INSTITUTE OF AERONAUTICAL ENGINEERING

(Autonomous)
Dundigal, Hyderabad -500 043

MECHANICAL ENGINEERING

COURSE LECTURE NOTES

Course Title	**UNCONVENTIONAL MACHINING PROCESSES**
Course Code	**AMEB50**
Programme	B.Tech
Semester	V
Course Coordinator	Mr. M. Sunil Kumar, Assistant Professor.
Course Faculty	Mr. M. Sunil Kumar, Assistant Professor.
Lecture No	1-60
Topic Covered	All

Course Objectives:

The course should enable the students to:	
I	Understand the need and importance of non-traditional machining methods and process selection.
II	Gain the knowledge to remove material by thermal evaporation, mechanical energy process.
III	Apply the knowledge to remove material by chemical and electro chemical methods.
IV	Analyze various material removal applications by unconventional machining process.

COURSE OUTCOMES (CO's)

CO 1. Compare non-traditional machining, classification, material applications in material removal process
CO 2. Summarize the principle and processes of abrasive jet machining.
CO 3. Understand the principles, processes and applications of thermal metal removal processes.
CO 4. Identify the principles, processes and applications of EBM.
CO 5. Understand the principles, processes and applications of Plasma Machining.

COURSE LEARNING OUTCOMES(CLOs):

Students who complete the course will have demonstrated the ability to do the following:

CLO Code	**At the end of the course, the student will have the ability to:**
AMEB50.01	Understand of fundamentals of the non- traditional machining methods and industrial applications.
AMEB50.02	Compare Conventional and Non- Conventional machining and analyze the different elements of Ultrasonic Machining and its applications.
AMEB50.03	Identify and utilize fundamentals of metal cutting as applied to machining.
AMEB50.04	Understand a problem and apply the fundamental concepts and enable to solve problems arising in metal removal process.
AMEB50.05	Explore the ability to define andformulate the properties of cutting tool materials and characteristics.
AMEB50.06	Illustrate the variables in Abrasive Jet Machining.
AMEB50.07	Explain the different elements of Chemical and Electro chemical Machining and its applications.
AMEB50.08	Comparison between non-traditional machining process with the traditional parameters, energy sources, economics of processes, shape and size of the material.
AMEB50.09	Illustrate different parameters of Electrical Discharge Machining.
AMEB50.10	Develop methods of working for minimizing the production cost.

AMEB50.11	Apply the best suitable advanced manufacturing process for processing of Unconventional materials employed in modern manufacturing industries.
AMEB50.12	Study the parametric influences during processing of materials using developed models.
AMEB50.13	Analyze the different elements of Laser and Electronic Beam machining
AMEB50.14	Apply unconventional machining process in various industrial applications.
AMEB50.15	Analyze and simulate various industrial problems in advanced machining processes using EBM and LBM

Syllabus:

MODULE-I INTRODUCTION

Need for non-traditional machining methods, classifications of modern machining processes, considerations in process selection, materials application, Ultrasonic machining: Elements of the process, mechanics of metal removal, process parameters, economic considerations, application and limitations, recentdevelopments.

MODULE-II ABRASIVE JET MACHINING

Abrasive jet machining, water jet machining and abrasive water jet machining: basic principles, equipments process variables, mechanics of metal removal, MRR, applications and limitations; Electro chemical processes: Fundamentals of electro chemical machining, electro chemical grinding, electro chemical honing and deburring process, metal removal rate in ECM, tool design, surface finish and accuracy, economic aspect of ECM, simple problem for estimation of metal removal rate.

MODULE -III THERMAL METAL REMOVAL PROCESSES

General principle and applications of Electric discharge machining, electric discharge grinding, electric discharge wire cutting processes, power circuits in EDM, mechanism of metal removal in EDM, process parameters.

Selection of tool electrodes and dielectric fluids, surface finish and accuracy, characteristics of spark eroded surface and machine tool selection, wire EDM principle and applications.

MODULE -IV ELECTRON BEAM MACHINING

Generation and control of electron beam for machining, theory of electron beam machining, comparison of thermal and non thermal processes, general principle and applications of laser beam machining, thermal features, cutting speed and accuracy of cut.

MODULE -V PLASMA MACHINING

Application of plasma for machining, metal removal mechanism, process parameters, accuracy and surface finish and other applications of plasma in manufacturing industries; Chemical machining principle, maskants, etchants, applications.

Text Books:

1. V. K. Jain, “Advanced Machining Processes”, Allied Publishers, 1stEdition,2013.
2. Pandey P. C., Shah H.S., “Modern Machining Processes”, Tata McGraw-Hill, 1stEdition, 2013.

Reference Books:

1. Bhattacherya A, “New Technology”, The Institute for Engineers, 1stEdition,1973.
2. C. Elanchezhian, B. VijayaRamnath, M. Vijayan, “Unconventional Machining processes”, Anuradha Publication, 1stEdition,2005.
3. M. K. Singh, “Unconventional Machining processes”, New Age International Publishers, 1stEdition, 2010.

MODULE-I

MANUFACTURING

Manufacturing processes can be broadly divided into two groups:

a) primarymanufacturingprocesses : Provide basic shape andsize

b) secondary manufacturing processes : Provide final shape and size with tightercontrolondimension,surfacecharacteristics

Material removal processes once again can be divided into two groups

1. Conventional MachiningProcesses
2. Non-TraditionalManufacturingProcessesornon-conventionalManufacturing processes

TRADITIONAL MACHINING

Traditional, also termed conventional machining Processes remove material in the form of chips by applying forces on the work material with a wedge shaped cutting tool that is harder than the work material under machining condition.

The major characteristics of conventional machining are:

- Generallymacroscopicchipformationbysheardeformation
- Materialremovaltakesplaceduetoapplicationofcuttingforces
- Cutting tool is harder than work piece at room temperature as well as under machiningconditions

Demerits of conventional machining processes:

- ✓ In conventional machining, metal is removed by chip formation which is an expensive and difficultprocess
- ✓ Chipsproducedduringthisprocessareunwantedby-products
- ✓ Removal of these chips and their disposal and recycling is a very tedious procedure, involving energy andmoney.
- ✓ Very large cutting forces are involved in this process. so proper holding of the workpiece is mostimportant
- ✓ Due to the large cutting forces and large amount of heat generated between the tool and the workpiece interface, undesirable deformation andresidualstressesaredevelopedintheworkpiece.
- ✓ It is not possible to produce chips by conventional machining processfor delicate components like semiconductor.

NON-TRADITIONAL MACHINING (NTM)

Non-Traditional machining also termed unconventional machining processes. Unconventional machining processes is defined as a group of processes 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 tools as it needs to be used for traditional manufacturing processes. Extremely hard and brittle materials are difficult to machine by traditional machining processes such as turning, drilling, shaping and milling. Non traditional 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.

- Veryhardfragilematerialsdifficulttoclampfortraditionalmachining
- When the work piece is too flexible orslender
- When the shape of the part is toocomplex

Several types of non-traditional machining processes have been developed to meet extra required machining conditions. When these processes are employed properly, they offer many advantages over traditional machining processes.

Merits of unconventional machining process:

- ✓ It increasesproductivity
- ✓ It reduces number of rejectedcomponents
- ✓ close tolerance ispossible
- ✓ The tool material need not be harder than workpiece material as in conventionalmachining
- ✓ Harder and difficult to machine materials can be machined by this process
- ✓ Themachinedsurfacedonothaveanyresidualstresses

MATERIAL REMOVAL PROCESSES

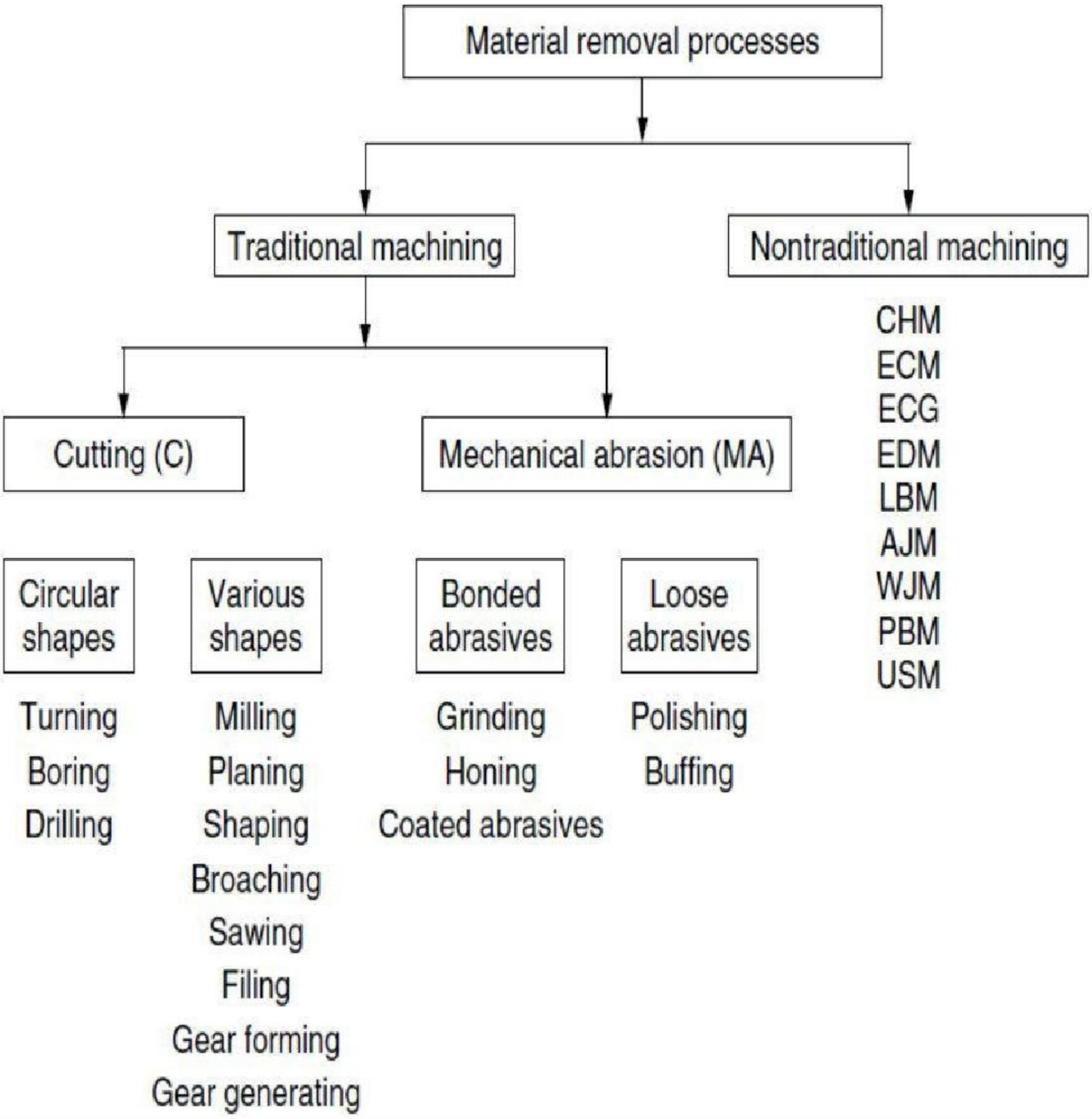


Fig. Material removal processes.

NEED FOR NON-TRADITIONAL MACHINING (NTM)

- ExtremelyhardandbrittlematerialsorDifficulttomachinematerialsare difficulttomachinebytraditionalmachiningprocesses.
- Whentheworkpieceistooflexibleorslendertosupportthecuttingor grindingforces.
- When the shape of the part is toocomplex.
- Intricateshapedblindhole–e.g.squareholeof15mmx15mmwitha depth of 30mm
- Deepholewithsmallholediameter–e.g.φ1.5mmholewithl/d=20
- Machining ofcomposites.

CLASSIFICATION OF NON-TRADITIONAL MACHINING (NTM) PROCESSES

Classification of NTM processes is carried out depending on the nature of energy used for material removal.

1. MechanicalProcesses
   - Abrasive Jet Machining(AJM)
   - Ultrasonic Machining(USM)
   - Water Jet Machining(WJM)
   - Abrasive Water Jet Machining(AWJM)
2. ElectrochemicalProcesses
   - Electrochemical Machining(ECM)
   - Electro Chemical Grinding(ECG)
   - Electro Chemical Honing(ECH)
   - Electro Chemical Deburring(ECD)
3. Electro-ThermalProcesses
   - Electro-discharge machining(EDM)
   - Laser Jet Machining(LJM)
   - Electron Beam Machining(EBM)
4. ChemicalProcesses
   - Chemical Milling(CHM)
   - Photochemical Milling(PCM)

PROCESS SELECTION:

SELECTION OF PROCESSESS FOR DIFFERENT MATERIALS:

All methods are not suitable for all materials. Depending on the material to be machined, following methods can be used as shown in the table

s.no.	Material	Method of Machining
1	Non-metals likeceramics, plastics and glass	USM, AJM, EBM, LBM
2	Refractories	USM, AJM, EDM, EBM
3	Titanium	EDM
4	Super alloys	AJM, ECM, EDM, PAM
5	Steel	ECM, CHM, EDM, PAM

SELECTION OF PROCESSESS FOR APPLICATIONCONSIDERATIONS:

Typical applications of nontraditional processes include special geometric features and work materials that cannot be readily processed by conventional techniques. In this section, we examine these issues. We also summarize the general performance characteristics of nontraditional processes.

Workpart Geometry and Work Materials: Some of the special workpart shapes for which nontraditional processes are well suited are listed in Table below along with the nontraditional processes that are likely to be appropriate.

Table: **Workpart geometric features and appropriate nontraditional processes**

s.no	**GeometricFeature**	**LikelyProcess**
1	Very small holes. Diameters less than 0.125 mm (0.005 in), in some cases down to 0.025 mm (0.001 in), generally smaller than the diameter range of conventional drillbits.	EBM, LBM
2	Holes with large depth-to-diameter ratios, e.g., d/D > 20. Except for gun drilling, these holes cannot be machined in conventional drilling operations	ECM, EDM
3	Holes that are not round. Non-roundholes cannot be drilled with a rotating drillbit.	EDM, ECM
4	Narrow slots in slabs and plates of various materials. The slots are not necessarily straight. In some cases, the slotshave extremely intricate shapes	EBM, LBM, WJC, wire EDM, AWJC
5	Micromachining. In addition to cutting small holes and narrow slits, there are other material removal applications in whichthe Workpart and/or areas to be cut are very small.	PCM, LBM, EBM
6	Shallow pockets and surface details in flat parts. There is a significant range in the sizes of the parts in this category,frommicroscopic integrated circuit chips to large aircraft panels.	CHM
7	Special contoured shapes for mold and die applications. These applications are sometimes referred to as die-sinking	EDM, ECM

Limitations of Unconventional machining process:

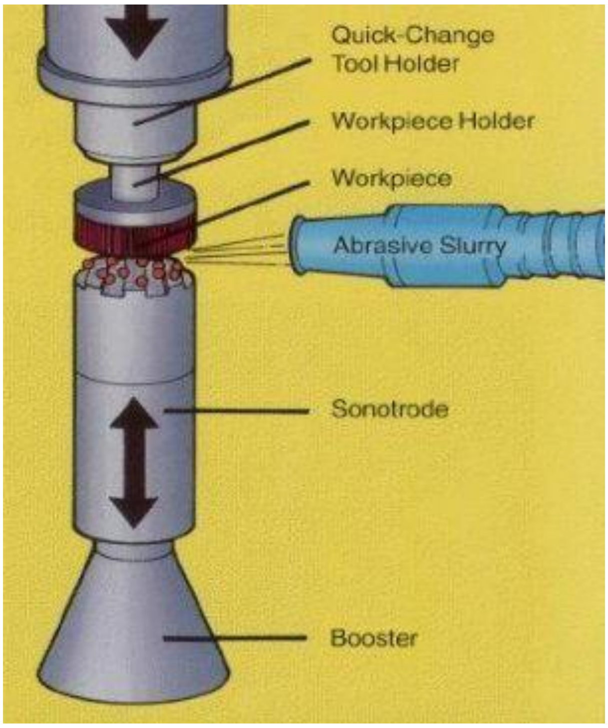
- ✓ UnconventionalMachiningprocessesaremoreexpensive
- ✓ Metal removal rate islow
- ✓ AJM,CHM,PAM,andEBMarenotcommerciallyeconomicalprocesses

MODULE - II

Ultrasonic machining (USM) is the removal of hard and brittle materials using an axially oscillating tool at ultrasonic frequencies [18–20 kilohertz (kHz)].Duringthatoscillation,theabrasiveslurryofB4CorSiCiscontinuously fed into the machining zone between a soft tool (brassor steel) and the workpiece.The abrasive particles are, therefore, hammered into the work piece surface and cause chipping of fine particles from it. The oscillating tool, at amplitudes ranging from 10 to 40 µm, imposes a static pressure on the abrasive grains and feeds down as the material is removed to form the required tool shape (Fig. 2.1). Balamuth first discovered USM in 1945 during ultrasonic grinding of abrasive powders. The industrial applications began in the 1950s when the new machine tools appeared. USM is characterized by the absence of any deleterious effect on the metallic structure of the work piece material.

The machining system

The machining system is composed mainly from the magneto stricter, concentrator, tool, and slurry feeding arrangement. The magnetostrictoris energized at the ultrasonic frequency and produces small-amplitude vibrations. Such a small vibration is amplified using the constrictor (mechanical amplifier) that holds the tool. The abrasive slurry is pumped between the oscillating tool and the brittle work piece. A static pressure is applied in the tool-work piece interface that maintains the abrasiveslurry.



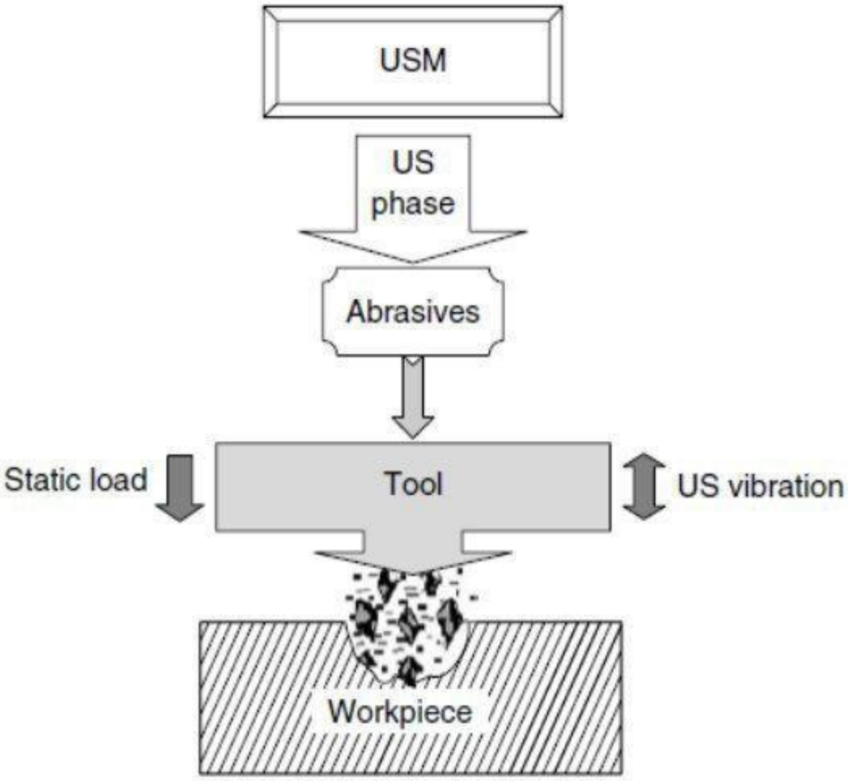


Figure 2.1 USM components.

USM is mechanical material removal process or an abrasive process used to erode holes or cavities on hard or brittle work piece by using shaped tools, high frequency mechanical motion and an abrasive slurry. USM offers a solution to the expanding need for machining brittle materials such as single crystals, glasses and crystalline ceramics, and increasing complex operations to provide intricate shapes and work piece profiles. It is therefore used extensively in machining hard and brittle materials that are difficult to machine by traditional manufacturing processes. The hard particles in slurry are accelerated toward the surface of the work piece 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 itsown.

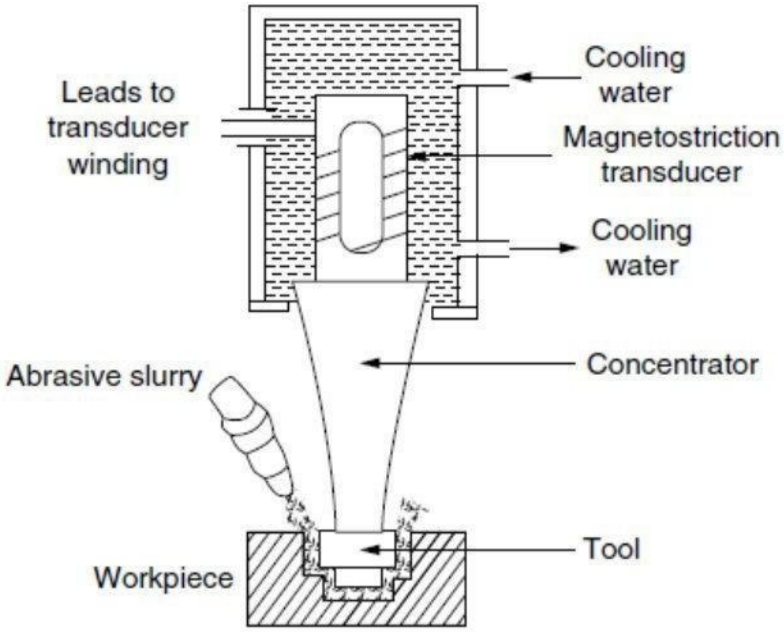


Fig., Main elements of an ultrasonic machining system

USM is primarily targeted for the machining of 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 properties of materials are concerned. This process is able to 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, suchas high-carbon steels.

