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Experimental Investigation to Improve Metal Removal Rate (MRR) and Surface Roughness in Electrochemical Machining

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ABSTRACT

Electrochemical machining (ECM) is a non-traditional machining process which is the controlled removal of metal by anodic dissolution in an electrolytic cell in which the workpiece is the anode and the tool is cathode. In ECM, metal removal rate (MRR) takes place due to atomic dissolution of work material. Electrochemical dissolution is governed by Faraday's laws.I n this study the ECM is used to remove metal from the internal hole of the workpiece from aluminum alloy using NaCl solution. The rates of improvement in MRR are (6.48, 1.81, 3.74, 13.24, 3.11) % for current densities of (2.82, 4.24, 5.65, 7.07, 8.48) A/cm^2 respectively, when compared with the stationary tool, and the rotating electrode gives better surface finish than the stationary electrode, were the enhancement rates in roughness are (7, 31.72, 7.91, 15.49, 1.34)% for current density values of (2.82, 4.24, 5.65, 7.07, 8.48) A/cm^2 respectively.

Keywords: Electrochemical Machining (ECM), Metal removal rate MRR, Surface Roughness, Rotating Tool.

تحقيق تجريبي لتحسين معدل إزالة المعدن (MRR) والخشونة السطحية في التشغيل الكهروكيميائي

الخلاصة

التشغيل الكهروكيميائي يطلق على نوع من أنواع التشغيل اللاتقليدي(ECM) والدي من خلاله تتم إزالة معدن مسيطر عليها بواسطة التحلل الانودي في خلية الكترووليتية حيث إن القطعة المشغلة هي الانود والعدة هي الكاثود وفي التشغيل الكهروكيميائي تتم أزالة المعدن بطريقة الأدابةوحسب قوانين فراداي . في هذا البحث استخدمت طريقة (ECM) في إزالة المعدن لتوسيع الثقب الموجود في القطعة المشغلة من سبيكة الألمنيوم (Al Zn Mg Cu1.5-DIN 1725-1) باستخدام المحلول الالكتروليتي (NaCl). إن نسب التحسين في معدل إزالة المعدن (MRR) هي (6.48، 1.81، 13.24، 3.74، 3.11)% لقيم كثافة التيار (2.82، 5.65، 4.24، 7.07، 8.48) أمبير/سم2 بالتتابع. وعند مقارنة العدة الدوارة مع العدة الثابتة أعطت نتائج أفضل بالنسبة لخشونة السطح . حيث ان نسب التحسن بالخشونة هي (7، 31.72، 15.49، 7.91، 1.34)% لقيم كثافة التيار (2.82، 5.65، 4.24، 7.07، 8.48) أمبير/سم2 بالتتابع.

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INTRODUCTION

Metal removal rate (MRR) is an important characteristic to evaluate efficiency of non traditional machining process. In electrochemical machining (ECM), metal removal rate takes place due to atomic dissolution of work material. Electrochemical dissolution is governed by faraday's laws which is based on using electrolytic cell in which the workpiece is the anode and the tool is cathode, so the theoretical metal removal rate is depended on the amount of atomic weight and the valence of each elements in the alloy were taken from the standard table of the chemical reaction of the elements . Then improving metal removal rate during reaction depend on many parameters such as current density, voltage, electrolyte concentration, in addition to tool shape and surface finish[1]. Many researchers study , T.SEKAR ,et al, show that the higher MRR is achieved with circular and spiral with inclined hole geometries, so the tool geometry is one of influencing factors for achieving the higher MRR[2]. The shaped tool (cathode) is connected to the negative polarity and the workpiece (anode) is connected to the positive polarity. The electrolyte flows through the small inter electrode gap, thus flushing away sludge and heat generated during machining process[5] . Electrochemical machining (ECM) was developed to machine difficult-to-cut materials, and it is an anodic dissolution process based on the phenomenon of electrolysis, whose laws were established by Michael Faraday. In ECM, electrolytes serve as conductors of electricity. ECM offers a number of advantages over other machining methods and also has several disadvantages.

Advantages: There is no tool wear, machining is done at low voltages compared to other processes with high metal removal rate, small dimensions can be controlled, hard conductive materials can be machined into complicated profiles, workpiece structure suffer no thermal damages, suitable for mass production work and low labor requirements[3].

