A Finite Element Analysis of Orthogonal Machining Using Different Tool Edge Geometries and End Relief Angles

Shravankumar C [1*], Bharat.S.Kodli [2*]

[1*] *PG Student, production Engineering, PDA College of Engineering, Gulbarga-585102, Karnataka (INDIA)*

[2*] *Professor, Department of Mechanical Engineering, PDA College of Engineering, Gulbarga-585102, Karnataka (INDIA)*

ABSTRACT

Stress analysis plays important role in structural safety and stability of the system. Prior estimation of stress and deformation helps in better design and manufacture of products. Generally residual stress and plastic strain plays important role in fatigue life of the structures. Higher residual stress reduces the load carrying capacity of the member along with source of crack generation. The machining is an important parameter in the manufacturing process and is used for sizing and shaping the members for the required functionality. But machining operations involves lot of complexity with heat development and phase change of materials etc. Estimation of plastic strain and residual stresses are very complicatory with this problems involving both geometrical and material nonlinearity. cutting tools are essential machine members for manufacturing process.The Finite Element Method (FEM) is selected using the ANSYS. Five models of cutting tools will be selected having edge radii of (0.01, 0.05, 0.1, 0.15, and 0.2) mm.

Keywords: *cutting tool, tungsten carbide, ANSYS.*

1. INTRODUCTION

Manufacturing technology has been the driving force behind modern economics since the Industrial Revolution (1770). Metal shaping processes, in particular, have created machinery and structures that permeate almost every aspect of human life today. Although manufacturing techniques have become more sophisticated, many processes and tool designs are still based on experience and intuition. There are mainly two distinct classes of solid-state manufacturing processes. Deformation processes produce the required shape, with the necessary mechanical properties, by plastic deformation in which the material is moved and its volume is conserved. Machining processes produce the required shape by removal of selected areas of the work-piece through a machining process. Most machining is accomplished by straining a local region of the work-piece by the relative motion of the tool and the work-piece. Although mechanical energy is the usual input to most machining processes, some of the newer metal removal processes employ chemical, electrical and thermal energy. Machining is usually employed to produce shapes with high dimensional tolerance, good surface finish and often with complex geometry. Machining is a secondary processing operation since it is usually conducted on a work-piece that was produced by a primary process such as hot rolling, forging or casting, etc. More than almost 80 percent of all manufactured parts must be machined before they are completed. There is a wide variety of machining processes and machine tools that can be utilized. Since the development of machine tools is parallel to the industrialization of the society, it is an old field with much specialized terminology and jargon. Metal cutting processes are widely used to remove unwanted material and achieve dimensional accuracy and desired surface finish of engineering components. In metal cutting processes, the unwanted material is removed by the cutting tool, which is significantly harder than the work-pieceThe first one is the lecture delivered by F. W Taylor (1907) on “The art of cutting metals” in which up to twelve cutting variables that influenced the cutting speed selection were analyzed with a primary objective of “getting better and cheaper work out of machine shop” which was well supported by his yet another notable contribution Taylor equation to predict the tool life [1]. Piispanen and Dr. Merchant (1944) both independently put forth the concept of orthogonal cutting process concept where only two axis are considered at a given point of time which simplifies the complex 3 dimensional oblique cutting into a simple 2 dimensional orthogonal cutting process as shown in figure no:1.

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

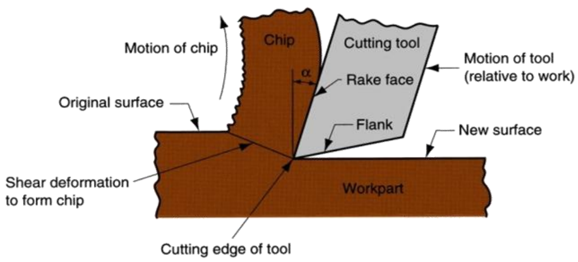

Fig no:1: orthogonal cutting process

If the cutting face of the tool is at 90^o to the direction of the tool travel the cutting action is called as orthogonal cutting. If the cutting face of the tool is inclined at less than 90^o to the path of the tool then the cutting action is called as oblique cutting.

2. METHODOLOGY:

- Modelling the work piece and cutting tool with required parameters
- Meshing the problem. Usage finer mesh at the region of cutting
- Application of boundary conditions executing the problem
- Finding the stress condition in the problem.
- Finding the residual stress for different nose radius
- Similarly finding residual stress formation due to change in end relief angle
- Results presentation

A. Material:

Workpiece material: steel
Tool material: tungsten carbide

Table no: 2.1: material properties.

