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Design and Analysis of Single Point Cutting Tool by Varying rake angle

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Abstract

In the engineering industry Metal cutting process forms the basis and is involved indirectly or directly in the manufacture of every product of our modern civilization. The study of metal cutting is very important and knowledge in the fundamentals of machining of materials is essential. Theory of metal cutting will help to develop a scientific approach in solving problems encountered in machining.

In this project "Design and Analysis of Single Point Cutting Tool by varying rake angle", by varying rake angles the metal cutting theory is studied and this have been extended to tool-geometry, materials used and its properties, working conditions and its characteristics, effects of variable parameters like feed, cutting speed, and depth of cut during the machining process.

This project includes modeling of single point cutting tool with commercial angles in CATIAV5R20 and then the analysis is done in ANSYS15.0. After post processing the results of analysis, we modified the geometrical design and designed various tools with different back rake angles, analyzed them individually.

Keywords:

cutting tool;
cutting speed;
feed;
depth;
Catia;
Ansys.

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1. Introduction

The study of machine tools and metal cutting is one of the most fascinating experiences. Material machining is done to adopt higher surface finish, complex geometric shapes, close tolerances.

Material removal is most expensive one when compared to all the manufacturing processes available. This is because, to achieve the desired shape some amount of material will be removed in the form of chips from the raw material and also a lot of energy should be expanded in the process of material removal. So, when there is no option for manufacturing process this type of material removal process is chosen as other alternative. However, all components undergo in the removal operation invariably at one point or the other..

Machine tool can be defined as holing components which holds the cutting tools and it have ability to remove metal from the work-piece, to obtain the desired shape with given configuration, size and finish. Machine tools are also known as mother machines because, without them components cannot be produced in desired form.

Machining is the process of removing the unwanted material from parent material of the metal by using a machine tool. This metal cutting can be done either by single point cutting tool or multi-point cutting tool. Some of the metal cutting operations are Drilling, Milling, Boring, T urning, Planning, Shaping, Broaching, etc. The machining operation is significantly affected by physical properties and chemical composition properties of the metal of the work piece, tool geometry and its material used.

There are two types of metal cutting by a single point cutting tool. They are orthogonal cutting and oblique cutting.

Orthogonal Cutting:

During this cutting process, the cutting face of the tool will be at right angle to the line of action of the tool then it is called orthogonal cutting and the direction of the chip flow will be perpendicular to the cutting edge. This type of cutting produces sharp corners. In the orthogonal cutting, the tool life will be less. Generally parting off, broaching and slotting operations are done in this method.

There are two forces orthogonal cutting. They are Cutting and Feed forces. The Radial force is zero because the face of the cutting tool is at right angle to the line of action of force.

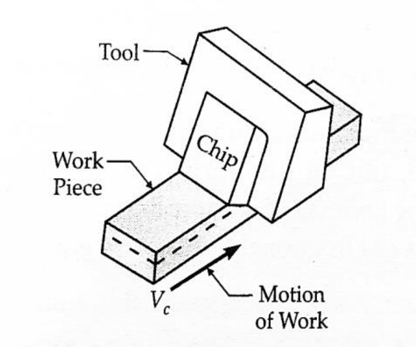


Figure 1.1: Orthogonal Cutting

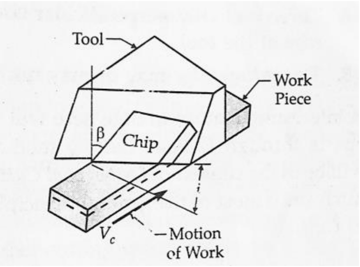


Figure 1.2: Oblique Cutting

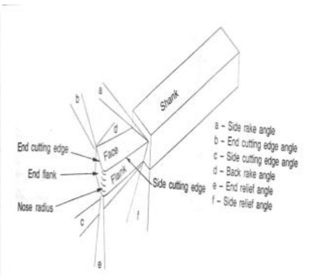


Figure 1.3: Geometry of a Single-point Cutting Tool

Under the process of cutting, if the cutting face of the tool is inclined and it is less than right angle to the line of action of the tool then it is known as oblique cutting. Here, the direction of the chip flow will make an angle to the cutting edge. This cutting produces chamfer at the end of cut.

In oblique cutting, the tool life will be more. Generally all machining operations are done in this method.

There are three mutually perpendicular components of cutting forces at the cutting edge of the tool. The cutting edge may or may not be longer than the width of the cut. Cutting forces greater than Feed force greater than Radial force. The forces are in the order of:

$$F_c > F_t > F_r$$

The geometry of single point tool consists of three orthographic views. A single-point tool consists of the shank or the body and a neck, which is known as the operating end. The use of the shank is to hold tool in the tool post or tool holder. The tool neck has the following elements: Face, Cutting Edges, Flank, and Nose. Here face is the surface on which the chip impinges from the work piece along which it flows as it is separated from the work. The flanks are the two surfaces of the tool facing the work. They are called the main flank or the side flank and the end flank or auxiliary flank.

