**A Review Study on Miniaturization- A Boon or Curse**

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**Abstract**

This paper is focused on the main parameters, physics and applications behind the manufacturing of micro components. Here, the future potential and demand in the field of micromachining from the perspective of the recent research has been reported. The review includes topics of process physics, specific cutting energy, ductile mode machining, edges chipping, cutting fluid and surface finishing of the micro components. The brief description about the tools and systems for micromachining are also mentioned. Some of the machining techniques for instance ultrasonic machining, water jet machining and vibration based machining are discussed which is used to machine generally all ceramic glass materials. The benefits, limitation and application of these machining techniques are also elaborated. Problems occur during micro machining such as chipping, cracks and surface roughness during machining or fabrication has also reported. It is revealed that proper selection of parametric combination and tool size and shape would lead to reduction in chipping formation. Other issues such as metrology in micromachining, viewpoint for forthcoming opportunities and challenges in miniaturization of components are also discussed. Subsequently, it is reported that the necessity of micromachining metrology instruments, to measure the various shape and sizes of micro parts is a key future aspect needed to be carried out. Coordinate measuring machine (CMM) is revealed as a significant technique to quantify defects occur during machining as well as compute the size and shapes of the micro components.

***Keywords:*** Micromachining; Ductile mode of machining; Miniaturization; Minimum Quality Lubricant (MQL)

1. **INTRODUCTION**

As time passes the manufacturing of smaller or micro components/parts has become the main center of attraction for the researchers and engineers. According to Dornfeld [1], in the early century, the micro products have demand in the field of art and followed with science and engineering because of its new applications, least in cost range, high-quality product and better performance. Conventional, as well as non conventional machining processes have always played a vital role to convert raw material into the finish product. Similarly, the ability of machining at the micro level is continuously improved day by day. In the research work of Taniguchi [2], the micromachining and their related parameters were studied for the past 60 years. In Fig 1, micromachining accuracy range with respect to 1940s to 2000s year was analyzed Taniguchi [2]. Fig 1 represents the material machining accuracy during one cycle of the manufacturing process. According to Ghosh et al. [3], as the technology is improved, scientists and researchers are facing a huge number of troubles in the field of fabrication. The brainstorming points for the research developers are low machinability with new materials, precise and dimensional accuracy, less production along with high productivity.



**Fig 1.** Micromachining capability versus time [2]

According to Rajput [4], micromachining is a concern with miniaturization of shape and size of the product by conventional as well as non-conventional machining techniques. In that case, metal removal rate is in micro dimensional level. Major applications of micromachining are such as integrated circuits, small surgical tools, fuel injection nozzles, micro-effectors to handle biological cells and compact electrical circuits. Vibration is applied to the cutting tools to perform machining without any external force in conventional machining. For abrasive machining, diamond and hard ceramics material tools are generally used. In optical and electronics sectors, micro diamond tool is used with an accuracy of 0.01 micron along with high surface finishing. During ductile mode of machining, diamond fabricates super finish surface on hard as well as brittle materials. For electronic and magnetic-based material like silicon, ceramics, quartz wafers etc. are fabricated by abrasive micro lapping. On the other hand, micromachining is also done in large number by non-conventional machining such as micro EDM, micro laser machining, chemical machining and thermal erosion.

According to Kalpakjian et al. [5], in the electronics field, materials like semiconductors were invented in the 1940s. The invention of the transistor set, cellular telephones and automotive control devices becomes one of the greatest developments in the history of technology. The transistor was the motivated source of development for the complex integrated circuits. Nowadays ICs have merits like a high degree of complexity, reduced size and less cost factor. As the modern production technology came into the picture, the size of the components diminished. Fabrication of a tiny range of microelectronics products takes place in a dust proof environment. Dirt free laboratories are broadly used for micro fabrication generally for the maximum of 0.5 µm particles per cubic foot. To develop the micro parts, MEMS (microelectromechanical systems) devices is used. MEMS are consisting of electrical as well as mechanical systems by means of characteristics size i.e. 1 mm. For the fabrication of electronics components, the batch process technologies are applied even though the alternative process also considered. Some of the extended applications of MEMS devices are precise rapid sensors, artificial organs, ink jet printers and accelerometers. Alting et al. [6] studied about the micro-engineering field of micro size products design parameters as well as the various fabrication methods for manufacturing small-scale components.

**2. RECENT STUDIES**

Some of the studies have been done to observe the different factors and parameters of the micromachining techniques. After the Second World War, a new evolution came and that was the industrialization. As time moves on, the development in the field of manufacturing inclined drastically. The conventional machining and non-conventional machining processes were generally applied for fabrication. The demand of the market was focused on the machining and manufacturing of hard as well as brittle materials. On the other hand, the demand of the precise, high surface finished and micro dimension products were also increased, especially in the industries like electronics, biomedical, aircraft, defense and automobile. Definitely, the miniaturization of the products leads to a large extent of applications. In spite of this, miniaturization is also creating some negative effects on the cost of manufacturing, metrological instrumentation, working stability etc. Here the study elaborates that the miniaturization is a boon or curse.