Material Details	Young's Modulus (Gpa)	Poison ratio	Density (kg/m^3)	Yield stress (Gpa)	Tangent Modulus (Gpa)
Cutting tool	600	0.15	13	-	-
Work Piece	180	0.3	8.49	0.9	0.445

3. RESULT:

Results & Discussion

The analysis has been carried out using Finite element simulation using Ansys. The meshed models are imported to Ansys and using Eulerian analysis, the problem has executed to find the stress condition during cutting operation and residual stress formation after the machining operation. The residual stresses forms the source for crack formation. So the effect of nose radius on residual formation is done with different radius of edge. S*tarting with no edge radius and increasing edge radius*

3.1 Results with Variation of Nose Radius

3.1.1 Case: Nose Radius Zero:

The results for nose radius zero are as follows. In the all results, initial pictures of stresses will be provided during machining and later pictures will be provided with residual stress formation. Finally a comparative analysis will be done to check the effect of nose radius on the structure.

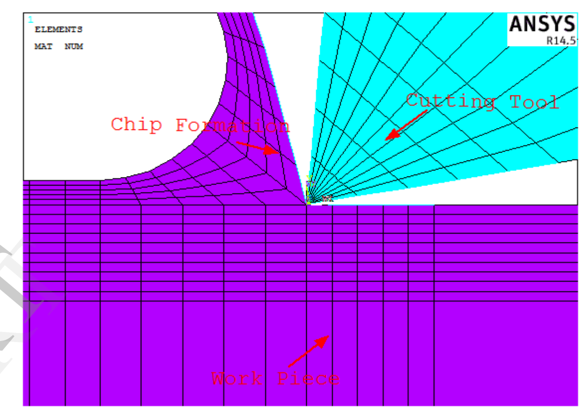

Fig3.1: Mesh pattern at the zone of Machining

The figure3.1 shows mesh formation at the zone of machining .Euler an algorithem allows the flow of mesh along with deformation. Cutting tool is given a depth of cut of 0.2mm with 0.5mm cutting distance for simulation. Away from the stress concentration region, the mesh is made big to reduce the solution time for the problem. The geometry is split using Ansys Boolean operations to obtain map mesh. Map mesh helps to get good results compared to the free mesh. Plane42 element with plane stress with thickness option is used for solving the problem. This option is enough to convert a three dimensional problem to two dimensional problem. Contact elements are defined between the chip geometry and cutting tool. Target169 and contac173 elements are used for representation of the problem. The stress results are as follows.

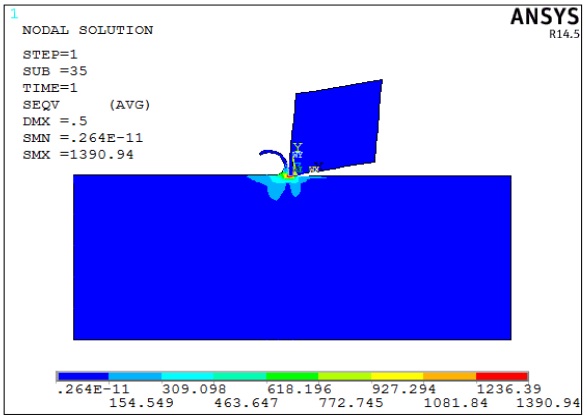

Fig3.2: Vonmises stress in the structure

The figure3.2 shows developed vonmises stress in the structure. Maximum vonmisessi around 1390.9Mpa. The maximum stress is shown by red colour region. The stress increase shows problem is in plastic region as it is crossing the yield stress of the material. The stresses are localized as observed from the figure. It can be observed from the figure that stresses are concentrated near the zone of machining.

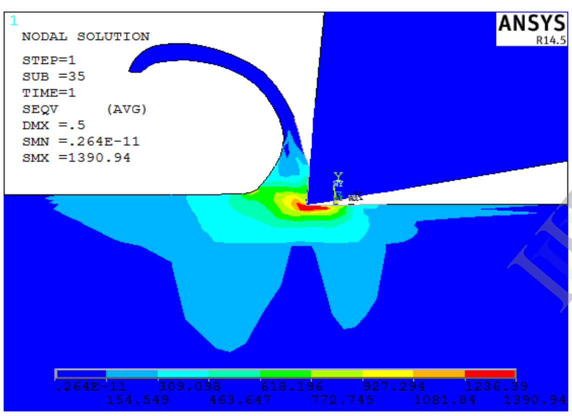

Fig3.3: Stress condition at the machining zone

The figure3.3 stress vonmises stress at the zone of machining. At the tip edge of the cutting tool, more stress can be observed. The deformation at the zone of stress concentration can be observed. Various colours represent stress condition at different places. The propagation of stress also can be observed at different locations.

