**VII Semester Mechanical Engineering**

**Subject: Micro and Nano manufacturing (7ME6.1A)**

**Solution**

**Ans 1. Micromachining** may refer to: The technique for fabrication of 3D and 2D structures on the micrometer scale. Super finishing, a metalworking **process** for producing very fine surface finishes. Various micro electromechanical systems. Bulk **micromachining.**

Micromachining is used to fabricate three-dimensional microstructures and it is the foundation of a technology called Micro-Electro-Mechanical-Systems (MEMS). Bulk micromachining and surface micromachining are two major categories (among others) in this field. This book presents advances in micromachining technology. For this, we have gathered review articles related to various techniques and methods of micro/nano fabrications, like focused ion beams, laser ablation, and several other specialized techniques, from esteemed researchers and scientists around the world. Each chapter gives a complete description of a specific micromachining method, design, associate analytical works, experimental set-up, and the final fabricated devices, followed by many references related to this field of research available in other literature. Due to the multidisciplinary nature of this technology, the collection of articles presented here can be used by scientists and researchers in the disciplines of engineering, materials sciences, physics, and chemistry.

**Ans 1.** Plastic deformation, as explained in earlier section, involves motion of dislocations. There are two prominent mechanisms of plastic deformation, namely slip and twinning. Slip is the prominent mechanism of plastic deformation in metals. It involves sliding of blocks of crystal over one other along definite crystallographic planes, called slip planes. In physical words it is analogous to a deck of cards when it is pushed from one end. Slip occurs when shear stress applied exceeds a critical value. During slip each atom usually moves same integral number of atomic distances along the slip plane producing a step, but the orientation of the crystal remains the same. Steps observable under microscope as straight lines are called slip lines. Slip occurs most readily in specific directions (slip directions) on certain crystallographic planes. This is due to limitations imposed by the fact that single crystal remains homogeneous after deformation. Generally slip plane is the plane of greatest atomic density, and the slip direction is the close packed direction within the slip plane. It turns out that the planes of the highest atomic density are the most widely spaced planes, while the close packed directions have the smallest translation distance. Feasible combination of a slip plane together with a slip direction is considered as a slip system.

Shear stress is maximum for the condition where λ = ø = 45 ْ. If either of the angles are equal to 90 ْ, resolved shear stress will be zero, and thus no slip occurs. If the conditions are such that either of the angles is close to 90 ْ, crystal will tend to fracture rather than slip. Single crystal metals and alloys are used mainly for research purpose and only in a few cases of engineering applications. Almost all engineering alloys are polycrystalline. Gross plastic deformation of a polycrystalline specimen corresponds to the comparable distortion of the individual grains by means of slip. Although some grains may be oriented favorably for slip, yielding cannot occur unless the unfavorably oriented neighboring grains can also slip. Thus in a polycrystalline aggregate, individual grains provide a mutual geometrical constraint on one other, and this precludes plastic deformation at low applied stresses. That is to initiate plastic deformation, polycrystalline metals require higher stresses than for equivalent single crystals, where stress depends on orientation of the crystal. Much of this increase is attributed to geometrical reasons.

Once the yielding has occurred, continued plastic deformation is possible only if enough slip systems are simultaneously operative so as to accommodate grain shape changes while maintaining grain boundary integrity. According to von Mises criterion, a minimum of five independent slip systems must be operative for a polycrystalline solid to exhibit ductility and maintain grain boundary integrity. This arises from the fact that an arbitrary deformation is specified by the six components of strain tensor, but because of requirement of constant volume, there are only independent strain components. Crystals which do not possess five independent slip systems are never ductile in polycrystalline form, although small plastic elongation may be noticeable because of twinning or a favorable preferred orientation. The second important mechanism of plastic deformation is twinning. It results when a portion of crystal takes up an orientation that is related to the orientation of the rest of the untwined lattice in a definite, symmetrical way. The twinned portion of the crystal is a mirror image of the parent crystal. The plane of symmetry is called twinning plane. Each atom in the twinned region moves by a homogeneous shear a distance proportional to its distance from the twin plane. The lattice strains involved in twinning are small, usually in order of fraction of inter-atomic distance, thus resulting in very small gross plastic deformation. The important role of twinning in plastic deformation is that it causes changes in plane orientation so that further slip can occur. If the surface is polished, the twin would be still visible after etching because it possesses a different orientation from the untwined region. This is in contrast with slip, where slip lines can be removed by polishing the specimen. Twinning also occurs in a definite direction on a specific plane for each crystal structure. However, it is not known if there exists resolved shear stress for twinning. Twinning generally occurs when slip is restricted, because the stress necessary for twinning is usually higher than that for slip. Thus, some HCP metals with limited number of slip systems may preferably twin. Also, BCC metals twin at low temperatures because slip is difficult. Of course, twinning and slip may occur sequentially or even concurrently in some cases.

**Ans 2.** Burrs are one of the most serious obstacles to precision manufacturing and manufacturing process automation. Burrs are formed in various machining process as a result of plastic deformation due to plasticity during mechanical manufacturing process and have been defined as undesirable projections of material beyond the edge of a workpiece. Recently, the trends of machined parts move towards more miniaturization and precision, burrs cause many problems during inspection, assembly, and manufacturing automation of precision components.

