Numerical Analysis on Influence of Side Rake Angle on Stress Development in Single Point Cutting Tool

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Abstract: Machining is process where material is removed from the work piece due to the contact of the work piece with cutting tool. During this cutting process, tip of the tool is going to witness the high stress due to the generation of high heat in the tip by contact of tip tool with work piece. For single point cutting tool most important geometry are rake angles (side & back rake angles). The rake angles affect the ability of the tool to shear the work material and form the chip. It can be positive or negative. In relation to minimize stresses induced at tip of the tool, this attempt aims to predict the effect of the side rake angles in the tool geometry over the tool. In this study by inducing the forces on the tip of the cutting tool and by changing the tool geometry (side rake angle), the stress concentration over the tip of the tool is calculated. The modelling of tool is carried in CATIA V5 R20, followed by structural analysis using the same CATIA V5 R20 (Generative structural Analysis) Analysis study on single point cutting tool is carried out by varying the side rake angle value which aids in minimize the stresses developed within the tool. Results indicate that the side rake angle has significant influence on stress development and through this analysis the recommended side rake angle is determined.

Key words: Side Rake angle, Cutting Tool, Vonmises stress.

1. INTRODUCTION

All manufacturers presume to have higher productivity in their machining processes, continually improve performance and reduce costs. Therefore, major improvements in the design of cutting tools are needed. The tool geometry has an important factor on cutting forces and cutting forces are essential sources of information about productive machining. Due to more demanding manufacturing systems, the requirements for reliable technological information have increased. This calls for a reliable analysis in cutting in the cutting zone (cutter work piece chip system).

1.1 Tool Terminology

The tool terminology of single point cutting tool is as shown in fig 1. The physical tool terminology is most important to predict the tool life.

Symbol used in figure are:

α_b– Back rake angle; α_s – Side rake angle; θ_e – End relief angle; θ_s – Side relief angle;

C_e – End cutting edge angle; C_s – Side cutting edge angle.

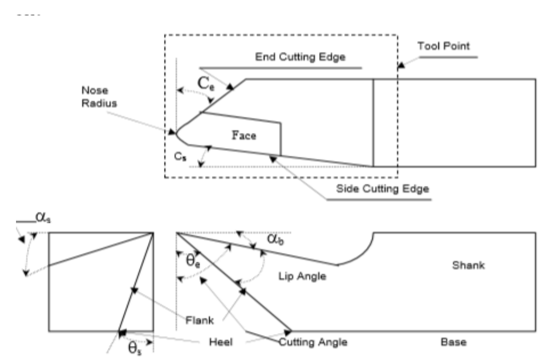

Fig 1: Tool geometry.

The important terminology required for present study is as follows.

Back Rake Angle:

The angle between face of the tool and a line parallel with the base of the tool, measured in a perpendicular plane through the side cutting edge is called back rake angle. It is the angle which measures the slope of the face of the tool from the nose toward the rear. If the slope is downward toward the nose, it is negative back rake angle. And if the slope is downward from the nose, it is positive back rake angle. If there is not any slope, back rake angle is zero.

Side Rake Angle:

The angle between the face of the tool and a line parallel with the base of the tool, measured in a plane perpendicular to the base and side cutting edge is called side rake angle. It is the angle that measures the slope of the tool face from cutting edge. If the slope is towards the cutting edge, it is negative side rake angle. If the slope is away from the cutting edge, it is positive side rake angle. All the tool angles are taken with reference to the cutting edge and are, therefore, normal to the cutting edge. A convenient way to specify tool angle is by use of a standardized abbreviated system called tool signature. Sometimes it is also called as tool character. Tool signature also describes how the tool is positioned in relation to the work piece.

2. PROBLEM STATEMENT

Single-point cutting tool is commonly used in the manufacturing industries. The setup parameters (tool geometry) play a vital role in the life of the cutting tool. If the tool geometry is not effective, the stress acting in the single point cutting increases as a result tool life decreases. In this project the effective tool geometry is going to be determined. Which means that by varying the side rake angle the tool strength is verified. By varying the side rake angle the stresses and deflection developed in the tool need to be verified. For the present study the side rake angle has been varied in the range 6^0 to 8^0.