Disadvantages: A huge amount of energy is consumed that is approximately 100 times that required for the drilling of steel, safety issues on removing and disposing of the explosive hydrogen gas generated during machining, and difficulty in handling and containing the electrolyte [4].

this paper was focused on rotating tool instead of stationary tool to improve MRR, so that the machining accuracy in ECM largely depends on the tool.

Estimation of theoretical material removal rate(MRR_{th})

The engineering materials are quite often alloys rather than element consisting of different elements in a given proportion [6,7]. When the anode is made up of an alloy instead of a pure metal (or single element). The value of electrochemical equivalent of the alloy is not known [8]. The theoretical metal removal of an alloy can be calculated by summing up the charges required for the removal of each element from a given volume of alloy according to following formulas:

$$MRR_{th} = \frac{100}{\rho F}\left[\frac{1}{\frac{X_1 V_1}{A_1}+\frac{X_2 V_2}{A_2}+\frac{X_3 V_3}{A_3}+ ...etc}\right] cm^3/amp\ sec \quad ....(1)$$

$$MRR_{th}(\text{in } cm^3/sec) = MRR_{th} \text{ in}(cm^3/amp\ sec) \times I \qquad \ldots\ldots (2)$$

$$MRR_{th}(\text{in g/sec}) = MRR_{th}(\text{in } cm^3/sec) \times \rho \qquad \ldots\ldots\ldots (3)$$

where:
A=atomic weight
ν=valence
F = Faraday's constant = 96500 coulombs
I = current (Amper)
ρ= density of the material (g/cm^3)
X_i = composition of element in alloy.

Table (1) Chemical composition of alloy being used in the experimental work [9].

Metal	Si%	Fe%	Cu%	Mn%	Mg%	Cr%	Ni%	Zn%	Al%
AL Zn Mg Cu1.5-DIN 1725-1	0.059	0.206	1.84	0.206	2.17	0.190	0.001	5.57	remain

Table (2) density, atomic weight, and valence of the alloy[9].

Element	Density g/cm^3	Atomic weight	Valence
Si	2.33	28.086	4
Fe	7.86	55.845	2
Cu	8.92	63.546	2
Mn	7.43	54.938	2
Mg	1.738	24.305	2
Cr	7.19	51.996	2
Ni	8.90	58.693	2
Zn	7.1	65.38	4
Al	2.712	26.97	3

Estimation of experimental material removal rate (MRR_{exp})

The actual material removal rate can be determined by the e question:[6]

$$MRR_{exp} = \frac{wb - wa}{Time} \ (g/sec \text{ or } g/min) \qquad \ldots\ldots (4)$$

Where:

Wb = weight of the workpiece before ECM operation (g)
Wa = weight of the workpiece after ECM operation (g)

Estimation of current efficiency (η)

The current efficiency is defined as the ratio of the observed amount of metal dissolved to the theoretical amount predicted from Faraday's law, for the same specified conditions of electrochemical equivalent, current, [10].

$$\eta = \frac{\text{Actual metal removed}}{\text{Theoretical amount of metal removed}} \times 100\% \quad \text{.....(5)}$$

Current efficiency (η) depends greatly on the material of the workpiece, type of electrolyte as well as machining conditions, mainly on the current density, the temperature and the flow rate of electrolyte. For an efficiency of 100%, the total current is carried by ions of dissolved metal. For zero efficiency, the current passes without metal dissolution [11].

Experimental work

The electrochemical cell consist of electrolyte solution (NaCl +water) and power supply DC current with pump for electrolyte flow rate at different medium concentration as shown in Figure (1).

1-First experiment was done under the cutting conditions using different values of current density as shown in table (3) with stationary tool and then calculate metal removal rate (MRR) and surface roughness of work material.

2-Second experiment was done at the same cutting conditions of the first test only using rotating tool instead of stationary tool, then compare the result between them.

3- Surface roughness device used to measure roughness of workpiece as shown in Figure (2) by moving probe inside diameter of workpiece then give reading of roughness in micron (μm) .

The ECM cell that used in the experimental work is shown in figure (1).

