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Design and Development of Travelling Wire Electro Chemical Machining Process

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A B S T R A C T

Slicing of hard and brittle materials is a challenge of manufacturing industries for the points of dimensionally accuracy and miniature of the work. Wire Electro Chemical Machining (WECM) has a potential to machine such types of materials in recent times. In the present article, it has been aimed to focus the design and development of WECM using line diagram with keeping the basic principle and past literature. This design depicts a setup of experimental machine of WECM using travelling wire. The fluid flows fluent analysis of electrolyte has been studied to analysis Velocity Contour, Velocity Path line, Pressure Contour, Pressure Path line, Temperature Contour, Temperature Path line, Wall Shear Stress Contour, Scaled Residual during WECM using ANSYS 17.2 software.

Keywords: WECM; ANSYS; Fluid Flow Fluent Analysis

1. Introduction

Electrochemical machining (ECM) is an unconventional conductive metal removal technique which is generally used for very hard materials or materials that are difficult to machine using conventional machining methods. Electrochemical reactions at atomic level occur between both the electrodes in which anode behaves as work-piece and cathode as tool. ECM has many advantages in processing metallic conducting materials i.e. high metal removal rate, high surface finish and low thermal or mechanical stresses. ECM has extensive applications in the automotive, petroleum, aerospace, textile, medical, electronics and micromachining industries.WECM possesses the property of ECM that includes electrochemical dissolution of conductive materials irrespective of their hardness and toughness of anode. Also there will be no tool wear, heat affected zones, residual stresses, cracks and burrs.

Metal wire as cathode is used instead of classical ECM tool in wire ECM. The main advantage of using wire in WECM is that it inhibits the property of ECM without the requirement of making the tool, which is complex, costly and time consuming. Moreover, intricate shapes can also be made easily with the help of wire. The movement of wire can be programmed accordingly or can be controlled manually. In programmed system the wire can be moved in a programmed path. Now the focus is on the electrolyte used in this process. Generally in ECM the electrolyte used is sodium chloride (NaCl), but as per survey sodium hydro-oxide (NaOH) has least corrosive property.

2. Review of Literature

Wire electrochemical machining process is the finest surface machining process. This process is the unconventional machining process. All engineering materials used to machine with the use of this process with high efficiency and better accuracy. There is not always compulsory that all the parameters which are input in this machining process should contribute in surface finish work and material removal rate. Some parameters are comparable to others

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with the help of past surveys. In this table it used to compare work piece material, Tool material, Electrolyte, Input parameters, Output parameters, Major findings related to wire electrochemical machining process summarized in Table1.

Table 1: Summarized Machining parameters of Wire electrochemical machining processes.

Work piece material	**Tool material**	**Electrolyte**	**Input parameters**	**Output parameters**	**Major findings**	**Ref.**
Stainless Steel 304		$NaNO_3$	Dia. of wire 200µm, applied voltage of 9 V, Concentration of solution 6g/L at 29 °C, feeding rate of 1.2µm/s, thickness of work piece 5mm, wire traveling velocity of 0.02 m/s.	Machining accuracy and stability	Experiment investigated, influence of parameters like the wire traveling velocity, the feeding rate, the applied voltage, and the electrolyte concentration.	Zeng2015 [1]
Carbon Steel	Copper	$NaNO_3$	Dia. of wire 0.3 – 0.43mm, applied voltage of 30 V, Concentration of solution 20wt% at 25-30 °C, thickness of work piece 20mm, wire tension 13.7N-98.0N , Electrolyte pressure 0.05-1.8MPa, Nozzle dia. 1.4-2.7mm, Pulse period 0.2-10ms, current 30-200A, feed rate 0.1mm/min			R. Maeda 1984 [2]
0Cr18Ni9	Tungsten wire	$NaNO_3$	Dia. of wire 20µm, applied voltage of 10 V, Concentration of solution 10g/L at 25 °C, feeding rate of 0.5µm/s, thickness of work piece 5mm, wire traveling velocity of 0.75 m/s, axial electrolyte flow, 800µm straight slit.	Processing stability and machining Efficiency, accuracy	Processing stability and machining efficiency can be improved by a higher electrolyte flow rate. The range of applicability of tool flow rate is below 0.75 m/s. Lower initial machining gap.	Wang 2011 [3]
Stainless Steel 304	Molybdenum	$NaNO_3$	Dia. of wire 100µm, applied voltage of 13 V, Concentration of solution 5g/L at 30 °C, feeding rate of 1µm/s, thickness of work piece 20mm, wire traveling velocity of 0.35 m/s, pulse duty cycle 50%, pulse frequency 1kHz, Insulating tube material glass, insulating tube inner and outer dia. 0.35-0.65mm, dist. Bet. Insulting tube and work piece 0.05mm.	Surface quality	Characteristics of stray-current attack in reciprocated TW-ECM were identified. In addition, insulating methods were proposed to reduce the stray-current attack.	Zeng2014 [4]
Stainless Steel 304	Molybdenum	$NaNO_3$	Dia. of wire 0.1mm, applied voltage of 13 V, Concentration of solution 5g/L at 30 °C, feeding rate of 1µm/s, thickness of work piece 20mm, wire traveling velocity of 0.35 m/s, pulse duty cycle 50%, pulse frequency 1kHz, slit width 177µm, standard deviation 1.5µm and aspect ratio is up to 113	homogeneity of the slit, machining accuracy and stability	The combination of pulse ECM and reciprocated traveling wire electrode can enhance the accuracy by timely replenishing of the electrolyte.	Qu 2014 [5]