3. MODELLING OF CUTTING TOOL

The single point cutting tool has been solid modeled by using CATIA V5 R20, solid modelling computer aided design software. CATIA is a solid modeller, and utilizes parametric feature-based approach to create models and assemblies. Parameters refer to constraints whose values determine the shape of or geometry of the model or assembly. Parameters can be either numeric parameter, such as tangent, parallel, concentric, horizontal or vertical etc. numeric parameters can be associated with each other through the use of constraint relations.

The main dimension of the tool is summarized as follows shown in table 1.

Tool Signature	**0-7-7-7-15-15-0.8**
Back rake	0^0
Side rake	7^0
End relief	7^0
Side relief	7^0
End cutting-edge angle	15^0
Side cutting-edge angle	15^0
Nose radius	0.8

Table 1: Tool signature

Above tool geometry was taken in American Standard Associative System. By the help of literature survey [1], we had taken the typical tool cutting parameters.

The single point cutting tool has been solid modelled by using CATIA V5 R20. The 3D and 2D views are shown in fig 2 and fig 3.

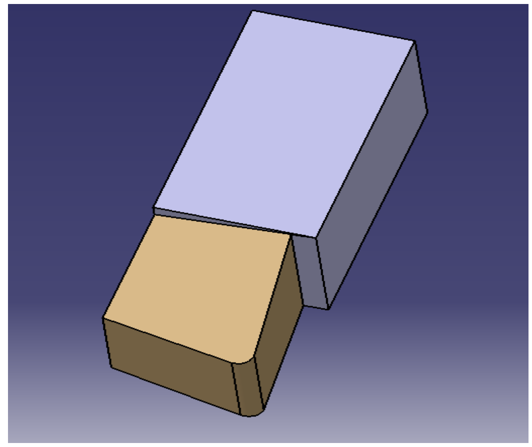

Fig 2: 3D view of CARBON STEEL Model

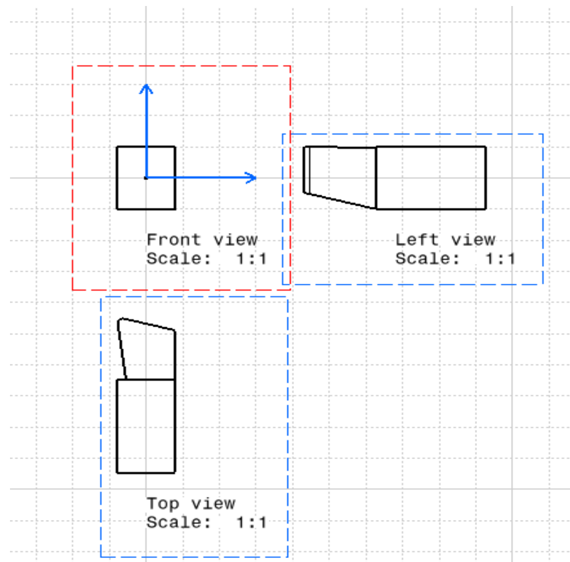

Fig 3: 2D view of carbon steel model

4. ANALYSIS OF TOOL MODEL

The analysis of the single point cutting tool is carried out by CATIA V5 R20 using **CATIA** Generative Structural Analysis**.**

Generative structural analysis is useful to acquire the various structural characteristics of your parts and products in a 3D environment. Using these tools allows you to analyze your parts or products to determine their structural qualities before they are manufactured.

4.1 Open the Basic document. This is a basic part. You must have a material defined for any part that you wish to create an analysis on. Therefore, the first step will be to apply a material to the part. Select the Apply Material icon in the bottom toolbar. The Library window appears as shown in fig 4.

