iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 Issue: VIII Month of publication: August 2017

DOI: http://doi.org/10.22214/ijraset.2017.8114

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue VIII, August 2017- Available at www.ijraset.com

Experimental Studies on EDM of Al 7075/B_4c/Gr Hybrid Composite using RSM Box-Behnken Approach

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Abstract : Currently, automotive, military, aerospace, electrical industries are looking at some of the advanced materials like Titanium, Nickel, High Temperature Resistance Steels (HTRS), Ceramics and Composites. Metal Matrix Composites (MMCs) are one of the attractive and inspired materials due to its properties like high specific strength, light weight, specific stiffness, wear resistance, corrosion resistance and elastic modulus.In this work, a Material Removal Rate (MRR) and Surface Roughness (Ra) study on the Electrical Discharge Machining (EDM) of hybrid Al 7075/B_4C/Gr composite has been considered. Plan and analyzed the experiments using Response Surface Methodology (RSM) with box-behnken design. Current, pulse on time, pulse off time and voltage were selected as input parameters to investigates the EDM output characteristics in terms of MRR and SR. Optimization of the process parameter by using RSM box behnken approach for hybrid Al–7075/B_4C/Gr composite. The optimized levels of the EDM process parameters were determined through the ANOVA. The relative importances among the input parameters were find out through ANOVA.
Keywords: Al–7075/B_4C/Gr Composite, Stir Casting, Response surface methodology, material removal rate, Surface roughness.

I. INTRODUCTION

In past four decades aluminum composites materials demand increases in various industries of aerospace, automobile, aviation, electrical, military, sports and engineering components [1-2]. These materials have light weight, high specific strength hardness, good wear resistance and low thermal expansion coefficient. Due to high hardness of these Al Metal Matrix Composites (MMCs), it was observed that difficulty in machining, which causes serious tool wear due to the abrasive nature of reinforcing particles and hence shortens the life of the tool. For the machining of MMCs advanced machining techniques are used such as water jet, laser beam and plasma [3-5]. But the above processes have proven to highly expensive for that reason electrical discharge machine is selected as this process is low in cost and has high MRR and low surface roughness [6]. EDM in composite materials has various goals in the formation of phases with different physical and mechanical properties. The matrices of MMCs have a high thermal conductivity and low melting point at the same time the brittle reinforcement is considered by a low thermal conductivity and high melting point. The high thermal conducting of composites had good resistivity and more efficiency of EDM processes [7-8]. B. H. Yan et al studied experimental results of Al2O3 composite materials; surface roughness depends on the quantity of reinforcement particles with both conductivity (electrical and thermal), such that the usage of increasing the discharge energy cans procludes increasing the discharge craters [9]. P. Cichosz et al investigated the influense of different machining parameters on the performance of mixed fibres and matrix material in the affects surface area of the EDM of Al matrix composites. It was found that the low discharge current parameters existed in a thin layer with a recast layer structure of increased hardness. It was also found that the increasing the material removal rate formed a very rough finishing with poor surface integrity [10]. In this present investigation, influence of EDM process parameters has been studied on AI 7075/B4C/GR metal matrix hybrid composite reinforced with 12%of B4C and 3% Gr particles fabricated via STIR CASTING technique. The electrical discharge machining is done on AI 7075/B4C/GR hybrid composite using 14 mm diameter electrolyte copper and EDM oil as dielectric fluid. The objective of the present investigation is to study the influence of machining parameters, such as current, pulse on time, pulse off time and voltage on MRR, and SR and to obtain the optimum combinations using RSM box with behnken design technique.

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II. EXPERIMENTAL PROCEDURE

In the fabrication of Al7075 hybrid metal matrix composite (Al7075+ B_4C +Gr) stir casting technique is used. Al7075 is the matrix material; boron carbide and graphite are reinforcing particles. About 1.2kg of pure Al7075 was melted in the crucible at 850 ^{0}C. 44 microns sized particles of boron carbide and graphite were pre-heated and introduced into the cricible of molten alloy. The molten alloy was then stirred with a mechanical stirrer made of graphite for a duration of 10mins. The stirrer is maintained at a speed of 700rpm. the molten metal combined with reinforcements is poured into a cast iron mould and was left in air to cool down to room temperature[11]. The chemical composition of the base material is given in Table 1.

