STUDY OF UNCONVENTIONAL MACHINING PROCESSES

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ABSTRACT

Unconventional manufacturing processes are defined as a group of procedures that remove excess material by various techniques involving mechanical, thermal, electrical, or chemical energy or combinations of these energies but do not use a sharp cutting tool as it needs to be used for traditional manufacturing processes. Harsh and brittle materials are difficult to machine by conventional machining processes such as turning, drilling, shaping, and milling. Nontraditional machining processes, also called advanced manufacturing processes, are employed where traditional machining processes are not feasible, satisfactory, or economical due to special reasons as outlined below.

• Very hard fragile materials difficult to clamp for traditional machining
• When the workpiece is too flexible or slender
• When the shape of the part is too complex

Several types of nontraditional machining processes have been developed to meet different required machining conditions. When these processes are correctly employed, they offer many advantages over nontraditional machining processes. The standard nontraditional machining processes are described in this section.

Manufacturing processes can be broadly divided into two groups.
a) Primary manufacturing processes: Provide basic shape and size
b) Secondary manufacturing processes: Provide final shape and size with tighter control on dimension, surface characteristics
Material Removal Processes Once Again Can Be Divided Into Two Groups
1. Conventional Machining Processes
2. Nontraditional Manufacturing Processes or Unconventional Machining processes
Conventional Machining Processes mostly remove material in the form of chips by applying forces on the work material with a wedge-shaped cutting tool harder than the work material under machining conditions.

1. INTRODUCTION

1.1.THE MAJOR CHARACTERISTICS OF CONVENTIONAL MACHINING ARE:

• Material removal takes place due to application of cutting forces – energy domain can be Classified as mechanical
• Cutting tool is more challenging than workpiece at room temperature as well as under machining Conditions

Non-conventional manufacturing processes are defined as a group of procedures that remove excess material by various techniques involving mechanical, thermal, electrical or chemical energy or combinations of these energies but do not use sharp cutting tools as it needs to be used for traditional manufacturing processes. Material removal may occur with chip formation, or even no chip formation may take place. For example, in AJM, chips are microscopic, and in the case of Electrochemical machining, material removal occurs due to electrochemical dissolution at the atomic level.

1.2. NEED FOR UNCONVENTIONAL MACHINING PROCESSES

• Tough and brittle materials or Difficult to machine material are difficult to Machine by traditional machining processes.

• When the workpiece is too flexible or slender to support the cutting or grinding Forces when the shape of the part is too complicated.

1.3. CLASSIFICATION OF UCM PROCESSES:

1. Mechanical Processes
• Abrasive Jet Machining (AJM)
• Abrasive Water Jet Machining (AWJM)
• Water Jet Machining (WJM)
• Ultrasonic Machining (USM)
2. Electrochemical Processes
• Electrochemical Machining (ECM)
• Electro Chemical Grinding (ECG)
• Electro Jet Drilling (EJD)
3. Electro-Thermal Processes
• Electro-discharge machining (EDM)
• Laser Jet Machining (LJM)
• Electron Beam Machining (EBM)
4. Chemical Processes
• Chemical Milling (CHM)
• Photochemical Milling (PCM)

1.4. BRIEF OVERVIEW

1 ULTRASONIC MACHINING

USM is a mechanical material removal process in which the material is removed by repetitive impact of abrasive particles carried in liquid medium on to the work surface, by a shaped tool, vibrating at the ultrasonic frequency.

2 ABRASIVE JET MACHINING

It is the material removal process where the material is removed or machined by the impact erosion of the high-velocity stream of air or gas and abrasive mixture focused on the workpiece.

3. LASER BEAM MACHINING

Laser-beam machining is a thermal material-removal process that utilizes a high- Energy, Coherent light beam to melt and vaporize particles on the surface of metallic and non-Metallic workpieces. Lasers can be used to cut, drill, weld, and mark. LBM is particularly suitable for making accurately placed holes

4. ELECTRON EAM MACHINING

It is the thermo-electrical material removal process on which the material is removed by the high-velocity electron beam emitted from the tungsten filament made to impinge on the work surface, where the kinetic energy of the shaft is transferred to the work piece material, producing intense heat, which makes the material melt or vaporize it locally.

