

Conduct Research and Compare the Impact of Technological Parameters on Surface Roughness while Processing on Electric Discharge Machine (EDM) with Copper Wire Electrode and Molybdenum Wire Electrode

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Abstract: Surface roughness or surface quality is one of the main criterias to evaluate the quality of processing procedure as well as the quality of products processed by that method. Research on surface roughness of workpiece processed by Electric Discharge Machining method in order to analyze influencing factors as well as evaluate their influence on surface roughness. Therefore, there are the bases for choosing the appropriate parameters and system for each technology step. This report represents some research results, comparison of the effects of pulse time, discharge current, 'h' blank thickness on surface roughness while processing C45, CT3, P9 steel on an Electric Discharge machine with copper electrode wire and molybdenum electrode wire.

Keywords: Machining optimization; influence of machining parameters; electrical discharge machining; wire electrical discharge machining (WEDM).

1. Introduction

Nowadays, with the rapid development of science and technology across all fields, mechanical products increasingly require higher quality, greater levels of production automation, and especially improved accuracy and surface finish. Therefore, traditional machining technologies using conventional machines are often unable to meet these growing demands, which limits the competitiveness of products in the market. This reality necessitates the development and research of advanced machining technologies, as well as the optimization of machining parameters, in order to enhance surface accuracy in particular and overall product quality in general.

The research and manufacturing of components with complex geometries and high surface quality requirements are typically carried out using modern or specialized equipment, one of which is Wire Electrical Discharge Machining (WEDM). The surface quality or surface roughness obtained from WEDM differs significantly from that produced by conventional machining methods. The machined surface in WEDM is characterized by numerous spherical protrusions and crater-like depressions, commonly referred to as peaks and discharge craters.

The surface roughness value depends on various factors and machining conditions, including workpiece thickness, discharge current, pulse duration, voltage, wire feed rate, and especially the dielectric fluid and cooling conditions. Effective cooling, lubrication, and cleaning during machining help reduce friction, extend wire life, and improve surface quality (smoothness and brightness). Additionally, they facilitate debris removal and ion transport, prevent corrosion, and enhance overall machine performance, which is particularly important when machining thick workpieces and hard materials.

Based on these practical considerations, the authors have conducted a focused study and investigation to compare and optimize machining conditions in order to propose solutions for improving surface quality. The study entitled “Conduct research and compare the impact of technological parameters on surface roughness while processing on Electric Discharge Machine (EDM) with Copper wire electrode and Molybdenum wire electrode.” has significant practical relevance. In addition to its scientific contribution, the research not only supports training activities at the Vietnam–Japan Center, Hanoi University of Industry, but also has practical applications in the machining of SUS304 stainless steel door pins at Ha Yen Company.

2. Wire EDM and Effects of Dielectric Fluids on Surface Quality

Wire Electrical Discharge Machining (WEDM) is a process that utilizes a thin conductive wire (typically 0.1–0.3 mm in diameter), continuously fed and guided along a predefined path to generate a cut on the workpiece. This method is commonly used to machine through-holes with complex geometries, such as those found in stamping dies, injection molds, and die-casting molds, as well as for manufacturing electrodes used in die-sinking EDM, machining narrow slots, intricate contours, and inspection gauges [1].

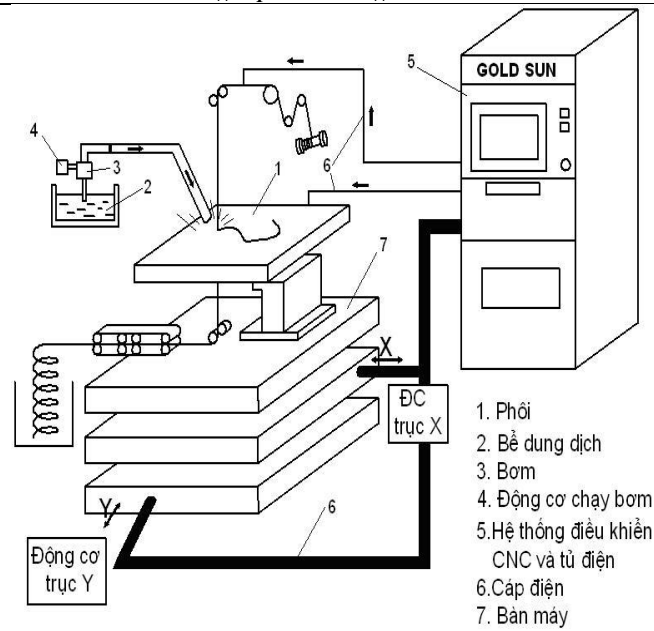


Fig. 1.1: Schematic diagram of the WEDM machine principle [2]