Burrs have to be removed by a deburring process for functional and aesthetic reasons after the part is machined. However, deburring processes are usually not very precise and may decrease the precision of the machined parts, damage surface finish, and produce residual stresses in the component. Moreover, adding a deburring process means extra cost, extra manufacturing time, and an extra machining station. Gillespie [[1](https://www.hindawi.com/journals/amse/2012/956208/#B1)] found that on precision components, deburring operations can account for as much as 30% of the total part cost. Since burr generation in cutting cannot be avoided completely, it is very important to find a solution for minimizing the burr formation or more effective deburring method. It is also necessary to understand the burr formation mechanism and the relationship between the parameters involved in the machining operation and burr formation. A thorough analysis of mechanism of burr formation may improve the quality of the machined parts greatly and thus be critical.

A great deal of research has focused on the development of more efficient deburring techniques to reduce the cost of deburring. In contrast, only a few studies have been carried out on the mechanisms of burr formation and the influence of cutting parameters to assist in the reduction of burrs and the production of burr-free components. Gillespie [[2](https://www.hindawi.com/journals/amse/2012/956208/#B2)] identified the machining burrs into four specific types based on the mechanism of their formation: poisson burr, rollover burr, tear burr, and cutoff burr. Iwata et al. [[3](https://www.hindawi.com/journals/amse/2012/956208/#B3)] discussed the dependence of burr formation on the stress field in machining. In order to clarify the effects of tool and workpiece geometry on burr formation, it is desirable to simulate, as closely as possible, these types of stress fields along the workpiece edge for various tool and workpiece geometry combinations. Ko and Dornfeld [[4](https://www.hindawi.com/journals/amse/2012/956208/#B4)] proposed a quantitative model of burr formation for ductile materials in orthogonal machining. Later, Ko and Dornfeld [[5](https://www.hindawi.com/journals/amse/2012/956208/#B5)] proposed a new model that caters for both ductile and brittle materials in orthogonal cutting. Chern [[6](https://www.hindawi.com/journals/amse/2012/956208/#B6)] extended Ko and Dornfeld’s model of burr formation with more realistic machining operations and cutting conditions. According to his observation, four different types of burrs—knife-edge, curl, wave, and secondary burr—were formed with variations in depth of cut and in-plane exit angle. Guo and Dornfeld [[7](https://www.hindawi.com/journals/amse/2012/956208/#B7)] developed a 3D finite element model for drilling with two sets of backup materials to investigate mechanisms of drilling burr minimization and predict cutting forces. Park and Dornfeld [[8](https://www.hindawi.com/journals/amse/2012/956208/#B8)] developed the finite element model of the burr formation in 2D orthogonal cutting with a plane strain assumption and investigated the influences of various process parameters. The four stages of burr formation, that is, initiation, initial development, pivoting point, and final development stages, are investigated based on the stress and strain contours with the progressive change of geometry at the edge of the workpiece. In addition, the characteristics of thick and thin burrs are clarified along with the negative deformation zone formed in front of the tool edge in the final development stage. Park and Dornfeld [[9](https://www.hindawi.com/journals/amse/2012/956208/#B9)] also conducted finite element simulation to investigate mechanisms of burr minimization by backup material and concluded that the burr can be effectively minimized by this way. Min et al. [[10](https://www.hindawi.com/journals/amse/2012/956208/#B10)] also present a general finite element model for burr formation in metals. And these simulation tools show excellent correlation with experimental results. The advantage of the simulation approach is that a wide range of parameters can be evaluated relatively quickly. Saunders and Mauch [[11](https://www.hindawi.com/journals/amse/2012/956208/#B11)] also developed a finite element model of burr formation to address the limitations of classical models of burr formation in drilling. Toropov and Ko [[12](https://www.hindawi.com/journals/amse/2012/956208/#B12)] proposed a model of the burr formation mechanism when burrs are formed in the feed direction during turning operation. Two cases have been considered in this study: continuous burr development, when the burr grows uninterruptedly, and discontinuous development, when the burr being formed is cut off and is renewed with each revolution of the workpiece. The model allows predicting burr height and thickness and is able to simulate burr development. Deng et al. [[13](https://www.hindawi.com/journals/amse/2012/956208/#B13)] established a coupled thermomechanical model of planestrain orthogonal metal cutting including burr formation is presented using the commercial finite element code. A simulation procedure based on Normalized Cockroft-Latham damage criterion is proposed for the purpose of better understanding the burr formation mechanism and obtaining a quantitative analysis of burrs near the exit of orthogonal cutting. Sartkulvanich et al. [[14](https://www.hindawi.com/journals/amse/2012/956208/#B14)] focused on the effects of tool geometry and flank wear upon burr formation in face milling of a cast aluminum alloy. 3D face milling simulations were conducted to investigate more realistic chip flow and burr generation. Comparisons were made for burrs produced from 3D simulations with a sharp tool, 3D simulations with a worn tool, and face milling experiments. Some recommendations for cutting tool design were made to reduce burr formation in face milling.

Up to now, little research on burr at top side is reported in the literature. The experimental work and practical theoretical models including finite element analysis are also scarce. The advantages of using finite element method to study machining can be seen from the following aspects: Material properties can be handled as functions of strain, strain rate and temperature. The interaction between chip and tool can be modeled as the sticking and sliding frictional behavior. And nonlinear geometric boundaries such as the free surface of the chip can be represented and used.