In the process of metal cutting edges are formed by the intersection of the flank and the face. They are called the main or side cutting and end cutting edge. The side or the main cutting edge is the main sharp edge for the cutting process. This is formed by the intersection of side flank and the face. The end cutting edge is formed by the intersection of the face and the end flank. The nose is the element formed at the junction of the end cutting edges and side cutting edge. This junction or the nose has a curve of small radius known as nose radius.

Cutting tool angles:

The geometry of the cutting tool is defined by five angles these are described below:

- ***Side Rake Angle:*** Side rake angle is the angle between line parallel to the base of the tool and the tool face and is measured in a plane perpendicular to the side cutting edge and the base. This angle gives the slope of the face of the tool from the cutting edge.

- ***Back Rake Angle:***Back rake angle is also commonly called rake angle. It is the angle between the normal to the machined surface at the cutting edge to the face of the cutting tool. Rake angles may be positive, negative or zero. The strength of the tool is a function of rake angle. A tool with a positive rake angle will have less cross-sectional area for resisting the cutting forces. Hence, the strength of the tool is maximum when rake angle is negative.

- ***Relief Angle:***The relief angle is the angle between the tangent to the machined surface at the cutting edge and the flank of the cutting tool. The side face of the flank forms side angle and the end face of the flank form relief angles. The relief angles enable the flank of the cutting tool to clear the work-piece surface and prevent rubbing. These relief angles are also referred to as clearance angles.

- ***End Cutting Edge Angle:***This is the angle formed by the end cutting edge with the machined surface is called end cutting edge angle. This angle provides a clearance for that portion of that cutting edge, which is behind the nose radius. This angle reduces the length of the cutting edge in contact with the work. It is undesirable to have a cutting edge, just contact the work surface without actually cutting. This results in rubbing action, causing more tool wear and may spoil the surface finish.

- ***Side Cutting Edge Angle:***Angle formed by the side cutting edge with the normal to machined surface is known as side cutting edge angle. It is essential for enabling the cutting tool at the start of the cut to the first contact the work back from the tool tip. A large side cutting edge angle increases the force component, which tends to force the cutting tool away from the work-piece.

2. Cutting Tool Materials

Cutting tool performance will always depend on the material used. This material used in maching application should have properties such as hot hardness, wear resistance, and toughness. Here, toughness and wear resistance are two characteristics, which are, independent and the gain of one results in the loss of another.

By considering the needs of the industry, e.g. good surface finish, higher rates of production, close tolerances, etc., various tool materials have been developed. The development of new tool materials came into existence in many cases has brought the necessary for a change in the design trend of machine tools and to use the potentialities of tool materials for higher productivity. The tool materials developed include high. speed steels, tool steels, Ceramics, Synthetic diamond and Carbides.

High Speed Steel

Alloying steel with Tungsten, Chromium, Molybdenum, etc. produces alloy steel known as high speed steel (HSS). It can retain the hardness up to 600 ^{0}C. Owing to its superior hot hardness and wear resistance, it can be widely used. It can operate at cutting speeds 2-3 times greater than carbon steels. HSS can be classified into three types based on alloying elements and their percentage:

- ***8-4-1 HSS:*** In this alloy steel, it contains of 1% Vanadium, 4% Chromium, and 8% Molybdenum and it functions as effectively as 18-4-1 HSS. It has excellent toughness and cutting ability. This type of steel is also known as Molybdenum based HSS.

- ***18-4-1 HSS:***In this alloy steel, it contains1% Vanadium, 4% Chromium, and18% Tungsten. This type of steel has good stability and provides good hot hardness. This type of steel is known as Tungsten based HSS.

- ***Cobalt based HSS:*** This steel contains of 2-15% Cobalt. It increases wear resistant and the hot hardness. As the hot hardness is very high it can be operated at very high speeds. This steel is also known as super high speed steel.

Carbides

In carbide mostly we will find tungsten carbide as its primary ingredient. In the purpose of steel machining carbide will be much suitable and it consists of 8% Cobalt, 10% Titanium and 82% Tungsten carbide. These carbides have very high hardness, temperatures and have high thermal conductivity. These carbides have a strong tendency in forming of pressure welds at low cutting speeds and hence they should be operated at high speeds compared to those used for HSS tools.

Turning

In this operation excess material is removed from the work piece to produce cylindrical surface or a cone shaped surface. This operation is carried out on lathe. Various types of turnings on lathe can be performed are taper turning, eccentric turning and straight turning.

Forces in Turning:

The forces in a turning operation are very important in the design of machine tools. While machining the tool must have ability to withstand all the forces without causing much significance to vibrations, deflection or chatter during the time of operation.

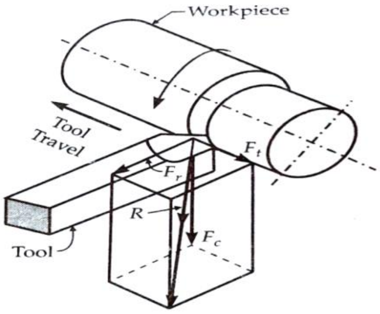


Figure 1.4: Forces acting on a Single Point Turning Tool

There are three principal forces during a turning process:

- **Cutting or Tangential Force:** Cutting force acts directly on to the work piece and the tool tip acts downward allowing deflection of the work-piece upward. Cutting forces gives force on the tool for the required cutting operation. Cutting force depends on the material.
- **Feed or Thrust Force:** Feed force acts in longitudinal direction and pushes the tool away from chuck. So it is also called as thrust force.
- **Radial Force:** Here the force acts in the radial direction and it tries to push the tool away from work-piece.

