IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 22, Issue 1 Ser. 1 (Jan. – Feb. 2025), PP 30-36
www.iosrjournals.org

Comparative Study Of Copper And Brass Tools In Micro-Hole Drilling Of SuperNi 276 Using EDD

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Abstract
SuperNi 276 is widely recognized for its outstanding corrosion resistance and high-temperature performance, making it an essential material in the aerospace and power generation sectors. However, fabricating precise micro-holes in this alloy presents challenges with conventional machining methods. This study investigates the application of Electro Discharge Drilling (EDD) to produce high-quality micro-holes in SuperNi 276. By varying input parameters such as pulse on time, pulse off time, and peak current—using tool diameters of 0.5 mm, 0.6 mm, 0.7 mm, and 0.8 mm while maintaining a constant voltage of 2V—key output parameters, including Tool Wear Rate (TWR) and Material Removal Rate (MRR), were evaluated. Copper tools in EDD achieved a higher maximum MRR of 0.115938 mm³/sec but exhibited significant wear with a TWR of up to 0.7391 mm/sec. In contrast, brass tools demonstrated minimal wear, with a TWR of just 0.0026 mm/sec, making them suitable for applications requiring extended tool life. Although the maximum MRR for brass tools was moderate at 0.065940 mm³/sec, they provided a balance between machining efficiency and tool longevity. Microhardness testing revealed that brass tools enhance the hardness of the recast layer while minimizing hardness in the heat-affected zone (HAZ) due to superior heat dissipation, leading to improved material integrity.

Keywords: *SuperNi 276, Electro Discharge Drilling (EDD), recast layer, heat-affected zone (HAZ), material removal rate (MRR), tool wear rate (TWR)*

Date of Submission: 22-01-2025 Date of Acceptance: 02-02-2025

I. Introduction

SuperNi 276 is a nickel-molybdenum-chromium superalloy known for its excellent corrosion resistance and high strength, even in extreme environments. These qualities make it ideal for demanding applications like turbine blades, chemical processing equipment, and other high-stress engineering components. Because it can withstand harsh conditions while remaining stable, it is widely used in aerospace, power generation, and environmental engineering.

Micro drilling is a specialized machining process used to create very small holes, ranging from micrometers to millimeters in size. This technique is essential in industries such as aerospace, electronics, and medical devices, where precision and miniaturization are crucial. Electrical Discharge Micro Drilling (EDD) is an advanced method that uses electrical sparks to erode conductive materials that are difficult to machine with traditional methods. The process generates localized heat through electrical discharges between the tool and the workpiece in a dielectric fluid, allowing for high precision and the creation of complex shapes. Drilling micro holes in SuperNi 276 using EDD requires careful adjustment of input parameters to achieve the best results in terms of tool wear rate, material removal rate, and machining time.

Numerous studies have aimed to refine EDD techniques for superalloys and composites. Jain et al. [1] optimized Pulse Electrochemical Jet Drilling (PEJD) on Incoloy 800, minimizing radial overcut and taper. Kumar et al. [2] introduced a self-flushing tool electrode for EDD on Ti6Al4V, enhancing depth and MRR. Lalit Kumar et al. [3] investigated Electrical Discharge Micro Drilling (EDMD) for ZM21 Mg alloy, creating porous architectures for tissue engineering applications. Mao et al. [4] explored assisted EDD and powder-mixed EDM for hard-to-machine materials, improving MRR and tool wear. Singh et al. [5] utilized a Taguchi L16 array to optimize micro-EDM, identifying capacitance as a critical performance factor. Machno et al. [6] studied EDD in Inconel 718, highlighting the importance of debris removal for maintaining quality. Vasudevan et al. [7] examined small-hole drilling in YSZ-coated superalloys, concluding that Abrasive Water Jet Machining (AWJM) best preserved material integrity. Additionally, Doan et al. [8] optimized EDD parameters to achieve significant MRR improvements, while Harane et al. [9] identified the impact of tool geometry on performance. Pant et al. [10] focused on EDM for microholes in Nimonic 80A, and Sawant et al. [11] determined that WCu electrodes delivered high MRR in μEDD. Kumar et al. [12] highlighted the role of peak currents in minimizing recast layers, and

Ansari et al. [13] enhanced EDD on magnesium nanocomposites using Taguchi and ANOVA methods.

