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Taguchi-Grey Established Optimisation for M2-tool Steel with Conventional/PM Electrodes on EDM with and without Powder Mixing Dielectric

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ABSTRACT

Confront exercise deals with the influence of parameters, such as polarity, electrode type, concentration of abrasive powder, peak current, voltage and duty cycle by using Taguchi's L36 mixed orthogonal array on M2 tool steel with 99% copper and powder metallurgy copper-titanium (Cu-Ti) by electric discharge machining (EDM) process with and without abrasive powder mixed dielectric for material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR). The parameters affecting the MRR, TWR and SR should be recognised and optimised for desired results using Main effects plot for Means and analysis of variance (ANOVA). Grey relation analysis optimises the results by following normalised, dev. Seq. Δ and Grey relational coefficient φ values to convert into single Grade. The confirmation experiment test can be done to formalise the present work with optimal set of parameters and Rank. Grey relation analysis found that the copper-titanium tool electrode gives better results with powder mixed dielectric and to meliorate machining performance and shows improvement in overall outcomes up to 17-27%. Scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) analysis are employed for the work surface quality assurance in this research.

Keywords: Abrasives, ANOVA, EDM, EDS, Grey relational analysis, Powder metallurgy, SEM

INTRODUCTION

The non-orthodox shaping proficiencies are utilised mostly in fabricating three-dimensional complex and intricate machine components. Among the other non-orthodox methods of forming processes, Electric Discharge Machining (EDM) has drawn a

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great deal of investigators' and mortals' care because of its liberal progressive applications due to simple machining in standard and abrasive mixed dielectric liquid to improves the MRR and TWR (Dewangan, Gangopadhyay, & Biswas, 2015). Latterly, tool fabrication in many studies of EDM technology through Powder Metallurgy process is an option of tooling electrodes where the suitable dimensions of unlike materials can be made from individual dies, for reduction of electrode monetary value (Manikandan, Kumanan, & Sathiyanarayanan, 2017; Nain, Garg, & Kumar, 2017). The material removal from both the electrodes in EDM process is through dissolving and vaporisation when thermal energy is produced by sparks (Nayak & Mahapatra, 2016) with minimal interval of time to reach the best surface finish in modern manufacturing markets (Satpathy, Moharana, Dewangan, & Sahoo, 2015). The electric discharge machining of NiTi alloy has unique properties and application to achieve larger value of MRR, smaller for TWR and SR with variation of input parameters (Priyadarshini & Pal, 2015). The structural features of M2 tool steel coatings are obtained through thermal cycling in the form of carbide treated stratum on surface. The TWR in dry electrical discharge machining by plasma optical emission spectroscopy was developed for dissimilar electrode polarities (Sharma, Khanna, & Gupta, 2015). A research on M2 steel structure with EDM using W tool electrode for obtaining maximum MRR and minimum Electrode Wear Rate (EWR) values and the surface irregularities, homogenous dispersion of particles may be concluded by Atomic Force Microscopy (AFM), Scanning Electron Microscopy (SEM) and X-Ray Diffraction (XRD). The reduction of TWR with new technique named SEDCM using copper tool electrode with side-insulation and low-conductivity electrolyte (Reddy, Deepthi, & Jayakrishna, 2015). The effects of various input parametric quantity and effect of their best combination and more significant factor on MRR are determined using Taguchi's technique and Analysis of Variance (ANOVA) table on EN45 steel tool in EDM. The optimised value of MRR for high tensile strength grade material was compared by assuring the fluctuation in the erroneousness (Tripathy & Tripathy, 2016). The use of fuzzy-based algorithmic program in precision manufacturing for anticipation of output parameters in EDM and Ultrasonic EDM with overall low expenditure and greater accuracies was done (Unune & Mali, 2017). Literature review shows there are not many studies on EDM of M2 tool steel material to find out the MRR, TWR and SR with conventional and powder metallurgy tool electrode in standard and powdered mixed dielectric. Thus, in this study, the main objective was to optimise the best parameters for the multiple responses with the use of Minitab 17 statistical software based ANOVA combined with Grey relation analysis.

