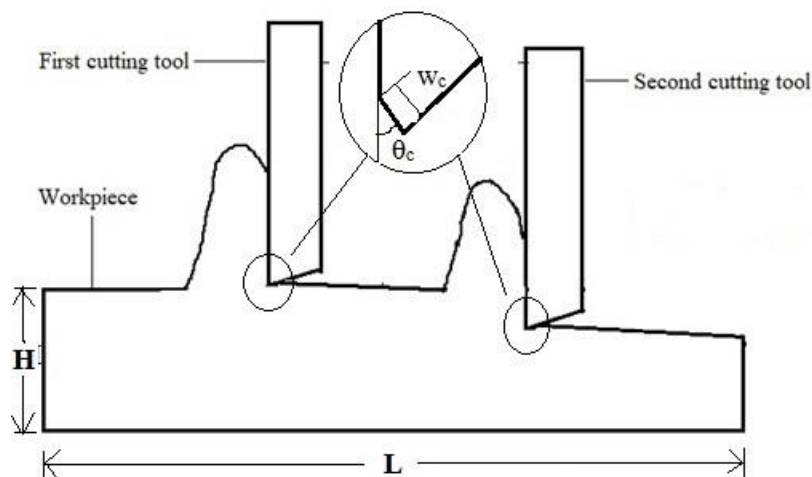


Fig. 1. Schematic view of simultaneous turning process with chamfered cutting tool

2 Computational Steps

2.1 Modelling of features and material

A 2D view of the model is generated using ABAQUS 6.14 software. The workpiece is of rectangular cross-section with length and height equal to 2 mm mm respectively. The tool is of certain appropriate dimension. The cutting tool material is uncoated carbide and the workpiece material is AISI 4340 steel. The Johnson-Cook material model is used for the simulation of the cutting process. The J-C parameter for the workpiece material AISI 4340 steel is shown in Table 1.

Table 1 J-C parameters for AISI 4340 steel

A	B	C	N	m	D ₁	D ₂	D ₃	D ₄	D ₅
792.0	510.0	0.014	0.260	1.030	0.050	3.440	-2.120	0.002	0.610

The flow stress is calculated by

$$\bar{\sigma} = (A + B\bar{\epsilon}^n) \left[1 + C \ln \left(\frac{\dot{\bar{\epsilon}}}{\dot{\bar{\epsilon}}_0} \right) \right] \left[1 - \left(\frac{\theta - \theta_{room}}{\theta_{melting} - \theta_{room}} \right)^m \right] \quad (1)$$

The damage of material is determined by

$$D = \Sigma \left(\frac{\Delta \bar{\epsilon}}{\bar{\epsilon}_f} \right) \quad (2)$$

The equivalent plastic strain is given by

$$\bar{\epsilon}_f = \left[D_1 + D_2 \exp \left(D_3 \frac{P}{\sigma} \right) \right] \left[1 + D_4 \ln \left(\frac{\bar{\epsilon}}{\bar{\epsilon}_0} \right) \right] \left[1 + D_5 \left(\frac{\theta - \theta_{\text{room}}}{\theta_{\text{melting}} - \theta_{\text{room}}} \right) \right] \quad (3)$$

2.2 Deformation model

Explicit dynamic analysis is used in those cases which are non-linear and involve large deformations and contact change like machining process. The mechanical solution is obtained using the explicit central difference integration rule.

2.3 Contact Modelling

The kinematic contact method is used to enforce the contact constraints between the rake surface of the cutting tool and the chip surface. The penalty contact approach is used for this purpose taking coefficient of friction constant.

2.4 Constrain model with mesh

The base or bottom surface of the workpiece is kept fixed. Both the tools are fixed along y-directions and the velocity is imparted in x-directions. The computation was performed for the chamfer widths of 0.10 mm, 0.15 mm and 0.20 mm and chamfer angles of 10°, 30° and 50°. The feeds are taken from certain literature. The velocity is taken 150 m/min and the distance between the cutting tools is kept constant equal to 1 mm.