Some researchers adopted 2D FEM simulation programs to provide some insight to the fundamental understanding of burr formation [[10](https://www.hindawi.com/journals/amse/2012/956208/#B10), [13](https://www.hindawi.com/journals/amse/2012/956208/#B13), [15](https://www.hindawi.com/journals/amse/2012/956208/#B15), [16](https://www.hindawi.com/journals/amse/2012/956208/#B16)]. However, most of these models are two-dimensional, which can only be used for the analysis of roll burr formation in orthogonal cutting because of geometrical simplicity and is not suitable for predicting burr at top edge for its geometrical complicity. To date, there is few 3D finite element model has not been reported in the literature for analyzing burr formation at the top edge. In addition, in most of the finite element models developed so far, few commercial finite element codes have been employed. In order to improve the fundamental understanding of burr formation and process optimization for producing favorable surface integrity, theoretical modeling of burr formation has economic as well as scientific importance.

Since burrs are the cause of misfits in precision assembly, in this research, a general practical 3D FEA model has been developed to analyze the burr formation at top edge during groove cutting. A study concentrates on mechanism of burr formation in groove cutting and the influence of the main cutting parameters, namely, feed, rake angle, and cutting velocity on burr formation are presented in this paper.

#### 2. Finite Element Modeling of Groove Cutting

The sketch of rectangular groove cutting is shown in Figure [1](https://www.hindawi.com/journals/amse/2012/956208/fig1/) with the burr formed at the top edge. A rectangular groove is formed by turning using high speed steel cutting tools. This study mainly aims at the burr formation at top edge and the relationship between the parameters involved in the rectangular groove cutting operation. A 3D thermomechanically coupled finite element model of groove cutting process has been developed by using commercial finite element code (Deform-3D) as shown in Figure [2](https://www.hindawi.com/journals/amse/2012/956208/fig2/). The modeling approach is based on updated Lagrange formulation for large plastic deformation analysis to simulate the chip formation and burr formation. In the finite element simulation, the concepts of symmetry and antisymmetry are often useful and can reduce the size of the model (the total number of nodes and elements), which can reduce the analysis run time as well as the demands on computer resources. In Figure [1](https://www.hindawi.com/journals/amse/2012/956208/fig1/), for both the geometry and boundary conditions of the finite element model is identical on either side of a dividing plane B-B, the model then can be simplified to 180 degree segment due to symmetry. For the radius of bar-shaped workpieces used in experimental groove cutting is larger and the modeled section in the finite element simulation study is very small, the geometric shape of the modeled segmental material can be approximately taken as a cuboid. The cuboid has length 5 mm, width 3.5 mm, and height 2 mm. The workpiece model includes more than 200,000 elements. A very fine mesh density is defined at the cutting zone to obtain fine process output distributions.

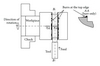
[](https://www.hindawi.com/journals/amse/2012/956208/fig1/)

Figure 1: Burrs produced in the rectangular groove cutting operation.

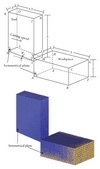
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Figure 2: The geometry and mesh models of rectangular groove cutting.

The workpiece material used for the plane-strain orthogonal metal cutting simulation is Al6061-T6. The workpiece is a deformable body with rigid-plastic material data, which depends on strain, strain rate, and temperature. Its flow curve is represented by several tabulated data, which depends on strain, strain rate, and temperature. These data represent the material flow curve at different strain rates and temperatures, while strain changes between 0 and 0.1. A sample flow curve for Al6061 at strain rate 103 and 104 can be seen in Figure [3](https://www.hindawi.com/journals/amse/2012/956208/fig3/). In the cutting process, the deformation at the cutting zone takes place at elevated temperatures and strain rates. For example, in the simulations performed, the temperature reaches above 300°C and the strain rates are in the order of 105 s−1. Therefore, the flow stresses at other strain rate state and temperature state are obtained by extrapolation.

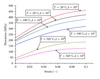
[](https://www.hindawi.com/journals/amse/2012/956208/fig3/)

Figure 3: Flow stress for Al6061-T6.

The surface ABCD and HIJK is the symmetry surfaces for workpiece and cutting tool, respectively. The surface ABFE, BCGF, and FGHE of the workpiece are fixed in all directions. The cutting tool is modeled as a rigid body which moves at the specified cutting speed by using 125,000 elements. A very fine mesh density is defined at the tip of the tool and at the contact zone to obtain fine temperature distributions. The minimum element size for the workpiece and tool mesh was set to 0.025 and 0.009 mm, respectively.

The heat sources responsible for large temperature rise during groove cutting include:(a)heat generation due to plastic deformation of the workpiece (mechanical energy) in the primary and secondary deformation zones;(b)heat generated at the tool-chip and tool-workpiece interface due to friction.

For the heat transfer calculation, the following assumptions were made:(a)the main sources of heating in metal cutting process are the plastic work and the friction at the tool/workpiece interface. In this study, 90% of the plastic deformation and 100% of the frictional work is assumed to be converted into heat;(b)the tool-chip contact is thermally perfect, namely, a very large value for the interface heat transfer coefficient is used;(c)the surface ABFE, BCGF of workpiece and surface HLOK, KJNO of tool are away from the cutting zone and remain at the room temperature; other free surfaces on the workpiece, chip, and tool, heat loss due to heat convection was considered;(d)Heat transfer by radiation is considered insignificant and negligible. Therefore, it is not therefore taken into account.

