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# ANALYSIS OF ELASTOMER TURNING UNDER DIFFERENT RAKE ANGLES

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## ABSTRACT

Many industries and academic centers are looking for alternativesto improve the manufacturing quality, performance of the tool, optimum cutting conditions and cost reduction that help for better understanding of the metal cutting process. One of these alternatives is the Finite element method. The inelastic-plastic finite element method is established in this learning to examine the influence of the tool rake angle on the cutting force, chip contour, total energy and stress developed in machined work piece during the precision orthogonal turning process of elastomer. The results specify that an increase in the tool rake angle evidences to reduction in the cutting force established, smoother chip contour and a decrease in the total energy of the turning process under different cutting speeds.

**Keywords:** finite element method, tool rake angle, chip contour, cutting force, total energy.

## INTRODUCTION

Elastomer products are most commonly produced by either moulding process or curing process. In these methods the major disadvantages being the high initial cost and flexibility to design changes. An alternate approach to produce elastomer component is the machining process. Because of its very low modulus elasticity and flexibility in nature machining of elastomers find a challenging process. However, in ambient machining conditions rubber workpiece is difficult to hold using work holding device in machine tools. These problems in normal cutting conditions impose the development of inventive cutting techniques

Cryogenic machining has brought significant benefits to machining of metals. In cryogenic machining of elastomers very little research has been directed. Shih A J *et al*. [3] carried out experiments to study the influence of different machining factors on chip morphology, machined workpiece surface state, and cutting forces. They concluded that different shapes chip generated because of the significant influence of cutting speed, feed and cutting tool rake angel in elastomer machining. Strenkowski J S *et al.* [4-5] studied the effect of rake angle, clearance angle, feed rate, cutting speed and workpiece temperature during orthogonal cutting experiments. According to them, to obtain a better surface finish rake angle of the cutting tool shows an imperative role.

A series of cutting experiments under different Rake angle, Cutting speed, Feed and constant Depth of cut has been conducted on Cutting Force and Chip Morphology under ambient and Cryogenic condition. From experimental data it can be clearly seen that increase of cutting force become more significant with higher cutting speeds for cryogenic cutting. This is due to a larger modulus of rubber and increased rigidity of rubber at lower temperatures leading to less workpiece material flow underneath the tool clearance surface which is very much beneficial in maintaining cutting stability and achieving a good machined surface finish. In contrast, the rake angle of the tool plays an important role in generating a smooth machined surface. Tools with a large rake angle produce a smooth surface with ribbon-like chips. Conversely, rough surfaces and discontinuous chips are generated with tools with a small rake angle.

However, cryogenic machining of elastomers has not yet been widely introduced in the industry. Difficulties such as unsteadiness of the machining practicecausing in reduced material removal rate, griping the elastomer workpiece and building machining environment for cryogenic cutting process and to maintain stable cryogenic temperature of the workpiece during the entire machining process. This demands the use of finite element method, a significant computational tool for numerical examination of chip formation during machining of elastomers and estimation of cutting force. The cutting force developed and the type of chip formed is the foremost parameters defining effectiveness of the machining process.

This paper is concentrated on the evaluation on simulation and analysis of machining of elastomers using ANSYS workbench-17. The inelastic-plastic finite element method is developed in this study to investigate the effect of the tool rake angle on the cutting force, chip contour, total energy and force developed in machined process during the orthogonal turning process of elastomer. Further, it describes the experimental results obtained on our in-house cryogenic machining as well as respective computational results related to machining process obtained with the finite element model of cryogenic assisted turning.

## METHODOLOGY

### Specimen preparation

For this study, Nitrile Rubber material was selected. Grounded on standard ASTM testing [1], the sample having shore hardness of 80, lowest tensile strength of 15 $N/mm^2$, elongation at break of 200% and glass transition temperature of $-30^0$c. The selected geometry for the experiments was a tube workpiece with 45mm in internal diameter, 60 mm in outer diameter and 60 mm in length. In order to study the effect of cryogenic

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temperature under material machinability, samples were cooled through immersion in a container with liquid nitrogen.