In case of turning operation, cutting force, radial force and tangential force (F_c, F_t and F_r) can be easily determined using the relation for resultant R:

$$R = \sqrt{(F_c^2 + F_t^2 + F_r^2)}$$

modelling of tool in catia

Geometry of the Tool

The geometry of the tool that used to develop part modeling in CATIA V5R20 is given below

Width (B) - 25
Height (H) – 40
H/B ratio = 1.6

Back Rake Angle (degrees)	Side Rake Angle (degrees)	End Relief Angle (degrees)	Side Relief Angle) (degrees)	End Cutting Edge Angle (degrees)	Side Cutting Edge Angle (degrees)	Tool Radius (mm

7^0	10^0	5^0	5^0	15^0	15^0	0.5
8^0	10^0	5^0	5^0	15^0	15^0	0.5
9^0	10^0	5^0	5^0	15^0	15^0	0.5
10^0	10^0	5^0	5^0	15^0	15^0	0.5

Table 3.1: Geometry of the Tool

Modelling of tool

The rough sketch of the tool shank in CATIA tool is shown below

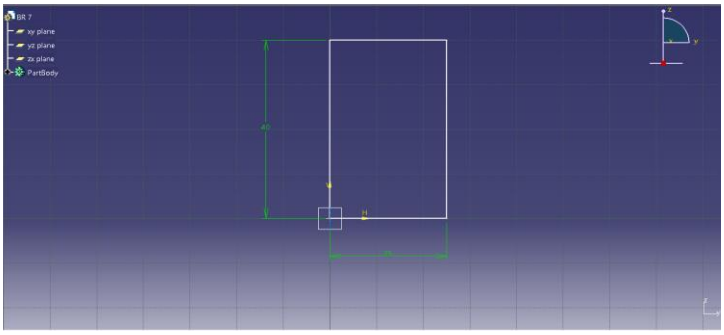


Figure 3.1: Geometrical Representation of Tool Shank in CATIA V5R20

The shank of the tool is obtained by giving PAD to the sketch as shown below

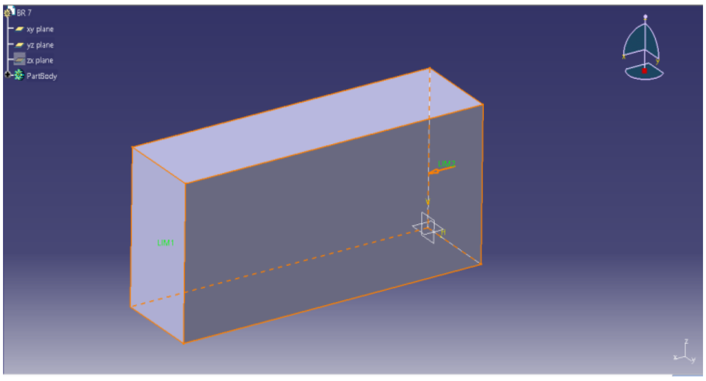


Figure 3.2: Part Model of Shank

The sketch of the tool bit with side rake and side clearance angle is shown below

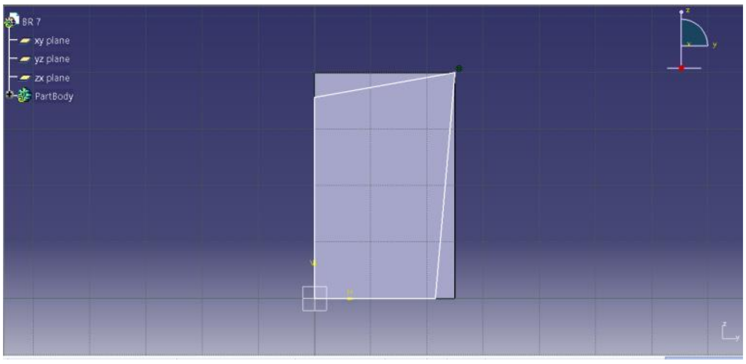


Figure 3.3: Sketch of Tool Bit

The sketch is given PAD command and the obtained is shown below

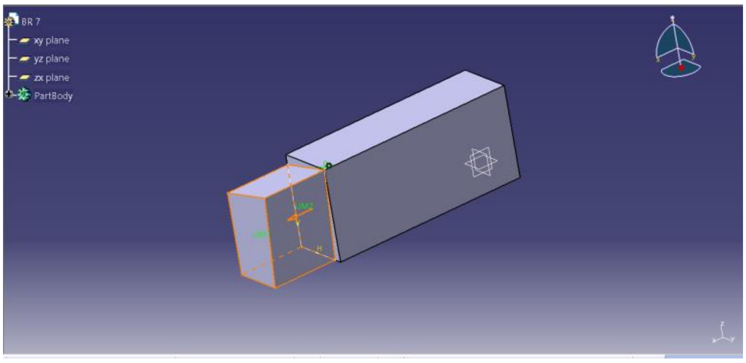


Figure 3.4: Part Model of Tool (Step – I)