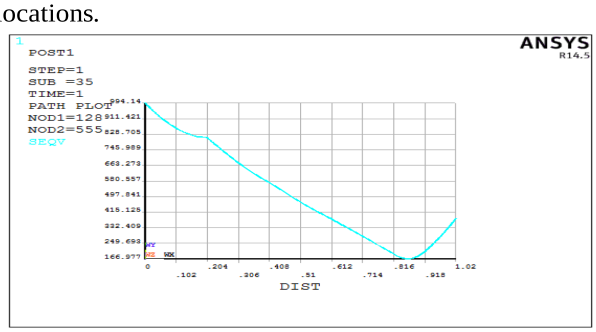

Fig3.4: Stress along the shear Plane

The stress development along the shear plane is shown. At the point of contact more stress can be observed and the stress value is reducing to the outer end.

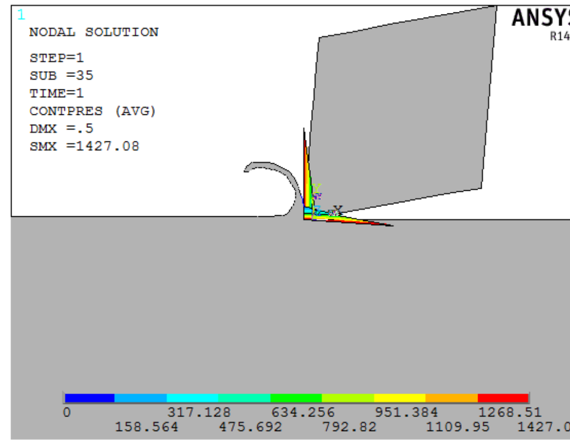

Fig3.5: Contact pressure generation

The figure3.5 shows contact pressure development in the problem. The contact pressure shows maximum value of 1427Mpa as shown by red colour. Maximum contact pressure can be observed at the tip of the cutting tool. Contact pressure development can be observed in the orthogonal directions.

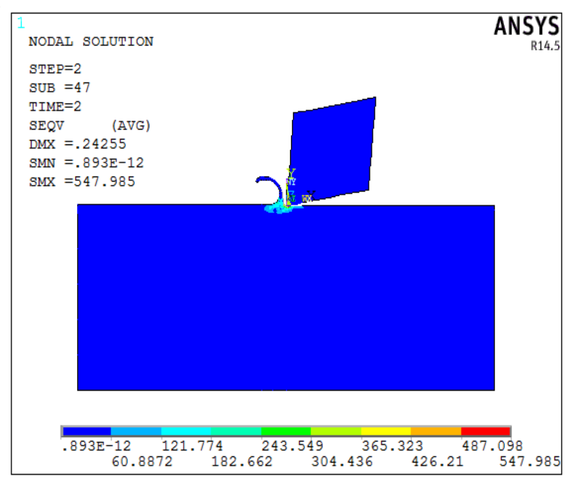

Fig3.6: Residual stress generation in the problem

The figure3.6 shows residual stress formation in the problem. Maximum residual stress is around 547.985Mpa as shown in the figure. This formation indicates the member is in permanent deformation and forms the source for crack generation if stress is not relieved. The stress of 547.985 is m*uch* higher compared to the yield stress of the material.

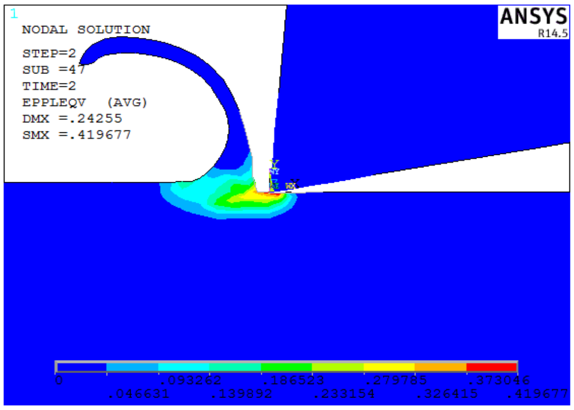

Fig3.7: Plastic strain development in the problem

The figure3.7 shows plastic strain development of 0.419677. From the strain estimates one can estimate the type of chips formed during the machining operations. Also the plastic strain indicates the permanent deformation set up in the structure.

