Chapter 2

Overview of Hybrid Machining Processes (HMPs)

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Unique applications of advanced machining processes

Some challenges which can be met by AMPs only (a) drilling an inaccessible hole (normal to the wall in the present case); (b) drilling a large number closely spaced holes; (c) machining at nano-, micro- and meso-level (d) machining of parts with typical intricate features and (e) machining deep holes on a curved surface, i.e. turbine blade.[1]

AMPs and their combination with conventional or unconventional machining processes can be used for process improvement.
Hybrid Machining processes

Hybrid production/manufacturing means the combination of processes/machines in order to produce parts in a more efficient and productive way.

A general objective of hybrid manufacturing is the “1 + 1 = 3” effect, meaning that the positive effect of the hybrid process is more than the double of the advantages of the single processes.

Hybrid can have several meanings:

(1) combination of different active energy sources which act at the same time in the processing zone (e.g. laser assisted turning);

(2) processes which combine process steps that are usually performed in two or more process steps
Classification of hybrid machining processes

1. **Combined or mixed-type processes** in which all constituent processes are directly involved in the material removal.

2. **Assisted-type processes** in which only one of the participating processes directly remove material, while the other only assists in removal by having a positive effect on the conditions of machining.

Classification of hybrid machining processes [2]

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Assisted hybrid processes

1. Vibration assisted hybrid machining processes:

Vibration assisted grinding is a rather new technology where a superposition of conventional grinding and a vibration (most often in the ultrasonic range) is established.

Vibration assisted grinding set-up (generation of vibration by piezo elements in the tool holder system) [2]
Vibration assisted EDM

- In vibration assisted EDM, an additional relative movement is applied in the system tool electrode, workpiece and dielectric fluid in order to increase the flushing efficiency, resulting in a higher material removal rate and better process stability.
- In micro-EDM process flushing conditions and discharge gap state have been identified as main influences. Improved flushing strategies and optimized discharge gap control circuits have led to great improvements.
- The periodic relative movement between tool and workpiece causes a flow of the dielectric and an agitation of the debris particles in the dielectric medium. Due to this phenomenon, a settlement of debris on the bore ground and the agglomeration of particles are reduced and the state of the gap is equalized.
Principle of vibration assisted EDM [2]
**Ultrasonic-Assisted ECM (USECM)**

Electrochemical dissolution and the formation of a passivating oxide layer occur on the workpiece surface by ion formation and movement within the electrolyte producing a high intensity current flow. The passivating layer is then removed by these ultrasonically accelerated abrasives that impact the workpiece surface. This process also helps to maintain a constant inter-electrode gap.
2. Heat-Assisted HMPs

The use of an external heat source improves the machinability by minimizing the machining forces, improving the work surface, integrity and enhancing the tool life. This heat source may be in the form of a laser beam, electron beam, plasma beam, high-frequency induction or electric current etc.

Laser-assisted machining is one of the important and most widely used category of the heat-assisted HMPs.

Laser-assisted HMPs are of two types:

1. Laser-assisted mechanical machining: in which, a laser is used to heat the workpiece ahead of the cutting tool during conventional machining processes such as turning, milling and grinding.

2. Laser-assisted advanced machining: where laser assistance enhances the material removal in electrolytic dissolution and electro discharge-based AMPs.
I. Laser assisted turning

❖ In this process, the main material removal mechanism is still the one occurring in conventional cutting, but the laser action softens the workpiece material, so machining of high alloyed steels or some ceramics becomes easier.
❖ The laser beam is directly focused in front of the cutting tool, resulting in easier machining and higher process performance.
II. Laser assisted ECM (LAECM)

The primary role of a laser in ECM is to improve the localization of the dissolution process. The main mechanism of material removal in laser-assisted ECM (LAECM) is enhanced by electrolytic dissolution because of an improved thermal activation brought upon by a focused laser beam.

Additionally, it also helps in removing the passivating metallic oxide layers formed on the workpiece due to the evolution of oxygen at the anode during the electrolysis process.

A schematic of the LAECM process [1]
III. Laser-Assisted EDM (LAEDM)

❖ **EDM drawbacks:** Lengthy machining times and high tool wear
❖ **Laser drawbacks:** Formation of a recast layer and heat-affected zones (HAZ) and low surface quality of the workpiece.