Theabrasives(25-60mmindia.)inthe(water-based,upto40%solid volume) slurry includes: Boron carbide, silicon carbide and aluminum oxide.

Applications

ThebeautyofUSMisthatitcanmakenonroundshapesinhardandbrittle materials.

Drilling small holes

Making Complex contours

Slots making

Logo making etc.

Advantage of USM

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

Anymaterialscanbemachinedregardlessoftheirelectricalconductivity Especially suitable for machining of brittlematerials

MachinedpartsbyUSMpossessbettersurfacefinishandhigher structuralintegrity.

USMdoesnotproducethermal,electricalandchemicalabnormal surface.

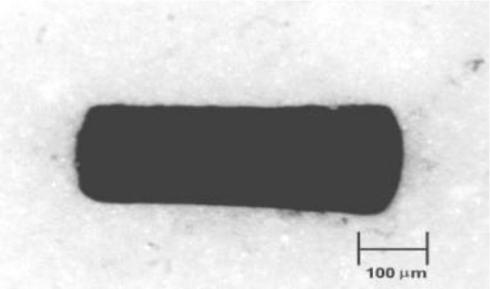
Some disadvantages of USM

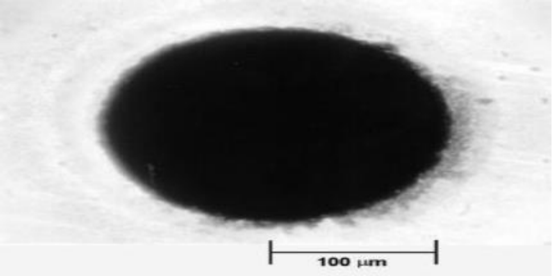
USMhashigherpowerconsumptionandlowermaterial-removalrates than traditional fabricationprocesses.

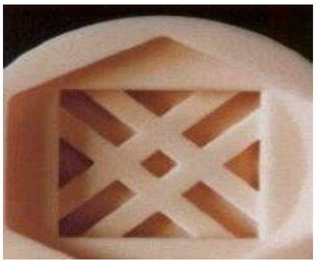
Tool wears fast in USM.

Machining area and depth is restraint in USM.

ULTRASONIC MACHINIE PARTS







Material removal process

The complete material removal mechanism of USM, which involves three distinct actions:

1. Mechanicalabrasionbylocalizeddirecthammeringoftheabrasive grainsstuckbetweenthevibratingtoolandadjacentworksurface.
2. Themicrochippingbyfreeimpactsofparticlesthatflyacrossthe machininggapandstriketheworkpieceatrandomlocations.
3. Theworksurfaceerosionbycavitationintheslurrystream. Therelativecontributionofthecavitationeffectisreportedtobeless than 5 percent of the total materialremoved.

The dominant involved in USM of all materials is direct hammering. Soft and mechanism of elastic materials like mild steel are often plastically deformedfirstandlaterremovedatalowerrate.

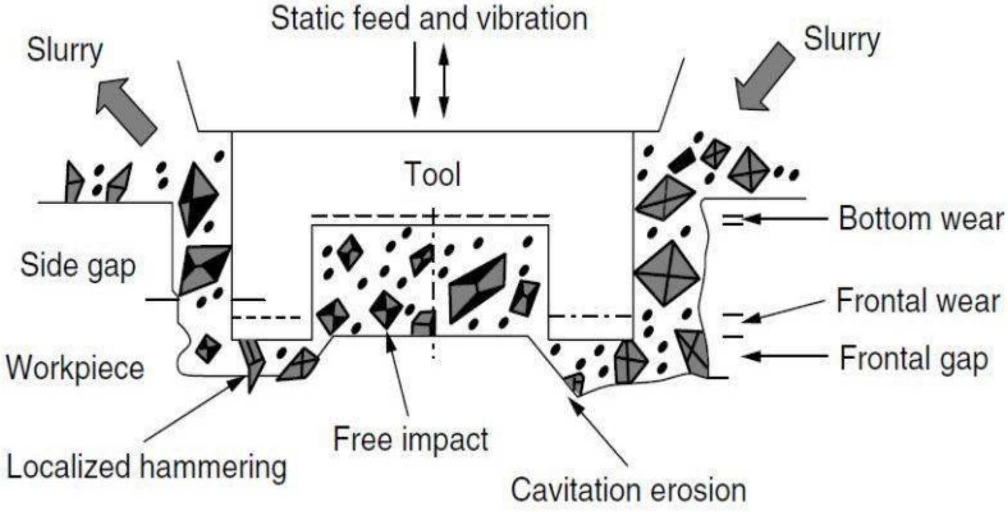


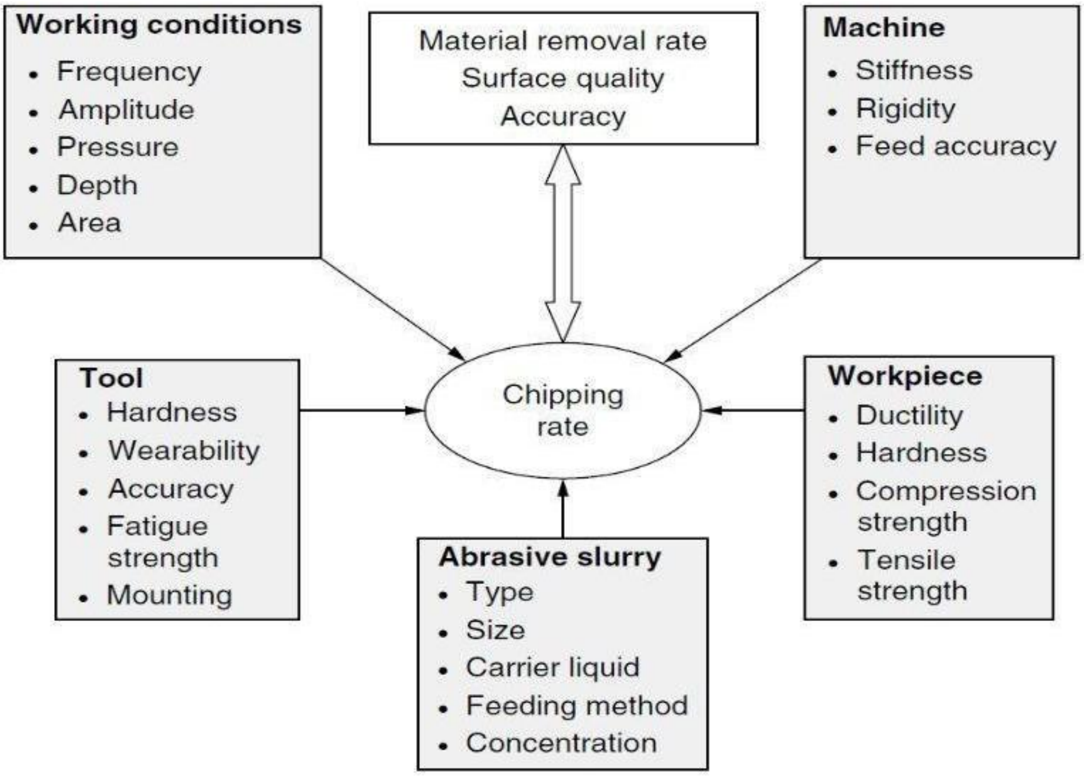
Fig., material removal process inUSMP

In case of hard and brittle materials such as glass, the machining rate is high and the role played by free impact can also be noticed. When machiningporousmaterialssuchasgraphite,themechanismoferosion is introduced. The rate of material removal, in USM, depends, first of all, on the frequency of tool vibration, static pressure, the size of the machined area, and the abrasive and work piece material. The material removal rate and hence the mach inability by USM depends on the brittleness criterion which is the ratio of shearing to breaking strength of a material. According to glass has a higher machinability than that of a metal of similar hardness. Moreover, because of the low brittleness criterion of steel, which is softer, it is used asatool material the important parameters that affect the performance of USM, which are mainly relatedto the tool, work piece material, abrasives, machining conditions, and the ultrasonic machine.

InUSM,thematerialremovalrate(MRR)cangenerallybedescribed using the followingformula.,

$$\mathrm{MRR} = 5.9\mathcal{F}\left(\frac{S}{H_0}\right)R^{0.5}Y^{0.5}$$

Factors affecting USM performance:



The following Factors affecting from USMPare

Working conditions Tools
Abrasive slurry Work
piece

Tool oscillation. The amplitude of the tool oscillation has the greatest effect of all the process variables. The material removal rate increases with a rise in theamplitudeofthetoolvibration.Thevibrationamplitudedeterminesthe between the tool and work piece. Under such circumstances the kinetic energy rises, at larger amplitudes, which enhances the mechanical chipping action and consequently increases the removal rate. A greater vibration amplitude may lead to the occurrence of splashing, which causes a reduction of the number of active abrasive grains andresultsinadecreaseinthematerialremovalrate.

Abrasive grains.

Both the grain size and the vibration amplitude have a similar effect on the removal rate. According to McGeough (1988), the removal rate rises at greater grain sizes until the size reaches the vibration amplitude, at which stage, the material removal rate decreases. When the grain size is large compared to the vibration amplitude,there is a difficulty of abrasive renewal in the machining gap.Because of its higher hardness, B4C achieves higher removal rates than silicon carbide (SiC) when machining a soda glass work piece 33 percent lower for tool steel, and about 35 percent lower for sintered carbide.

Workpiece impact-hardness.

The machining rate is affected by the ratio of the tool hardness to the workpiece hardness. In this regard,the higher the ratio, the lower will be the material removal rate. For this reason soft and tough materials are recommended for USM tools.

Tool shape.

The machining rate is affected by the tool shape and area. An increase in the tool area decreases the machining rate due to the problem of adequately distributing the abrasive slurry over the entire machining zone. It has been reported by McGeough (1988) that, for the same machining area, a narrow rectangular shape yields a higher machining rate than a square cross-sectional one. The rise in the static feed pressure enhances the machining rate up to a limiting condition, beyond which no further increase occurs.

Dimensional accuracy.

Generally the form accuracy of machined parts suffers from the following disturbing factors, which cause oversize,conicity, and out of roundness.

Side wear of the tool
Abrasive wear
Inaccurate feed of the tool holder
Form error of the tool
Unsteadyandunevensupplyofabrasiveslurryaroundtheoscillating Tool.

Overcut.

The process accuracy is measured through the overcut (oversize) produced during drilling of holes. The hole oversize measures the difference between the hole diameter, measured at the top surface, and the tool diameter. The side gap between the tool and the machined hole is necessary to enable the abrasives to flow to the machining zone under the oscillating tool. Hence the grain size of the abrasives represents the main factor, which affects the overcut produced. The overcut is considered to be about two to four times greater than the mean grain size when machining glass and tungsten carbide. It is about three times greater than the mean grain size of B4C (mesh numbers 280–600). However, the magnitude of the overcut depends on many other process variables including the type of work piece material and the methodoftoolfeed.IngeneralUSMaccuracylevelsarelimitedto0.05mm.

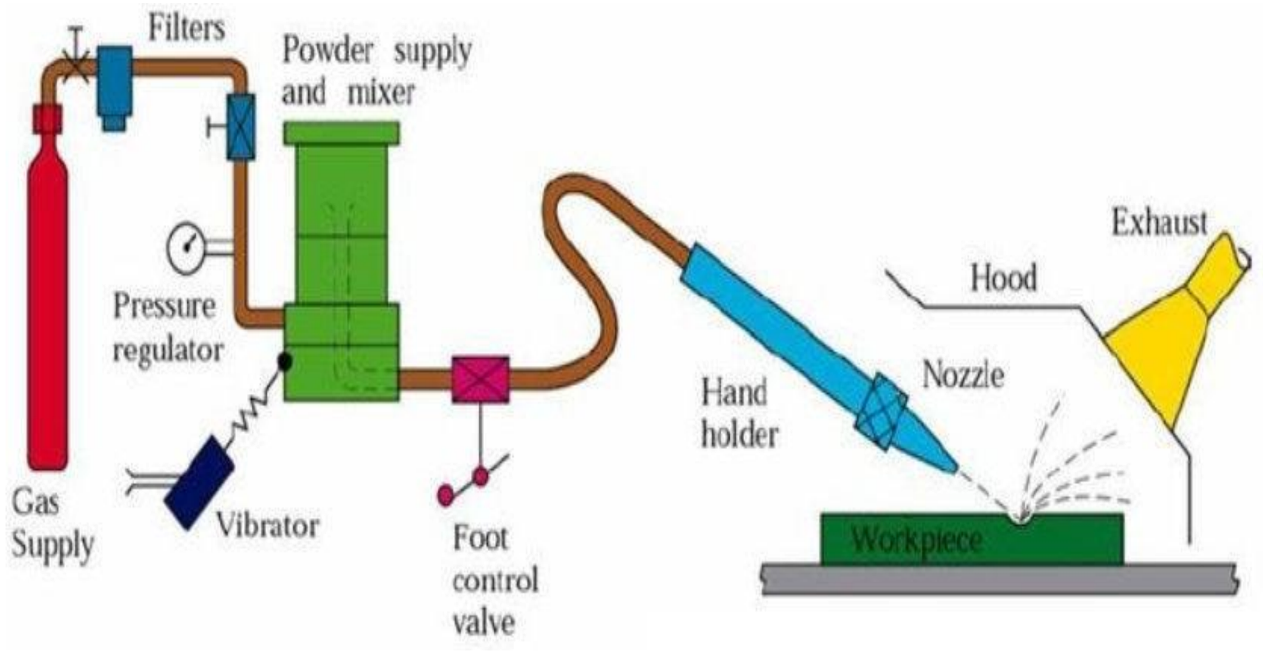
Conicity

Theovercutisusuallygreaterattheentrysidethanattheexitoneduetothe cumulativeabrasioneffectofthefreshandsharpgrainparticles.

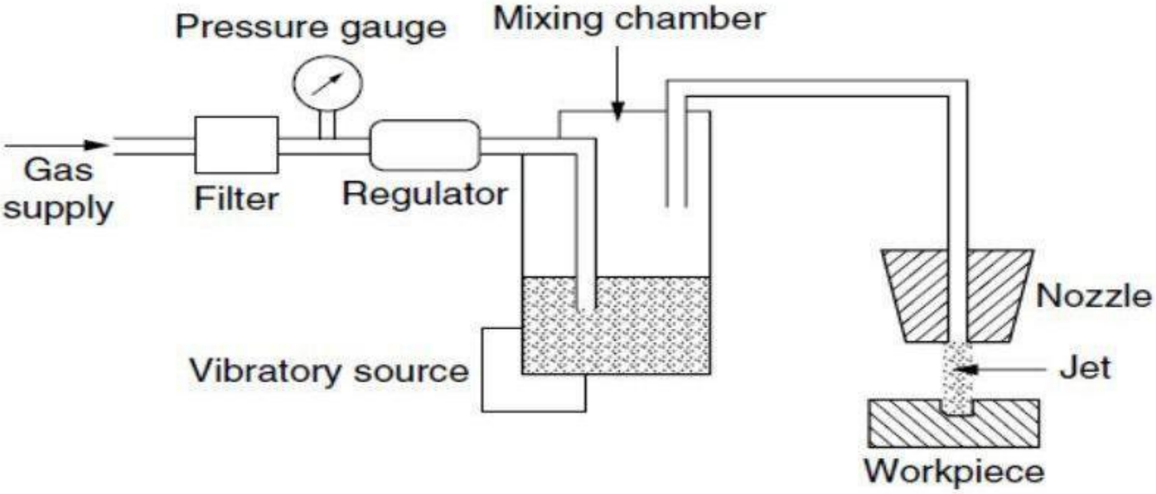
Abrasive Jet Machining

In abrasive jet machining (AJM) a focused stream of abrasive grains of Al2O3orSiCcarriedbyhigh-pressuregasorairatahighvelocityismade to impinge on the work surface through a nozzle of 0.3- to 0.5-mm diameter.The process differs from sandblasting (SB) in that AJM has smaller diameter abrasives and a more finely controlled delivery system. The workpiece material is removed by the mechanical abrasion (MA) action of the high-velocityabrasiveparticles.AJMmachiningisbestsuitedformachiningholes in superhard materials. It is typically used to cut,clean, peen, deburr, deflash, and etch glass, ceramics, or hard metals.

Machining system



In the machining system shown in a gas (nitrogen, CO2, or air)is supplied under a pressure of 2 to 8 kg/cm2. Oxygen should never be used because it causes a violent chemical reaction with workpiece chips or abrasives. After filtration and regulation, the gas is passed through a mixing chamber that contains abrasive particles and vibrates at 50 Hz.From the mixing chamber, the gas, along with the entrained abrasive particles (10–40 μm), passes through a 0.45-mm-diameter tungsten carbide nozzle at a speed of 150 to 300 m/s. Aluminum oxide (Al2O3) and siliconcarbide powders are used for heavy cleaning, cutting, and deburring.Magnesium carbonate is recommended for use in light cleaning and etching, while sodium bicarbonate is used for fine cleaning and the cutting of soft materials. Commercial-grade powders are not suitable because their sizes are not well classified. They may contain silica dust,which can be a health hazard. It is not practical to reuse the abrasive powder because contaminations and worn grit will cause a decline of themachining rate. The abrasive powder feed rate is controlled by the amplitude of vibrations in the mixing chamber. The nozzle standoff distanceis 0.81 mm. The relative motion between the workpiece and the nozzle is manually or automatically controlled using cam drives, pantographs,tracer mechanisms,orusingcomputercontrolaccordingtothecutgeometry required. Masks of copper, glass, or rubber may be used to concentrate the jet stream of abrasive particles to a confined location on theworkpiece. Intricate and precise shapes can be produced by using masks with corresponding contours.



Nozzle at a speed of 150 to 300 m/s. Aluminum oxide (Al2O3) and silicon carbide powders are used for heavy cleaning, cutting, and deburring.Magnesium carbonate is recommended for use in light cleaning and etching, while sodium bicarbonate is used for fine cleaning and the cutting of soft materials. Commercial-grade powders are not suitable because their sizes are not well classified. They may contain silica dust,which can be a health hazard. It is not practical to reuse the abrasive

powder because contaminations and worn grit will cause a decline of the machining rate. The abrasive powder feed rate is controlled by the amplitude of vibrations in the mixing chamber. The nozzle standoff distance is 0.81 mm. The relative motion between the workpiece and the nozzle is manually or automatically controlled using cam drives, pantographs,tracer mechanisms, or using computer control according to the cut geometry required. Masks of copper, glass, or rubber may be used to concentrate the jet stream of abrasive particles to a confined location on the workpiece. Intricate and precise shapes can be produced by using masks with corresponding contours. Dust removal equipmentisincorporatedtoprotecttheenvironment.

Applications

1. Drillingholes,cuttingslots,cleaninghardsurfaces,deburring, polishing.
2. Deburring of cross holes, slots, and threads in small precision parts that require a burr-free finish, such as hydraulic valves, aircraft fuel systems, and medicalappliances
3. Machiningintricateshapesorholesinsensitive,brittle,thin,or difficult-to-machinematerials
4. Insulationstrippingandwirecleaningwithoutaffectingtheconductor
5. Micro-deburring of hypodermicneedles
6. Frostingglassandtrimmingofcircuitboards,hybridcircuitresistors, capacitors, silicon, andgallium
7. Removaloffilmsanddelicatecleaningofirregularsurfacesbecause the abrasive stream is able to followcontours.

Advantages

Theprocessisusedformachiningsuperalloysandrefractorymaterials. It is not reactive with anywork piece material.
No tool changes are required.
Intricate parts of sharp corners can be machined.
Themachinedmaterialsdonotexperiencehardening. Material
utilization ishigh.

Limitations

The removal rate is slow.
Stray cutting can’t be avoided (low accuracy of }0.1 mm).
Thetaperingeffectmayoccurespeciallywhendrillinginmetals.
Theabrasivemaygetimpededintheworksurface.
Suitable dust-collecting systems should be provided. Soft
materials can’t be machined by the process.
Silica dust may be a health hazard

Abrasive Water Jet Machining

WJM is suitable for cutting plastics, foods, rubber insulation, automotive carpeting and headliners, and most textiles. Harder materials such as glass, ceramics, concrete, and tough composites can be cut by adding

abrasives to the water jet during abrasive water jet machining (AWJM),

which was first developed in 1974 to clean metal prior to surface treatment of the metal. The addition of abrasives to the water jet enhanced the material removal rate and produced cutting speeds between 51 and 460 mm/min. Generally, AWJM cuts 10 times faster than the conventional machining methods of compositematerial.