5. ELECTROCHEMICAL MACHINING

It is the controlled removal of metals by the anodic dissolution in an electrolytic medium, where the workpiece (anode) and the tool (cathode) are connected to the electrolytic circuit, which is kept, immersed in the electrolytic medium

6. ELECTROCHEMICAL GRINDING

ECG is the material removal process in which the material is removed by combining electrochemical decomposition as in the ECM process and abrasive due to grinding.

7. PLASMA ARC MACHINING

Plasma is defined as the gas, which has been heated to a sufficiently high temperature to

Become ionized.

8. WATER JET MACHINING

Water jet cutting can reduce the costs and speed up the processes by eliminating or reducing expensive secondary machining processes. Since no heat is applied to the materials, cut edges are clean with minimal burr. Cracked edge defects, crystallization, hardening, reduced weldability, and machinability are concentrated in this process.

9. ELECTRICAL DISCHARGE MACHINING

EDM is the controlled erosion of electrically conductive materials by the Initiation of rapid and repetitive spark discharge between the electrode tool to the cathode and work to anode separated by a small gap kept in the dielectric medium's path. This The process is also called spark erosion.

2. MECHANICAL PROCESSES

- Abrasive Jet Machining (AJM)
- Abrasive Water Jet Machining (AWJM)
- Water Jet Machining (WJM)
- Ultrasonic Machining (USM)

2.1 ABRASIVE JET MACHINING (AJM)

In Abrasive Jet Machining (AJM), abrasive particles are made to impinge on the work material at a high velocity. The high-velocity abrasive particles remove the material by micro-cutting action and brittle fracture of the work material. In AJM, generally, the abrasive particles of around 50 μm grit size would impinge on the work material at a velocity of 200 m/s from a nozzle of I.D. of 0.5 mm with a standoff distance of around 2 mm. The abrasive particles' kinetic energy would be sufficient to provide material removal due to brittle fracture of the workpiece or even micro-cutting by the abrasives.

Schematic Arrangement Of Ajm

2.1.1. Process Parameters and Machining Characteristics

Abrasive: Material – Al2O3 / SiC/glass beads
Shape – irregular/spherical
Size – 10 ~ 50 μm
Mass flow rate – 2 ~ 20 gm/min
Carrier gas: Composition – Air, CO2, N2
Density – Air ~ 1.3 kg/m3
Velocity – 500 ~ 700 m/s Pressure – 2 ~ 10 bar
Flow rate – 5 ~ 30 pm
Abrasive Jet : Velocity – 100 ~ 300 m/s
Mixing ratio – mass flow ratio of abrasive to gas
Stand-off distance – 0.5 ~ 5 mm
Impingement Angle – 60 ~ 90
Nozzle: Material – W.C.
Diameter – (Internal) 0.2 ~ 0.8 mm
Life – 10 ~ 300 hours

2.1.2. Modeling of material removal

Material removal in AJM occurs due to brittle fracture of the work material due to the impact of high-velocity abrasive particles.

2.1.3. Modeling has been done with the following assumptions:

(i) Abrasives are spherical in shape and rigid. The mean grit characterizes the particles
diameter
(ii) The kinetic energy of the abrasives are fully utilized in removing material
(iii) Brittle materials are considered to fail due to brittle fracture, and the fracture volume is deemed to be hemispherical with

a diameter equal to the choral length of the indentation
(iv) For ductile material, removal volume is assumed to be similar to the indentation work due to particulate impact

2.2. WATER JET MACHINING (WJM)

2.2.1. Introduction

Water jet cutting can reduce costs and speed up the processes by eliminating or facilitating expensive secondary machining process. Since no heat is applied to the materials, cut edges are clean with minimal burr. Cracked edge defects, crystallization, hardening, reduced weldability, and machinability are concentrated in this process. Water jet technology uses the principle of pressurizing water to too high pressures and allowing the moisture to escape through a tiny opening called "orifice" or "jewel." Water jet cutting uses the beam of water exiting the orifice to cut soft materials. This method is not suitable for cutting hard materials. The inlet water is typically pressurized between1300 – 4000 bars. This high pressure is forced through a tiny hole in the jet el, which is usually 0.18 to
0.4 mm in diameter. Picture of water jet chining process.

