# A Comprehensive review of micro-cutting operation – micro milling tools

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**a b s t r a c t**

Micro tooling is a leap in manufacturing due to its precision and accuracy because you work at the grain level. Micro cutting provides versatility along with high machining accuracy and superior surface quality of micro features. Many studies have shown either through simulations or experiments that the geometries of micro tools in micromachining play a very significant role in improving the efficiency of the final machined product. Some conventional processes like micro turning, micro-milling, micro grinding, micro forming, micro-drilling follow the same pattern. Researchers have developed custom micro milling tools, but the design constraints for micro-milling tools have not been implemented. This leads to the lack of development in micro tooling. This paper aims at incorporating the design requirements for custom micro tooling, tool defects, tool features, tool performance, and effects on different types of work pieces, based on the works of former researchers. The analysis concludes with recommendations for an integrated method of designing and production by not following the conventional rules on traditional tools, but the formation of a separate model for micro tools.

## Introduction

The most important part of the subtractive machining process is its cutting tools. Out of several cutting processes, milling at the micro level is suitable and advanced way of creating high complex with dimensions at three dimensional level which are used in the field like Micro-electro-mechanical systems and also in high-precision of rough and brittle materials such as glass, metal super-alloy, and ceramic goods. The greatest problem for mechanical milling at micro level is the faulty model and the productivity gives out that in extended tool manufacturing the factor of time durations and results in typical and high costs due to typical tool manufacturing methods, and even worse, it slower the value of the geometric precision of the produced equipment, making it impossible to obtain reasonable micro-machining accuracy and surface quality. [1–8].

This size reduction can be seen in some of the normal micro-milling parameters: feed per toothless than 1 mm, cutting depth 2–15 mm, the speed value of the spindle is exceeding over than 400,000 rpm, and the geometrical diameter of the required tool is less than 0.25 mm. The machine which is used to level at micro level itself must be unique to this field and analyzed and produces with high standards, with a positioning accuracy of 0.1 mm. Micro milling is a milling machine with cutting equipment less than 1000µm or narrow structures of one or two perpendicular dimensions of up to 1000µm. The hexagonal end mill has a uniform axial angle of rake, axial angle of clearance, radial angle of rake, and radial angle of clearance, making the same surface condition feasible on all side and bottom surfaces to be machined. An inside and out examination and execution of miniature cutting mechanics and fundamentals is needed to be allowed for effective industrial adaptation in the design and manufacturing of micro tools [9].

Also, the existing commercial processes used to produce tools at micro level and the failure part of the wear is struggled by some of failure tools aspect like tools which are fractured at prone level, only when tools are used with techniques which are not at the optimum level, which results in making the process of machining rough, leads the materials to be fragile, complicated and unattractive [10]. The tool deflection, which further leads to inaccuracy and burr formation at entry and exit of the workpiece can be controlled by tool patterning but from the industrial point of view, the potential cutting rates in brittle machining and the constraint on simple tool patterning are neither sustainable nor economic [10]. Components made by micro milling are ordinarily utilized in various industries, such as pharmaceutical, optical, and mold/die industries. It can be found that the size effect has a significant role to play in the selection of both the working material (grain size) and the tooling (edge radius). Since we are working on grain level, whenever a chunk of grain is removed it leads to an uneven surface [11].

The positive aspect of this process is low magnitude forces and temperature registered during micro-milling, however, due to the plowing effect observed when the uncut chip thickness is decreased, the real cutting force can be of high magnitudes. Finally, burr forming is the main consideration concerning the consistency of the finished part [64].

## 2.Established and continuing micro milling tools

### 2.1. Literature review of paper on tools.

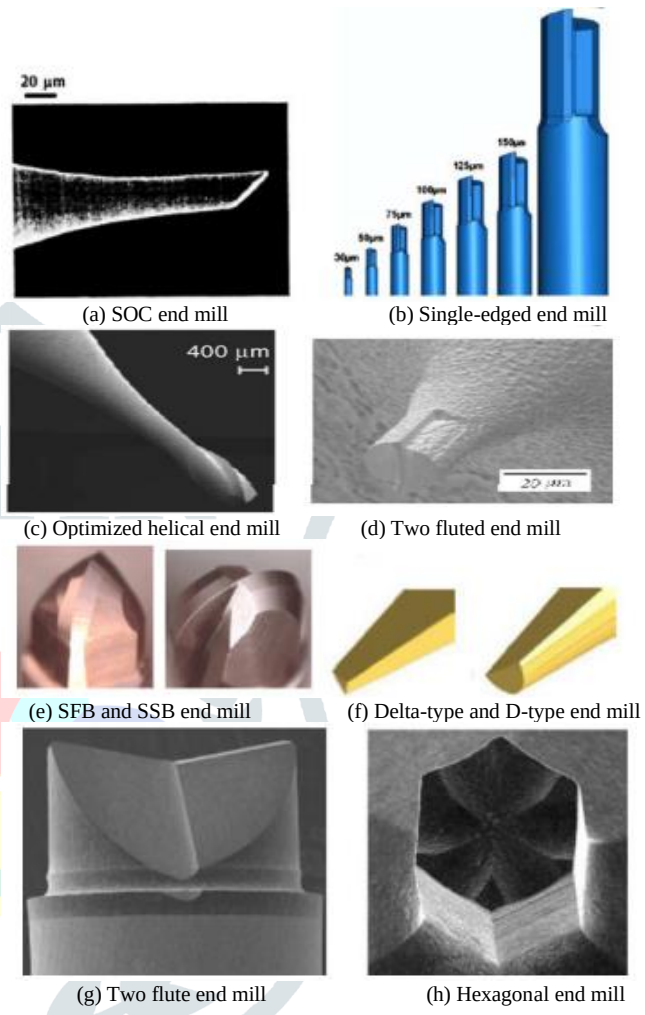
Based upon our literature searches, taken only for aspects of a micro-milling tool the following literature on the nature and manufacturing of micro milling tools is reviewed and summarized. In general, there is no limitation on the imagination of making a micro-milling tool edge. The basic limitation occurs when the tooltip is so thin and that it shows out the deflection.