Research indicates voltage has minimal impact on output parameters [14-21] like MRR, TWR, and machining time. Hence, in this work, voltage is kept constant while varying current, pulse on/off time, tool diameter, and tool material. An L16 orthogonal array, designed using the Taguchi method, is employed to minimize the number of experiments. TWR, MRR, and microhardness in the recast layer and HAZ is being analyzed.

II. Methodology

Material selection

SuperNi 276

SuperNi 276, supplied by MIDHANI Ltd., Hyderabad, is employed for steam turbine blade manufacturing in power generation. The primary elements and their weight percentages are listed in Table 1.

Table 1: Composition of SuperNi 276.

Major constituent element	Weight (%)
Nickel (Ni)	58.2
Chromium (Cr)	16.2
Molybdenum (Mo)	16.1
Tungsten (W)	3.1
Iron (Fe)	4.2

EDD machine and tool material

The EDD machining experiments are conducted at Sri Sai Vinayaka CNC Technologies (DK703C, Jiangsu, China), Balanagar, Hyderabad, using distilled water as the dielectric medium. Copper and brass tubular tools with diameters of 0.5mm, 0.6mm, 0.7mm, and 0.8mm are used for machining Super Ni 276. The machining process is performed as per ASTM B643 standards.

Control parameters

The control parameters for EDD experimentation include peak current (I), pulse on time (Ton), pulse off time (Toff), and tool diameter (D), while voltage is kept constant at 2V. These factors are pivotal in determining drilling performance and output quality. The selected parameter ranges are as follows: tool diameter (0.5 mm to 0.8 mm), pulse on time (10 µs to 40 µs), pulse off time (2 µs to 5 µs), and peak current (2 A to 5 A).

Estimation of output parameters

While machining, output parameters such as Material Removal Rate (MRR) and Tool Wear Rate (TWR) are measured. Post-machining, the recast layer and heat-affected zone (HAZ) form due to heat generation, leading to changes in microhardness and elemental composition. The thickness of these zones is examined using an Olympus BX53M microscope, while the changes in constituent elements are analyzed through Energy Dispersive X-ray Spectroscopy (EDS) using the ZEISS SmartEDX system (Sigma 300, Germany). To assess variations in hardness, the Vickers microhardness test (Mitutoyo HM-200, Japan) is conducted on the base material, the recast layer, and the HAZ. Furthermore, changes in the chemical composition of Super Ni 276 after EDD with copper and brass tools may affect the base material, introducing unwanted elements into the recast layer and HAZ, which could influence the material's mechanical properties. The photography of the equipment used in the present study is shown in fig 1.

Fig. 1. (a) EDD machine (b) Vickers hardness tester

III. Experimental Investigation

Estimation of MRR and TWR

To study the impact of control parameters on output parameters, 256 experiments would be required. To optimize this number, the four-factorial Taguchi method is applied. Consequently, an L16 orthogonal array is used in this work. The levels and values for Taguchi's L16 orthogonal array are presented in Table 2. MRR and TWR are estimated based on design

Evaluation of microhardness

Microhardness refers to the measurement of a material's hardness on a small scale, typically using minimal loads to create an indentation on the material's surface. After EDD, microhardness tests are conducted using Vickers micro hardness tester on the base material, recast layer zone, and HAZ to evaluate changes in hardness resulting from micro-drilling.

