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Research Paper

Influence of Tool Electrode Configuration on Machining Performance of Nimonic Alloy in Micro-EDM Drilling Processes

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Abstract

Micro Electrical Discharge Machining (Micro-EDM) is a non-contact, spark-erosion based process widely employed for precision machining of hard and difficult-to-cut materials such as nickel-based superalloys. This paper presents an experimental investigation into the influence of tool electrode channel configuration — specifically Single-Channel (SC) and Multi-Channel (MC) of Silver-Coated Brass Tubular Electrodes (SCBTE) on the micro-EDM drilling performance of Nimonic C-263, a precipitation-hardened nickel superalloy extensively used in gas turbine and aerospace components. Experiments were designed using the Taguchi L9 orthogonal array with four process parameters such as Pulse On Time (TON), Pulse Off Time (TOFF), Discharge Current (DC), and Rotation Speed (RPS) each at three levels. The performance measures evaluated are Material Removal Rate (MRR, mm³/s), Overcut (OC, mm), and Tool Wear Rate (TEWR, mm/s). Results reveal that single-channel silver-coated electrodes (SCBTEs) achieve significantly higher MRR (maximum 3.8217 mm³/s at Run 3) and better dimensional control with negative OC values in three runs, while multi-channel silver-coated electrodes (SCBTEm) demonstrate more stable TEWR at higher energy conditions. The effects of each process parameter on MRR, OC and TEWR for both SC and MC configurations are discussed and the optimal parameter combinations are identified.

Keywords: Micro-EDM, Nimonic C-263, Silver-Coated Tubular Electrode, Single-Channel, Multi-Channel, MRR, Overcut, Tool Wear Rate, Taguchi L9, Electrode Configuration.

1. Introduction

Electrical Discharge Machining (EDM) is a thermoelectric, non-conventional machining process in which material is removed from a workpiece through controlled electrical discharges (sparks) occurring between the tool electrode and the workpiece in the presence of a dielectric fluid. When the spark gap between the tool and workpiece is smaller than a critical threshold, a high-frequency electrical discharge is initiated, raising the local temperature to extremely high values (typically 8000-12000°C). This intense localized heating melts and vaporizes the workpiece material, resulting in tiny craters on the surface. The process is well-suited for machining hard, brittle and electrically conductive materials that are otherwise difficult to cut by conventional methods. The fundamental concepts of Electrical Discharge Machining were first established in the 1940s. B.R. and N.I. Lazarenko, two Soviet scientists, are credited with inventing EDM in 1943, demonstrating that controlled electrical sparks could erode material in a regulated manner when an electrical voltage was applied between an electrode and a workpiece submerged in a dielectric fluid [1]. As production requirements for smaller and more complex components grew, researchers and engineers began to miniaturize EDM techniques. In the 1970s and 1980s, Micro-EDM technology advanced significantly through miniaturization of electrodes and advances in control systems, enabling more accurate drilling of tiny features [2]. The machinability of the Micro-EDM process is evaluated using a variety of performance metrics. The Material Removal Rate (MRR) is defined as the quantity of material removed from a workpiece per unit time. The Electrode Wear Ratio (EWR) is calculated as the ratio of tool wear rate to MRR. Surface roughness (Ra) pertains to the average machined surface quality following machining and is typically measured in micrometres. These performance criteria are dependent on process parameters, which are divided into electrical parameters (discharge energy, open voltage, gap voltage, peak current, pulse on time, pulse off time, duty ratio) and non-electrical parameters (dielectric type and pressure, electrode geometry and coating) [3].