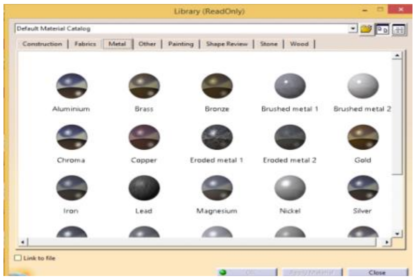

Fig 4: Material selection icon.

Then choose required material from the obtained list and Select OK to apply the material. Now that the part has a material applied to it, an analysis may be created. Carbon steel is used as the material for the tool and the properties of the carbon steel tool are listed below in table 2.

Material	Carbon steel
Density	7.79 g/m^3
Young's modulus	210 Gpa
Specific heat	450 j/kg-k
Thermal expansion	11.9 µm/m-k
Ultimate strength	550 Mpa
Poisson's ratio	0.29
Yield strength	520 Mpa

Table 2: Properties of carbon steel

Switch to the Generative Structural Analysis workbench. It is located in the Start menu under Analysis and Simulation. This will create an analysis of the part. The case analysis will be linked back to the original part. The New Analysis Case window appears as shown in fig 5. Then to define what type of analysis you would like to do.

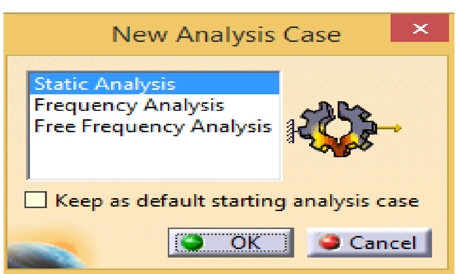

Fig 5: Analysis case window.

Select the Static Analysis case and select OK. This creates a Static Case analysis document. You will see the Static Case branch in the specification tree. You actually have a new document up at this point.

4.2 Meshing

By default, a mesh and some model properties are applied to each body in the part when the analysis is created. For now, we will work with the default mesh and properties. Later in the course, we will experiment with adjusting the mesh and properties in order to refine the results. The mesh and model properties are represented by the following symbols in the 3D environment shown in fig 6.

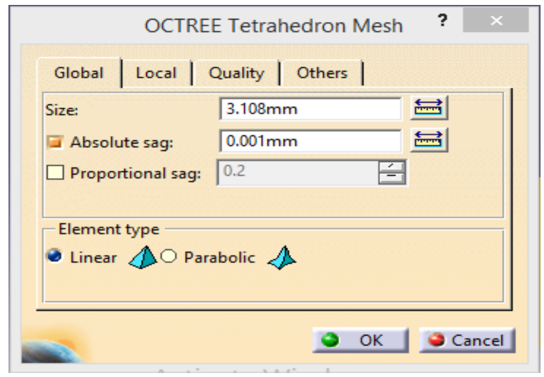

Fig 6: Mesh properties.

The absolute sag should be very less because it denotes the accuracy level, if the absolute is very less, and then our values are accurate. After entering the absolute sag, click ok. The model appears as shown in fig 7.

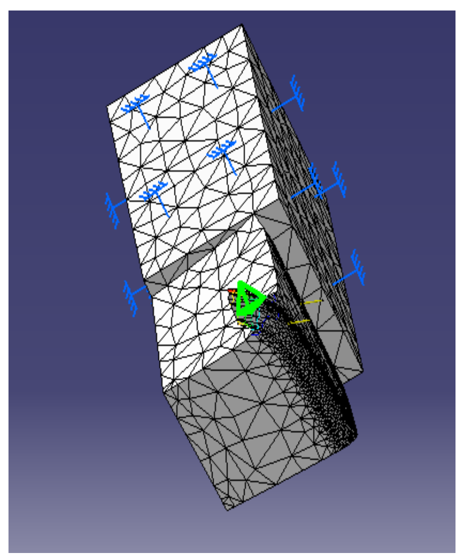

Fig 7: Meshing model of Tool.

