Hybrid Electrochemical Processes

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Abstract - *Electrochemical machining (ECM) is a manufacturing technology that allows metal to be precisely removed by electrochemical oxidation and dissolution into an electrolyte solution. ECM is suited for machining parts fabricated from "difficult to cut" materials and parts with complicated and intricate geometries. In ECM, the work piece is the anode and the tool is the cathode. Compared to mechanical or thermal machining processes where metal is removed by cutting or electric discharge/laser machining, respectively, ECM does not suffer from tool wear or result in a thermally damaged surface layer on the work piece. Consequently, ECM has strong utility as a manufacturing technology for fabrication of a wide variety of metallic parts and components, and includes machining, de-burring, boring and polishing processes. ECM provides particular value in that application is straightforward to high strength/tough and workhardening materials such as high strength steel, chromecopper alloy, cobalt-chrome alloy and tantalum- tungsten alloy. Since the material removal process involves no mechanical interaction between the tool and the part. A variety of commercial and military production applications are envisioned as well suited for ECM techniques. The ECM process is most widely used to produce complicated shapes such as turbine blades with good surface finish in difficult to machine materials. It is also widely and effectively used as a de-burring process.*

Key Words: Electrochemical machining (ECM), electrolyte solution, complicated and intricate geometries, manufacturing technology, mechanical interaction, complicated shapes, good surface finish.

1. INTRODUCTION

In the hybrid electrochemical machining processes, the major material removal mechanism is either chemical dissolution (CD) or electrochemical dissolution (ECD). These machining processes are enhanced by using mechanical machining action or thermal assistance. The combination of these phases leads to high material removal rates and improved surface quality. In the case of the thermally assisted processes using a laser beam (LB), the local heating of the inter electrode gap enhances the dissolution process in laser-assisted chemical etching (LAE) or laser-assisted electrochemical machining (ECML) during which the current density rises and the dissolution phase becomes more intensive leading to a more productive machining process. The introduction of a mechanical machining phase assists electrochemical machining (ECM) removal rates by changing the inter electrode gap conditions for the enhanced dissolution process. Under such conditions mechanical DE passivation of the machined surface, by removing thin layers of oxides and other compounds from the anode, is ensured. This makes the surface dissolution and hence the smoothening process more intensive. Mechanical abrasion (MA) is combined with ECM to form many hybrid processes such as electrochemical grinding (ECG), electrochemical honing (ECH), and electrochemical super finishing (ECS). Furthermore, ultrasonic- assisted electrochemical machining (USMEC) employs an ultrasonic (US) machining component with ECD to improve electrolyte flushing and hence the material removal rate. The mechanical action of the fluid jet (FJ) enhances the CD during electrochemical buffing (ECB).

2. DESCRIPTION

2.1 ELECTROCHEMICAL GRINDING

Ir ECG is a hybrid machining process that combines MA and ECD. The machining rate, therefore, increases many times; surface layer properties are improved, while tool wear and energy consumption are reduced. 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. Electrochemical grinding (ECG) utilizes an abrasive grinding wheel, electrolyte solution, and a work piece, as shown in Fig-1. A grinding wheel is used as a cutting tool as a cathode and the work piece is an anode. During the process, electrolytic fluid, typically sodium nitrate, is pumped into the space between the work piece and the grinding wheel. Other electrolytes used include sodium hydroxide, sodium carbonate, and sodium chloride. This electrolytic fluid will cause electrochemical reactions to occur at the work piece surface which oxidize the surface, thereby removing material. As a consequence of the oxidation which occurs, layers of oxide films will form on the work piece surface, and these need to be removed by the grinding wheel. Depending on the grain size of these particles, a constant inter electrode gap (0.025 mm or less) through which the electrolyte is flushed can be maintained.