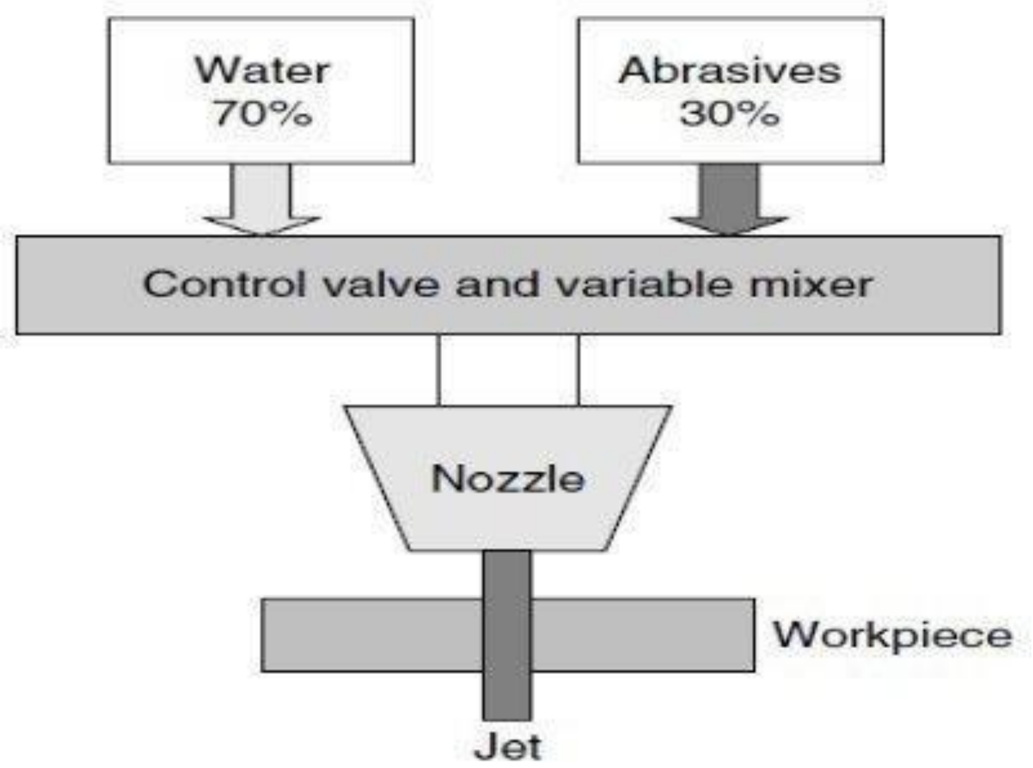


Fig., AWJM elements.

AWJMusesalowpressureof4.2bartoacceleratealargevolumeof awater(70percent)andabrasive(30percent)mixtureuptoavelocity of 30 m/s. Silicon carbides, corundum, and glass beads of grain size 10 to 150 µm are often used as abrasive materials Using such a method, burrs of 0.35 mm height and 0.02 mm width left in steel component after grinding are removed by the erosive effect of the abrasives while water acts as an abrasive carrier that dampens its impact effect on the surface. The introduction of compressed air to the water jet enhances the deburring action.

The machining system

ThebasicmachiningsystemofAWJMincorporatesthefollowing elements.

Water delivery

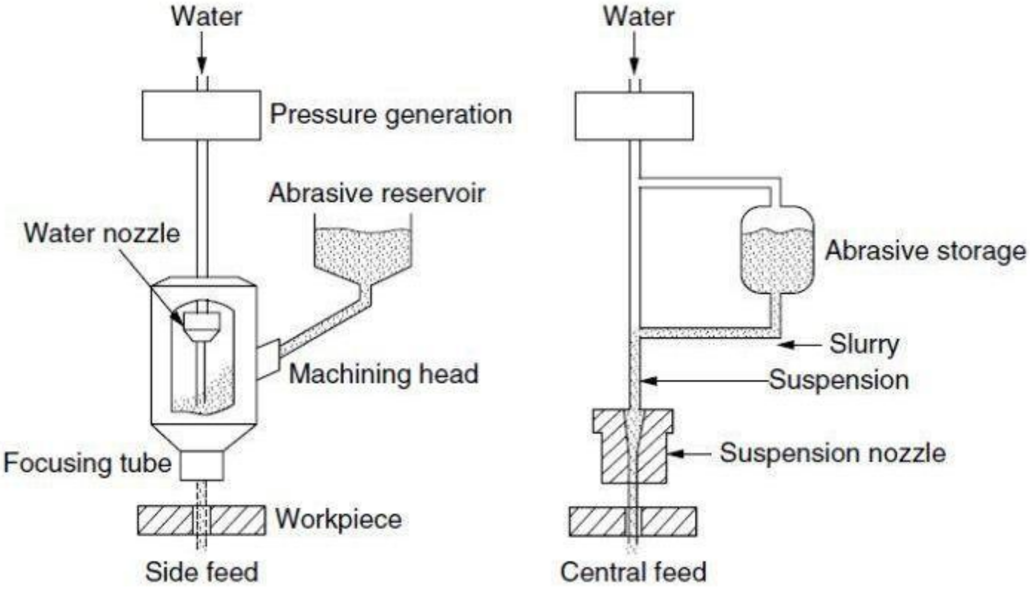
brasive hopper andfeeder Intensifier

Filters

Mixing chamber

Cutting nozzles

Catcher



ig., Injection and suspension jets.

Process capabilities

Typical process variables include pressure, nozzle diameter, standoff distance, abrasive type, grit number, and workpiece feed rate. An abrasive water jet cuts through 356.6-mm-thick slabs of concrete or
76.6-mm-thick tool steel plates at 38 mm/min in a single pass. The
produced surface roughness ranges between 3.8 and 6.4 µm, while tolerances of □}0.13 mm are obtainable. Repeatability of 0.04 mm, squareness of 0.043 mm/m, and straightness of 0.05 mm per axis are expected. Foundry sands are frequently used for cutting of gates and risers. However, garnet, which is the most common abrasive material, is 30 percent more effective than sand. Duringmachiningofglassacuttingrateof16.4mm3/minisachieved,whichis
4 to 6 times that for metals. Surface roughness depends on the work piece material, grit size, and type of abrasives. A material with a high removal rate produceslargesurfaceroughness.Forthisreason,finegrainsareusedfor

machining soft metals to obtain the same roughness as hard ones. The decrease of surface roughness, at a smaller grain size, is related to the reduced depth of cut and the undeformed chip cross sec tion. In addition the larger the number of grains per unit slurry volume, the more that fall on a unit surface area.A carrier liquid consisting of water with anticorrosive additives has a much greater density than air. This contributes to higher acceleration of the grains with a consequent higher grain speed and increased metal removal rate.

Applications

Abrasivewaterjetcuttingishighlyusedinaerospace,automotiveand electronicsindustries.
Inaerospaceindustries,partssuchastitaniumbodiesformilitary aircrafts,engine
Components (aluminium, titanium, heat resistant alloys), aluminium body parts and interior cabin parts are made using abrasive water jet cutting.
In automotive industries, parts like interior trim (head liners, trunk liners,doorpanels)andfibreglassbodycomponentsandbumpersare
madebythisprocess.Similarly,inelectronicsindustries,circuitboards
andcablestrippingaremadebyabrasivewaterjetcutting.

Advantages of abrasive water jet cutting

In most of the 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

Advantages of abrasive water jet cutting

In most of the 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

Surfacefinishdegradesathighercutspeedswhicharefrequentlyused for roughcutting.

Themajordisadvantagesofabrasivewaterjetcuttingarehighcapital cost.

high noise levels during operation

Precise,multiplanecuttingofcontours,shapes,andbevelsofany angle.

Limitations of abrasive water jet cutting

Cannot drill flat bottom

Cannot cut materials that degrades quickly with moisture

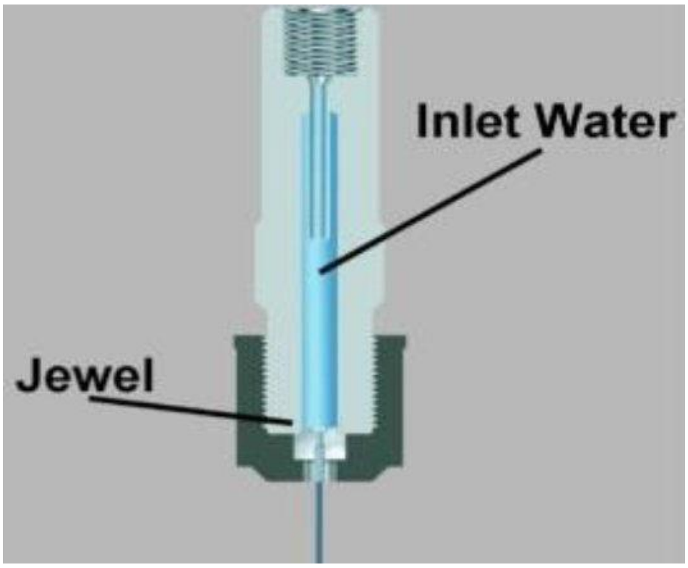
Surfacefinishdegradesathighercutspeedswhicharefrequentlyused for roughcutting.

Themajordisadvantagesofabrasivewaterjetcuttingarehighcapital cost.

high noise levels during operation

Water Jet Machining

Water jet cutting can reduce the costs and speed up the processes by eliminating or reducing expensive secondary machining process. Since no heat is applied on the materials, cut edges are clean with minimal burr. Problems such as cracked edge defects, crystallisation, hardening, reduced weldability and machinability are reduced in this process. Water jet technology uses the principle of pressurising water to extremely high pressures, and allowing the water to escape through a very small 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 pressurised between 1300 –4000 bars. This high pressure is forced through a tiny hole in the jewel, which is typically o.18 to 0.4 mm in diameter.



Applications

Water jet cutting is mostly used to cut lower strength materials such as wood, plastics and aluminium. When abrasives are added, (abrasive water jet cutting)strongermaterialssuchassteelandtoolsteelcanbecut.

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 properties of the material.

Unlike machining or grinding, water jet cutting does not produceany dust or particles thatare harmful if inhaled.

Disadvantages of water jet cutting

Oneofthemaindisadvantagesofwaterjetcuttingisthatalimited numberofmaterialscanbecuteconomically.

Thick parts cannot be cut by this process economically and accurately. Taper is also a problem with water jet cutting in very thick materials. Taper is when the jet exits the part at different angle than it enters the part, and cause dimensionalinaccuracy.

Material removal rate

the abrasive particles from the nozzle follow parallel paths for a short distance and then the abrasive jet flares outward like a narrow cone. When the sharp-edged abrasive particles of Al2O3 or SiC hit a brittle and fragile material at high speed, tiny brittle fractures are created from which small particles dislodge. The lodged out particles are carried away by the air or gas.

The material removal rate VRR, is givenby

$$\mathrm{VRR} = KNd_a^{\,3}v^{3/2}\left(\frac{\rho_a}{12H_w}\right)^{3/4}$$

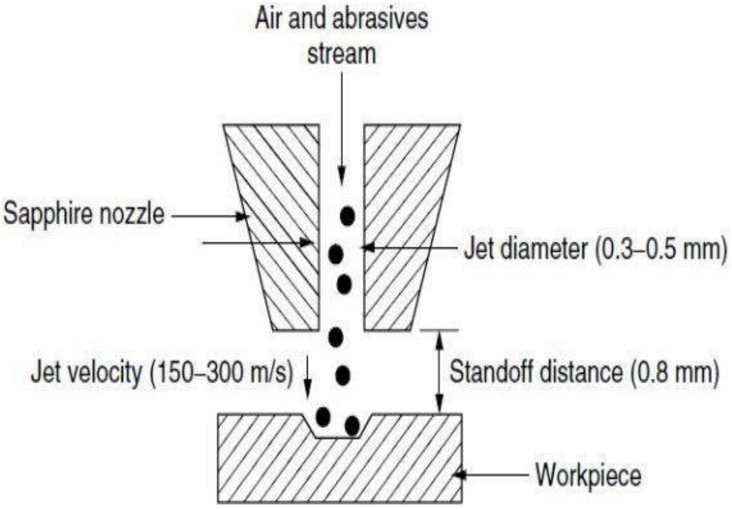


Fig., material removal rate in AJM process. where *K*

= constant

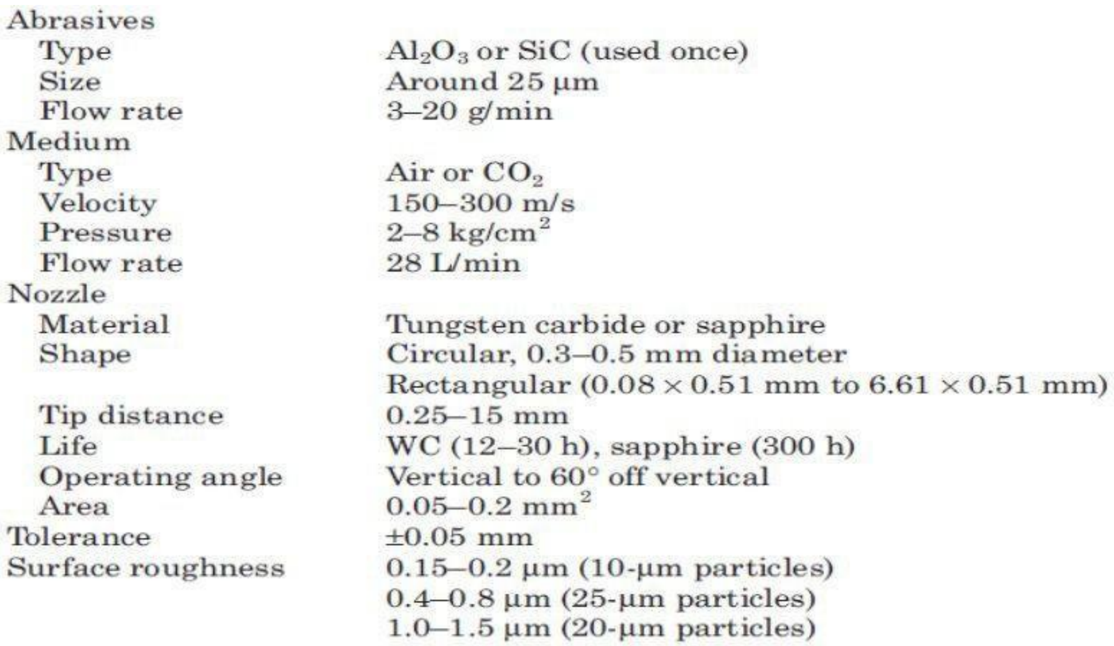
N = number of abrasive particlesimpacting/unit area

da = mean diameter of abrasive particles,μm

ra= density of abrasive particles, kg/mm3 *Hw*= hardness number of the work material *n* = speed of abrasive particles,m/s

The material removal rate, cut accuracy, surface roughness, and nozzle wear are influenced by the size and distance of the nozzle; composition,strength, size, and shape of abrasives; flow rate; and composition, pressure,and velocity of the carrier gas. The material removal rate is mainly dependent on the flow rate and size of abrasives. Larger grain sizes produce greater removal rates. At a particular pressure, the volumetric removalrateincreaseswiththeabrasiveflowrateuptoanoptimumvalueand then decreases with any further increase in flow rate. This is due to the fact that the mass flow rate of the gas decreases with an increase in the abrasive flow rate and hence the mixing ratioincreases causingadecreaseintheremovalratebecauseofthedecreasingenergy available for materialremoval.

AJM Process Characteristics

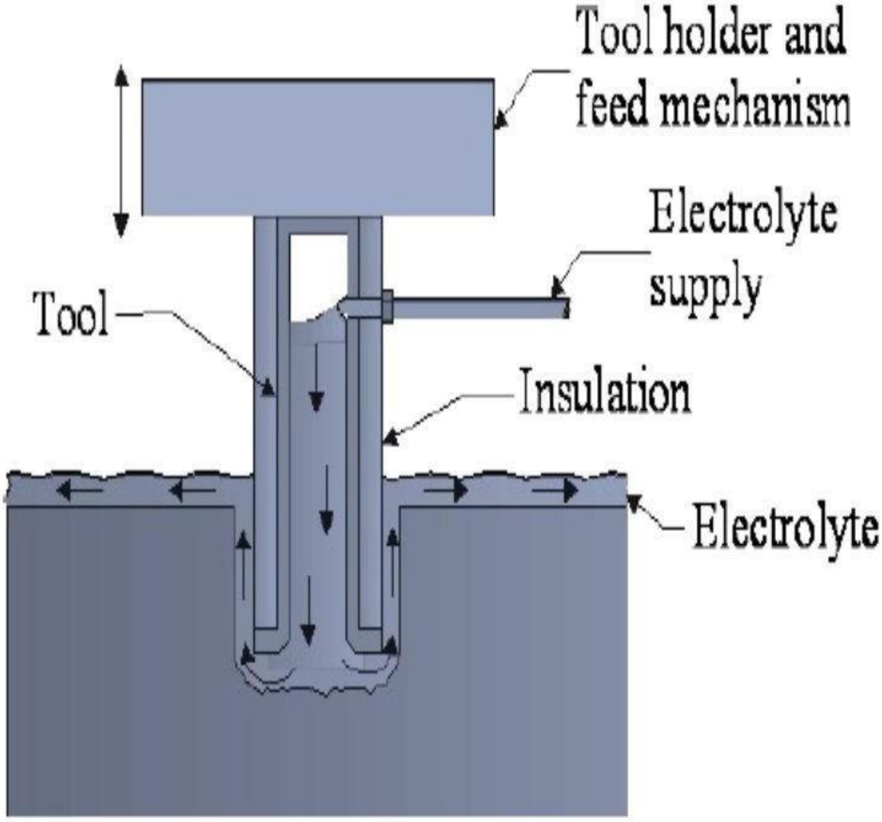


Abrasives	
Type	Al_2O_3 or SiC (used once)
Size	Around 25 μm
Flow rate	3–20 g/min
Medium	
Type	Air or CO_2
Velocity	150–300 m/s
Pressure	2–8 kg/cm^2
Flow rate	28 L/min
Nozzle	
Material	Tungsten carbide or sapphire
Shape	Circular, 0.3–0.5 mm diameter Rectangular (0.08 × 0.51 mm to 6.61 × 0.51 mm)
Tip distance	0.25–15 mm
Life	WC (12–30 h), sapphire (300 h)
Operating angle	Vertical to 60° off vertical
Area	0.05–0.2 mm^2
Tolerance	±0.05 mm
Surface roughness	0.15–0.2 μm (10-μm particles) 0.4–0.8 μm (25-μm particles) 1.0–1.5 μm (20-μm particles)

MODULE-III

Electrochemical Machining (ECM)

Electrochemical machining (ECM) is a metal-removal process based on the principle of reverse electroplating. In this process, particles travel from the anodic material (workpiece) toward the cathodic material (machining tool). A current of electrolyte fluid carries away the deplated material before it has a chance to reach the machining tool. The cavity produced is the female mating image of the tool shape.



Similar to EDM, the work piece hardness is not a factor, making ECM suitable for machining difficult-to –machine materials. Difficult shapes can be made by this process on materials regardless of their hardness. The ECM tool is positioned very close to the workpiece and a low voltage, high amperage DC current is passed between the work piece and electrode.

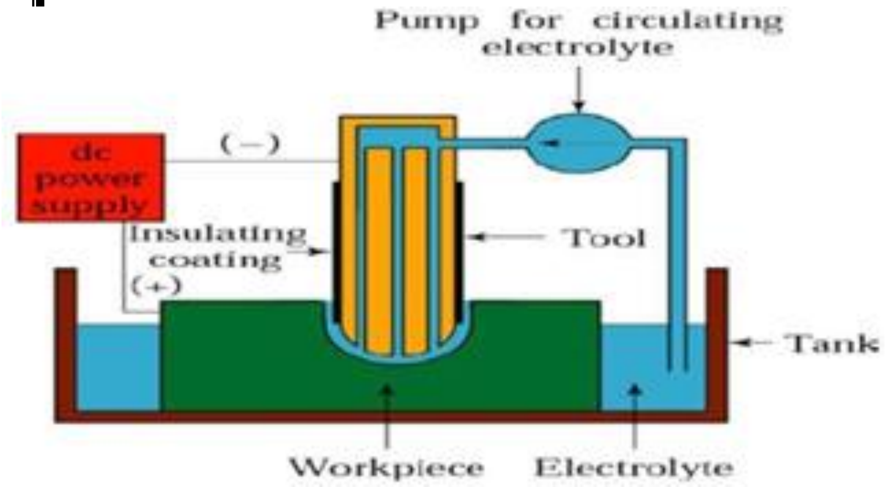


Fig.,Parts made by ECM

Advantages of ECM

Thecomponentsarenotsubjecttoeitherthermalor mechanical stress. No tool wear during ECMprocess.

Fragilepartscanbemachinedeasilyasthereisnostressinvolved.

ECMdeburringcandeburdifficulttoaccessareasofparts.

High surface finish (up to 25 µm in) can be achieved by ECM process. Complex geometrical shapes in high-strength materials particularly in the aerospace industry for the mass production of turbine blades, jet- engine parts and nozzles can be machined repeatedly and accurately. Deep holes can be made by thisprocess

Limitations of ECM

ECMisnotsuitabletoproducesharpsquarecornersorflatbottoms becauseofthetendencyfortheelectrolytetoerodeawaysharp profiles.