METHODOLOGY AND MATERIALS

In this study, M2 tool steel was selected as work material having chemical composition based % of weight as shown in Table 1 and to obtain best results, tool electrodes used are conventional copper and powder metallurgy copper–titanium with different concentration by weight on SMART ZNC (S50) EDM machine, with and without aluminium (0 gm/l, 3 gm/l and 6 gm/l) powder mixed in the dielectric at constant flushing pressure during machining. The input parameters for the present work having two levels for polarity and other parameters are shown in Table 2 (Kumar, Payal, & Beri, 2017). The range of each process parameter was selected based on capacities and previous studies on EDM machine and through pilot experiments.

Table 1
Chemical Composition of M2 Tool Steel

Elements	C	Cr	W	Mo	Va	Ma	Si	S	P	Fe
Wt%	0.87	4.2	5.50	4.9	1.95	.23	0.32	0.31	0.30	Balance

Note. Adapted from AZO Materials. Copyright 2012 by AZO Materials. In the public domain

Table 2
Levels of Machining Parameters with Factors Designation

Factors	Process Parameters	Levels with values		
		1st Level	2nd Level	3rd Level
A	Polarity	Straight	Reverse	
B	Electrode Type	Cu	Cu-Ti1 PM Electrode	Cu-Ti1 PM Electrode
C	Concentration of	Al abrasive (g/l)	0	3
D	Peak Current (A)	4	7	10
E	Gap Voltage (V)	40	50	60
F	Duty cycle	0.7	0.8	0.9

Note. Adapted from "EDMed M2 steel Surface Quality Evaluation with Cu-Ti PM Processed Electrode," D. Kumar, H. S. Payal, & N. Beri. (2017). *International Journal of Materials Science, 12*(2), p. 398. Copyright 2017 by Research India Publications. Adapted with permission

The design of experiments selected for the study was Taguchi's L36 mixed orthogonal array shown in Table 3.

The outcome variables are MRR and TWR with difference in weights (work piece and Tool electrode) before and after machining operation based on time taken for each experiment and restated for obtaining actual value of weight. The electronic weighing scale Brand Citizen CY-220 Precision Balance of Resolution 0.001 gram and Linearity (+/-) 0.003 gram was used for the study as shown in Figure 1. After the experiment ended, the surface roughness was carried out by Digital Roughness tester, Surftest SJ-401- MITUTOYO to determine the surface roughness of M2 tool steel sample.

Table 3
Design of Experiment with Factors and Outcomes

Expt.	Polarity	Electrode	Abrasive	Current	Voltage	Duty Cycl	MRR mm^3	TWR mm^3	SR µm
1	-ve	Cu	0	4	40	0.7	0.000132	0.000022	0.15
2	-ve	CuTi1	3	7	50	0.8	0.000943	0.000013	1.71
3	-ve	CuTi2	6	10	60	0.9	0.001333	0.000615	0.55
4	-ve	Cu	0	4	40	0.8	0.00002	0.000009	0.51
5	-ve	CuTi1	3	7	50	0.9	0.001077	0.000215	0.6
6	-ve	CuTi2	6	10	60	0.7	0.000971	0.000157	2.16