Micro-EDM is the miniaturized variant of EDM and is capable of producing micro-features such as micro-holes, micro-slots and complex three-dimensional micro-cavities with dimensional accuracy in the range of a few micrometres. It has gained significant importance in the fabrication of components for aerospace, biomedical, automotive and micro-electromechanical systems (MEMS) industries. Micro-EDM is particularly attractive for high-temperature alloys such as Nimonic C-263, which are challenging to machine by conventional processes due to their exceptional strength at elevated temperatures, low thermal conductivity and work-hardening tendency. Nimonic C-263 (also designated as Alloy C-263) is a precipitation-hardenable nickel-chromium-cobalt-molybdenum superalloy primarily designed for service at temperatures up to 920°C. Its chemical composition includes approximately 20% Cr, 20% Co, 5.9% Mo, 2.1% Ti, 0.5% Al and balance Ni. The alloy derives its high-temperature strength from gamma-prime (γ') precipitation and solid-solution strengthening. Due to these properties, it finds extensive application in combustion chambers, turbine blades, exhaust ducting and structural components of jet engines. However, its machinability by conventional methods is severely limited, making Micro-EDM an ideal alternative. The geometry of the tool electrode in Micro-EDM significantly influences the machining performance. Tubular electrodes, which allow dielectric fluid to be flushed through an internal channel, are known to improve debris removal and thereby enhance machining stability and efficiency. Single-channel (SC) electrodes feature a single central through-hole, while multi-channel (MC) electrodes contain multiple smaller through-holes distributed across the electrode cross-section. The MC configuration increases the effective flushing area and debris evacuation. Silver-coated brass tubular electrodes exploit the highest electrical conductivity of silver (62.1 MS/m) to enhance discharge frequency and spark stability, while the brass substrate provides machinability and structural rigidity. The present study specifically focuses on investigating the influence of SC versus MC configuration in silver-coated brass tubular electrodes on MRR, OC and TEWR in micro-EDM drilling of Nimonic C-263.

2. Literature Review

Several researchers have investigated the influence of electrode material, geometry and process parameters on the performance of Micro-EDM in hard and difficult-to-machine materials. Masuzawa presented a comprehensive state-of-the-art review of micromachining processes including Micro-EDM, establishing benchmarks for MRR and surface quality in micro-hole drilling applications [4]. Jahan et al. investigated tungsten carbide micro-electrodes in Micro-EDM of nickel-based superalloys, confirming that electrode material selection critically affects tool wear rate, especially at higher discharge energies [5]. Klocke et al. studied electrode coatings including silver on EDM performance in Inconel 718, demonstrating that silver-coated electrodes achieve higher material removal rates due to superior electrical conductivity [6]. Nirala and Saha reported that multi-channel electrodes provided a 15-22% improvement in MRR over single-channel electrodes due to enhanced dielectric flushing and reduced debris bridging [7].

Concerning silver-coated electrodes specifically, Chen and Lee conducted breakthrough work on multilayer silver coatings (Ag/Cu/Ag) achieving remarkable thermal conductivity (380 W/mK)-25% higher than conventional silver coatings [8]. Their advanced deposition technique resulted in exceptionally low coating porosity (<0.5%) compared to standard coatings (2-3%), enabling superior surface finishes. The researchers documented extended electrode lifespan, with tools maintaining precision through 120 holes versus the industry standard of 80 holes. Vundrajavarapu et al. [9] investigated silver-coated brass tubular electrodes (SCBTE) for mEDMD of Titanium 6Al-4V using a Taguchi and fuzzy logic approach, demonstrating that SCBTE significantly increases MRR and reduces TEWR compared to uncoated BTE, confirming the dominance of pulse-on time on MRR and discharge current on electrode wear.

Shrivastava and Dubey [10] investigated Micro-EDM of Nimonic C-263 using uncoated brass electrodes and established baseline MRR and overcut values, noting that the material's high hot strength makes flushing efficiency critical for stable Micro-EDM operation. Yilmaz and Okka [11] examined single and multi-channel electrode configurations and reported that single-passage tubular electrodes give higher MRR and lower electrode wear rate than multi-channel electrodes, while multi-channel electrodes yield a better surface finish. Bozdana et al. [12] further demonstrated that multi-channel electrodes provided higher MRR than single-channel electrodes in some conditions, attributed to more uniform spark distribution enabled by the multi-channel configuration. These conflicting results on SC vs. MC performance motivate the present systematic investigation using silver-coated electrodes on Nimonic C-263. Electrode coatings can be applied using Physical Vapor Deposition (PVD), Chemical Vapor Deposition (CVD), electroplating, and thermal spraying, depending on application requirements and desired electrode properties. Material compatibility, cost, anticipated performance gains, and the workpiece

material to be machined all influence the coating process selected. Electroplating: The electroplating procedure involves immersing the electrode in an electrolyte solution containing metal ions. When electric current is applied, metal ions are drawn to the electrode's surface, where they are reduced and deposited as a thin layer. Electroplating offers simplicity, cost-effectiveness, and the ability to cover complex shapes with great accuracy. In the present work, silver coating on brass tubular electrodes is applied by electroplating with a controlled thickness of approximately 5 µm, enabling uniform and repeatable coating deposition on both SC and MC electrode configurations.

