AIJREAS VOLUME 1, ISSUE 11 (2016, NOV) (ISSN-2455-6300) ONLINE
ANVESHANA'S INTERNATIONAL JOURNAL OF RESEARCH IN ENGINEERING AND APPLIED SCIENCES

# FINATE ELEMENT ANALYSIS OF MULTI POINT CUTTING TOOL

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## ABSTRACT:

*In this paper, temperature at tool-tip interface is determined, generated in high-speed machining operations. Specifically, three different analyses are comparing to an experimental measurement of temperature in a machining process at slow speed, medium speed and at high speed. In order to compare to experimental results produced as part of this study. Four flute and two flute micro end mills are modeled and analyses are done. Later a comparison between the two cuttings tools is observed. Multi point cutting tool has been solid modeled by using CAD Modeler Siemens 8.0 and FEA carried out by using ANSYS Workbench 14.5.*

***Keywords:*** *Multi Point Cutting Tool (carbide) tool and Carbide tip tool (P - 30), Computer Aided Design (CAD), milling, Fluke 62 max IR thermometer (Range -40 $^0$C to 650 $^0$C), Finite Element Analysis, Solid Modeling.*

## INTRODUCTION

The fabrication of a wide variety of parts and products in various fields, like aeronautics, automotive, biomedical, and medical and electronics requires proper finishing for proper mating and functioning of products. A variety of operations like milling, drilling, turning, grinding, EDM and water jet cutting are utilised to fabricate and finish parts. One of the most common and important form of machining is the milling operation, in which material is cut away from the workpiece in the form of small chips by feeding it into a rotating cutter to create the desired shape. Milling is typically used to produce parts that are not axially symmetric and have multiple features, such as holes, slots, pockets, and even three dimensional surface contours. Contoured surfaces, which include rack and circular gears, spheres, helical, ratchets, sprockets, cams, and other shapes, can be readily cut by using milling operation. Recently, micro milling process has gained immense popularity due to market requirements and technological advancements which has lead to fabrication and use of micro structures. It possesses several advantages like ease of use, capability to produce complex three dimensional geometries, process flexibility, low set-up cost, wide range of machinable materials and high material removal rates. This chapter develops the background for the present work and discusses the need to take up this work. It presents a review of available relevant literature. Objectives of the present work along with methodology adopted to accomplish them are also discussed here.

Conventional milling has a wide range of industrial applications and is used where there is a requirement of complex shapes, removal of large amounts of material, and accuracy. However, with the advancement in technology, more and more industries are leaning towards the use and fabrication of miniaturized parts and products. In the present scenario, micromachining is increasingly finding application in various fields like biomedical devices, avionics, medicine, optics, communication, and electronics. Among all micro-machining operations, micro-milling and micro-drilling are the two most important operations. In today's competitive world, every industry is dependent on the adequate functionality of its micro components. Automobile and aerospace industries need extremely good quality machined components due to greater complexity of the workpiece, tighter tolerances, miniaturization and use of new composite materials. In case of biomedical devices, there are stringent requirements for form and finish of the product like metallic optics and cochlear implants. Good surface finish of micro-components is needed for proper functioning of the products, and for proper mating of micro-parts. Protruding edges at the boundary of the machined surface are called burrs. Burr removal is necessary for good surface finish. In case of conventional milling, surface finishing is done by either improving the machining setup or changing the tool geometry. Burr removal can be done by using various deburring processes. However, controlling burr formation in micro milling can be very challenging because of the sub-micrometer size of the burrs produced. Furthermore, in micro-milling operation, deburring solutions utilized in conventional machining are not allowed due to inherent material characteristics or limitations in part geometry. Deburring processes allowed in micro milling are expensive and can lead to micro structural damage. Optimisation of various machine parameters, like cutting speed, feed rate and depth of cut, or tool parameters, like rake and relief angle, can help in minimization of micro-burrs in micro milling operations. An accurate surface geometry of micro milling cutters is one of the essential parameters responsible for the control of micro burrs in micro milling. Very limited work has been done on the control and minimisation of micro burrs formed during micro milling operation. Virtual finite element analysis of micro burr formation during micro milling process is a cost effective method for obtaining optimised tool parameters for minimum burr formation