To simulate the chip formation, an automatic adaptive remeshing procedure is performed very frequently to deal with large deformation without losing accuracy. So that the workpiece mesh is frequently updated and modified, especially at the edge of the cutting tool, to follow the tool progress. This technique makes possible to simulate chip separation from the workpiece without any arbitrary predefinition. In this study, a new mesh is generated when the tool penetrates the workpiece by a critical value, which is assumed to be 30 percent of the smallest element edge length currently existing in the mesh.

In a groove cutting process, due to high stresses, high strain rates, and high temperatures, a high mechanical power is dissipated in the tool-chip interface thus leading to many structural modifications of the contacting pieces. Therefore, no universal contact law exists which can predict friction forces among a wide range of cutting conditions. Friction is difficult to model in metal cutting. Nowadays, it is widely accepted that two distinct contact regions, namely, the sticking region and the sliding region, exist simultaneously along the tool-chip interface [[17](https://www.hindawi.com/journals/amse/2012/956208/#B17), [18](https://www.hindawi.com/journals/amse/2012/956208/#B18)]. In the sticking region, a critical friction stress, , is considered to exist, while in the sliding region, a coefficient of friction, , is often assumed with regard to the Coulomb friction law. In this model, a classical Coulomb friction law is assumed to model the tool-chip and the tool-workpiece contact zones. Friction factor is defined as , where τ is frictional shear stress and  is the work material shear flow stress. A value of  is assumed, this one has been determined according to rake face friction factor identification results.

#### 3. Results and Discussions

##### **3.1. Burr Formation**

An important aspect of metal cutting simulations is the correct modeling of the material separation in front of the tool. Possible approaches are either to predefine a separation line and then separate the nodes on this line when a certain criterion is reached. It is also possible to simulate the metal cutting process without node separation. Instead, the formation of a continuous chip assumed to be due to plastic flow. As the tool advances, all nodes move on the tool surface and the elements may deform strongly. The material that overlaps with the tool can be removed during a remeshing step. Frequent remeshing is necessary so that the amount of material removed remains small. This simple approach has the advantage that it converges more easily and no material separation line is prescribed.

This study uses the deformation technology for burr formation in simulations. The workpiece is remeshed whenever a predefined threshold value of tool penetration occurs. Therefore, a new boundary for the workpiece at the tool-chip interface is determined and the workpiece is remeshed according to it forming the chip. The default threshold value of tool penetration is two times the contact tolerance value, which is by default 0.3 times the minimum element edge length. In addition, a penetration check can be selected to be performed at each iteration or the end of increments. Figure [4](https://www.hindawi.com/journals/amse/2012/956208/fig4/) shows the deformed mesh and distributions of the effective stress for the model run at 50 m/min cutting speed after machining a distance of 0.01 mm and 1.70 mm, respectively. Successful separation of the material from the workpiece, together with smooth chip flow up the rake face of the tool, is observed. Figures [4](https://www.hindawi.com/journals/amse/2012/956208/fig4/)(a) and [4](https://www.hindawi.com/journals/amse/2012/956208/fig4/)(b) show most of the maximum shear stress exhibits a finite region in the shear plane and larger region ahead of tool. The distribution of effective stress shows that the workpiece is most deformed in the chip-tool contact surface.

[fig4](https://www.hindawi.com/journals/amse/2012/956208/fig4/)

Figure 4: The history of the chip formation and the contour of effective stress.

Figure [5](https://www.hindawi.com/journals/amse/2012/956208/fig5/) shows that force components with the time. It can be observed that a steady state is reached very quickly after the initiation of the cutting process. Indeed, the cutting force appears to have attained a constant value at the time of 0.24 ms, indicating the achievement of a steady state. (Both the cutting and the thrust forces have reached the steady state after a tool path of about 2 mm.) When the chip geometry is stable, cutting force reaches a value of 513 N. All experiments were conducted on turning lathe. The cutting tool and conditions used for these experiments were the same as those used in simulations. No coolant was used in the machining. A three-component dynamometer (piezoelectric transducer, Kistler 9257), made by Kistler Co., was clamped on the machine bed to measure the cutting force. The signal generated by the piezoelectric transducer was first amplified by a charge amplifier and then connected to an A/D converter in the PC. The cutting force was determined by the processing using customized measuring force software. The experimental force is also shown in Figure [5](https://www.hindawi.com/journals/amse/2012/956208/fig5/). The comparison of the predicted steady-state cutting forces with measured (mostly transient) cutting forces shows that finite element simulation can basically capture the trend observed in the experimental data. The quantitative differences between the predicted and measured data are reasonable. The differences between the experimental and predicted cutting force may be attributed to the following reasons: (i) the extrapolation errors of the material flow stress data at high strain rates and temperatures; (ii) the simplified friction model used for the tool-chip interface; (iii) cutting edge radius.

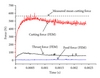
[](https://www.hindawi.com/journals/amse/2012/956208/fig5/)

Figure 5: A comparison of simulated forces with experimental forces.