Most material removal is by the electrochemical reactions which occur at the work piece surface. Five percent or less of the material removal is carried out by the abrasive action of the grinding wheel. The fact that most material is not removed by abrasive action helps increase the life of the grinding wheel, that is, the tool will take a long time to wear down. The electrolytic fluid serves another useful purpose - it flushes out leftover material in between the grinding wheel and work piece. The Abrasive particles bonded to the grinding wheel will help to electrically insulate the space between the grinding wheel and work piece. The contribution of each machining phase to the material removal from the work piece has resulted in a considerable increase in the total removal rate QECG, in relation to the sum of the removal rate of the electrochemical process and the grinding processes QECD and QMA. This kind of grinding is mostly used because it can shape very hard metals and also because it is a chemical reducing process, the wheel lasts a longer time than normal grinding wheel can. Produces a smoother, burr-free surface and causes less surface stress than other grinding methods.

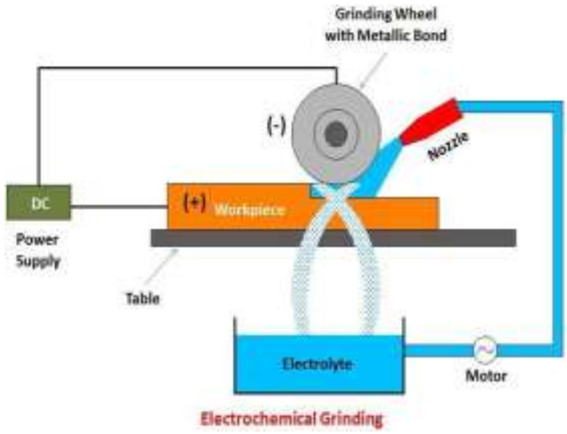

Fig -1: Electrochemical Grinding

2.2 ELECTROCHEMICAL HONING

Electrochemical honing (ECH) combines the high removal characteristics of ECD and MA of conventional honing. The process has much higher removal rates than either conventional honing or internal cylindrical grinding. Honing is a machining process in which a hone tool is used. A hone tool is a tool that simultaneously rotates as well as translates. In honing, a clear metal surface is formed by rubbing the abrasive stone against the work piece. A hone tool consists of abrasive stones that are used for the rubbing the metal surface. There are several types of the honing tools which are available in the market but each honing tool has those abrasive stones. In the ECH, electrolytes like Sodium Chloride, Sodium Nitrates are used. Here, the abrasive tool is inserted into the work piece. The work piece acts as an anode while the abrasive tool acts as the cathode. When the tool is inserted into the cylindrical work piece electrolyte is passes on the tool. As the metal part of the tool apart from the stones is conductive, it reacts with the electrolyte. Due to this the inside part the cylindrical work piece is get finished. The abrasive stones gives the final and neat finishing.

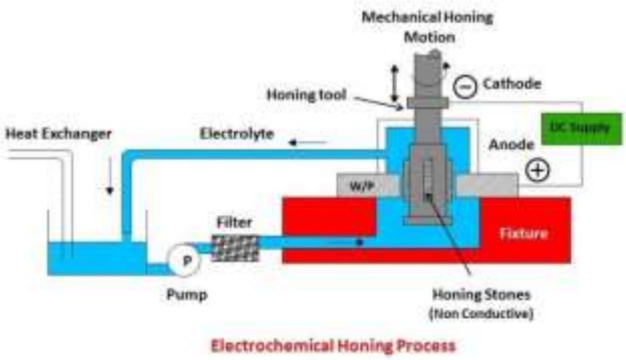

Fig -2: Electrochemical Grinding

The majority of material is removed by the ECD phase, while the abrading stones remove enough metal to generate a round, straight, geometrically true cylinder. During machining, the MA removes the surface oxides that are formed on the work surface by the dissolution process. The removal of such oxides enhances further the ECD phase as it presents a fresh surface for further electrolytic dissolution. The electrolyte provides electrons through the ionization process, acts as a coolant, and flushes away chips that are sheared off by MA and metal sludge that results from ECD action. The material removal rate for ECH is 3 to 5 times faster than that of conventional honing and 4 times faster than that of internal cylindrical grinding. Tolerances in the range of ±0.003 mm are achievable, an electrolyte is used and the temperature of this electrolyte is maintained around 38-40 degree Celsius. The pressure during this entire process is approximately equal to the 1000 kPa.