4.3 Clamping

Select the Clamp icon. The Clamp window appears as shown in fig 8. Then, select the faces which are to be fixed and click ok and the faces which are needed are fixed.

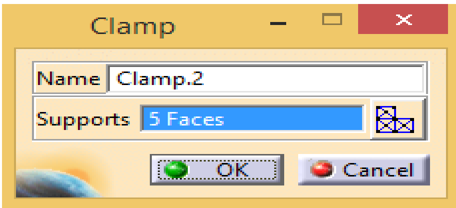

Fig 8: Clamp window icon.

4.4 Load Conditions and Boundary Conditions

Select the Distributed Force icon. The Distributed Force window appears as shown in fig 9.

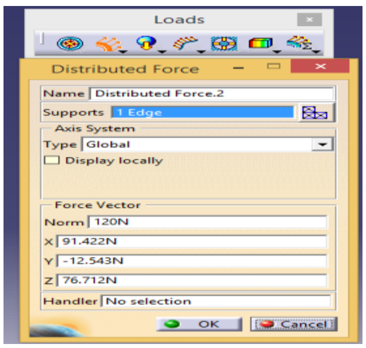

Fig 9: Distributed force window.

Cutting Forces are the three dimensional in nature: The present works investigate the effect of different forces on varying tool geometries. It considers the three cases of forces on the tool which are the experimental measured by Dynamometer as follows.

Shear force (Fy) = -12.543 N

Cutting force (Fz) = 76.712 N

Radial force (Fx) = 91.422 N

Normal force on tool (N) = 120 N

4.5 Computation

Select the Compute icon.The Compute window appears as shown in fig 10.

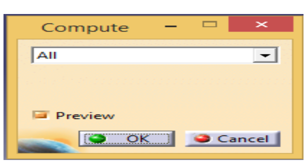

Fig 10: Compute icon.

Selecting option "All" Computes everything. Mesh Only Computes the mesh only. Analysis Case Solution Selection Allows you to select a specific case solution to compute. Selection by Restraint Computes based off of an individual constraint. Select All and select OK. The Computation Resources Estimation window appears as shown in fig 11.

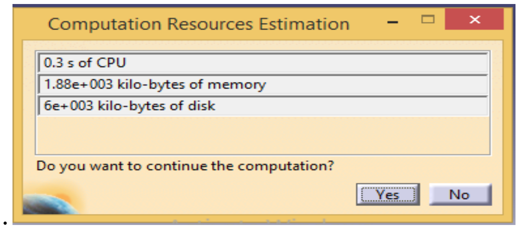

Fig 11: Computation Resources Estimation window.

Then select "Yes". The analysis is computed. The obtained results are presented and discussed in next section in detail.

5. RESULTS AND DISCUSSION

Static analysis of Cutting tool is performed using CATIAV5 R20 (GENERATIVE STRUCTURAL ANALYSIS) software, by considering the pre-determined conditions (necessary boundary conditions and loads) to achieve the results within the allowable limits.

Static analysis of Carbon steel cutting tool is performed by using the CATIA software by considering the forces as follows.

Shear force (Fy) = -12.543 N

Cutting force (Fz) = 76.712 N

Radial force (Fx) = 91.422 N

Normal force on tool (N) = 120 N

The system computes the results to find the displacements, Principal stress, Von-Misses stress values, Estimated Load Errors values shown in fig 12 to fig 16.