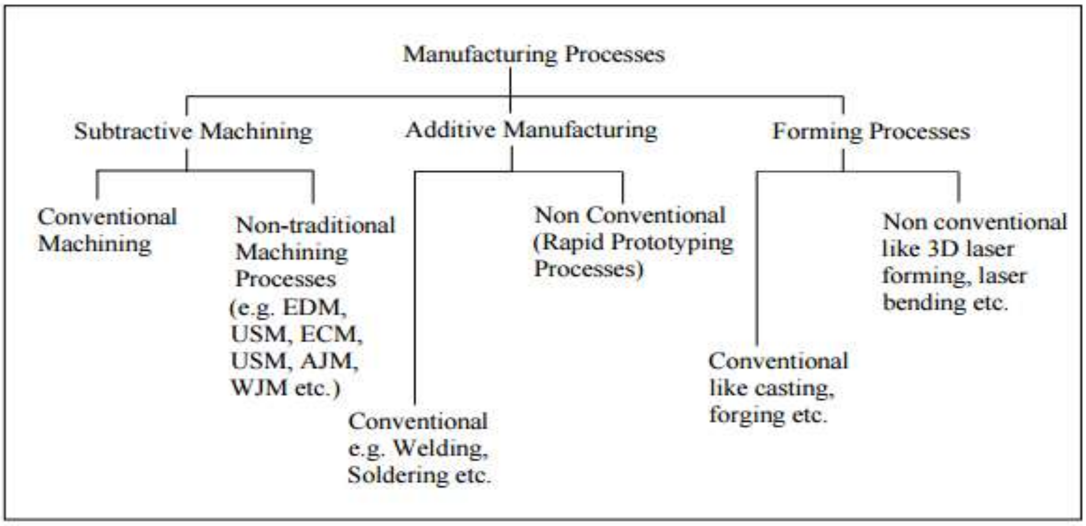


Figure 1: Classification of Manufacturing Processes

## TYPES OF MILLING OPERATIONS SLOT, END MILL, AND BALLNOSE CUTTERS

End mills (middle row in image) are those tools which have cutting teeth at one end, as well as on the sides. The words *end mill* are generally used to refer to flat bottomed cutters, but also include rounded cutters (referred to as *ball nosed*) and radiused cutters (referred to as *bull nose*, or *torus*). They are usually made from high speed steel or cemented carbide, and have one or more flutes. They are the most common tool used in a vertical mill.

### Roughing end mill

Roughing end mills quickly remove large amounts of material. This kind of end mill utilizes a wavy tooth form cut on the periphery. These wavy teeth form many successive cutting edges producing many small chips, resulting in a relatively rough surface finish. During cutting, multiple teeth are in contact with the workpiece reducing chatter and vibration. Rapid stock removal with heavy milling cuts is sometimes called *hogging*. Roughing end mills are also sometimes known as ripping cutters.

### Ball nose cutter

Ball nose cutters or ball end mills (lower row in image) are similar to slot drills, but the end of the cutters are hemispherical. They are ideal for machining 3-dimensional contoured shapes in machining centres, for example in moulds and dies. They are sometimes called *ball mills* in shop-floor slang, despite the fact that that term also has another meaning. They are also used to add a radius between perpendicular faces to reduce stress concentrations.

There is also a term *bull nose* cutter, which refers to a cutter having a corner radius that is fairly large, although less than the spherical radius (half the cutter diameter) of a ball mill; for example, a 20-mm diameter cutter with a 2-mm radius corner. This usage is analogous to the term *bull nose center* referring to lathe centers with truncated cones; in both cases, the silhouette is essentially a rectangle with its corners truncated (by either a chamfer or radius Don).

### Slab mill

High speed steel slab mill

Slab mills are used either by themselves or in gang milling operations on manual horizontal or universal milling machines to machine large broad surfaces quickly. They have been superseded by the use of cemented carbide-tipped face mills which are then used in vertical mills or machining centres.