In [1], considering a plane which has features like, the oblique-cut mill at micro level (Fig. 1 a) was formed and get analyzed by technique of grooving, and also with the help of spider pattern technique a work piece which is composed with aluminum is fabricated. In [2], a special type of single-edged milling process at micro level was built to avoid the predictable problems in the future which get showcased having multi-edged milling tools at micro level with inadequate precision in the manufacturing of micro-tools (Fig. 1 b). Tools with a radius of 150 and 22.5µm were used to machine grooves to validate and evaluate the construction of these tools.

In [3], the two-flute helical end mill was optimized based on a complex load and strain analysis was done with the help of the finite element process. A special type of end mills which are helical in shape and in optimized condition made of TiAlN in addition to coated with WC were analyzed to lower the value of stiffness of the PMX190CrVMo20 from 62HRC to 52HRC. (Rockwell Hardness Number).

In [4], the incorporation of WEDG and FIB sputtering (Fig. 1 d) has contributed to the development of a form of the two-flute end mill. The produced tools at micro level were used in the process of milling the channels

at micro level on polymer results in with the average surface roughness, Ra of 80 nm.




(a) SOC end mill (b) Single-edged end mill

(c) Optimized helical end mill (d) Two fluted end mill

(e) SFB and SSB end mill (f) Delta-type and D-type end mill

(g) Two flute end mill (h) Hexagonal end mill

**Fig.1 Milling Tools at micro level taken from Literature. Reprinted Images. [1-8]**

In [5], a super-finished ball-nosed end mill (SFB) and a super-speed ball-nosed end mill (SSB) are produced (Fig. 1 e). The SFB has a cutting edge with a value of negative angle of rake near to −45 °. The SSB similar cutting edge when compared with SFB, but the value of rake angle is near−20 °. The tools which are made of cubic boron nitride is analyzed in order to cut SKD11 (60HRC) die-cut steel and STAVAX (52HRC) hardened stainless steel. The high rate of surface integrity is obtained by super-finished ball-nosed end mill and super-speed ball-nosed end mill is roughly 1.8 and 1.0µm Rz respectively.

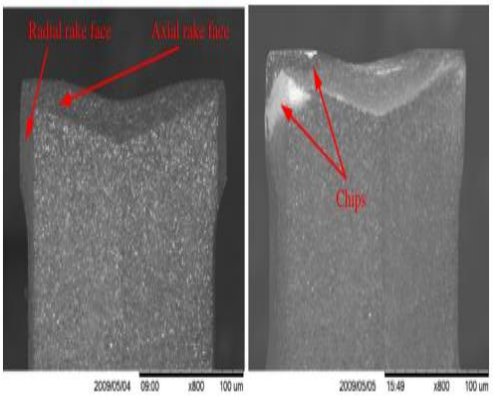
In [6], explains that Δ-type and D-type end mills (a) SOC mill (b) Single edge end mill (c) Optimized helical end mill (d) Two-flute end mill (e) SFB & SSB (f)-type and D-type end mill (g) Two-flute end mill (h) Hexagon end mill. These tools at micro level which are used in milling process are developed based on a FEM study (Fig. 1f). The tungsten carbide end mills are analyzed by excluding out the brass. The highest value of surface roughness of 100 nm can be obtained.

From the experiments, it is shown that the Δ-type end mill is not suitable for brass machining due to its wide negative angle, which resulted in the surface of the machined part worse. The benefit of a D-type end mill is it has the higher value of rigidity and improved cutting efficiency. In [7], from that, a 20µm tungsten carbide cylinder, four types of mills which are finished at micro level were produced using a grinding method for micro grooving on duralumin. The experimental findings offered three recommendations for the tool which is optimized for the grooving process at micro level, and the (type-e) was created and analyzed to reach better surface integrity and higher expectancy of tool life. A 20-edged milling instrument at micro level was made of polycrystalline diamond is grounded and polished with

