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### ANALYSIS OF SINGLE POINT CUTTING TOOLS WITH DIFFERENT TOOL MATERIALS AND JOB MATERIALS

**Deepesh Gehlot<sup>1</sup>, Anil Elisala<sup>2</sup>**

<sup>1</sup>Assistant Professor, <sup>2</sup>Research Scholar

<sup>1,2</sup> BM College of Engineering and Technology, Indore (M.P.) INDIA

#### ABSTRACT

Cutting technologies are the engines behind manufacturing. Without cutting, none of modern product would ever been place into service. Developing new materials directly wants analysis for method windows in cutting. Vast engineering efforts brought cutting within the position where it's these days and despite all rumors attempting to declare, that cutting is superannuated or cutting analysis is finished it's still a significant field of analysis and prone to fast innovations. Considering these facts present research work is devoted to investigations in cutting tools. For this purpose a single point cutting tool was targeted and investigations were made on Vonmises stresses and total deformations considering different types of tool materials and job materials. The tool materials were molybdenum high speed steel (Mb HSS) and Cubic Boron Nitride (CBN). The job materials were aluminium and tool steel. During the analysis, variation of parameters were analyzed by analyzing cutting forces, and varying depths of cut to 0.5 mm, 1 mm, 1.5 mm and 2 mm, and rack angles to 0°, 2°, 4°, 6°, and 8°. The results show that during the machining, cutting forces contribute greatest as compared to thrust and feed forces, and increase with depth of cut. Results of Vonmises stress analysis shows these stresses increase with increase in rack angle and depths of cut, irrespective of type of job material and tool material. At 1.5 mm and 2 mm depths of cut, von-misses stresses show same intensity, but value of deformations changes which depends on the type of materials used for tooling and job.

**Keywords:** Single point cutting tool, CBN, HSS, rack angle.

#### INTRODUCTION

The life of a tool is important in metal cutting since considerable time is lost whenever a tool is replaced or reset. Cutting tools lose its sharpness as usage continues and their effectiveness decrease over time. At some point during the life-span of the tool, it is necessary to replace, index or re-sharpen and reset the tool. Tool life is a measure of the length of time a tool will cut effectively. The life of cutting tool depends upon many factors, such as the microstructure of the material being cut, metal removal rate, the rigidity of the setup and effects of cutting fluid. Of all the factors the cost of cutting tool is very high. Tools of H.S.S, carbide, diamond tip cost very high. Therefore it is necessary to pay attention to increase the tool life. As the tool life increases, the variable cost decreases. In exact mechanism of metal cutting briefly stated is that a cutting tool exerts a compressive force on the work piece. Under this compressive force the material of the work piece is stressed beyond its yield point causing the material to deform plastically and shear off. The sheared material begins to flow along the cutting tool face in the form of small pieces called chips.

Considering above mentioned facts present research is devoted to the investigations in cutting tools. In present research work single point cutting tools are targeted. The materials for tools are Mb HSS and CBN (cubic boron nitride), and the materials for jobs are aluminium and tool steel. During the research work, analysis of different forces as well as effects of depths of cut and rack angles on von-misses stresses and deformation during turning operations are analyzed. For the purpose of analysis, a simulation approach is targeted, and the software used for analysis is ANSYS 14.0.

Following are the objectives of present research work.

- 1) Analysis of different forces acting on cutting tools during turning of hard and soft materials;
- 2) Analysis of effect of changes in rack angles during turning operations; and
- 3) Analysis of the effect of depths of cut on forces generated during turning operations considering different tool as well as job materials

**LITERATURE REVIEW**

Present section tells about the details of research contributions of different researchers in the field of cutting tools, and concludes with identified gaps in research, the details of which are presented in upcoming sections.

**Research Contributions in the Field of Cutting Tools**

Details of research contributions made by different researchers in the field of cutting tools are as follows.

*Table 1: Research Contributions in the Field of Cutting Tools*

S.No	Researchers (Year)	Contribution
1.	Orlowski <i>et al.</i> (2017)	The cutting force is an energetic impact of cacophonous material, and can be thought-about from a point of view of contemporary fracture mechanics. Forecasting of the shear angle in cutting broaden potentialities for modeling of the cutting process even for skinny uncut chips. Such mathematical model has been developed here for description of the orthotropic materials' cutting on the bottom of fracture theory, and includes work of separation (fracture toughness) in addition to the material plasticity and friction. the initial methodology of simultaneous determination of the fracture toughness and therefore the shear yield strength on the premise of wood cutting forces (or cutting power) is additionally conferred in this paper. The set of information necessary for computation is simply obtained whereas cutting wood with common rotating tools, such as a circular saw or a router bit. The results generated embody each fracture toughness and shear yield stresses in the shear plane, separately for two anatomical directions of wood. The simplicity and reliability of this methodology provides wide range of practical applications.
2.	Liu <i>et al.</i> (2017)	Orthogonal cutting may be a simplified two-dimensional model that neglects several geometric complexities, that describes complicated three-dimensional cutting method quite well in most cases. The orthogonal cutting ought to satisfy the plane strain assumption to stop the in depth deformation perpendicularly to the cutting direction owing to the pressure between the cutting tool and also the work piece, that is named as the side flow. To satisfy this assumption, the depth of cut (the uncut chip width) needs to be much larger than the feed (the uncut chip thickness) with a definite ratio. However, this criterion is not valid all the time. This paper presents an experimental study of the side flow with completely different cutting conditions by comparing the profiles of the cross section of the machined chip in machining of aluminum alloy. it is shown that the upper ratio between the uncut chip width and the uncut chip thickness (chip width-to-thickness ratio) and also the lower cutting speed will forestall the side flow during chip formation. A new criterion for plane strain assumption has been planned during this study as well.
3.	Garcia-Gonzalez <i>et al.</i> (2016)	Infrared thermography through transparent cutting tools has been accustomed measure the chip-tool interface temperature. It's of interest to increase this technique to review changes in interface temperature once tool coatings are used. an initial attempt is created here to measure the chip-tool interface temperature distribution once cutting Ti6Al4V with a TiN coated YAG tool. The TiN coating thickness is kept low at concerning 100 nm to minimize the temperature distinction between the front (chip-TiN interface) and therefore the back (TiN-YAG interface) faces of the coating. The transparency of the YAG tool permits