2.2.2. Applications

Water jet cutting is mostly used to cut lower strength materials such as wood, plastics, and aluminum. When abrasives are added (abrasive water jet cutting), more substantial materials such as steel and tool steel.

2.2.3. Advantages Of Water Jet Cutting

• There is no heat generated in water jet cutting, which is especially useful for cutting tool steel and other metals where excessive heat may change the material's properties

.•, Unlike machining or grinding, water jet cutting does not produce any dust or particles that are harmful if inhaled.

• Other advantages are similar to abrasive water jet cutting

2.2.4. Disadvantages of water jet cutting

• One of the main disadvantages of water jet cutting is that a limited number of materials can be cut economically.
This process cannot cut • Thick parts economically and accurately.
• Taper is also a problem with water jet cutting in very thick materials. The taper is when the jet
exits the part at a different angle than it enters the territory and causes dimensional inaccuracy.

2.3. ABRASIVE WATERJET MACHINING (AWJM)

2.3.1. Introduction

Abrasive water jet cutting is an extended version of water jet cutting. The water jet contains abrasive particles such as silicon carbide or aluminum oxide to increase the material removal rate above that of water jet machining. Almost any type of material ranging from hard, brittle materials such as ceramics, metals, and glass to incredibly soft materials such as foam and rubbers can be cut by abrasive water jet cutting. The narrow cutting stream and computer-controlled movement enable this process to produce parts accurately and efficiently. This machining process is especially ideal for cutting materials that cannot be missed by laser or thermal cut. This process can cut metallic, non-metallic, and advanced composite materials of various thicknesses. This process is particularly suitable for heat-sensitive
materials that cannot be machined by techniques that produce heat while

machining. The schematic of abrasive water jet cutting is similar to water jet cutting apart from some more features underneath the jewel, namely abrasive, guard, and mixing tube. In this process, high-velocity water exiting the glory creates a vacuum that sucks abrasive from the abrasive line, which combines with the water in the mixing tube to form a high-velocity beam abrasive.

2.3.2.Applications

Abrasive water jet cutting is highly used in aerospace, automotive, and electronics industries.

In aerospace industries, parts such as titanium bodies for military aircraft, engine components (aluminum, titanium, and heat resistant alloys), aluminum body parts, and interior cabin parts are made using abrasive water jet cutting. In automotive industries, details like interior trim (headliners, trunk liners, and door panels) and fiberglass body components and bumpers are made by this process. Similarly, in electronics industries, circuit boards and cable stripping are made by abrasive water jet cutting.

2.3.3 . Advantages of abrasive water jet cutting

• In most cases, no secondary finishing required
• No cutter induced distortion
• Low cutting forces on workpieces
• Limited tooling requirements
• Little to no cutting burr
• Typical finish 125-250 microns
• Smaller kerf size reduces material wastages
• No heat-affected zone
• Localises structural changes
• No cutter induced metal contamination
• Eliminates thermal distortion
• No slag or cutting dross
• Precise, multi-plane cutting of contours, shapes, and bevels of any angle.

2.3.4.Limitations of abrasive water jet cutting

• Cannot drill flat bottom
• Cannot cut materials that degrade quickly with moisture
• Surface finish degrades at higher cut speeds, which are frequently used for rough cuts. The significant disadvantages of abrasive water jet cutting are high capital cost and high noise levels during operation. A component cut by abrasive water jet cutting is shown in Figure. As it can be seen, large parts can but cut with very narrow kerfs, which reduces material wastages. The intricate shape part made by abrasive water jet cutting

2.3.5. Abrasive water jet cutting

• WJM - Pure
• WJM - with stabilizer
• AWJM – entrained – three-phase – abrasive, water and air
• AWJM – suspended – two-phase –abrasive and water o direct pumping
i. Indirect Pumping
ii. Bypass pumping