### Side-and-face cutter

The side-and-face cutter is designed with cutting teeth on its side as well as its circumference. They are made in varying diameters and widths depending on the application. The teeth on the side allow the cutter to make *unbalanced cuts* (cutting on one side only) without deflecting the cutter as would happen with a slitting saw or slot cutter (no side teeth).

Cutters of this form factor were the earliest milling cutters developed. From the 1810s to at least the 1880s they were the most common form of milling cutter, whereas today that distinction probably goes to end mills.

### Involute gear cutter

Involute gear cutter – number 4:

- 10 diametrical pitch cutter
- Cuts gears from 26 through to 34 teeth
- 14.5 degree pressure angle

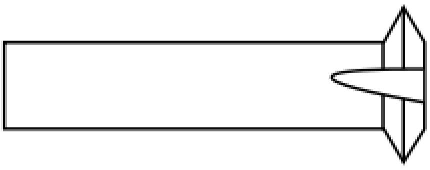
There are 8 cutters (excluding the rare half sizes) that will cut gears from 12 teeth through to a rack (infinite diameter).

### Hob

Hobbing cutter

Aluminium chromium titanium nitride (AlCrTiN) coated hob using Cathodic arc deposition technique, These cutters are a type of form tool and are used in hobbing machines to generate gears. A cross section of the cutter's tooth will generate the required shape on the workpiece, once set to the appropriate conditions (blank size). A hobbing machine is a specialized milling machine.

### Thread mill



A diagram of a solid single-form thread cutting tool

A solid multiple-form thread **milling cutter**.

Whereas a hob engages the work much as a mating gear would (and cuts the blank progressively until it reaches final shape), a thread milling cutter operates much like an end mill, traveling around the work in a helical interpolation.

### Face mill

Face mill tipped withcarbide inserts

A face mill is a cutter designed for facing as opposed to e.g., creating a pocket (end mills). The cutting edges of face mills are always located along its sides. As such it must always cut in a horizontal direction at a given depth coming from outside the stock. Multiple teeth distribute the chip load, and since the teeth are normally disposable carbide inserts, this combination allows for very large and efficient face milling.

(i) Results in the form of Von Mises Stress and deformation of selected cutters.
(ii) Compare the results with experimental procedure.

## LITERATURE SURVEY

**C. Betegon Biempica et al (2007),** the aim of this paper is to study the residual stresses in an UIC-60 rail and their reduction by means of roller straightening. Both experimental and numerical investigations have been carried out in the past to reveal the formation of dominant longitudinal residual stresses. However, the agreement between both investigations was not particularly good. The finite element method (FEM) has also been used to simulate one, two and three-dimensional analyses of a rail during roller straightening processes. The present model considers the longitudinal movement of a rail through the straightening machine, contact conditions between rail and rollers and kinematic hardening so as to take into account the plastic behavior of the rail material (steel). These results were compared with the experimental investigations and good agreement was observed. In this respect, this paper presents a novel, more realistic numerical simulation by FEM for the roller straightening process. Finally, an improvement of the straightening process in order to obtain smaller residual stress in the rail section is proposed.

**Z. Barsoum et al (2008),** this was paper presented on welding simulation procedure is developed using the FE software ANSYS in order to predict residual stresses. The procedure was verified with temperature and residual stress measurements found in the literature on multi-pass butt welded plates and T-fillet welds. The predictions show qualitative good agreement with experiments. The welding simulation procedure was then employed on a welded ship engine frame box at MAN B&W. A subroutine for LEFM analysis was developed in 2D in order to predict the crack path of propagating fatigue cracks. The objective was to investigate fatigue test results from special designed test bars from the frame box where all test failed from the no penetrated weld root. A subroutine was developed in order to incorporate the predicted residual stresses and their relaxation during crack propagation by isoperimetric stress mapping between meshes without and with cracks, respectively. The LEFM fatigue life predictions shows good agreement with the fatigue test result when the residual stresses are taken into account in the crack growth analysis. W.L.