ECMcanbeappliedtomostmetalsbut,duetothehighequipment costs,isusuallyusedprimarilyforhighlyspecializedapplications.

Material removal rate

MRR, in electrochemical machining:

MRR = C .I. h (cm3/min)

Where.,

C: specific (material)

removal rate (e.g., 0.2052 cm3/amp-min for nickel);

I: current (amp);

h: current efficiency (90–100%).

The rates at which metal can electrochemically remove are in proportion to the current passed through the electrolyte and the elapsed time for that operation. Many factors other than current influence the rate of machining. These involve electrolyte type, rate of electrolyte flow, and some other process conditions.

Electrochemical Grinding

Electrochemical grinding (ECG) utilizes a negatively charged abrasive grinding wheel, electrolyte solution, and a positively charged workpiece,as shown in Fig. 6.2. The process is, therefore, similar to ECM

except that the cathode is a specially constructed grinding wheel instead of a cathodic shaped tool like the contour to be machined by ECM. The insulating abrasive material (diamond or aluminum oxide) of the grinding wheel is set in a conductive bonding material. In ECG,thenonconducting abrasive particles act as a spacer between the wheel conductive bond and the anodic workpiece. Depending on the grain size of these particles, a constant interelectrode gap (0.025mmorless)throughwhichtheelectrolyteisflushedcanbemaintained.

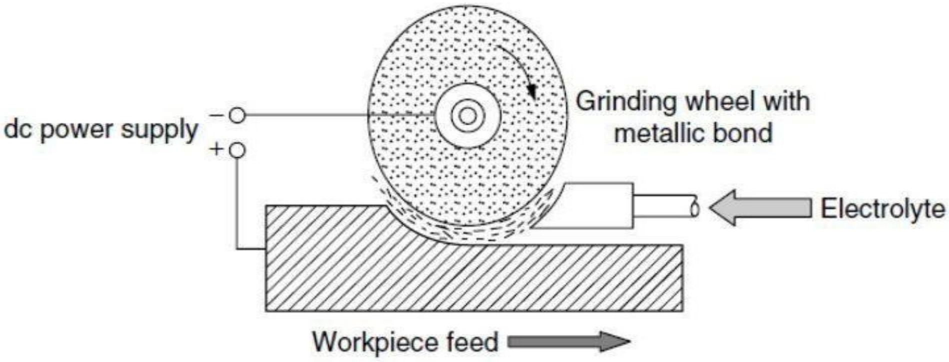
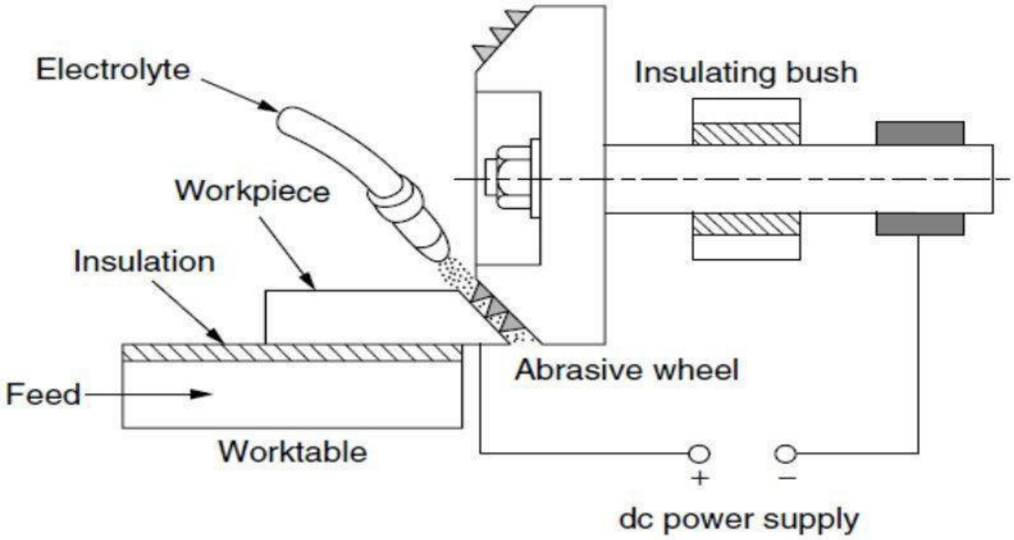


Fig., Surface ECG.

The abrasives continuously remove the machining products from the working area. In the machining system shown in Fig. 6.3, the wheel is a rotating cathodic tool with abrasive particles (60–320 grit number) on its periphery. Electrolyte flow, usually NaNO3, is provided for ECD.The wheel rotates at a surface speed of 20 to 35 m/s, while current ratings are from 50 to 300A.



Removal rates by ECG are 4 times faster than by conventional grinding,and ECG always produces burr-free parts that are unstressed. The volumetric removal rate (VRR) is typically 1600 mm3/min. McGeough (1988) and Brown (1998) claimed that to obtain the maximum removal rate, the grinding area should be as large as possible to draw greater machining current, which affects the ECD phase. The volumetric removal rate (mm3/min) in ECG can be calculated using the following equation:

$$\mathrm{VRR} = \frac{\varepsilon I}{\rho F}$$

Where

e = equivalent weight, g

I = machining current, A

r = density of workpiece material,g/mm3

F = Faraday’s constant, C

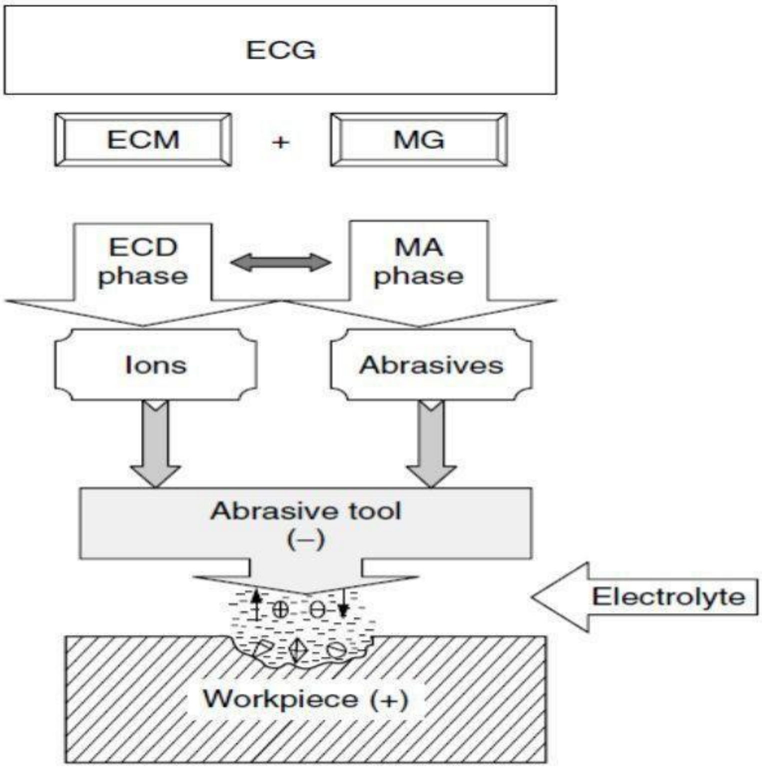
The speed of penetration of the grinding wheel into the workpiece, *Vg* (mm3/min), is given by Kalpakjian (1997) as follows:

$$V_g = \frac{\varepsilon}{\rho F} \frac{\upsilon}{g_w K_p} \kappa$$

Where

v = gap voltage, V
gw= wheel-workpiece gap, mm
Kp= coefficient of loss (1.5–3)
k = electrolyte conductivity, Ω–1mm–1

ECGisahybridmachiningprocessthatcombinesMAandECD.The machiningrate,therefore,increasesmanytimes;surfacelayerproperties are improved, while tool wear and energy consumption are reduced. While Faraday’s laws govern the ECD phase, the action of the abrasive grains depends on conditions existing in the gap, such as the electric field, transport of electrolyte, and hydrodynamic effects on boundary layers near the anode. The contribution of either of these two machining phases in the material removal process and in surface layer formation depends on the process parameters.



The work of the abrasive grains performs the mechanical depolarization by abrading the possible insoluble films from the anodic workpiece surface. Such films are especially formed in case of alloys of many metals and cemented carbides. A specific purpose of the abrasive grains is, therefore, to depassivate mechanically the workpiecesurface.

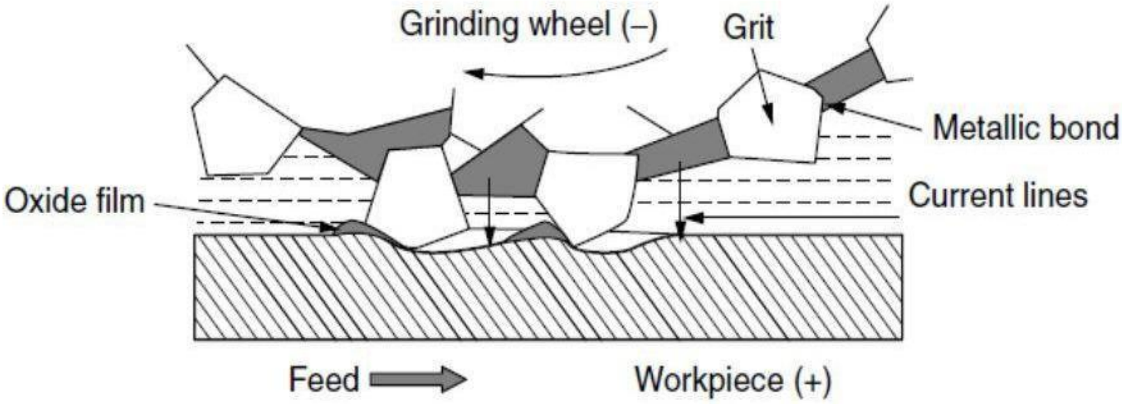


Fig., ECD and MA in the machining gap during ECG.

Applications

The ECG process is particularly effectivefor

1. Machining parts made from difficult-to-cut materials, such assintered carbides,creep-resisting(Inconel,Nimonic)alloys,titanium alloys, and metallic composites.
2. Applicationssimilartomilling,grinding,cuttingoff,sawing,and tool and cuttersharpening.
3. Productionoftungstencarbidecuttingtools,fragileparts,andthinwalled tubes.
4. Removaloffatiguecracksfromsteelstructuresunderseawater.In such an application holes about 25 mm in diameter, in steel 12 to 25 mm thick, have been produced by ECG at the ends of fatigue crackstostopfurtherdevelopmentofthecracksandtoenablethe removal of specimens for metallurgicalinspection.
5. Producingspecimensformetalfatigueandtensiletests.
6. Machiningofcarbidesandavarietyofhigh-strengthalloys

Advantages

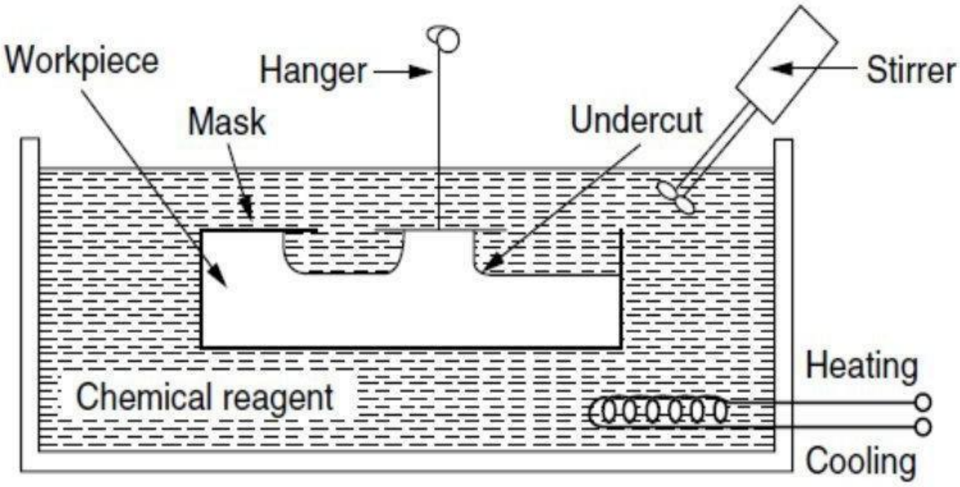
Absence of work hardening Elimination of
grinding burrs
Absence of distortion of thin fragile or thermo sensitive parts Good surface
quality
Production of narrow tolerances Longer
grinding wheel life

Disadvantages

Higher capital cost than conventional machines Process
limited to electrically conductive material Corrosive nature of
electrolyte
Requires disposal and filtering of electrolyte

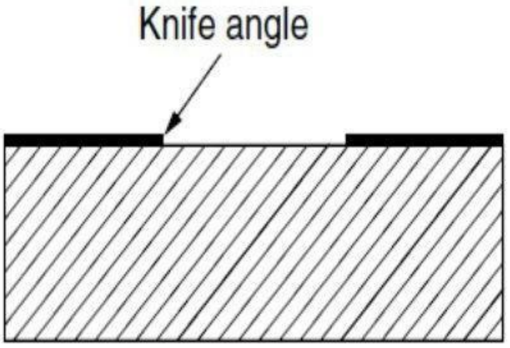
Chemical Machining (CM)

Chemical machining (CM) is the controlled dissolution of workpiece material (etching) by means of a strong chemical reagent (etchant). In CM material is removed from selected areas of workpiece by immersing it in a chemical reagents or etchants; such as acids and alkaline solutions. Material is removed by microscopic electrochemical cell action, as occurs in corrosion or chemical dissolution of a metal. This controlled chemical dissolution will simultaneously etch all exposed surfaces even though the penetration rates of the material removal may be only 0.0025–0.1 mm/min. The basic process takes many forms: chemical milling of pockets, contours, overall metal removal, chemical blanking for etching through thin sheets; photochemical machining (pcm) for etching by using of photosensitive resistsin
microelectronics; chemical or electrochemical polishing where weak chemical reagents are used (sometimes with remote electric assist) for polishing or deburring and chemical jet machining where a single chemically active jet is used.

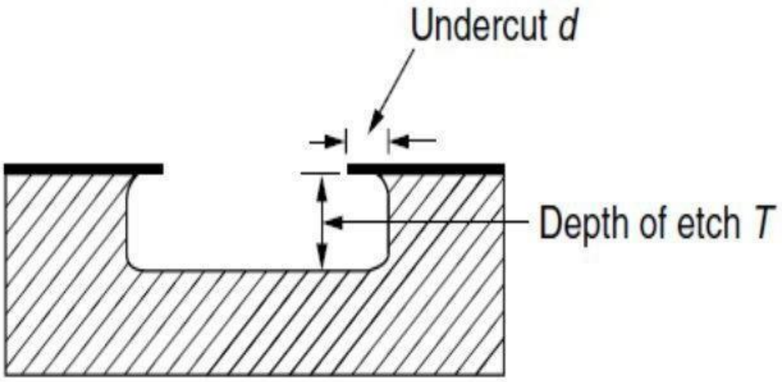


CHM consists of the following steps:

1. Preparingandprecleaningtheworkpiecesurface.Thisprovidesgoodadhesion of themasking material and assures the absence of contaminants that might interfere with the machiningprocess.
2. Maskingusingreadilystrippablemask,whichischemicallyimpregnable andadherentenoughtostandchemicalabrasionduringetching.
3. Scribing of the mask, which is guided by templates to expose the areas that receive CHM. The type of mask selected depends on the size of the workpiece, the number of parts to be made, and the desired resolution of details. Silk-screen masks are preferred for shallow cuts requiring close dimensionaltolerances.
4. Theworkpieceisthenetchedandrinsed,andthemaskisremoved before the part is finished.



Before etching



After etching

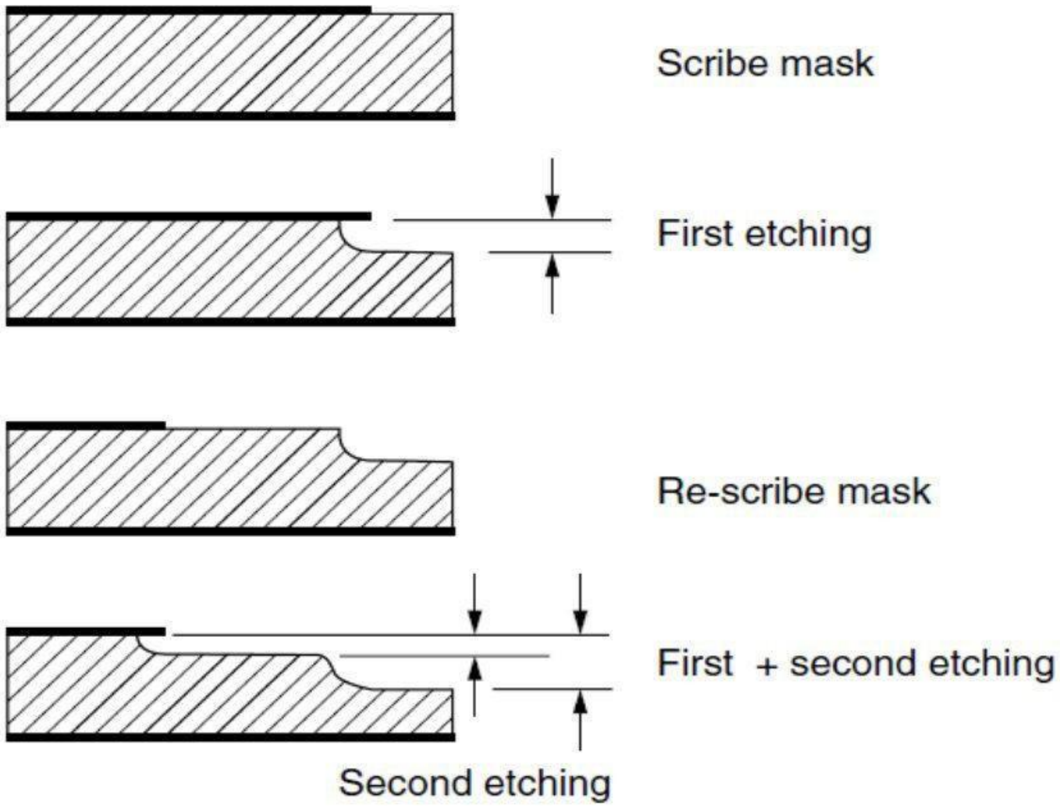


Fig.,Contour cuts by CHM.

CHM will not eliminate surface irregularities, dents, scratches, or waviness.SuccessivestepsofmaskremovalandimmersionasshowninFig. 3.3 can achieve stepped cuts. Tapered cuts (Fig. 3.4), can also be produced without masking the work piece by controlling the depth and rate of immersion orwithdrawalandthenumberofimmersions.Continuoustapers,asgreatas 0.060 mm/mm for aluminium and 0.010 mm/mm for steel alloys.

Tooling for CHM

Tooling for CHM is relatively inexpensive and simple to modify. Four different types of tools are required: maskants, etchants, scribing templates,and accessories.

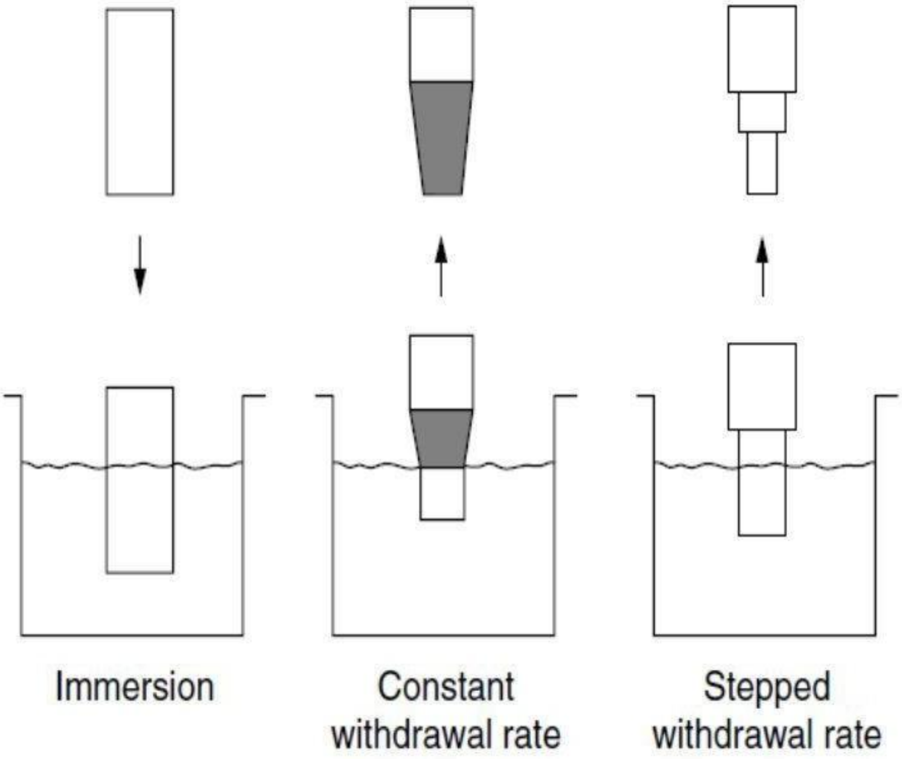


Fig., Machining tapers and steps by CHM.