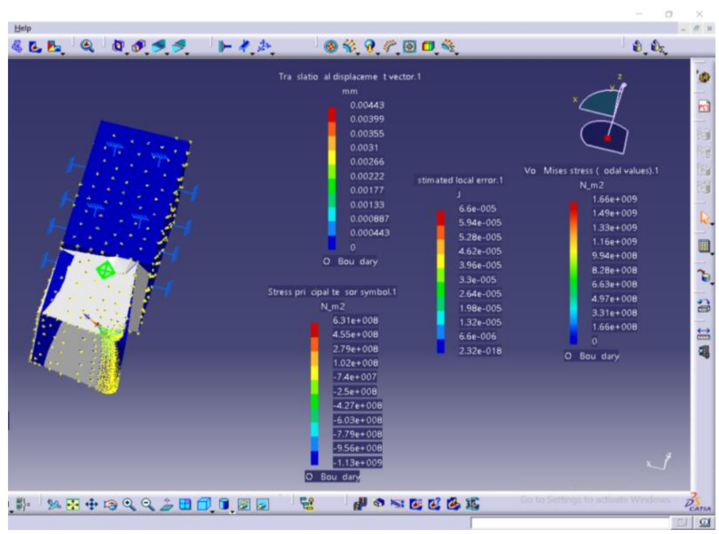

Fig 12 Tool Analysis Result with 6^0 Side rake angle.

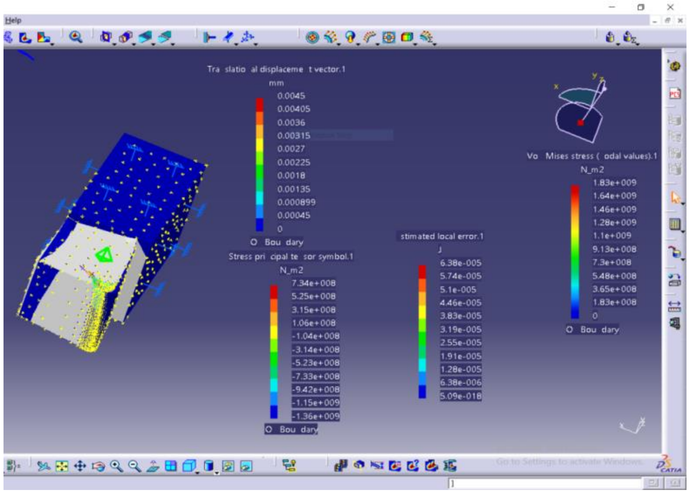

Fig 13 Tool Analysis Result with 6.5^0 Side rake angle.

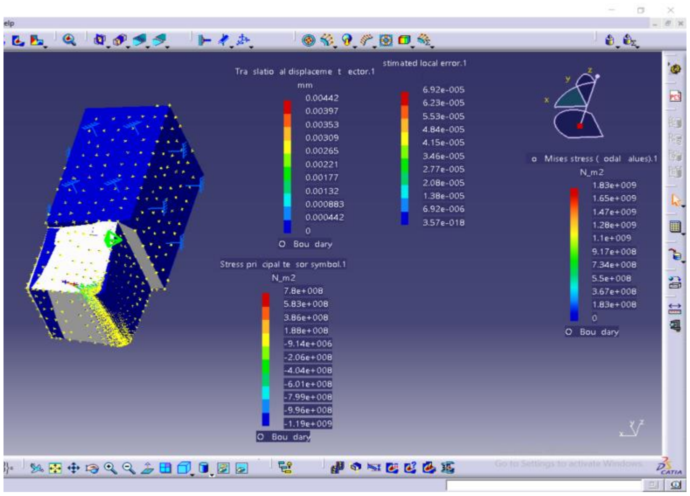

Fig 14 Tool Analysis Result with 7^0 Side rake angle.

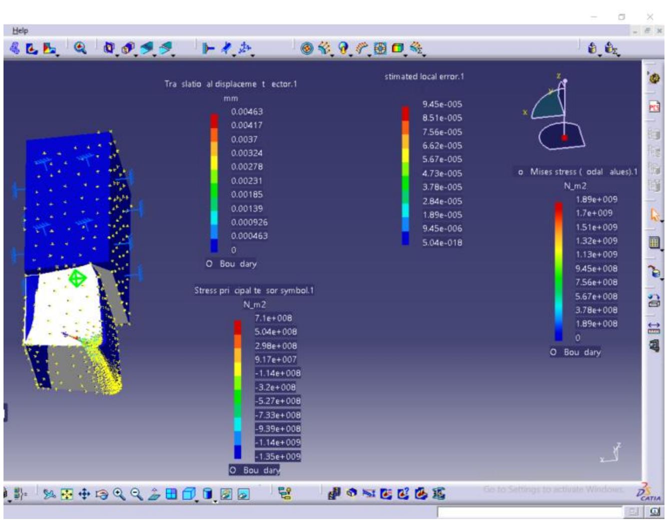

Fig 15Tool Analysis Result with 7.5^0 Side rake angle.