**Solution:**
❖ Hybridization of LBM and EDM as LAEDM addresses their respective disadvantages. LAEDM is generally used in micro-machining applications for reducing production time and eliminating the recast layer and HAZ caused by laser ablation.
**Laser-Assisted EDM (LAEDM)**

A short-pulsed laser beam capable of producing high ablation rates is used to roughly pre-machine the basic part features (i.e. groove, hole, cavity). This is subsequently followed by micro-EDM within a suitable dielectric to remove the surface defects caused by the thermal effects of laser ablation and to finish the feature.

Concept of LAEDM process  [1]

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3. Magnetic field assisted machining processes

Magnetic field-assisted HMPs rely on the enhancement of the primary machining/finishing process by the addition (assistance) of magnetic field with the aim to improve workpiece surface quality and material removal rate.

1. Magnetic field-assisted EDM (MAEDM)
2. Magnetic field-assisted abrasive flow machining (MAAFM)
I. Magnetic Field-Assisted EDM (MAEDM)

- Debris accumulation in the machining zone that adversely affects performance and efficiency has always been a perennial problem in EDM.
- Adding magnetic field enhances the process stability and increases the efficiency of the EDM component by effective removal of machining debris from the machining zone.
I. Magnetic Field-Assisted EDM (MAEDM)

➢ The introduction of the magnetic field exerts a magnetic force perpendicular to the electrode’s motion. As a result, debris particle in the machining zone is subjected both to a magnetic force and to a centrifugal force.
➢ The resultant force which is the vector summation of the magnetic and centrifugal forces ensures effective and rapid flushing of debris particles.
II. Magnetic field-assisted abrasive flow machining

Magnetic field-assisted abrasive flow machining (MAAFM) is an important hybrid AFM process where the assistance of a magnetic field provides the means of controlling the cutting forces and consequently the outcome of the process includes higher surface finish and finishing rate. This process is capable of producing a surface roughness as small as 8-10 nm.

Mechanism of finishing in magnetic field-assisted abrasive flow machining  [1]

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4. External Electric Field-Assisted machining

**Laser Percussion Drilling for Highly Reflective Metals**

- Laser percussion drilling has gained great attention in the industry due to its wide industrial applicability and usage in processing of various materials, such as metals, glass, and ceramics.

- Laser percussion drilling is also characterized by a noncontact machining process, smaller beam spot size, high operating speeds, great flexibility, and accuracy. However, it is difficult to apply laser percussion drilling to highly reflective target surfaces, such as aluminium, which reflect the optical energy and dramatically reduce the processing efficiency.

- This drawback lengthens the drilling time, increasing the cost of the process and decreasing the yield.

- Using the electric field influences the behaviour of the plasma plume during laser percussion drilling. The depths of the drilled holes, obtained in the presence of applied electric field, are deeper than those obtained in the normal case. These results are due to the effect of the electric force by which the plume particle could be accelerated in the electric field.
Femtosecond laser micromachining of silicon with an external electric field

Machining of silicon wafers with fs lasers the debris was formed as a result of aggregation of small particles such as atoms or atomic clusters on the substrate surface instead of large-scale droplets or fragments, which are commonly observed with nanosecond lasers.

In order to prevent particles from redepositing onto the Si surface an electric field during the fs laser machining is applied. It is assumed that the charged ions in the plasma cloud would be attracted to the electrodes.

fs laser micromachining of Si without the external electric field
and with external electric field [3,4]
Combined hybrid machining

Combined or mixed HMPs are those processes in which two or more energy sources/tools/mechanisms are combined and have a synergetic effect on the material removal process. They can further be categorized as electrochemical HMPs and thermal HMPs.
Electrochemical Hybrid Machining Processes (ECHMP)

ECM offers many advantages, namely
(i) process performance being independent of mechanical properties of the workpiece material
(ii) production of largely stress-free surface
(iii) good surface finish and integrity
(iv) higher productivity due to higher MRRs

Limitations:
(i) passivation of workpiece surface by non-conducting metal oxide layer formation due to the evolution of oxygen gas at the anode
(ii) applicability to only electrically conducting materials
(iii) corrosion of machining elements and surroundings due to the use of an electrolyte
(iv) chemical damage caused to workpiece surface
(v) the dependence of accuracy on the inter-electrode gap which requires efficient flushing
Need of ECHMP

Conventional finishing processes such as grinding, mechanical honing, buffing and superfinishing are inexpensive and give good surface quality, but the use of abrasives imparts some inherent limitations such as

(i) high tool wear;
(ii) low productivity and
(iii) mechanical damage to the finished surface.