**Chan et al (2008),** In the traditional metal-formed product development paradigm, the design of metal-formed product and tooling is usually based on heuristic know-how and experiences, which are generally obtained through long years of apprenticeship and skilled craftsmanship. The uncertainties in product and tooling design often lead to late design changes. The emergence of finite element method (FEM) provides a solution to verify the designs before they are physically implemented. Since the design of product and tooling is affected by many factors and there are many design variables to be considered, the combination of those variables comes out with various design alternatives. It is thus not pragmatic to simulate all the designs to find out the best solution as the coupled simulation of non-linear plastic flow of billet material and tooling deformation is very time-consuming.

**Sharma parveen (2008),** in present highly competitive environment need for better design features along with reduced costing has become very important. Rapid Prototyping also referred to as solid free-form manufacturing, computer automated manufacturing, and layered manufacturing has obvious use as a vehicle for visualization. In addition, RP models can be used for testing, such as when an airfoil shape is put into a wind tunnel. Rapid tooling arises from rapid prototyping, such as silicone rubber molds and investment casts. Rapid manufacturing arises from rapid prototyping to use rapid prototyping systems to directly produce parts which are functional end-use item with the advantage that there is no need for tooling.

**Zhichao li (2006),** Grinding is one of the important operations employed in modern manufacturing industry to remove materials and achieve desired geometry and surface finish. Simultaneous double side grinding (SDSG) and ultrasonic vibration assisted grinding (UVAG) are two typical cost effective grinding processes which are utilized to grind semiconductor materials and high performance ceramic materials, respectively. The objectives of this research are to investigate several technical issues in modern grinding processes by using theoretical, numerical, and experimental research approaches. Those technical issues are related to SDSG and UVAG, which have been chosen as two typical grinding processes for this research. This thesis reviews the literature on SDSG (covering process applications, modeling of grinding marks, and modeling of wafer shapes) and UVAG (covering process applications, edge chipping, and coolant effects, etc). The theoretical research work of this thesis is conducted by developing mathematical models for grinding marks and wafers shapes in SDSG of silicon wafers. These developed models are then used to study the effects of SDSG parameters on the curvature of the grinding marks, the distance between adjacent grinding marks, and the wafer shapes.

**Madnaik S.D. et al (1987),** Metal forming problems generally involve large plastic deformations. In cold forming most materials have a nonlinear strain hardening behavior. F.E.M. solutions of such problems require elastic plastic analysis and an incremental approach. While a number of such approaches exist they require fairly small step size and hence a large computational effort. Madnaik, Maiti and Chaturvedi (I) had proposed a modification to the tangent modulus method of Yamada et al (2) and showed that this method is able to solve the problem of plane strain compression with considerably less computational effort and reasonable accuracy; and presented results to show the stress distributions at various levels of reductions and for different aspect ratios (3).

**K Choil et al (2006),** Three-dimensional finite element analysis of arc-welding processes is presented with emphasis on practical applications for numerical simulation. We use an 26 implicit numerical implementation for Leblond's transformation plasticity constitutive equations, which are widely used in steel-structure welding. Several numerical examples, particularly including a large structure undergoing significant elastic–plastic deformations before welding, are presented to demonstrate the effectiveness of the threedimensional analysis of welding processes. J.C. Outeiro et al (2008), Critical issues in machining of difficult-to-cut materials are often associated with short tool-life and poor surface integrity, where the resulting tensile residual stresses on the machined surface significantly affect the component's fatigue life.

**Xinmin Lai et al(2007),** This paper was presented on mechanisms studies of micro scale milling operation focusing on its characteristics, size effect, micro cutter edge radius and minimum chip thickness. Firstly, a modified Johnson–Cook constitutive equation is formulated to model the material strengthening behaviors at micron level using strain gradient plasticity. A finite element model for micro scale orthogonal machining process is developed considering the material strengthening behaviors', micro cutter edge radius and fracture behavior of the work material. Then, an analytical micro scale milling force model is developed based on the FE simulations using the cutting principles and the slipline theory. Extensive experiments of OFHC copper micro scale milling using 0.1mm diameter micro tool were performed with miniaturized machine tool, and good agreements were achieved between the predicted and the experimental results.