Table 2: Taguchi's L16 orthogonal array with values of levels

Experiment No.	Tool diameter (mm)	Pulse on time (μs)	Pulse off time (μs)	Current (A)
1	0.5	10	2	2
2	0.5	20	3	3
3	0.5	30	4	4
4	0.5	40	5	5
5	0.6	10	3	4
6	0.6	20	2	5
7	0.6	30	5	2
8	0.6	40	4	3
9	0.7	10	4	5
10	0.7	20	5	4
11	0.7	30	2	3
12	0.7	40	3	2
13	0.8	10	5	3
14	0.8	20	4	2
15	0.8	30	3	5
16	0.8	40	2	4

IV. Results And Discussions

MRR and TWR

Figure 2 shows the specimens after EDD with copper and brass tools. Analyzing the experimental data from Table 3, which details the process parameters for micro-hole machining using copper and brass tools on EDD, the focus is on maximizing MRR while minimizing TWR. The MRR and TWR are estimated using equations (1) and (2):

$$\text{TWR}= \frac{\text{Initial length of the tool-Final length of the tool}}{\text{Time taken for machining}} \quad (1)$$

$$\text{MRR}= \frac{\text{Volume of the material removed}}{\text{Time taken for machining}} \quad (2)$$

For the copper tool, the lowest recorded TWR is 0.0171 mm/sec in Experiment No. 1, while the maximum MRR is 0.115938 mm^3/sec in Experiment No. 16. On the other hand, the brass tool shows an even lower minimum TWR of 0.0026 mm/sec in Experiment No. 14, demonstrating its advantage in minimizing tool wear. The highest MRR for the brass tool is 0.065940 mm^3/sec, found in Experiment No. 11, which, while not as high as the maximum MRR for copper, is still considerable.

Considering these factors, the brass tool emerges as the better option for applications prioritizing tool longevity due to its significantly lower TWR. Although the copper tool achieves a higher maximum MRR, the brass tool maintains a good balance with a moderate MRR and minimal tool wear. Therefore, for applications that require both durability and efficient material removal, the brass tool is recommended due to its superior TWR performance while providing a sufficient MRR. The changes in MRR and TWR for copper and brass tools are shown in figure 3 and 4.

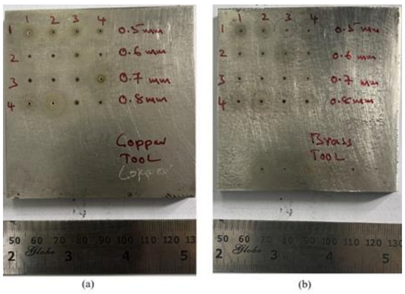

Fig. 2. Specimen after EDD with (a) copper tool and (b) brass tool.

Table 3: MRR and TWR of SuperNi 276 for copper and brass tools

Experiment No.	Copper tool		Brass tool	
	TWR (mm/sec)	MRR (mm3/sec)	TWR (mm/sec)	MRR (mm3/sec)
1	0.0171	0.002872	0.0478	0.005120
2	0.0562	0.006615	0.1386	0.011658
3	0.1132	0.007406	0.1548	0.014018
4	0.1333	0.008722	0.1940	0.017575
5	0.3438	0.052988	0.3529	0.049871
6	0.7391	0.073722	0.1111	0.015700
7	0.1585	0.020678	0.0303	0.006423
8	0.5000	0.070650	0.2692	0.032608
9	0.3333	0.054950	0.1558	0.029973
10	0.3333	0.059177	0.3415	0.056290
11	0.2750	0.057698	0.4286	0.065940
12	0.0359	0.010349	0.0680	0.015700
13	0.0750	0.025120	0.0625	0.018840
14	0.0367	0.010048	0.0026	0.007709
15	0.4516	0.097239	0.0870	0.032765
16	0.5000	0.115938	0.1078	0.029553

