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Overview of Hybrid Micromachining and Microfabrication Techniques

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Abstract

Hybrid micromachining and microfabrication techniques utilize concurrent deed of two or more micromachining procedures with assistance of some vitality in removal of material to augment the advantages and diminish the prospective difficulties observed in specific material ejection methods. There are different instances, like compound processes, energy aided micromachining methods, thermally aided micromachining, pulse-aided micromachining, and combined hybrid micromachining processes. This study introduces a unique categorization and analyses of the previous and current exploration and functions of the hybrid micromachining and microfabrication procedures and emphasizing its influences on performance characteristics. Even though it is an enthusiastic research field

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Sandip Kunar, Golam Kibria, Prasenjit Chatterjee and Asma Perveen (eds.) Hybrid Micromachining and Microfabrication Technologies: Principles, Varieties and Applications, (1–16) © 2023 Scrivener Publishing LLC

in unconventional and significant micromachining and microfabrication methods subsequently, inadequate acquaintance about proficiencies in shape, sizes, and controlling mechanisms is still the most important restraint in the progress of these procedures. In the adjacent future, there is plenty of opportunity for hybrid micromachining and microfabrication processes in studying of material removal at microlevel, consequence of residue strains, and working environment.

***Keywords*:** Hybrid, micromachining, microfabrication

1.1 Introduction

From the last decades, there has been an enhanced benefit in microfabrication and micromachining techniques that have gained the creativity of investigators and industrial engineers from manufacturing sectors, mainly aviation, biomedical, and automobile. Emerging micromachining and microfabrication techniques are evidently continuing advances in microlevel industries, metrology, and machines to accomplish the requirements associated with the characteristics of microfeature [1]. Hybrid techniques state the conception of high-quality characteristics with shapes and sizes varying in micro level for different materials. The prerequisite for microproduct reduction continues to create several methodological restraints on discrete precision machining procedures, which are not constantly achievable to independently create a microcomponent meeting prerequisite, i.e., accuracy, surface quality, and shape intricacy. Also, the micro level measurements influence the specific method on functional characteristics and limit the application of self-regulating machining procedure. For instance, production techniques such as lithography are the utmost prevalent micromachining and microfabrication approaches that are accomplished to create microfeatures. Though, the limited choice of substrate materials, higher investment, and inability is unable to produce complex structures and inevitable clean room surroundings limit the usage of MEMS methods in micromachining and microfabrication fields [2].

Due to challenging in microfabrication and micromachining area and restrictions of discrete machining methods, researchers are concentrated to emerging hybrid micromachining and microfabrication methods, in which two or more techniques are composed together for micromachining to improve the benefits of fundamental procedures, while at that time diminishing their adversative problems when they are functional independently. The performing qualities of a hybrid procedure are significantly distinct from those methods in terms of efficiency, machining quality, and precision [3].

Hybrid micromachining is described as the combination of two or more micromachining methods to eradicate material [4]. The functional characteristics of hybrid micromachining and microfabrication approaches are significantly diverse from those that are distinctive for the constituent procedures when accomplished distinctly [5]. The hybrid machining method is to signify the amalgamation of different machining techniques with dissimilar capability of material exclusion [6]. These techniques are the approaches in which material eradication is owing to instantaneous action of two or more micromachining or microfabrication techniques or perform with the assistance of some energy in which the performance of the method enhanced pointedly, or else which are incredible when the procedures are utilized independently.

This chapter efforts to categorize recent hybrid micromachining and microfabrication techniques into pertinent classification and elucidate several methods utilized by researchers. The aim of this chapter is to deliver an appraisal on the different investigation works stated in the field of hybrid micromachining and microfabrication techniques to realize the machining capability of hybrid methods. This chapter efforts to deal with different hybrid methods in micro domain.

1.2 Classification of Hybrid Micromachining and Microfabrication Techniques

The category of hybrid micromachining and microfabrication techniques is classified with the utilization of procedural capability and/or energy/tools resources. Hybridization of microfabrication and micromachining methods is carried out with the following conditions:

- (i) Hybridization of different methods into a compound procedure in which material removal arises because of concurrent action of different methods.
- (ii) With aiding of various energy resources in material elimination to enhance performance of primary micromachining method.
- (iii) Utilization of specifically devised hybrid tool that can perform the hybrid micromachining operation at a same time.

In the first type, compound process comprises techniques in which two or more techniques are employed for concurrent action of material removal such that substantial modifications in process operation can be accomplished. For instance, in EDG method, effective material removal occurs because of electro-discharge and grinding action compared to electro-discharge machining method. The second type, energy aided methods, the material removal is occurred owing to preliminary machining action, only certain amount of energy is utilized to enhance machining performances. For instance, in laser aided milling, the laser initially warms the material for removal, improving the material elimination capability of the milling approach. By the laser source for preheating substrate, the advanced materials are machined effortlessly. The third type utilizes a specific hybrid tool that performs single-time machining for different surfaces.