1) Advantages

- In case hard materials, the tradition machining techniques are not applicable. But this is the perfect process for hard or tough materials.

- No heat is produced during this whole technique.
- It gives you one of the best surface finishing.
- This method gives you the desired low tolerance.

2) Disadvantages

- More number of equipment are required during this process.
- The cost of machines is too much high to carry out this process.
- Skilled labor is needed to implement this metal removing process.
- It is only applicable to the hard materials mostly.

3) Applications

- ECH is widely used in the petrochemical and power generation industries.
- It is also used in correcting the gear teeth errors.
- The ECH is used for processing different materials like carbide, titanium alloys, Inconel, Incoloy, Titanium alloys, etc.
- It is also used in increasing the lifespan of the roller, sleeves, dies, gears, internal cylinders, etc.

2.3 ELECTROCHEMICAL SUPER FINISHING

Conventional super finishing by vibration grinding is a micro finishing operation in which the surface microirregularities are removed by the continuous and slow reciprocation of abrasive sticks that move along the work piece length. In electrochemical super finishing (ECS), the combination of electrolytic dissolution (ECD) and mechanical scrubbing (MS) improves the performance of the conventional super finishing process. As a result of such a combination, the dissolution process assists the small stock removal rate due to the mechanical chipping action.

The high stock removal capabilities combined with the ability to generate close dimensions gave high merits to the ECS process in all fields of industry. The need for initial grinding, which is required before conventional super finishing, is avoided. ECS can be used when other processes fail to yield high removal rates or generate the required size in difficult-to-machine alloys as well as tool steel. The power of the oxide film depends on the electrolyte used. Some electrolytes possess fairly strong power to reduce the ECD with their protective film.

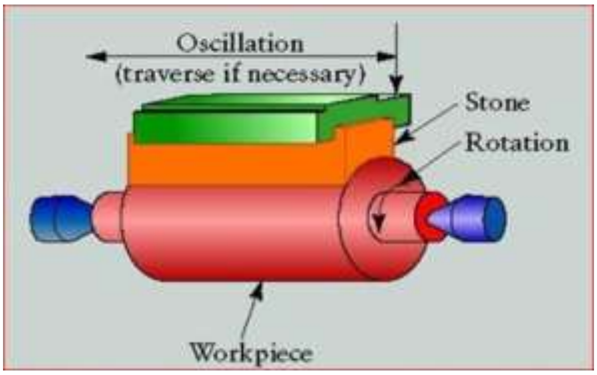

Fig-3 Electrochemical super finishing

1) Advantages

- Increasing part life.
- Decreasing wear.
- Closer tolerances.
- Higher load bearing surfaces.

2) Disadvantages

- Super finishing requires grinding or a hard turning operation beforehand, which increases cost.
- Super finishing has a lower cutting efficiency because of smaller chips and lower material removal rate.
- Super finishing stones are softer and wear more quickly.

3) Applications

- Steering rack components.
- Fuel injector components.
- Camshaft lobes.
- Hydraulic cylinder rods, bearing races.

2.4) ELECTROCHEMICAL BUFFING

Mechanical buffing is a slow finishing process used for achieving smooth, bright, and mirror like surfaces. The process is carried out under dry conditions, which raises dust and makes the working environmental conditions unsuitable. ECD of the anodic specimen mainly takes place on the surface of the specimen where it is rubbed by the carbon cloth buff. Electrolytes of NaCl or NaNO3 are supplied to the machining zone using a suitable pump. The machining current flows from the work piece to the cathode through the carbon cloth. The current density, the type of electrolyte, and the work piece material control the polishing speed.