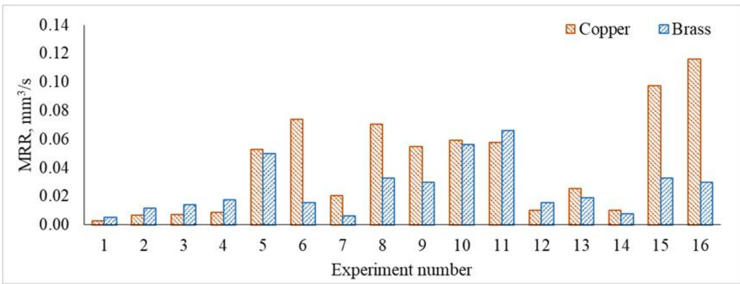

Figure 3: MRR Variation for Copper and Brass Tools

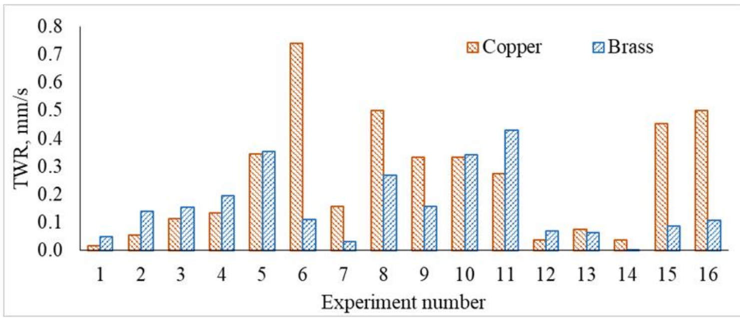

Figure 4: TWR Variation for Copper and Brass Tools

Analysis of microhardness

Microhardness testing of the base material, HAZ, and recast layer zone was performed using a Vickers microhardness tester. Table 4 summarizes the measured microhardness values for SuperNi 276, processed with a copper tool under varying control parameters during EDD.

Table 4: Microhardness at base material, HAZ, recast layer zone of copper tool and brass tool

Experiment No.	Copper tool			Brass tool		
	Base material	Recast layer zone	HAZ	Base material	Recast layer zone	HAZ
1	343.2	347.4	319.6	347.2	334.6	320.6
2	351.9	345.9	324.6	345.9	340.1	323.5
3	348.6	354.3	317.3	350.6	341.7	311.6
4	341.8	347.6	326.4	342.6	334.3	317.7
5	345.3	368.1	325.2	342.4	350.6	338.4
6	351.1	342.6	316.4	348.2	352.6	315.9
7	344.3	341.6	326.2	346.6	345.2	329.2
8	348.6	335.3	331.6	342.8	356.6	326.6
9	341.9	328.8	316.5	348.1	344.8	317.9
10	346.1	334.3	324.1	342.6	348.1	324.1
11	341.4	327.6	319.6	349.4	356.4	336.6
12	343.2	335.1	314.4	343.8	345.1	321.3
13	344.2	327.6	307.1	346.4	355.9	314.1
14	344.8	338.3	313.8	349.1	357.6	329.8
15	345.6	326.9	314.6	342.5	338.2	317.7
16	337.6	345.1	324.2	343.8	334.7	326.9

Base material

The microhardness of the base material remains relatively consistent across all experiments, regardless of the tool used. For the copper tool, values range between 337.6 HV and 351.9 HV, while for the brass tool, they lie between 342.4 HV and 349.4 HV. These stable values indicate that the base material experiences minimal thermal or mechanical alterations during the EDD process. The localized nature of EDD ensures that the heat and material removal are confined to the machined area, preserving the inherent hardness of the base material.

Recast layer zone

The recast layer exhibits the highest hardness among the tested zones, with values ranging from 327.6 HV to 368.1 HV for the copper tool and 334.3 HV to 357.6 HV for the brass tool. This increased hardness is primarily due to the rapid solidification of molten material during the EDD process. The thermal cycling and rapid quenching of this layer lead to the formation of a hard, brittle structure, often characterized by refined microstructures and potential alloying effects from the tool material. Notably, the brass tool typically results in slightly higher hardness in the recast layer compared to the copper tool. This is attributed to the higher thermal conductivity of brass, which facilitates faster heat dissipation, promoting a finer microstructure in the solidified layer.