**B. Ganesh babu et al (2008),** the cutting forces exerted by the cutting tool on the work piece during a machining action to be identified in order to control the tool wear and occurrence of vibration, thus to improve tool-life. Modeling of cutting force in milling is often needed in machining automation. The objective of this study is to predict the effects of cutting parameters on the variations of cutting forces during end milling operation of Al SiC metal matrix composite material. Cutting forces are measured for varies feed rates. In this study Response Surface Methodology is used by designing four factors, five level central composite rotatable design matrixes with full replication; for planning, conduction, execution and development of mathematical models.

## FINITE ELEMENT ANALYSIS

Computer-aided engineering (CAE) is the application of computer software in engineering to evaluate components and assemblies. It encompasses simulation, validation, and optimization of products and manufacturing tools. The primary application of CAE, used in civil, mechanical, aerospace, and electronic engineering, takes the form of FEA alongside computer-aided design (CAD).

### Finite element analysis

In general, there are three phases in any computer-aided engineering task:

- Pre-processing – defining the finite element model and environmental factors to be applied to it
- Analysis solver – solution of finite element model
- Post-processing of results using visualization tools

### Proposed Method for Analysis

Various outputs and characteristics of the metal cutting processes such as cutting forces, stresses, temperatures, chip shape, etc. can be predicted by using FEM without doing any experiment.

Lagrangian method Lagrangian formulation is used mainly in problems on solid mechanics. In this, the mesh moves and distorts with the material being modeled as a result of forces from neighboring elements. It is highly preffered when flow of material involved is unconstrained. Boundaries and chip shape need not be known beforehand. Simulation of discontinuous chips or material fracture can be done by using chip separation criteria in metal cutting models based on Lagrangian formulation. However, metal being suffers severe plastic deformation and distortion occurs. Mesh regeneration is therefore needed. Chip separation criteria also must be provided. Eulerian method In Eulerian formulation, the FE mesh is fixed spatially, which allows materials to flow from one element to the next. Besides, fewer elements are required for the analysis, which reduces the computation time. However, determination of the boundaries and the chip shape needs to be done prior to the simulation. Also during the analysis, the tool-chip contact length, the contact conditions between tool-chip and the chip thickness, have to be kept constant

Arbitrary Lagrangian-Eulerian (ALE) method Arbitrary Lagrangian-Eulerian (ALE) combines the best features of Eulerian and Lagrangian formulations. In ALE formulation, the material flow is followed and Langrangian step is used to solve displacement problems, while the mesh is repositioned and Eulerian step is used to solve velocity problems. Eulerian approach is used for modeling the tool tip area where cutting process occurs. Hence, without using remeshing, severe element distortion is avoided. Lagrangian approach is used for the unconstrained material flow at free boundaries.

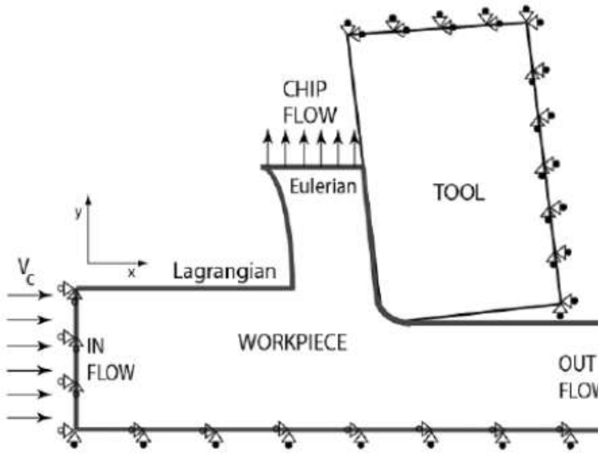


**Figure: Eulerian and Lagrangian boundary conditions in ALE simulation**

### Development of Three Dimensional CAD model

Method involved in the design of a cutter includes:

- Creation of cross-sectional profile of the tool and helix generation
- Flute creation using slot operation
- Creation of back surface of the tool
- Cutting edge generation

Parameters involved in generating the cross sectional profile are:

- Rake angle of the tool
- Relief angle of the tool
- Tool diameter
- Number of flutes

Parameters involved in modeling the helix are:

- Height of the tool
- Diameter of the tool
- Pitch of the helix
- Helix angle of the tool

The three dimensional CAD models of both the flat end mills was produced by performing ansys work bench

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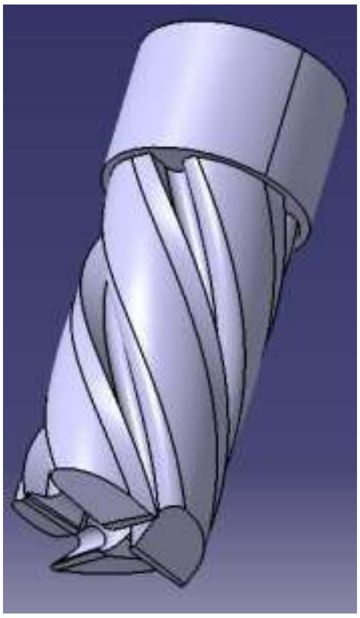


**CAD MODEL OF THE TOOL**

Once a three dimensional CAD model of micro end mill cutter is developed, a no.

of downstream applications can be performed, one of which is detailed finite element analysis and simulation of micro end mill during micro machining. Here, the static analysis of the micro end mill and simulation of burr formation process in micro milling has been carried out. In this work, tool material used is Tungsten Carbide (WC). Cemented carbides (WC-Co) are recently being used instead of tungsten carbides. Cemented carbide is a composite material containing a binder like cobalt (Co) which provides increased tool hardness.

The workpiece is a cuboidal block of aluminium alloy Al6061-T6 which is used in many aerospace applications. Al6061-T6 is a T6 tempered aluminium alloy containing magnesium and silicon as its major alloying elements.

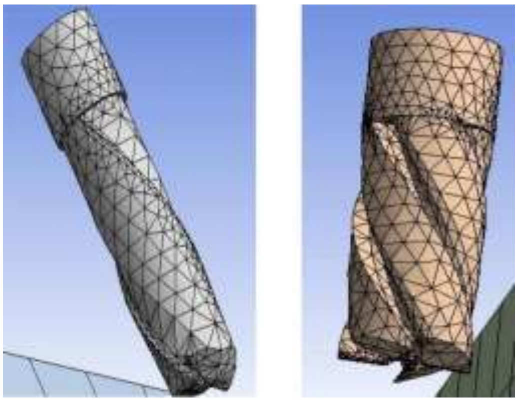

a) (b)

