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# APPLICATION OF ELECTRO-CHEMICAL MACHINING (ECM) FOR PROCESSING MATERIALS USED IN EXTREME CONDITIONS

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**Abstract:** Electro-Chemical Machining (ECM) is the generic term for a variety of electro-chemical processes. ECM is used to machine work pieces from metal and metal alloys irrespective of their hardness, strength or thermal properties, through the anodic dissolution, in aerospace, automotive, construction, medical equipment, micro-systems and power supply industries. The Electro Chemical Machining is extremely suitable for machining of materials used in extreme conditions. General overview of the Electro-Chemical Machining and its application for different materials used in extreme conditions is presented.
**Keywords:** Electro Chemical Machining (ECM), processing, materials, extreme conditions

## 1. INTRODUCTION

Electro Chemical Machining, abbreviated ECM, is an advanced metal-working technique which can machine products that are difficult or impossible to design through conventional machining [1,2]. It is an extremely accurate technique, capable of machining any electrically conductive work piece due to the fact that the technology is based on electrolysis (i.e., chemical change, especially decomposition, produced in an electrolyte by an electric current). ECM is used in aerospace, automotive, construction, medical equipment, micro-systems and power supply industries.

Almost all kinds of metal can be electro-chemically machined, especially high-alloyed nickel - or titanium-based ones, as well as hardened materials [3].

As it is a contactless procedure with no heat input, the process is not subject to any of the disadvantages experienced with traditional machining methods, e.g. tool wear, mechanical stresses, micro-fissures caused by heat transfer or the need for subsequent deburring operations. All electro-chemical machining processes are characterized by stress-free stock removal, gentle transitions and top-quality surfaces without burr formation.

During the process the metal work piece is dissolved (Machining) locally through electricity (Electro) and chemistry (Chemical) until it reaches the required complex 3D end shape.

## 2. PRINCIPLE OF ELECTRO CHEMICAL MACHINING

Electro Chemical Machining is based on the principle of electrolysis. The ECM tool (cathode) is positioned close to the work piece (anode) and a low-voltage, high-amperage direct current is passed between them via an electrolyte flowing through the anode-cathode gap (figure 1) [3]. Material is removed by anodic dissolution and is carried away by the electrolyte. A charge exchange takes place between the cathode and the anode in an aqueous electrolyte solution which targets specific areas of the workpiece. This can be used to create contours, ring ducts, grooves or bell hollows with no contact, but with very high precision. The removed material is precipitated from the electrolyte solution in the form of metal hydroxide. The machining can be carried out regardless of the structural condition of the metal and both soft and hard materials, including exotic metals, can be machined.

The components are subjected to neither thermal nor mechanical stresses.

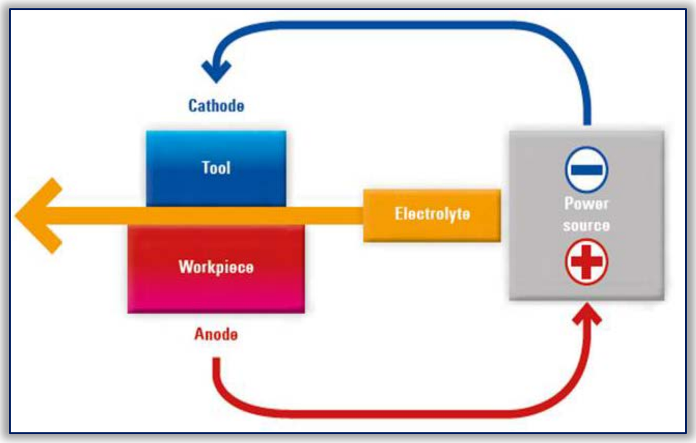

Figure 1-Functional principle of Electro-Chemical Machining [3]

The principle scheme of Electro-Chemical Machining process is presented in figure 2.

The work piece is mounted in a fixture electrically isolated from the tank and other machine parts. The work piece is connected to the positive terminal (anode) of the Power Supply. The tool is connected to the negative terminal (cathode).The electrolyte is continuously flowing through a hole in the tool to the gap between the work piece and the tool surfaces. The tool is moving towards the work piece at a constant speed. The gap between the tool and the work piece is kept constant. Stable behavior of the process is a result of a control of the power supply voltage. The final shape of the work piece formed as a result of the electrochemical machining process conforms the shape of the tool.

