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Non-Conventional Machining Of Si-C

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Abstract: *In recent years, aluminium alloy based metal matrix composites (MMC) are gaining importance in several aerospace and automobile applications. Aluminium has been used as matrix material owing to its excellent mechanical properties coupled with good formability. Addition of Si-C as reinforcement in aluminium system improves mechanical properties of the composite. In this paper, AlSi-C composite was prepared by powder metallurgy route. Powder metallurgy homogeneously distributes the reinforcement in the matrix with no interfacial chemical reaction and high localized residual porosity. Si-C particles containing different weight fractions (10 and 15 wt. %) and mesh size (300 and 400) is used as reinforcement. Though AlSi-C possess superior mechanical properties, the high abrasiveness of the Si-C particles hinders its machining process and thus by limiting its effective use in wide areas. Rapid tool wear with poor performance even with advanced expensive tools categories, it is a difficult-to-cut material. Non-conventional processes such as electrical discharge machining (EDM) could be one of the best suited method to machine such composites. Four machining parameters such as discharge current (I_p), pulse duration (Ton), duty cycle (□),flushing pressure (Fp) and two material properties weight fraction of Si-C and mesh size, and four responses like material removal rate (MRR), tool wear rate (TWR), circularity and surface roughness (Ra) are considered in this paper. Taguchi method is adopted to design the experimental plan for finding out the optimal setting. However, Taguchi method is well suited for single response optimization problem. The influence of each parameter on the responses is established using analysis of variances (ANOVA) at 5% level of significance. It is found that discharge current, pulse duration, duty cycle and wt% of Si-C contribute significantly, where flushing pressure and mesh size of Si-C contribute least to the multiple performance characteristic index.*

Keywords: *ANOVA, Electrical Discharge Machining, L_{16} Orthogonal, MPCI, Taguchi Method.*

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I. Introduction

Surface texturing is generally defined as modification of surface of a substrate or work piece material by means of imparting suitable surface roughness or fabricating required surface structures. Hence textured surfaces in other way called as structured engineered surfaces. The term surface texturing was coined in early 1930s but it was used in 1940s for the first time when honing method was applied to produce stripes on cylinder-liner surface in order to improve frictional characteristics[1]. From there onwards, the technology of texturing has spread widely in the fields of industrial, biomedical and military applications.

Depending on surface requirement and texture method used, texturing can be formed as micro pits or micro pillars. The word textured surfaces used only to describe surfaces containing engineered structures (micro holes, micro rods). In general, fabrication processes can be categorized based on the way material is modified in order to generate surface texture are briefly discussed below[2]

1. Material adding methods
2. Material removal methods
3. Material displacement technologies
4. Self- forming method

The current study focuses on some of material adding methods and material removal methods and the same are discussed briefly in the following sections.

1.1 Tool material

The primary requirements of any tool material are-
1. It should be electrically conductive.
2. It should have good machinability.
3. It should have low erosion rates.

4. It should have high melting point.
5. It should have high electron emission.

The commonly used electrode materials are copper, brass, copper tungsten alloy, silver tungsten alloy, tungsten carbide, graphite and copper graphite. The tool material which is made up of- “***copper tungsten alloy***” because

1. Extreme hardness, High wear resistance.
2. Wide energy band gap, High max current density.
3. High temperature conductivity and operation.
4. High electric field breakdown strength.
5. High saturated electron drift velocity.

II. Material selection

Material selection is one of the impotent processes for any investigation based on the recent development and their end applications. The Si-C of hardness 120.9 HV at load 100gms are considered for present investigation due to exclusive use of automobile components. The spark fusion oil rated 450 is used as a dielectric fluid for EDM process and electrolytic tungsten copper of 6 mm diameter as an electrode for present investigation. Si-C is obtained from the open market with assay 99% (metal basis) and Particle size: 300 mesh (50 µm), 400 mesh (37 µm)

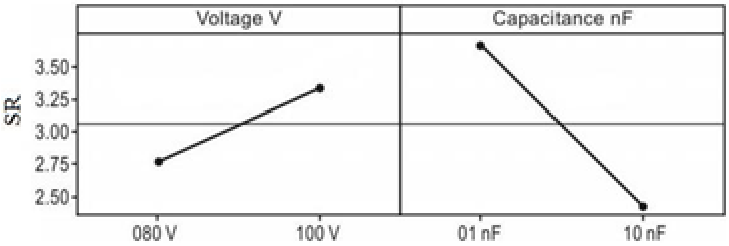


Figure 1. Effect of voltage and capacitance on surface roughness[3]