Stainless Steel 304	Tungsten wire	H_2SO_4	Dia. of wire electrode10μm, applied voltage of 8 V, Concentration of solution 0.05M (mol/L) , feeding rate of 0.1μm/s, thickness of work piece 100μm, pulse period 6μs, pulse time 20, 40, 60, 80ns ,	Increase machining efficiency	When the pulse on time was 80 ns, the optimal wire electrode amount was three. And the machining efficiency using three wire electrodes was enhanced to be twice that using a wire electrode.	Xiaolong 2016 [6]
Mild Steel	Brass	NaCl	Dia. of wire electrode 0.2-2.0mm, Applied voltage of 10-40V, Feeding rate of 0.1-0.5 mm/min, Overlap distance 0.3 mm, Rotational speed 300-900rpm, Electrolytic concentration 250g/L, Electrolyte flow rate 15L/min, Initial frontal gap 1mm, Nozzle dia. 6mm, Machining distance 11mm.	Material Removal rate, Surface roughness, Roundness error.	Wire feed rate increases, surface roughness improves, productivity increases, roundness error improved.	Tahi ali El taweel 2010 [7]
Titanium alloy (TC1)		NaCl +$NaNO_3$	Electrolyte concentration (%) 10% NaCl + 10% NaNO3, Nozzle-work piece distance (mm) 5, Electrolyte flow rate (m Æ s_1) 42, Working voltage (V) 18, Wire feedrate (mm Æ min_1) 0.6	Machining productivity is increased.	Wire electrochemical machining with axial electrolyte flushing is presented to machine titanium alloy (TC1) .	Qu 2013 [8]
			Inlet pressure p/[bar]- 5,10.Oulet pressure p/[bar]-1,Revoution n/[1000/min]-2,5,10,25,50.Wire diameter d/[µm]-300,Cutting height 1/[mm]-13.	Influence of different wire geometries and different windings of the elliptical shaped wire were investigated. Finally, the fluidic behavior of different working gaps were presented.	In this wire ECM process the electrolyte flushing and the rotation effect is getting critical with high feed rates and high workpiece heights. Nevertheless, the flushing can be improved by a structured and rotating wire.	F.Klocke 2017 [9]
Tungsten carbide		H_2SO_4	Concentration: 0.8mol/L, wire feed rate: 0.2 μm/s Pulse-on time: 150 ns, pulse rate: 1MHz, Working voltage (V) 3-5, Slit width at entrance (μm) 0-85, Overcut at entrance (μm) 0-65,	consequently better cutting precision can be obtained with a relatively high machining stability	Capability of producing complex shaped micro metal tool effectively, with coupling motion control between rotation of work piece and horizontal and vertical feeding of micro wire. Pulse-on time, working voltage, and solution concentration Influence the overcut of cutting slit markedly.	Zhuang Liu 2014 [10]

3. Fundamental and Design Model of Wire Electrochemical Machining

The line diagram shown below is a representative diagram of wire electrochemical machining process. The wire wrapped along pullies is used to provide tension in the wire and used as tool material for machining process. Work piece is placed in the container containing electrolyte. The electrochemical reaction takes place in the presence of electrolyte and the tool is constantly travelling and wrapped from one pile to another. For electrochemical reaction power supply is provided with considering cathode as tool and anode as work piece.