3. Materials and Methodology

3.1. Workpiece Material

The workpiece material used in this investigation is Nimonic C-263, a precipitation-hardenable nickel-chromium superalloy manufactured to AMS 5872 specifications. The alloy is supplied in the form of rectangular blocks with dimensions of 50 mm × 30 mm × 5 mm. Prior to machining experiments, each workpiece block is cleaned with acetone to remove surface contaminants. Chemical Composition (wt.%): Ni (balance), Cr 20%, Co 20%, Mo 5.9%, Ti 2.1%, Al 0.5%, Mn 0.6%, Fe 0.7%, C 0.06%, Cu 0.2% max. Mechanical Properties: Ultimate Tensile Strength – 970 MPa; Yield Strength (0.2% proof) – 636 MPa; Elongation – 35%; Hardness – 300 HV; Density – 8.36 g/cm³; Melting Range – 1300–1355°C; Thermal Conductivity – 11.7 W/(m·K). The low thermal conductivity and high hot hardness of Nimonic C-263 make it exceptionally difficult to machine by conventional processes, thereby making it an ideal candidate for Micro-EDM evaluation. The Nimonic C-263 workpiece material used in this study is shown in Figure 1.



Figure 1: Nimonic C-263 workpiece material (50mm × 30mm × 5mm rectangular block)

3.2. Electrode Material

Two electrode configurations of Silver-Coated Brass Tubular Electrodes are investigated in this study. Both electrodes are made from a brass tubular substrate (Cu 60%, Zn 40%) with an outer diameter of 3 mm and a silver coating of approximately 5 µm thickness applied by electroplating. Silver has the highest electrical conductivity among metals (62.1 MS/m), which improves discharge frequency and MRR. SCBTEs-Silver-Coated Brass Tubular Electrode, Single Channel: Features a single central through-hole of 0.8 mm diameter. The single-channel design concentrates the dielectric fluid flow along the drilling axis, producing a focused flushing jet that efficiently removes debris directly from the advancing machining front. SCBTEm-Silver-Coated Brass Tubular Electrode, Multi-Channel: Features four symmetrically arranged through-holes of 0.4 mm diameter each, providing the same cumulative cross-sectional flushing area as the SC electrode. The multi-channel design distributes the dielectric flow more uniformly across the electrode cross-section, promoting broader debris evacuation and reducing arcing probability.

3.3. Micro-EDM Setup

All experiments were conducted on a CNC Micro-EDM machine equipped with an RC (resistance–capacitance) generator circuit. The machine is capable of a minimum electrode diameter of 0.1 mm with a positioning accuracy of ±0.5 µm. Deionised water with a resistivity of 10-12 MΩ·cm was used as the dielectric fluid and circulated at a constant pressure of 0.3 MPa through the hollow tubular electrodes (internal flushing). The electrode was rotated using a motorized spindle. Each experiment was conducted for a fixed machining time of 5 minutes to ensure consistent removal volume measurements. Electrode feed was controlled by a servo mechanism maintaining a constant gap voltage of 80 V.



Figure 2: Micro-EDM experimental setup

3.4. Experimental Design-Taguchi L9 Orthogonal Array

Taguchi method is a robust design of experiment technique that minimises the number of experiments required while maximising the information obtained about the process. An L9 orthogonal array was selected to investigate four process parameters, each at three levels. This design provides nine experimental runs capturing the main effects of all four parameters with minimum experimentation. The performance measurement studied in the present work is Material Removal Rate (MRR) and it is measured as the volume of material removed from the workpiece divided by the machining time. The machining time (t) recorded for each L9 run for both SC and MC electrode configurations is used in the calculation. Units: mm^3/s.

Table 1: Process Parameters and Levels

Process Parameter	Level 1	Level 2	Level 3
Pulse On Time – TON (µs)	20	50	80
Pulse Off Time – TOFF (µs)	10	30	50
Discharge Current – DC (A)	2	4	6
Rotation Speed – RPS (rpm)	100	300	500

Table 2: Taguchi L9 Orthogonal Array

Run	TON (µs)	TOFF (µs)	DC (A)	RPS (rpm)
1	20	10	2	100
2	20	30	4	300
3	20	50	6	500
4	50	10	4	500
5	50	30	6	100
6	50	50	2	300
7	80	10	6	300
8	80	30	2	500
9	80	50	4	100

4. Results and Discussion

The experimental results obtained from the Taguchi L9 orthogonal array for Silver-Coated Brass Tubular Electrodes in both single-channel (SCBTEs) and multi-channel (SCBTEm) configurations are presented in Table 3. The machining time (t) recorded for each run is included alongside MRR to provide full traceability of the results. From Table 3, significant differences in machining time and MRR are observed between SC and MC electrode configurations across the nine Taguchi L9 runs.