Table 1 Chemical composition of Al 7075 alloy

Element	Al	Zn	Fe	Cu	Si	Ti	Mg	Cr
%	89.13	5.56	0.4	1.54	0.33	0.2	2.52	0.32

The experiments were performed on a Formatics EDM 50 die sinking machine with Electronica PRS-20 controller. The electrode fed downwards under DC servo control into the work piece. Electrol EDM oil is used as the dielectric fluid for machining, which is regularly used in die-sinking machines for high machining speed and good surface finished. Experiments were conducted with positive polarity electrode.The Electrolyte copper with dimensions 14mm diameter and 70mm length is selected as an electrode. The Workpiece with dimensions of 60 mm length, 30 mm width and 20 mm thickness is employed.

Table 2 Experimental conditions

Working conditions	Description
Work piece	Al 7075 B_4C/Gr composite
Electrode material	Electrolyte copper
Electrode polarity	Positive
Depth of cut	0.5 mm
Discharge Gap	0.75 µm
current	0-11 Amp
open voltage	110V
Discharge gap voltage	0-60V
Pulse on time	0-50µ
Pulse off time	0-40µ
Dielectric Fluid	EDM OIL
Dielectric pressure	0.75 Mpa

Each experiment was conducted for Machining depth 0.5mm. Prior to machining, the work pieces and electrode were cleaned and polished. The workpiece was firmly clamped in the vice and immersed in the electrol EDM oil. The die sinking EDM machine experimental set up and conditions shown in Table 2 and Figure 1. The weight of the workpiece and the electrode tool has been measured using a digital weighing balance (citizen) before and after the commencement of machining to calculate the MRR and TWR respectively. Surface roughness of the machined work pieces were measured using Handy surf equipment.

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Figure 1 Experimental setup

A. Evaluation of MRR and RA

EDM performance, regardless of the type of the electrode material and dielectric fluid, is measured usually by the following criteria:

1) Metal removal rate (MRR) (mm^3/min)
2) Surface Roughness (Ra) (µ)

The MRR is the workpiece weight loss (WWL) under a period of machining time in minutes, i.e.

$$MRR\ (mm^3/min) = \frac{WWL\ (g) \times 1000}{\rho w\ (g/cm^3) \times Tm(min)}$$

WWL (mm^3/min) = (Wb – Wa)
Where:
Wb = weight of workpiece material before machining (g)
Wa = weight of workpiece material after machining (g)
Tm = machining time (min)
ρ_w = density of work piece material (g/cm^3)

3) *Surface Roughness (Ra):* In this study SR is calculated by using Handysurf instrument. Surface roughnesses are referred to the roughness or smoothness of a given surface. In this study, it was measured in terms of R_a (Roughness average), which is an arithmetic average of peaks and valleys of a workpiece surface measured from the centerline of evaluation length. It was measured by the surface roughness tester.

B. Box-Behnken RSM Approach

Box-Behnken is a method of statistical design which does not contain fractional factorial design to obtain optimum responses. It consists of less number of trials. The BBD has less number of trials than CCD with the same number of factors and is used in the present investigation to conduct EDM experiments. The analytical response surface models were developed using Minitab 17.0 statistical software. Twenty seven sets of experiments were conducted according to the BBD response surface method. In this approach has been carried to perform the experimental work to develop the mathematical relationship between process parameters and each output response and to analyze the effects of process parameters on these responses. The experimental process parameters are shown in the Table 3.

Table 3 Process parameters and their levels

S.NO	PARAMETERS	UNITS	LEVELS		
			-1	0	1
1	Current	A	7	9	11
2	Ton	µs	25	35	45
3	Tof	µs	15	25	35
4	Voltage	V	40	50	60

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The experimentation along with regression analysis facilitates the modeling of the desired response to several input process parameters. The experiment is designed to allow estimation of interaction and even quadratic effects and thus, provides an idea of the local shape of the response surface [12-13]. In RSM, a relationship is formed between the desired response and the independent input parameters which can be represented by equation .

$Y_i=f(x_1, x_2, x_3\ldots\ldots\ldots\ldots\ldots\ldots\ldots x_k) \pm €$

Where y_i is the desired response, f_is the response functions, x_1, x_2, x_3, input functions, € error function.

III. RESULTS AND DISCUSSION

This part consists of experimental results, expressing the influence of four input parameters such as current, pulse on time, pulse off time and voltage on various response parameters including MRR and SR by RSM Box-Behnken design.