Table 3 *(continue)*

7	-ve	Cu	0	7	60	0.7	0.000176	0.000033	0.16
8	-ve	CuTi1	3	10	40	0.8	0.001	0.000383	2.96
9	-ve	CuTi2	6	4	50	0.9	0.000767	0.000533	0.78
10	-ve	Cu	0	10	50	0.7	0.000582	0.000036	0.11
11	-ve	CuTi1	3	4	60	0.8	0.0007	0.000146	0.79
12	-ve	CuTi2	6	7	40	0.9	0.000717	0.000633	2.66
13	-ve	Cu	3	10	40	0.9	0.000899	0.00003	0.92
14	-ve	CuTi1	6	4	50	0.7	0.00036	0.00006	1.75
15	-ve	CuTi2	0	7	60	0.8	0.000549	0.00022	2.21
16	-ve	Cu	3	10	50	0.7	0.00006	0.000007	0.35
17	-ve	CuTi1	6	4	60	0.8	0.000516	0.000156	0.06
18	-ve	CuTi2	0	7	40	0.9	0.000695	0.000419	2.13
19	+ve	Cu	3	4	60	0.9	0.001227	0.000068	0.11
20	+ve	CuTi1	6	7	40	0.7	0.004117	0.000017	0.59
21	+ve	CuTi2	0	10	50	0.8	0.006	0.000065	1.24
22	+ve	Cu	3	7	60	0.9	0.007083	0.001	1.36
23	+ve	CuTi1	6	10	40	0.7	0.003773	0.000205	1.91
24	+ve	CuTi2	0	4	50	0.8	0.000455	0.001	0.27
25	+ve	Cu	6	7	40	0.8	0.010556	0.001667	1.19
26	+ve	CuTi1	0	10	50	0.9	0.003795	0.000564	1.59
27	+ve	CuTi2	3	4	60	0.7	0.002244	0.000044	0.09
28	+ve	Cu	6	7	50	0.8	0.007647	0	0.11
29	+ve	CuTi1	0	10	60	0.9	0.003667	0.000697	1.7
30	+ve	CuTi2	3	4	40	0.7	0.003	0.000478	0.66
31	+ve	Cu	6	10	60	0.8	0.016167	0.001	0.94
32	+ve	CuTi1	0	4	40	0.9	0.00091	0.000449	2.56
33	+ve	CuTi2	3	7	50	0.7	0.001105	0.000447	0.51
34	+ve	Cu	6	4	50	0.9	0.004545	0.000091	0.15
35	+ve	CuTi1	0	7	60	0.7	0.001167	0.000071	0.08
36	+ve	CuTi2	3	10	40	0.8	0.004833	0.00131	0.75

Figure 1. CY-220 Precision Balance. From “Precision Balances CY Series,” by Citizen Scales, n.d., (http://www.citizenscales.com/pdf/Precision%20Balance%20(CY%20Ceries).pdf). In the public domain

The average value of surface roughness (Ra value) is found by measuring the different sets of readings thrice on different position of the surface.

Grey Relational Analysis

In this analysis, response data after experimentation can be normalised in the range between zero and one and the process is known as normalisation. The normalised data is correlated between ideal and actual experimental data for computing the grey relation coefficients and obtaining grey relation grade . This data is further used for all quality features of the multi-response process. Its main idea to examine the geometric unsure and insufficient data between mention data sequence and several comparative data sequences.

RESULTS AND DISCUSSION

Table 3 shows experimental outcomes MRR, TWR and SR, the effects of input parameters after machining on M2 tool steel with tool electrodes (Cu, CuTi1, CuTi2) in standard as well as aluminium powder mixed dielectric have been shown by main effect plot for Means as per Figure 2, 3 and 4. For MRR, the objective is "larger the better" and for TWR and SR its "smaller the better".