Figure [6](https://www.hindawi.com/journals/amse/2012/956208/fig6/) shows the material flow state during the groove cutting. It can be easily observed the undeformed layer is plastic deformed and pushed forward. Most of the undeformed layer material, that is, material in the shear zone I, move in the direction of the cutting velocity and finally formed the chip. The value of the velocity of material in zone I is approximately equal to the cutting velocity and the direction is also tightly along tool movement. Only a small fraction of the undeformed layer, that is, material in the shear zone II, deviation from the direction of cutting velocity, and flow into the bulk top side and finally some of them turn into burr. Though the velocity is at very low level, most of outflow volume of the bulk may be harmful burr. Though the burr generation in conventional groove cutting cannot be avoided completely, optimized machining parameters may decrease the volume, that is, minimize the burr size. The burr profile in mesh style and cubic style is shown in Figure [7](https://www.hindawi.com/journals/amse/2012/956208/fig7/)(a) after the cutting process gets to steady. It can be observed that the burr height and burr size increasing after the tool cut into the workpiece and then advances forward. The metallographic sample is also sectioned to the area of the steady burr formation by discharge machining. And then the experimental burr profile is copied from optical microscope images of the burr sample. Figure [7](https://www.hindawi.com/journals/amse/2012/956208/fig7/)(b) shows the simulated and measured profiles of the steady burr. It seems that the established model simulate burr development with considerable accuracy.

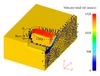
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Figure 6: The material flow analysis during the cutting phase.

[fig7](https://www.hindawi.com/journals/amse/2012/956208/fig7/)

Figure 7: Burr formation at the top edge in rectangular groove cutting.

##### **3.2. Influence of Machining Parameters**

Burr height was used as a burr size indicator in the present work as this was a relatively easy way of measurements. The height was measured as the average of 10 measurements for Burrs on top edge. Predicted burr profile is shown in Figure [8](https://www.hindawi.com/journals/amse/2012/956208/fig8/) for three different feed rates. It is quite obvious that the burr height at top edge increased steadily as the feed rate increases, while other machining parameters keep constant. The mean values of burr height are 0.07453, 0.10812, and 0.14074 mm, respectively, at the feed rate of 0.1, 0.2, and 0.3 mm. It can be concluded that the burr height is relatively larger for precision pats. It may introduce dimensional errors and cause of misfits in precision assembly. As mentioned previously, the Burr at the top side is formed by lateral deformation of the material when the cutting edge enters the workpiece. At low feed rate values, the volume of undeformed layer is small and can plastic flow more easily, therefore, relatively fewer of material flow into the bulk side and turned into burr. Whereas at high feed rate values the volume of undeformed layer is lager and plastic flow become difficulty. The material at the bilateral of undeformed layer is difficult to move forward and prior to move into the bulk side. Therefore, the volume of material that flows into the bulk side increased and the burr became larger.

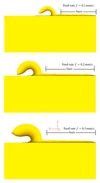
[](https://www.hindawi.com/journals/amse/2012/956208/fig8/)

Figure 8: Burr profiles for different feed rate.

Figure [9](https://www.hindawi.com/journals/amse/2012/956208/fig9/) shows the simulated burr profile under three different tool rake angle conditions. Regardless of the rake angle, the burr height keeps at a very low level during machining. The variation in rake angle significantly changes the magnitude of the burr height. The values of burr height are 0.14074, 0.09353, and 0.0786 mm, respectively, at the rake angles of 0°, 15°, and 30°. It is quite obvious that the maximum burr height at top edge decrease as the rake angle increases. Further, it is also noted that as the rake angle increases from 0° to 15°, the maximum height decreases from 0.14074 to 0.09353 mm, representing a reduction of around 0.05351 mm. However, it was also found that when the rake angle increases from 15° to 30°, the maximum value of burr height decreases from 0.09353 to 0.0786 mm, a mere difference of 0.01493 mm. This clearly indicates that the decrease of the burr height is quite limited when the rake angle increases from 15° to 30°. However, as the rake angle decreases from 15° to 0°, the increase of burr height goes beyond 50 percent from the previous amount.

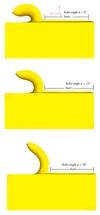
[](https://www.hindawi.com/journals/amse/2012/956208/fig9/)

Figure 9: Burr profiles for different rake angle.

In this study, the effect of cutting velocity and minor clearance angle on burr formation were also numerical studied. The minor clearance angle is illustrated in Figure [10](https://www.hindawi.com/journals/amse/2012/956208/fig10/) and is defined as the angle between the cutting velocity vector in orthogonal cutting and tool minor cutting edge plane. Comparison with the feed rate and rake angle, the effect of cutting velocity and minor clearance angle on the burr size are very slight. While the minor clearance angle increased increases from 0° to 30°, the burr height decreases from 0.14074 to 0.13813 mm, a mere difference of 0.00261 mm. While cutting velocity increased from 0.5 m/s to 2.5 m/s, the burr height decreases from 0.14074 to 0.13813 mm, representing a mere difference of 0.00261 mm. This clearly indicates that the effect of cutting velocity and minor clearance angle in the presented range on burr size are quite limited.

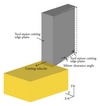
[](https://www.hindawi.com/journals/amse/2012/956208/fig10/)

Figure 10: The definition of minor clearance angle.