The back rake angle is given by using SLOT command and the obtained is shown below

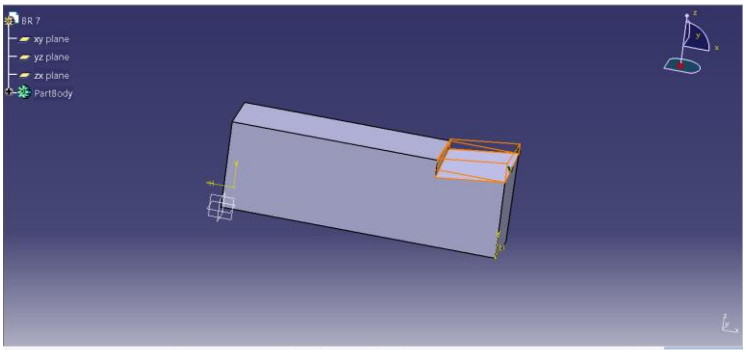
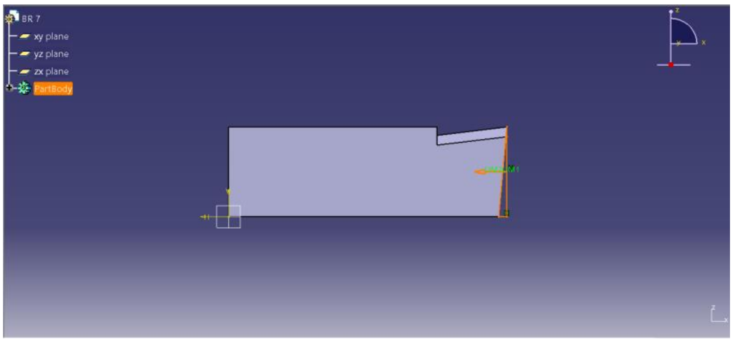


Figure 3.5: Part Model of Tool (Step – II)

The end relief angle is given by using POCKET command and the obtained is shown below



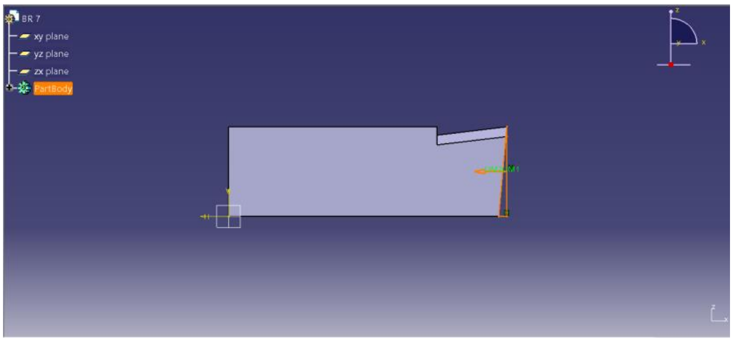


Figure 3.6: Part Model of Tool (Step – III)

The side cutting edge angle is given by using SLOT command and the obtained is shown below

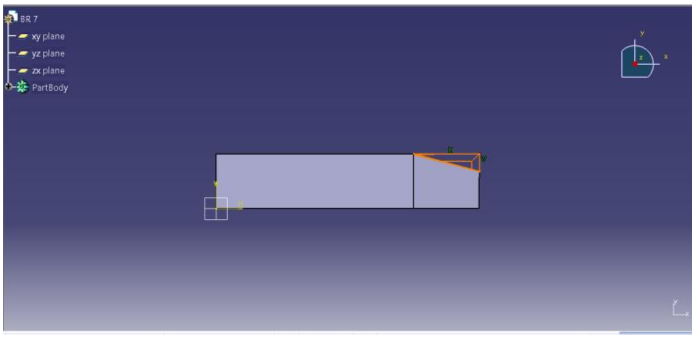


Figure 3.7: Part Model of Tool (Step – IV)

The end cutting edge angle is given by using SLOT command and the obtained is shown below

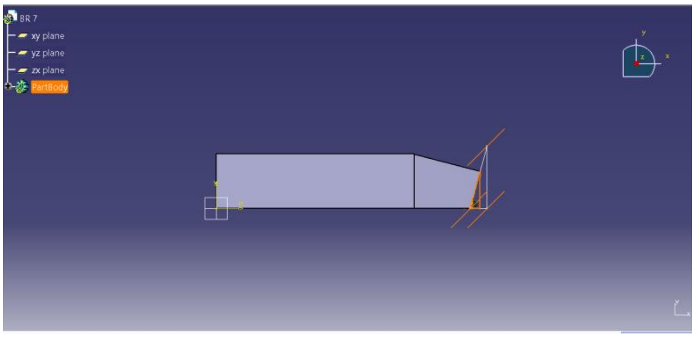


Figure 3.8: Part Model of Tool (Step – V)