Table 4 Experimental layout and their response parameters results

Std Order	Run Order	Current	Pulse On Time	Pulse Off Time	Voltage	MRR (mm^3/min)	SR (Ra)
26	1	9	35	25	50	78.537	3.76
13	2	9	25	15	50	77.233	3.40
7	3	9	35	15	60	71.121	4.09
3	4	7	45	25	50	52.337	3.18
1	5	7	25	25	50	39.220	2.75
25	6	9	35	25	50	72.537	3.91
23	7	9	25	25	60	51.557	3.58
15	8	9	25	35	50	49.269	3.37
17	9	7	35	15	50	63.296	3.16
22	10	9	45	25	40	73.445	4.46
16	11	9	45	35	50	47.769	3.80
14	12	9	45	15	50	75.733	4.44
12	13	11	35	25	60	111.247	4.69
18	14	11	35	15	50	136.923	5.15
10	15	11	35	25	40	120.636	5.26
2	16	11	25	25	50	117.464	4.17
8	17	9	35	35	60	50.565	3.68
9	18	7	35	25	40	71.009	2.93
11	19	7	35	25	60	47.620	2.99
20	20	11	35	35	50	108.959	4.58
21	21	9	25	25	40	74.945	3.89
6	22	9	35	35	40	66.545	3.95
4	23	11	45	25	50	108.346	5.32
19	24	7	35	35	50	45.333	2.52
27	25	9	35	25	50	72.537	4.04
24	26	9	45	25	60	50.057	4.23
5	27	9	35	15	40	81.917	4.75

A. ANOVA Analysis and Mathematical Equation on MRR

Experiments are designed and conducted using the Box benkin design matrix mentioned in Table 4 and performance characteristics measured. The experimental values are good agreement between the design variables and experimental data is measured by the

ANOVA results. After backward elimination process, fit summery for MRR is given in Table 5 Selected models will be statistically important, if P value of model < 0.05 insignificant terms are eliminated from the reduced model. P value for model is significant observed in the Table 5. The value of R^2 98.12 % and adj. R^2 97.32% called coefficient of determination is over 99% also, test of lack of fit shows insignificant effects which must be required for a good model. Table 4 shows that the input parameters current, pulse on time, pulse off time and voltage, interaction of current and pulse on time; pulse off time and voltage have significant effects. The other non- important terms are removed to fairly fit the model.

Table 5 ANOVA for the Material Removal Rate (mm^3/min)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	8	17873.5	2234.19	118.65	0.000
Linear	4	2450.9	612.72	32.54	0.000
A	1	1233.0	1233.03	12.38	0.002
B	1	340.3	340.26	18.07	0.000
C	1	1582.0	1582.0	84.02	0.000
D	1	308.3	308.3	16.37	0.001
Square	2	2839.6	2839.6	75.40	0.000
A*A	1	1910.7	1910.7	101.47	0.000
B*C	1	446.1	446.1	23.69	0.000
2 Way Interaction	2	172.6	86.30	4.58	0.025
A*B	1	123.6	123.61	6.56	0.020
A*D	1	49.0	49.0	2.60	0.124
Error	18	338.9	18.83		
Lack Of Fit	16	314.9	19.68	1.64	0.444
Pure Error	2	24.0	12.00		
Total	26	18212.4			
S	4.3392		R-Sq (Adj)	97.31%	
R-Sq	98.14%		R-Sq(Pred)	95.66%	

The final mathematical equation for MRR in actual terms and coded is given by as:

MRR=238.8- 60.7*A+ 8.33*B- 1.148*C- 2.461*D+ 4.320*A*A-0.0835*B*B-0.278*A*B+0.175*A*D

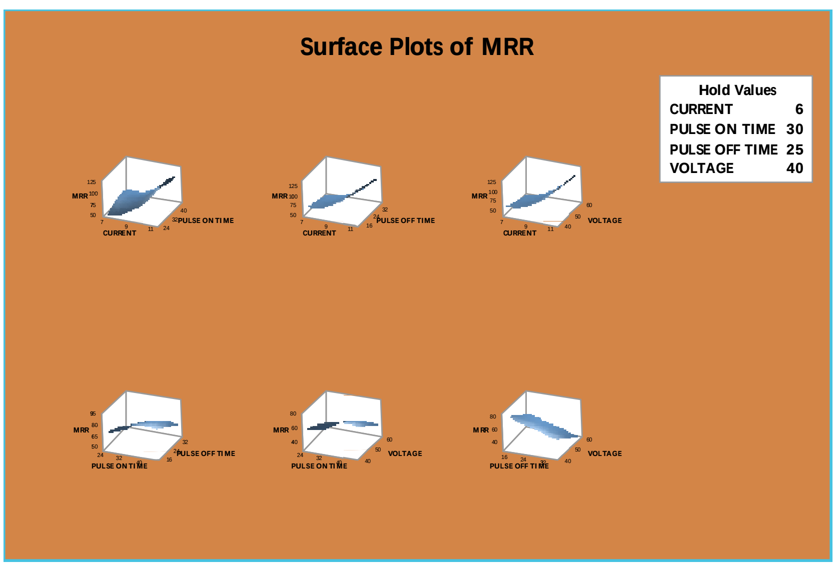

Figure 2 interaction parameters effect on MRR

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Based on the Figure 2 shows that the maximum values of MRR may be indicated with the interaction of higher levels of current (11 amp) and pulse on time (35 µs) and lower levels of pulse off time (15 µs) and voltage (40V) respectively.

B. ANOVA Analysis and Mathematical Equation on SR

Experiments are designed and conducted using the Box-benkin design matrix mentioned in Table 4 and performance characteristics measured. The experimental values are good agreement between the design variables and experimental data is measured by the ANOVA results. After backward elimination process, fit summery for SR is given in Table 6 Selected models will be statistically important, if P value of model < 0.05 insignificant terms are eliminated from the reduced model. P value for model is significant observed in the Table 6. The value of R^2 98.66 % and adj. R^2 98.06% called coefficient of determination is over 99% also, test of lack of fit shows insignificant effects which must be required for a good model. Table 6 shows that the input parameters current, pulse on time, pulse off time and voltage, interaction of current and pulse on time; current and voltage have significant effects. The other non- important terms are removed to fairly fit the model. The final mathematical equation for MRR in actual terms and coded is given by as:

Table 6 ANOVA for the Surface Roughness (Ra)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	14.5873	1.6208	105.06	0.000
Linear	4	5.7640	1.4409	93.41	0.000
A	1	2.7494	2.7494	178.22	0.000
B	1	0.0121	0.0121	0.78	0.389
C	1	0.1983	0.1983	12.85	0.002
D	1	0.8885	0.8885	5.74	0.028
Square	1	0.2812	0.2812	18.23	0.001
D*D	1	0.2812	0.2812	18.23	0.001
2 Way Interaction	4	0.3597	0.0899	5.83	0.004
A*B	1	0.1297	0.1267	8.22	0.011
A*D	1	0.1040	0.1040	6.74	0.019
B*C	1	0.0909	0.0909	5.89	0.027
B*D	1	0.0380	0.0380	2.46	0.135
Error	17	0.2623	0.0154		
Lack Of Fit	15	0.2230	0.0148	0.76	0.703
Pure Error	2	0.0392	0.0196		
Total	26	18212.4			
S	0.1039		R-Sq (Adj)	98.06%	
R-Sq	98.66%		R-Sq(Pred)	96.61%	

SR = 2.31 + 0.577*A-0.0144*B+0.0183*C-0.1260*D+0.001837*D*D+0.00890*A*B- 0.00806*A*D- 0.001244*B*C

Based on the Figure 3 shows that the maximum values of SR may be indicated with the interaction of higher levels of current (7 amp) and pulse on time (25 µs) and lower levels of pulse off time (35 µs) and voltage (40V) respectively.

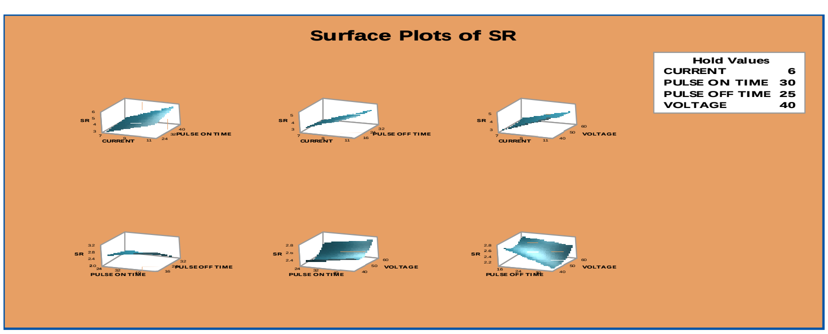

Figure 3 interaction parameters effect on SR

IV. CONCLUSIONS

Al 7075/B_4C/Gr hybrid composite machining on electrical discharge machining using RSM Box-Behnken Approach was carried out. Based on the experimental results the following can be drawn.