**2.1 Process Physics**

In the research work of Hackert et al. [7], Jet electrochemical machining process play a vital role to generate complex as well as critical shape components by control over the movement of the nozzle and electric current rate. In this machining process, direct current was supplied by an electrolyte jet between the workpiece as an anode and the tool as a cathode. The electrolytic liquid jet was driven at an average velocity of 20 m per sec through a small size nozzle. This process has an ambient air medium. The pulses free pump provides the constant and stable pressure supply of steady flow electrolyte and it was fascinated the well-defined geometrical shape jet. The jet perpendicularly strikes over the workpiece surface. Here, as the current rate increases to some extent, it leads to incline the surface finishing micro range i.e. 1000 Amp per cm2. On the other side, geometry and design consideration of the nozzle also helps to get precise machining. As the diameter size of the nozzle reduced up to 50 m, it leads to a decrease in the material removal rate. By providing flat electrolyte jet, it gives the application like grooves and slots while without any nozzle movement [8]. The extended jet shape fascinated the high metal removal rate as compared to the cylindrical shape jet. Multiple electrolyte nozzles provide further improvement in the machining process and also help in increasing its applications.

Jian et al. [9] studied the development related to the ceramic reinforcement matrix material under micromachining. Many of the sectors such as defense, energy resources, medical, automobile, aeronautical, biotechnology used the material like Metal matrix composite materials (MMC). The eye-catching properties of Metal matrix composite materials are mechanical properties included light in weight, creep resistance property, low thermal expansion rate, high strength, less fatigue failure, anti-corrosion and anti-oxidation, and good wear resistance. Some of the specific applications of MMC materials while considering its major properties are microsensors; micro holes in optical, microfluidic channels for fuel cells, a micro-nozzle array for multiplexed electrospray systems and actuators. The MMC materials like aluminum-based MMCs (Al-MMCs) or magnesium-based MMCs (Mg-MMCs) possess light weight and high toughness property and that gave the good option to manufacture the parts for such applications [10–12]. Under suitable conditions, miniature parts may lead to positive effects on energy efficiency. According to researcher while working on the micromachining process, the small size workpiece can be manufactured more efficiently included as less economy with high quality. On the other hand, macro-scale level manufacturing required to concentrate on the modeling the process states, parameters related to cutting forces and tool vibration, also the workpiece dimensional accuracy and surface reliability.

Micromachining techniques have sustained many characteristics related to the conventional machining. [1] As the size of the material going toward miniaturization the characteristic of the material remains same up to some extent. Once the ratio between the workpiece size to the tool dimension (width or length) became diminish. The miniaturization of the size may lead to affect the all the parameters which were related during micromachining. Parameters like the depth of cut with respect to the tool edge radius. It was also got that the microstructures of workpiece material were affected by the cutting mechanism. The core difference between the micromachining and micromachining existed in the cutting mechanism. In micromachining, the cutting mechanism was explained as the material shearing with respect to the tooltip and it leads to chip formation. On the other hand, Micromachining depends on more complex mechanisms which are relevant with the workpiece size effect. According to this study, the size effect meant as the influence due to the small ratio of the cutting depth to the tool edge radius than the material acts as homogeneous and isotropic in nature. Von Turkovich and Black [13] accompanied research related to orthogonal micromachining. It was observed that the formation of chips for aluminum and copper crystals with respect to the depths of the cut had range starts from 1 μm to 100 μm, specifically at low cutting speed.

In another work, Nouraei et al. [14] worked on the models related to abrasive slurry jet micromachining. In abrasive slurry jet micromachining (ASJM), high-pressure water was accelerated by the pump to flush out the suspended abrasive particles like garnet or aluminum oxide (Al2O3). By mechanical erosion, the removal of the material takes place while in the presence of a small quantity of heat. In abrasive slurry jet micromachining, high-velocity slurry jet has high machining ability that leads as a fabrication of small sizes of holes and slots [15]. Moreover, the operating parameters for the abrasive jet machining like flow rate or pressure of slurry jet flow rate, concentration level, impact angle and traverse speeds provided control over the erosion rate for machining various depth or width components. The plunger type water pump is used in the process. In this system, a jet of the abrasive mixture was mixed with the high-pressure water by plunger water pump before going into exit orifice.

**2.2 Minimum chip thickness and specific cutting energy**

In the micromachining process, both isotropic and anisotropic cutting operations were extensively inspired by the ratio between the depth of cut to the effective tool cutting edge radius. The magnitude of the chip thickness was in the same direction of the edge radius of the cutting tool. Hence, a slight variation in the depth of cut considerably affects the cutting process. The depth of cut to the effective tool cutting edge radius ratio explained as the active material removal mechanism like cutting, slipping or plowing and also this ratio represented as the quality machining and surface roughness. Fig.2 represents the chip formation, sliding and plowing in orthogonal metal cutting. Fig 3 illustrates the SEM photographs of typical chips formed by orthogonal flying cutting at a cutting speed of 754 m /min.

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| **Fig.2.** Chip formation, Sliding and plowing in orthogonal metal cutting [18] | **Fig 3.** SEM Photographs of typical chips formed by orthogonal flying cutting (cutting speed 754 m /min) [1] |

It was found that in case of minimum chip thickness, no chip will form below this minimum limit, similarly below the minimum depth of cut no material removal will occur. It was concluded that the identification of the required minimum chip thickness was required to make sure the accurate and precise cutting and simultaneously avoid sliding and plowing of the cutting tools [1, 16]. In this work, Lucca and Seo [17] found the different effects of the geometry of single crystal diamond tool edge on the specific energy while using workpiece of Te-Cu material in the ultra-precision orthogonal fly cutting operation. Experimentation based results and effects were investigated. The nominal rake angle had an excessive impact on the specific energy while the depth of cut was lesser than the profile of tool edge, similarly the effective rake angle when the depth of cut approaches the size of edge contour. It was examined that the total specific energy was significantly increased at small depths of cut in micromachining of copper. Hence, the specific energy was closely related to the minimum chip thickness and would be another indicator for cutting mechanism changes and process control [18].