Heat-Affected Zone (HAZ)

The microhardness in the HAZ is generally lower than in the recast layer and comparable to or slightly lower than the base material. For the copper tool, HAZ hardness values range from 307.1 HV to 331.6 HV, while for the brass tool, they fall between 314.1 HV and 336.6 HV. This decrease in hardness is due to thermal softening caused by prolonged exposure to elevated temperatures without material melting. The microstructure in the HAZ may undergo recovery or slight coarsening, leading to reduced hardness. However, the brass tool shows slightly higher hardness in HAZ compared to the copper tool, likely because its better heat dissipation minimizes the extent of thermal softening.

Across all zones, the brass tool generally results in higher hardness values compared to the copper tool, particularly in the recast layer and HAZ. This can be attributed to the superior thermal conductivity of brass, which allows for more effective heat management during EDD. As a result, the extent of thermal damage in the

HAZ is reduced, and the recast layer benefits from refined microstructural transformations. The variation of these findings is shown in figure 5. These findings emphasize the critical role of tool material in influencing the microhardness distribution across different zones.

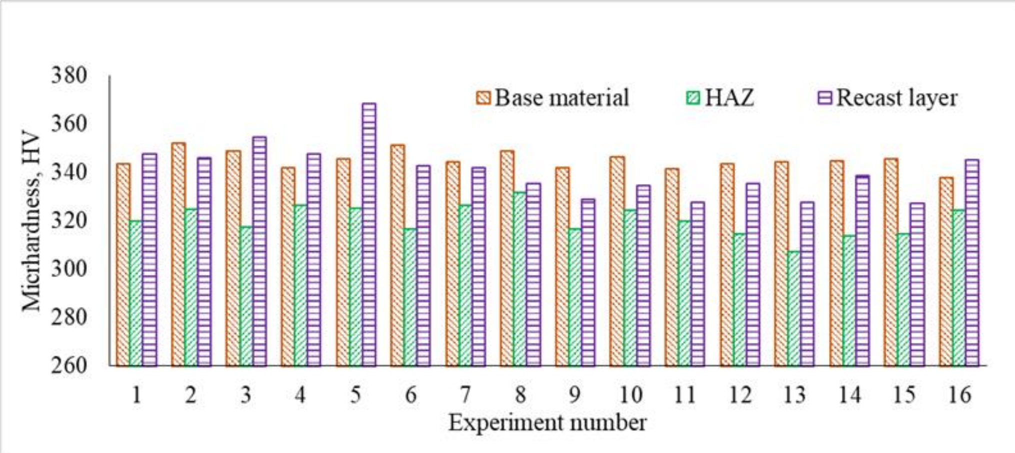

Figure 5: Variation of microhardness in various zones using copper tool

V. Conclusions

The experimental study on EDD of SuperNi 276 using copper and brass tools provides valuable insights into tool performance, MRR, and TWR. The findings indicate that while copper tools achieve a higher maximum MRR, they also experience greater tool wear. In contrast, brass tools excel in minimizing TWR, making them more suitable for applications requiring extended tool life. Although the highest MRR for brass tools is moderate, it offers a balance between machining efficiency and reduced wear. Experiment 1 (copper tool) and Experiment 15 (brass tool) are identified as optimal for minimizing thermal effects while preserving material functionality, reducing rework, and maintaining structural integrity. The study further emphasizes the significant influence of tool material on microhardness distribution, with brass tools enhancing recast layer hardness and reducing HAZ softening due to superior heat dissipation. Notably, brass tools, particularly with a tool diameter of 0.8 mm, pulse on time of 20 µs, pulse off time of 4 µs, and current of 2 A at a constant voltage of 2 V, deliver more consistent results with minimal deviation, ensuring material integrity. For applications requiring both efficient material removal and minimal tool wear, brass stands out as the preferred choice due to its optimal balance of moderate MRR and significantly lower TWR.

Acknowledgments: Not Applicable

Author contributions: All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Nakarkanti Saidulu, P. Lakshminarayana, K. Buschaiah. The first draft of the manuscript was written by Nakarkanti Saidulu and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Conflicts of interest or competing interests: The authors have no relevant financial or non-financial interests to disclose.

Data and code availability: Not Applicable

Supplementary information: Not Applicable

Ethical approval: The present work doesn't involve any human samples, tissues, and/or biological samples.

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