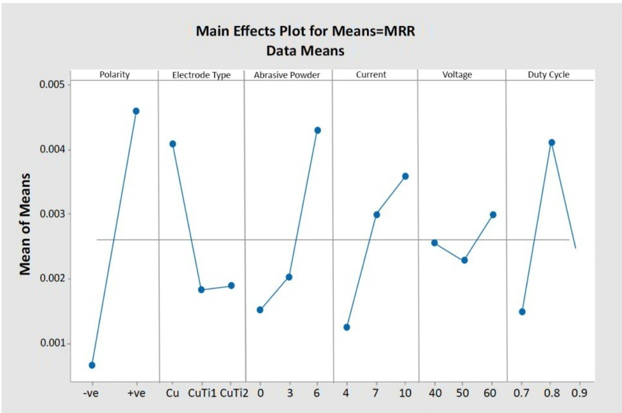

Figure 2. Main Effects Plot for Means-MRR

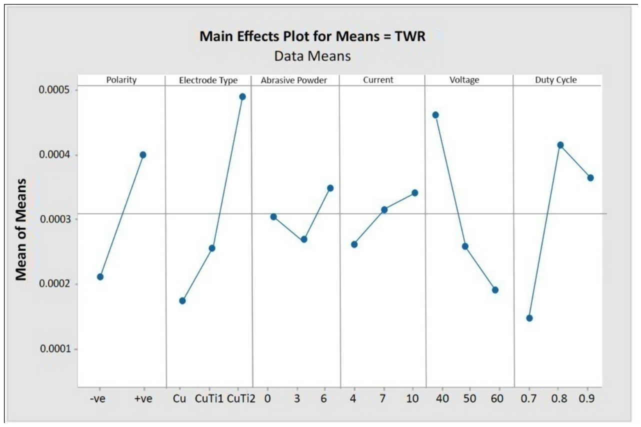

Figure 3. Main Effects Plot for Means-TWR

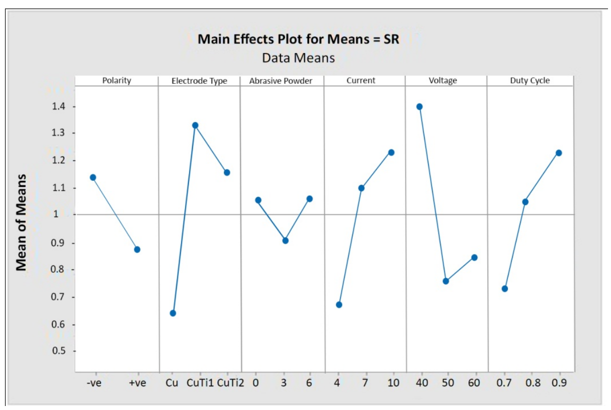

Figure 4. Main Effects Plot for Means-SR

As per Figure 2, better MRR result found at straight polarity with maximum value of current, voltage and concentration of abrasive material in dielectric at average value of duty cycle when conventional copper tool electrode was used. From Figure 3, it is clear that TWR produces the most effective result when EDM is in straight polarity, powder metallurgy tool electrode in maximum abrasive powder mixed in dielectric with average value of duty cycle during continuous increase of current and decrease of voltage values (Long, Phan, Cuong, & Jatti, 2016). Figure 4 shows copper-titanium powder metallurgy tool electrode with reverse polarity in maximum concentration of abrasive powder during machining with continuous increase of current and duty cycle at minimum voltage value. All the analyses were carried out using MINITAB 17 statistical software.

The Grey relation analysis colligated with ANOVA is suited for a new technique for optimisation in EDM process. The Genichi Taguchi statistical tool was commonly used to optimise the single response but with the help of Grey technique more than one response optimisation can be done effectively. With this technique the responses MRR, TWR and SR (Ra) are converted into a single value, known as Grade. For computing the Grade value in Table

4, the following procedure is adopted: The two equations used for calculating the normalised (Ni) data for the present study are: Higher the better for MRR as per equation (1) and Lower the better for TWR and SR as per equation (2).

$$Ni(s)=(Zi(s)-min.Zi(s))/(max.Zi(s)-min.Zi(s)) \quad [1]$$

$$Ni(s)=(max.Zi(s)-Zi(s))/(max.Zi(s)-min.Zi(s)) \quad [2]$$

Where ‘i’ means number of experiments, it varies from 1 to 36, Max Zi(s) and Min Zi(s) are Sth response maximum and minimum values.

Determination of deviation sequences

$$\Delta = (1\text{- Normalised value of the MRR, TWR and SR}) \quad [3]$$

and Grey relational coefficient (φ) may be calculated as

$$\varphi=(\Delta min.+\delta\Delta max.)/(\Delta ai(s)+\delta\Delta max.) \quad [4]$$

Where, Δmin is the minimum value of absolute difference, and δ is the distinguishing coefficient lies between zero to one but in this work, it is 0.5 and Δai is the absolute difference between Δo (S) to Δi (S).

After averaging the Grey relational coefficient value followed by equation (5), the value of the grade is obtained shown in Table 4 with their ranks.

Table 4
Grey Relation Grade with Rank

Exp. No.	Grade	Rank	Exp. No.	Grade	Rank	Exp. No.	Grade	Rank
1	0.750241	5	13	0.646283	14	25	0.495108	28
2	0.599641	19	14	0.57757	21	26	0.492626	30
3	0.558428	23	15	0.511575	27	27	0.765541	1
4	0.69527	12	16	0.71963	10	28	0.635936	16
5	0.624044	17	17	0.727549	9	29	0.468757	33
6	0.5323	26	18	0.47343	32	30	0.574316	22
7	0.744298	7	19	0.747351	6	31	0.692304	13
8	0.455295	34	20	0.704511	11	32	0.454347	35
9	0.540699	25	21	0.640534	15	33	0.58768	20
10	0.755505	2	22	0.48414	31	34	0.751014	4
11	0.619681	18	23	0.545483	24	35	0.752601	3
12	0.423198	36	24	0.737641	8	36	0.49414	29
Average Means of GRG=0.6105								