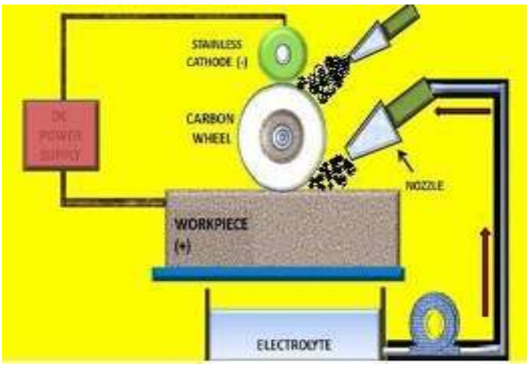

Fig-4 Electro chemical buffing

For high-speed polishing, a NaCl electrolyte is used where high current density is ensured.

Advantages

- Improved Corrosion Resistance-Parts that are susceptible to corrosion require aggressive finishes.
- De burring-untreated metal parts can have jagged edges that can be harmful during application use, especially in the medical field.
- Decorative Finish-Following Electrochemical buffing, metal parts have a bright, shiny surface that cannot be achieved by other metal finishing processes.

Disadvantages

- Rough surface defects cannot be removed;
- Electro surfacing multiphase alloys may cause roughening due to selective dissolution of different phases

Applications

- Electro polishing has many applications in the metal finishing industry because of its simplicity and its ability to be used on irregularly shaped objects, such as stainless steel drums of washing machines.
- Stainless steel surgical devices.

- Copper semiconductors.

2.5) ULTRASONIC-ASSISTED ECM

To improve technological factors in electrochemical machining, introduction of electrode tool ultrasonic vibration is justifiable. This method is called as ultrasonically assisted electrochemical machining (USAECM). The ultrasonic vibration facilitate removal of reaction byproduct and heat from machining zone , favors diffusion , minimizes passivation , creates optimal hydrodynamic conditions, improve aspect ratios, and influences electrolytic reactions through son chemical reaction. The demand for machining hard and brittle materials is steadily increasing in many applications. Ultrasonic machining (USM) produces parts having better surface quality. The material removal rate and hence the machining productivity is low. On the other hand ECM has the advantage of achieving high machining rates as well as better surface quality. While USM is suitable for hard and brittle materials such as ceramics. Merging the two processes has the advantage of combining their virtues especially when tackling difficult-to-machine composite materials. Ultrasonic-assisted electrochemical machining (USMEC) combines both ECM for removing the metallic conducting parts and USM for removing the non- conducting hard and brittle phases.

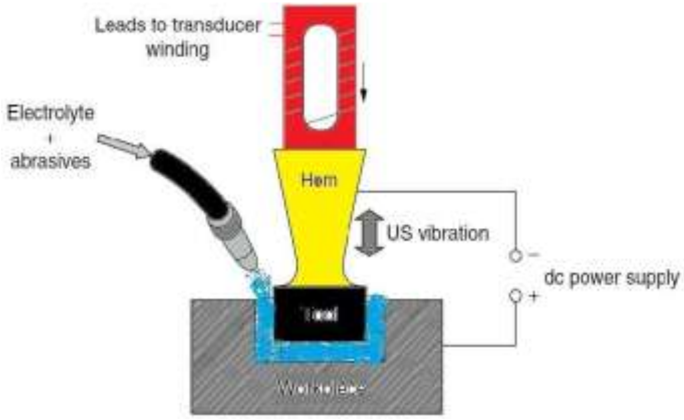

Fig 5 Ultrasonic-Assisted ECM

Electrolyte replaces water as an abrasive carrier liquid. A voltage of 3 to 15 V dc is normally used and ensures current densities between 5 and 30 A/cm2. Besides the dissolution process, the machine head and hence the cathodic tool are vibrated at the ultrasonic frequency of 20 kHz and an amplitude of 8 to 30 μm. USMEC process parameters include those related to ECM and USM.