The experiments were carried out in a PSG A141 lathe (2.2 KW) using the set up shown in Figure-1. During all machining tests, the cutting force was measured by using kistler dynamometer for different rake angle of the tool with three different cutting speeds and also chips are collected for further analysis.

**Figure-1.** Experimental set-up of elastomer turning process.

**Experimental design**

The machining experiments were carried out using High Speed Steel (HSS) under ambient and cryogenic conditions. In cryogenic condition, the rubber stiffness was increased by cooling the work piece in liquid nitrogen before conducting the turning tests. Based on previous studies [10, 15] the machining parameters were selected with three factors and three levels per factor, as indicated in Table-1.

**Table-1.**Factors and levels.

| Design factors | Unit | Notation | Levels | | |
|---|---|---|---|---|---|
| | | | -1 Low | 0 Medium | 1 High |
| Rake angle | Degree | A | 10 | 30 | 50 |
| Cutting speed | m/min | B | 68 | 109 | 150 |
| Feed | mm/rev | C | 0.11 | 0.18 | 0.25 |

HSS tools with varying rake angles were used in experiments. In order to facilitate the statistical analysis, three replications for each combination of process parameters were carried out. Therefore, a total of 81 experiments were executed.

Response Surface Methodology (RSM) is a collection of statistical and mathematical techniques useful for developing, improving, and optimizing processes. By careful design of experiments, the objective is to optimize a response (output variable) which is influenced by several independent variables (input variables). An experiment is a series of tests, called runs, in which changes are made in the input variables in order to identify the reasons for changes in the output response. In this research, 20 sets of experiments are sorted using the standard ordering and are carried out according to experimental design matrix. The design is a two-level full factorial with 8.Factorial points, augmented with additional 6 Centre and 6 axial points.

**Finite element method**

An explicit dynamic ANSYS/workbench is employed in current study to design the two dimensional finite element model of elastomer turning process. The lagrangian formulation method was used for material continuum to develop the model. The workpiece is modelled as rectangular block and tool with relief angle and three different back rake angles. To satisfy the appropriate stable displacement boundary condition the bottom surface and side surface opposite to cutting surface of the workpiece were fixed in all direction. The single point cutting tool was designed to have different tool rake angle with vertical reference and controlled to move alongside the machining direction with a fixed velocity of 69 m/s, 109 m/s and 150 m/s. The single point cutting tool was assumed as a rigidbody because of the significantly high modulus of the high speed steel tool material.

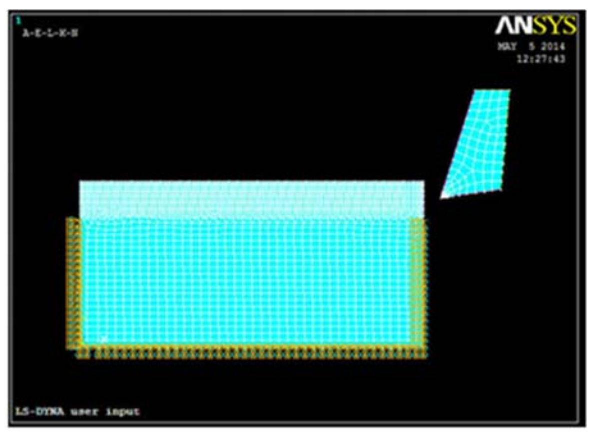


**Figure-2.** Finite element model for elastomer machining.

A two-dimensional finite element model was constructed using explicit finite element software package ANSYS/workbench, Lagrangian formulation was used for material continuum to develop the plane-strain model. The geometry of machining is shown in Figure-2. The tool tip radius was taken to be 0.008 mm Strenkowski *et al*, [2005]. The bottom nodes of the workpiece were fixed along the horizontal and vertical directions to satisfy the appropriate displacement boundary condition. The tool was constrained to move along the cutting direction (x-direction) with different cutting speed. The tool was modelled as a rigid body because of the significantly high modulus of the HSS tool material.