		near infrared radiation emitted by the rear face of the TiN coating to be imaged. A novel methodology is employed to measure the emissivity of the TiN/YAG interface. Using this technique, and the available blackbody calibration of the temperature vs. intensity response of the imaging system, the images are converted into temperature maps. The performance of the coated tool is additionally evaluated in terms of machining force and tool wear characteristics. Coatings that remain intact during the experiments can reduce ambiguity in interpretation of the results.
4.	Lu <i>et al.</i> (2016)	Cutting tools are direct performers in material cutting processes of nc machining, whereas the degree of cutter attrition and breakage directly influences the standard of production. Mean while tool condition recognition may be a key technique in automatic and unmanned machining process. Aimed toward this downside, the popularity of tool-condition based on machining feature in real-time is expressed. Machining options are used to build relationships between geometry, processing technology and monitoring signals so as to provide the premise for cutter condition identification. Feature info is established with experimental results and a cutter condition recognition system is established primarily based on this information. Experimental results recommended that the planned technique solves the problem of tool condition monitoring, particularly for production with multi varieties and small-batches.
5.	Koleva <i>et al.</i> (2015)	In the paper the chances of activity the dimensions of parts using the cutting tool that had machined the surfaces of the part are investigated. Described are the principal theme of the measuring device and its application for dimensional measurements. The method leads to additional efficient machining on CNC lathes. the applying of the tactic leads to automatic dimensional control, which otherwise would need specialized activity instrumentation or would result in increased idle time of the machine tool, automatic dynamic setup of the cutting tool, and automatic tolerance assurance using check-up data point surfaces. Reportable are the theoretical analysis of the measurement errors and also the methodology of predicting the accuracy of the measurements using the cutting tool itself. The results presented are experimental results of applying the system for direct dimensional measurements using the cutting tool on CNC lathe.

### Gaps in the Research

On the basis of survey of available literature, following research gaps are being identified.

- 1) There is almost nil research available which shows the analysis of different forces generated during turning of soft as well as hard materials;
- 2) There is almost nil research present which shows the comparison of different materials of cutting tools for machining soft and hard materials;
- 3) There is almost nil research available which shows the effect of changes in rack angle and depth of cut on the performance of cutting tools.

Based on the gaps identified, objectives of the research work are being investigated.

### SOLUTION METHODOLOGY

Present section tells about details of mathematical equations for determining forces during turning operations, and software used for simulation of the case problem, the details of which are presented in upcoming sub sections.

**Forces during Turning: Mathematical Expressions**

According to Shambharkar et al. (2016), in any metal cutting operation in a lathe there acts a force R on the tool. This force R can be resolved into *three* components.

1.  $F_x$ ; a force in horizontal plane, parallel to the direction of the feed (thrust force);
2.  $F_y$ ; a force in horizontal plane perpendicular to the direction of feed (feed force); and
3.  $F_z$ ; a force in vertical plane, perpendicular to both  $F_y$  and  $F_x$  (cutting force).

Empirical formula determining the  $F_z$  can be expressed as under:

$$F_z = C_p \times t^X \times S^Y \times K \quad (3.1)$$

...where,

$C_p$  = coefficient, characterized by the work material and condition of working such as tool, coolant;

$t$  = depth of cut;

$S$  = feed in mm/revolution;

$K$  = overall correlation, consisting of actual condition of working and tool angles, which varies from 0.9 to 1.0.

The components approximately connected by the following expression

$$F_x / F_z = 0.3 \quad (3.2)$$

...and

$$F_y / F_z = 0.2 \quad (3.3)$$

**Software used for Simulation**

In the present research work, the software used for simulation is ANSYS, the details of which are presented as follows.

ANSYS is considered as one of the renowned tools in the field of simulation, developed by ANSYS Inc., USA. It can be used successfully for the purpose of simulating problems of thermal analysis, structural analysis, computational fluid dynamics, harmonic analysis, modal analysis, transient dynamics, buckling, and other categories. In addition to this, software also offers the facility to develop simple models. With the help of inbuilt library, one can find out the properties of materials, and even add the desired properties or new materials with the known values of properties. ANSYS also include a set of models to solve complex problems of engineering, architecture, physical sciences, mathematical models and other applications. Following are the salient features of the software:

- Offers excellent simulation facility;
- Easy modules for different types of complex analysis like modal, transient, etc;
- Offers different theoretical perspective to solve a problem with different inbuilt models;
- Simple parts can be easily created;
- Inbuilt library to offer material properties; and
- Better graphics facilities.

In present research work software version ANSYS 14.0 is being used for analysis purposes.