III. Experimentation

For fabricating arrayed structures, the whole experimentation was carried out on die sinking EDM (model: ELECTRONICA –ELECTRAPLUS PS 50ZNC) as shown in Fig. 2. The tool electrode used for the experiment was made from tungsten copper which acts as cathode and silicon carbide was used as a work piece, acts as anode. A servo controlled mechanism was used to maintain constant gap between anode and cathode called inter electrode gap. The electrodes are immersed in a dielectric fluid called EDM oil (Freezing point = 94℃, specific gravity = 0.763).

3.1 Specimen fabrication

Based on the exhaustive literature survey, it is concluded that powder metallurgy method of the solid phase processing methods serves better than other process. Powder metallurgy (P/M) is one of the processing techniques adopted for silicon carbide reinforced aluminium composites because relatively lower temperatures (below melting point) are involved in P/M processing. Homogenous, high strength and net shape components of aluminium-silicon carbide composites can be produced through powder metallurgy (PM) route. The undesirable interfacial reactions and development of detrimental intermetallic phases are negligible in Al Si-C composites as compared to the cast composites.

- Supply voltage - 420 V, 3-phase, 50Hz
- Open gap voltage - 140±5% tolerance
- Electrode -Electrolytic copper, 6mm dia
- Dielectric -spark fusion oil Rated 450
- Dielectric pressure - 250 N/m^2
- Depth of cut - 2mm
- Gap width - 0.05mm

Figure 2. Experimental setup[4]

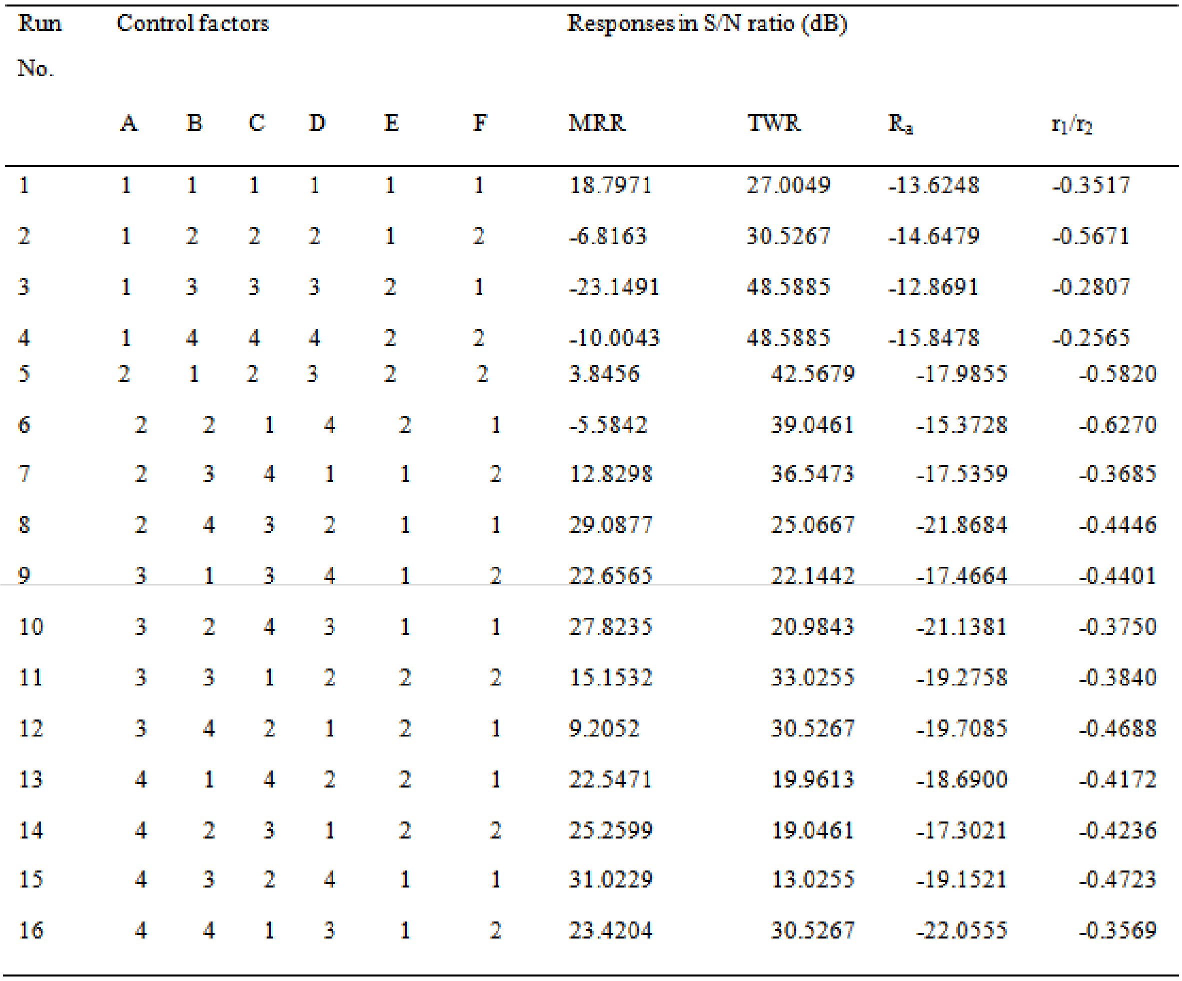
Table 1.Experimental parameter and their level