diamond wheels in [8]. Finite element (FE) simulation is usually used to evaluate the chip forming process and improve the precise cutting force. Thepsonthi et al.1008 suggested a 3D FE model simulate full immersion milling with Ti-6Al-4V titanium alloy.
The model was used to research the effect on process efficiency of increasing tool edge radius due to wear. Cutting pressures, cutting temperatures, chip flow, and burr shape was greatly influenced by tool wear.
Attanasio et al.1009 studied the tool run-out results of thin-wall milling and used them in the 3D FE model. The process efficiency improvement is due to the tool run-out Phenomena (Tool run-out is a phenomenon that occurs due to deviation between the theoretical cutting edge trajectory and the actual cutting edge trajectory, it is the sum of the geometrical displacements of the spindle axis, tool-holder axis and tool axis from the theoretical rotation axis.) and it was shown by the experiment and the simulation. Regulation and optimization of the efficiency of the milling machine are critical to achieving effective micromachining processes. Masuzawa and Tönshoff [58] defined micromachining as using an unreformed chip thickness varying from 0.1 to 200 micrometers. Subsequently, Masuzawa [59] claimed that the spectrum of micromachining varied in terms of time, individual machining strategy, type of item, or content. Liu et al. [60] explained that the unreformed thickness of the chip was equal to the cutting-edge radius of the instrument in micromachining. Chae et al. [62] described micromachining as a manufacturing technique for making gadgets smaller than anticipated and parts with highlights of different sizes from numerous micrometers to a couple of millimeters. Dornfeld et al. [62] characterized micromachining as a mechanical cutting framework with an instrument commitment of less than 1 mm, using geometrically characterized front lines.

## 2.2. Advantages and limitations of conventional micro milling tools.

Large number of tools at micro level are explained above that they are difficult to come over with parameters like rake angles and cutting-edge radius which are suitable for particular work piece materials.
As seen in previous studies [6, 10] the angles of the rake and the edge radius of the instrument have a direct relationship to the surface consistency and the cutting power of the micro unit. They can be varied for ductile and brittle materials, taking into consideration the various types of substance elimination. In [2], explained that due to the factor called tolerances in manufacturing aspect the value around ±10µm on a tool which is at micro level, only a single cutting edge is often used.
Due to that, it resulted in increased tool wear, cutting force, lower surface quality, and a high risk of breakage of the tool at the micro level so that the single edge end mill is built-in [2]; as so far, the load which is centrifugal and the deformation as the tool rotates more than 100,000 rpm cannot be removed, particularly for milling tools at micro level in larger sizes. This will result in the chattering of the tool which in turn will cause the degradation of machined geometry precision and surface quality and hence the non-symmetrical tool geometries described in the literature will be favored over ultra-small tools.




(a) Before Machining (b) After Machining

**Fig.2 Shows chip fusion and edge defect in micro mill**

The chip disposal rate is lower in the aspect of milling at the micro level, that the chips typically have the dimensions at the sub-micron level, which in result makes the chip disposal very difficult even under flood-level conditions.
Fig.2 indicates that the chips are combined to the axial and radial surfaces of the milling instrument at the micro level under flood fluid conditions that are observed by the authors. But still, some milling operations at micro level are need to be done without the help of cutting fluid at all, so that the actual problem arises that how to achieve the equilibrium between a good chip disposal space on the instrument and good rigidity of the tool [9].
Also, there exists a limitless potential of using the micro tool to deliver a miniature item which leads to the conservation of raw material and also saves energy like carrying and storage required, several metallic alloys, composites, polymers, and ceramic materials can also be manufactured to form practical devices. Several bio-micro-electro-mechanical systems (bio-MEMs) facilities are currently exploring ways to manufacture bio-MEMs based on micro-mechanical plastic, micro-injection, and hot embossing processes.

## 3.Design outline standards and processes for micro-milling tools.

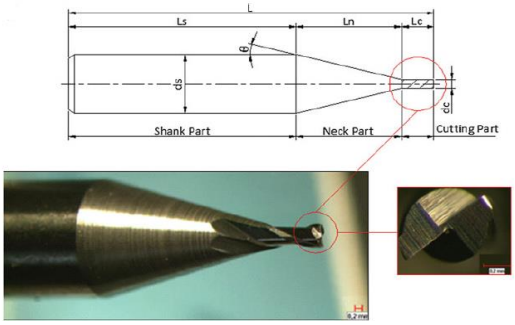
### 3.1.1. Fabrication method

A precise mathematical and manufacturing processes, and a machine is needed to design and produce a superior micro tool providing good machining accuracy, durability, and reproducibility [14].
Significant explorations have been carried out to upgrade the proficiency of micro tools using innovative production methods and techniques, but the actual problem while in the machining of hard materials still remains.
The manufacturing of tools at micro level is a difficult stage in the whole machining process, also including the knowledge of the geometric parameters at the optimal condition, the number, and form of the cutting-edge radii, and the properties of the components, along with the strengths, features, advantages, and disadvantages of the various processing methods and related costs [15].
Usually, the manufacturing of tools at micro level is heavily gone through a pattern of an individual but, in some cases, different methods like variations in electronic, laser, ion-focused beam (FIB), electro discharge machining (EDM), and hybrid manufacturing methods are not needed a patterning method. Methods for bonding the tool surface and the coatings are often used to achieve the desired efficiency. Besides, finishing methods, such as mechanical grinding techniques, are often carried out to produce a precise form and surface quality [15].