**RESULT AND DISCUSSIONS**

In order to obtain more accurate solution for the machining process the experimental values obtained are

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compared with design of experiment values and finite element method values. For the analysis varying back rake angles of 10, 30 and 50 degrees were designed with a constant feed rate and at different cutting speed. The results were analyzed to obtain cutting force, total energy and Chip formation.

**Cutting force**

The mathematical relationship between cutting force and cutting variables were established using experimental test results from planned set of experiments; face-centered center composite design. Quadratic regression equation was developed for predicting cutting force (N) within selected experimental conditions using response surface methodology. From the observed data and regression coefficient for cutting force, the response function has been determined in un-coded units as:

Cutting force (N) = $152.5 - 1.564A - 0.094B + 52C + 0.0051A^2 - 0.00145B^2 + 177C^2 + 0.00343AB + 0.113AC + 0.154BC$.

Where A, B and C are the decoded values of rake angle, cutting speed and feed respectively. The mathematical model values obtained for cutting force is compared with experimental values as shown in Figure-4.The mathematical model values obtained is compared with experimental values as shown in figure.3. As seen in Figure-4, the fits between experimental cutting force values and model generated values are very close by. In the prediction of cutting force values the average absolute error for RSM is found to be within 2%.

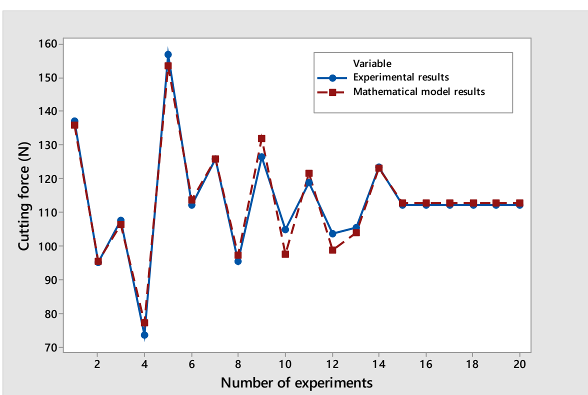
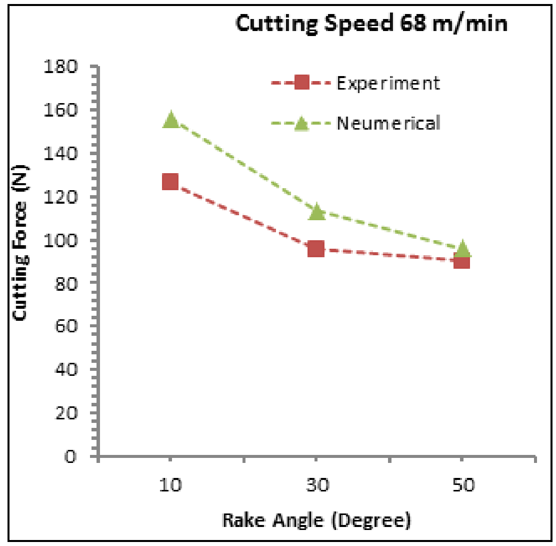
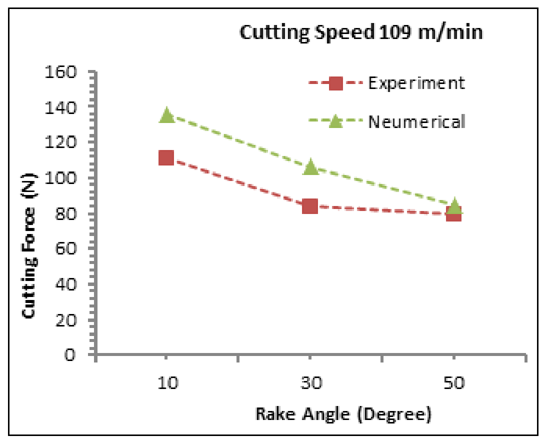