**CASE STUDY**

Present section is devoted to application of research tools on the case problem, the details of which are presented as follows.

**Implementation of Research Tools to the Case Problem**

Following are the details of stepwise procedure used to solve the research problem.

1. First of all values of different forces acting on the cutting tool during turning were investigated with the help of equations (3.1 to 3.3), for hard and soft materials for different depths of cut. For this purpose, job materials chosen were mild steel and tool steel. Diameters of shafts are taken as 5 centimeters. The feed rate was chosen as 0.286

mm/revolution. The analysis was done for  $x = 1$  mm and  $y = 0.5$  mm. The depths of cut adopted were 0.5 mm, 1 mm, 1.5 mm, and 2 mm respectively. Values of  $C_p$  in equation 3.1 are taken as 225 for Mb HSS and 252 for CBN.

2. In next step, effect of variations of rack angles, depths of cut and tool as well as job materials was investigated. For this purpose, first of all a standard single point cutting tool was designed using modeling software with the following tool signature.

- a) Total length = 12 cms
- b) Tip formation = 4.5 cms
- c) Back rake angle =  $0^\circ$
- d) Side rake angle =  $7^\circ$
- e) End relief angle =  $6^\circ$
- f) Side relief angle =  $8^\circ$
- g) End cutting edge angle =  $15^\circ$
- h) Side cutting edge angle =  $16^\circ$ , and
- i) Nose radius = 0.8 mm

3. In next step, geometry was imported in simulation software (ANSYS 14.0) and first of all its meshing was performed, due to which it was now able to experience changes in accordance with different working conditions. With the help of meshing, the model was broken down in to 2667 nodes, and 1350 elements. Mesh elements were of triangular type. Figure ..... Shows the meshed geometry.

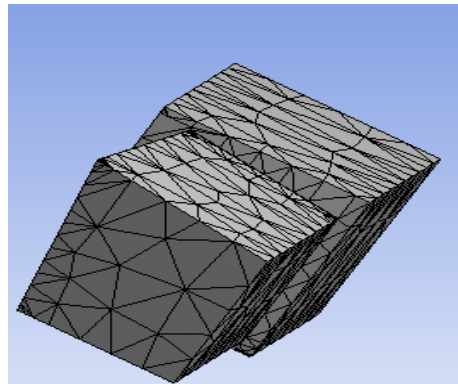


Figure 1: Meshed Geometry

4. In next step, evaluation of cutting tools under different rack angles, depths of cut and job materials was carried out. Analysis was done under Static *Structural mode* provided in the software. The cutting tool materials were Mb HSS and CBN. Following are the properties of cutting tool materials used in the analysis.

Table 2: Properties of Cutting Tool Materials (Source: [www.ozomaterials.com](http://www.ozomaterials.com))

S.No	Cutting tool Material/ Property	Mb HSS	CBN
1.	Density ( $\text{kg/m}^3$ )	8160	3350
2.	Young's Modulus (MPa)	210000	505000
3.	Poisson's Ratio	0.3	0.3

## Results and Discussion

Present section is devoted to the results obtained from research work and associated discussion, the details of which are presented in upcoming sub sections.

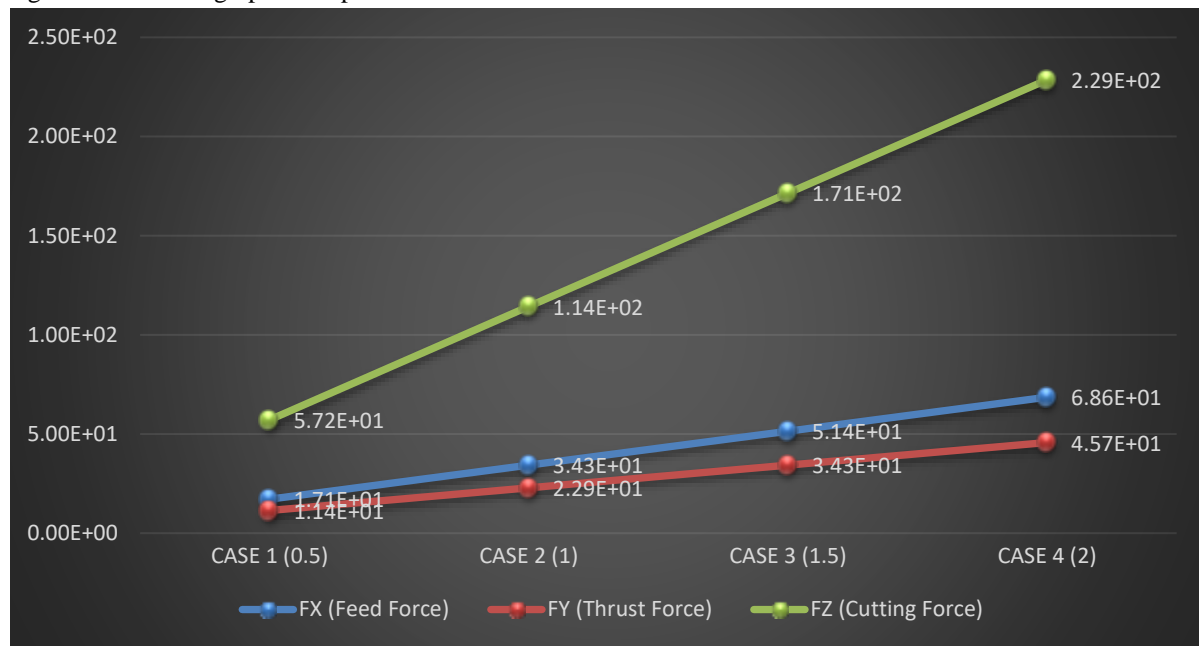
**Results**

Following are the results obtained from force analysis of cutting tools.