Figure : Meshing performed on (a) two flute and (b) four flute micro end mill

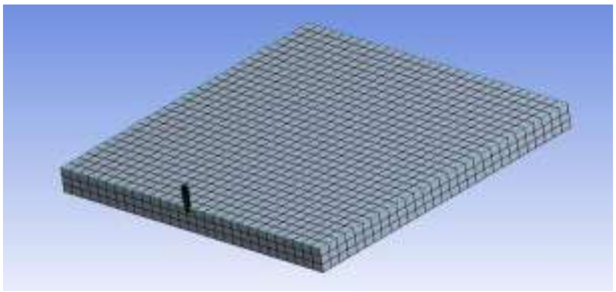


Figure : Meshing performed on the work piece

## Static finite element analysis

*Analysis*

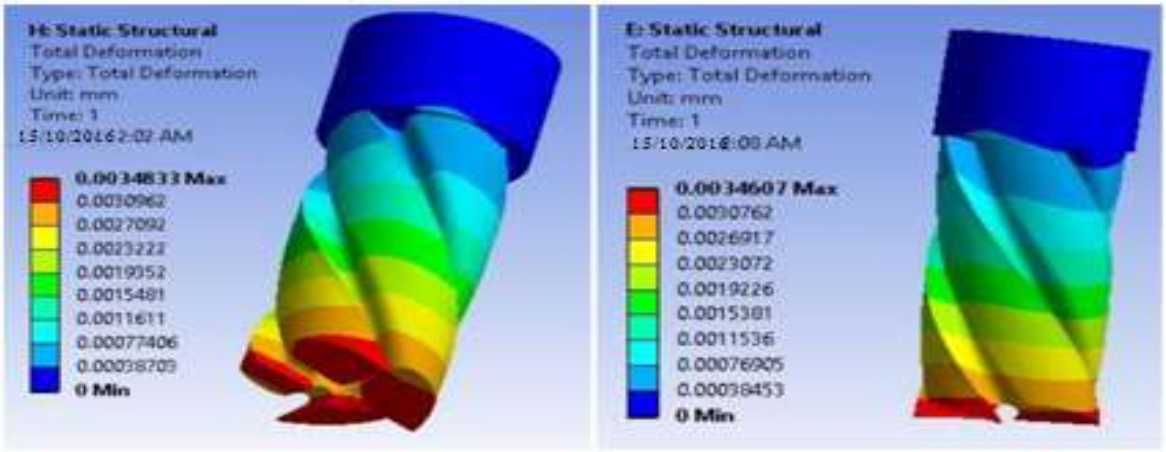
For static analysis at any particular instantaneous time, forces are considered on a single flute in feed direction ($F_x$), normal direction ($F_y$), and axial direction ($F_z$) for an axial depth of 0.2mm. The input forces for this analysis are obtained from the work done by Zaman et al. [2005] in which the analytical cutting force expressions developed in were simulated for a set of cutting conditions and were found to be comparable to experimental results..

The applied forces in feed, normal and axial directions are $F_x$ = 3.82 N, $F_y$ = 4.01 N and Fz = -0.34 N.

Cutting forces used as input

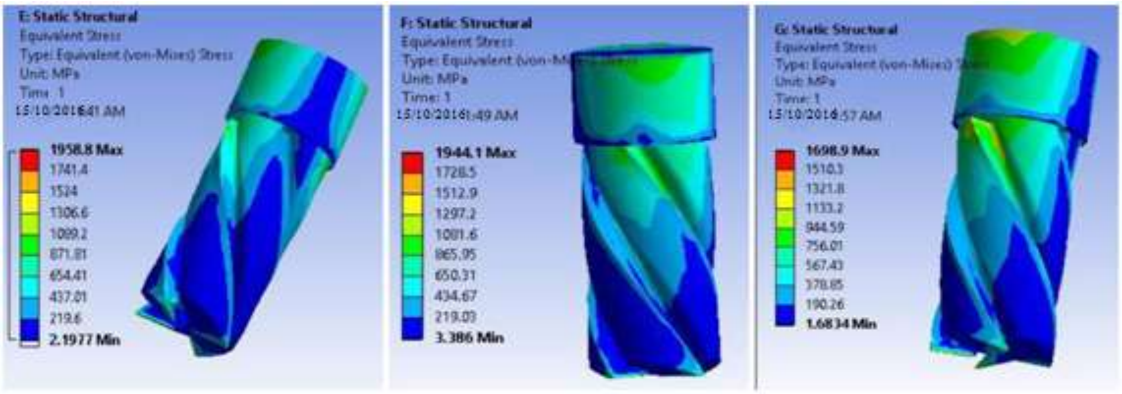
| | |
|---|---|
| Force in feed direction ($F_x$) | 3.82 N |
| Force in normal direction ($F_y$) | 4.01 N |
| Force in axial direction ($F_z$) | -0.34 N |
| Cutting force applied ($F_c$) | 5.548 N |