Level	Peak current (I) (Amp)	Pulse-On time (T_{on}) (μs)	Flushing Pressure (f_P) (Bar)	Duty Cycle (%)
1	1	100	0.9806	80
2	3	200	1.9613	85
3	5	300	2.1419	90
4	7	400	3.9226	95

Table 2. Experimental layout of L_{16} orthogonal array

Run No.	Control factors							Responses		
	A	B	C	D	E	F	MRR (mm^3/min)	TWR (mm^3/min)	R_a (micron)	r_1/r_2
1	1	1	1	1	1	1	8.7067	0.0446	4.80	0.9603
2	1	2	2	2	1	2	0.4562	0.0297	5.40	0.9367
3	1	3	3	3	2	1	0.0695	0.0037	4.40	0.9681
4	1	4	4	4	2	2	0.3160	0.0037	6.20	0.9708
5	2	1	2	3	2	2	1.5569	0.0074	7.93	0.9351
6	2	2	1	4	2	1	0.5257	0.0111	5.87	0.9303
7	2	3	4	1	1	2	4.3802	0.0148	7.53	0.9584
8	2	4	3	2	1	1	28.4699	0.0558	12.40	0.9500
9	3	1	3	4	1	2	13.5776	0.0781	7.47	0.9505
10	3	2	4	3	1	1	24.6136	0.0892	11.40	0.9577
11	3	3	1	2	2	2	5.7235	0.0223	9.20	0.9567
12	3	4	2	1	2	1	2.8857	0.0297	9.67	0.9474
13	4	1	4	2	2	1	13.4078	0.1004	8.60	0.9530
14	4	2	3	1	2	2	18.3229	0.1116	7.33	0.9523
15	4	3	2	4	1	1	35.5753	0.2232	9.07	0.9470
16	4	4	1	3	1	2	14.8260	0.0297	12.67	0.9603

Table 3. S/N ratio of responses



Run No.	Control factors						Responses in S/N ratio (dB)			
	A	B	C	D	E	F	MRR	TWR	R_a	r_1/r_2
1	1	1	1	1	1	1	18.7971	27.0049	-13.6248	-0.3517
2	1	2	2	2	1	2	-6.8163	30.5267	-14.6479	-0.5671
3	1	3	3	3	2	1	-23.1491	48.5885	-12.8691	-0.2807
4	1	4	4	4	2	2	-10.0043	48.5885	-15.8478	-0.2565
5	2	1	2	3	2	2	3.8456	42.5679	-17.9855	-0.5820
6	2	2	1	4	2	1	-5.5842	39.0461	-15.3728	-0.6270
7	2	3	4	1	1	2	12.8298	36.5473	-17.5359	-0.3685
8	2	4	3	2	1	1	29.0877	25.0667	-21.8684	-0.4446
9	3	1	3	4	1	2	22.6565	22.1442	-17.4664	-0.4401
10	3	2	4	3	1	1	27.8235	20.9843	-21.1381	-0.3750
11	3	3	1	2	2	2	15.1532	33.0255	-19.2758	-0.3840
12	3	4	2	1	2	1	9.2052	30.5267	-19.7085	-0.4688
13	4	1	4	2	2	1	22.5471	19.9613	-18.6900	-0.4172
14	4	2	3	1	2	2	25.2599	19.0461	-17.3021	-0.4236
15	4	3	2	4	1	1	31.0229	13.0255	-19.1521	-0.4723
16	4	4	1	3	1	2	23.4204	30.5267	-22.0555	-0.3569