**2.3 Ductile mode machining**

In the research of Zhong et al. [19], the ductile or partial ductile modes of machining for brittle materials were considered. For fabricating the ultra-precise mirrors and an optical lens, the single point diamond tool was used during turning operation. Although a diamond tool has not able to create the non-symmetry shape and size for the brittle components. Nowadays, lenses and mirrors-based industries performed different shaping operation such as grinding, polishing and lapping [20, 21]. Because of the high hardness property of the ceramics material like silicon carbide, aluminum oxide, and zirconium oxide, to get the dimensional accuracy the diamond grinding wheel was to get precise finishing workpiece. Metallurgical and manufacturing experts put the focus on to machine brittle materials with a lesser surface roughness or surface damage. In traditional grinding, the fractured surfaces of the workpiece required lapping and polishing operation usually for brittle materials. Though, the idea of the ductile or partial ductile mode of machining for brittle materials, resultant as a large range of applications on materials like glass, silicon, germanium and silicon carbide [22].

According to Bifano et. al [23], manufacturing of brittle material in form of micro dimensions was a brainstorming task. The fabrication of brittle material such as ceramics, optical glasses, refractory material etc. was not precise and economical machining by conventional machining processes because of continuous variation in the brittle material geometry as well as with higher material removal rate. It was found that a large amount of surface roughness, as well as subsurface cracking, would generate while machining of brittle material under traditional machining processes at a high rate of depths of cut. To get rid of that problem, machining in a ductile mode under a low depth of cuts had been proposed by many researchers. When machining occurs under a critical depth of cut to fabricate brittle materials in form of ductile mode, it induced least surface crack with high surface finish components [1].

According to Ueda et al. [24], several ceramic materials such as ZrO2, WC-Co, Al2O3 and SiC behave as a ductile material when fabrication of ceramics materials would under the ductile mode of machining while declined in the depth of cut. On the other hand, if cutting speed would increase material like Si3N4 would also behave as ductile material. It was because of high fracture toughness property of the material. Another researcher found that any brittle or hard material would be machined as a ductile fashion while modifying the depth of cut to a suitably small range [25].

**2.4 Edges and Surface finish**

In conventional machining, limitations like poor edge and surface finishing, surface defects and burrs would be the brainstorming issues. Although various process optimization and post processes were implemented to reduce its effects. In an article, researcher had worked in the reduction of micro-level chipping as well as cracking at the hole exit of drilling ceramic workpiece by rotary ultrasonic machining (RUM). Here, scanning electron microscope and optical microscope was employed to evaluate the exit [26]. The machining parameters were spindle speed of 1000 rpm, the feed rate of 7 μm/s and ultrasonic power 25 %, respectively. Fig. 4 shows the microscopic view of hole exit to visualize the chipping. Fig. 5 describes the sectioned hole at constant drilling parameters (a) Ultrasonic machining (USM), (b) Rotary ultrasonic machining (RUM).



**Fig. 4.**Microscopic view of hole exit to visualize the chipping [26]



**Fig. 5.**Description of the sectioned hole at constant drilling parameters (a) Ultrasonic machining (USM), (b) Rotary ultrasonic machining (RUM) [26]

It was notified that the exit chipping was apparently reduced while deploying RUM. It was concluded that the estimated response of exit crack was 24.558 µm and the experimental results were calculated as 25.378 µm [26].

Owing to ultrasonic vibration of the tool, the trajectory motion of the diamond abrasive is sinusoidal which leads to enhancement of hole quality [27]. During the RUM process, the brittle material was persisting tensile and shear stresses which were created by normal force [28]. In a study of rotary ultrasonic machining (RUM), the grinding process is carried out on optical BK7 and K9 glass samples. Effect of ultrasonic power on cutting forces, edge chipping and torque were considered. It was found that at higher ultrasonic power rate, the cutting force, as well as torque, is reduced. A similar effect is also noticed in case of edge chipping. Least size of edge chipping is noticed between 40 to 80 % of ultrasonic power [29]. A past researcher worked on the edge chipping reduction by making a hole on quartz glass by rotary ultrasonic drilling (RUD) process. It was stated that the reduction in cutting force leads to the crack size reduction. It was also mentioned that the cracks induced by rotary ultrasonic drilling are smaller in size than induced by conventional drilling [30]. Lv et al. demonstrated a high-frequency vibration-based mechanism on hole entrance chipping in RUD process of BK7 glass. It was mentioned that during the rotary ultrasonic drilling process, scale-like cracking appeared nearby hole which is lesser in amount than the defect occurred during conventional drilling [31]. Babbar et al. worked on milling of C/SiC composites that was fabricated by needling technique & chemical vapor infiltration to get good quality surface [32]. The surface quality concern has also play important role for neurosurgical bone grinding [33-34]. Another work concentrated on the biocompatible PLA scaffold specimen for bioactivity investigation has been taken place [35]. Another technique i.e. magnetic abrasive finishing has been used for surface finishing on flat brass workpiece [36-37]. Some other work has shown influence of metallurgical & mechanical properties i.e. micro-hardness and corrosion behavior on AISI 304 SS Welds to achieve best quality surface [38-39]. Hybrid activated flux has been used with tungsten inert gas welding process to refine the workpiece quality [40].