*Table 3: Forces obtained with Soft Materials*

S. No	Depth of Cut	Forces		
		F <sub>x</sub>	F <sub>y</sub>	F <sub>z</sub>
1.	0.5	17.14669	11.43113	57.15565
2.	1	34.29339	22.86226	114.3113
3.	1.5	51.44008	34.29339	171.4669
4.	2	68.58678	45.72452	228.6226

Figure 2 shows the graphical representation of above results.



*Figure 2: Graphical Representations of Forces generated in cutting tools with Soft Material*

*Table 3: Forces obtained with Hard Materials*

S. No	Depth of Cut	Forces		
		F <sub>x</sub>	F <sub>y</sub>	F <sub>z</sub>
1.	0.5	19.2043	12.80286	64.01432
2.	1	38.40859	25.60573	128.0286
3.	1.5	57.61289	38.40859	192.043
4.	2	76.81719	51.21146	256.0573

Figure 3 shows the graphical representation of above results.

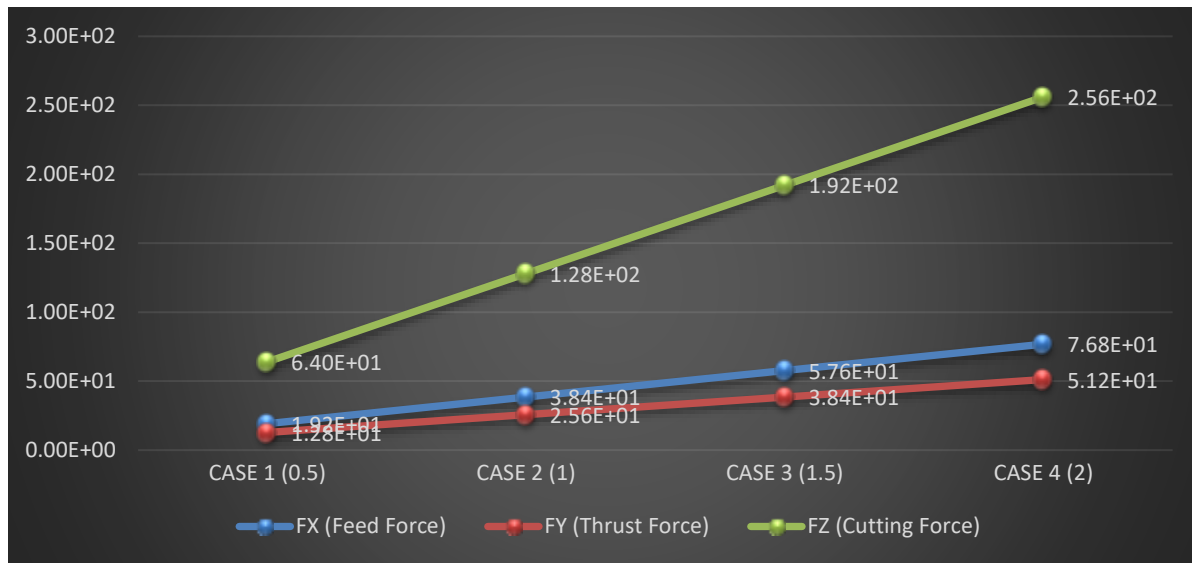


Figure 3: Graphical Representations of Forces generated in cutting tools with Hard Material

Summary of results for HSS tool – soft material is presented as follows.

Table 4: Summary of results for HSS tool – Soft Material

S.No	Rack Angle	Depth of Cut	Max. Vonmises Stress	Total Deformation
1.	0	0.5	67.522	0.0016828
2.		1	135.04	0.0033
3.		1.5	202.13	0.0050
4.		2	269.65	0.0067
5.	2	0.5	484.53	1.0108
6.		1	969.07	2.0225
7.		1.5	1450.9	3.0228
8.		2	1935.5	4.0347
9.	4	0.5	2047	0.0404
10.		1	4094	0.0245
11.		1.5	6130	0.065
12.		2	8177	0.296
13.	6	0.5	2446.8	350.44
14.		1	4893.6	392.88
15.		1.5	7330.2	669.37
16.		2	9776.9	11448
17.	8	0.5	2446.8	872.66
18.		1	4893.6	4162.9
19.		1.5	7330.2	15759
20.		2	9776.9	7109.3

Graphical representations of above results are as follows.