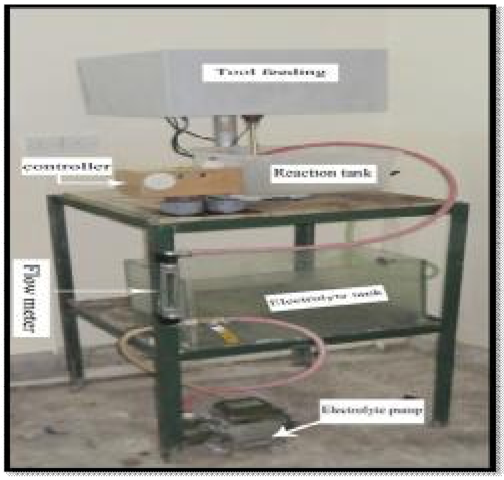

Figure (1) ECM cell used in experimental Work.

Figure (2) surface roughness device.

Tool and workpiece description

The tool (cathode) used in experimental work is a cylindrical rod made from brass with a diameter of (Ø 10mm). The reason for using brass metal is easy to machining, having high electrical conductivity, and high corrosion resistance. The workpieces are (10) pieces from cylindrical shaft with dimensions of (Ø70mm outside diameter, 13mm hole diameter, and 45 mm height) as shown in figure (3). The amount of atomic weight and the valence of each elements in the alloy is taken from the standard table of the chemical reaction of the elements [9].

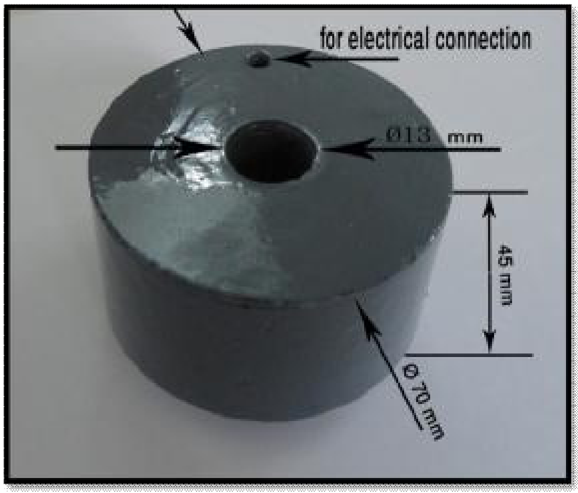

Figure (3) Workpiece being used in the experimental work

Results and discussion

Effect of tool rotation on MRR

The results of studying the effects of tool rotation are shown in table (3). The machining gap is (1.5mm), machining time (8 minutes), electrolyte concentration (200 g/l), electrolyte flow (8 l/min), electrolyte temperature (35˚C), and tool rotation (620 r.p.m) .

Table (3) the experimental results of the effects of rotary action of tool on MRR

Electro-lyte concentration (g/l)	Current value (Amper)	Current density (A/cm^2)	Tool rotation (r.p.m)	Flow rate (l/min)	Weight before machining (g)	Weight after machining (g)	Gap (mm) ±0.1	MRR_{th} (g/min)	MRR_{exp} (g/min)	Efficiency η %
200	40	2.82	0	8	406.69	405.11	1.5	0.2346	0.1975	84.18
200	40	2.82	620	8	415.35	413.66	1.5	0.2346	0.2112	90.02
200	60	4.24	0	8	418.42	415.74	1.5	0.3519	0.3350	95.19
200	60	4.24	620	8	410.24	407.51	1.5	0.3519	0.3412	96.95
200	80	5.65	0	8	420.25	416.65	1.5	0.4693	0.4500	95.88
200	80	5.65	620	8	413.53	409.79	1.5	0.4693	0.4675	99.61
200	100	7.07	0	8	406.57	402.51	1.5	0.5866	0.5075	86.51
200	100	7.07	620	8	421.95	417.27	1.5	0.5866	0.5850	99.72
200	120	8.48	0	8	179.05	173.77	1.5	0.7038	0.6600	93.77
200	120	8.48	620	8	188.21	182.76	1.5	0.7038	0.6812	96.78

Figure (4) shows that an improvement of MRR was done by using the rotational tool compared with the stationary tool, where the significant effect of rotary action of tool over MRR is better than the stationery tool. From figure (4) the experimental metal removal rate (MRR) at current density of (7.07 A/cm^2) using stationary tool increased with low value compared with other current densities may be due to the changing in controlled machining conditions such as electrolyte temperature during machining operation. Figure (5) shows the experimental material removal rate (MRR_{exp}) with rotary tool values are very near to the theoretical values compared with that achieved by using stationary tool, the MRR increases with rotation action of tool because there is more mobility of the ions from the metal to the solution increasing the speed of the chemical reactions. The rates of improvement in MRR are (6.48, 1.81, 3.74, 13.24, 3.11)% for current densities of (2.82, 4.24, 5.65, 7.07, 8.48) A/cm^2 respectively.