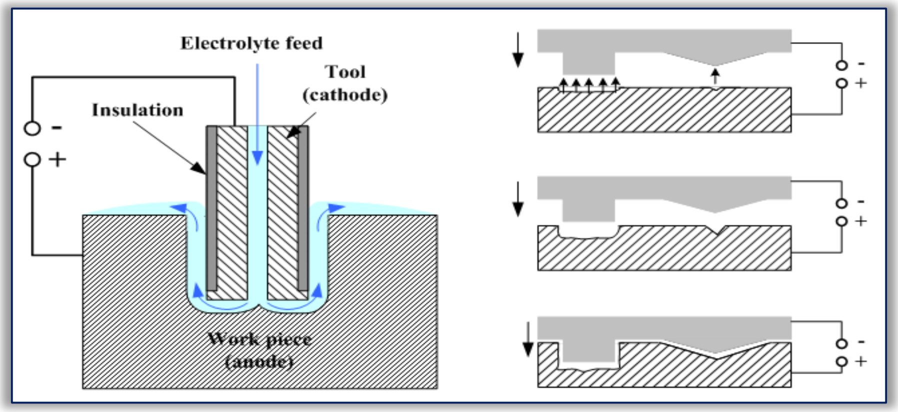


Figure 2 -The principle scheme of Electro-Chemical Machining process [4,5]

## 3. ELECTROLYTE IN THE ELECTRO CHEMICAL MACHINING

The electrolyte in the processes of Electro Chemical Machining has several functions: the current is carried between the tool and the workpiece through electrolyte, the produced heat is dissipated by the liquid electrolytic solution, the product of machining is removed by the solution and it keeps the reactions continuous by supplying the elements necessary for the reaction.

For different types of machined materials different types of electrolytes are used in Electro Chemical Machining:

- Sodium chloride (NaCl) at the concentration of 20% - for ferrous alloys (e.g. Steels and cast irons and cobalt alloys).
- Sodium nitrate (NaNO3) - for ferrous alloys.
- Hydrochloric acid (HCl) - for nickel alloys.
- A mixture of sodium chloride (NaCl) and sulfuric acid (H2SO4) - for nickel alloys.
- A mixture of 10% hydrofluoric acid (HF), 10% hydrochloric acid (HCl), 10% nitric acid (HNO3) - for titanium alloys.
- Sodium hydroxide (NaOH) - for tungsten carbide (WC).

The selection of the electrolyte should be done by considering the following matters: required machining rate, required dimensional accuracy and surface texture and integrity.

The electrolyte should possess several important properties [6]:

- Electrolyte must possess high electrical conductivity.
- Electrolyte should possess high specific heat.
- The viscosity must be as low as possible.
- The electrolyte must be chemically stable.
- Electrolyte must be chemically active to cause the better metal or material removal rate.
- Electrolyte should not form any type of excess layer on the top of electrolyte, tool or the work piece.
- Electrolyte should not be toxic and corrosive.
- Electrolyte should be economical and easily available.

Perfect electrolyte flow across the machining tool is mandatory for proper machining. Cavitation is likely to be occurred in the tool. So proper care is necessary to keep the tool in shape. Tool design must ensure the uniform flow of electrolytic solution in all machining areas. Optimum flow of the electrolyte is desired because excessive flow can cause erosion of the tool.

Mainly two types of flows are used: divergent flow and convergent flow.

Convergent flow provides a smoother flow of electrolytes.

The advantages of convergent flow system are:

- improved surface finish
- improved uniform and predictable side over cut as well as front machining gap,
- less prone to arcing,
- clean operating environment and
- stray currents make it possible to be eliminated unwanted machining.

But it is also important to be mentioned that machining in convergent flow is much expensive than divergent.

## 4. COMPONENTS OF ELECTRO CHEMICAL MACHINING EQUIPMENT

An industrial Electro Chemical Machining equipment consists of the following 4 systems (components) (figure 3) [4,5,6]:

- DC Power supply. The machining rate in electrochemical machining is proportional to the electric current density. In order to achieve high values of the machining rate electrochemical machining is commonly performed at a high direct current exceeding 1000 A. The gap between the tool and the work piece must be low for high-pitched correctness, thus the voltage must be small to prevent a short circuit. The voltage of the process is 5-25 V. The control system uses some of this electrical power.