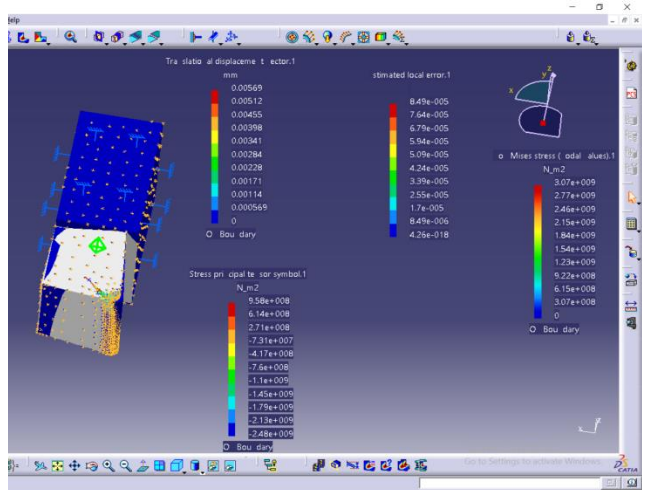

Fig 16 Tool Analysis Result with 8^0 Side rake angle.

Comparison of Results

The results obtained by varying side rake angle from 60 to 80 are shown in table 3.

Side rake angle (deg)	Von mises stress (N/m^2)	Principal stress(N/m^2)	Displaceme nt (mm)	Error
6	$1.66X\ 10^9$	$6.31X\ 10^8$	0.00443	$6.6X\ 10^{-5}$
6.5	$1.83X10^9$	$7.34X\ 10^8$	0.0045	$6.38X\ 10^{-5}$
7	$1.83X\ 10^9$	$7.8X\ 10^8$	0.004432	$6.92X\ 10^{-5}$
7.5	$1.89X\ 10^9$	$7.1X\ 10^8$	0.00463	$9.45X\ 10^{-5}$
8	$3.07X\ 10^9$	$9.58X\ 10^8$	0.00569	$8.49X10^{-5}$

Table 3: Analysis results of single point cutting tool with different side rake angle.

Observing fig 17 to fig 19, the developed displacements, principal stress, vonmises stresses are compared. Fig 17 shows that the vonmises stress increases with increase of side rake angle. The increase in side rake angle results in reduction of tool cross section area normal to the direction of feed, in other words the force developed direction. Thus results in increase of stress development. The response of tool considering principal stresses (fig 18) or displacement (fig 19) is almost similar to that of the case of analysis based on vonmises stress. With increase in side rake angle, the cutting force acting at the tip of the tool tends to act eccentrically. The reduction in side rake angle causes the decrease of flank thickness (from base to face) of tool from cutting edge to the other end. This cause lowering the support at the end, opposite to cutting edge which there by the tool strength decreases. Also at the higher side rake angle, the support at the end opposite to cutting edge looses close to the shank of the tool which results in cutting force off set in the plane normal to the direction of tool feed. This in turn results in increase of stress development. So finally the above said reasons results in increase of stress with increase of side rake angle. But at the same time too lower side rake angles are not preferred, because minimal angle is needed to guide the flow of the chips on to the face of the tool.

Results shows that the side rake angle more than 7.5^0 results stress and displacement development increases drastically. Therefore side rake angle less than 7.5^0 is preferable. Though the stress and displacement developed is decreasing with decrease of side rake angle, too small angle cannot be applied. With too lower angle practical problems may arise: the developed chip shape and size may not allow feasible machining operation. The chips thus formed cannot slide over the face of the tool, which thereby may struck between tool and work piece. So to conclude the optimum side rake angle experimental analysis need to be carried.