2.1. Material Removal Mechanism

In WEDM, material removal is based on the electrical discharge erosion effect generated by sparks occurring between two electrodes (Fig. 1.2). These sparks act independently within a dielectric medium. Material removal occurs as the discharge generates high temperatures that melt and vaporize material from both electrodes. A direct current (DC) power supply is applied to a pulsed circuit with a voltage ranging from 30 to 250 V and a frequency of 50 to 500 kHz, producing square-wave pulses between two electrodes separated by a small gap (typically 0.01–0.5 mm) [1].

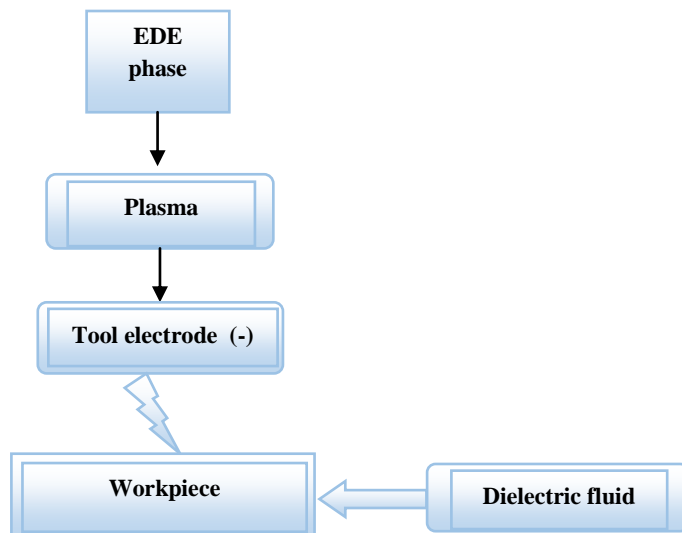


Fig. 1.2: Material removal mechanism in WEDM [1]

2.2. Machining Accuracy

The machining accuracy in Wire Electrical Discharge Machining (WEDM) typically ranges from 0.002 to 0.003 mm. This accuracy is influenced by initial errors, particularly those associated with the equipment, such as measurement errors, lack of straightness, lack of perpendicularity of motion axes, vibration, and the rigidity of the technological system and clamping table. The overall machining error is also affected by inherent process errors in electrical discharge machining.

Typical error ranges are as follows:

- Process-related errors up to 0.03 mm; external vibration errors up to 0.02 mm; measurement device errors up to 0.005 mm; and wire guide system rigidity errors up to 0.015 mm.
- Errors due to thermal deformation of machine components and assemblies: approximately 0.035 mm.
- Errors due to thermal expansion of the workpiece and measuring components caused by prolonged machining (up to 0.006 mm for workpieces with thickness up to 50 mm).

2.3. Debris Removal in WEDM

During the machining process, debris removal is essential to improve the insulating capability of the dielectric fluid, as well as to cool both the electrode and the workpiece. The main debris removal techniques in Wire Electrical Discharge Machining include:

- **Axial flushing under pressure (coaxial flow):** The dielectric fluid is injected into the discharge gap at high pressure (typically 15–20 bar) through a guiding system. This method requires good contact between the wire guide and the workpiece to maintain sufficient pressure within the discharge gap.
- **Natural circulation flow:** This method is applied when the workpiece is submerged in the dielectric fluid during machining.

2.4. Machined Surface Characteristics in WEDM

In wire EDM machining, two types of discharge gaps can be observed simultaneously:

- **Frontal discharge gap (gf):** the distance between the wire and the workpiece measured along the wire feed direction.
- **Lateral discharge gap (gls):** the distance between the wire and the workpiece measured perpendicular to the wire feed direction.