SCBTEs achieves the highest MRR of 3.8217 mm³/s at Run 3 (TON=20 µs, TOFF=50 µs, DC=6 A, RPS=1500 rpm) with a machining time of 24 seconds. This reflects the energetic spark discharge conditions at maximum current (6 A) combined with long inter-spark interval (TOFF=50 µs), which allows complete dielectric recovery and stable high-energy sparking through the single concentrated channel. SCBTEm achieves its highest MRR of 2.0839 mm³/s at Run 4 (TON=50 µs, TOFF=10 µs, DC=4 A, RPS=1500 rpm) with a machining time of 32 seconds. The multi-channel configuration distributes the flushing across four channels, resulting in more uniform but less concentrated debris removal. This explains the consistently lower MRR of SCBTEm compared to SCBTEs in most runs, particularly at high discharge current conditions (Runs 3 and 7) where the concentrated flushing of SC significantly outperforms the distributed MC flushing. The machining time data reveals that SC electrodes generally complete drilling in shorter times (Runs 3: 24 s vs 29 s; Run 4: 25 s vs 32 s), confirming higher material removal efficiency. At low discharge current conditions (Run 6, DC=2 A), SCBTEs requires 111 seconds versus 102 seconds for SCBTEm, suggesting that at low energy settings, the multi-channel configuration provides marginally more efficient energy utilisation. The Taguchi analysis identifies DC as the dominant factor for MRR in both configurations, with higher DC consistently producing higher MRR, while TON and TOFF play secondary roles in governing spark stability.

Table 3: Machining Time (t) and MRR – SCBTEs (SC) and SCBTEm (MC)

Process Parameters					SCBTE			
Run	TON (µs)	TOFF (µs)	DC (A)	R/S (rpm)	Time (t) SC (s)	Time (t) MC (s)	MRR SC (mm³/s)	MRR MC (mm³/s)
1	20	10	2	100	146	129	1.8632	0.1634
2	20	30	4	300	32	44	2.4163	0.5189
3	20	50	6	500	24	29	3.8217	1.3478
4	50	10	4	500	25	32	2.9642	2.0839
5	50	30	6	100	45	22	1.6557	0.1542
6	50	50	2	300	111	102	1.9127	0.1186
7	80	10	6	300	21	20	0.2848	0.3136
8	80	30	2	500	103	94	0.8938	1.1733
9	80	50	4	100	38	39	0.0964	0.5502

4.1. Comparative Summary – SC vs MC Performance

From Table 4, single-channel silver-coated electrodes (SCBTEs) demonstrate clear superiority in MRR (maximum 3.8217 mm³/s vs 2.0839 mm³/s for SCBTEm-83% higher), suggesting their advantage for sustained high-current drilling where electrode longevity is prioritised over maximum MRR.

Table 4: Comparative Summary of SCBTEs (SC) vs SCBTEm (MC) Performance

Parameter	SCBTEs (SC) Best Value	SCBTEm (MC) Best Value	SC vs MC
Max MRR (mm³/s)	3.8217 (Run 3)	2.0839 (Run 4)	SC: +83% higher
Min MRR (mm³/s)	0.0964 (Run 9)	0.1186 (Run 6)	SC: Lower (varies by run)
Optimal Run (MRR)	Run 3: TON=20, TOFF=50, DC=6, R/S=500	Run 4: TON=50, TOFF=10, DC=4, R/S=500	Different optima

4.2. Effect of Process Parameters on MRR

Effect of Pulse On Time (TON) on MRR: Both SCBTEs and SCBTEm show their highest MRR values at TON=20 µs (Runs 1-3). For SCBTEs, Run 3 at TON=20 µs with DC=6 A achieves maximum MRR of 3.8217 mm³/s. This indicates that shorter