In the case of micromachining, researchers required to do more work in this research area because of the geometrical structure limitations or characteristics have more critical which could not be sought out by micromachining. In medical applications, different working materials such as NiTi, surgical implants-based materials have been manufactured by micro-milling technique. These materials have properties like ductility and work hardening while fabrication. It leads to high burr formation and adhesion. While due to ductility nature of the material, it forms adverse chip formation, long size and continuously twisted chips. As far as the micro range, the chips interference between the chip formation and the tool tip generated poor surface finish surface with burrs for final workpiece [41]. In another research, an experimental work performed on the micro-slot milling especially on copper and aluminum, which got several standard burr types depending on location and work geometry. These burrs were similar as produced in micromachining under different cutting parameters and mechanism [42]. Sharma et al. [43] has tried to eliminate the chipping using multi-shaped abrasive tools while creating blind holes on float glass specimen. The list of tools which were used are pin pointed abrasive tool, hollow abrasive coated tool, flat cylindrical tools and concave tool. Whole experiments work has been carried out by conventional drilling (CD) and rotary ultrasonic drilling (RUD) processes. The chipping mechanism for each multi-shaped abrasive tools have been reported. The final results revealed that RUD process has possessed smallest size of chipping as compared to CD. The concave circular tool was recommended as the best tool to get least chipping distance i.e. 0.1145 mm. In another multi-shaped tool study, it was investigated that concave circular tool has generating least amount of tool wear. The minimum weight loss is 4.92% after CD and 1.96 % after RUD using concave circular tool [44]. Sharma et al. [45] investigated the surface roughness of the float glass after rotary ultrasonic drilling. The parametric optimization technique was used to achieve the least surface roughness value i.e. 1.09 μm. The best parametric combination was noticed as feed rate (6 mm/min), spindle rotation speed (5000 rpm) and amplitude (20 μm).

**2.5 Workpiece and Design issues**

In this research study [46], the mass production of the microcomponents is not suitable because of less rate of productivity. Although, micro drilling, micro milling and micro turning operation could able to fabricate 3 D concave and convex shape microcomponents, particularly by single point diamond tool. Though to manufacture the high quality and reliable products, the micromachining techniques would fascinate the proper tooling for the micro mass production techniques like micro die casting, micro-molding, and micro-farming. It was found that the diamond tool could be the best tool to fabricate the precise as well as mold lifespan under micromolding process. But diamond would not find suitable for hard ferrous material and tool steels because of its chemical instability while coming in contact with ferrous material.

In another research, Schaller et al. [47, 48] presented that tungsten carbide-based tool would manufacture the martensitic steel with a width of 220 μm to 420 μm and depth of 200 μm to 330 μm. Also, these molds would fabricate metal along with plastic and ceramic.

**2.6 Machines, tools, and systems for micromachining**

The development happened in previous two eras lead to an enhancement in capabilities, accuracy nd stiffness for micromachining processes over conventional machining processes. These micro processes were widely used in the manufacturing of optical lenses as well as for surgical instruments. Some other benefits of ultra-precision machining over conventional processes would be such as compact space, energy, resources, reconfiguration easiness and effortless [1]. Single crystal diamond material has wear resistance, ease of operation and hardness property that’s why it was recommended for micro cutting and micro grinding. The diamond tool was especially befitted to non-ferrous materials. Since the diamond was highly affinity to iron, such as brass, aluminum, copper, and nickel [49, 50]. In another process, the focused ion beam technique has also considered manufacturing micro tools. Various micro-grooving i.e. 13 μm diameter and micro-threading cutting tools of high-speed steel and tungsten carbide are fabricated while using focused ion beam technique. With dimensional accuracy, there are also some vibration related problems in the micro tools while rotating at high speed. In the research work, Huang et al. [51] analysis the dynamic faces of the micro-drilling process. It was investigated that the natural frequency of a micro drill declined as the thrust force rises. Stiffness property also plays a vital role during manufacturing micro dimensional parts. In another study, pyramidal micro tools were fabricated with tip size of 2 μm to get fine surface quality and machining accuracy during micro machining of metal sheet. Also, the Mechanical Strength of micro tools was improved. The final outcome shows that the high quality holes has been achieved [52]. Fig. 6 shows the 5 Axis control Ultra-Precision machining center. Fig 7 (a) and (b) represents the images of ultra precise micro tools and large aspect ratio micro tools under optimum machining conditions.

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| **Fig 6**. Commercial 5 Axis control Ultra-Precision machining center [1] | **Fig 7.**Overview of produced micro tools under optimum machining conditions (a) Ultra-precise tool (b) Extremely large aspect ratio micro tools [52] |

**2.7 Cutting fluid**

The fundamentals of lubrication and cutting fluid used were discussed during micromachining [41]. It was found that proper quantified supply of lubrication is essential factor in micromachining. Two important factors of lubricants are: Primarily, the flow pressure rate of lubricants during machining in which could affect the behavior of the cutting tool. Secondary, after considering the diminished rate of flow or appropriate flow rate, exclusion of left over cutting fluid would be a brainstorming issue during micromachining. Therefore, every machinist or engineer should exceptionally take care of courses such as cooling, transporting chips, optimum lubrication, and debris through micromachining. There were two dissimilar conditions for lubrication related to edges and surface quality was discussed. These were: MQL (Minimum quantity lubrication) and Dry lubrication. It was found that lubrication under dry condition contain burrs form at entire trench measurement and under minimum quantity lubrication condition, burrs form simply at the end of the trench. Furthermore, during minimum quantity lubrication conditions, the surface side walls quality was far superior and chip adhesion on the surface of the tool surface was far inferior. Some investigations were also carried out on the appropriate combination of nozzle distance, types of supply method for example continuous and intermittent type to get the best micromachining effects. Observably, MQL performs much better in micro milling processes. Various unconventional fluids such as dry ice (CO2) were widely used in micromachining, especially for machining Nickel Titanium (NiTi) material. Fig. 8 illustrates the micro end milling experiments under the minimum quality lubricant and dry conditions, where NiTi shape memory alloy was used as work piece material.