1.2.1 Compound Processes

Microfabrication and micromachining of microparts can be accomplished with distinct advantages with the assistance of chemical and electro-physical procedures as there is no explicit contact between the tool and substrate between these procedures. Combining these methods to create hybrid technique, further advances in unique benefits over specific method because of their less advantages [2]. In compound methods, there is instantaneous action of two or more machining techniques that completely entail in material removal action. Significant research outcomes are stated in these methods combining various techniques through various methods; some approaches are described.

In electro discharge micromachining (EDM), discharge energy considerably influences the machining quality. The surface finish reduces with greater voltage and current. The heating effect creates microdefects, residual stresses, etc. in EDM. To avoid these problems, innumerable studies are conveyed in hybrid electro-discharge micromachining since last decades. In compound hybrid micromachining processes, EDM is hybridized with other techniques, i.e., abrasive electro-discharge grinding (AEDG), electro discharge grinding (EDG), etc.

EDG confiscates from advanced materials by quick sparking phenomena between substrate and revolving tool that are divided by the dielectric fluid. This process utilizes a revolving tool, resulting in improved flushing proficiency of the method. Consequently, the material is efficiently removed from disparity and the unwanted materials are not stored in the machining space, whereas the accumulation of debris is a key difficulty with undesirable impact on functioning of the method in EDM. Several investigators are reported to find the significant parameters that influence the performances of the EDG method. Material removal and surface integrity can be enhanced by suitable input factors. To acquire greater material removal, greater machining current and higher duty cycle with positive polarity of electrode are utilized [7]. Researchers are concentrated for machining of delicate materials using EDG because no mechanical forces are applied through performance time, and it provides better machining than EDM because of the rotary wheel [8].

AEDG is a procedure in which the combined impact of grinding method and EDM is applied to improve the machining characteristics [9]. In this process, the grinding wheel is used instead of metallic or graphite electrode. Therefore, mechanical abrasion and discharge erosion take place for material removal. It is also known as electro-discharge abrasive grinding (EDAG) in various research papers. This procedure is suitable for machining engineering ceramics, and metal composites. Minimum surface roughness values are compared using three kinds of machining, i.e., electro-erosion grinding, hybrid grinding (AEDG), and traditional grinding [10]. The surface textures are associated with traditional grinding, and it is observed that irregular peaks are more in micro level in AEDG than traditional grinding method.

ECDM is a hybrid micromachining technique, where material ejection takes place through electrical discharges and electrolysis. This method is mostly used for microfabrication and micromachining of fragile materials such as quartz, refractory bricks, etc. [11]. The material removal is as much as 4 to 45 times than EDM and ECM. The combined form of this method is utilized for hole drilling, which is known as 3D micro structuring [12–15]. This method is specifically efficient for machining of HSTR alloys. This method is applied as microgrinding to improve the quality of coarse surface on glass material [16]. The procedure enhances the surface quality of ECDM structures and decreases the total structuring time of hybrid procedure compared to other traditional grinding procedure.

ECDG is a hybrid procedure of EDG and ECM, which merges the electrolysis, electro-discharge erosion and mechanical abrasion of the grinding procedure. Excess material is eliminated from the substrate by the electrolysis, the mechanical action of abrasives, and the erosion because of the spark phenomena. It is applied for conductive material's machining. This method can grind hard and brittle materials for greater harder materials. The surface quality is achieved up to 0.13 to 0.75 μm, and the dimensional precision is obtained up to 0.0013 mm [17]. The grinding aided ECDM is used for finishing of metal matrix composites and achieved the surface roughness up to 10 times lower compared to that of the workpiece machined exclusive of grinding assistance [18].

1.2.2 Methods Aided by Various Energy Sources

(i) Thermally aided machining
The advanced materials have extensive uses in different areas, i.e., biomedical, aviation, etc. and their necessity is expanding; however, they are very tricky to process because of their properties like higher strength and lower thermal conductivity. Generation of précised 3D structures is carried out by micromilling and micromachining. The machining force at the microlevel is much greater compared to the macro-level, which creates micromachining of advanced materials [19]. The reduced surface finish of substrate and failure of the tool are occurred due to higher cutting force. Thermally aided micromachining assists for generating the high-aspect-ratio and intricate 3D microfeatures in different advanced materials. This assisted method uses exterior thermal resources to improve the temperature of the machining area for assisting the machining of material as decreases the residual stress of materials with higher heat. This method lowers the powered processing energy on the tool. The heat resources are pertinent for thermal assisted machining, which have the subsequent features: (i) higher thermal energy for quick heating of the material; (ii) easy controlling of the heated areas; and (iii) satisfactory cost of traditional machines. Until now, plasma [20, 21], induction coils [22, 23] and laser [24–36] are employed. However, the characteristics, i.e., higher heating intensity and controlling of heat resource become laser more favourite for thermally assisted machining.