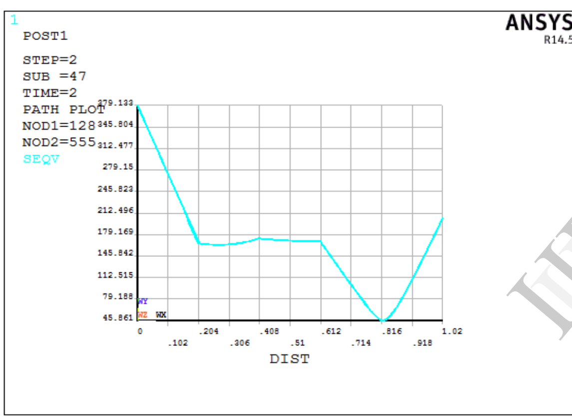

Fig3.8: Residual Stress along the shear plane

The figure3.8 shows residual stress along the shear plane. Initially the stress is more and later stress graph is constant with reduced value up to certain distance and later it is dropping. Again at the final stage this value is increasing.So finite element estimations helps to find this type of complex stress pattern.

Table3.1: Results comparison for Nose radius and other parameters of machining.

Radius of the nose	Vonmises Stress	Residual Stress	Contact Pressure	Plastic Strain
-	1390.9	547	1427	0.419677
.05	1389.8	642	1427	0.451
0.1	1357	632	1382	0.4416
0.15	1242	594	1152	0.416
0.2	1162	559	931	0.394

The table.3.1shows effect of radius of the nose on the structural parameters like vonmises stress, residual stress , contact pressure and plastic strain in the members. The results shows reduced developed vonmises stress on the workpiece with the increase in the radius of the nose. Reduction in vonmises stress shows improved design of the problem. Similarly contact pressure is also reducing from 1427 to 931 Mpa. So reduced contact pressure, shows reduced load requirement for the cutting operation. Similarly requirement of rigidity of the cutting tool will be reduced. Residual stresses shows reduced values along with the increase in nose radius. This is also an important parameter for manufacturing process. Reduced residual stress indicates higher life and higher load carrying capacity for the cutting tool material. Similarly the increased nose radius shows reduction in the plastic strain value. This helps in increase in the load carrying capacity of the member. But the results for nose radius equal to zero shows slight variation with increase in nose radius.