The machined side surface is typically non-uniform due to molten material formed in the frontal gap, gas bubbles, and debris particles adhering to the surface. These factors contribute significantly to surface roughness. The surface roughness value is strongly influenced by the discharge current; higher current levels result in increased surface roughness. (Fig. 1.3)

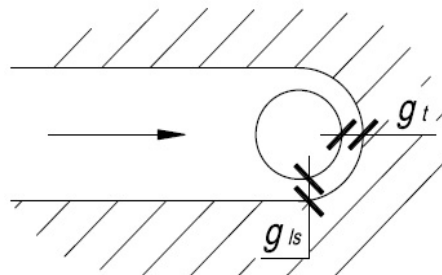


Fig. 1.3: Discharge gap between two electrodes [1]

2.5. Wire-Cutting Oil and Soluble Oil in EDM

In conventional machining, a fluid is typically used to cool the machining zone in order to minimize thermal effects on both the workpiece surface and the cutting tool. However, in Electrical Discharge Machining (EDM), besides the two primary elements—the tool electrode and the workpiece connected to two poles—an essential factor for material removal and debris evacuation is the dielectric fluid, including wire-cutting oil and soluble oil solution. (Fig. 1.4)



Fig. 1.4: Wire-cutting oil used in the molybdenum wire EDM machine

Therefore, the main functions of the dielectric fluid in EDM are:

- Providing electrical insulation between the two electrodes (tool and workpiece).
- Facilitating ionization.
- Cooling the machining zone.
- Removing debris from the discharge gap.

a. Wire-Cutting Oil

In this study, the authors used JIARUN JR 1-A wire-cutting oil, manufactured in China. Its main advantages and properties are summarized as follows:

Advantages:

- Suitable for a wide range of metallic materials.
- Excellent lubrication and anti-wear performance.
- Safe for operators.
- Safe for machine operation.
- Good cleaning capability, reducing oil loss due to workpieces and finished products.
- Minimizes oil consumption.

Properties:

- **Color:** yellow-brown or milky white (depending on ambient temperature conditions).
- **Mixing ratio:** 1:15–20 (i.e., 1 liter of oil can be mixed with 15–20 liters of water).
- Can be directly mixed with tap water (groundwater and hard water should be avoided).
- Provides a relatively thick lubrication film.
- **Surface quality:** workpieces are easily separated after lubrication, with no visible erosion defects; the machined surface appears clean and uniform without transfer marks.
- **Molybdenum wire life:** significantly increased, with wire consumption reduced by approximately 50%.
- **Lubrication performance:** suitable for high-current machining conditions (above 3.0 A for standard machines and above 4.0 A for medium-speed wire systems).
- High durability, high efficiency, low wire consumption, and easy cleaning.

b. Soluble Oil Solution

Soluble oil (water-miscible cutting fluid) typically consists of base oil (mineral or synthetic), water (which constitutes the majority), and various essential additives such as emulsifiers, extreme-pressure (EP) additives, corrosion inhibitors, anti-foaming agents, biocides, and pH stabilizers. These components work together to provide effective lubrication and cooling, reduce wear, and protect both the cutting tool and the workpiece during machining.

Main components:

- **Base oil:**
 - **Mineral oil:** widely used with reasonable cost.
 - **Synthetic oil:** higher durability and performance.
 - **Semi-synthetic oil:** combines the advantages of both types.
- **Water:**

Accounts for approximately 90–95% of the solution and plays a primary role in heat dissipation (cooling).
- **Specialized additives:**
 - **Emulsifiers:** ensure uniform dispersion of base oil in water, forming a stable emulsion.
 - **Extreme-pressure (EP) additives:** enhance load-carrying capacity, reduce wear, and protect tools under high-pressure conditions.
 - **Corrosion inhibitors:** prevent rust and corrosion of machine components and workpieces.
 - **Biocides:** inhibit the growth of bacteria and fungi that can cause odor and fluid degradation.
 - **Anti-foaming agents:** reduce foam formation during machining.
 - **pH stabilizers:** maintain stable pH levels, preventing fluid degradation and corrosion.