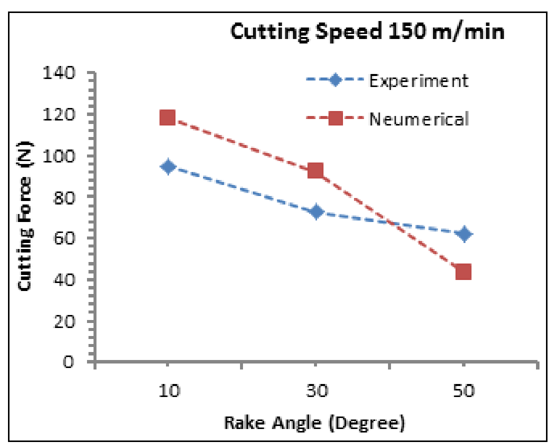

**Figure-3.** Comparison of cutting force values of experimental and mathematical results under cryogenic condition.




(a)




(b)




(c)

**Figure-4.** Comparison of cutting force values of experimental and numerical results under cryogenic condition.

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It is also evident from Figure-4 plots that the deviation of cutting force at three different tool rake angle with in elastomer machining at three different cutting speeds. It shows that the similar trend of variation in cutting force obtained in numerical results with different cutting speed. The magnitude of force decreases as the tool rake angle increases from 10 degrees to 50 degrees. The decrease in cutting force mainly because, when the elastomer is in cryogenic condition the built-up edge formation will not occur, thus when the cutting speed increases the force value decreases for increases in tool rake angle.

**Chip shape**

The tool is considered rigid and the work piece is deformable for the analysis. The tool moves from the right edge of the work-piece and moves left as it cuts through the work piece. The chip formation for the different rake angles are shown in the Figures-6. Three different rake angles were adopted for the tool geometry: 10º, 30º and 50º. For 10º discontinuous chips were formed and surface finish would be poor. For 30º and 50º rake angles continuous ribbon like chips were formed. However surface finish for 50º rake angle was found to be better. As the rake angle increase the chip tends to narrow due to low adhesion in tool-work piece region, moreover the work for chip folding is smallest. It's also noticeable that the increase of rake angle leads to smooth the tip of chip. The leading motive behind it is that for small rake angle the machining action frequently changes into a pushing and pressing force. Figure-5(a) shows the deformation of chip obtained for $10^0$ rake angle. It is evident from images that the chip separation is not clearly done at altered machining speeds.

Figure-5(b) shows the deformation of chip for $30^0$ rake angle. When chip separation at low speed (68 m/min) the chip length was shorter whereas at cutting speed of 109 m/min the chip length increased but at the top surface chip we could observe the separation of surface which may result into discontinuous chip. Figure-5(c) the chip separation at $50^0$ rake angle of the tool. The continuous chip is formed at cutting speed of 150m/min and the movement of chip over the rake face is away from the cutting region. The finite element simulation of chip deformation and experimental chip observation shows that at high speed with $50^0$ rake angle of the cutting tool geometry continuous ribbon like chips are formed. When continuous chips are formed leads to better surface finish of the elastomer workpiece in cryogenic condition.