Maskants

Maskants are generally used to protect parts of the workpiece where CD action is not needed. Synthetic or rubber base materials are frequently used. Table 3.1 shows the different maskants and etchants for several materials together with the etch rate and etch factor. Maskants should, however, possess the following properties:

1. Be tough enough to withstand handling
2. Adhere well to the workpiece surface
3. Scribe easily
4. Be inert to the chemical reagent used
5. Be able to withstand the heat generated by etching
6. Be removed easily and inexpensively after etching

Spraying the mask on the workpiece through silk screen, on which the desired design is imposed, combines the maskant application with the scribing operation since no peeling is required. The product quality is, therefore, improved as is the ability to generate finer details.However, the thin coating layer applied when using silk screens will not resist etching for a long time as will the cut-and-peelmethod.

Photoresist masks, which are used in photochemical milling (PCM), also combine both the coating and scribing operations. The relatively thin coats applied as dip or spray coats will not withstand rough handling or long exposure times to the etchant. However, photoresist masks ensure high accuracy, ease of repetition for multiple-part etching, and ease of modification. The accuracy obtained for lateral dimensions depends on the complexity of the masking. Typical tolerances for the different masks are as follows:

Cut-and-peel masks ±0.179mm Silk-
screen resist ±0.077 mm Photoresist
±0.013 mm

Etchants

Etchantsareacidoralkalinesolutionsmaintainedwithinacontrolledrangeof chemical composition and temperature. Their main technical goals are to achieve thefollowing:

1. Good surfacefinish
2. Uniformity of metalremoval
3. Control of selective and intergranularattack
4. Controlofhydrogenabsorptioninthecaseoftitaniumalloys
5. Maintenance of personalsafety
6. Bestpriceandreliabilityforthematerialstobeusedinthe construction of the processtank.
7. Maintenanceofairqualityandavoidanceofpossibleenvironmental Problems.
8. Low cost per unit weightdissolved
9. Abilitytoregeneratetheetchantsolutionand/orreadilyneutralize and dispose of its wasteproducts

Process parameters

CHM process parameters include the reagent solution type, concentration, properties,mixing,operatingtemperature,andcirculation.Theprocessisalso affectedbythemaskantanditsapplication.Theseparameterswillhavedirect impactsontheworkpieceregardingthefollowing:

1. Etch factor (*d*/*T*)
2. Etching and machiningrate
3. Productiontolerance
4. Surfacefinish

To machine high-quality and low-cost parts using CHM, we must consider the heat treatment state of the workpiece, the grain size and range of the workpiece material, the size and finish control prior to CHM, the direction of rolling and weld joints, and the degree of coldwork

Advantages

The process has the followingadvantages:

Weightreductionispossibleoncomplexcontoursthataredifficultto machine using conventionalmethods.
Simultaneousmaterialremoval,fromallsurfaces,improvesproductivity and reduceswrapping.
No burrs are formed.
No stress is introduced to the workpiece, which minimizes the part distortion and makes machining of delicate parts possible.
A continuous taper on contoured sections is achievable.
Thecapitalcostofequipment,usedformachininglargecomponents,is relativelylow.
Design changes can be implemented quickly. A less skilled operator is needed.

Limitations

CHM does have limitations and areas ofdisadvantage:

Only shallow cuts are practical: up to 12.27 mm for sheets and plates,3.83 mm on extrusions, and 6.39 mm on forgings.
Handling and disposal of chemicals can be troublesome.

Handmasking,scribing,andstrippingcanbetime-consuming, repetitive, andtedious.

Surface imperfections are reproduced in the machined parts. Metallurgical homogeneous surfaces are required for best results. Deep narrow cuts are difficult to produce.

Fillet radii are fixed by the depth of cut. Porous castings yield uneven etched surfaces.

Weldedareasfrequentlyetchatratesthatdifferfromthebasemetal. Material removal from one side of residually stressed material can result in a considerabledistortion.

The absence of residual stresses on the chemically machined surfaces canproduceunfavourablefatiguestrengthcomparedwiththeprocesses that induce compressive residualstresses.

Hydrogenpickupandintergranularattackareaproblemwithsome materials.

Thestraightnessofthewallsissubjecttofilletandundercutting limitations.

Scribing accuracy is limited and complex designs become expensive.

Applications

All the common metals including aluminium, copper, zinc, steel, lead, and nickel can be chemically machined. Many exotic metals such as titanium,molybdenum,andzirconium,aswellasnon-metallicmaterials including glass, ceramics, and some plastics, can also be used with the process.

CHM applications range from large aluminium airplane wing parts to minute integrated circuit chips. The practical depth of cut ranges between2.54to12.27mm.Shallowcutsinlargethinsheetsareofthe mostpopularapplicationespeciallyforweightreductionofaerospacecomponents. Multiple designs can be machined from the same sheet at the same time. CHM is used to thin out walls, webs, and ribs of parts that have beenproducedbyforging,casting,orsheetmetalforming,asFurtherprocess applications related to improvingsurface.

characteristics include the following:

1. Eliminationofalphacasefromtitaniumforgingsandsuperplasticformed parts
2. Eliminationofthedecarburizedlayerfromlowalloysteelforgings
3. EliminationoftherecastlayerfrompartsmachinedbyEDM
4. Removalofsharpburrsfromconventionallymachinedpartsofcomplex shapes
5. Removal of a thin surface from forgings and castings prior to penetration In section below the surface (required for the detection of hiddendefects).

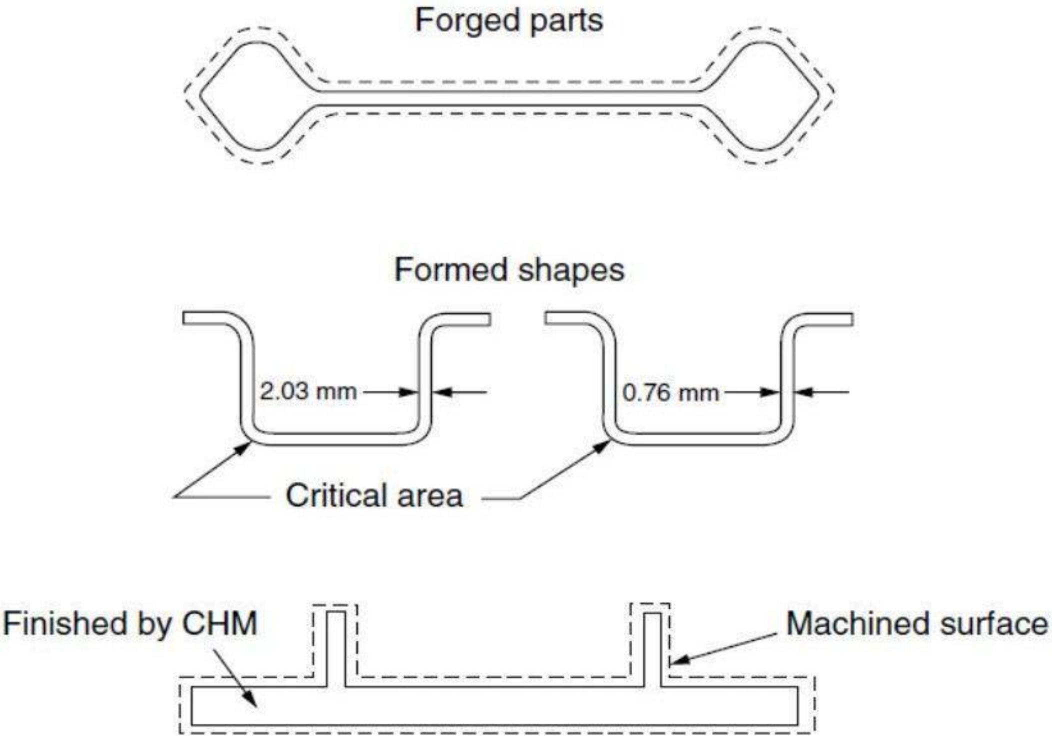


Fig., Thinning of parts by CHM

MODULE-IV

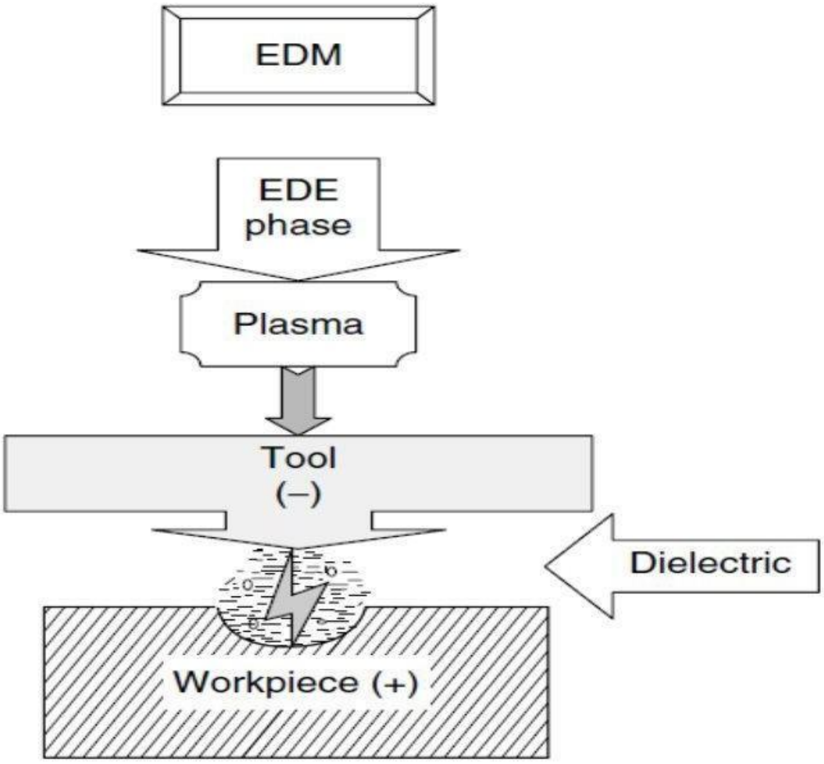
Electro discharge Machining(EDM)

Introduction

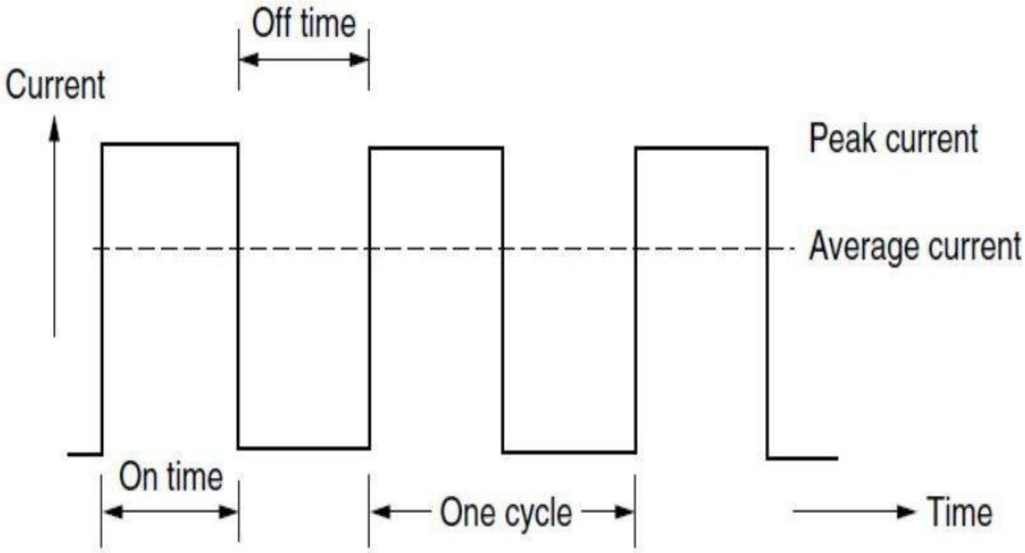
The history of electrodischarge machining (EDM) dates back to the days of World Wars I and II when B. R. and N. I. Lazarenko invented the relaxation circuit (RC). Using a simple servo controller they maintained the gap width between the tool and the workpiece, reduced arcing, and made EDM more profitable. Since 1940, die sinking by EDM has been refined using pulse generators, planetary and orbital motion techniques,computer numerical control (CNC), and the adaptive control systems.During the 1960s the extensive research led the progress of EDM when numerous problems related to mathematical modeling were tackled.The evolution of wire EDM in the 1970s was due to the powerful generators,new wire tool electrodes, improved machine intelligence, and better flushing. Recently, the machining speed has gone up by 20 times,which has decreased machining costs by at least 30 percent and improved the surface finish by a factor of 15. EDM has the followingadvantages.

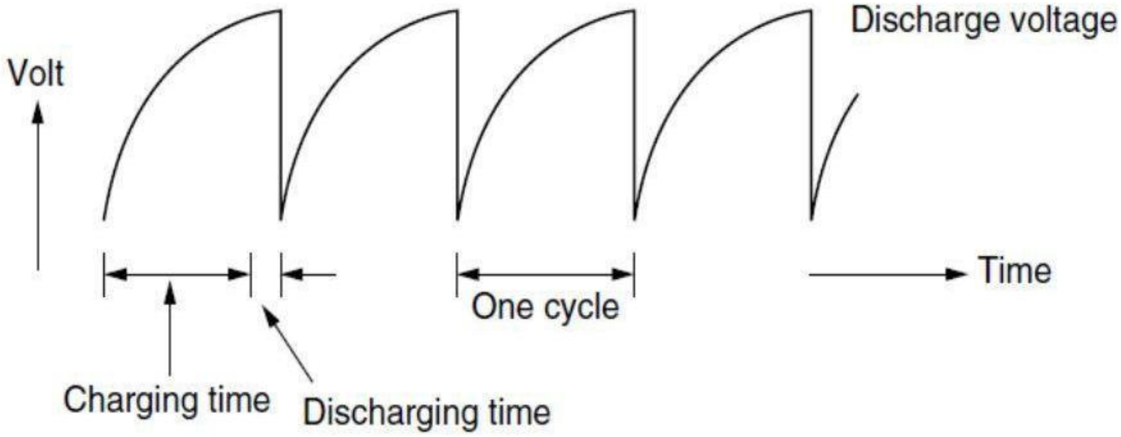
1. Cavitieswiththinwallsandfinefeaturescanbeproduced.
2. Difficult geometry ispossible.
3. TheuseofEDMisnotaffectedbythehardnessofthework material.
4. The process isburr-free.

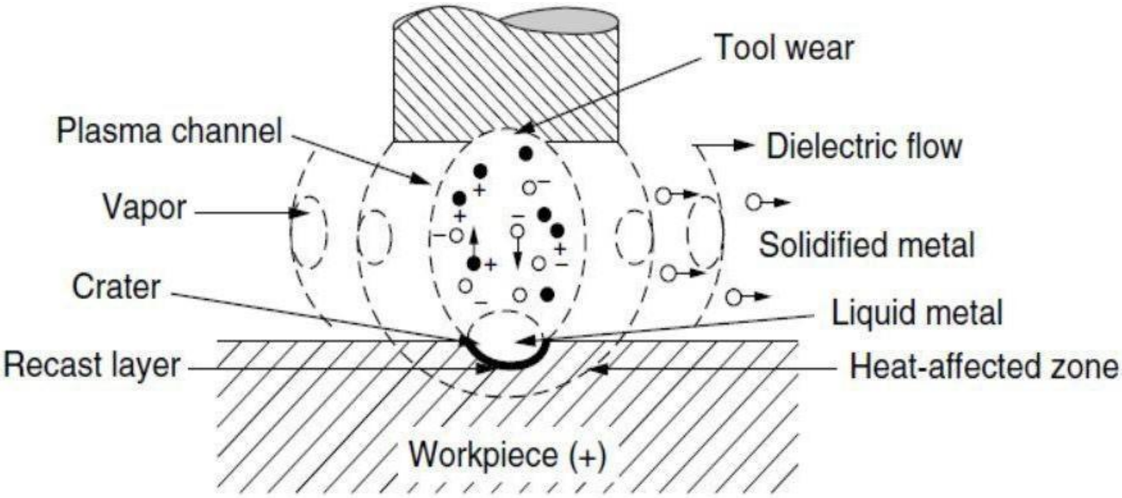
Mechanism of material removal



In EDM, the removal of material is based upon the electrodischarge erosion (EDE) effect of electric sparks occurring between two electrodes that are separated by a dielectric liquid as shown in above fig., Metal removal takes place as a result of the generation of extremely high temperatures generated by the high-intensity discharges that melt and evaporate the two electrodes. A series of voltage pulses of magnitude about 20 to 120 V and frequency on the order of 5 kHz is applied between the two electrodes, which are separated by a small gap, typically 0.01 to 0.5 mm. When using RC generators, the voltage pulses, shown in Fig. 5.3,are responsible for material removal.


Off time
Current
Peak current
Average current
On time
One cycle
Time


Discharge voltage
Volt
Time
One cycle
Charging time
Discharging time

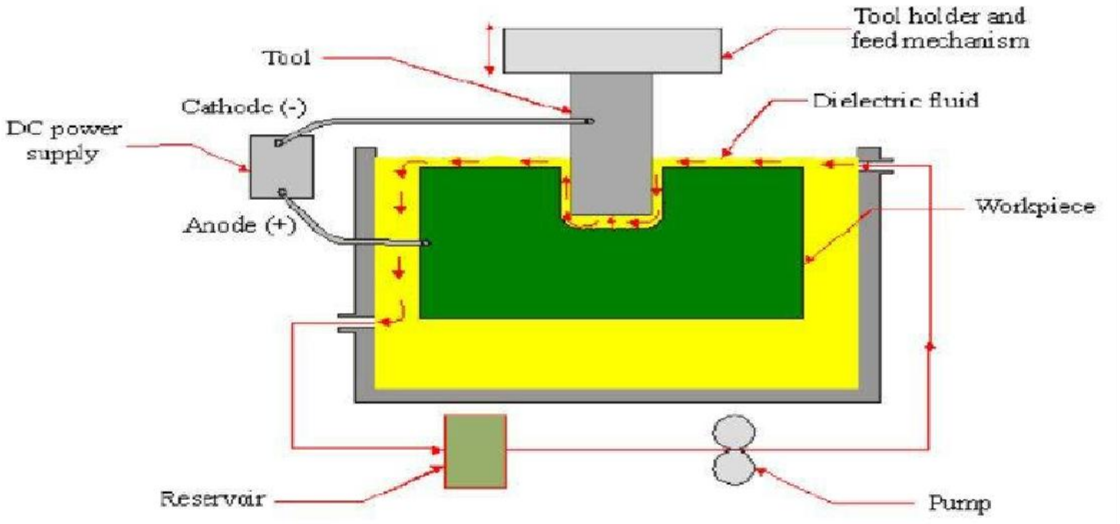


Fresh dielectric fluid rushes in, flushing the debris away and quenching the surface of the workpiece. Unexpelled molten metal solidifies to form what is known as the recast layer. The expelled metal solidifies into tiny spheres dispersed in the dielectric liquid along with bits from the electrode. The remainingvaporrisestothesurface.Withoutasufficientofftime,debriswould collect making the spark unstable. This situation creates an arc, which damagestheelectrodeandtheworkpiece.Therelationbetweentheamountof material removed from the anode and cathode depends on the respective contribution of the electrons and positive ions to the total current flow. The electron current predominates in the early stages of the discharge. Since the positiveionsareroughly104timesmoremassivethanelectrons,theyareless easily mobilized than the electrons. Consequently the erosion of the anode workpiece should be greater than that of the cathode. At the end of the EDM action, the plasma channel increases in width, and the current density across the interelectrode gap decreases. With the fraction of the current due to the electrons diminishing, the contributions from the positive ions rise, and proportionallymoremetalisthenerodedfromthecathode.The high frequency of voltage pulses supplied, together with the forward servo- controlled tool motion, toward the workpiece, enables sparking to be achieved along the entire length of the electrodes. Figure 5.4 shows the voltage and current waveforms during EDM. Figure 5.6 shows the periodic discharges occurring when using an RC generator inEDM.

Working principle of EDM process

Electrical discharge machining (EDM) is one of the most widely used non-traditional machining processes. The main attraction of EDM over traditional machining processes such as metal cutting using different tools and grinding is that this technique utilises thermoelectric process to erode undesired materials from the work piece by a series of discrete electrical sparks between the work piece and the electrode. A picture of EDM machine in operation is shown in Figure 1.

The traditional machining processes rely on harder tool or abrasive material to remove the softer material whereas non-traditional machining processes such as EDM uses electrical spark or thermal energy to erode unwanted material in order to create desired shape. So,the hardness of the material is no longer a dominating factor for EDM process. A schematic of an EDM process is shown in Figure 2, where the tool and the workpiece are immersed in a dielectric fluid.



EDM removes material by discharging an electrical current, normally stored in a capacitor bank, across a small gap between the tool (cathode) and the workpiece(anode)typicallyintheorderof50volts/10amps.

Application of EDM

The EDM process has the ability to machine hard, difficult-to-machine materials. Parts with complex, precise and irregular shapes for forging, press tools, extrusion dies, difficult internal shapes for aerospace and medical applications can be made by EDM process. Some of the shapes made by EDM process are shown in Figure 3.