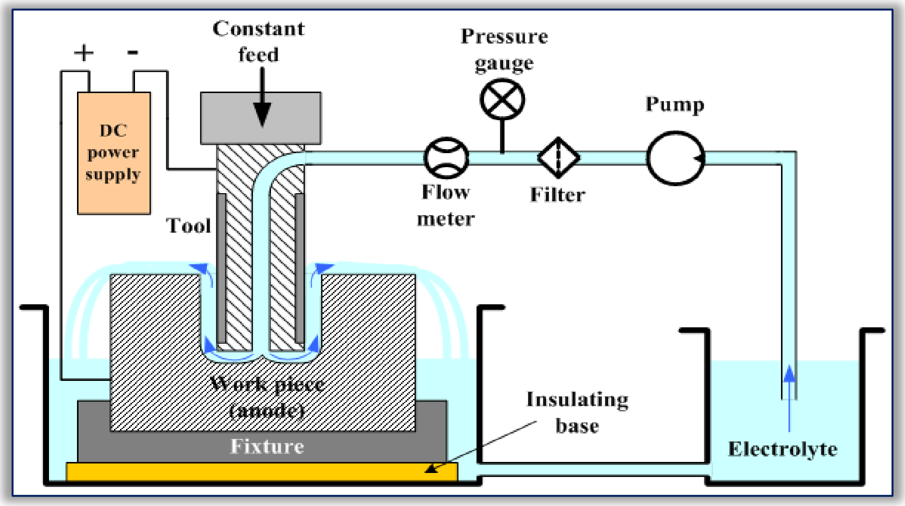


Figure 3 -The components of Electro Chemical Machining equipment [4,5,6]

# Electrolyte circulation system. The products of the electrochemical reaction should be removed from the gap between the work piece and the tool. Accumulation of the reaction products causes decrease of the process efficiency and reduction of the rate of machining. Therefore the electrolyte flow speed should be high. Commonly it is in the range 300-3,000 m/min (1,000-10,000 ft/min). The inlet pressure should be in between 0.15-3 MPa. The electrolyte system should comprise a fairly strong pump. The electrolyte is continuously filtered in order to trap the precipitated reaction products (sludge).

# Control system. Electrical parameters of the process (voltage and current)), tool feed speed and parameters of electrolyte circulation system (inlet and outlet pressure of electrolyte, temperature of electrolyte) are controlled by the control system, which provide stable and efficient operation of the unit

# Mechanical system. It consist of the table, the frame, work enclosure (prevents the electrolyte from spilling), the work head (where the tool is mounted).The tools (electrodes) are also part of the mechanical system. One of the most important parameters of electrochemical machining is maintaining a constant voltage level. This is achieved by the control system providing a movement of the tool at a constant speed equal to the linear rate of machining. The process in a steady state is performed at a constant (typically gap 0.1-0.4 mm / 0.004-0.016”). A firm fixation of the work piece provided by the fixture, the table and the frame is also important for stable operation of the system at a constant gap. Conventional machining equipment including CNC machines may be modified for electrochemical machining process.

## 5. APPLICATIONS OF ELECTRO-CHEMICAL MACHINING

Electro Chemical Machining is mainly used in the areas where conventional machining techniques are not feasible [7]. Theoretically Electro Chemical Machining could be used for machining the all electro conductive metals and alloys. The usual applications of Electro Chemical Machining are:

# Machining of hard materials and heat resistant materials. The process parameters and the tool life time do not depend on the hardness of the work piece. Therefore electrochemical machining is often used for machining hard materials.

# Machining of cavities in forging dies, drilling deeper holes and irregular shaped holes which can not be obtained by conventional machining methods.

# Machining of complex profiles like turbine wheels, turbine and jet blades.

# Die sinking. Electro Chemical Machining is often used as an alternative to the cavity type electric discharge machining (EDM).

# Fabrication of thin walled parts. Electrochemical machining does not produce surface stress in the work piece therefore even very brittle and easily deformed materials may be machined in thin walled shapes.

# Grinding of a work piece by a rotating wheel, which performs grinding operation through an electrolyte. The wheel is conductive and catholically connected. Non-conductive hard particles are set on the wheel surface. The particles provide a constant gap through which an electrolyte is continuously fed. Hard and brittle materials are ground by the method.