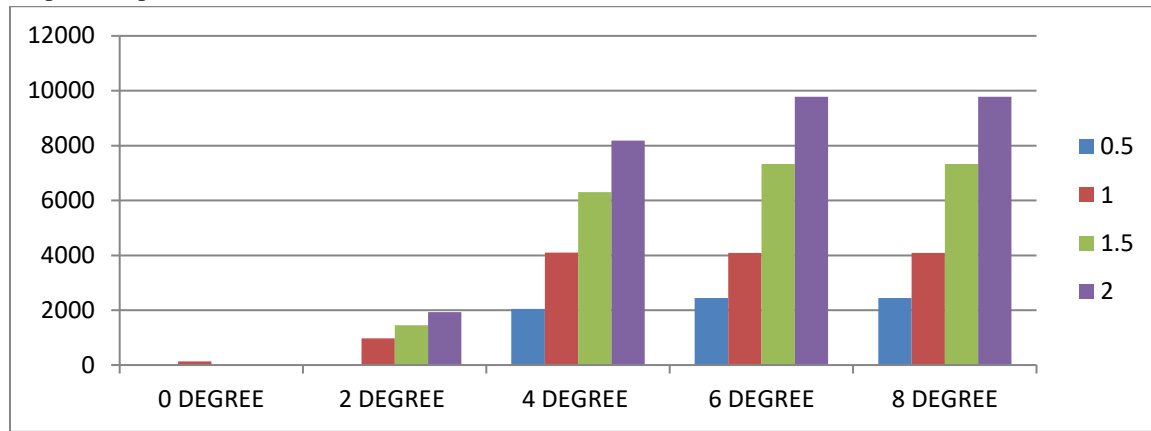


Figure 4: Stress Analysis for HSS-Soft Material

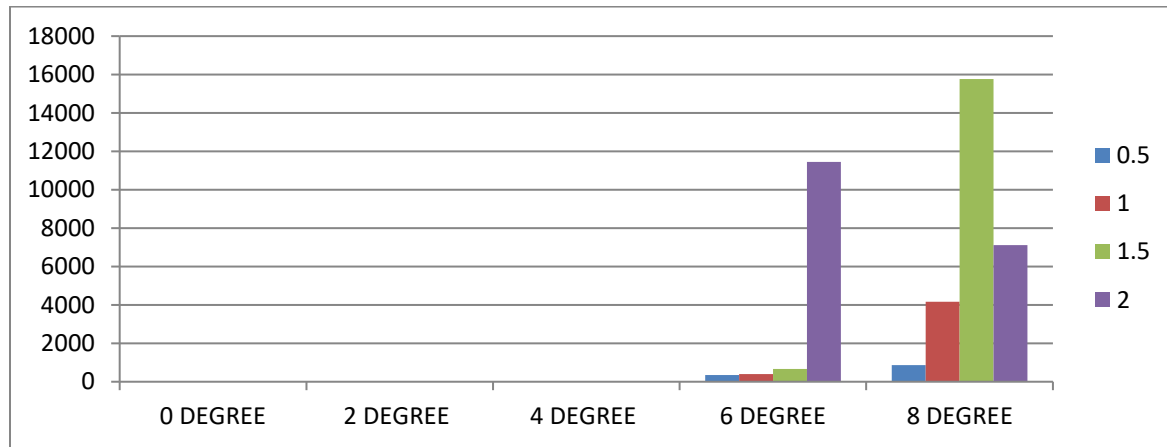


Figure 5: Deformation Analysis for HSS-Soft Material

Summary of results for HSS tool – Hard material are presented as follows.

Table 5: Summary of results for HSS tool – Hard Material

S.No	Rack Angle	Depth of Cut	Max. Von-misses Stress	Total Deflection
1.	0	0.5	75.981	0.00189
2.		1	151.52	0.00377
3.		1.5	227.07	0.0056
4.		2	302.61	0.0075
5.	2	0.5	544.89	1.1359
6.		1	1087.1	2.2608
7.		1.5	1629.3	3.3942
8.		2	2171.5	4.5139
9.	4	0.5	2301.8	0.0090
10.		1	4592.6	0.07
11.		1.5	6883.4	0.063
12.		2	9174.2	0.25113



13.	6	0.5	2750.1	207.39
14.		1	5489.9	1379
15.		1.5	8229.8	15633
16.		2	10970	19062
17.	8	0.5	2750.1	597.72
18.		1	5489.9	1416.1
19.		1.5	8229.8	6814.3
20.		2	10970	7305.5

Graphical representations of above results are as follows.