Grade= $\lambda i = \frac{1}{n} \sum \varphi i(s)$ from 1 to 36

Table 4 shows that experiment no. 27 has greatest grade with rank 1 and experiment no. 12 has smallest grade value with rank 36. This proves that experiment no. 27 is more eminent 0.002244; EWR is 0.000044 and SR is 0.09 with average Means of GRG=0.6105 and on the basis of the Table 5, the best optimal levels with their rank shows that PM tool electrode is best parameter and polarity having no impact for better response.

Table 5
Optimal Levels for Grade

Factors	Parameters	Level-1	Level-2	Level-3	Max-Min	Rank
A	Polarity	0.6124	0.6086	---------	0.0038	6
B	Electrode Type	0.5852	0.6916	0.5548	0.1368	1
C	Powder Conc.	0.6079	0.6098	0.6138	0.0059	5
D	Current	0.6015	0.6466	0.5834	0.0632	4
E	Voltage	0.5593	0.6337	0.6385	0.0792	3
F	Duty Cycle	0.5554	0.6087	0.6675	0.1121	2

R.A. Fisher developed statistical software ANOVA which is most useful to examine and generalise the relationship amongst the input and response parameters having three or more means. In these analyses, the smaller P-value shows that the coefficient is significant. This will point to the variation against important input parameters. The polarity having the most significant parameter and voltage is less impact that affects the multiple process response during experimentation. ANOVA for grade as per Table 6 is used to find the best parameters for multi-optimisation.

Table 6
ANOVA for Grade

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Polarity	1	0.004587	0.004587	0.004587	19.44	0.000
Electrode type	2	0.002383	0.002383	0.001191	5.05	0.015
Conc. of Abrasive Powder	2	0.002549	0.002549	0.001275	5.40	0.012
Current	2	0.002450	0.002450	0.001225	5.19	0.013
Voltage	2	0.000710	0.000710	0.000355	1.51	0.242
Duty Cycle	2	0.004023	0.004023	0.002011	8.52	0.002
Residual Error	24	0.005663	0.005663	0.000236		
Total	35	0.022365				

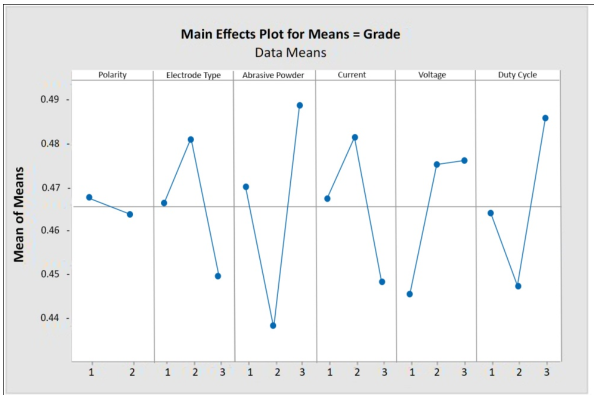

Figure 5. Main Effects Plot for Means-Grade

From Figure 5, it is found that the reverse polarity with powder metallurgy tool electrode have composition of Cu-90% and Ti-10% by weight in maximum concentration of aluminium abrasive powder i.e. 6gm/l in dielectric fluid with current (7 amp.), voltage (60 V) and duty cycle having 0.9 values.

Confirmation Experiment

Three confirmation experiments in Table 7 can be done to confirm the best optimal parameters by averaging their results and the predicted values obtained by applying equation (6) within the confidence interval 95% of responses.

$$\beta = \beta m + \sum 0 \quad (\beta i - \beta m) \qquad [6]$$

Where β is the optimal level, βm is means of Grade and βi is corresponding value of Grade.

The overall improvement lies between 17- 27% and it shows it's substantial through Taguchi-Grey technique for multi-optimisation features in EDM with aluminium powder mixed dielectric and powder metallurgy tool electrodes.