3. Experimental Study and Comparison of the Effects of Wire-Cutting Oil and Soluble Oil on Surface Quality of Sus304 in Wedm

3.1. Schematic Diagram of the WEDM Process

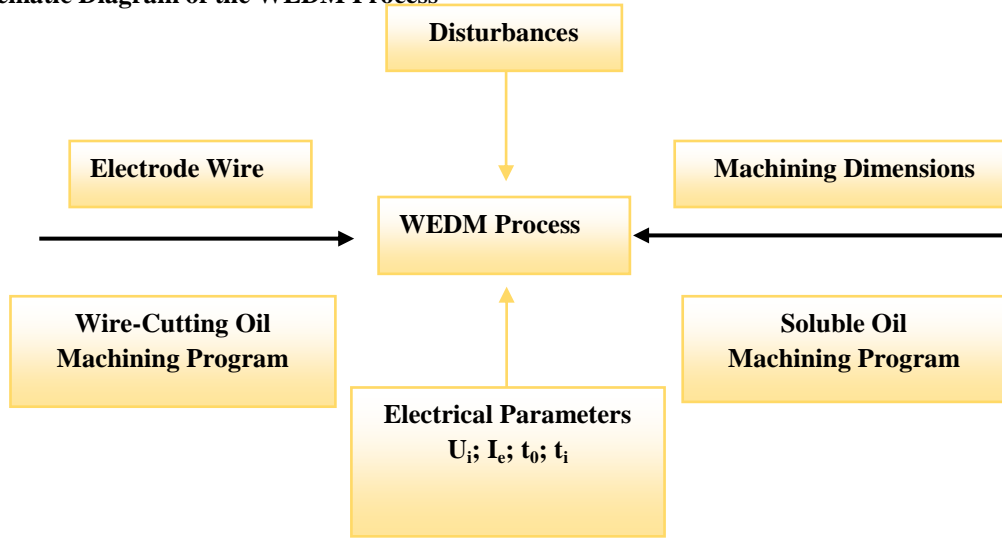


Fig. 1.5: Qualitative model of the electrical discharge machining process [4]

3.2. Experimental Conditions

3.2.1. Goldsun WEDM Machine

The equipment used in this experiment is a molybdenum wire Electrical Discharge Machine, model **GS 2532B**, manufactured by Goldsun. The technical specifications of the machine are presented in Table I.

Table I: Technical Specifications of GS 2532B WEDM Machine

Worktable size	mm	400 x 580
Table travel	mm	250 x 320
Maximum workpiece thickness	mm	300
Maximum workpiece weight	kg	200
Maximum taper angle	Độ	6 ⁰
Wire diameter	mm	□0,1 □0,2
Maximum machining speed	mm ² /ph	≤160
Machining accuracy	mm	0,015
Maximum discharge current	A	5
Machine dimensions	mm	1360x1060x1750
Net weight	kg	1300 kg



Fig. 1.6: Goldsun GS2532B WEDM machine

3.2.2. Workpiece

Workpiece material: SUS304 stainless steel

Table II Chemical Composition of SUS304 Stainless Steel (wt.%)

Material	Chemical composition (wt.%)					
	C	Cr	Ni	Mn	P	S
SUS304	0.08	18.0 ÷ 20.0	8.0 – 10.50	2.0	0,045	0,030

Material Properties:

- **Corrosion resistance:**

SUS304 contains elements such as Cr, Ni, and S, which enhance corrosion resistance and prevent rusting when exposed to chemicals. This makes it widely used in construction, architecture, and food processing industries.

- **Thermal resistance:**

This material performs well at both low and high temperatures. The presence of Ni helps prevent brittleness at low temperatures. It can operate effectively in the temperature range of approximately 425°C to 860°C, with intermittent oxidation resistance up to 870°C and continuous resistance up to 925°C. Heat treatment is typically performed at 1010–1120°C followed by rapid cooling.

- **Ductility:**

As an austenitic stainless steel, SUS304 exhibits excellent ductility, maintaining its properties even at low temperatures. It is easily formed, bent, and rolled into thin sheets, making it suitable for a wide range of manufacturing applications.

- **Weldability:**

SUS304 demonstrates excellent weldability and can be processed using most welding methods and techniques.

- **Workpiece dimensions:**

+ Diameter: Ø8mm

+ Length: 41mm



Fig. 1.7: Workpiece dimensions

3.2.3. Electrode Wire

The electrode wire used in this study is molybdenum wire, which is manufactured from molybdenum—a material known for its high temperature resistance, excellent wear resistance, and high mechanical strength. With an ultra-thin diameter, typically around 0.18 mm, this type of wire is widely used in industries requiring high precision and durability.