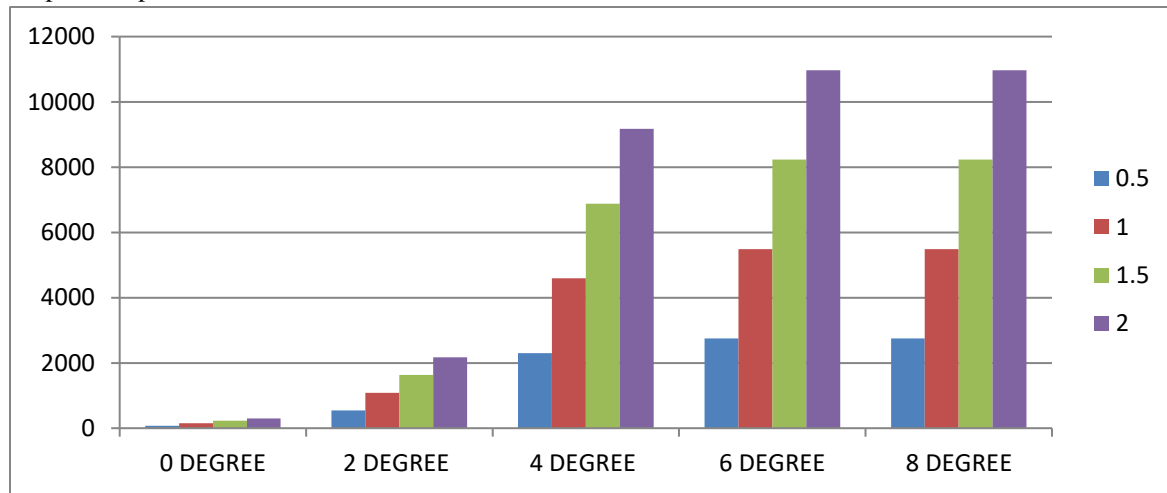


Figure 6: Stress Analysis for HSS-Hard Material

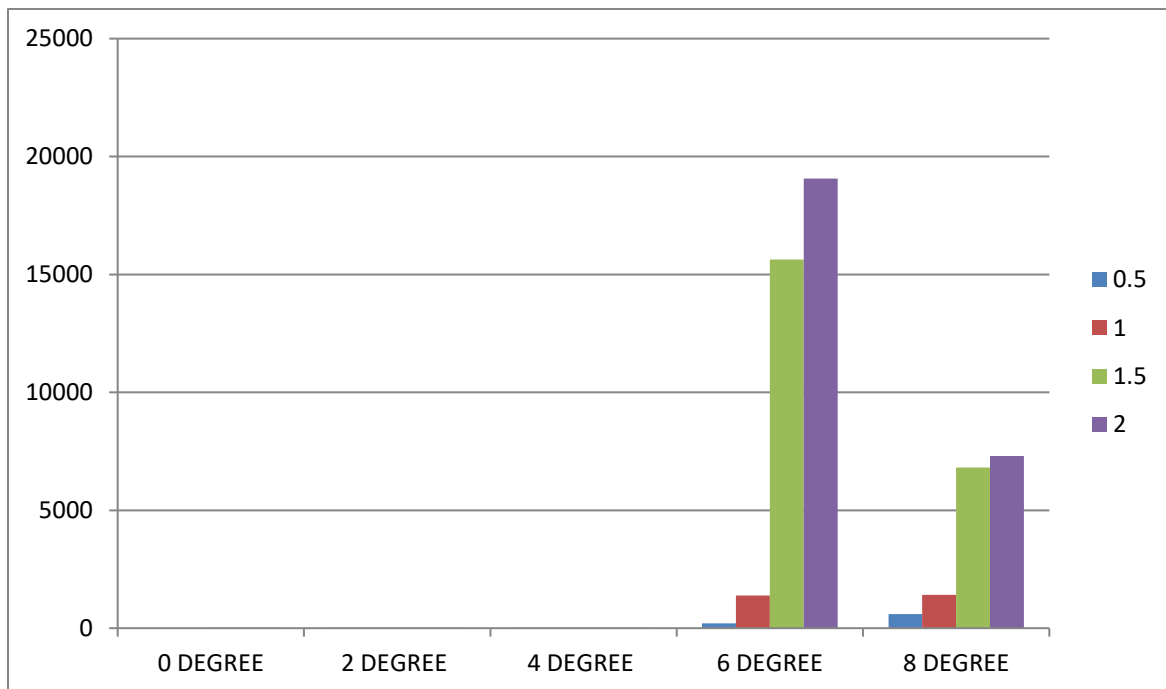


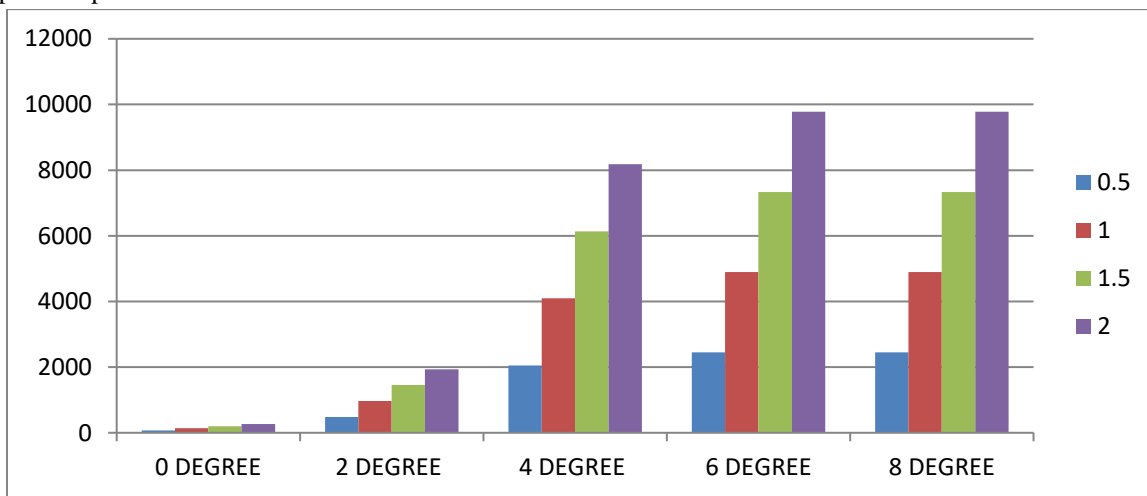
Figure 7: Deformation Analysis for HSS-Hard Material

Summary of results for CBN tool – Soft Material are presented as follows.

*Table 6: Summary of results for CBN tool – Soft Material*

S.No	Rack Angle	Depth of Cut	Max. Von-misses Stress	Total Deformation
1.	0	0.5	67.522	0.00069978
2.		1	135.04	0.0013996
3.		1.5	202.13	0.0020938
4.		2	269.65	0.0027935
5.	2	0.5	484.53	0.41991
6.		1	969.07	0.83809
7.		1.5	1450.9	1.2542
8.		2	1935.5	1.6674
9.	4	0.5	2047	58.889
10.		1	4094	157.22
11.		1.5	6130	4367.4
12.		2	8177	0.01102
13.	6	0.5	2446	133.49
14.		1	4893.6	653.83
15.		1.5	7330.2	3937.9
16.		2	9776.9	2723.4
17.	8	0.5	2446.8	3410.5
18.		1	4893.6	3314.2
19.		1.5	7330.2	4367.5
20.		2	9776.9	1665.4

Graphical representations of above results are as follows.