2.4. ULTRASONIC MACHINING (USM)

2.4.1. Introduction

USM is a mechanical material removal process or an abrasive process used to erode holes or cavities on the complex or brittle workpiece using shaped tools, high-frequency mechanical motion, and an abrasive slurry. USM offers a solution to the expanding need for brittle machining materials such as single crystals, glasses, and polycrystalline ceramics, and increasing complex operations to provide intricate shapes and workpiece profiles. Therefore, it is used extensively in machining hard and brittle materials that are difficult to machine by traditional manufacturing processes. The hard particles in the slurry are accelerated toward the workpiece's surface by a tool oscillating at a frequency up to 100 kHz - through repeated abrasions, the tool machines a cavity of a cross-section identical to its own. USM is primarily targeted for machining hard and brittle materials (dielectric or conductive) such as boron carbide, ceramics, titanium carbides, rubies, quartz, etc. USM is a versatile machining process as far as the properties of materials are concerned. This process can effectively machine all materials, whether they are electrically conductive or insulator.

For an effective cutting operation, the following parameters need to be carefully considered:

• The machining tool must be selected to be highly wear-resistant, such as high-carbon steel.

• The abrasives (25-60 μm in dia.) in the (water-based, up to 40% substantial volume) slurry Include Boron carbide, silicon carbide, and aluminum oxide.

Applications

The beauty of USM is that it can make non-round shapes in hard and brittle materials.

Ultrasonically machined non-round-hole part

2.4.2Advantage of USM

USM process is non-thermal, non-chemical, creates no changes in the microstructures, chemical or physical properties of the workpiece, and offers virtually stress-free machined surfaces.

• Any materials can be machined regardless of their electrical conductivity

• Especially suitable for machining of brittle materials

• Machined parts by USM possess a better surface finish and higher structural integrity.

• USM does not produce thermal, electrical, and chemical abnormal surface

2.4.3. Disadvantages of USM

• USM has higher power consumption and lower material-removal rates than traditional Fabrication processes.

• Tool wears fast in USM.

• Machining area and depth is restraint in USM.

ELECTRICAL BASED PROCESSES

3. ELECTRICAL BASED PROCESSES

• Electrical Discharge `Machining (EDM)

• Wire Cut Electrical Discharge Machining (WCEDM)

3.1. Electrical Discharge `Machining (EDM)

Electrical discharge machining (EDM) is one of the most widely used nontraditional machining processes. The main attraction of EDM over traditional machining processes such as metal cutting using different tools and grinding is that this technique utilizes a thermoelectric process to erode undesired materials from the workpiece by a series of discrete electrical sparks between the workpiece and the electrode. A picture of the EDM machine in operation. The traditional machining processes rely on the more challenging tool or abrasive material to remove the softer material. In contrast, nontraditional machining processes such as EDM use an electrical spark or thermal energy to erode unwanted material to create the desired shape. So, the hardness of the material is no longer a dominating factor for the EDM process. A schematic of an EDM process where the tool and the workpiece are Immersed in a dielectric fluid. EDM removes material by discharging an electrical current, typically stored in a capacitor bank, across a small gap between the tool (cathode) and the workpiece (anode) typically in order

3.1.1. Application of EDM

The EDM process can machine hard, difficult-to-machine materials. With intricate, precise, and irregular shapes for forging, press tools, extrusion dies, the EDM process can make complicated internal forms for aerospace and medical applications. Some of the conditions created by the EDM process are shown in Figure.

3.1.2. Working principle of EDM

A high voltage is applied across the narrow gap between the electrode and the workpiece. This high voltage induces an electric field in the insulating dielectric present in the narrow gap between electrode and workpiece. This causes conducting particles suspended in the dielectric to concentrate at the points of the strongest electrical field. When the potential difference between the electrode and the workpiece is sufficiently high, the dielectric breaks down. A transient spark discharges through the dielectric fluid, removing a small amount of material from the workpiece surface. The volume of the material removed per spark discharge is typically in the range of 10-6 to 10-6 mm3. The following formula calculates the material removal rate, MRR, in EDM:

MRR = 40 I / Tm 1.23 (cm3/min)

Where I am the current amp, T.M. is the melting temperature of the workpiece at 0C.