Table 4. Normalization of S/N ratio of responses

Run	Control factors						Normalized responses in S/N ratio (dB)			
No.										
	A	B	C	D	E	F	MRR	TWR	Ra	r_1/r_2
1	1	1	1	1	1	1	0.7743	0.3930	0.9177	0.7431
2	1	2	2	2	1	2	0.3014	0.4921	0.8063	0.1617
3	1	3	3	3	2	1	0	1	1	0.9346
4	1	4	4	4	2	2	0.2426	1	0.6757	1
5	2	1	2	3	2	2	0.4983	0.8307	0.4430	0.1213
6	2	2	1	4	2	1	0.3242	0.7316	0.7274	0
7	2	3	4	1	1	2	0.6641	0.6614	0.4919	0.6977
8	2	4	3	2	1	1	0.9642	0.3385	0.0203	0.4923
9	3	1	3	4	1	2	0.8455	0.2564	0.4995	0.5045
10	3	2	4	3	1	1	0.9409	0.2237	0.0998	0.6802
11	3	3	1	2	2	2	0.7070	0.5623	0.3025	0.6559
12	3	4	2	1	2	1	0.5972	0.4921	0.2554	0.4270
13	4	1	4	2	2	1	0.8435	0.1950	0.3663	0.5662
14	4	2	3	1	2	2	0.8936	0.1692	0.5174	0.5489
15	4	3	2	4	1	1	1	0	0.3160	0.4176
16	4	4	1	3	1	2	0.8596	0.4921	0	0.7290

Table 5. Correlation coefficient matrix for the responses

Correlation Coefficient	MRR	TWR	Ra	Circularity
MRR	1.000			
TWR	-0.866	1.000		
Ra	-0.714	0.465	1.000	
r_1/r_2	-0.008	0.167	0.035	1.000

Table 6. Eigenvalues, eigenvectors, proportion explained and cumulative proportion explained computed for the four responses

	PC_1	PC_2	PC_3		PC_4
Eigenvalue	2.3868	1.0113	0.5365		0.0654
Eigenvector					
1. MRR	-0.627	-0.116	0.146		0.757
2. TWR	0.576	-0.100	-0.575		0.572
3. R_a	0.518	0.134	0.791		0.297
4. r_1/r_2	0.086	-0.979	0.150		-0.107
Proportion explained	Or				
	59.7	25.3	13.4		1.16
variance (%)					
Cumulative total (%)	59.7	85	98.4		100

3.2 Analysis of variance (ANOVA)

Analysis of variance (ANOVA) is performed on the MPCI values and shown in Table 7. It is conformed that factors A, B, C and E are the dominant control parameters due to their higher contributions to the total variance. These four factors account for nearly 82.05% of the total variance in the MPCI. The error is contributing 17.08% and the rest are factors D and F.

Table 7. Analysis of variance (ANOVA) on MPCI

Factor	DF	Seq SS	Adj SS	Adj MS	F-value	Percentage Contribution
A	3	0.1061	0.1062	0.0354	0.6900	35.54
B	3	0.0610	0.0610	0.0203	0.4000	20.46
C	3	0.0521	0.0520	0.0173	0.3400	17.45
D	3	0.0016	0.0015	0.0005	0.0100	0.53
E	1	0.0257	0.0256	0.0256	0.5000	8.60
F	1	0.0010	0.0009	0.0009	0.0200	0.34
Error	1	0.0510	0.0509	0.0509	1.0000	17.08
Total	15	0.2985				100.00

R-Sq = 82.9 %

3.3 Analysis of variance (ANOVA)

Analysis of variance (ANOVA) is performed on the MPCI values and shown in Table 8. It is conformed that factors A, B, C, D and E are the dominant control parameters due to their higher contributions to the total variance. These five factors account for nearly 90.94% of the total variance in the MPCI along with 8.70% of the error. From ANOVA it is studied that the first five factors are contributing more. For this process it is found that five factors are affecting the machining process as compared four in the previous one. Also contribution of error is less as compared.