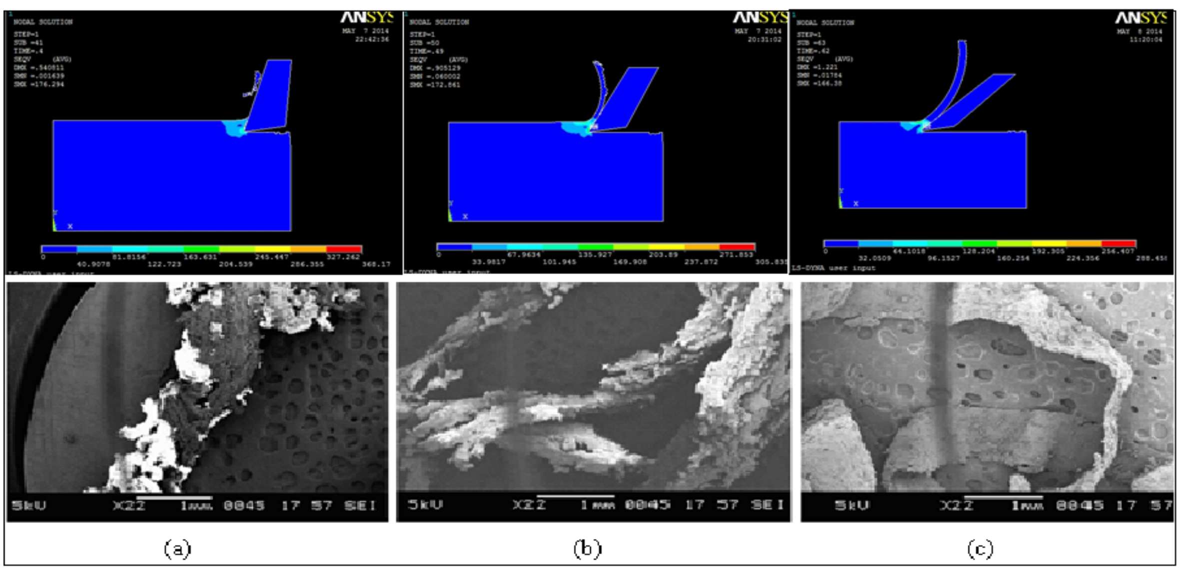


**Figure-5.** Comparison of SEM images of experimental chips (bottom) and numerical chips (top) formed under cryogenic cutting condition (a) $10^0$ rake angle (b) $30^0$ rake angle (c) $50^0$ rake angle

**Effect of rake angle on total energy**

Total energy for machining can be divided into number of components, like energy required for deformation, frictional energy, energy required to curl the chip and energy required to produce new surface area. For positive angles, magnitude of total energy decreases when the rake angle increases as obtained in Figure-6.

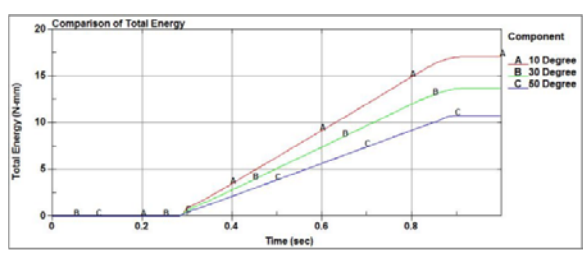


**Figure-6.** Comparison of total energy values at different rake angles.

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This behaviour is affected by friction, forces and cutting power which are usually of a larger value for lesser rake angles.

**CONCLUSIONS**

It has been seen that machining is an important and complex process still in development. Machining simulation provides a better understanding and helps industries and universities find a clear picture of the complexities involved. Amongst some of them, the morphology of chips and the effect of cutting parameters were observed. The rake angle influences meaningfully numerous factors of the process. Based on current analysis and discussion, the following conclusions may be drawn:

Constant smooth chips are related with a better surface finish, which happened with 50 degree rake angle tools. In contrast, irregular chips are related with a coarse machined surface that caused from cutting with 10 degree rake angle tools.

The value of cutting force developed decreases in magnitude as the tool rake angle increases. Finite element analysis showed that higher cutting tool rake angle and higher cutting speed about 83.48% decline in magnitude of cutting force is observed.

For positive angles, magnitude of total energy decreases when the rake angle increases. This behaviour is affected by friction, forces and cutting power which are usually of a larger value for lesser rake angles.

Finite element analysis showed that with modification of cutting tool geometry in terms of rake angle and curved rake surface continuous chips are produced at 500 rake angle and 150 m/min and also about 75 N drops in magnitude of cutting force obtained.

The distribution in the work piece where residual stress appears is larger for lower rake angles. This phenomenon occurs due to the shearing action of cutting tool.

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