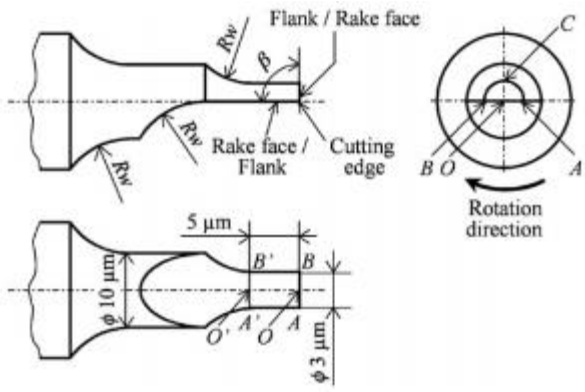
A quick overview of the manufacturing processes followed, and get analyzed by comparing with recent developments in this area. Guidelines have been designed especially for ultra-precision milling machines, but can also be extended to traditional milling machines and custom-built milling machines. The instrument must be a micro-finished mill with a diameter of less than 1 mm.
The tool run-out can be restricted by the use of a tool holder with precision collets instead of other holder types.
In addition to the normal milling machine equipment, a data acquisition system for forces is needed for the evaluation process. Cutting forces are irreplaceable details for knowing the cutting dynamics and calculating the tool run-out. The development of an accurate measuring method is difficult due to a variety of problems.
The load cell shall have an accuracy of at least 0.01 N. The load cell sampling rate must be selected as the best possible trade-off between appropriate file size and efficiency of acquisition. Aliasing can be eliminated by setting a relatively high sampling rate [38]. Modeling of the micro-milling process using Johnson-Cook Constitutive Equation to determine the flow stress needed for plastic deformation of the work material was undertaken by Ozel et al. [66], who found out that a minimum uncut chip thickness equal to 30%-36% of the tool edge radius is required to allow chip formation when cutting AISI 4340 steel (42-45 percentage).
However, further phase simulation of the finite element resulted in slightly lower values for feed and radial powers. Similarly, the temperature in the cutting region was found to be too low. A similar analysis was carried out, using an analytical model specifically developed for micro-milling, which considers the effect of the number of teeth and the tool radius on the uncut chip thickness, in addition to the feed rate and the rotation angle of the tool. A fair contrast between simulated and experimental findings revealed that unstable cutting (without chip formation) takes place while micro-milling with an uncut chip thickness equal to 20% of the tool edge radius. On the other side, as the uncut chip thickness is greatly raised to 80 percent of the tool edge radius, cutting is performed adequately.

### 3.1.2. Geometrical morphology

The geometry of the cutting tool at micro level with symmetric features gives out the benefits of more accuracy in machine tools and also in machining methods at optimum condition, an error of cutting-edge difference of about ±3.0µm has resulted for an SFB with a radius of 500.0µm [5], a radius error of 1.60µm has resulted for an end mill which is the hexagonal type with a radius of about 250.0µm and an error in the cutting-edge variation of about ±2.0µm has been reached for a recently made ball end mill.




(a)




(b)

**Fig.3 Schematic diagram showing (a) tool geometry (b) micro-cutting tool geometry were (L: Tool length, Ls: shank length, Ln: neck length, Lc: cutting length, ds: shank diameter, dc: cutting, Θ: neck angle), a cross-section of a two fluted end mill, enlarged view of a cutting edge, side view of the end mill. Reprinted image. [5]**

## 3.1.3. Across Macro to Micro

As we know that micro tools do not work the same as the macro tools with scaled down dimensions, therefore following the same process to make the tool will not work. The chip formation, material removal, and heat concentration are different in macro tools as said by authors. Therefore, new mathematical models and manufacturing processes should be developed. We should decrease the large contact in angle of clearance; tool features and surfaces on both upper and lower of the tool should be taken to decrease unnecessary contact. Chip disposal rate, in front of the face of the rake, must be taken into account mostly in typical cutting conditions like no cutting fluid and pressurized air at higher value is used. Avoidance of downsizing design of commercial tools. The regular two / four-flute helical end mill is not suited for cutting loads at micro level and objections; and also, sometimes the structure does not scale correctly, resulting in localized weakness of the cutting edges and low stiffness, eventually causing chipping and fracture. Commercial macro tool designs, as stated above, do not comply with the geometrical specifications that micro tools need. In Li et al. [18], analyzed that from the fabrication of end mills at micro level that larger wear, lower rate of surface finish, and premature tool failure partially resulted from the design of the tool.

Besides, they recommended that the basic implementation and geometric features of the tool be closely interlinked. By paying careful attention and incorporating it in the modernization of the standardized methodologies used by the industry, superior efficiency in the durability and consistency of the micro tools can be obtained. They also note that industrial micro tool designs usually have a rough edge that weakens the center of the structural material of the tool and the strength of the cutting edge that gradually causes chipping and fracturing of the edge corners. These type of the tools often have positive rake angle, which results in increased production of tension and accelerated wear, greatly decreasing the tool diameter [18]. Extremely negative angle geometries in micro end mills are favored for ductile machining of brittle materials. A greater angle of the neck and a shorter underneath configuration is needed for better stiffness. Research shows that having a cross-section shape for the leading edge will reduce the tension concentration of the corner edge.