2.6) LASER-ASSISTED ECM

Laser assisted jet electrochemical machining (LAJECM) is a hybrid process that combines a laser beam with an electrolyte jet thereby giving a non-contact tool electrode that removes metal by electrochemical dissolution.

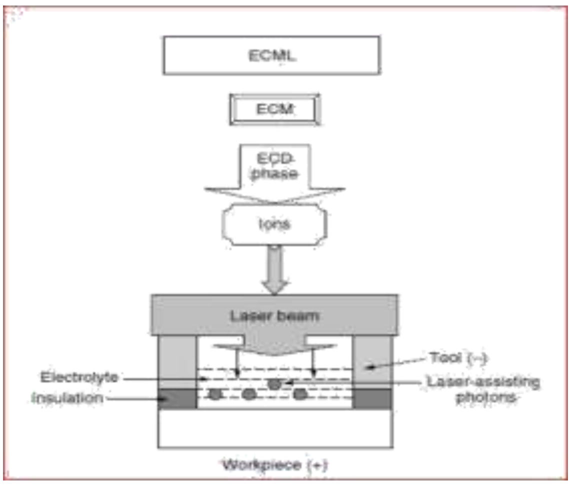

Fig 6 Laser assisted jet electrochemical machining(LAJECM)

The laser beam effectively improves the precision of LAJECM as it is able to direct the dissolution to specifically targeted areas. This prevents the machining from unwanted areas due to stray current. LAJECM combines two different sources of energy simultaneously: energy of ions (ECM) and energy of photons (a laser beam). The main aim of combining a laser with a jet of electrolyte (giving a laser-jet) is to assist electrochemical dissolution from a specific work piece surface area. Electrochemical dissolution is the main material removal mechanism supported by the parallel action of the low power (average power of 375 MW) laser beam. Thermal energy enhances the kinetics of electrochemical reactions providing faster dissolution. It also aids in breaking down the oxide layer found on some materials in certain electrolytes that inhibit efficient dissolution. In laser assisted ECM, the application of a laser beam to the machined surface is an efficient way for increasing the temperature of the machining zone during laser-assisted electrochemical machining (ECML). The wavelength of laser radiation should be chosen in such a way as to minimize the energy adsorbed by the electrolyte layer, which should be as thin as possible. The heat of the laser beam causes many physical and chemical phenomena on the machined surface as well as on the surface layer of the material.

Advantages

- The advantage of LAJECM is that the laser beam can be easily aimed on the work piece surface and therefore, together with the flushing electrolyte jet, dissolution can be accelerated in any desired direction. This „localization effect" enhances accuracy by limiting stray machining action.

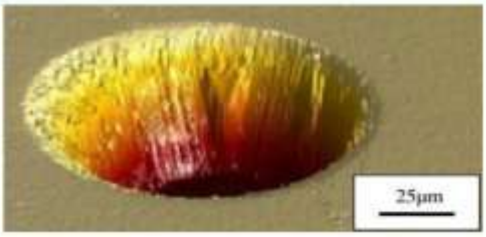

Fig: Micrograph of a hole drilled with LAJECM [1]

Fig 7 After hole drilling with LAJECM Disadvantages

- Basically the laser beam must be maintained coaxially with an electrolyte jet and in a single spot on the work piece. This is obviously difficult due to the hydrodynamic behavior of the jet as well as the gas evolution at the cathode.
- Gas evolution may also disturb a jet making the electrolyte flow more turbulent and thus causing the laser-jet spot to drift.

3. CONCLUSIONS

- The concept of electrochemical process has huge market in present industrial scenario.
- The metal removal rate by ECM is much higher than that of the CNC.
- Power requirements for ECM are comparatively high.
- The tolerance obtained by EDM and ECM is within the range of CNC machining, which means satisfactory dimensional accuracy can be maintained. All processes obtained are of satisfactory surface finishes.
- Capital cost for ECM is very high when compared to conventional CNC machining

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