*Figure 8: Stress Analysis for CBN-Soft Material*

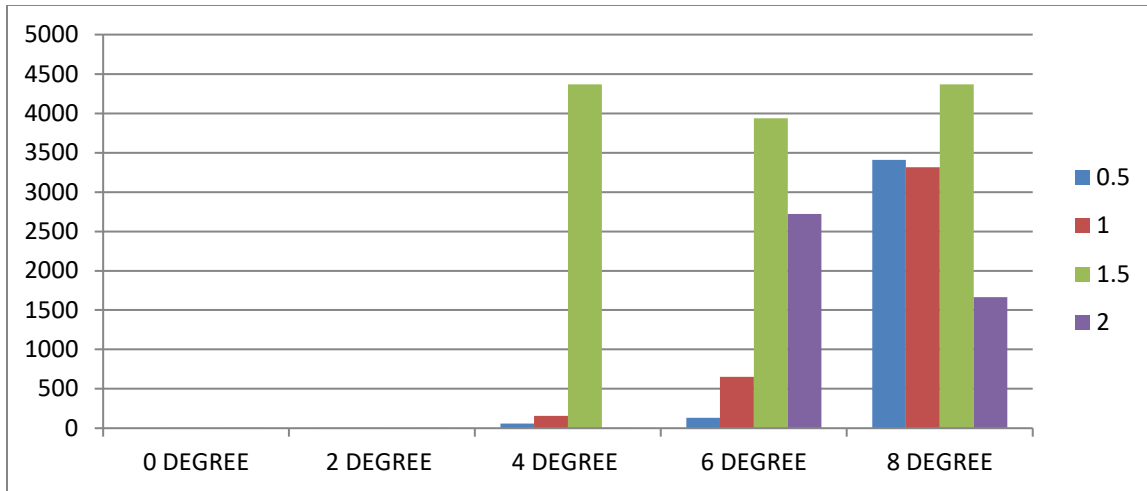


Figure 9: Deformation Analysis for CBN-Soft Material

Summary of results for CBN tool – hard material presented as follows.

Table 8: Summary of results for CBN tool – Hard Material

S.No	Rack Angle	Depth Of Cut	Max. Von-misses Stress	Total Deformation
1.	0	0.5	75.981	0.00078813
2.		1	151.152	0.0015706
3.		1.5	227.07	0.0023532
4.		2	302.61	0.0031357
5.	2	0.5	544.89	0.47349
6.		1	1087.1	0.94031
7.		1.5	1629.3	1.4082
8.		2	2171.5	1.8801
9.	4	0.5	2301.8	83.265
10.		1	4592.6	801.06
11.		1.5	6883.4	0.048589
12.		2	9174.2	5517.9
13.	6	0.5	2750.1	899.19
14.		1	5489.9	2816.5
15.		1.5	8229.8	673.44
16.		2	10970	1100.6
17.	8	0.5	2750.1	21.94
18.		1	5489.9	11611
19.		1.5	8229.8	5049.5
20.		2	10970	24571

Graphical representations of above results are as follows.