The Tool modelled in CATIA software is shown below

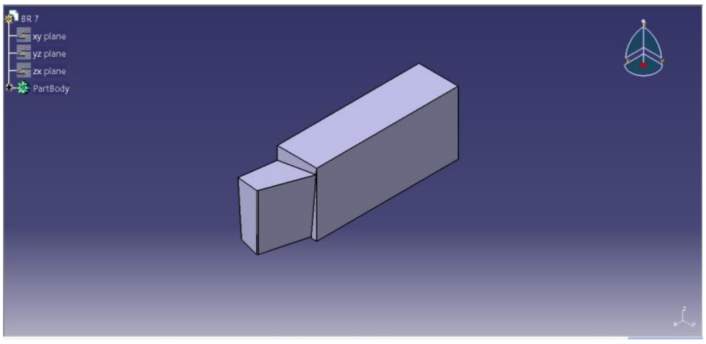


Figure 3.9: Designed Tool with Back Rake Angle 7^0

Similarly three more tools are designed in CATIA software by varying Back Rake angle (7^0, 8^0, 9^0, and 10^0) as shown in fig. below respectively

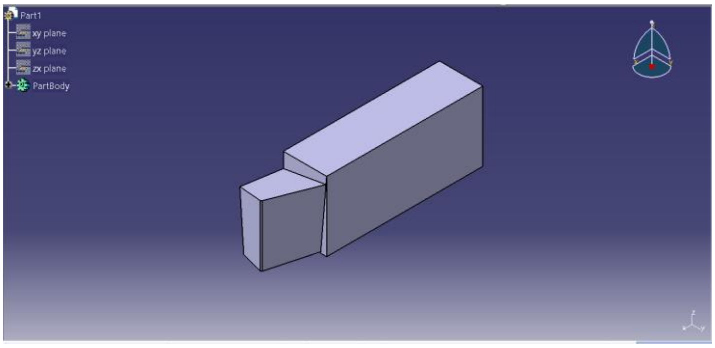


Figure 3.10: Designed Tool with Back Rake Angle 8^0

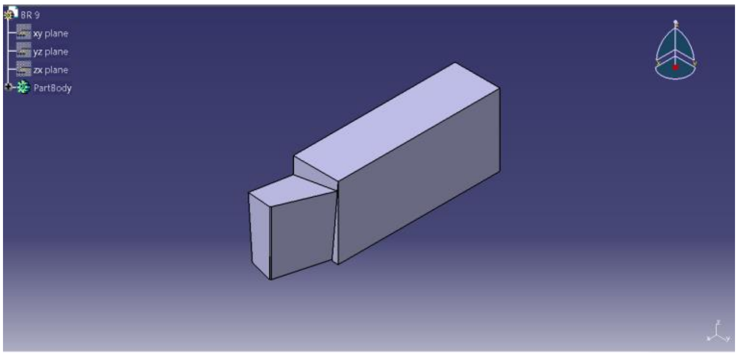


Figure 3.11: Designed Tool with Back Rake Angle 9^0

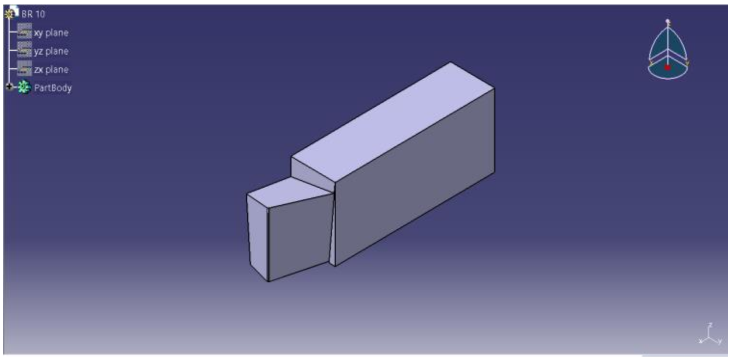


Figure 3.12: Designed Tool with Back Rake Angle 10^0

Anlysis of tool

All the models dawn in Catia are imported into Ansys in .igs format and analysis is done by varying speed, feed and depth of cut, various forces acting on the single point cutting tool are obtained. The various forces thus obtained are used for determining the von-mises stress, von-mises strain and deformation. Analysis of the tool is done in the Static Structural Module.

Engineering Data

In Engineering Data, the materials and their properties are taken into consideration. For the project, 8-4-1 High Speed Steel and Cemented Carbide are considered.
The material properties for 8-4-1 HSS are as follow:

Table 4.1: Material Properties of 8-4-1 HSS:

Density	8160 kg/m^3
Young’s Modulus	210 GPa
Poisson’s Ratio	0.3
Yield Strength	3250 MPa

The material properties of Cemented Carbide are as follows:

Table 4.2: Material Properties of Cemented Carbide

Density	15630 kg/m^3
Young’s Modulus	550 GPa
Poisson’s Ratio	0.234
Ultimate Strength	3448 MPa

Geometry:

The part modelling of CATIA file is saved in the ‘.igs’ format and then imported to Static Structural Module.