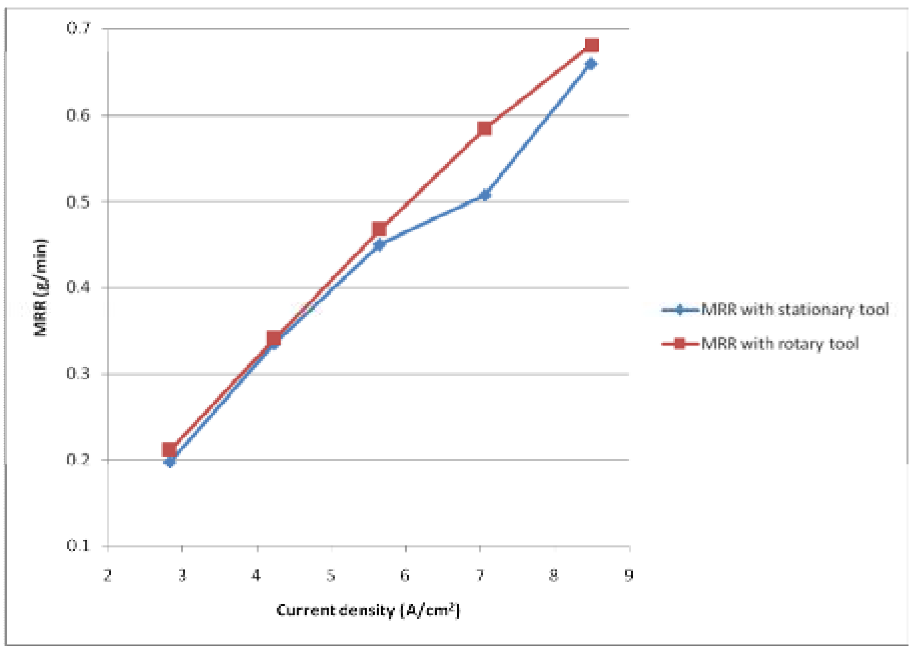

Figure (4) Effect of rotary action of tool on MRR compared with stationary tool.

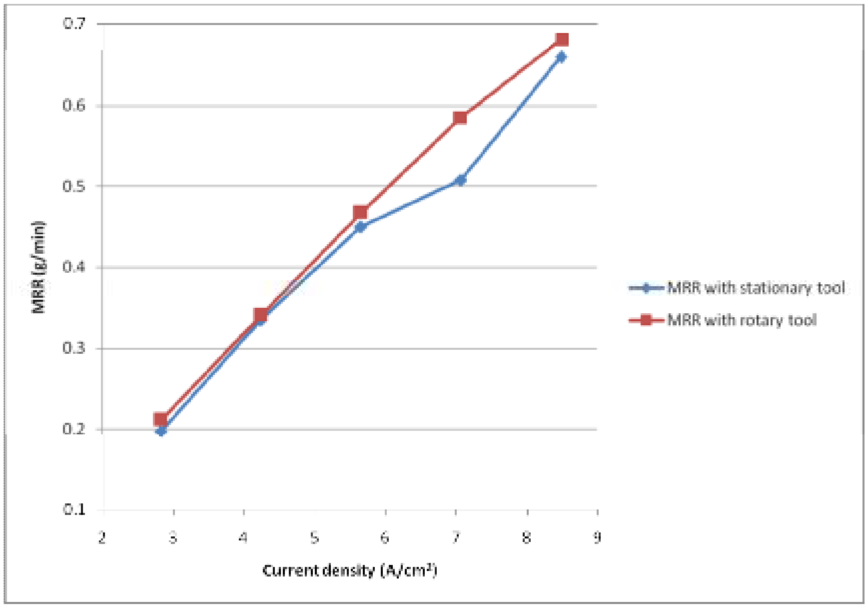

Figure (5) Experimental MRR in rotary and stationary cases

with the theoretical MRR

Also the efficiency is improved by using rotary tool compared with that using a stationary tool was shown in Figure (5). The efficiency is improved by (6.48, 1.81,3.74,13.24,3.11)% for (2.82, 4.24, 5.65, 7.07, 8.48) A/cm^2 respectively. Were maximum improvement obtained at current density of (7.07 A/cm^2).