#### 4. Conclusions

(1)A 3D finite element model to simulate rectangular groove cutting operation has been developed using commercial finite element software, employing experimentally determined mechanical properties at elevated strain rates and temperatures. The comparison of the simulated and experimental burr profile and cutting force proves that the developed model can capture the thermomechanical mechanisms in rectangular groove cutting and can simulate burr development with considerable accuracy.(2)Parametric studies can be performed in order to understand the influence of different cutting parameters on the burr formation process in rectangular groove cutting operations. Although it is not possible to avoid burr formation by altering the cutting parameters, the burr size can be reduced significantly by selecting the appropriate values.(3)The results show the burr height at top edge increased steadily as the feed rate increases. The mean values of burr height are 0.07453, 0.10812, and 0.14074 mm, respectively, at the feed rate of 0.1, 0.2, and 0.3 mm. For the larger feed rate values, the volume of undeformed layer is lager and plastic flow become difficulty. The material at the bilateral of undeformed layer is difficult to move forward and prior to move into the bulk side to form the burrs.(4)The variation in rake angle significantly changes the magnitude of the burr height. The values of burr height are 0.14074, 0.09353, and 0.0786 mm, respectively, at the rake angles of 0°, 15°, and 30°. It is quite obvious that the maximum burr height at top edge decrease as the rake angle increases. The decrease of the burr height is quite limited when the rake angle increases from 15° to 30°. However, as the rake angle decreases from 15° to 0°, the increase of burr height goes beyond 50 percent from the previous amount.(5)The effect of cutting velocity and minor clearance angle in the traditional range on burr size is quite limited.(6)Computer modeling of burr formation, which belongs to the new concept of computational machining or virtual machining simulation, especially using a commercial FE code widely available to engineers and industry, constitutes a very useful tool for the prediction of the surface integrity of the workpiece as well as the optimum machining parameters, thus reducing the need for resorting to extensive cutting experiments.

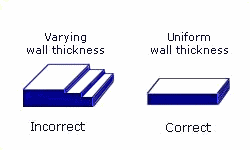
Ans 2. The more universal material representation in MD further allows us to go beyond ideal, single crystalline structures and to also consider polycrystals, defect structures, pre-machined or otherwise constrained workpiece models and nonsmooth surfaces. Various applicationspecific boundary conditions may be applied. In recent years the number of applications considering quantum mechanics for the interactions between atoms has been steadily increasing. However, here only the more classical atomistic approach will be presented. Figure 1.1. Concept of a molecular dynamics cutting model setup Figure 1.1 shows a general description of an often applied concept for MD cutting process simulation, i.e. the orthogonal cutting condition, and includes the essential elements of MD modeling

Cutting Force • The cutting force exhibits a linear relationship with the undeformed chip thickness when micro and nano scale machining is conducted above the edge radius of the tool. • When the undeformed chip thickness is smaller than the edge radius of the tool, a non-linear variation in the cutting forces is observed. • The specific cutting and thrust energies increase significantly in a non-linear fashion when micro and nano scale machining is performed at undeformed chip thicknesses smaller than the edge radius of the tool. • The cutting speed has negligible effect on the cutting force at undeformed chip thicknesses less than 1 µm for both materials studied.

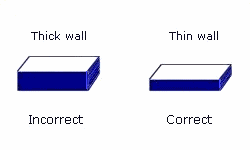
# Ans. 3 Injection Molding Design Considerations

Simple and complex shapes can be injection molded, however certain design guidelines should be followed:

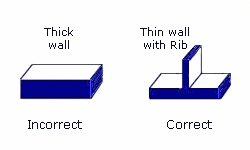
* Make sure the shape will [cool properly](https://www.emachineshop.com/injection-molding-cooling/) by avoiding thick areas.
* Avoid thick When the design does not allow for additional structures to improve strength, consider using a stronger material, such as glass fiber filled plastic.
* Consider specifying a fire retardant material when necessary.
* A small rough spot will appear at the gate; a small line will occur at the parting line; and a round mark will occur at ejector pins.
* Consider specifying where to place the gate and parting line and what surface finish to use – polished, matte, textured.
* Since a seam between two halves of a box is difficult to fully hide, consider making the joint pronounced – to make it look like it is decorative.
* Contoured parts warp less than flat parts.
* Review existing injection molding components for additional ideas and techniques.
* Use an approximately uniform wall thickness throughout your design.



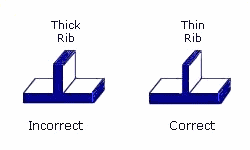
* Keep walls thin – typically between 1/32" and 1/10". This allows for proper cooling and reduces cost by minimizing use of material. Thin walls also reduce problems with material shrinkage. Although some unevenness will occur due to shrinkage, walls as thick as 1/5" can be used. Keep wall thickness at least wall length / 50. Keep 90 deg walls under 0.25" high. Keep thickness of ejection pin surface wall at least .07".



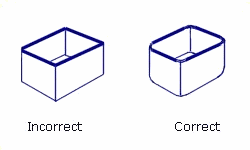
* To strengthen parts, instead of using thicker walls, use additional structures such as ribs. Use fillets at the base of ribs.



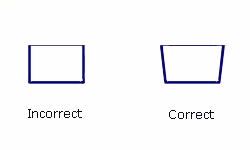
* When using a rib make it about half the main wall thickness.



* Round corners and edges wherever possible.