Fig. 1.8: Molybdenum wire electrode

Key characteristics of molybdenum wire:

- **High temperature resistance:** Molybdenum has a melting point of approximately 2623°C, enabling stable operation under high-temperature conditions.
- **Corrosion resistance:** Molybdenum exhibits strong resistance to many chemical environments, making it suitable for harsh working conditions.
- **High precision:** With a diameter of 0.18 mm, molybdenum wire is well-suited for machining small and intricate components requiring high accuracy.
- **Long service life:** The wire has a smooth surface, low wear rate, and can be reused multiple times.
- **Ductility and flexibility:** It can be easily bent or shaped without fracture or deformation.

3.2.4. Measurement Equipment

Surface roughness measurements and corresponding data were obtained using a **TESA Rugosurf 10G** surface roughness tester, with results displayed on a computer. (Fig. 1.9)

Other experimental results were conducted at the Machining Practice and Laboratory, Vietnam–Japan Center, Hanoi University of Industry.



Fig. 1.9: TESA – Rugosurf 10G

Main technical specifications:

- **Standard:** ISO 3274
- **Accuracy:** Class 1 (according to ISO 3274)
- **Resolution:** 0.001 μm
- **Measuring force:** 0.75 mN
- **Stylus:** diamond tip, 90° angle, 2 μm radius
- **Measured parameters:** Ra, Rz, Rmax, Rq, Rt, RMS
- **Display:** integrated screen, units in mm and inch
- **Memory:** stores the most recent measurement
- **Interface:** RS-232 port
- **Design:** compact, durable, and portable

3.2.5. Determination of the Effects of Wire-Cutting Oil and Soluble Oil on Surface Quality

To analyze the influence of wire-cutting oil and soluble oil solution on surface quality, experiments were conducted under the following machining conditions:

- SUS304 workpieces were machined using each type of dielectric fluid.
- Workpieces with identical dimensions were machined under the same cutting regime, with four main technological parameters on the WEDM machine: discharge voltage (U_e), discharge current (I_e), pulse duration (t_i), and wire feed speed (V_d).
- The required surface roughness after machining was within the range: $R_a = 3.2 \div 6.3 \mu\text{m}$
- The evaluation length for surface roughness measurement was: 2.5 mm

Table III: Initial Machining Parameters Using Wire-Cutting Oil

Initial Machining Parameters						
$\varnothing_{\text{wire}}$ (mm)	v_d (m/ph)	v_{gc} (mm/ph)	Dielectric fluid	I_e (A)	U_e (V)	t_i (μs)
0,18	12	3	Wire-cutting oil	5	100	64

Table IV: Initial Machining Parameters Using Soluble Oil

Initial Machining Parameters						
$\varnothing_{\text{wire}}$ (mm)	v_d (m/ph)	v_{gc} (mm/ph)	Dielectric fluid	I_e (A)	U_e (V)	t_i (μs)
0,18	12	3	Wire-cutting oil	5	100	64

Where:

- $\varnothing_{\text{wire}}$: wire diameter
- V_{wire} : wire feed speed along the wire axis
- $V_{\text{Feed rate}}$: machining feed rate

3.3. Experimental Results

3.3.1. Effect of Soluble Oil on surface roughness and surface finish in machining SUS304

The experimental results obtained when machining with wire-cutting oil

Machining Parameters	Sample No	Measurement Results	
		R_a	R_z
I_e (A) U_e (V) V_{wire} (m/ph) $V_{\text{Feed rate}}$ (mm/ph)	1	11.499	59.914
	2	9.827	41.590
	3	9.292	43.838
	4	9.827	41.590
	5	8.110	37.398
	6	8.893	39.116
	7	9.784	45.143
	8	9.156	42.026
	9	10.525	50.710
	10	8.462	37.646

3.3.2. Influence of Wire-Cutting Oil on surface roughness and surface finish of SUS304 in WED

Machining Parameters	Sample No	Measurement Results	
		R_a	R_z
I_e (A) U_e (V) V_{wire} (m/ph) $V_{\text{Feed rate}}$ (mm/ph)	1	6.699	31.875
	2	6.227	30.525
	3	7.986	34.826
	4	5.084	29.132
	5	7.116	36.669
	6	7.842	32.867
	7	6.911	37.942
	8	4.910	29.942
	9	7.438	35.419
	10	3.852	22.474