Laser-aided machining is a prominent procedure that affects the rapid heating ability of laser with concentrated beam, challenging to machining by mechanical machining method. It is extremely concerned as stated by the progress of elevated power laser and improved in its pertinency. Laser is utilized for aiding grinding, electrochemical machining, and electro discharge machining processes to enhance their functioning. The material removal and laser heating occur concurrently in laser-assisted turning. This method is applied in various types of numerous diverse materials. It has demonstrated the effective way in lowering tool wear and forces when utilized to machine the advanced materials, i.e., titanium alloys, silicon nitride, Inconel, etc. Most of these findings are performed by Nd:YAG laser and CO_2 lasers. Most of these research explore that laser assisted turning procedure helps for reducing the cutting forces, boosting the tool life and surface quality. In laser-aided milling method, the combination of milling machine and laser is occurred in which the tool is revolving.

This occurrence of rotating tool is a problematic task. This method utilizes lower laser power to heat up the material, which is eliminated by the tool instantly behind it. This method is carried out utilizing microball end-milling tool on tool steel and demonstrated higher machining precision, and lower surface roughness. The surface finish improves as the cutting speed rises owing to the presence of laser heating. Improvement of thermal assisted milling method is safer, reliable, and accessible for engineering applications.

(ii) Media-aided machining

In this method, mechanical and heating characteristics of higher pressurized jet of emulsion and water are focused into the machining zone to enhance traditional machining of difficult materials for aerospace and defence applications. The pressurized liquid can offer advantages such as effective chip instability and decrease in machining forces, particularly in advanced materials. It can also enhance the lubricating characteristics and decrease heat responses on the cutting tools [37]. The turning assisted method is carried out with pressurized coolant for machining operation and surface finishing investigation is conducted on steel, Inconel 718, etc. [38]. The utilization of coolant with this method is responsible for hydraulic pressure between the chip and the rake face of tool, lowering the cutting forces and chip size and reducing tool erosion. More understandings into the effect of contact length, and surface finish in jet-aided turning of Inconel 718 are introduced. The machining capability of Inconel 718 is experimentally investigated in traditional and alternative higher pressurized cooling conditions [39]. The experimental outcomes demonstrate that the tool erosion and cutting forces significantly reduce with the supply of pressurized coolant to the machining zone. Cryogenic machining is utilized to affect the performance and is applied to reduce the machining temperature and improve the chemical constancy of the cutting tool and workpiece and is anticipated to enhance the performance capability of advanced materials [40–43].

(iii) Vibration-aided machining

This method is employed to different techniques from facing to grinding. These combined method performs precision machining with tool vibration and small amplitude. Here, the tool tip is moved with slight reciprocating motion. The tool can intermittently drop contact with the chip for proper sequences of frequency and cutting velocity. As a result, machining forces are lowered, and tiny chips are produced. This advances to enhance the surface quality, accuracy and burr free compared to traditional machining [44]. The constant flow of debris particles assists the stable performance in micro-EDM because of the application of tubular type substrate. However, a revolving spindle is not utilized in the creation of quadrilateral holes [45]. Many researchers have concentrated on ultrasonically aided micro-EDM to explore the influences of frequency on accuracy, machining rate, and so on [46]. The utilization of quivering unit is mostly used to improve dielectric movement, subsequent in efficient elimination of metal from craters [47–49], succeeding in lowest micro-racks and modifications of microstructure on substrate at greater material removal [50]. The vibration assisted workpiece has a substantial outcome on the machined characteristics of micro-EDM technique [51]. This method is more prominent for higher depth drilling on tungsten carbide [52]. The vibration assisted workpiece suggestively improves material removal, geometric accuracy, surface quality, and lower tool wear. Ultrasonic vibration-aided grinding is also known as rotary ultrasonic machining (RUM), is applied to investigate the machining capability of titanium [53], steels [54], etc. and most findings are stated that enhanced surface finish and better tool life are achieved at greater pulsation frequencies and smaller feed rates.

(iv) Pulse-assisted machining

Pulse-assisted electrochemical machining [55–57] offers an inexpensive and efficient technique for machining of advanced materials to generate intricate profiles, i.e., micro cavities, die, molds, etc. PECM improves the precision and machined quality because of a pulsed voltage with greater current density compared to electrochemical machining.