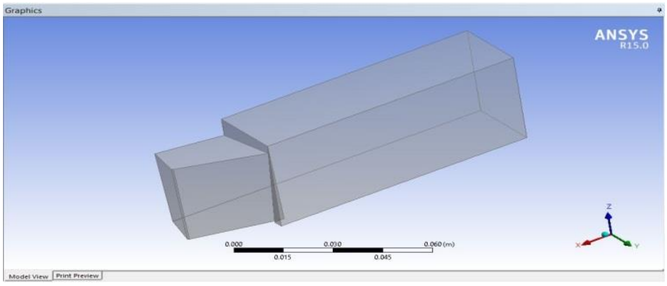


Figure 4.1: Geometry

Model:

The imported file geometry undergoes meshing, after which the physics is defined to the external domain. Fine Mesh is considered for good results.

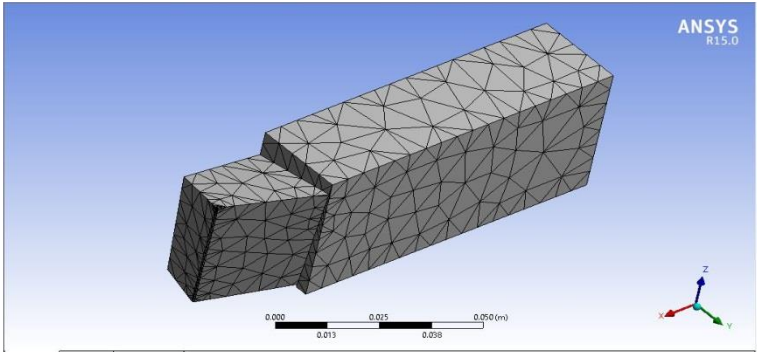


Figure 4.2: Meshing

Boundary Conditions:

The Boundary conditions for the tool are defined as follows:

The shank of the tool is fixed and the figure is shown below

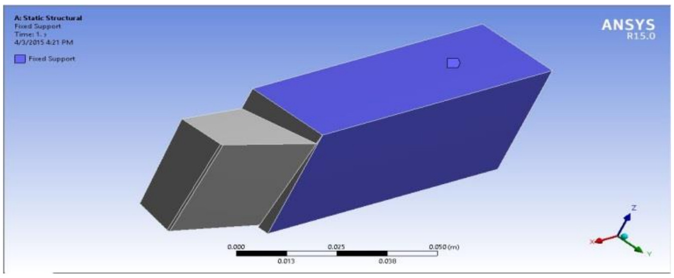


Figure 4.3: Fixed Support

Iteration No.	Speed (RPM)	Feed (mm/rev)	Depth of Cut (mm)	Forces (N)		
				Cutting Force	Feed Force	Radial Force
I	269	0.094	0.5	167.580	116.739	48.069
II	269	0.380	1.0	916.254	619.010	309.996
III	269	0.690	1.5	1084.986	811.287	509.139
IV	315	0.094	0.5	453.200	412.020	279.590
V	315	0.380	1.0	1013.730	902.520	146.169
VI	315	0.690	1.5	307.053	232.490	115.750
VII	525	0.094	0.5	631.764	559.170	243.288
VIII	525	0.380	1.0	247.212	164.808	103.986
IX	525	0.690	1.5	1092.834	813.249	471.861

Table 4.3: Boundary Conditions

The forces are given at the tip of the tool and it is shown in the ANSYS MECHANICAL tool below:

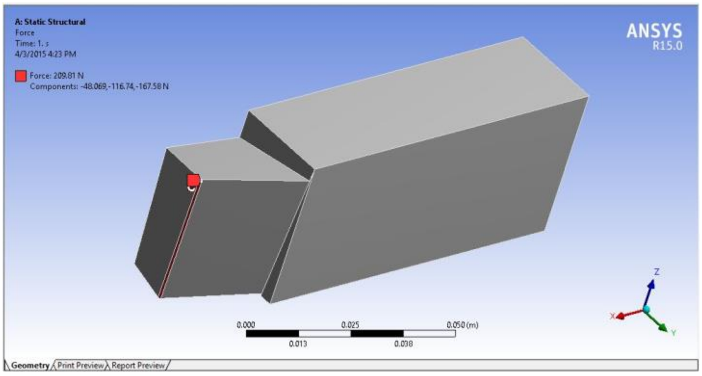


Figure 4.4: Boundary Conditions

Solutions and Results:

After applying the boundary conditions, the solutions and results for 8-4-1 HSS and cement carbides are as follows:

Results and discussion

Results of 8-4-1 HSS Tool:

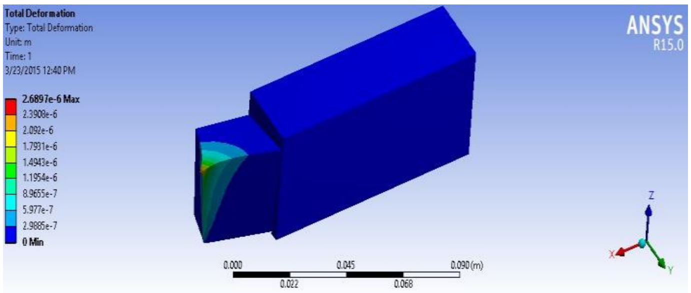


Figure 5.1: Deformation at 9^0 (Iteration – IX)