**Fig. 8.** Micro end milling experiments under MQL and Dry (Work material: NiTi shape memory alloy) [41]

In a study, distill water was used as a coolant while making blind holes in float glass with five different shapes of tool. It was mentioned that apart from coolant type, shape of the tool also play a crucial role of making fine hole quality [53]. For difficult-to-machine materials, dry machining and coolant machining could affect the generation of stresses during drilling operation The stress generation could further effects the defects such as chipping and surface roughness. In a study, drilling of float glass by rotary ultrasonic drilling process has been carried out with and without coolant. During drilling operation, the maximum cutting temperature occurred with coolant (water) was 50.56 oc and 62.11oc was noticed without coolant. Accordingly, it was reported that drilling with coolant created an improved hole quality. As, the stress formation has been decreased which was occurred because of rise in cutting temperature [54]. In another work, Bissacco et al. [55] explored the accuracy rate during micromachining under the effect of working fluid. In the case of ultra-precision machine tools, these tools have a position resolution equal to 1 nm with spindles up to the high speed of 100,000 rpm. It was found that on the other hand, if the spindle speed was high then the thermal distortion could cause inaccuracy. The cutting fluid and the spindle temperature were also varied a lot and it would lead to an error. At these stages, if there was a minor offset during machining produced by thermal distortion may lead to substantial errors. In a work of rotary ultrasonic milling, C/SiC composite has been fabricated by varying material density using chemical vapor infiltration and needling method. It was noticed that as the material density is increased, the average surface roughness value reached to 0.84 µm. Moreover, it was also mentioned that the tool wear has also affects the material density [56]. In some studies, biocompatible material (PLA scaffold) and neurosurgical bone related work has been reported [57-58].

**2.8 Machine components and controls**

During micromachining, advancement of machine tool components simultaneously study of process physics and its control units were desirable to acquire the best quality and high accuracy [59]. Study related to high-speed spindle, accurate positioning systems, jigs, and fixture devices were most essential for the optimum micromachining. Development related to ultra-precision positioning system was carried out while using a stepper motor and ball screw with 1 nm positional resolution with piezoelectric actuators.

Mizumoto et al. [60] established a mechanism based upon the tri-mode ultra-precision positioning along with twisting roller drive also the aerostatic guideway with an active integral restrictor. The position based resolution range of this instrument is 25 pm. Holmes et al. [61] developed a magnetic-bearing motion control stage with a positional resolution accuracy of 0.1 nm.

**2.9 Metrology in Micromachining**

Nowadays, it is understood that the micromachining techniques have the capacity to manufacture micro-size components of very precise dimension stability. To improve the manufacturing and control of the smaller feature components are required to get the precise quality. Monitoring by sensors provides treasured information about the micromachining practice that helps the double purpose of the monitor of quality and process control as well as sensors delivers the fully-automated manufacturing environment [62]. In this research work, various micromachining related measurement methods were considered. These methods were facilitated to measure the dynamics of displacement as well as force, properties of material and shape and size during machining at the micro level. As the dimensional ranges of the parts get diminished, the resolution techniques play a vital role to measure and compute it. Alongside, market demand rises to get an accurate, precise and efficient measurement of different applications stretching from simple geometry components to complex geometry objects such as micro holes or microspheres. Commonly, micromachining quantified instruments or devices can be classified into two separated groups. In the first group, a grouping of measurement instruments measured either height or changes in height. In this group, optical profile followers, atomic force microscopes, mechanical stylus instruments, and interference measurement devices such as laser interferometer devices could be included. In group two, measurement of the distance between edges of an article, electron microscopes and optical profilometer, it included such as mechanical, magnetic, optical and capacitive sensor along with workpiece holding table and a transducer to relocate the workpiece [63-64]. After investigated such devices still there are some cases such as micro parts include inside features such as holes, channels, and pockets. Here, Fig 7 showed the level of precision and control parameters varied with respect to sensor application.



**Fig. 9.** Sensor application vs level of precision and control parameters [62]

These are those micro parts or components where still there is no technology exist to measure such structures. In this study, Masuzawa et al. [65] established a vibro-scanning technique to quantify the inside dimensions of micro-holes. But this method has some constraints like it is restricted to only conductive materials. The cause of this restriction is that it practices a sensitive electrical switch by contacting a vibrating micro-probe onto the workpiece. There is an additional probe is used which utilized contact by bending of the probe [66]. Miyoshi et al. [67] established a profile measurement technique. It included the inverse scattering phase retrieval method. This test could measure surface profile with submicron accuracy along with symmetric and non-symmetric fine triangular grooves. In a work of Sharma et al. [68], coordinate measuring machine has been use to quantify the chipping measurements in horizontal and vertical direction at drilled hole exit corner of float glass. Finally, the volume of chipping is quantified accordingly.