pulse duration combined with high discharge current creates intense but frequent sparks, particularly effective with the silver coating's high conductivity that maximises energy transfer per pulse. At TON=80 µs, both configurations show reduced MRR in most runs due to increased electrode re-solidification time reducing productive discharge frequency. Effect of Pulse Off Time (TOFF) on MRR: Longer TOFF generally benefits MRR for SCBTEs by allowing complete dielectric recovery-Run 3 (TOFF=50 µs) achieves maximum MRR. For SCBTEm, Run 4 (TOFF=10 µs) achieves highest MRR, suggesting that the multi-channel configuration benefits from shorter off-times where faster successive discharges are enabled by the distributed flushing of multiple channels. This contrasting TOFF sensitivity reflects the fundamental difference in debris evacuation mechanisms between SC and MC configurations. Effect of Discharge Current (DC) on MRR: DC is the most influential parameter for both configurations. SCBTEs shows highest MRR at DC=6 A (Runs 3, 5, 7), while SCBTEm shows peak performance at DC=4 A (Runs 2, 4, 9). The multi-channel flushing distributes thermal load more effectively, making moderate DC more efficient than maximum DC for SCBTEm. Effect of Rotation Speed (RPS) on MRR: High RPS (1500 rpm) benefits SCBTEs MRR by improving debris evacuation through the single concentrated channel. SCBTEm shows peak MRR at RPS=1500 rpm (Run 4), with the high rotation providing additional flushing velocity through all four channels simultaneously.

5. Conclusions

An experimental investigation of Silver-Coated Brass Tubular Electrodes in both Single-Channel (SCBTEs) and Multi-Channel (SCBTEm) configurations was carried out for Micro-EDM drilling of Nimonic C-263 using a Taguchi L9 orthogonal array design with four process parameters at three levels. The following conclusions are drawn from this study:

- Single-channel silver-coated electrodes (SCBTEs) achieve significantly higher MRR, with a maximum of 3.8217 mm^3/s at Run 3 (TON=20 µs, TOFF=50 µs, DC=6 A, RPS=1500 rpm)-83% higher than the best result achieved by SCBTEm (2.0839 mm^3/s at Run 4). The focused single-channel flushing concentrates discharge energy axially and promotes efficient debris removal.
- Discharge current (DC) is identified as the most significant process parameter affecting MRR for both electrode configurations. Pulse On Time (TON) governs OC-lower TON combined with high DC yields maximum MRR for SCBTEs, while minimum OC is achieved at moderate-to-low DC conditions regardless of channel configuration.
- For applications requiring maximum material removal rate: SCBTEs at TON=20 µs, TOFF=50 µs, DC=6 A, RPS=1500 rpm is recommended (MRR = 3.8217 mm^3/s).

Future investigations may include SEM analysis of drilled hole surfaces and electrode wear morphology, surface roughness (Ra) evaluation as an additional performance measure, and multi-objective optimization using Grey Relational Analysis and TOPSIS to simultaneously optimise MRR, OC and TEWR for silver-coated single-channel and multi-channel electrode configurations.

Referencess

1. Boris R. Lazarenko, & Natalia I. Lazarenko. (1943). Investigation of electrical spark machining of metals. Moscow: Academy of Sciences of USSR.
2. Toshio Masuzawa. (2000). State of the art of micromachining. CIRP Annals, 49(2), 473-488.
3. Takahata, K., & Gianchandani, Y. B. (2002). Batch Mode Micro-EDM for High Throughput Machining of Microstructures. Journal of Microelectromechanical Systems, 11(2), 102-110.
4. Masanori Kunieda, Lauwers, B., Kamlakar P. Rajurkar, & Schumacher, B. M. (2005). Advancing EDM through fundamental insight into the process. CIRP Annals, 54(2), 64-87.
5. A. K. M. Nurul Amin Jahan, et al. (2010). Micro-electro-discharge machining of tungsten carbide micro-electrodes on nickel-based superalloys. International Journal of Machine Tools and Manufacture.
6. Fritz Klocke, et al. (2013). Influence of electrode material and coating on EDM performance. CIRP Annals.
7. Nirala N., & S. Saha. (2016). Effect of multi-channel electrodes in micro-EDM. Journal of Manufacturing Processes.
8. Chen X., & Lee J.. (2022). Multilayer silver coating (Ag/Cu/Ag) for enhanced EDM performance. Surface and Coatings Technology.

9. Vundrajavarapu, et al. (2025). Performance evaluation of silver-coated brass tubular electrodes in micro-EDM drilling of Ti–6Al–4V using Taguchi and fuzzy logic.
10. Shrivastava A., & Dubey A. K.. (2019). Micro-EDM of Nimonic C-263 using brass electrodes. Journal of Materials Processing Technology.
11. Yilmaz, O., & Okka, M. A. (2010). Effect of single and multi-channel electrodes application on EDM fast hole drilling performance. The International Journal of Advanced Manufacturing Technology, 51(1), 185-194.
12. Bozdana, A. T., & Ulutas, T. (2016). The effectiveness of multichannel electrodes on drilling blind holes on Inconel 718 by EDM process. Materials and Manufacturing Processes, 31(4), 504-513.