Solution:
Combine ECM with some conventional machining/finishing or AMP to develop an electrochemical HMP (ECHMP)
Electrochemical Grinding (ECG)

- ECG is the result of hybridizing ECM with the abrasive action of conventional grinding to machine hard and fragile electrically conducting materials efficiently, economically and productively without affecting the useful properties of these materials.

- ECG offers accurate and largely surface residual stress-free machining with no burrs and heat affected zone (HAZ) and, therefore, little distortion.
Equipment and Working Principle

❖ The non-conducting abrasive particles protrude just beyond the surface of the bonding material of the wheel helping to maintain a constant inter-electrode gap and act as spacers.
❖ Bonding materials such as copper, brass, nickel or copper impregnated resin are commonly used for the manufacture of metal-bonded grinding wheels.

❖ Functions of abrasive particles:
❖ to maintain the electrical insulation between anode workpiece and cathode.
❖ continuously remove any passive layer that may be formed on the workpiece surface by chemical reaction
❖ To determine workpiece shape and size
Three distinct zones in ECG process

Zone I, the material removal is purely due to electrochemical dissolution
In Zone II, the gas bubbles in the gap yield higher MRRs. Chemical or electrochemical reaction may result in the formation of a passive layer on the workpiece surface. The abrasive particles not only remove material from the work surface in the form of chips but also remove the non-reactive oxide layer.
Zone III, the material removal is done completely by electrochemical dissolution. This zone starts at the point where the wheel lifts just beyond the work surface. This zone contributes by removal of burrs that formed on the workpiece in zone II
EDM Combined with Conventional Machining

Electric Discharge Grinding (EDG):

EDG is a thermal HMP
- An electrically conductive grinding wheel is used as a tool electrode.
- Material removal occurs due to the electro discharge action.
- Abrasive component of the process ensures effective flushing which results in improved material removal rate and enhanced surface finish as compared to the conventional EDM process

Electric Discharge Diamond Grinding (EDDG)

A metal-bonded grinding wheel with embedded abrasive particles is used to enhance the machining productivity and surface finish.

$\text{Al}_2\text{O}_3$, $\text{SiC}$ and $\text{CBN}$ are commonly used abrasive in this process. When diamond is used as abrasive, this process is known as electric discharge diamond grinding (EDDG).
Electrochemical Discharge Machining (ECDM)

ECDM is a combination of electric discharge machining (EDM) and electrochemical machining (ECM). Used for the machining of electrically non-conducting materials such as insulating ceramics, glass, polymers etc.
A complex combination of electrolytic dissolution and spark erosion.
Voltage and current profile during the ECDM process

1. When voltage between cathode and anode increased, H$_2$ bubbles evolve at the cathode (region A–C)
2. Gas bubble insulation is broken and electrical discharge commences (point C)
3. Beyond point C the current drops and discharging continues.

Wire electrochemical discharge machining (WECDM): When a travelling wire is used as the tool electrode, i.e. cathode.
**Electrochemical Discharge Grinding (ECDG)**

Electrochemical discharge grinding (ECDG) hybridizes spark erosion, electrolytic dissolution and mechanical abrasion to machine electrically conductive workpieces

1. Dissolution occurs at the workpiece (anode) due to the electrochemical reaction
2. A passivating oxide layer is also formed on the work surface during the electrochemical reaction.
3. Subsequent electro-erosion phase, the spark discharges depassivate the oxide layer
4. Enhances the effectiveness of the electrochemical dissolution and thereby improves the workpiece material removal rate.

Working principle and mechanism of ECDG [1]
**Abrasive Water Jet Machining**

- Abrasive particles + Water Jet
- AWJM is being widely used, especially in cutting of harder or low machinability materials like Ti alloys, ceramics, metal matrix composites, concrete etc.
- Treated water is pumped to very high pressures
- An abrasive (e.g. garnet) is introduced into the water stream from an adjacent hopper and directed to a mixing chamber.

**Advantages:**
1. Marginal thermal stresses.
2. Comparatively faster process.
3. Cut surface is smoother
4. Very thin pieces can be cut
5. Any contour can be cut

Schematic of a typical AWJ machine [5]
References

5. Xichun Luo, Yi Qin, Hybrid Machining, Elsevier, 2018