Although to get more accuracy and precise measurements of the micro-parts, the cordimate measuring machine is a vital tool. Still, there are necessities of micromachining metrology instruments or devices, to measure the various shape and sizes of micro parts which is needed to be carried out in future.

1. **CONCLUSION AND BRIEF DISCUSSION**

Some of the decisive conclusions are summarized as below:

* Some of the major applications of micromachining are such as integrated circuits, small surgical tools and fuel injection nozzles. That makes the micromachining based study as a trending area of research.
* The diamond tool was especially befitted to non-ferrous materials. Since the diamond was highly affinity to iron, such as brass, aluminum, copper, and nickel. Many researchers are currently focused on such diamond coated abrasive tools for machining purposes.
* Multi-shaped abrasive tools were used while creating blind holes on float glass specimen to reduce the chipping at hole entrance. Pin pointed abrasive tool, hollow abrasive coated tool, flat cylindrical tools and concave tool were used during experimentation. The concave circular tool was recommended as the best tool to get least chipping distance i.e. 0.1145 mm.
* Several ceramic materials such as zirconium dioxide, tungsten carbide, aluminum oxide and silicon carbide (SiC) behave as a ductile material when machining occur under ductile mode of machining as declined in the depth of cut.
* As compare to conventional drilling process, rotary ultrasonic machining technique is recommended to achieve chippiong free machining with least tool wear.
* MQL performs much better in micro milling processes. Various unconventional fluids such as Dry ice (CO2) are widely used in micromachining, especially for machining Nickel Titanium based (NiTi) materials.
* To get more accuracy and precise measurements of the micro-parts, the cordimate measuring machine is a vital tool.
1. **FUTURE SCOPE**

Several key points of this research study, which encouraged further future investigation and research in the area of micromachining. These are:

* It was found that the diamond tool could be the best tool to fabricate the precise as well as mold lifespan under micromolding process. But diamond would not found suitable for hard ferrous material and tool steels because of its chemical instability while coming in contact with ferrous material.
* To get optimized dimensional accuracy, there are also some vibration related problems in the micro tools while rotating at high speed.
* The diminished rate of flow or appropriate flow rate, exclusion of leftover cutting fluid is a brainstorming issue during micromachining. Therefore, every machinist or engineer should exceptionally take care of courses such as cooling, transporting chips, optimum lubrication, and debris through micromachining.
* Still, there are necessities of micromachining metrology instruments or devices, to measure the various shape and sizes of micro parts include inside features such as holes, channels, and pockets.
* It was discussed that the more research work is still required in the area of electrochemical micromachining to do a deep study of its parametric optimization, local material removal rate, process mechanism and current density etc.
* Furthermore, there would be a plethora of research and advancement in the field of EMM would require in the various electronics and precision industry, exemplify as ultra-precision microfabrication, surface finishing of print bands, deburring and 3 D micromachining.
* Area related to the metrology of the micro parts is a brain storming research area which is needed to be carried out in future.