The experimental study, performed and analyzed by Fang et al [19], stated that the efficiency of the chip removal rate is increased by D-type shaped cutting-edge during machining at micro level. Proper research was carried out on various micro tool geometries, and it was found that the configuration of the D-shaped end mill framework for diameters within a range of 0.10 mm gives out the best performance in the manufacturing method at micro level. Continuing to this idea, a variety of round, D-shaped, triangular and square polycrystalline diamond tools at micro level are developed to process the material Bk7 glass with the help of a V-shaped slot block [20]. These results demonstrated that the D-shaped design had the lowest cutting force in both y and x directions, which resulted in better efficiency. There are some phenomena in micro-milling that preclude the effects of traditional milling from being applied directly to it. Unique models to take into account the three basic differences resulting from the dramatic size reduction have to be developed: 1. The microstructure of the work piece material cannot be considered to be homogeneous [45], as the scale of the instrument becomes smaller, the influence becomes more significant. In this job, we consider instruments greater than 0.1 mm, and we have not taken them into account for convenience.

The impact of the cutting-edge radius is not insignificant [46–48]: it affects the chip-forming process. The minimum chip thickness is a function of this parameter and defines the transition between two cutting conditions, where the chips are formed and where the plowing takes place [45,49]. Owing to the high efficiency of the tool [50] and the relative size of the cutting-edge radius, the resulting dynamic effects, i.e. forced vibration and regenerative chatter, vary from traditional milling in terms of stability conditions [49]. Based on the high degree of tool compliance [50], some authors suggest a new analytical model of cutting forces [51] that measures the thickness of the chip according to the real tool trajectory, which, in turn, is obtained by the instantaneous equilibrium between the cutting force and the elastic return force of the device, which is calculated mainly by the rigidity of the tool.

## 3.1.4. Material sorting and microstructures

Polycrystalline diamond and one-crystal diamond. Due to its high hardness and high thermal conductivity, SCD is the perfect tool material for ultra-precision cutting. Polycrystalline diamonds and SCDs can be formed by high temperature and pressure synthesis of compacted synthetic diamante particles. Both show very high thermal conductivity; and due to their extreme strength and the ability for making < 100 nm radii cutting edges, SCD is used for the machining of hard-cut materials requiring mirror quality finishing. However, their low fracture strength, susceptibility to thermal shock, and high cost limit their wider use [11].

Advanced knowledge of the physicochemical properties of the instrument and the work piece material is crucial for the effective production of a key cutting tool. As for precision machining, great understanding of the deformation process and microstructure is required for machining hard materially efficiently. Some of the essential properties that should be under analysis are crystallographic orientations, defects impurities, The border of grains, and density distribution. It is important to combine these material considerations to standardized the tool specification and cutting parameters for key cutting tools and machining parameters.

- Increase in hot hardness.
- superior fracture toughness and resistance to mechanical shock.
- Good resistance to wear.
- Chemical inertness and lack of affinity between the instrument and the work piece.
- Strong resistance to thermal shock.
- Heavy adhesion to the tool substrate for application of the coating.

Currently, no material can accomplish all of these characteristics; thus, the configuration of the material properties and the incorporation of surface modifications/coatings into the cutting tool are necessary. Current tool material for micro-cutting Bissasco et al. [5] studied the effect of various tool styles and diameters on surface roughness, in martensitic stainless-steel micro-milling, with a

hardness of 58 HRC. It is concluded that the geometry of the instrument, affects the collection of process parameters due to the size effect. Aramcharoen et al. [6] studied the impact of size on various machinability parameters in the micro-milling of hardened steel tool H13 (45 HRc) with a micro-milling diameter of 900µm.

The same research group [7] studied the effect of tool coatings on process parameters. They concluded that the TiN layer provides the best results in terms of edge radius wear, surface finish, and burr scale. Klocke et al. [8] analyzed process output in the micromachining of hardened steel X38CrMoV5 with a flat CBN micro mill with a diameter of 500µm. Afazov et al. [9] studied cutting forces in micro-milling of steel AISI H13, hardened between 35 and 60 HRC.

They modeled the cutting forces of FEM and concluded that an increase in material hardness results in higher cutting forces, a rise in heat production, and a decrease in stability limits. Dow et al. [10] used a force model and tool stiffness to increase precision in the milling of S-7 hardened tool steel (55 HRc) with 800µm extra-long ball end mills.

### 3.1.6. Layer or coating on tools

The immense amount of heat and friction forces produced by the interaction of the tool with the work piece will lead to early tool wears and poor machinability, which will eventually lead to inconsistency of the work piece surface. Coatings are a cost-effective solution that requires minimum material volume. Gupta et al [61] studied and tested cutting tools coated with PVD (Titanium nitride(TiN), Aluminum Chromium Nitride (AlCrN), and Titanium aluminum nitride TiAlN) for steel turning (Steel-C45). The data revealed that all three exhibited increased wear efficiency to a notable degree. Austenite and ferrite the balance of these two microstructures, combined with the considerable presence of chromium (usually > 20%), molybdenum, and nitrogen, enhances the properties that are very desirable for a broad range of applications where high corrosion resistance and high mechanical resistance are needed [39]. The machinability of duplex stainless steel 1.4462 (DIN EN 10088-1 [40]) under wet conditions (chlorine-based refrigerant oil + water) was studied using TNMG 160408-coated inserts.