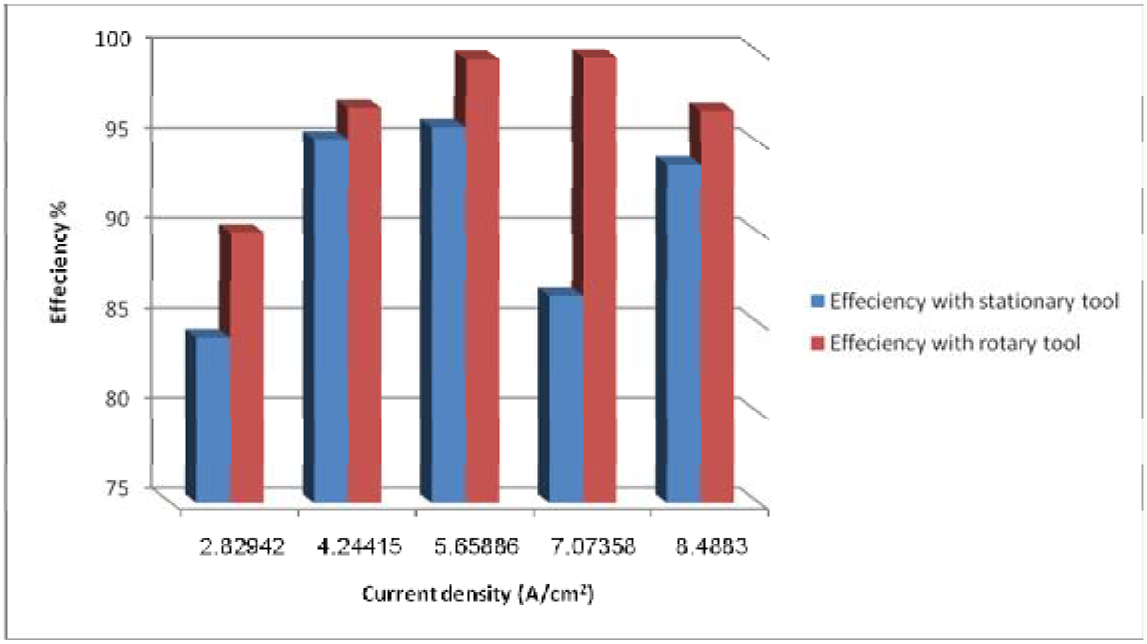

Figure (6) Efficiency of rotary and stationary tools at different current densities

Effect of tool rotation on surface roughness(R_a)

The results of study the effects of tool rotation on surface roughness are shown in the table (4). The machining gap is (1.5mm), machining time (8 minutes), electrolyte concentration (200 g/l), electrolyte flow (8 l/min), electrolyte temperature (35˚C), and tool, rotation (620 r.p.m).

Table (4) the experimental results of the effects of rotary action of tool on R_a

No. of exp.	Electrolyte concentration (g/l)	Current density (A/cm2)	Tool rotation (r.p.m)	Electrolyte flow rate (l/min)	Gap (mm) ±0.1	Work piece roughness before ECM operation (µm)	Work piece roughness after ECM operation (µm)
1	200	2.82	0	8	1.5	3.374	2.955
2	200	2.82	620	8	1.5	3.922	2.748
3	200	4.24	0	8	1.5	2.727	2.345
4	200	4.24	620	8	1.5	2.397	1.601
5	200	5.65	0	8	1.5	3.182	1.694
6	200	5.65	620	8	1.5	2.035	1.560
7	200	7.07	0	8	1.5	3.616	1.601
8	200	7.07	620	8	1.5	4.815	1.353
9	200	8.48	0	8	1.5	3.658	1.115
10	200	8.48	620	8	1.5	2.914	1.100

Figure (6) shows that when a stationary electrode was compared to the rotating electrode, it was found that the rotating electrode gives better surface finish than the stationary electrode. The enhancement rates are (7%, 31.72%, 7.91%, 15.49%, 1.34%) for current density values (2.82, 4.24, 5.65, 7.07, 8.48) A/cm^2 respectively. The effect of rotary action on R_a at higher current density is marginal effect compared with that effect at low current density as shown in figure(6).