4. Results and Discussion

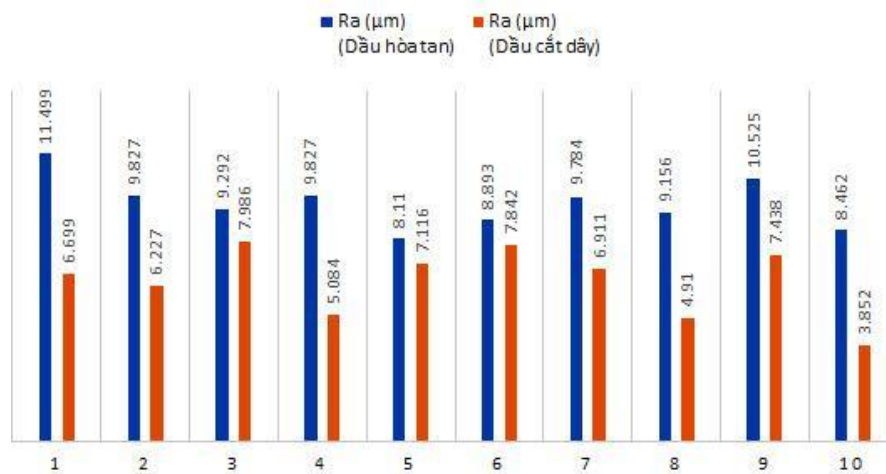


Fig. 1.10: Comparison of surface finish when machining with wire-cutting oil and soluble oil

Based on the plotted results illustrating the influence of machining parameters on surface roughness in WEDM using wire-cutting oil and soluble oil, it is observed that in both cases, SUS304 workpieces were machined under identical input parameters. The results indicate the following:

- **When using wire-cutting oil**, the measured surface roughness values across 10 samples were relatively low and consistently distributed, with an average value of approximately $R_a = 5.277 \mu\text{m}$. Based on experimental observations and analysis, the effects of wire-cutting oil on surface quality can be explained as follows:
 - **Stable spark gap formation:** The higher dielectric strength of oil compared to water enables a smaller and more stable spark gap, reducing wire vibration and producing a smoother and more uniform surface.
 - **Effective cooling and lubrication:** Wire-cutting oil provides efficient cooling, minimizing thermal deformation and preventing surface burning, thereby reducing micro-crater formation.
 - **Efficient debris removal:** The oil effectively removes debris from the machining zone, reducing secondary discharges that can deteriorate surface quality.
 - **Reduced wire vibration:** Due to its viscosity and stability, the oil minimizes excessive wire oscillation, ensuring a straight cutting path and preventing surface waviness.
- **When using soluble oil**, the measured surface roughness values across 10 samples were significantly higher compared to wire-cutting oil, with an average value of approximately $R_a = 9.537 \mu\text{m}$, which is nearly double the required specification range. The higher surface roughness observed when using soluble oil can be attributed to the following factors:
 - **Poor surface finish (high roughness):** Due to limited lubrication capability (water-dominant composition), friction increases during machining, resulting in a rougher surface.
 - **Edge burning and surface damage:** If the oil concentration is too low, the reduced lubrication leads to excessive heat generation, causing edge burning and potential alteration of the surface structure.
 - **Surface corrosion:** The high water content in soluble oil may lead to temporary corrosion if the emulsion is unstable or lacks sufficient corrosion inhibitors.
 - **Burr formation:** Insufficient cutting performance and increased tool wear can result in burr formation and reduced edge sharpness.
 - **Reduced dimensional accuracy:** Unstable emulsion conditions or overheating (due to contamination) may cause uneven machining, directly affecting dimensional accuracy and reliability.

5. Conclusion

Based on the experimental results, the following conclusions can be drawn:

- When using wire-cutting oil in WEDM, the discharge current within the spark gap remains stable, significantly reducing thermal deformation and surface burning. As a result, the machined surface exhibits improved smoothness and overall quality.
- In contrast, when using soluble oil, the machined surface shows higher roughness and lower surface quality. This is primarily due to insufficient lubrication and reduced corrosion resistance, which lead to increased friction, surface burning, and deterioration of the machined surface.

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