* For easy release of the part from the mold, add a slight taper to the sides (typically ~ 2 deg) – especially for textured walls and walls higher than 0.25".



Lighter colors hide flow patterns better than dark colors. Choose the right material from the table. Drawing dimensions should be of the final part – material shrinkage will automatically be considered in the design of the mold. Use raised text instead of recessed text when possible. Where walls meet at a 90 angle, round inside and outside to at least .05" radius – sharper outside corners can create molding problems and sharper inside corners will increase tooling cost. Keep holes at least .015" from edges. It should not be possible to fully hide a 0.3" diameter ball anywhere inside the material.

**Ans 3.** The concept of fabricating on-machine high-aspect-ratio micro-electrodes arises from the need to fabricate small and deep micro-holes in micro-electrical discharge machining (micro-EDM). In the present study, investigations are conducted on the fabrication of high-aspect-ratio micro-electrodes using two simple and cost-effective micro-EDM-based processes: the ‘turning-μEDM’ hybrid process and the ‘moving-electrode-block-μEDM’ process. Process descriptions and important aspects for successful fabrication of high-aspect-ratio micro-electrodes are discussed. In addition, the application of these micro-electrodes in the fabrication of deep micro-holes in tungsten carbide using normal micro-EDM and vibration-assisted micro-EDM is presented. It is found that the turning-μEDM process can generate finer micro-electrodes for easily machinable materials such as brass, but its application to the machining of deep micro-holes in tungsten Carbide is limited by the extreme tool wear of the brass electrode. The block-μEDM process can generate microelectrodes with hard, difficult-to-cut, and high-melting-point materials such as copper tungsten (alloy) and tungsten with much higher aspect ratios. However, the taper angle of the fabricated micro-electrodes is a common problem in the stationary block-μEDM process. This problem is reduced to a great extent by using block-μEDM with a moving electrode. Micro-holes with an aspect ratio of 16.7 are achieved using vibration-assisted micro-EDM with the fabricated tungsten micro-electrode machined by the moving-electrode-block-μEDM process.

**Ans 4.** Microdrilling is characterized not just by small drills but also a method for precise rotation of the microdrill and a special drilling cycle. In addition, the walls of a microdrilled hole are among the smoothest surfaces produced by conventional processes. This is largely due to the special drilling cycle called a peck cycle. The smallest microdrills are of the [spade](http://pages.mtu.edu/~microweb/GRAPH/Drilling/DRILLGEO.JPG) type. The drills do not have helical flutes as do conventional drills and this makes chip removal from the hole more difficult. Drills with a diameter of 50 micrometers and larger can be made as twist drills. Drills smaller than this are exclusively of the spade type because of the difficulty in fabricating a twist drill of this size.

There are several important geometric characteristics of spade-type microdrills. First, the point of the drill is not a point at all. Even on conventional twist drills, the end is not truly pointed. Instead, the end of the microdrill consists of a cutting edge (called the chisel edge) made by two intersecting planes which also define the two primary cutting edges of the drill. The chisel edge removes material primarily by extrusion and cutting at high negative rake angle. The specific cutting energy along the chisel edge is relatively large compared to the drill's primary cutting edges. The chisel edge also adds to the drilling complexity because of the lack of a point. As the rotating drill first contacts the work piece (remember the drill has a very small structural rigidity) anything on the surface, including microroughness and material slope, will cause the drill to walk on the surface as it is trying to begin removing material. Walking is characterized by an eccentric motion of the drill as it turns perhaps coupled with a non-time- varying bending of the drill about its longitudinal axis. Depending on the feed per revolution of the drill during hole start-up, the drill may begin drilling at a slant with the drill deflected like an end-loaded cantilever beam (which it is with superimposed column loading). If permitted to continue, the drill will quickly break. If the drill is strong enough to survive the large stress imposed in it due to drilling at a slant, the resulting hole will be slanted rather than normal to the work surface.

A second consequence of the chisel edge is its relatively long length compared to the drill diameter. This results in a relatively high thrust force along the drill axis. While the sloped cutting edges are increasing the diameter of the hole machined by the chisel edge, the specific cutting energy along the cutting edge is normally lower than at the chisel edge. The result is a large thrust force compared to the diameter of the drill. Again, this size effect works against the microdrilling process similar to the size effect in micromilling.

Microdrills are typically made of either cobalt steel or micrograin tungsten carbide. The steel drills are less expensive and easier to grind but are not as hard or strong as the tungsten carbide drills. The drill point angle is based on the material to be drilled. The normal point angle is 118 degrees and 135 degrees is used for hard materials. The larger included point angle provides more strength at the drill point.

A microdrilling spindle uses a [vee-block](http://pages.mtu.edu/~microweb/GRAPH/Drilling/VBLOCK.JPG) bearing arrangement. The drill is mounted in the mandrel and is fabricated integral with the mandrel. The mandrel rides against four convex diamond surfaces which are the only points of contact. So long as the drill was ground with the mandrel supported in a similar manner, the drill will be concentric about an axis. That axis may not coincide with the mandrel axis but that is not significant as long as the offset is not sufficient to cause excessive vibration, and it normally is not. A small pulley is fastened to the drill mandrel and a drive belt passes around the pulley and drives the drill from an external motor. The belt tension is the only force holding the mandrel against the diamond pads and a slight upward component of the belt tension is used to retract the drill. The upper end of the mandrel rides against a ceramic material which provides the drill thrust force. This disk may also rest against a force sensor to measure drill thrust force which is often used to indicate the extent of drill wear.