The material removal rate, MRR, in EDM is calculated by the following foumula:

$$MRR = 40\, I / T_m^{1.23} \, (cm^3/min)$$

Where, I is the current amp,

T_m is the melting temperature of workpiece in ^{0}C

EDM electrodes

Material. Metalswithahighmeltingpointandgoodelectricalconductivity are usually chosen as tool materials for EDM. Graphite is the most common electrode material since it has fair wear characteristics and is easily machinable and small flush holes can be drilled into graphite electrodes. Copper has good EDM wear and better conductivity.It is generally used for better finishes in the range of 0.5 μm*Ra*.Copper tungsten and silver tungsten are used for making deep slots under poor flushing conditions especially in tungsten carbides. It offers high machining rates as well as low electrode wear. Copper graphite is good for cross-sectional electrodes. It has better electrical conductivity than graphite while the corner wear is higher. Brass ensures stable sparking conditions and is normally used for specialized applications suchasdrillingofsmallholeswherethehighelectrodewearisacceptable.

Movements.
In addition to the servo-controlled feed, the tool electrode may have an additional rotary or orbiting motion. Electrode rotation helps to solve the flushing difficulty encountered when machining small holes with EDM. In addition to the increase in cutting speed, the quality of the hole produced is superior to that obtained using a stationary electrode. Electrode orbiting produces cavities having the shape of the electrode. The size of the electrode and the radius of the orbit (2.54-mm maximum) determine the size of the cavities. Electrode orbiting improves flushing by creating a pumping effect of the dielectric liquid through the gap. **Polarity.** Electrode polarity depends on both the work piece and electrodematerials.

Electrode wear.

The melting point is the most important factor in determining the tool wear. Electrode wear ratios are expressed as end wear, side wear, corner wear, and volume wear as shown in given figure. The term *no wear EDM* occurs when the electrode-to-work piece wear ratio is 1 percent or less. Electrode wear depends on a number of factors associated with the EDM, like voltage, current, electrode material, and polarity. The change in shape of the tool electrode due to the electrode wear causes defects in the work piece shape. Electrode wear has even more pronounced effects when it comes to micromachining applications. The corner ratio depends on the type of electrode. The low melting point of aluminium is associated with the highest wear ratio. Graphite has shown a low tendency to wear and has the possibility of being molded or machined into complicated electrodeshapes

ThewearrateoftheelectrodetoolmaterialWtandthewearratioRw, described by Kalpakjian (1997),are

$$Wt = (11 \times 103) i Tt – 2.38$$

$$Rw = 2.25\ Tr – 2.3$$

where

Wt = wear rate of the tool, mm3/min

i = EDM current, A

Tt = melting point of the tool electrode, °C

Tr = ratio of the work piece to tool electrode melting points

Dielectric fluids.

The main functions of the dielectric fluid are to

1. Flush the erodedparticles from the machining gap
2. Provideinsulationbetweentheelectrodeandtheworkpiece
3. Coolthesectionthatwasheatedbythedischargingeffect

The main requirements of the EDM dielectric fluids are adequate viscosity, high flash point, good oxidation stability, minimum odor, low cost, and good electrical discharge efficiency (*www.unl.edu/nmrc/*). For most EDM operations kerosene is used with certain additives that prevent gas bubbles and de- odoring. Silicon fluids and a mixture of these fluids with petroleum oils have given excellent results. Other dielectric fluids with a varying degree of success include aqueous solutions of ethylene glycol, water in emulsions, and distilled water. Flushing of the dielectric plays a major role in the maintenance of stable machining and the achievement of close tolerance and high surface
quality. Inadequate flushing can result in arcing, decreased electrode life, and increased production time. Four methods of introducing dielectric fluid to the machining gap are considered at *www.unl.edu/nmrc/*.

Normal flow.

In the majority of EDM applications, the dielectric fluid is introduced, under pressure, through one or more passages in the tool and is forced to flow through the gap between the tool and the work piece. Flushing holes are generally placed in areas where the cuts are deepest. Normal flow is sometimes undesirable because it produces a tapered opening in the workpiece as shown in givenfigure.

Reverse flow.

This method is particularly useful in machining deepcavity dies, where the taper produced using the normal flow mode can be reduced. The gap is submerged in filtered dielectric, and instead of pressure being applied at the source a vacuum is used. With clean fluid flowing between the workpiece and the tool, there is no side sparking and, therefore, no taper is produced as shown in givenfigure.

Jetflushing.

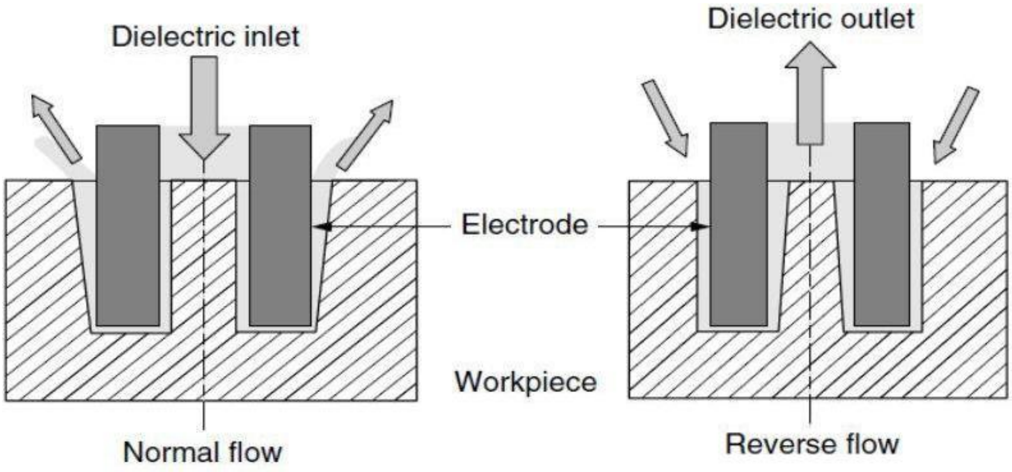
In many instances, the desired machining can be achieved by using a spray or jet of fluid directed against the machining gap. Machining time is always longer with jet flushing than with the normal and reverse flow modes.

Immersion flushing

For many shallow cuts or perforations of thin sections, simple immersion of the discharge gap is sufficient. Cooling and machining debris removal can be enhanced during immersion cutting by providing relative motion between the tool and workpiece (Zhixin,1995). Vibration or cycle interruption comprises periodic reciprocation of the tool relative to the workpiece to effect a pumping action of the dielectric fluid. Synchronized, pulsed flushing is also available on some machines. With this method, flushing occurs only during the nonmachining time as the electrode is retracted slightly to enlarge the gap.

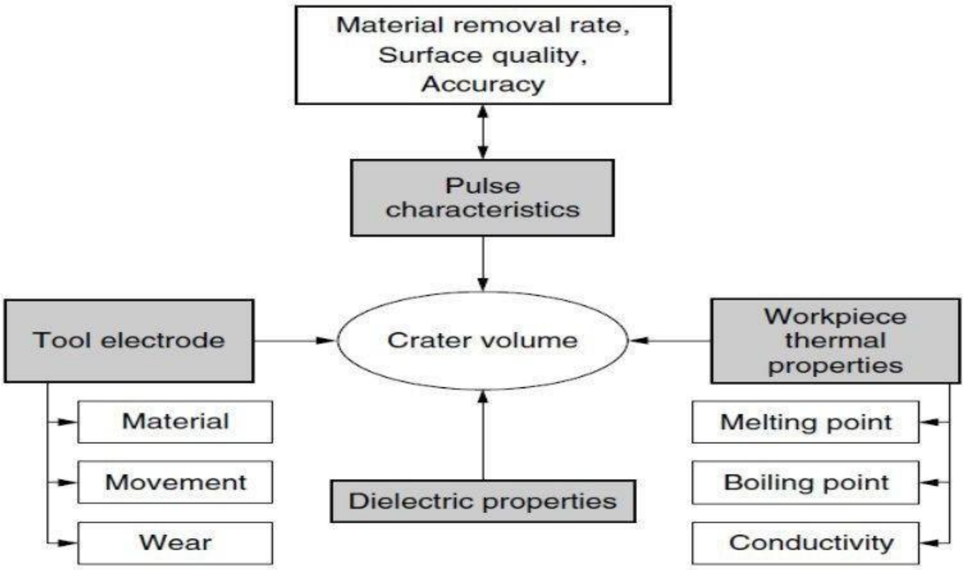
Increased electrode life has been reported with this system. Innovative techniques such as ultrasonic vibrations coupled with mechanical pulse EDM, jet flushing with sweeping nozzles, and electrode pulsing are investigated by Masuzawa (1990).

1. Flushingthroughthetoolismorepreferredthansideflushing.
2. Many small flushing holes are better than a few large ones.
3. Steadydielectricflowontheentireworkpiece-electrodeinterface is desirable.
4. Deadspotscreatedbypressureflushing,fromoppositesidesof the workpiece, should beavoided.
5. Aventholeshouldbeprovidedforanyupwardlyconcavepartof thetool-electrodetopreventaccumulationofexplosivegases.
6. Aflushboxisusefulifthereisaholeinthecavity



Material removal rates

In EDM the metal is removed from both the workpiece and the tool electrode. As can be seen from Fig. 5.12, the material removal rate depends not only on the workpiece material but on the material of the tool electrode and the machining variables such as pulse conditions,electrode polarity, and the machining medium. In this regard a material of low melting point has a high metal removal rate and hence a rougher surface. Typical removal rates range from 0.1 to 400 mm3 /min.



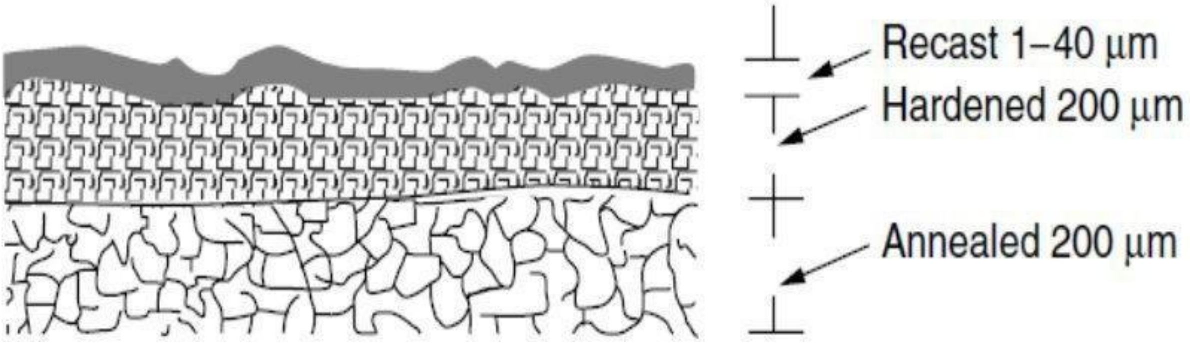
The results of machining rates and surface roughness for different materials. And explain the effect of pulse energy (current) and duration on the crater size and hence the removal rate. The material removal rate, or volumetric removal rate (VRR), in mm3/min, was described by Kalpakjian (1997):

$$VRR = (4 \times 104) i T_w – 1.23$$

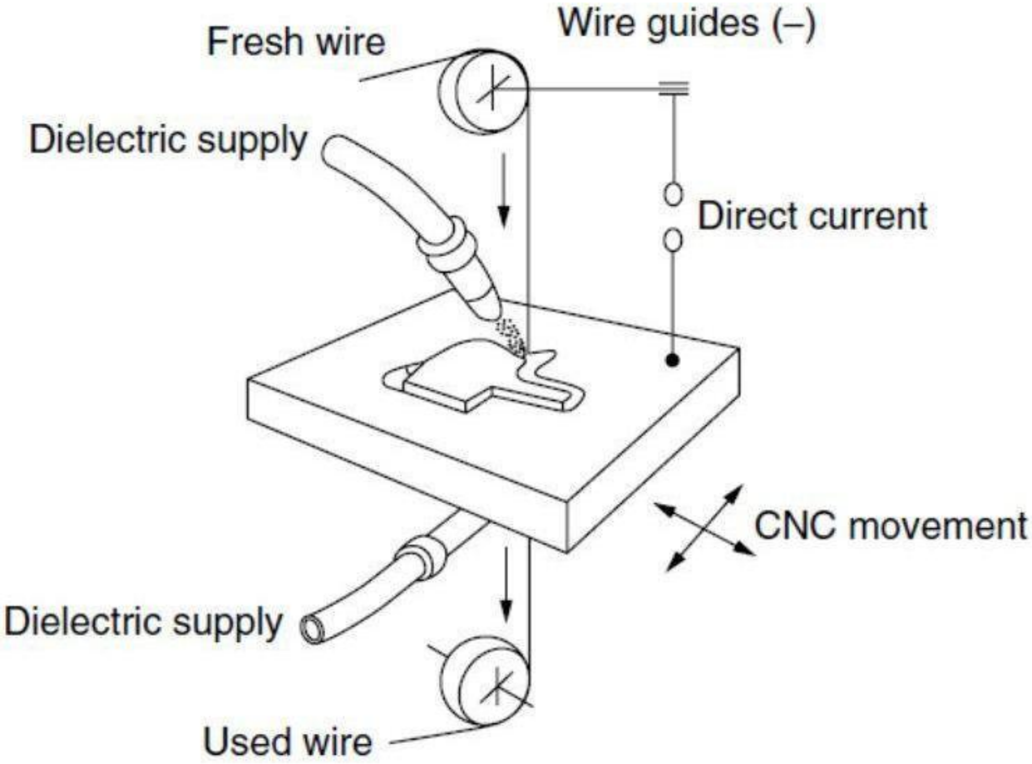
where i is the EDM current (A) and Tw is the melting point of the workpiece material(°C).

Heat-affectedzone

Choosing electrodes that produce more stable machining can reduce the annealing effect. A finish cut removes the annealed material left by the previous high-speed roughing. The altered surface layer, which is produced during EDM, significantly lowers the fatigue strength of alloys.The altered layer consists of a recast layer with or without microcracks,some of which may extend into the base metal, plus metallurgical alterations such as rehardened and tempered layers, heat-affected zones, and intergranular precipitates. Generally, during EDM roughing, the layer showing icrostructural changes, including a melted and resolidified layer, is less than 0.127 mm deep, while during EDM finishing, it is less than 0.075 mm. Posttreatment to restore the fatigue strength is recommended to follow EDM of critical or highly stressed surfaces. There are several effective processes that accomplish restoration or even enhancement of the fatigue properties. These methods includetheremoval of the altered layers by low-stress grinding, chemical machining,and the addition of a metallurgical-type coating, reheat treatment, and the application of shot peening.



Wire EDM machining process



EDM, primarily, exists commercially in the form of die-sinking machines and wire-cutting Machines (Wire EDM). The concept of wire EDM is shown in Figure 4. In this process, a slowly moving wire travels along a prescribed path and removes material from the work piece. 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 work piece in the presence of dielectric fluid, which creates a path for each discharge as the fluid becomes ionized in the gap. The area where discharge takes place is heated to extremely high temperature, so that the surface is melted and removed. The removed particles are flushed away by the flowing dielectric fluids.The wire EDM process can cut intricate components for the electric and aerospace industries. This non-traditional machining process is widely used to pattern tool steel for diemanufacturing.

The wires 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 in ab0ve figure. This process is usually used in conjunction with CNC and will only work when a part is to be cut completely through. The melting temperature of the parts to be machined is an important 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 wirematerials.

Advantages of EDM

The main advantages of DM are:

By this process, materials of any hardness can be machined;

No burrs are left in machined surface;

One of the main advantages of this process is that thin and fragile/brittle components can be machined without distortion;

Complex internal shapes can be machined

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.

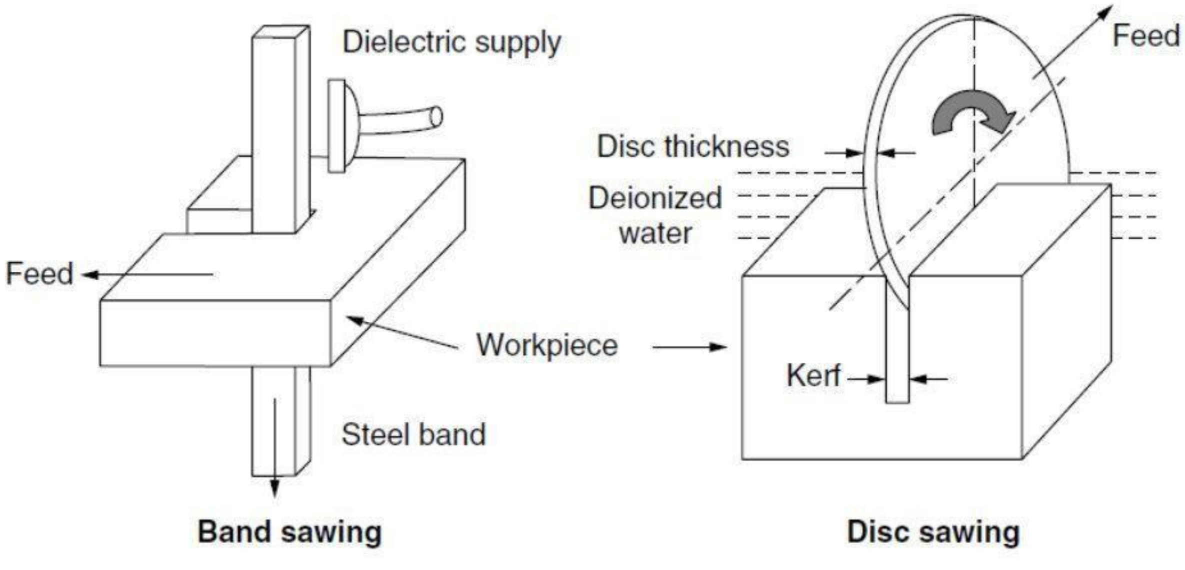
Applications:

Drilling.

EDM drilling uses a tubular tool electrode where the dielectric is flushed down the interior hole of the tube in order to remove machining debris. When solid rods are used; the dielectric is fed to the machining zone by either suction or injection through pre-drilled holes. Irregular, tapered, curved, as well as inclined holes can be produced by EDM. McGeough (1988) reported typical feed rates of 0.1 mm/min when drilling 0.1 to 0.5 mm diameters, leaving an overcut of 0.01 to 0.05 mm. Creating cooling channels in turbine blades made of hard alloys is a typical application of EDM drilling. The use of a computerized NCsystemenabledlargenumbersofholestobeaccuratelylocated

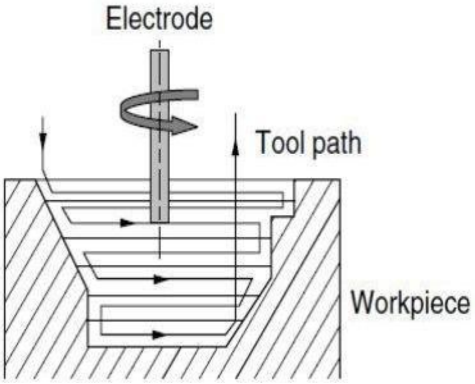
Sawing.

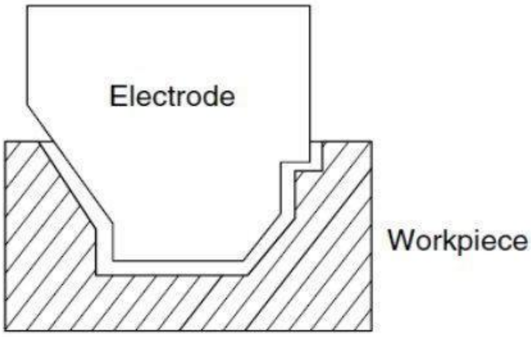
ED sawing, shown in below figure is an EDM variation that employs either a special steel band or disc. The process cuts any electrically conductive material at a rate that is twice that of the conventional abrasive sawing method. The cut produced has a smaller kerf besides being free from burrs. Cutting of billets and bars is a typicalapplication



Machining of dies and molds.