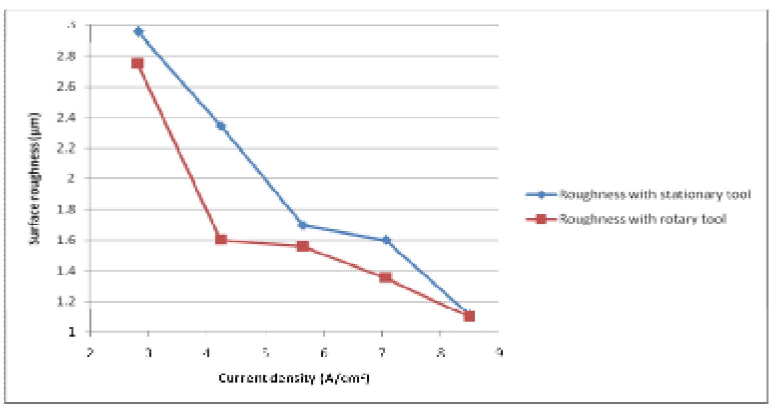

Figure (7) Ra with rotary and stationary tools at]different current densities

Figure (7) shows that the Ra decreases after all machining operation of ECM and the decreasing rates are (29.93, 33.2, 23.34, 71.9, 62.25)% for current densities (2.82, 4.24, 5.65, 7.07, 8.48) A/cm^2 respectively.

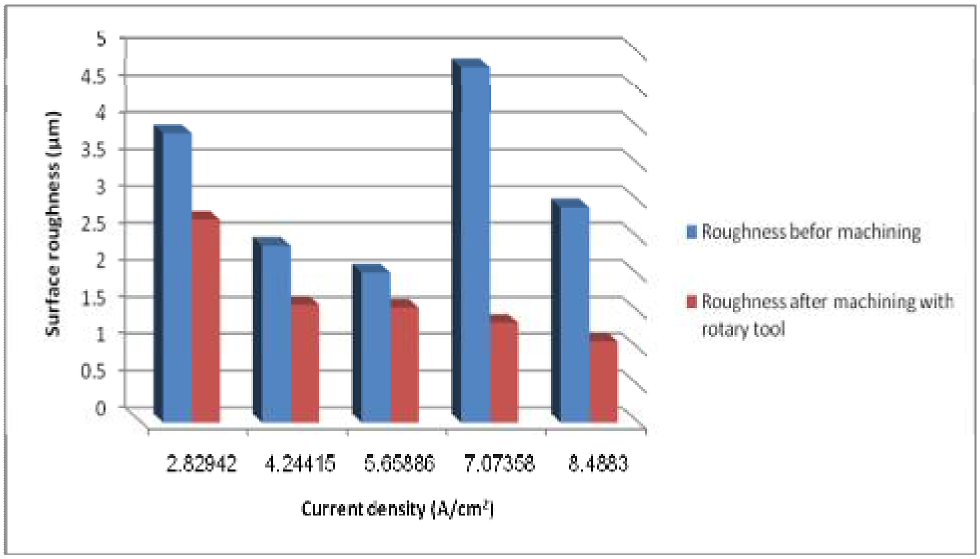

Figure (8) The differences in surface roughness before and after ECM machining in different current densities with rotational tool

CONCLUSIONS

- The MRR is improved by using rotary electrode compared with stationary electrode for the same machining conditions **.**The rates of improvement in MRR are (6.48, 1.81, 3.74, 13.24, 3.11)% for current densities of (2.82, 4.24, 5.65, 7.07, 8.48) A/cm^2 respectively.It is found the rotating electrode gives better surface finish than the stationary electrode. The enhancement rates are (7, 31.72, 7.91, 15.49, 1.34)% for current density values (2.82, 4.24, 5.65, 7.07, 8.48) A/cm^2 respectively.
- Also the efficiency is improved by using rotary tool compared with stationary tool. The efficiency is improved by (6.48, 1.81, 3.74, 13.24, 3.11)% for (2.82, 4.24, 5.65, 7.07, 8.48) A/cm^2 respectively.

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