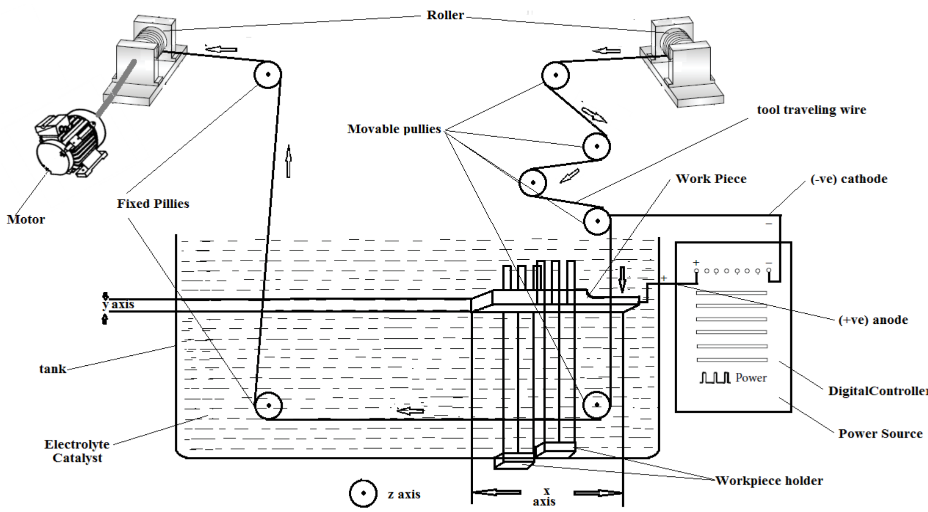

Fig 1: Line diagram of wire electro chemical machining process

For the movement of travelling wire a DC supply of 40000amp is supply in the motor with a voltage of 5-30 volt. This model doesn't require any pump, pressure gauge, filter etc. Electrolyte is poured in the container and the electrochemical reaction occurs in the container itself. As we know there is no contact between work piece and tool material in electrochemical machining either electrically or mechanically, so the gap maintained between tool and work piece is less than 50 microns. Wire of brass material of diameter 0.2 to 2 mm is used as tool because of high electrical and thermal conductivity, corrosion resistance and rigidity to withstand electrolytic flow. The feed rate in wire electrochemical machining process is about 0.1 to 0.5 mm/min.

In this model Rollers are used to releasing and winding of brass wire with the help of motor provided at the ends of rollers. The design is made for machining with multiple axes for complex Shapes of product with a better surface finish, because the pullies used to provide tension in the tool wire, while tension in the wire used to provide a proper finished product in machining. The movement of tool and work piece can be controlled with the help of digital controller according to the desired product required. The power source is used to supply electric current to work piece as anode and tool as cathode. The speed of metal removal process is not dependent on hardness and toughness of materials. Which means the exotic and hard alloys and hard steel can be dissolved as quickly as soft metal like aluminum. There is no need of pump, pressure gauge and filters as the electrolyte catalyst is dipped inside the tank where machining process is occur. There are two clamps positioned at the ends of container which is used to support the work piece inside the container containing electrolyte.

4. Analysis on Wire Electrochemical Machining

In this model of wire electrochemical machining process, analyzing is done on ansys 17.2 software. Behavior of electrolyte is main concern in this analysis. NaOH is taken as electrolyte and flow behavior of velocity, pressure, temperature and wall shear stress have been studied. The analysis is done on ansys fluent, where we assume the container having rectangular shaped filled with electrolyte.