## RESULTS

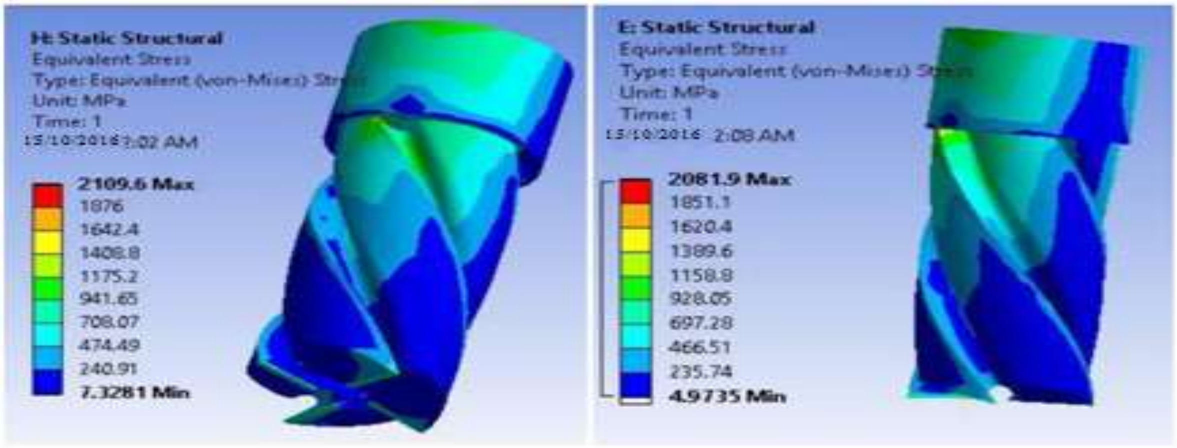


(d) Rake angle = 5º, Relief angle = 5º (e) Rake angle = 5º, Relief angle = 6º

Figure: Total deformation in the case of four flute micro end mills



(a) Rake angle = 0º, Relief angle = 10º (b) Rake angle = -2º, Relief angle = 6º (c) Rake angle = 3º, Relief angle =8º



(d) Rake angle = 5º, Relief angle = 5º (e) Rake angle = 5º, Relief angle = 6º

Figure: Von Mises stress in the case of four flute micro end mills

The results obtained are presented in Table

Table: Results of static finite element analysis of micro end mills

| No. of flutes | Rake angle (degrees) | Relief angle (degrees) | Maximum total deformation (mm) | Maximum Von Mesis stress (MPa) |
|---|---|---|---|---|
| 2 | 0 | 10 | 0.011532 | 1364.8 |
| | -2 | 6 | 0.063989 | 339.49 |
| | 3 | 8 | 0.006736 | 461.28 |
| | 5 | 5 | 0.006605 | 369.14 |
| | 5 | 6 | 0.0072553 | 505.52 |
| 3 | 0 | 10 | 0.0033076 | 654.41 |
| | -2 | 6 | 0.0033043 | 650.31 |
| | 3 | 8 | 0.0034248 | 567.43 |
| | 5 | 5 | 0.0034833 | 708.07 |
| | 5 | 6 | 0.0034607 | 697.28 |

From Table it can be seen that a two flute micro end mill cutter with rake angle -2° and relief angle 6° takes the least amount of Von Mises equivalent stress. In case of four flute micro end mills, the least amount of Von Mises stress is taken by tool with rake angle 3° and relief angle 8°.

The deformation values shown in the above figures actually occur momentarily due to vibration of the cutter which is not taken into account during the analysis.

## CONCLUSIONS AND FUTURE SCOPE

From the results obtained in ANSYS it can be observed that the deformation for four flute micro end mills tool is more than the two flute micro end mills tool by approximately 85%.This is due to the high density.

- Von Mises stress observed for Al6061-T6 tool is more than Tungsten Carbide tool
- Stress intensity for the Tungsten carbide material multi point tool is more than the Al6061-T6
- From the results the fail safe condition for the tool has been established by comparing with the practical data
- four flute micro end material can be used for the tool when the force

required for the milling process is more

- In this work, tool geometry optimization has been tried to be achieved by performing FE analysis on tools with different sets of rake and relief angles, for both two flute and four flute micro end mills. The results of the static finite element analysis of the tungsten carbide flat end micro milling tools offer the conclusion that in the given cutting conditions, the least amount of Von Mises stress generated in case of a two flute flat end micro mill cutter is for a cutter having rake angle -2$^o$ and relief angles of 6$^o$ and that in the case of four flute end micro mill cutter is for a cutter having rake angle 3$^o$ and relief angle 8$^o$..

## FUTURE SCOPE

The analysis can be carried out with different rotational speeds, under varing load and for different materials other then the materials used in this paper.

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