4. GRAPHICAL PLOTS:

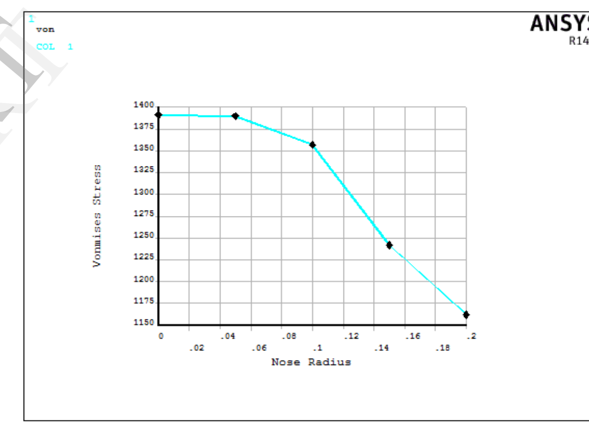

Fig4.1: Nose Radius to Vonmises Stress Plot

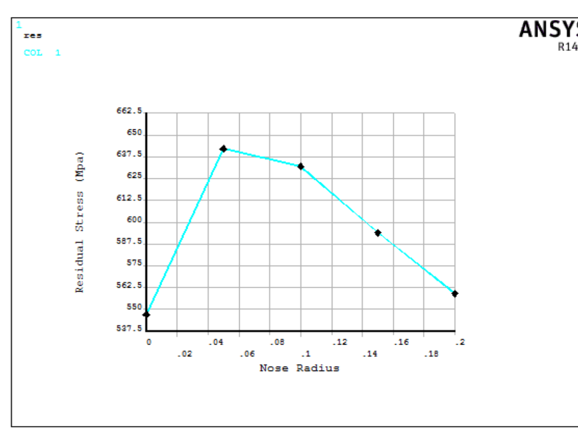

Fig4.2: Nose Radius to Residual Stress

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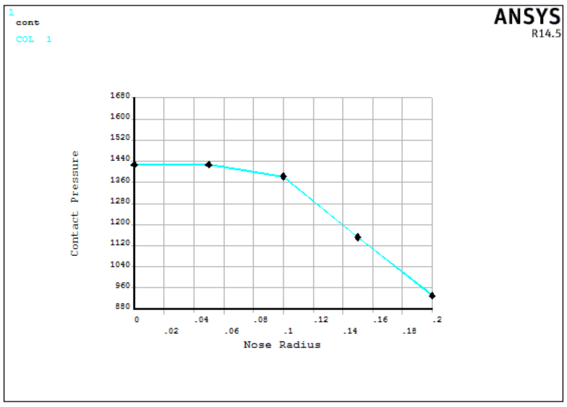