(v) Electromagnetic-aided machining

Many investigators are concentrated their attempts on magnetic force applications to support the production method presently and explored the advantageous consequences of magnetic force support in material removal. The viability and consistency of the magnetic media for machining are studied. This media is employed in different areas of surface polishing. The magnetic abrasive polishing method is applied to smooth the machined surface of steel [58]. Enhanced characteristic of EDM-machined surface is followed because of magnetic abrasive polishing technique [59]. The magnetic field around the workpiece is applied to enhance the machining capability in the abrasive flow machining (AFM) method [60]. The use of magnetic field is responsible for enhancing debris flow in EDM [61]. The greater material removal is achieved due to improved debris exclusion from gap in aid of magnetic fields [62, 63].

1.2.3 Processing Using a Hybrid Tool

A hybrid tool is used for machining of two or more planner surfaces. The tools of inconsistent type, multifunctional tools and tools of consistent type are distinguished for hybrid micromachining. These hybrid tools are more intricate and costly than traditional tools and may only be suggested for heavy production [64]. These tools of incompatible type comprise different comprehensive tools. They have excellent machining capability since they significantly improve the efficiency. Consistent tools are created by sequence of different cutting tools of several types. They are generally compound tools, but one-piece production is feasible. These hybrid methods accomplish two distinct types of cutting, deformation, and machining in different classifications.

1.3 Challenges in Hybrid Micromachining

Requirements for improvement of better instruments for ability of machining of précised intricate parts:

- Hybrid micromachining techniques are evidently expanding for production of complicated 3D microparts. The development of precision instrument is very significant to gather requirements.
- The microtool with précised movement with slight vibration will generate the precise microproducts.
- Précised controlling of machining factors is important since little variation will affect the machining performance.

Improvement of accurate actuators and positioning mechanism

- Actuators with high precision are incredibly significant. Efficient evaluation, design techniques and modelling for positioning and accurate high-speed actuators should be studied.
- The capability of Piezoelectric actuators for précised positioning and their design is studied. Moreover, study of thermal influences on accuracy is important.
- Advancement of receptive controller to meet higher functioning is crucial. Precision operation is reliable for producing precise surfaces.

Advancement of multi-functional tool for meeting micromachining requirements and improving research resources

- While generating intricate parts, consumers incessantly require higher accuracy with enhanced feature. To gather these requirements, multi-operational tooling at decreased investment is necessary.
- Controlling of microtools and microcomponents are complicated and required resources are supplied on machine tool.

On-machine production of electrode for hybrid electro discharge machining processes

- In this method, managing of micro tools is a challenging task because of their possibility of twisting during assignments.
- Moreover, precision of performance characteristics is influenced owing to higher tool wear in EDM.

Advancement of multi-operational CAD tool supporting computer-aided hybrid micromachining processes

- CAD and CAM software enabling production through hybrid micromachining and microfabrication processes are significant.
- For production of intricate parts, a particular CAD/CAM method is required for creating tool path and associated machining activity.

1.4 Conclusions

Hybrid micromachining and microfabrication is one of the dynamic research areas in production of microcomponents. This manuscript demonstrates a unique categorization of hybrid methods and evaluations of literature review, specifically, hybrid approaches, energy-aided methods, and procedures utilizing a hybrid tool. In micro level, hybrid methods are developing as crucial techniques. This methods demonstrate open new path of research for improving method abilities, diminishing their limitations, and spreading functional areas. The main limitations in the progress of hybrid schemes are inadequate acquaintance about compatibilities in sizes, and employing strategies associated to manufacturing products.

Additionally, the essential acquaintance will affect the product superiority of different materials is still inadequate, and there is sufficient possibility in studying concerns in material removal at microlevel, and consequence of residual strains in the future.

1.5 Future Research Opportunities

Hybrid micromachining and microfabrication techniques require several types of energy, concurrently which are affected at the same fabrication area. Fundamental issues of material elimination capability and the mechanism related with hybrid system are one of the upcoming research purposes. Additional forthcoming research opportunity is simulation and modeling of hybrid micromachining and microfabrication procedures. Simulation of such procedures is explored with dissimilar approaches, i.e., molecular simulation, multiscale modeling, etc. Simulation and modeling support improved fundamental aspects of the hybrid procedures. There is prerequisite of ultraprecision machines that keeps high stiffness, control mechanisms, accurate feed drives, and are furnished to recompense for dynamic and static aligning faults. The accuracy of these techniques is improved further with diminished holding and rearrangement of tool faults.

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