# Rough corners or edges can be turned into very smooth parts and the process is known as deburring.

## 6. MATERIALS POSSIBLE TO BE PROCESSED WITH ELECTRO-CHEMICAL MACHINING

With Electro Chemical Machining is possible processing of practically all groups of constructional steels and alloys used in the industry, including high-strength steels and alloys, metal-ceramics, nanostructure alloys.
This materials could be easily machined by Electro Chemical Machining [8]: alloy steels and construction steels, corrosive resistant steels, high-carbon chromium steels, stainless chrome-nickel steels, tool steels, chromium-nickel heat-resistant alloys, HSS, copper and copper alloys, nickel and nickel alloys, magnets, titanium and its alloys, ceramic-metal hard alloys (WC-Co, WC-TiC-Co), nanostructure steels and alloys.

## 7. ELECTRO CHEMICAL MACHINING OF MATERIALS USED IN EXTREME CONDITIONS

In the following figures 4-14 [9] are given several examples of Electro Chemical Machining (ECM) of different materials used in extreme conditions of temperature, loading, friction, wear, corrosion, in Energy, Transportation and Machinery manufacturing industries (figure 15) [10,11,12,13].

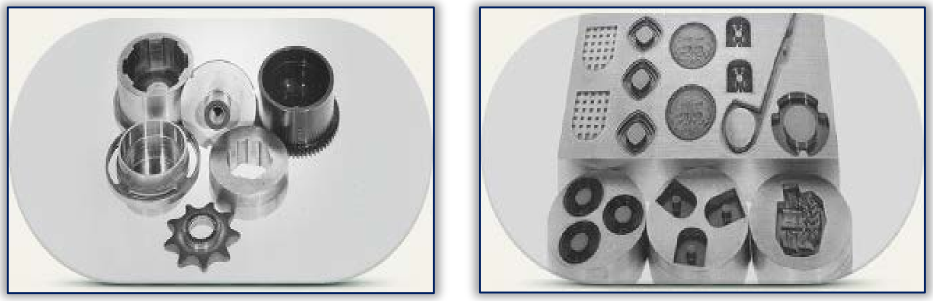

Figure 4-Examples of machined parts with ECM made from alloy steels and construction steels [9]

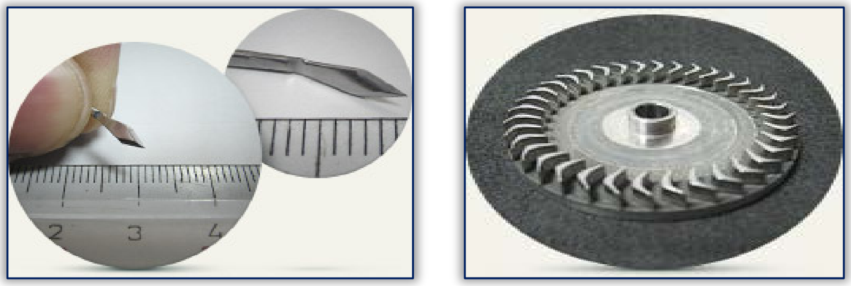


Figure 5-Examples of machined parts with ECM made from corrosive resistant steels [9]

Figure 6-Examples of machined parts with ECM made from high-carbon chromium steels [9]

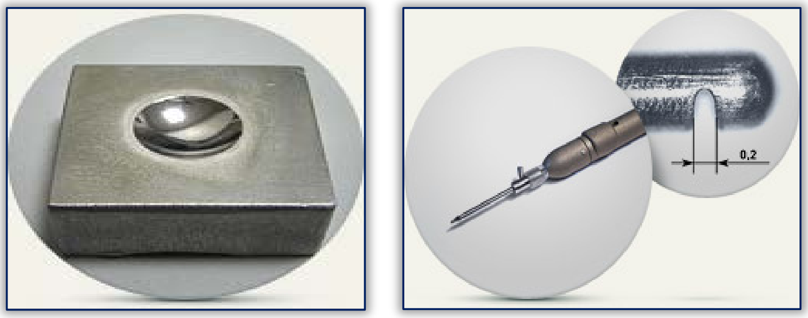


Figure 7-Examples of machined parts with ECM made from stainless chrome-nickel steels [9]

Figure 8-Examples of machined parts with ECM made from tool steels [9]

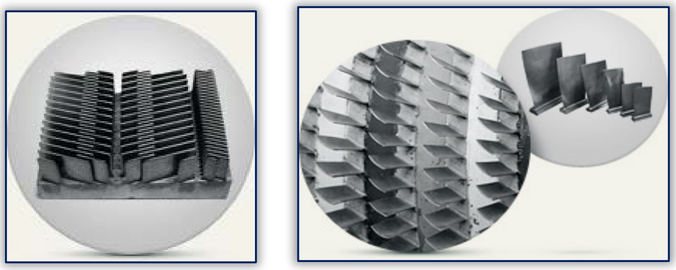

Figure 9-Examples of machined parts with ECM made from chromium-nickel heat-resistant alloys [9]