Microdrills must be used in a [peck](http://pages.mtu.edu/~microweb/GRAPH/Drilling/PECK.JPG) cycle wherein the drill is repeatedly withdrawn and reinserted into the hole being drilled. This is necessary to help clear chips from within the hole. A thin cutting fluid is also recommended to aid in chip clearing. The fluid should be moving, as in an air-oil mist rather than stagnant. Stagnant fluid will allow chips to reenter the hole along with the drill. The effect of not using a fluid is clearly [shown](http://pages.mtu.edu/~microweb/GRAPH/Drilling/STAG.JPG). The hole has more, large chips, on the order of 5 micrometers in size, and the drilling thrust force under such a condition is typically higher than if the chips are [cleared](http://pages.mtu.edu/~microweb/GRAPH/Drilling/CLEAR.JPG) from the hole. With no fluid to help clear chips, two hole is [packed](http://pages.mtu.edu/~microweb/GRAPH/Drilling/PACKED.JPG) with chip debris and the axial force on the drill is typically several times (2-3) higher than with fluid. In very soft materials, complete removal of the drill from the hole each peck cycle can cause a slight taper near the hole entrance. This can be avoided by incomplete removal of the drill. For softer materials, chip removal is not as severe a problem since the machining forces for such materials is normally lower than for hard materials but chips left in the hole can cause the drill to wander from an axial path and can result in a drilled hole with a center which does not lie along a line.

The recommended speeds and feeds for microdrilling are as varied as the materials which can be drilled. Microdrilling is not generally a high speed process since dwelling of the drill at the bottom of the hole can cause hardening of the work piece leading to increased drilling forces. For most metals, typical spindle speeds are in the 2000 to 4000 rpm range and feeds are in the range of a micrometer per revolution, or so. Care must be taken when drilling plastics to avoid melting of the material which can lead to adhesion of the plastic to the drill. This can cause drill breakage or poor sidewall smoothness.

The applicability of microdrilling as a complementary process with features produced by lithography and electroplating has been investigated. A cross section of a copper [microgear](http://pages.mtu.edu/~microweb/GRAPH/Drilling/CUGEAR.JPG) made by lithography is shown. The average roughness of the hub wall is 0.4 micrometers. A microdrilled hole in the same material gave a roughness of 0.15 micrometers over a much longer bore length. Microdrilling can also be used to augment lithography for mesoscopic (millimeter and larger) sized components. Often parallelism of deep holes is of concern. To determine typical values for parallelism of microdrilled holes, glass fibers were inserted into a number of holes drilled with a very slow starting sequence. This is necessary to ensure the drill does not walk on the surface of the part and that the hole axis aligns with the undeflected axis of rotation of the drill. Holes with a length-to-diameter ratio of 8 were drilled at 4000 rpm. The three-dimensional misalignment of the inserted fibers was measured to be 0.08 degrees (1.5 milliradians), which included skewing of the fiber in the hole due to oversize of the hole which was estimated to be 0.5 micrometers.

Microdrilling has one major disadvantage because of the drill geometry. Because of the drill point, a flat-bottomed hole can not be produced. If one is attempting to produce cylindrical cavities in a micromold, there must be a relatively thick plating base under the mold material, or the structural substrate of the mold could act as the plating base. To fully develop the diameter of the hole, projected onto a plane perpendicular to the drilling direction, requires the drill point to extend 30% of the drill diameter beyond the depth of the fully developed hole. For holes in the 100 micrometer region, requires a thick plating base to be deposited. One method for creating flat-bottomed blind holes is to use an end milling tool instead of a drill.

**Micro turning** is one of the tool based micromachining process used for manufacturing axi-symmetric miniaturized parts. This paper presents the development of **micro turning** setup and investigations on cutting forces and surface roughness during **micro turning** process.

**Ans 4**. Micro-milling is the removal of a small thickness (1 inch or less) of existing asphalt concrete prior to placing a surface treatment. The difference between cold milling and micro-milling is the texture left on the existing pavement. Micro-milling provides for a smoother surface than cold milling and is typically used before a slurry seal or microsurfacing treatment.

**Why?**

Micro-milling is performed for the same reason to why wood is often sanded prior to painting. Micro-milling removes old, oxidized pavement and previous surface treatments thus providing a surface which is more receptive to bonding to the new surface treatment. Micro-milling also results in a smoother ride and neat, clean edges near the gutters or other concrete roadway improvements for the new surface treatment to join to.

**When?**

Micro-milling is performed prior to the placement of a surface treatment such as a slurry seal or microsurfacing.

**How?**

Micro-milling machines are self-propelled machines which contain rotating drum with teeth. As the drum turns, the teeth come into contact with and remove asphalt pavement. As a result, the pavement surface contains a series of small, parallel ribs. Micro-milling uses a drum with a larger number of teeth which are very closely spaced. The pavement surface produced by micro-milling has more ribs which are more closely spaced resulting in a finer pavement texture. Sweepers follow behind the cold milling machine and remove any millings left on the pavement. The pavement texture is suitable for driving on for an extended period of time. There will be minimal additional wear to the pavement surface and only a very small amount of, if any, further pavement abrasion which would necessitate sweeping.