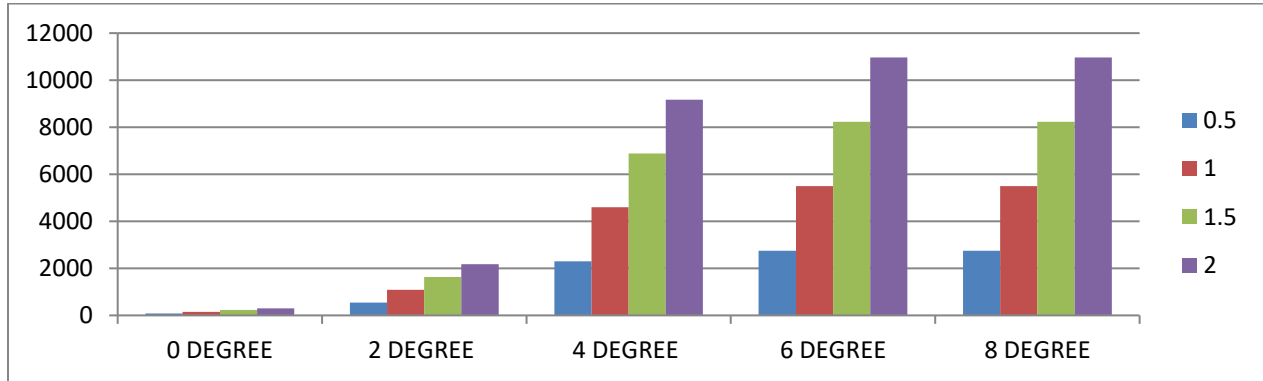


Figure 10: Stress Analysis for CBN-Hard Material

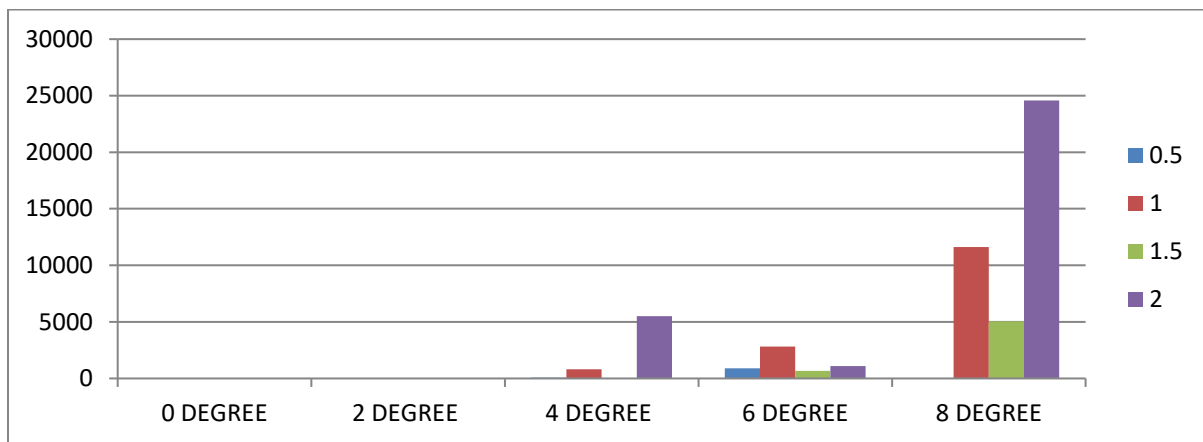


Figure 11: Deformation Analysis for CBN-Hard Material

### Discussion

From force analysis one can analyze that for both soft and hard materials forces on tools tend to have same nature. Figure 5.2 and Figure 5.3 show that thrust forces have minimum, feed forces have intermediate and cutting forces have the maximum effect on the cutting tool. From same figures one can find that amount of cutting forces contributes almost double as compared to other two components. Figures also indicate that all the three forces increase as depth of cut increases. As depth of cut increases difference in magnitude of cutting force as compared to other two component increases. This difference causes unbalancing in the tool due to which tool failure occurs. Thus in order to keep the cutting tool safe, this difference can be kept minimum, by using considerably less depth of cut.

On the analysis of stresses and total deformation from HSS – soft material combination it was found that von-misses stresses increases with increasing rack angle from 0 degrees to 8 degrees and with depths of cut. Results shows similarity of scores of von misses stresses for 6 degrees and 8 degrees rack angles. Moreover, deformations at 6 degree rack angle at depths of cut of 0.5 mm, 1 mm and 1.5 mm are lesser as compared to those at 8 degrees. For other angles negligible deformation was found, but due to lesser amount of cutting forces these angles are not suitable. In this combination, for lesser depths of cut 6 degree angles can be preferred as compared to 8 degree angles.

On analyzing the stresses and total deformations for HSS – hard material combination it was also found that von-misses stresses increases with increasing rack angle from 0 degrees to 8 degrees and with depths of cut. Results

shows similarity of scores of von misses stresses for 6 degrees and 8 degrees rack angles. In this case comparatively lesser values of total deformation were found at 8 degrees for high depth of cut. So, in these cases, 8 degree angles can be preferred.

Analysis of CBN – soft material combination also shows that von-misses stresses increases with increasing rack angle from 0 degrees to 8 degrees and with depths of cut. Results shows similarity of scores of von misses stresses for 6 degrees and 8 degrees rack angles. Results also report that at 6 degrees rack angle with 0.5 mm and 1 mm depths of cut values of total deformation are less as compared to those at 8 degrees with similar depths of cut. At 2 mm depth of cut deformation is also lesser than similar value at 6 degree and 2 mm depth of cut. So therefore, in such cases, for lesser depths of cut 6 degree rack angles can be preferred.

Combination of CBN-hard material also shows that von-misses stresses increases with increasing rack angle from 0 degrees to 8 degrees and with depths of cut. Results shows similarity of scores of von misses stresses for 6 degrees and 8 degrees rack angles. While considering deformations, results show that total deformations in the tool are very less at 6 degrees as compared to 8 degrees rack angles, due to which these angles can be preferred in order to avoid tool failure.

### **CONCLUSION, LIMITATIONS AND FUTURE SCOPE OF THE RESEARCH**

Present section is devoted to conclusion, limitations and future scope of the research work, the details of which are presented in upcoming sections.

#### **Conclusion**

Following are the conclusions drawn out of the research work.

1. Results of Force Analysis
  - a) During machining, cutting forces contribute greatest proportion as compared to feed forces and thrust forces;
  - b) Magnitude of these forces increases with increasing depth of cut; and
  - c) In order to keep the tool safe difference between these forces should be kept minimum.
2. Results of Stress and Deformation Analysis
  - a) Von - misses stresses increases with increase in rack angle and depths of cut, irrespective of type of job material and tool material;
  - b) At 1.5 mm and 2 mm depths of cut, von-misses stresses show same intensity, but value of deformations changes which depends on the type of materials used for tooling and job;

#### **Limitations and Future Scope of the Research**

Following are the limitations and associated future scope of the present research work.

1. The research work is limited to single point cutting tools only;
2. Present research work is limited to particular sets of job and tool materials; and
3. The research work is also limited to particular sets of rack angles and depths of cut changes.

Following points indicate the future scope of the research work.

1. An extensive research in the field of multi point cutting tools is still pending;
2. A comprehensive research work considering a vast set of tool and job materials can be undertaken; and
3. A detailed research considering more than one tool parameters and detailed set of depths of cut is can also be initiated.

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