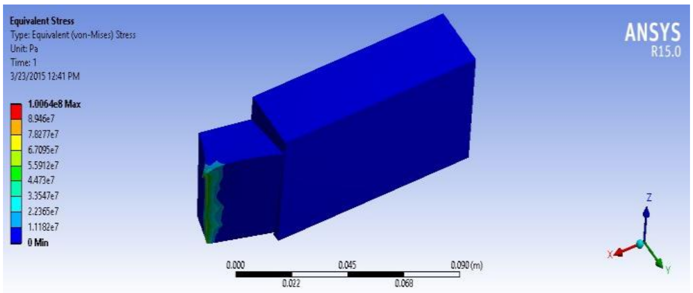


Figure 5.2: Stress at 9^0 (Iteration – IX)

Results of Cemented Carbide Tool:

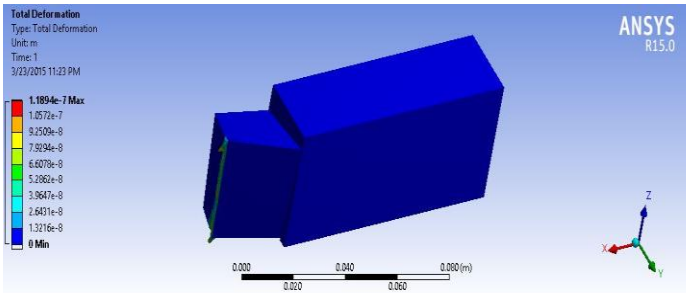


Figure 5.3: Deformation at 9^0 (Iteration – IX)

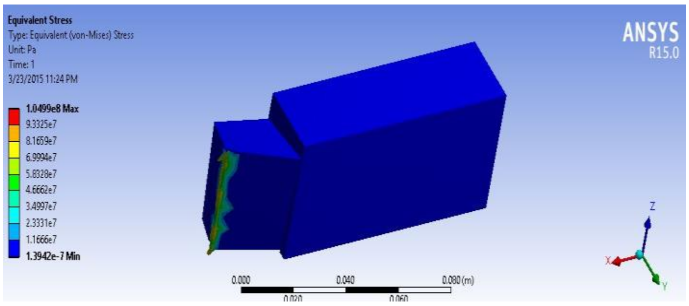


Figure 5.4: Stress at 9^0 (Iteration – IX)

RESULTS:

The results from the static structural analysis on the single point cutting tool using ANSYS are tabulated and are shown as follows:

Results and graphs of 8-4-1 HSS tool:

Iteration No.	FORCES	Stress (Pa)			
		Back Rake angle 7^0	Back Rake angle 8^0	Back Rake angle 9^0	Back Rake angle 10^0
I	206	1599.486	1580.203	1720.069	1658.109
II	313.92	2281.675	2262.443	2423.121	2333.525
III	402.21	2971.911	2893.007	3162.251	3046.008
IV	667.08	4379.904	4299.658	4729.231	4667.593
V	873.09	6380.027	6300.536	6907.801	6899.157
VI	1147.77	8499.965	8439.352	9189.895	9188.899
VII	1363.59	9009.356	8993.657	9503.256	9450.125
VIII	1442.07	10086.035	10078.887	10396.895	10247.153
IX	1451.88	10144.638	10060.402	10979.486	10973.349

Table 5.1: Stress values of 8-4-1 HSS tool

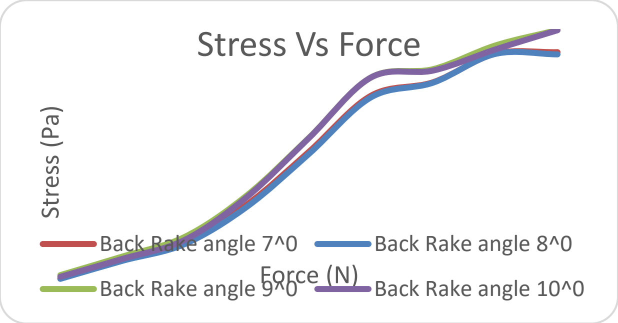


Figure 5.1: Stress vs Force for 8-4-1 HSS tool at different Back Rake angles

Iteration No.	FORCES	Deformation (mm)			
		Back Rake angle 7^0	Back Rake angle 8^0	Back Rake angle 9^0	Back Rake angle 10^0
I	206	0.00379	0.00368	0.00398	0.00411
II	313.92	0.00434	0.00419	0.00459	0.00476
III	402.21	0.00572	0.00554	0.00578	0.00583
IV	667.08	0.00606	0.00597	0.00613	0.00639
V	873.09	0.0065	0.00649	0.00697	0.00715
VI	1147.77	0.00689	0.00673	0.00719	0.00735
VII	1363.59	0.00709	0.00705	0.00742	0.00741
VIII	1442.07	0.00719	0.00718	0.00759	0.00761
IX	1451.88	0.00732	0.00723	0.00771	0.00779