The researchers concluded that refrigerant mineral oils + water had degraded the cutting tool, decreasing its lifetime by 65 percent. It has been checked that by increasing the cutting speed, the life of the tool has also degraded more rapidly, primarily due to higher feed speeds. This research also concluded that CVD (chemical vapor deposition) Ti (C, N)/Al2O3 / TiN is highly recommended for rough machining of duplex stainless steels due to a substantial improvement in the life of cutting speed inserts between 130 and 150 m / min

### 3.1.7. Construction of micro-patterning on tools surface

Developing high-performance micro tools requires significant study into microscopic behavior under complex machining conditions. This endeavor includes significant information on the physiochemical properties as well as the ability to successfully alter the compositional components and to synthesize a particular material and matrix substrate to satisfy the specifications for the machining of resistant materials.

Direct patterning provides a solution of most cost effective and least laborious solution for modification of surface of micro tools. Latest advances as in surface Engineering Cutting Tools It has been shown that these Micro Patterns or surfaces may have an impact on mechanical exercise during the cutting cycle [50].

Various geometrical microstructural pattern methods can be imposed on cutting instrument to improve wear resistance of tool tips. Studies have shown direct effects gain from the use of these novel features; however, their mode of operation is not pleasant. Established and optimum setup will depend heavily on individual tools/work, operations, material pieces ,and cutting conditions.

Liu et al [60] machined a series of cuts on a Al2O3 Ceramics, using a femtosecond laser to engrave microscale texture patterns on a tungsten carbide by rotating work piece. They demonstrated an increased surface strength and greater wear resistance to flank relative to un-textured tungsten insert. This resulted to obtain the configuration of the optimal range of micron spacing parameter for the tool texture for the best performance, Suggested relation between the geometry of the template and the orientation surface of the microstructure of the work piece.

Fang et al [30] reported that they improved the wear resistance of the flank face of PVD-coated micro-textured carbide tools when turning Inconel 718 with jet coolant. The temperature of the tool interface was lowered and the chip development enhanced. Optimized geometry has again been described for optimum performance. In addition, the cooling motion of the fluid flow has been observed, along with the increase in the coefficient of heat transfer due to the textured surface area, Reduction of temperature.

## 3.2. Traditional method uses for fabrication

### 3.2.1. Grinding

Grinding is the prevalent method used to render cutting instruments for traditional macro-machine applications. As grinding is extremely difficult to achieve dimensional precision while doing size reduction as tool itself is extremely small and this cycle applies lot of cutting force. This cannot be measured if we are working with instruments with micrometer level measurements that are deficient in [28] structural rigidity. Besides, when cutting tools are manufactured using the grinding process, [57] a vibration-assisted grinding method can remove the issue of significant production of scrap by breaking of the tool during the process. [29]

The benefits of using ultrasonic vibration-assisted grinding are that it reduces the grinding force on the tool and eventually decreasing the risk of tool breakage during machining of tools. Ultrasonic vibration-assisted grinding has managed to raise the aspect ratio to 50 percentages higher compared to standard grinding tools [57] and at the same time minimize the diameter of [ 57] cutting tools to 10 – 20 percentages. Which will help to reach the precision required. Electro-discharge grinding and electro-discharge grinding (EDG) are the two methods widely used in the manufacture of micro-components for various applications including micro-fluidic systems, etc. [8]. EDG is an important version of EDM, which is actually the hybridization of EDM and mechanical grinding. When this procedure is used without a grinding wheel, the substance is extracted by melting and [ 12] by spraying only.

### 3.2.2. µ-EDM

Aurich et al., Chen et al. and Cheng et al. used precision mechanical grinding wheels and micro-electro discharge machining (µ-EDM) for the manufacture of micro-cutting tools; but it is not simple to obtain accurate and complicated geometries. Aurich et al. manufactured micro-finish and grinding tools with diameters between 10 and 50µm and conducted cutting tests on metal and polymer materials. Their tools had a single edge with controllable rake and helix angles and were well fitted with polymers and some metals.

### 3.2.3 Focused ion beam (FIB)

The FIB can be used directly to produce a flat surface. However, it takes more time and resources after manufacturing. Owing to the porous properties of the deposited framework, it is regularly difficult to accomplish a smooth surface. For these purposes, a simplified and faster preparation approach is required.

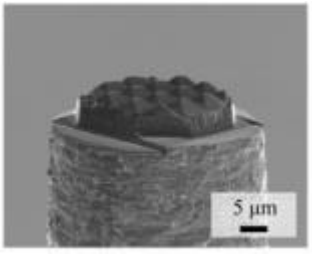



**Fig.4 Multiple lattice edge micro cutting tool fabricated by FIB. Reprinted image. [44]**

FIB typically creates rounded edges on the side of the facets, farthest from the ion source as a taper occurs within the boundary of the given pattern. According to research by Xu et al., [44] FIB milling sequence and instrument location relative to the ion source are key factors in the determination of correct tool-feature geometries, such as cutting edge(s), cutting length(s), rake angle, and clearance angle. In this analysis, the tool rotation was operated by a four-axis Nano stage manipulator (MCS-6C-IDESH, SmarAct GmbH, Germany) which could rotate freely. The tools were mounted vertically or horizontally in the FIB (COBRA FIB, Orsay Physics, France) chamber. Manufacturing methods were identical for single, double, and quadruple cutting-edge machines. Fig 4. Shows a multiple lattice edge micro cutting tool.