A. The max amount of MRR was obtained at current (11 amp) and pulse on time (35 µs) and lower levels of pulse off time (15 µs) and voltage (40V).

B. The minimum amount of SR was indicated at current (7 amp) and pulse on time (25 µs) and lower levels of pulse off time (35 µs) and voltage (40V).

C. The developed mathematical equation values and experimental values are within the range.

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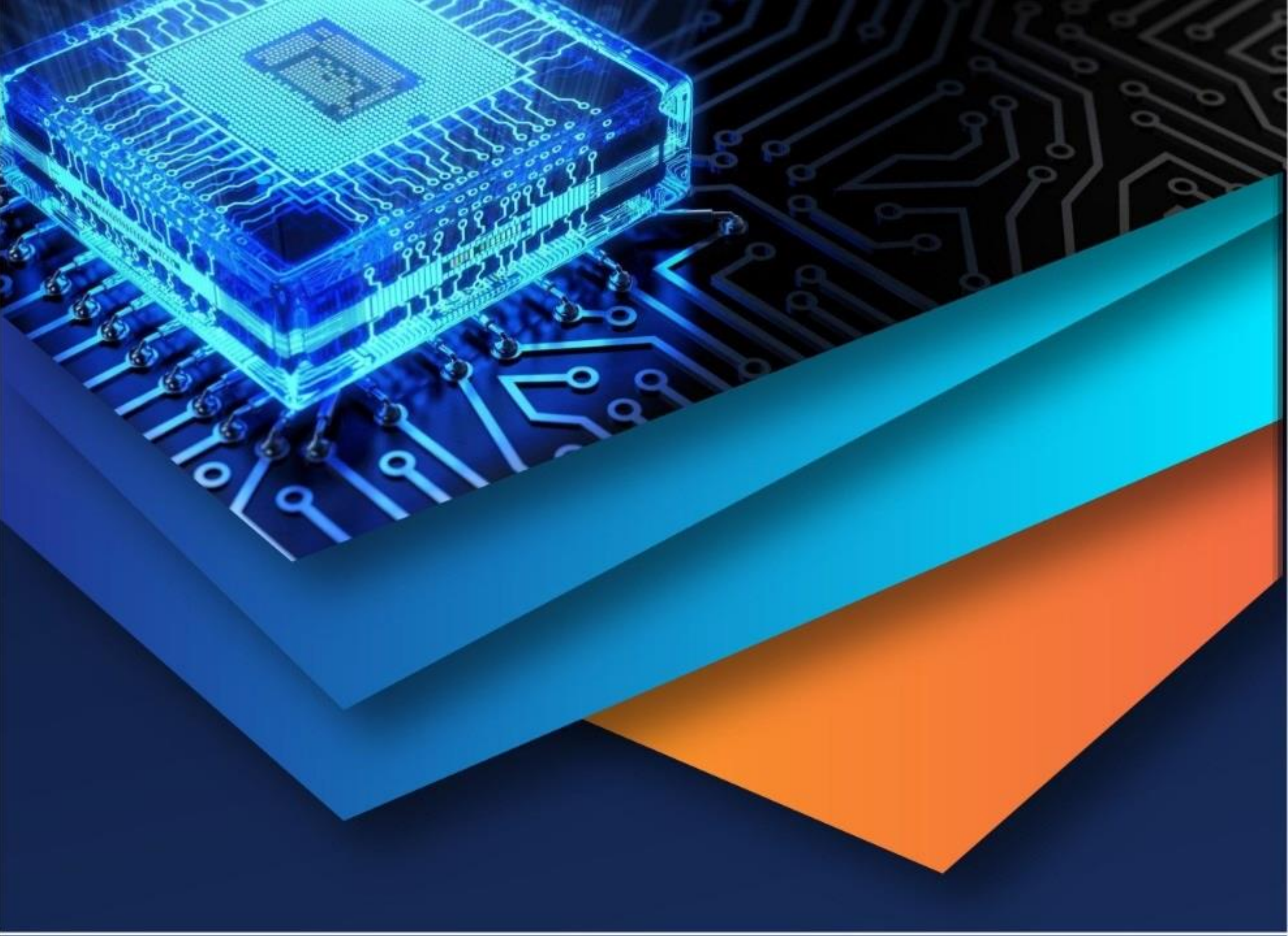

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