EDM milling uses standard cylindrical electrodes. Complex cavities are machined by successive NC sweeps of the electrode down to the desired depth. The simple-shaped electrode (Fig. 5.19) is rotated at high speeds and follows specified paths in the workpiece like the conventional end mills. This technique is very useful and makes EDM very versatile like the mechanical milling process. The process solves the problem of manufacturing accurate and complex-shaped electrodes for die sinking of three-dimensional cavities
shown in given figures. EDM milling enhances dielectric flushing due to the high-speed electrode rotation. The electrode wear can be optimized because of the rotational and contouring motions of the electrode. The main limitation in the EDM milling is that complex shapes with sharp corners cannot be machined because of the rotating tool electrode. the die sinking process. These numerous and time-consuming steps are greatly reduced using EDM milling as shown in below figure. EDM milling also replaces the conventional die making that requires the use of a variety of machines such as milling, wire cutting,and EDM die sinkingmachines





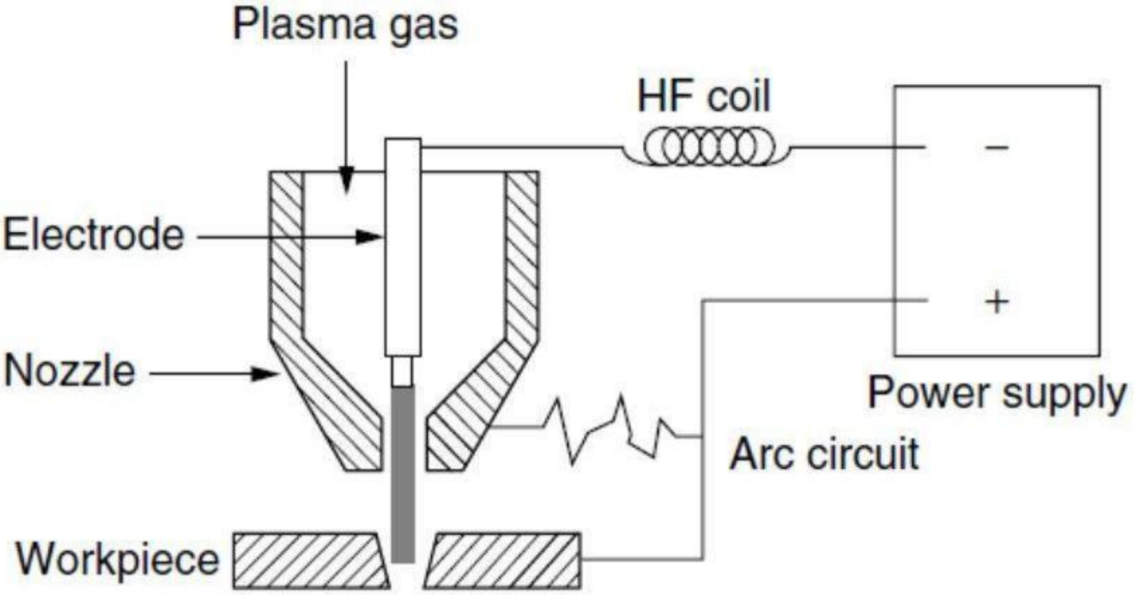
Plasma Beam Machining

Introduction

When the temperature of a gas is raised to about 2000°C, the gas molecules become dissociated into separate atoms. At higher temperatures,30,000°C, these atoms become ionized. The gas in this stage is termed plasma. Machining by plasma was adopted in the early 1950s as an alternative method for oxy-gas flame cutting of stainless steel, aluminium, and other nonferrous metals. During that time the process limitations regarding the low cutting speed, poor machining quality, and the unreliable equipment were clear. Recently machining of both metallic and nonconductive materials has become much more attractive. An important feature of plasma beam machining (PBM), is that it is the only fabricating method that works faster in stainless steel than it does in mildsteel.

Machining systems

In plasma machining a continuous arc is generated between a hot tungsten cathode and the water-cooled copper anode. A gas is introduced around the cathode and flows through the anode. The temperature, in the narrow orifice around the cathode, reaches 28,000°C, which is enough to produce a high- temperature plasma arc. Under these conditions, the metal being machined is very rapidly melted and vaporized. The stream of ionized gases flushes away the machining debris as a fine spray creating flow lines on the machined surface substantially higher than those of conventional single-point turning operation. Plasma machining systems are divided into plasma arc, plasma jet, shielded plasma, and airplasma

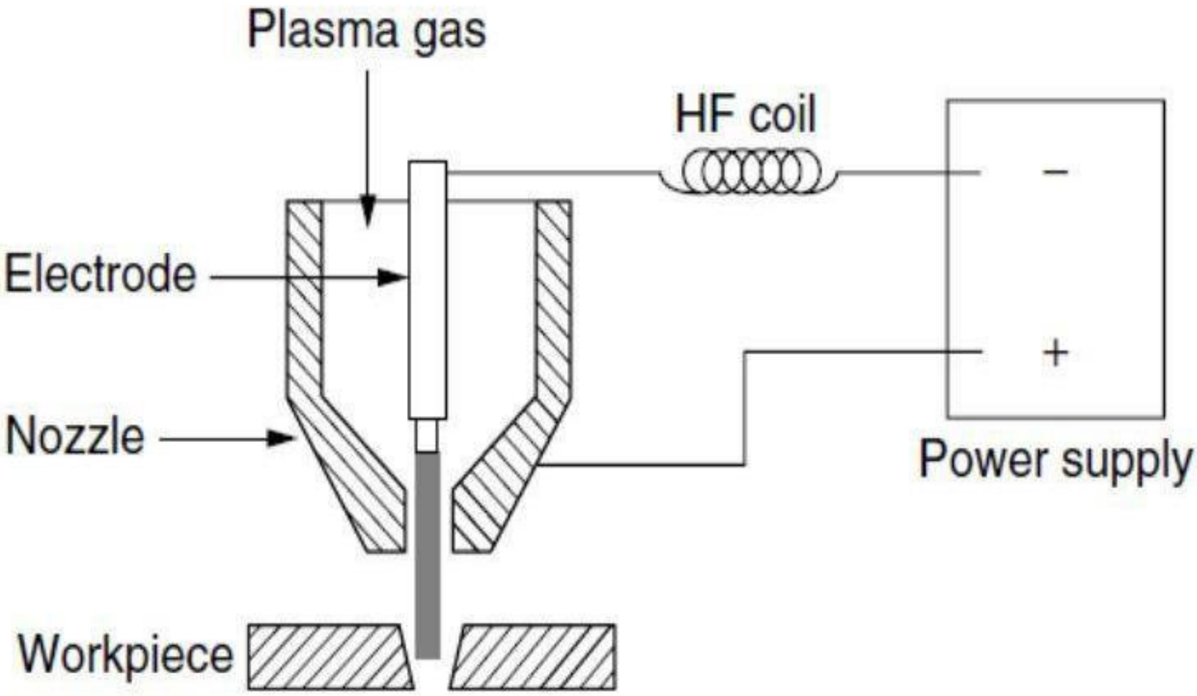


Plasma arc.

As shown in above figure the arc is struck from the rear electrode of the plasma torch to the conductive work piece causing temperatures as high as 33,300°C. The double arcing effect between the nozzle and the work piece damages the electrode and the work piece. High heat transfer rates are found to occur during plasma arc due to the transfer of all the anode heat to the work piece. Owing to the greater efficiency of plasma arc systems, they are often used for machining metals. Plasma arc does not depend on a chemical reaction between the gas and the work metal. Because the temperature is high, the process is suitable for any electrically conductive material including thosethatareresistanttooxy-fuelgascutting.

Plasma jet.

In this system, shown in above figure, the non transferred arc is operated within the torch itself. Only ionized gas (plasma) is emitted as a jet causing temperature as high as 16,600°C. Since the torch itself is the anode, a large part of the anode heat is extracted by the cooling water and is not effectively used in the material removal process. Nonconductive materials that are difficult to machine, by conventional methods, are often successfully tackled by the plasma jetsystem



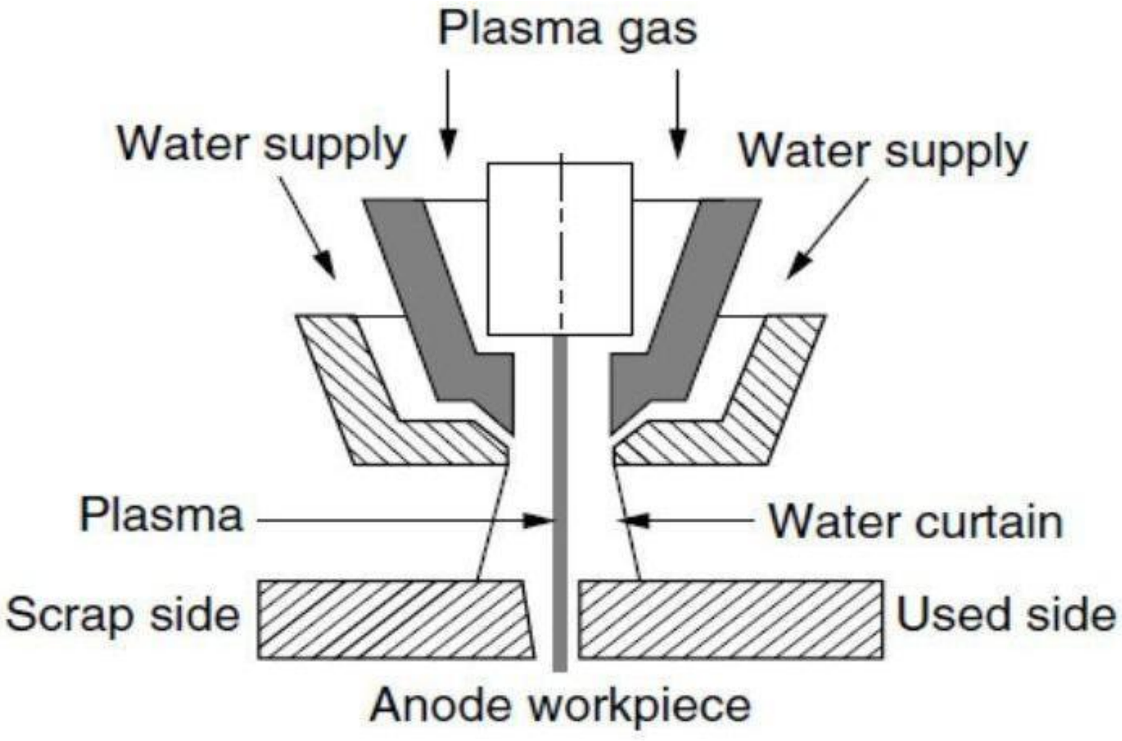
Shielded plasma

Gas-shielded plasma.

When machining different materials such as aluminium, stainless steel, and mild steel, assisting gases may have to be used in order to produce cuts of acceptable quality. In such a case an outer shield of gas, is added, around the nozzle, to reduce the effect of the atmosphere on the machining gas (nitrogen or argon). The shielding gas depends on the metal being machined. For stainless steel, aluminium and other nonferrous metals, hydrogen is often used as a shielding gas. Carbon dioxide is popular for ferrous and nonferrous metals.Formildsteels,airoroxygenmaybealsoused.

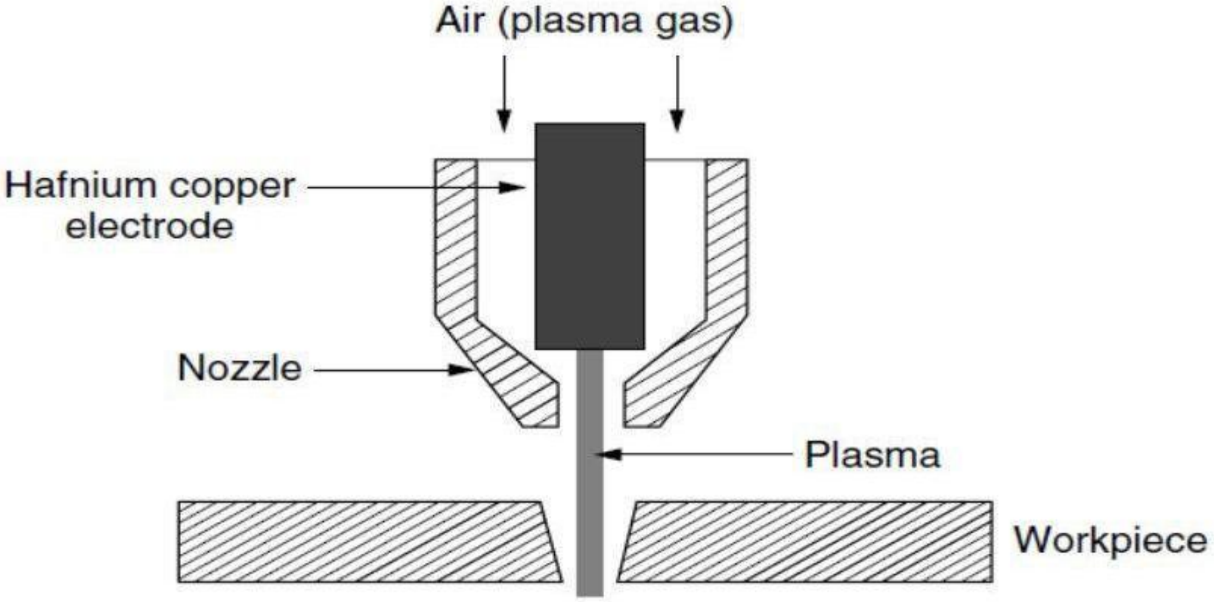
Water-shielded plasma.

As shown in figure, nitrogen is used for machining while the shield gas is replaced by water. Water forms a radial jacket around the plasma torch. The cooling effect of water is reported to reduce the width of the cutting zone and improve the quality of cut. However, no improvement in both the cutting rate and the squareness of the cut has been reported by McGeough (1988).



Air plasma.

Compressed air is used as the machining gas instead of nitrogen or argon When air is subjected to the high temperature of the electric arc, it breaks down into its constituent gases. Since the oxygen, in the resulting plasma, is very reactive especially with ferrous metals, machining rates are raised by 25 percent. The main drawback of this method is the heavily oxidized surface, which is frequently obtained in case of stainless steel and aluminium. Because tungsten is reactive with oxygen, hafnium copper (Hf–Cu) or hafnium zirconium(Hf–Zr)alloysalsoreplacetungstenelectrodes.



Material removal rate

During PBM absorbing the heat energy from the plasma jet directed to the work piece activates metal removal. The plasma torch blows the molten and evaporated metal away as a fine spray or vapour. The resulting cutting rates and hence the machinability depend on the work piece being machined as well as the type of the cutting and shielding gases that determine the maximum temperature transfer rates. The maximum machining speed, as an index of machinability for dual gas plasma of carbon steel, stainless steel, and aluminium, the shows the power consumption factor needed in plasma beam rough turning of some alloys. A low factor indicates either low energy required or high removal rates. The machining speed is found to decrease with increasing the thickness of the metal or the cut width in case of beveling.As the power is increased, the efficient removal of melted metal is found to need a corresponding rise in the gas flow rate. During plasma machining of 12-mm- thick steel plate using 220 kW the machining speed is 2500 mm/min, which is 5 times greater than that for oxy-gascutting.

Applications

1. PAM is an attractive turning method for difficult-to-machine materials by conventional methods. In this regard, cutting speeds of 2 m/min and a feed rate of 5 mm per revolution produced a surface finish of 0.5 mm *Rt*. The depth of cut can be controlled through the machining power or surface speed.
2. Computer numerical controlled PBM is used for profile cutting of metals that are difficult to tackle by oxyacetylene gas technique such as stainless steel and aluminium. A large number of parts can also be produced from one largesheetthuseliminatingshearingoperations.
3. PBM can cut 1.5-mm-deep, 12.5-mm-wide grooves in stainless steel at 80 mm3/min, using 50 kW as the cutting power. Such a high machining rate is 10 times the rate of grinding and chipping methods. Lower machining rates are obtainable when these grooves are cut in nonconductive materials. The groove dimension however depends on the traverse speed, arc power, and the angle and height of the plasmaarc.
4. The process is recommended for parts that have subsequent welding operations.

Advantages

Manyadvantagesofplasmatechnologyhavebeenmentionedat including

Requires no complicated chemical analysis or maintenance

Usesnoharmfulchlorinatedfluorocarbons,solvents,oracidcleaning chemicals

Operatescleanly,ofteneliminatingtheneedforvapordegreasing, solvent wiping, ultrasonic cleaning, and gritblasting

Requires no worker exposure to harmful chemicals Needs less energy to operate

Disadvantages

Thelargepowersuppliesneeded(220kW)arerequiredtocutthrough 12-mm-thick mild steel plate at 2.5m/min.

Theprocessalsoproducesheatthatcouldspoiltheworkpieceand produce toxicfumes.

MODULE-V

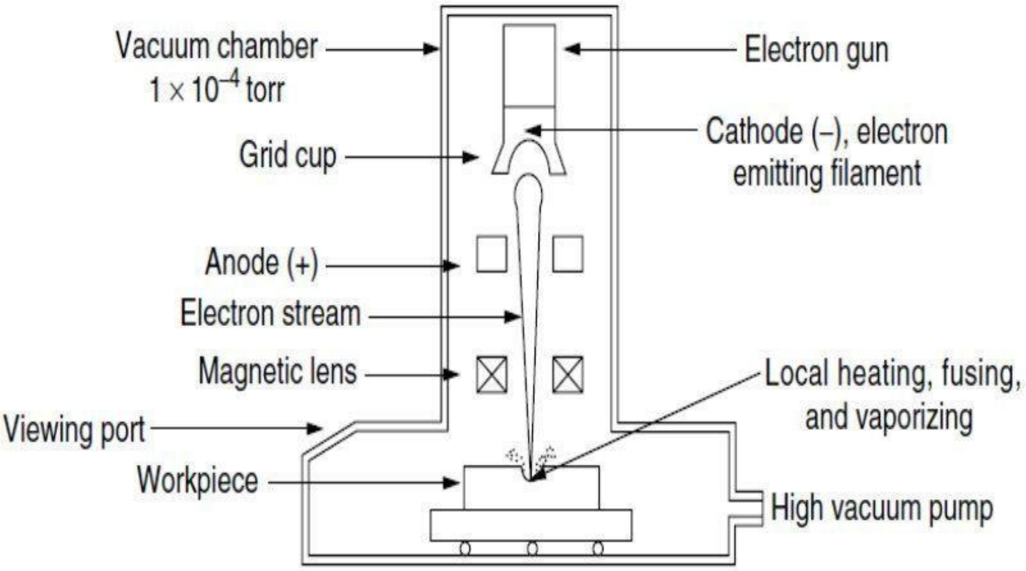
Electron Beam Machining

Introduction

The earliest work of material removal utilizing an electron beam was attributed to Steigerwald who designed a prototype machine in 1947.Electron beam machining (EBM) has been used in industry since the 1960s, initially in nuclear and aerospace welding applications. Drilling small holes, cutting, engraving, and heat treatment are a set of modern applications used in semiconductor manufacturing as well as micromachiningareas.

Basic equipment

The main components of EBM installation, are housed in a vacuum chamber, evacuated to about 10–4 torr. The tungsten filament cathode is heated to about 2500 to 3000°C in order to emit electrons. A measure of this effect isthe emission current, the magnitude of which varies between 20 and 100 mA. Corresponding current densities lie between 5 and 15 A/cm2. Emission current depends on the cathode material, temperature, and the high voltage that is usually about 150 kV. Such a high voltage accelerates a stream of electrons in the direction of the work piece. After acceleration, electrons, focused by the field, travel through a hole in theanode.



then refocused by a magnetic or electronic lens system so that the beam is directed under control toward the workpiece. The electrons maintain the velocity (228 × 103 km/s) imparted by the acceleration voltage until they striketheworkpiece,overawell-definedarea,typically0.25mmindiameter.

The kinetic energy of the electrons is then rapidly transmitted into heat, causing a corresponding rapid increase in the temperature of the work piece, to well above its boiling point, thus causing material removal by evaporation. With power densities of 1.55 MW/mm2 involved in EBM, virtually all engineering materials can be machined by this machining technique. Accurate manipulation of the work piece coupled with the precise control of the beam is reported by McGeough (1988) to yield a machining process that can be fully automated.

The way in which the focused beam penetrates the work piece is not completely understood, owing to the complexity of the mechanism involved. However, it is believed that the work piece surface is melted by a combination of electron pressure and surface tension. The melted liquid is rapidly ejected and vaporized, thus causing material removal rates of about 10 mm3/min. A pulsed electron beam at 104 Hz reduces the temperature of the work piece outside the region being machined. An early attraction of EBM was the comparatively large depth-to-width ratio (100:1) with applications in fine hole drilling becoming feasible. The absence of mechanical contact and the suitability for automatic control enhance the process capabilities, but the necessitytoworkinavacuumlengthensthefloor-to-floorcycletime.

Material removal rate

Thenumberofpulsesrequiredtoremoveaholeofdepth$g$canbedescribed in Nextpage.