Figure 10 -Examples of machined parts with ECM made from High Strength Steels [9]

Figure 11- Examples of machined parts with ECM made from nickel alloys [9]

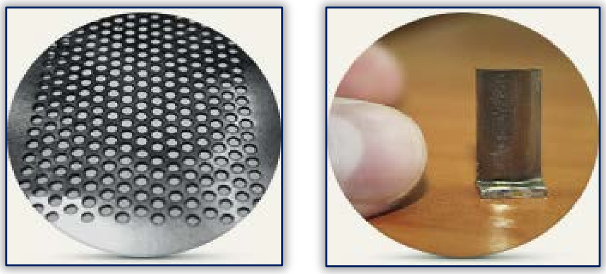

Figure 12-Examples of machined parts with ECM made from titanum alloys [9]

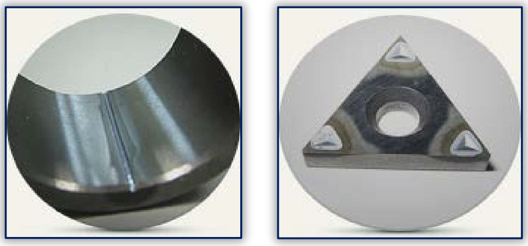

Figure 13-Examples of machined parts with ECM made from ceramic-metal hard alloys (WC-Co, WC-TiC-Co) [9]

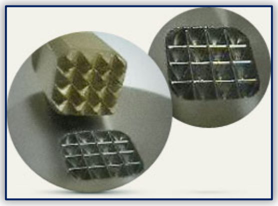

Figure 14.-Examples of machined parts with ECM made from nanostructure steels and alloys [9]

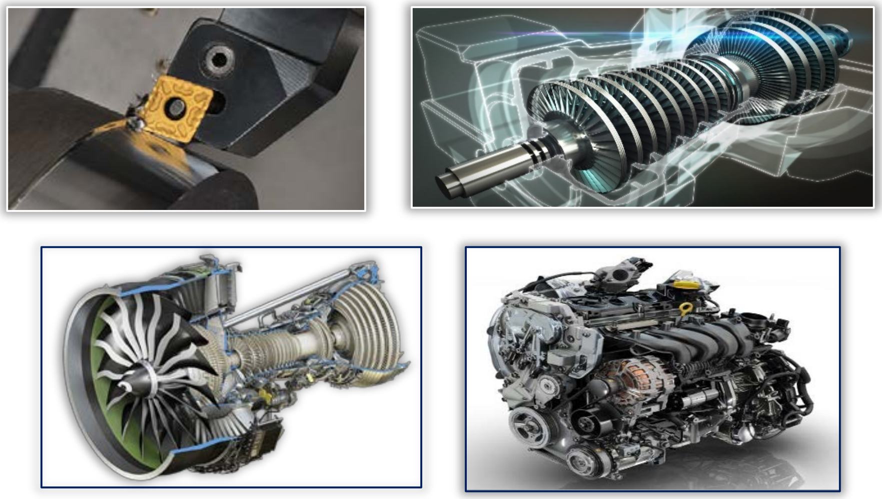

Figure 15-Examples of parts made from different materials used in extreme conditions of temperature, loading, friction, wear, corrosion, in Machinery manufacturing, Energy and Transportation industries [10,11,12,13]

## 8. CONCLUSION

Electro-Chemical Machining has a significant place among the methods of machining of conducting materials. It is applied in cases where alternative methods (especially the traditional ones) encounter problems: for operations which are time and hand-labour consuming. Electro-Chemical Machining is feasible for the machining of difficult-to-cut materials (high-strength, tough, hard, and brittle alloys, super-alloys), complex-shaped parts, and the machining in the difficult-to-reach areas. In some cases, Electro-Chemical Machining enables one to perform unique operations, for example, drilling of very small, deep, curved holes. The Electro-Chemical Machining processes are in progress, spread into new areas of modern technologies, for instance, micromachining.

Electro-Chemical Machining today is widely used in processing of materials used in extreme conditions of temperature, loading, friction, wear, corrosion, in Energy, Transportation and Machinery manufacturing industries.

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