FIB milling is typically used by machine tools with dimensions ranging from 15µm to 100µm. Rectangular, triangular, and other dynamic tool structure cutting tools are machined using FIB [55]. The rake and relief angle of the cutting edge was precisely controlled and finished using a directed ion beam. One of the [46] key benefits of FIB sputtering is the observation of the instrument during its manufacturing. The cutting-edge measurements can be reduced to the Nano-metric scale by specifically regulating the ion sputtering.

## 3.3. Tools slash and erosion

Increased cutting power, changes in measurements, and the need to adjust equipment, resulting in a lack of accuracy. Wear permits the closures of straight tools to be squared and blunt their diameter to be less than the nominal figure; end milling tools lose their radius (see Fig. 5).

This influence is very important when hard materials such as tempered steels with more than 50 HRC (molds) are machined. It can be reduced by using successive new equipment and applying the CAM software engineer in numerous periods of unpleasant machining and finishing. In general, efforts are made to execute the whole finishing process using the same method by extracting the smallest possible amount of material. This mistake must not be viewed in isolation: it has numerous consequences that have already been considered, such as improved cutting power, variations in diameter (which can be avoided by introducing a laser tool diameter measurement system), and error in instrument adjustment.

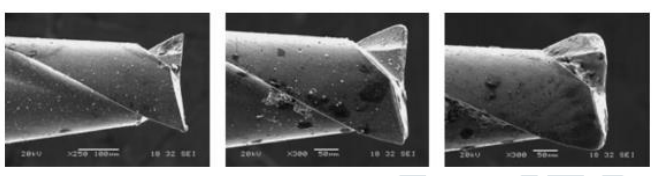


**Fig.5 Show tool tip bluntness after use. End mill losing its radius. Reprinted image [44]**

Since the cutting edge is not completely sharp, the overall uncut chip diameter is always less than the cutting-edge radius, so the real angle of the chip being shaped is very negative. Where the tool edge radius approaches the uncut chip thickness, the plowing takes place instead of the shearing. In addition to that, the differences in the hardness of two neighboring grains make micro-milling more difficult. The limit where the material action starts to vary from traditional cutting has been noted that, where the un-cut chip thickness is close to or less than the tooltip radius, the efficiency of the ball nose end micro-milling is hindered.

## 4. Burr formation and defect

The formation of burrs at the end of the cut is a process similar to the formation of chips. Burrs are unacceptable because they pose a challenge to the handling of machined parts and can conflict with subsequent assembly operations. They must be eliminated in subsequent deburring processes to allow the component to meet the specified tolerances.

Burr forming in micro-milling of stainless steel, brass, aluminum and cast iron [32] [33] [34] has been registered. However, the development of micro burrs in terms of cutting conditions has so far been studied only in aluminum [34]. Five separate burr styles were significant for the study of the effect of the cutting parameters on burr formation: the inlet side burrs on the down-milling side, the top burrs on the up-and down-milling side, the outlet burrs on the bottom of the burr, and finally the outlet side burrs on the up-milling side.

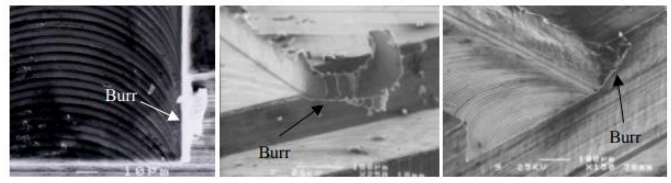



**Fig.6 Burr formation in Aluminum, Stainless steel and copper respectively. Reprinted Image. [35]**

### 4.1.1. Entrance burr

The curl-like entrance side burr was created, Fig.6. For a higher feed rate, the burr size is marginally higher for all products. The improvement in the depth of the cut resulted in a clear increase in the length of the burr for aluminum and copper. The lower strength of copper and aluminum made for better fracking and thus less material was developed for the burr [35].

### 4.1.2. Top burr

In Slot milling operations the top burrs exist in two distinct areas. One kind of top burr is shaped on the up-milling side and the other on the down-milling side of the cut. These burrs are difficult to extract in the micro slot milling process. These burrs cannot be extracted easily by traditional deburring operations. Wavy-type burr is produced in aluminum milling when the tool reaches the top surface of the work piece with a high feed rate. When the tool exits, a broken-type burr result. [35].

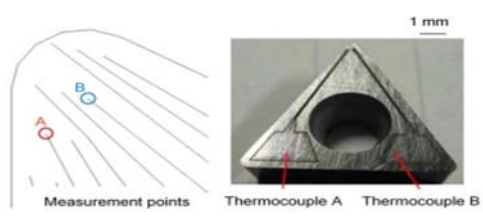
### 4.1.3. Exit burr

Still made in aluminum milling, regardless of the depth of the cut and feed. It is a flag-type burr, as seen in Figure 5. The length of the burr is nearly the same as the width of the slot. This burr is easier to extract than the top burr since it is partially stuck to the work piece. The escape burr at the foot of the aluminum slot can barely be heard. A broad bottom burr was shaped in stainless steel. At a limited depth of cut to 1/16 the bottom burr and the escape side burr are combined [35].