Table 5.2: Deformation values of 8-4-1 HSS tool

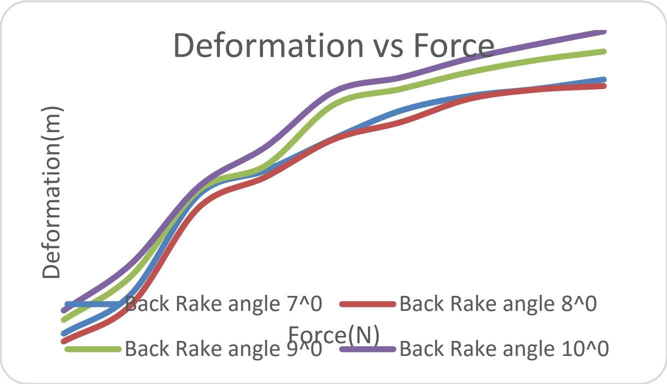


Figure 5.2: Deformation vs Force for 8-4-1 HSS Tool at different Back Rake angles

Results and graphs of Cemented Carbide tool

teration No.	FORCES	Stress (Pa)			
		Back Rake angle 7^0	Back Rake angle 8^0	Back Rake angle 9^0	Back Rake angle 10^0
I	206	1616.217	1809.444	1827.758	1850.787
II	313.92	2255.006	2528.287	2551.865	2582.461
III	402.21	2987.338	3276.739	3308.871	3349.117
IV	667.08	4569.993	4692.931	4734.823	4787.242
V	873.09	6639.565	6999.371	7099.445	7154.873
VI	1147.77	8592.884	9437.405	9851.262	9871.891
VII	1363.59	9023.159	9756.482	10457.486	10305.446
VIII	1442.07	10134.124	10306.483	10636.49	10505.456
IX	1451.88	10312.427	10514.257	10879.486	10790.473

Table 5.4: Stress values of Cemented Carbide tool

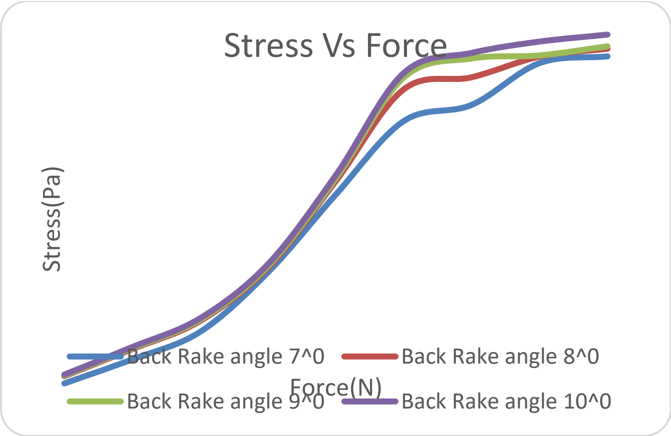


Figure 5.3: Stress vs Force for Cemented Carbide Tool at different Back Rake angles

	FORCES	Deformation (mm)

Iteration No.		Back Rake angle 7^0	Back Rake angle 8^0	Back Rake angle 9^0	Back Rake angle 10^0
I	206	0.00145	0.00061	0.00054	0.000535
II	313.92	0.00206	0.0009	0.000878	0.000823
III	402.21	0.00259	0.00134	0.00112	0.00105
IV	667.08	0.00352	0.00199	0.00181	0.00164
V	873.09	0.00434	0.00259	0.0024	0.00224
VI	1147.77	0.00583	0.00364	0.00322	0.0031
VII	1363.59	0.00654	0.00423	0.00386	0.00364
VIII	1442.07	0.00704	0.00499	0.00432	0.0042
IX	1451.88	0.00722	0.00564	0.00521	0.00499

Table 6.6 Deformation values of Cemented Carbide tool

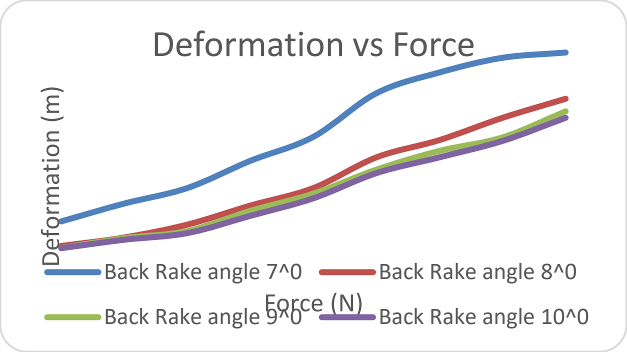


Figure 5.4: Deformation vs Force of Cemented Carbide Tool at different Back Rake angles

Conclusions

- The optimal tool geometry had more tool life than the basic tool. Depth of Cut has greatest influence on cutting force, followed by feed, while cutting speed has least influence.
- The temperature at the tip of the cutting tool during the time of machining is influenced by cutting speed
- It is observed as the cutting angles are increased the area throughout the body of the tool decreases, and the stress increases.
- Optimal angle is taken at the point of maximum stress obtained because maximum stress condition is observed at lower cross sectional area of tool tip while deformation produced by the tool in the work material is less at lower cross sectional area of the tool tip due to which the less cutting are generated and the heat generated by the tool will be less.
- For 8-4-1 HSS and Cemented Carbide the maximum stress condition was achieved at a Back Rake Angle of 9^0, when compared between Back Rake Angles 7^0,8^0, 9^0 and 10^0.
- When comparing across tool materials, by taking all the properties into account cemented carbide steel is best material.

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