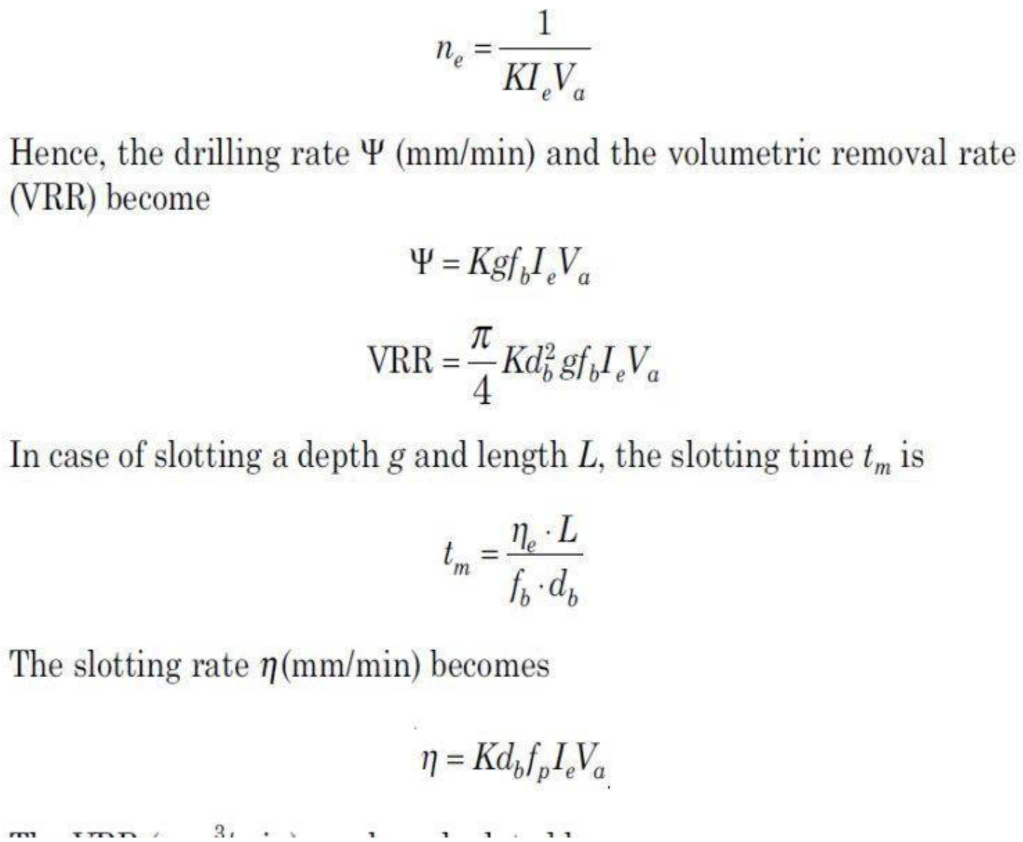
$$t_m = \frac{}{f_p}$$

$$f_p = \frac{1}{t_p + t_i}$$

The drilling rate Ψ (mm/min) can therefore be calculated by

$$\Psi = \frac{g f_p}{n_e}$$

According to Kaczmarek (1976), the number of pulses *ne* can simply be described as a function of the accelerating voltage *Va*and the emission current *Ie*by



$$n_e = \frac{1}{K I_e V_a}$$

Hence, the drilling rate Ψ (mm/min) and the volumetric removal rate (VRR) become

$$\Psi = K g f_b I_e V_a$$

$$\mathrm{VRR} = \frac{\pi}{4} K d_b^2 g f_b I_e V_a$$

In case of slotting a depth g and length L, the slotting time t_m is

$$t_m = \frac{\eta_e \cdot L}{f_b \cdot d_b}$$

The slotting rate η(mm/min) becomes

$$\eta = K d_b f_p I_e V_a$$

where ge= depth of hole removed per pulse,mm

g = depth of hole or slot required, mm

fp= frequency of pulses, s–1

tp= pulse time, µs

ti= pulse interval, µs

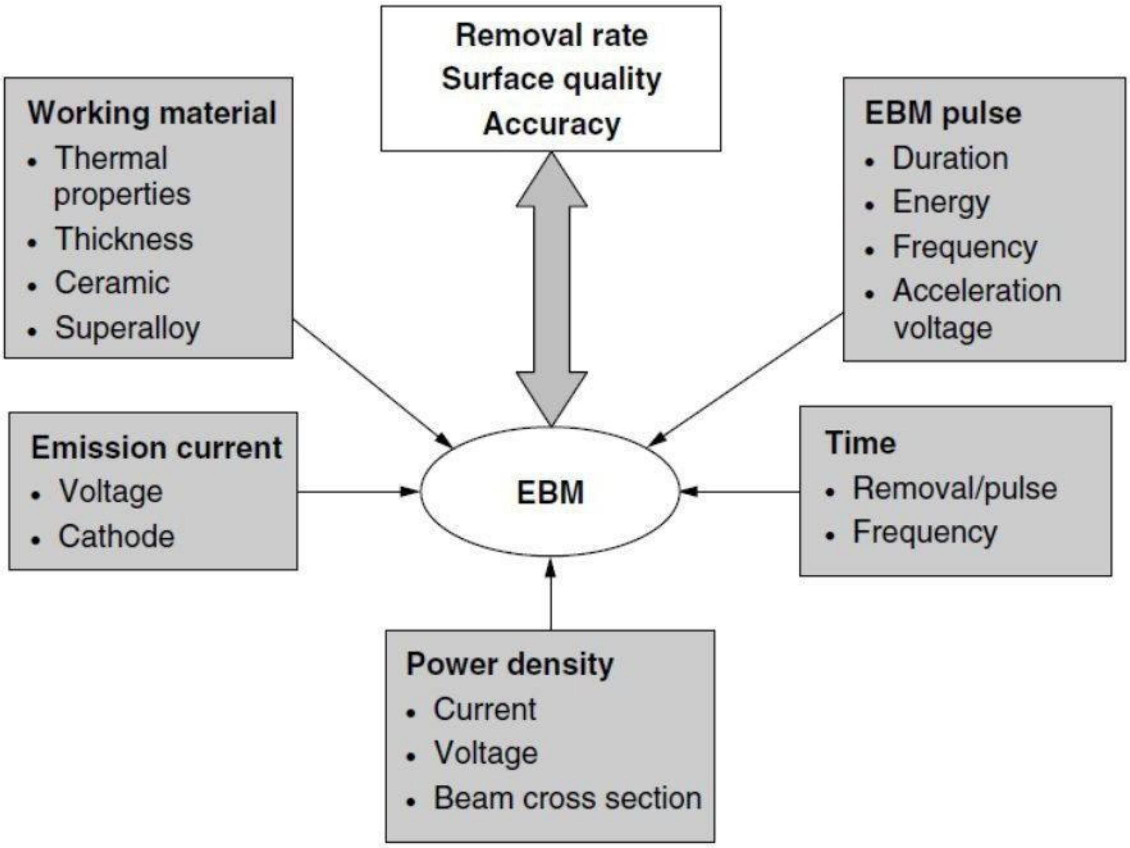
db= beam diameter in contact with the workpiece (slot width),mm

Va= beam accelerating voltage, kV

Ie= beam emission current, mA

K = constant

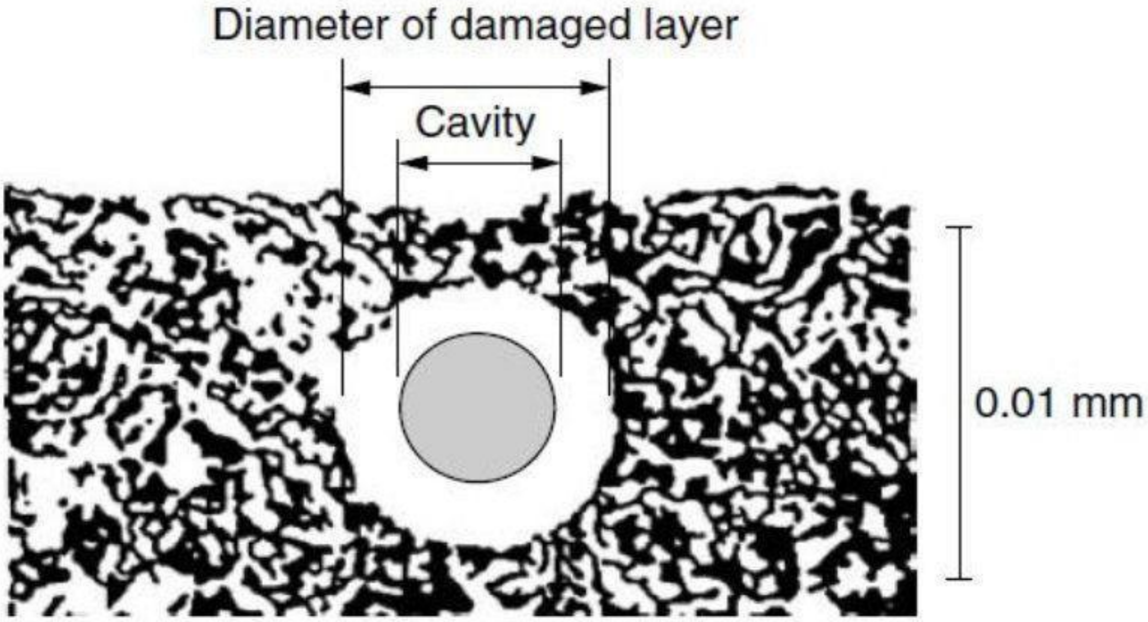
L = slot length, mm



The effect of pulse numbers on the accelerating voltage showed that increasing the hole depth requires a much greater rise in the number at low voltage, due mainly to a relative rise in heat losses resulting from the conduction and melting of the adjacent metal layers. For a given number of pulses, little improvement in material removal rate is obtained by increasingtheaccelerating voltage above 120 kV.

The increase of pulse duration raises the pulse energy available, which in turn reduces the number of pulses required to obtain the required machining result. Kaczmarek (1976) quoted an optimum working distance at which a minimum number of pulses are required. He pointed out that a focal point just below the upper surface of the workpiece is sometimes the most effective. The drilling rate by EBM (in holes per second) decreases with an increase in the thickness of the work piece as well as in the diameter of the hole to be produced.

The surface quality produced by EBM depends on the type of material. In this regard, the surface roughness increases with pulse charge for nickel, carbon, gold, and tungsten. Estimates of surface roughness for small holes and cuts are near to 1 μm*Ra*. Surface layers of material treated by EBM are affected by the temperature of the focused beam, illustrated by the white layer ring surrounding the hole, shown in Fig. 5.47. The diameter of the damaged layer increases with pulse duration and hole diameter. A typical heat-affected zone can be as much as 0.25 mm in EBM, which can be detrimental to the structural integrity of highly stressed components and, for such components, should be removed.



Applications:

Drilling.

Steigerwald and Mayer (1967) considered that for successful application, improved reproducibility, greater working speeds, and deeper holes of accurately controlled shapes are all needed. Boehme (1983) discussed drilling applications with an electron beam machine fitted with a system for numerically controlling the beam power, focus and pulse duration, and mechanical motion. Cylindrical, conical, and barrel-shaped holes of various diameters can be drilled with consistent accuracy at rates of several thousand holes per second. Holes at an inclination angle of about 15° were also possible. Boehme (1983) claimed that the largest diameter and depth of holes that can be accurately drilled by EBM are, respectively, 1.5 mm and 10 mm and that the aspect depth-to-diameter ratio is normally in the range of 1:1 to 1:15. For deeper holes, in the range of 2.5 to 7.5 mm, Steigerwald and Mayer (1967) emphasized the need for a stable power supply that can emit the required groups of pulses and that, for a well-controlled beam of closely defined diameter, the angle of aperture has a strong bearing on the shape of the hole produced. Holes of about 19 mm were produced. Drew (1976) showed EB- drilledholesinasuperalloyturbineblade atanglesof60°to90°.

Perforation of Sheets:

For perforation by EBM to be economically acceptable, 104 to 105 holes per second have to be produced.Thus single pulses lasting only a few microseconds are needed. In some applications the sheet or foil is stretched on a rotating drum, which is simultaneously shifted in the direction of its axis. Rows of perforations following a helical line are thereby produced. Manipulators capable of linear and rotating movements in four axes are used for EBM perforation of jet engine components. Foil made of a synthetic material has been perforated with 620 holes per square millimeter for filter application at a rate of one hole every 10 μs. EBM perforation can be applied to the production of filters and masks of colour television tubes. Other applications for perforation lie in sieve manufacture, for sound insulation and in glass fiber production.

Slotting:

Rectangular slots of 0.2 by 6.35 mm in 1.57-mm-thick stainless steel plate are produced in 5 min using 140 kV, 120 μA, a pulse width of 80 μs, and a frequency of 50 Hz. The rate of slotting depends on the work piece thickness. In this regard 0.05-mm-thick stainless steel was cut at a rate of 100 m/min, while 0.18-mm-thick stainless steel was cut at 50 m/min using similar machiningconditions.

Advantages

a. Drillingispossibleathighrates(upto4000holespersecond).
b. No difficulty is encountered with acuteangles.
c. Drillingparameterscaneasilybechangedduringmachining.
d. Nolimitationisimposedbyworkpiecehardness,ductility,andsurface Reflectivity.
e. No mechanical distortion occurs to the work piece since there is no contact.
f. The process is capable of achieving high accuracy and repeatability of0.1mmforpositionofholesand5percentfortheholediameter.
g. Theprocessproducesthebestsurfacefinishcomparedto otherProcesses.
h. Thecostisrelativelysmallcomparedtootherprocessesusedtoproduce Very smallholes.

Disadvantages

a. High capital equipmentcost
b. Longproductiontimeduetothetimeneededtogenerateavacuum
c. The presence of a thin recast layer
d. Need for auxiliary backing material

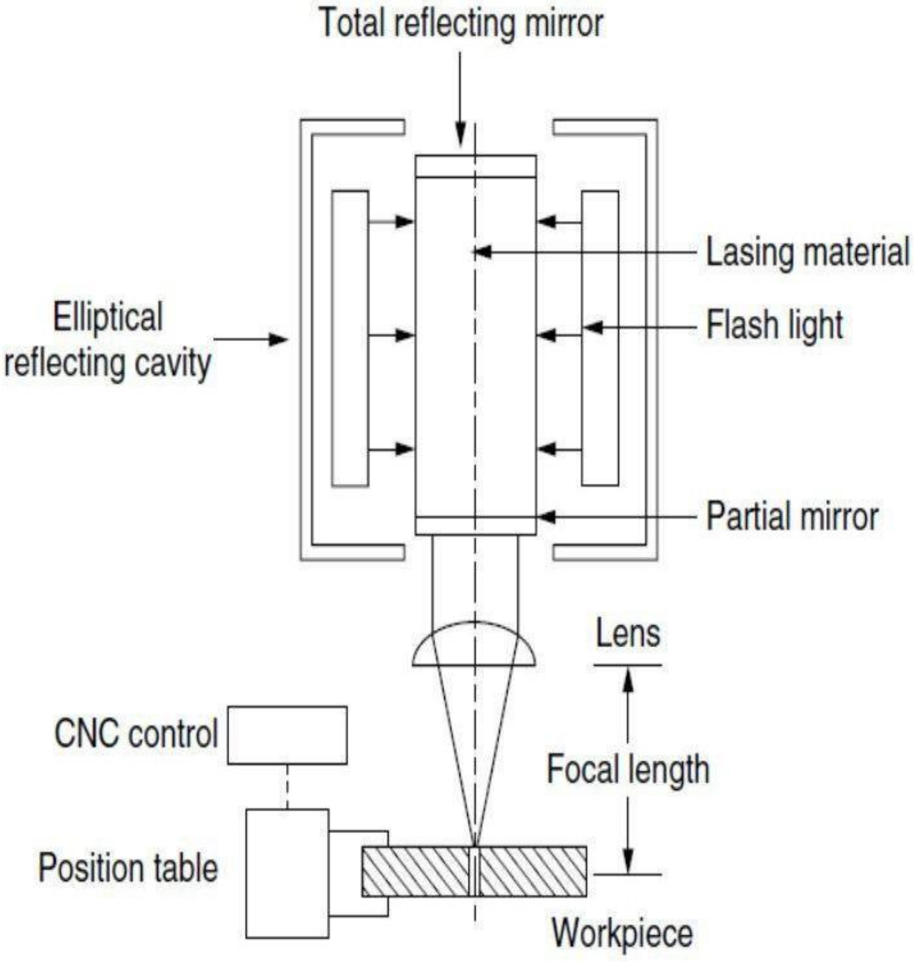
Laser Beam Machining

Introduction

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-metallicworkpieces. Lasers can be used to cut, drill, weld and mark. LBM is particularly suitable for making accurately placed holes. A schematic of laser beam machining is shown in Figure.

Different types of lasers are available for manufacturing operations which are asfollows:

- CO2 (pulsed or continuous wave): It is a gas laser that emits light in the infraredregion.Itcanprovideupto25kWincontinuous-wavemode.
- Nd:YAG: Neodymium-doped Yttrium-Aluminum-Garnet (Y3Al5O12) laser is a solidstate laser which can deliver light through a fibre-optic cable. It can provide up to 50 kW power in pulsed mode and 1 kW in continuous-wave mode.



Modern machining methods are established to fabricate difficult-to-machine materials such as high-strength thermal-resistant alloys; various kinds of carbides, fiber-reinforced composite materials, Satellites, and ceramics.

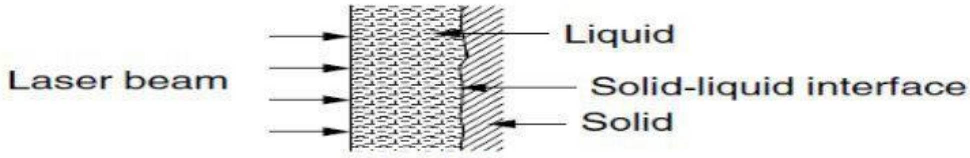
Conventional machining of such materials produces high cutting forces that, in some particular cases, may not be sustained by the work piece.

Laser beam machining (LBM) offers a good solution that is indeed more associated with material properties such as thermal conductivity and specific heat as well as melting and boiling temperatures. Laser is the abbreviation of light amplification by stimulated emission of radiation. A highly collimated, monochromatic, and coherent light beam is generated and focused to a small spot. High power densities (106 W/mm2) are then obtained. A large variety of lasers are available in the market including solid-state, ion, and molecular types in either continuous wave (CW) or pulsed mode (PM) of operation as shown in given figure. Lasers are widely used in many industrial applications including plating, heat treatment, cladding, alloying, welding, and machining. The LBM system is shown in figure.

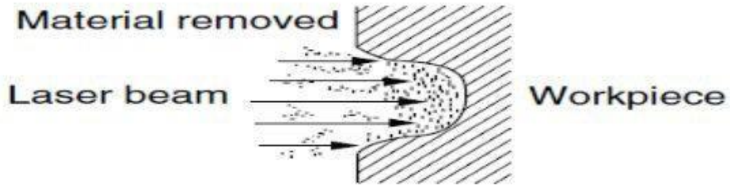
Material removal mechanism

As presented in Fig. 5.33, the un reflected light is absorbed, thus heating the surface of the specimen. On sufficient heat the work piece starts to melt and evaporates. The physics of laser machining is very complex due mainly to scattering and reflection losses at the machined surface. Additionally, heat diffusion into the bulk material causes phase change, melting, and/or vaporization. Depending on the power density and time of beam interaction, the mechanism progresses from one of heat absorption and conduction to one of melting and then vaporization. High intensity laser beams are not recommended since they form a plasma plume at or near the surface of the material with a consequent reduction in the process efficiency due to absorption and scattering losses. Machining by laser occurs when the power density of the beam is greater than what is lost by conduction, convection, and radiation, and moreover, the radiation must penetrate and be absorbed into thematerial.

(*a*) Absorption and heating



(*b*) Melting



(*c*) Vaporization

Fig., Physical processes occurring during LBM.

The power density of the laser beam ,*Pd*, is given by.,

$$P_d = \frac{4L_p}{\pi F_l^2 \alpha^2 \Delta T}$$

The size of the spot diameter *ds* is

ds *Fla*

The machining rate *f* (mm/min) can be described as follows.,

$$\phi = \frac{C_l L_p}{E_v A_b h}$$

$$A_b = \frac{\pi}{4}(F_l \alpha)^2$$

$$\phi = \frac{4C_l L_p}{\pi E_v (F_l \alpha)^2 h}$$

The volumetric removal rate (VRR) (mm3/min) can be calculated as follows.

$$\mathrm{VRR} = \frac{C_l L_p}{E_v h}$$

Where

Pd= power density, W/cm2

Lp= laser power, W

Fl= focal length of lens, cm Δ*T* =

pulse duration of laser,s*a* = beam

divergence, rad

Cl = constant depending on the material and conversion efficiency

Ev= vaporization energy of the material, W/mm3

Ab = area of laser beam at focal point,mm2

h = thickness of material, mm

ds = spot size diameter, mm

In LBM the work piece material is removed through several effects including reflection, absorption, and conduction of light that is followed by melting and evaporation. The behaviour of the work material with respect to these effects determines the material removal rate. Reflectivity depends on the wavelength, the properties of material, the surface finish, its level of oxidation and temperature.

Applications

Drilling.

Composite materials and some exotic alloys have been widely used in the fabrication of both structural and non-structural members of the airframes and engines of aircrafts. Super alloys are used frequently for the fabrication of aero-engine gas-path components such as blades, guide vans, after-burners, and castings where a temperature of 2000°C can be reached

Hole quality characteristics.

Diameter and depth. Using LBM it is economically effective to drill holes up to 1.5 mm in diameter. For large diameters, the trepanning method is recommended. The geometrical characteristics of laser-drilled holes are described in terms of their aspect ratio (depth-to-diameter ratio at mid span of the hole). The aspect ratio depends on the optical characteristics of the beam and on the optical and thermal properties of the material.

Advantages

Tool wear and breakage are notencountered.

Holescanbelocatedaccuratelybyusinganopticallasersystemfor Alignment.

Very small holes with a large aspect ratio can be produced.

Awidevarietyofhardanddifficult-to-machinematerialscanbe Tackled.

Machining is extremely rapid and the setup times are economical. Holes can be drilled at difficult entrance angles (10° to the surface). Becauseofitsflexibility,theprocesscanbeautomatedeasilysuchas theon-the-flyoperationforthingaugematerial,whichrequiresoneShot to produce a hole. Theoperatingcostislow.

Limitations

High equipment cost.

Tapers are normally encountered in the direct drilling of holes. Ablindholeofprecisedepthisdifficulttoachievewithalaser.