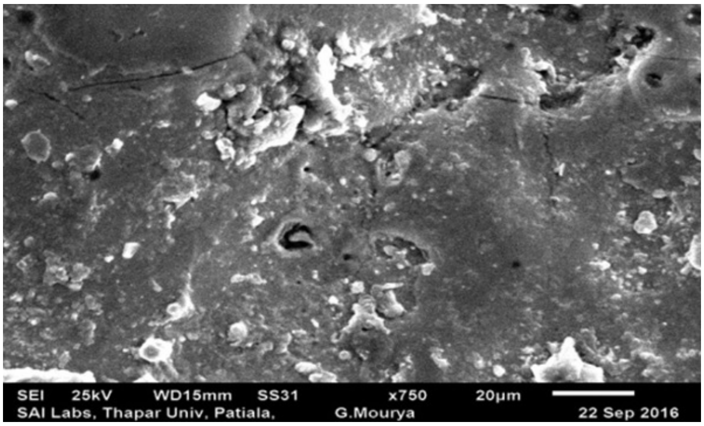

Figure 6. SEM after confirmation experiment

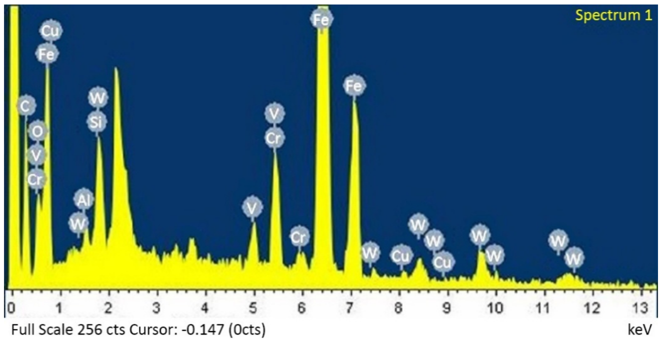

Figure 7. EDS after confirmation experiment

SEM (Figure 6) and EDS (Figure 7) analysis can be done after confirmation experiment and the sample piece of work surface first cut into two sections for exhibiting the surface layer to inquire the structure and composition. The surface effects are much better than machined with initial parametric considerations because some residuals of aluminium and titanium could be found as shown in EDS Figure 7.

Table 7
Confirmation Test Outcomes

Outcome Parameters		Optimal Parameters		
		Predicted	Experimentation Rank -1	Experimentation Rank -36
Levels	A1B1C1D1E1F1	Calculated by applying Equation (6)		
MRR (mm^3/min)	0.000132		A2B3C2D1E3F1	A1B3C3D2E1F3
TWR (mm^3/min)	0.000022		0.002244	0.000717
SR (µm)	0.15		0.09	2.66
Grey Relation Grade	0.750241	0.611167	0.765541	0.423198
Improvement with Rank-1 and Initial levels value through GRG=0.0153				
Improvement with Rank-36 and Initial levels value through GRG=0.3423				

CONCLUSION

The Taguchi's L36 mixed orthogonal array was used during Electric Discharge Machining of M2 tool steel executed with conventional Cu and powder metallurgy CuTi1, CuTi2 with and without aluminium abrasive powder mixed in dielectric. Copper electrode has better material removal rate with straight polarity in max. Concentration of abrasive powder with maximum current and voltage value by main effects plot for means whilst powder metallurgy tool electrode has minimum TWR and SR in straight as well as in reverse polarity. The ANOVA analysis exposed that the coefficients successfully utilised for the forecasting of MRR and TWR and SR. Grey relation analysis used for multi-optimisation features with optimal parameters found the reverse polarity with powder metallurgy tool electrode Cu- 90% and Ti-10% by weight in maximum concentration of aluminium abrasive powder i.e. 6gm/l in dielectric fluid with average current (7 amp.), maximum value of voltage (60 V) and duty cycle 0.9 having factors (A1B2C3D2E3F3) gives highest Grade, Rank 1. The overall improvement was 17%- 27% through GRG highest and lowest values in Rank-1 and Rank-36 with Initial level value. The residuals of aluminium and titanium could be found on the surface of material as proven by the SEM and EDS which stimulate the improvement in overall surface quality.

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