3 Computational Results and Discussions

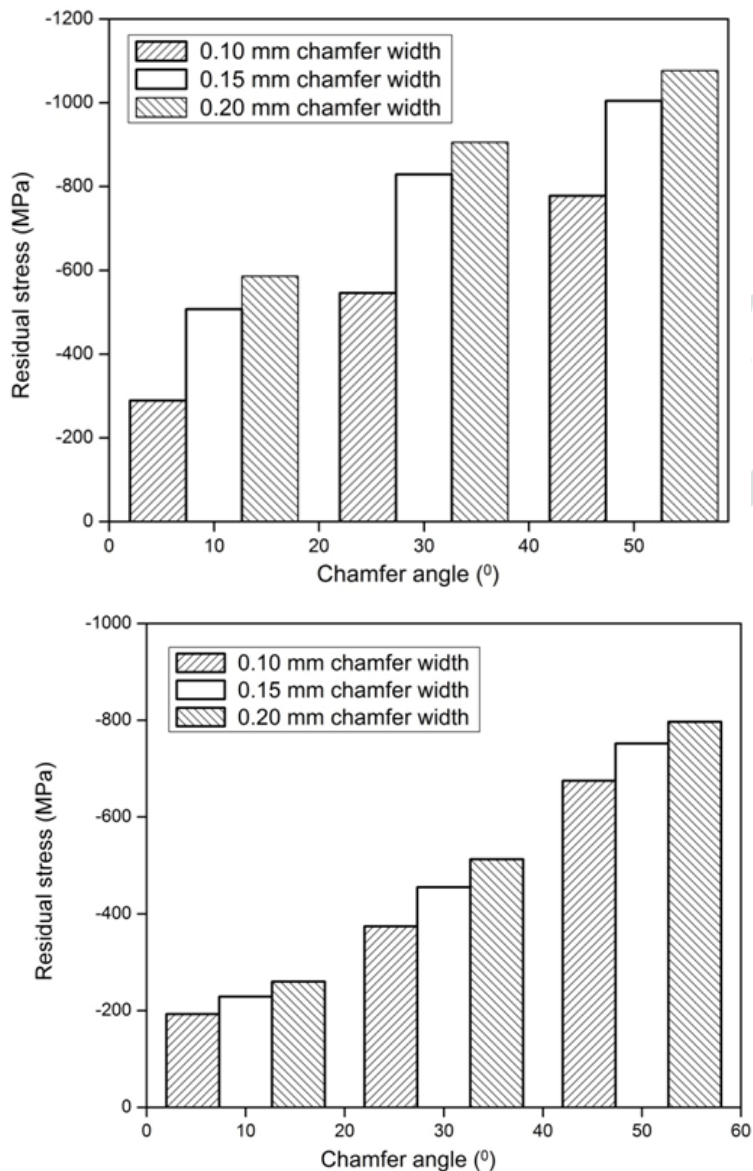


Fig. 2. Surface integrity for various process conditions

Figure 2 represents the influence of chamfer width and angle on the retained stresses for surface turned by the first tool. It can be noted that the retained stress increased with the escalation in chamfer width and chamfer angle. For the chamfer width of 0.10 mm,

compressive retained stress of the surface machined by the former tool was 289MPa. In this case, chamfer angle was taken 10° , feed 0.10 mm/rev and cutting speed 150m/min. The maximum circumferential compressive stress obtained was 1077MPa for a chamfer width of 0.20 mm, chamfer angle 50° and feed 0.10 mm/rev. Keeping chamfer angle 10° , feed 0.10 mm/rev and cutting speed 150m/min fixed, with the increase in chamfer width from 0.10mm to 0.15mm and 0.15mm to 0.20mm, the circumferential stresses increased by 75% and 15% respectively. Similarly, with the increase in chamfer angle from 10° to 30° and 30° to 50° , keeping chamfer width 0.10 mm, feed 0.1 mm/rev and cutting velocity 150 m/min, the circumferential stresses increased by 88% and 30% respectively. Due to the formation of the dead metal zone near the tool. The dead metal zone increase with the increase in chamfer angle due to the amount of material trapped under the tool.

In the similar manner, the axial compressive residual stresses also rises with the elevation in chamfer width and chamfer angle. For chamfer width of 0.10 mm, the axial compressive retained stress and surface integrity of the forward tool was 193 MPa. In this case, chamfer angle was taken 10° , feed 0.10 mm/rev and cutting speed 150 m/min. The highest axial compressive stress obtained was 797 MPa for a chamfer width of 0.20 mm, chamfer angle 50° and feed 0.10 mm/rev. Keeping chamfer angle 30° , feed 0.10 mm/rev and cutting speed 150m/min fixed, with the increase in chamfer width from 0.10mm to 0.15mm and 0.15mm to 0.20mm, the axial stresses increased by 21% and 13% respectively. Similarly, with the increase in chamfer angle from 10° to 30° and 30° to 50° , keeping chamfer width 0.15mm, feed 0.1 mm/rev and cutting velocity 150 m/min, the circumferential stresses increased by 95% and 65% respectively.