**References**

1. Dornfeld D, Min S, Takeuchi Y (2006) Recent Advances in Mechanical Micromachining. Annals of CIRP 55 (2): 745–768.
2. Taniguchi N (1983) Current status in and Future Trends of Ultra-precision Machining and Ultrafine Materials Processing. CIRP Annals 32 (2): 573–582.
3. Ghosh A, Mallik A.K (1986) Manufacturing Science (Book). Ellis Horwood ltd. 1st Edition: 1–707.
4. Rajput R.K (2007) A Textbook of Manufacturing Technology: Manufacturing Processes. Firewell Media: 1–899.
5. Kalpakjain S, Schmid S (2010) Manufacturing Engineering and Technology, Prentice Hall, Pearson; 7th Edition: 1–1216.
6. Alting L, Kimura F, Hansen H.N, Bissacco G (2003) Micro Engineering. CIRP Annals 52 (2): 635–657.
7. Matthias H. O, Gunnar M., Zinecker M, Andre M, Andreas S (2012) Micro machining with continuouselectrolytic free jet. Precision engineering 36 (4): 612–619.
8. Kunieda M, Mizugai K, Watanabe S, Shibuya N, Iwamoto N (2011) Electrochemical micromachining using flat electrolyte jet. CIRP Annals-Manufacturing Technology 60(1): 251–254.
9. Jian L, Juan L, Chengying X (2014) Interaction of the cutting tools and the ceramic reinforced metal matrix composites during micro-machining: A review. CIRP Annals 7(.2): 55–70.
10. Goh C. S (2007) Characterization of high performance Mg/MgO Nano composites. Journal of Composite Materials 41(19): 2325–2335.
11. Yan H, Wan J, Nie Q (2013) Wear behavior of SiCp-reinforced magnesium matrix composites. Wear 255 (1–6): 629–637.
12. Aust E, Elsaesser M, Hort N, Limberg W (2006) Machining of hybrid reinforced Mg-MMCs using abrasive water jetting. 7th Magnesium Technology Symposium. 7 (2): 345–348.
13. Von Turkovich B.F, Black J.T (1970) Micro-Machining of Copper and Aluminum Crystals. Transactions of the ASME 92 (1): 130–134.
14. Nouraei H, Kowsari K, Spelt J.K, Papini M (2014) Surface evolution models for abrasive slurry jet micro-machining of channels and holes in glass. Wear 309 (1-2): 65–73.
15. Nouraei H, Wodoslawsky A, Spelt J. K, Papini M (2011) Micro-machining using an Abrasive Slurry Jet. Wear of Materials, International Conference, USA.
16. Ikawa N, Shimada S, Tanaka H (1992) Minimum Thickness of Cut in Micromachining. Nanotechnology 3 (1): 6–9.
17. Lucca D.A, Seo Y.W (1993) Effect of tool edge geometry on energy dissipation in ultraprecision machining. CIRP Annals 42 (1): 83–88.
18. Lucca D.A, Rhorer R.L, Komanduri R (1991) Energy Dissipation in the Ultra-precision Machining of Copper. CIRP Annals 40 (1): 69–72.
19. Zhong Z.W (2003) Ductile or partial ductile mode machining of brittle materials. Int. Journal of Adv. Manuf. and Tech 21: 579–585.
20. Balson P, Pung R (1991) Diamond wheel selection criteria for grinding advanced engineering ceramics. Technical Paper of Society of Manufacturing Engineers: 1–20.
21. Malkin S, Ritter J E (1989) Grinding mechanisms and strength degradation for ceramics, Journal of Engineering for Industry 111 (2): 167–174.
22. Blake P.N, Scattergood R.O (1990) Ductile regime machining of germanium and silicon. Journal of American Ceramic Society 73 (4): 949–957.
23. Bifano T. G, Dow T. A, Scattergood R.O (1991) Ductile regime grinding: A new Technology for machining brittle materials. Journal of Engineering for Industry, Transactions of the ASME 113 (2): 184–189.
24. Ueda K, Sugita T, Hiraga H (1991) J-Integral approach to material removal mechanisms in microcutting of ceramics. CIRP Annals 40 (1): 61–64.
25. Shimada S, Ikawa N, Inamura T, Takezawa N, Ohmori H, Sata T (1995) Brittle ductile transition phenomena in microindentation and micromachining. CIRP Annals 44 (1):523–526.
26. Liu J. W, Baek D. K, Ko T. J (2014) Chipping minimization in drilling ceramic materials with rotary ultrasonic machining. Int J Adv Manuf Technol 72: 1527–1535.
27. Wang J, Zhang J, Feng P, Guo P (2018) Damage formation and suppression in rotary ultrasonic machining of hard and brittle materials: A critical review. [Ceramics International](https://www.sciencedirect.com/science/journal/02728842) [44(2](https://www.sciencedirect.com/science/journal/02728842/44/2)): 1227–1239.
28. Singh, RP, Singhal S (2016) Rotary Ultrasonic Machining: A Review. Materials and Manufacturing Processes 31(14):1795–1824.
29. Hu Y, Wang H, Ning F, Li Y, Cong W (2017) Surface grinding of optical bk7/k9 glass using Rotary ultrasonic Machining: An experimental study. Proceedings of the ASME- 12th International Manufacturing Science and Engineering Conference: 1–7.
30. Wang J, Zha H, Feng P, Zhang J (2016) On the mechanism of edge chipping reduction in rotary ultrasonic drilling: A novel experimental method. Precision Engineering 44: 231–235.
31. Lv D, Jhang Y, Peng Y (2016) High-frequency vibration effects on hole entrance chipping in rotary ultrasonic drilling of BK7 glass. Ultrasonics 72: 47–56.
32. Babbar A, Sharma A, Jain V, Jain AK (2019) Rotary ultrasonic milling of C/SiC composites fabricated using chemical vapor infiltration and needling technique. Materials Research Express Apr 24.
33. Babbar A, Jain V, Gupta D (2019) Neurosurgical Bone Grinding. InBiomanufacturing 137–155.
34. Babbar A, Jain V, Gupta D (2019) Thermogenesis mitigation using ultrasonic actuation during bone grinding: a hybrid approach using CEM43° C and Arrhenius model. Journal of the Brazilian Society of Mechanical Sciences and Engineering 41(10):401.
35. Babbar A, Singh P, Farwaha HS (2017) Regression model and optimization of magnetic abrasive finishing of flat brass plate. Indian J Sci Technology 10: 1–7.
36. Babbar A, Singh P (2017) Parametric Study of magnetic abrasive finishing of UNS C26000 flat brass Plate. International Journal of Advanced Multidisciplinary research 9(2): 83–89.
37. Kumar M, Babbar A, Sharma A, Shahi A S (2019) Effect of post weld thermal aging (PWTA) sensitization on micro-hardness and corrosion behavior of AISI 304 weld joints. IOP Conf. Series: Journal of Physics: Conf. Series 1240 012078.