Table 8. Analysis of variance (ANOVA) on MPCI

Factor	DF	Seq SS	Adj SS	Adj MS	F-value	Percentage Contribution
A	3	0.3116	0.31164	0.10388	2.1400	56.24
B	3	0.0593	0.05930	0.01977	0.4100	10.76
C	3	0.0272	0.02698	0.00899	0.1900	4.91
D	3	0.0199	0.01992	0.00664	0.1400	3.59
E	1	0.0855	0.08554	0.08554	1.7700	15.44

F	1	0.0021	0.00209	0.00209	0.0400	0.38
Error	1	0.0484	0.04844	0.04844	1.0000	8.70
Total	15	0.5539				100

R-Sq = 91.3 %

From the study below, it is cleared that optimal parameter setting i.e. $A_1B_2C_2D_4E_2F_2$ is same for both the cases.

IV. Result and Discussion

This chapter houses the experimental findings. The data are plotted and also presented in the format of table and graphical methods. The experimental data are examined and analysed in great details. Optimal parameter settings are calculated by hybridizing Taguchi. Analysis of variance is performed to get the contribution of parameters.

Six process parameters (factors) considered in this study are discharge current (A), pulse-on-time (B), duty cycle (C), flushing pressure (D), weight percentage of silicon carbide in MMC (E), and Mesh size of silicon carbide (F) as shown in Table 1 with their levels. Four output responses/quality characteristics MRR, TWR, R_a and r_1/r_2. A L_{16} mixed model Taguchi's experimental design is considered as shown in Table 2. The experiments are conducted as explained. The responses are measured. The responses are converted to signal-to-noise ratios. For MRR and circularity, higher-the-better type characteristic is used and for TWR and surface roughness, lower-the-better type characteristic is used for converting responses into S/N ratios as shown in Table 3.

The predictive relation for optimal factor combination is given for the MPCI value (Calculated from PCA-Fuzzy approach) in the equation:

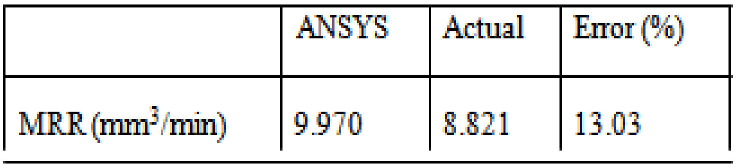
$$\hat{\eta}_{MPCI} = \bar{T} + (\bar{A}_1 - \bar{T}) + (\bar{B}_2 - \bar{T}) + (\bar{C}_2 - \bar{T}) + (\bar{D}_4 - \bar{T}) + (\bar{E}_2 - \bar{T}) + (\bar{F}_2 - \bar{T}) \qquad (1)$$

where $\hat{\eta}_{MPCI}$ is the predicted MPCI value, T is overall experimental average (MPCIs),and A_1, B_2 , C_2 , D_4 , E_2 and F2 are mean response for factors at designated levels. Predicted MPCI value for optimal setting is found 0.727 by using the above equation and shown in Table 9. As for initial conditions $A_1B_2C_3D_4E_2F_1$, the predicted MPCI is found to be 0.619. It is observed that predicted MPCI vale for the optimal condition has 0.108 increases over the predicted value of the initial condition.