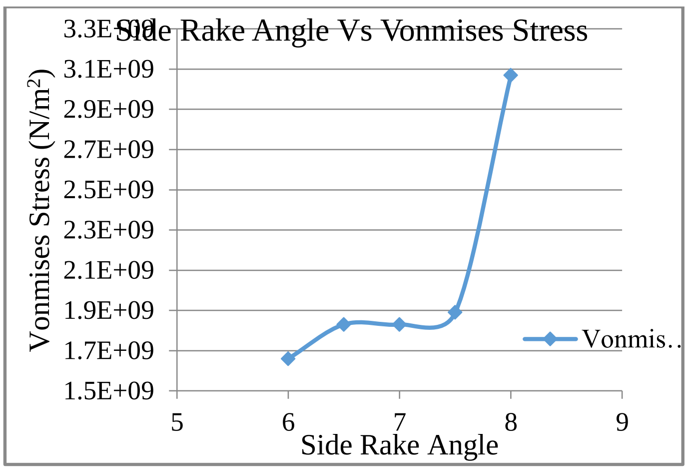

Fig 17: Vonmises stress developed with different side rake angles.

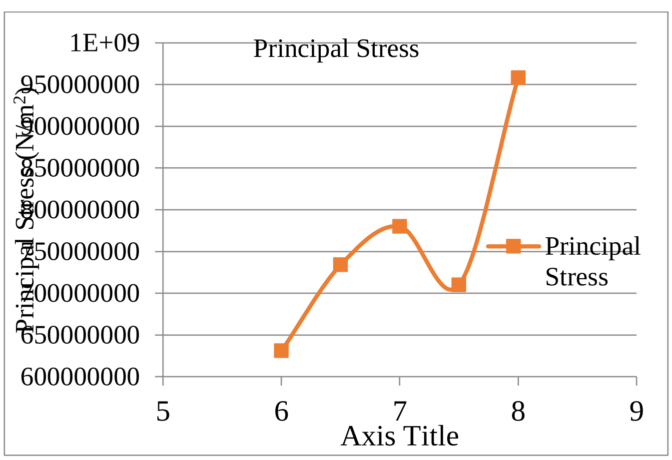

Fig 18: Principal stress developed with different side rake angles.

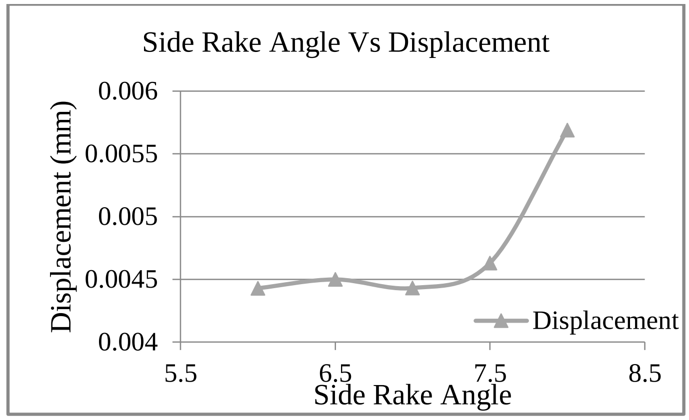

Fig 19: Displacement developed with different side rake angles.

6. CONCLUSION

Tool geometry plays a vital role in the tool life of the cutting tool, mainly side rake angles .As the side rake angle increases, the stress also increases .The vonmises stress is low for the side rake angle less than 7.5^0. The optimum range from 6^0 to 7.5^0 of side rake angle resulting in low stress development. From the considered range of side rake angle, the suitable rake angle for better tool life is 6^0. Further to identify optimum side rake angle, other parameters like feed rate, tool material etc need to be varied and thereby to carry experimental analysis to study practical problems like chip formation effect.

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