1. Fluid flow fluent Analysis on Electrolyte

a) Velocity

i) Contour

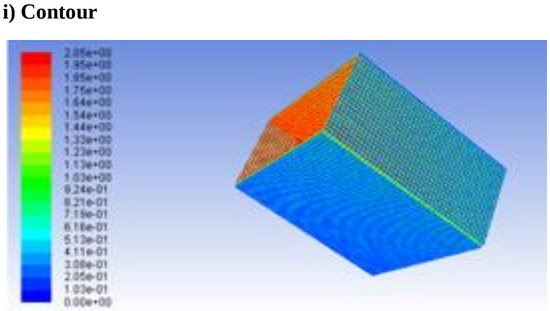

Fig 2: Velocity Contour of electrolyte

ii) Vector

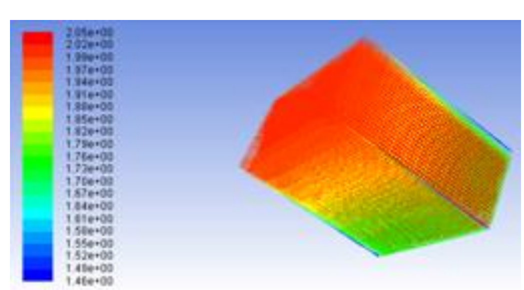

Fig 3: Velocity Vector of electrolyte

In this analysis we take fluid medium as electrolyte of NaOH solution, in which one side is mark as inlet and another is outlet, rest the side is considered as walls. Velocity of fluid flow is taken as 0.2 cm/s. Fig 2 and 3 shows the velocity contour of fluid i.e. electrolyte and velocity vector of fluid, In velocity contour we apply velocity at every single particle and the output shows average cross sectional velocities of electrolyte with the value varies from 0 to 2.05 mm/s. Velocity vector shows the rate of change of position of a particle; the vector shows magnitude and direction of every single particle of electrolyte with value varies from 1.46 to 2.05 mm/s.

b) Pressure

i) Contour

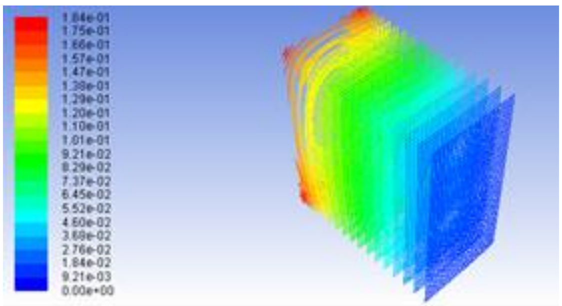

Fig 4: Pressure Contour of electrolyte

ii) Path line

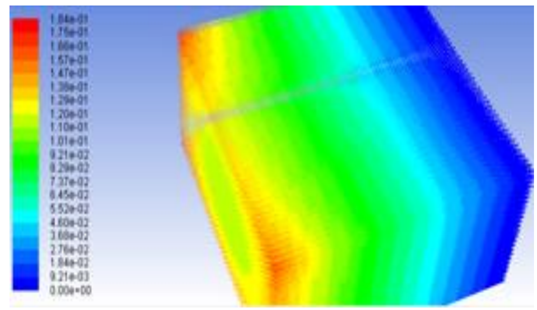

Fig 5: Pressure pathline of electrolyte

Fig 4 and 5 shows pressure contour and pressure pathlines of electrolyte respectively. The gauge pressure measured at outlet is zero Pascal. Pressure contour shows pressure at different layers of electrolyte with a value ranges from 0 to 0.184 N/m^2. Pathlines are obtained when single fluid behavior is studied i.e. trajectories of individual fluid particles over a certain period of time.

c) Temperature

i) Contour

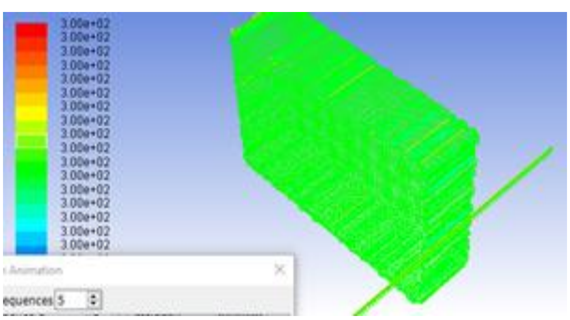

Fig 6: Temperature contour of electrolyte

ii) Path line

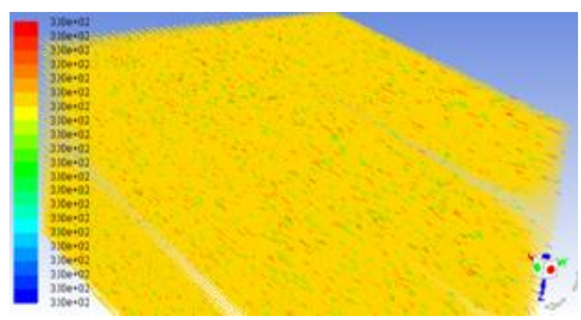

Fig 7: Temperature Path line of electrolyte

Fig 6 and 7 shows temperature contour and temperature pathline respectively, for a given set of inputs the effect of temperature on work piece and tool has been shown in temperature contour and temperature pathline for electrolyte. Clearly it is seen from the figure that the temperature contour shows a constant quantity therefore temperature of electrolyte is assumed to be constant at room temperature. Moreover the temperature pathline also shows a constant quantity in the direction of flow of fluid.