Fig.4.3: Nose Radius to Contact Pressure

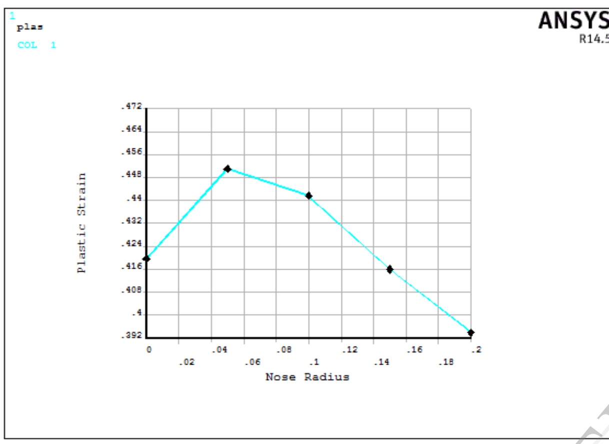

Fig4.4: Nose Radius to Plastic Strain

A. Case 1: Relief angel : 5 ^{0}

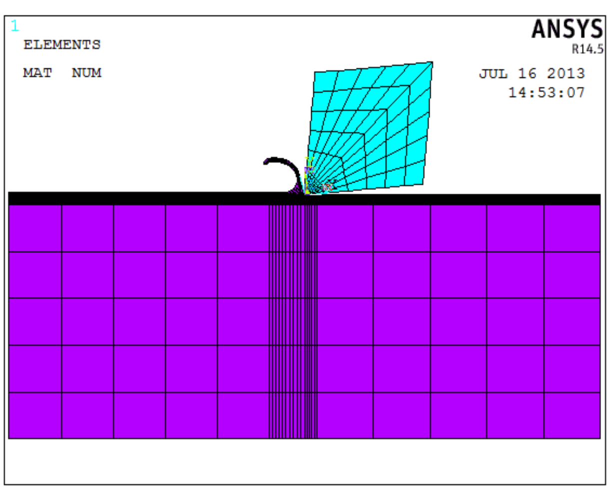

Fig4.5: Geometrical Model

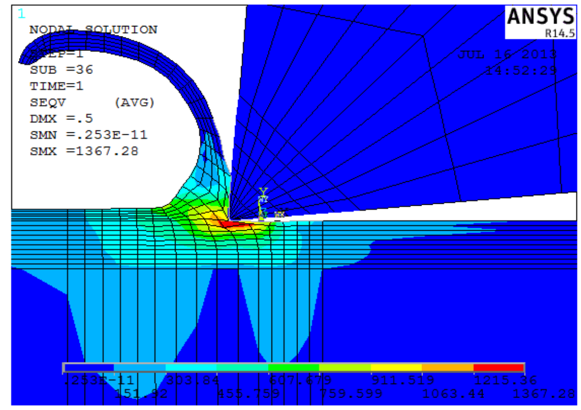

Fig4.6: Vonmises Stress plot

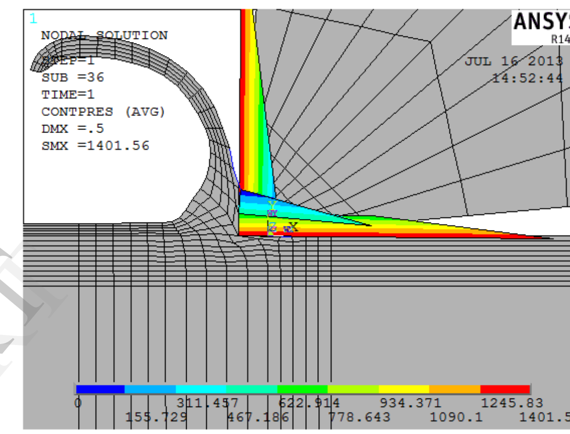

Fig4.7: Contact Pressure Plot

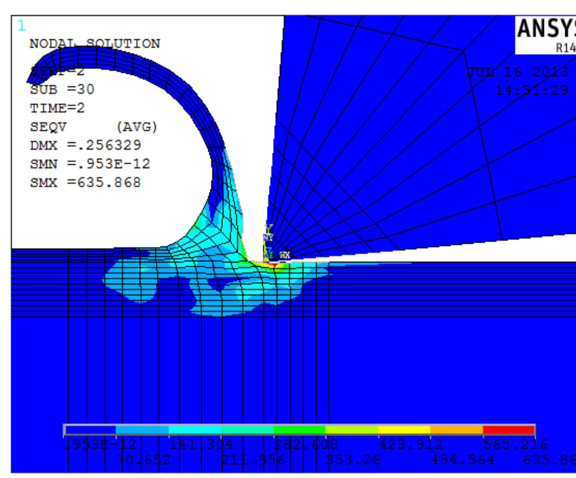

Fig 4.8: Residual Stress Plot

B. With change in Relief angle:

Table 4.1: Parameter comparison with End Relief Angle

End Relief Angle	Vonmises Stress	Residual Stress	Contact Pressure	Plastic Strain
5	1367	635.8	1401	0.445146
10	1357	632	1382	0.4416
15	1329	622	1335	0.435156
20	1288	611	1251	0.427566

The table 4.1 shows effect of end relief angle on structural parameter of stability using Finite element analysis. With the increase in the relief angle, the stress values are reducing which is important parameter of stress condition. Even residual stresses are reducing with the angle. Similarly contact pressure and plastic strain values are reducing. So with reference to the work piece, the increased relief angle improves the life of the work-piece. But major parameters in the life of work piece are residual stress and plastic strain. These are the sources of failures of members by initiating crack on the surface. So the design can be done in such a way as to reduce the plastic strain in the structure.

5. CONCLUSIONS

The structural nonlinear analysis is carried out to find the structural integrity of cutting for changes in the nose radius and end relief angle. The summary of results is as follows.

- Initially the cutting tool is modelled using Ansys mixed up approach by combining top down and bottom up approach. This approach helped to create the required fillet at the nose region and work plane option for required end relief angle.
- The geometrical models are meshed with quad elements for better convergence in the nonlinear problem with mixed boundaries of contact. Work plane option is used for cutting the geometry for 4 sided geometry to create the quad mesh. Size options are used to create equal number of elements which creates node to node convergence.
- The meshed geometries are applied with necessary material properties. The work piece material is given with elastic-plastic material properties with strain hardening parameter. A feed o 0.5 mm is given for checking the parameters.
- Targe169, contac172 elements are defined to analysed the mixed moving boundary region with eulerianalgorithem.
- The structural parameters of interest like vonmises stress, residual stress, contact pressure and plastic strains are captured to find better life and durability of the cutting tool material.
- Initial analysis for change in nose radius shows, reduced values for vonmises stress(1389-1162Mpa), , residual stress(642 - 559), contact pressure(1427-931Mpa), Plastic strain (0.451-0.394) which are desirable features for cutting tool design. This helps in protecting the crack generation on the work piece which will enhance load carrying capacity and higher fatigue life for the members.
- Further analysis with end relief angle also shows similar trends for vonmises, residual, contact pressure and plastic strain. Reduction of values for Vonmises(1367-1288Mpa), Residual stress (635.8Mpa -611Mpa),Contact pressure(1411Mpa-1251Mpa), plastic strain (0.4450.427) can be observed for end relief angle variation from 5 degrees to 20 degrees. This is also a good trend for better life of the work piece where residual stress and plastic strains are reducing. Plastic strain and residual stress are the two most important members to reduce the cracking pattern in the work piece under cyclic loads.
- All the necessasary pictures are represented with pictorial plots.

Further Scope:

- Ls-Dyna simulation can be used for usage of explicit algorithm to analyse flow boundary conditions with ALE techniques.
- Modal analysis can be carried out find resonant conditions
- Thermal analysis can be done to find the thermal effect on the stress generation
- Topology optimisation can be carried out better design of cutting tool
- Lubrication effect can be analysed
- Composite material usage for cutting tool can be carried out

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