Table 9. Comparison between initial and optimal conditions

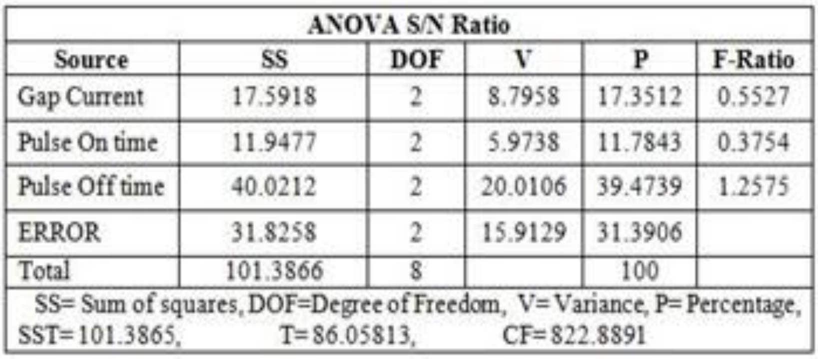
Performance characteristics	Initial condition	Optimal condition	Gain
	A1B2C3D4E2F1	A1B2C2D4E2F2	
MPCI confirmed	0.641	0.732	0.091
MPCI prediction	0.619	0.727	0.108
MRR (mm^3/min)	6.012	8.821	2.809
TWR (mm^3/min)	0.046	0.020	0.026
Surface roughness (micron)	5.769	3.071	2.698
Circularity (r_1/r_2)	0.967	0.977	0.010

Table 10. Comparison between ANSYS and actual MRR



	ANSYS	Actual	Error (%)
MRR (mm^3/min)	9.970	8.821	13.03

Table 11. ANOVA S/N Ratio



ANOVA S/N Ratio					
Source	SS	DOF	V	P	F-Ratio
Gap Current	17.5918	2	8.7958	17.3512	0.5527
Pulse On time	11.9477	2	5.9738	11.7843	0.3754
Pulse Off time	40.0212	2	20.0106	39.4739	1.2575
ERROR	31.8258	2	15.9129	31.3906	
Total	101.3866	8		100	

SS= Sum of squares, DOF=Degree of Freedom, V= Variance, P= Percentage,
SST= 101.3865, T= 86.05813, CF= 822.8891

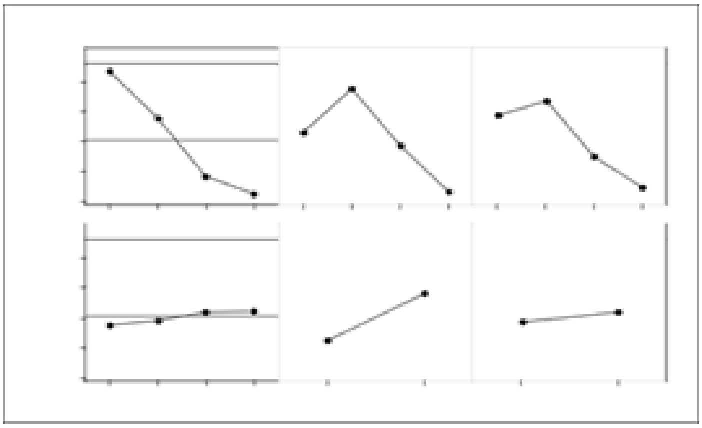


Figure 3. Response graph for MPCI value

V. Conclusion

From the statistical analysis, it is observed that the process parameter such as, discharge current, pulse on time duty factor, weight % have the significant effect on the multi performance characteristic (MPCI) contributing 82.05%. The effect of flushing pressure and mesh size of Si-C has less. Treating MPCI as an equivalent single response, the MPCI value is analysed by Taguchi's method. From the response plot it is found that, the optimal setting is 1amp discharge current, 200 µs pulse-on time, 85 % duty cycle, 3.9226 bar flushing pressure, 15% of Si-C, and 400 mesh sizes. With this optimal setting, the optimal responses MRR, TWR, Surface roughness and Circularity are found as 8.821mm^3/min, 0.020mm^3/min, 3.071 micron and 0.977 respectively. From this experiment it is framed that a difficult-to-cut material i.e. AlSi-C with better mechanical properties is easily machined by the non-traditional machining process i.e. EDM with improved quality characteristics with high dimensional accuracy. This concludes nonconventional machining process is a good replaceable for the expensive conventional machining process of MMCs.

5.1 Scope of future work

1. Electrical discharge machining has great potential in fabrication of textured surface of different types and geometry. Following issues may be taken up to further explore the concept.
2. Attempt laser assisted machining on ceramics.
3. Attempt to design a more efficient/accurate ductile machining model.
4. White layer thickness can also be calculated.

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