38. Sharma A, Kumar M. Shahi A.S (2018) A Sensitization Studies on the Metallurgical and Corrosion Behavior of AISI 304 SS Welds. Advances in Manufacturing Processes, Lect. Notes Mechanical Engineering. Chapter-17: 257-265. doi: <https://doi.org/10.1007/978-981-13-1724-8_25>
39. Babbar A, Kumar A, Jain V, Gupta D (2019) Enhancement of activated tungsten inert gas (A-TIG) welding using multi-component TiO2-SiO2-Al2O3 hybrid flux. Measurement 1; 148:106912.
40. Singh D, Babbar A, Jain V, Gupta D, Saxena S, Dwibedi V (2019) Synthesis, characterization, and bioactivity investigation of biomimetic biodegradable PLA scaffold fabricated by fused filament fabrication process. Journal of the Brazilian Society of Mechanical Sciences and Engineering 41(3):121.
41. Weinert K., Kahnis P, Petzoldt V, Peters C (2005) Micro-Milling of steel and NiTi SMA. 55th CIRP General Assembly, STC-C section meeting presentation file, Turkey.
42. Lee K, Dornfeld D. A (2002) An experimental study on burr formation in micro milling aluminum and copper. Transactions of the NAMRI/SME 30:1–8.
43. Sharma A, Jain V, Gupta D. (2019) Comparative Analysis of Chipping mechanics of Float glass during Rotary Ultrasonic Drilling and Conventional Drilling: For multi-shaped tools. Machining Science and Technology. https://doi.org/10.1080/10910344.2019.1575402.
44. Sharma A, Jain V, Gupta D. (2018) Multi-Shaped Tool Wear Study during Rotary Ultrasonic Drilling and Conventional Drilling for Amorphous Solid. Journal of Process Mechanical Engineering 0: 1–10.
45. Sharma A, Jain V, Gupta D. (2018) Enhancement of surface roughness for brittle material during rotary ultrasonic machining. In MATEC Web of Conferences. EDP Sciences 249: 01006.
46. Klocke F, Weck M, Fischer S, Ozmeral H, Schroeter R. B, Zamel S (1996) Ultra-precision machining and manufacturing of micro components 3: 172–177.
47. Schaller T, Heckele M, Ruprecht R, Schubert K (1999) Micro fabrication of a mold insert made of hardened steel and first molding results. Proceedings of the ASPE 20: 224–227.
48. Schaller T, Mayer J, Schubert K (1999) Approach to a Micro structured mold made of steel. Proceedings of the EUSPEN 1: 238–241.
49. Brinksmeier E, Malz R, Riemer O (1996) Micromachining ductile and brittle materials in optical quality. VDI Berichte 221–229.
50. Weck M, Fischer S, Vos M (1997) Fabrication of Micro components using ultra-precision Machine Tools. Nanotechnology 8 (3): 145–148.
51. Huang B. W (2004) The drilling vibration behavior of a twisted Micro drill. Journal of Manufacturing Science and Engineering. Transactions of the ASME 126(4): 719–726.
52. Ohmori H,Katahira K, Uehara Y, Watanabe Y, Lin W (2003) Improvement of Mechanical Strength of Micro Tools by Controlling Surface Characteristics. CIRP Annals 52 (1): 467–470.
53. Sharma A, Jain V, Gupta D. (2018) Tool wear analysis while creating blind holes on float glass using conventional drilling: A multi-shaped tools study. Advances in Manufacturing Processes. Proceedings of ICEMMM, Lect. Notes Mechanical Engineering, Chapter-17: 175–183.
54. Sharma A, Jain V, Gupta D. (2019) Experimental investigation of cutting temperature during drilling of Float glass specimen. 3rd International Conference on Aerospace, Mechanical and Mechatronic Engineering (CAMME) 1–6 (In press).
55. Bissacco G, Hansen H. N, Chiffre, D. L (2005) Micro-milling of hardened tool steel for mold making applications. Journal of Materials Processing Technology 167(2-3): 201–207.
56. Otsuka J, Hata S, Shimokohbe A, Koshimizu S (1998) Development of Ultra-precision table for ductile mode cutting. Journal of the Japan Society for Precision Engineering 64 (4): 546–551.
57. Singh D, Babbar A, Jain V, Gupta D, Saxena S, Dwibedi V. (2019) Synthesis, characterization, and bioactivity investigation of biomimetic biodegradable PLA scaffold fabricated by fused filament fabrication process. Journal of the Brazilian Society of Mechanical Sciences and Engineering 41(3):121.
58. Babbar A, Jain V, Gupta D. (2019) Neurosurgical Bone Grinding. InBiomanufacturing Springer International Publishing: 137-155.
59. Otsuka J, Ichikawa S, Masuda T, Suzuki K (2005) Development of a small Ultra-precision positioning device with 5 nm resolution. Measurement Science and Technology 16 (11): 2186–2192.
60. Mizumoto H, Yabuta Y, Arii S, Tazoe Y, Kami Y (2005) A Picometer positioning system using active aerostatic guide way. Proceedings of the International Conference on Leading Edge Manufacturing in 21st Century, Japan: 1009–1014.
61. Holmes M, Trumpet D, Hocken R (1995) Atomic scale precision motion control stage. CIRP Annals 44 (1): 455–460.
62. Lee Y (2000) Monitoring and planning for open architecture manufacturing of precision machining using acoustic emission. Ph.D. Dissertation, Mechanical Engineering, University of California, CA.
63. Umeda A (1996) Review on the Importance of Measurement Technique in Micro machine Technology. Proceedings of SPIE-The International Society for Optical Engineering 2880:26–38.
64. McGeough J. A (2002) Micromachining of Engineering Materials. Marcel Dekker Inc., New York.
65. Masuzawa T, Hamasaki Y, Fujino M (1993) Vibro-scanning method for non-destructive measurement of small holes. CIRP Annals 42 (1): 589–592.
66. Kim B, Masuzawa T, Bourouina T (1999) Vibroscanning method for the measurement of micro hole profiles. Measurement Science and Technology 10 (8): 697–705.
67. Miyoshi T, Takaya Y, Saito K, (1996) Micro-machined profile measurement by means of optical inverse scattering phase method. CIRP Annals 45 (1):497–500.
68. Sharma A, Jain V, Gupta D. (2018) Characterization of Chipping and Tool wear during drilling of Float glass using rotary ultrasonic machining, Measurement 128: 254–263.