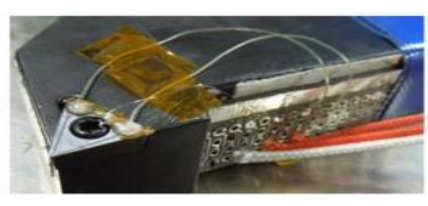
## 5. Experimental setups and evaluations

As taken from the different literature we came across this experiment which nicely shows the parameters and results for the experiment. The tests were carried out at the Nano milling center AZ150 and in machining conditions with feed rate=0.2µm / tooth, Axial depth of cut (Ad) = 1µm, and spindle speed (Rotational frequency of spindle) =120,000 rpm; flood fluid flow and micro tools were fully engaged during machining. If the depth of cut is greater than 40µm, the reverberation can be heard and the spindle ceases due to friction forces. [13]

It's 16. Cui et al [28] carried out theoretical and experimental experiments on the temperature of the instrument in the final milling process, taking into account the mechanism of flank wear. Using a Ti6Al4V work piece and an 8µm TiN-coated carbide end mill, a modified thermal imaging system was used to measure the heat generated in the tool. These results have shown that the dependency of the tool temperature and the cutting force on the feed per tooth and the cutting speed lead to the wear of the flank. They reported that when flank wear started, the temperature increased and reached its peak temperature at the start of wear, and then reaches a steady state as the tool material was rounded.




(a)



(b)

**Fig.7 (a) two sensors pointing at rake face, (b) sensor setup. Reprinted image.**

[29]

Sugita et al [29] have built an incorporated thermocouple microarray on the rake face of the cutting instrument. Two sensor points implanted in the instrument showed accurate simultaneous thermal measurements. (Fig.7), which is promising to be applied in the architecture of the thermal sensor tool. Accurate and reproducible tool monitoring systems be incorporated into the machining stage to allow the advancement of the ideal quality product.

Experimental testing is carried out on cold work tool steel AISI D2, hardened to 62 HRC, with a tensile strength of 1100 MPa. The high-speed milling center Sodick MC430L (Fig. 2) is used for testing. System properties are tree axis power, hybrid high-speed spindle bearing with a potential spindle rotation of 40,000 min-1, linear magnetic feed motion motor with a resolution of 0.1µm, probable acceleration up to 1 G, contact probe work piece set-up, BLUM Micro automatic tool set-up and HSK-25 tool holder.

The cutting tool consisted of two flute flat end mills, coated with a TiAlN coating, made by SECO. The end mill diameter was 600µm and the corner radius was 0.05 mm. This end mill has an extra-long neck of 5 mm so that the aspect ratio is greater than 8. The revolution angle is 7.25 °, with a helix of up to 0.9mm. The diameter of the mounting instrument is 3 mm. The method parameter combined in the experiment: cutting depth (ap) with values 5 and 10µm; cutting speed (VC) with values: 30, 40, and 50 m / min; feed per tooth (fz) with values: 4, 8, and 12µm. The procedure was carried out in dry conditions and used the MQL lubrication technique. There were 36 variations, with a minimum of 2 repetitions per variation. Surface consistency was measured by using Mitutoyo microscope tool manufacturer TM-505 (75x zoom), surface roughness was measured with the help of Mitutoyo Surftest SJ-301 device. Channels were scanned and burrs on the edge were analyzed with Keyence laser scanner LJ-G015 fitted with a specific moving table [31].

## 6. Conclusion and outcomes

Additional considerations to be kept in mind include:
Optimizing the template by preparing the edge of the instrument to increase stability and wear resistance. Key reinforcement of the tool structure and the localized cutting edge.

1. Selection and modification of tool substrate elements, based on relevant application and manufacturing methods.
2. Tool surface interface properties compared to structural properties and microstructure.
3. Integrating an appropriate minimum quantity of lubricant into the structure of the instrument.
4. Consideration of internal coolants within the framework of the instrument.
5. This has the ability to dramatically increase tool life in tandem with machine parameters optimization and machining techniques to reduce excess wear conditions.
6. The effect of burr forming can be reduced by using a new tool and making a final cut without any load.

The study showed micro tooling and macro tooling do not follow the same set of geometrical configuration and tool specification, it tells that the cutting ratio decreased with an increase in the ratio of the tool edge radius to the cutting depth. The temperature gap in the work piece was also found to increase in front of the cutting edge due to the material flow relative to the cutting tool. As far as tool content is concerned (Fig. 6), single-crystal diamonds are suggested for non-ferrous alloys, whereas fine-grained tungsten carbide is preferred for steels. TiAlN is the primary coating agent used in tungsten carbide cutters. Although the use of high-speed steel as a tool material is expected to decline, the market shares of micro-cutting single crystal diamond tools are expected to rise over the next few years. Byrne et al. [2] argued that surface roughness values of approximately 5 nm can be obtained by micromachining components with dimensions of 1µm.
Besides, it is recognized that one significant feature related to miniaturized parts is the rise in the ratio of surface area to weight. E.g., the above-mentioned authors report that the weight of the automobile anti-lock braking system has been reduced to 29 percent (from 6.2 to 1.8 kg) [65].
Micro milling forces are low due to the limited shear area, but the real cutting force increases significantly as the uncut chip thickness is reduced due to the plowing effect. The use of laser or vibration helped by micro-milling to minimize the shear strength of the work material encourages, on the one hand, more stable tool life behavior. On the other side, though, laser-assisted micro-milling can affect the efficiency of the machined surface.

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