3.1.3. Advantages of EDM

The main advantages of D.M. are:

- By this process, materials of any hardness can be machined;
- No burrs are left in the machined surface;
- One of the main advantages of this process is that thin and fragile/brittle component can be machined without distortion;
- Complex internal shapes can be machined

3.1.3. Limitations of EDM

The main limitations of this process are:

- This process can only be employed in electrically conductive materials;
- Material removal rate is low, and the process overall is slow compared to conventional machining processes;
- Unwanted erosion and over cutting of material can occur;
- Rough surface finish when at high rates of material removal.

3.1.4. Dielectric fluids

Dielectric fluids used in the EDM process are hydrocarbon oils, kerosene, and deionized water.

The functions of the dielectric fluid are to:

- Act as an insulator between the tool and the workpiece.
- Act as coolant.
- Act as a flushing medium for the removal of the chips.

The electrodes for the EDM process usually are made of graphite, brass, copper, and copper tungsten alloys.

3.1.5. Design considerations for the EDM process are as follows:

- Deep slots and narrow openings should be avoided.
- The surface smoothness value should not be specified too fine.

Another machining process should do • Rough cut. Only finishing operation should be done in this process as MRR for this process is low.

3.2. WIRE CUT ELECTRICAL DISCHARGE MACHINING (WCEDM)

EDM, primarily, exists commercially in the form of die-sinking machines and wire process, a slowly moving wire travels along a prescribed path and removes material from the workpiece. Wire EDM uses electro-thermal mechanisms to cut electrically conductive materials. The material is removed by a series of discrete discharges between the wire electrode and the workpiece in the presence of dielectric fluid, which creates a path for each shot as the liquid becomes ionized in the gap. The area where combustion occurs is heated to too high temperatures so that the surface is melted and removed. The removed particles are flushed away by the flowing dielectric fluids.

Conclusion

coated wires are also used extensively in this process. The wire used in this process should posse's high tensile strength and good electrical conductivity. Wire EDM can also employ to cut cylindrical objects with high precision. The sparked eroded extrusion dies are presented. This process is usually used in conjunction with CNC and will only work when a part is cut entirely through. The melting temperature of the parts to be machined is an

essential parameter for this process rather than strength or hardness. The surface quality and MRR of the machined surface by wire EDM will depend on different machining parameters such as applied peak current and wire materials. The cables for wire EDM is made of brass, copper, tungsten, molybdenum. Zinc or brass coated wires are also used extensively in this process. The wire used in this process should posses' high tensile strength and good electrical conductivity. Wire EDM can also employ to cut cylindrical objects with high precision. The sparked eroded extrusion dies are presented. This process is usually used in conjunction with CNC and will only work when a part is cut entirely through. The melting temperature of the parts to be machined is an

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References:

1. *Teti, R. Machining of Composite Materials.CIRP Ann.2002,51, 611–634. [CrossRef]*
2. *2.Davim, J.P.Machining Composite Materials; ISTE-Wiley: London, UK, 2009; ISBN 978-1-84821-103-4.*
3. *Lopresto, V.; Caggiano, A.; Teti, R. High-Performance Cutting of Fibre Reinforced Plastic Composite Materials.Procedia CIRP2016,46, 71–82. [CrossRef]*
4. *4.Komanduri, R. Machining of Fiber-Reinforced Composites.Mach. Sci. Technol.1997,1,113–152.*
   5. Gordon, S.; Hillery, M.T. A review of the cutting of composite materials.Proc. Inst. Mech. Eng. Part L J. Mater.Des. Appl.2003,217,35–45.
   6. Dandekar, C.R.; Shin, Y.C. Modeling of machining of composite materials: A review.Int. J. Mach. Tools Manuf.2012,57, 102–121.
   7. Abrão, A.M.; Faria, P.E.; Rubio, J.C.C.; Reis, P.; Davim, J.P. Drilling of fiber-reinforced plastics: A review.J. Mater. Process. Technol.2007,186, 1–7. 8. Li, H.; Qin, X.; He, G.; Jin, Y.; Sun, D.; Price, M. Investigation of chip formation and fracture toughness in orthogonal cutting of UD-CFRP.Int. J. Adv. Manuf. Technol.2016,82, 1079–1088.
   09. Qi, Z.; Zhang, K.; Cheng, H.; Wang, D.; Meng, Q.