d) Wall Shear Stress Contour

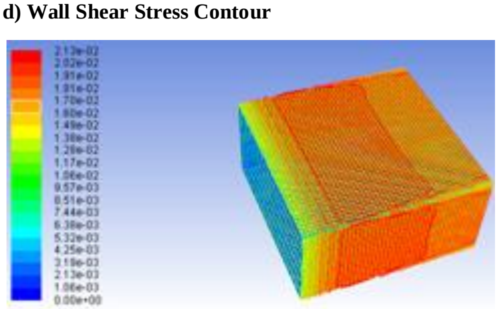

Fig 8: Wall shear stress contour of electrolyte

e) Scaled Residual

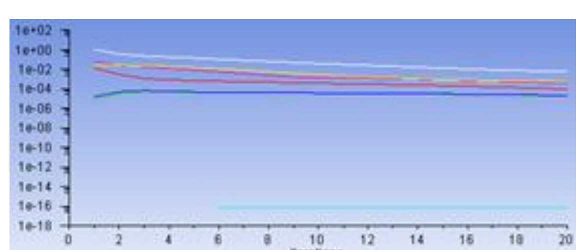

Fig 9: Scaled Residual of electrolyte

Wall shear stress on electrolyte surfaces has been shown in fig 8. The walls of the container is having a variable stress concentration with a value varies from 0 N/m^2 at the inlet and outlet to 0.213 N/m^2 at the walls. The contour diagram is shown in the figure above clearly shows the walls doesn't have a fixed value of stress concentration. Fig 9 shows the graph of scale residual between iteration and time steps. From the graph itself it is depicted that the time steps is very less and varies from 10^{-5} to 1 s and the iterations almost tends to constant value.

5. Reaction Involved

In wire electrochemical machining process the reactions involve between the tool Brass (composition of copper Cu and zinc Zn) and electrolyte NaOH as:

$2Cu + 2NaOH\ (aq) \rightarrow Cu(OH)_2 + 2Na$ (precipitation reaction)

$Zn + NaOH\ (aq) \rightarrow Na_2ZnO_2 + H_2$ (multi step reaction)

Steps involved in multi step reactions are

$Zn + 2NaOH\ (aq) \rightarrow Zn(OH)_2 + 2Na$ (precipitation reaction)

$2\ Zn(OH)_2 + 2NaOH \rightarrow Na_2ZnO_2 + 3H_2O$

The reaction involve between the Work piece Titanium alloy and the Electrolyte NaOH as:

$TiO_2 + 2NaOH \rightarrow Na_2TiO_3 + H_2O$

The reaction involve between the Work piece Structural steel and the Electrolyte NaOH as:

$Fe + NaOH + H_2O \rightarrow Na_2[Fe(OH)_4] + H_2$

Reaction involved in electrolyte

Cathode (Tool)

$Na^+ + e^- \rightarrow Na$

$Na + H_2O \rightarrow Na\ (OH)$

$2H^+ + 2e^- \rightarrow H_2\ (g)$

Anode (Work piece)

$Fe \rightarrow Fe^{2+} + 2e^-$

$Fe^{2+} + 2(OH)^- \rightarrow Fe(OH)_2$

These reactions show the effects on electrolyte as it reacts with tool and work piece. The above three reaction shows the effect on electrolyte, tool and work piece. The reactions are (i) when the brass as tool is reacted with electrolyte (ii) the reaction between the work piece (titanium alloy) and electrolyte and (iii) the reaction between work piece (structural steel) and electrolyte and what are the effect on electrolyte when the reaction is involved between tool and work piece with electrolyte. Then there is reaction involves at electrolyte, Cathode (-ve) as tool and anode (+ve) as work piece. Although most of the reactions occurs at subsequent stages of the process and consist of the formation of hydroxides or other complex compounds depending on the composition of electrolyte.

6. Conclusion

The modeling and analysis of wire electrochemical machining process is done above. The model is shown in the figure using line diagram of wire electrochemical process. From the above discussions we conclude few points which we get from the analysis as:

1. It is tabulated that different researchers have been represented different ideas and major findings related to input parameters, output parameters, work pieces and electrolytes in their research.
2. The velocities at the walls are minimum or we can say zero compared to velocity within the container having a value of 2.05 mm/s.
3. The pressure value shown in pressure diagram is 0.184 N/m^2 and is constantly varies from 0 to maximum value as shown in figure 4 and 5.
4. Temperature variations of electrolyte in electrochemical machining process are almost constant at room temperature irrespective of the tool, work piece and electrolyte.
5. Wall shear stress is minimum at inlet and outlet and maximum at the walls with a value varies till maximum reaches at 0.213 N/m^2.

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