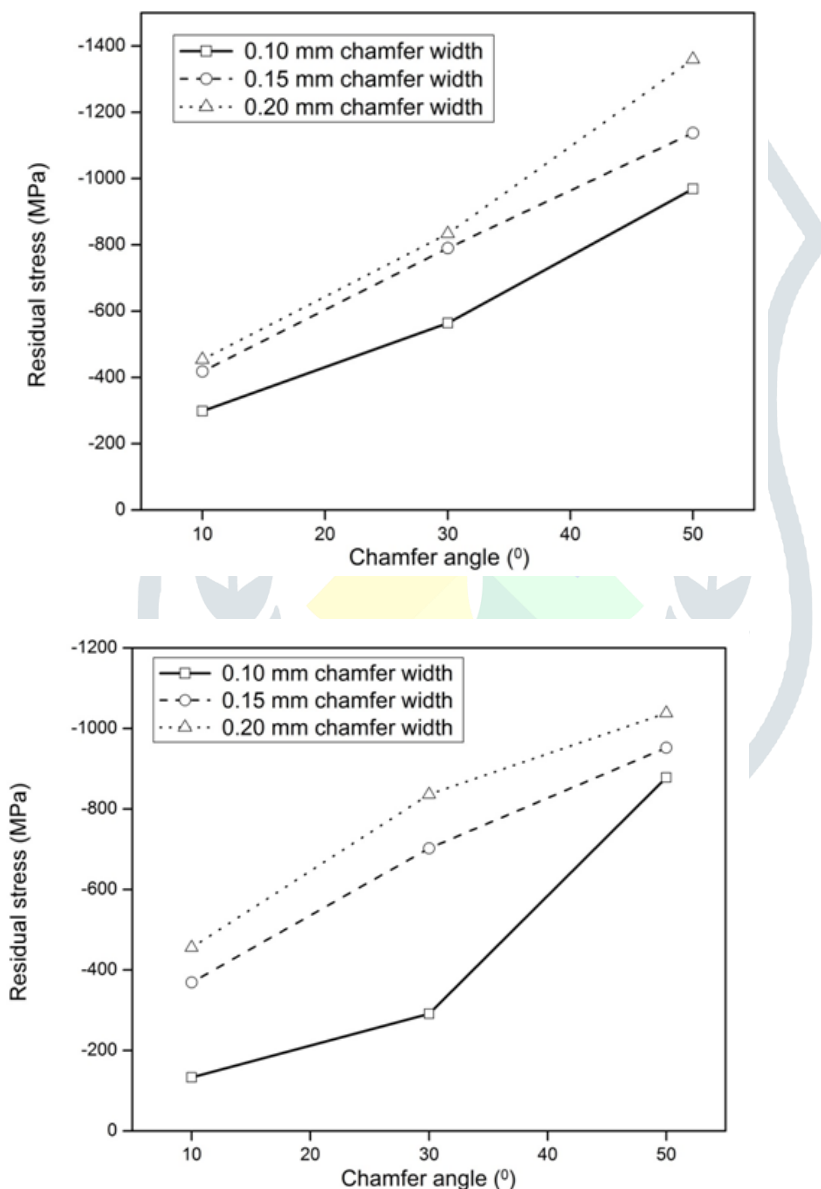


Fig. 3. Surface integrity of the surface machined by second tool

The similar trend is observed for the compressive retained stresses of the surface machined by the second tool. Figure 3 represents the variation of surface integrity with the escalation in chamfer width and chamfer angle. In this retained stresses are synonymous with residual stress.

4 Conclusion

In this work, finite element calculations were performed to present the impact of chamfer width and angle on the surface residual stress. This helps in uncovering the process mechanism and implementation of the chamfered tools in the cutting process.

1. In duplex turning process, it was found that with the rise in chamfer width or angle, the cutting and feed forces are found to increase.
2. Also, the circumferential and axial residual stresses also rised with the rise in tool parameters.
3. The chamfer angle has a dominant role on the residual stresses as compared to the chamfer width.

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