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Research paper

Examination of The Process Parameters for Machining Nimonic Alloy 75 on WEDM with A Cryogenically Treated Tool

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Abstract

This investigative analysis examines how various process variables affect Surface Roughness (Ra) and Kerf Width (KW) during the WEDM process. The experiments used Nimonic Alloy 75 sheets as the raw material and tested two types of tool electrodes: cryogenically treated (CT) brass wires and non-cryogenically treated (NCT) brass wires. The main control variables evaluated in this study included the type of tool electrode, wire feed rate (WF), wire tension (WT), Ton, and Toff. The thickness of the Nimonic Alloy 75 and the diameter of the wire (0.25 mm) were kept constant throughout the operation. The design of experimentation was taken based on the Taguchi L9 Orthogonal Array (OA), and ANOVA was utilized to evaluate Ra, KW, and the microstructures of the workpieces, which were examined under a Scanning Electron Microscope for both types of electrodes. The results indicated that the optimized values for Ra and KW of the machined parts were 4.78 µm and 0.276 mm, respectively, when using the cryogenically treated tool, as it yielded better results compared to the non-cryogenically treated tool.

***Keywords**: Cryogenically treated brass wire; Kerf width; Surface Roughness; Taguchi orthogonal array; WEDM.*

1. Introduction

WEDM is a material cutting technique that uses electrothermal processes to cut materials by rapidly melting and evaporating them with a wire electrode. In this process, electrical pulses generated by the wire create sparks between the workpiece and the tool. To cool, flush, and remove debris from the material being worked on, various dielectric fluids are utilized. Common choices for these fluids include transformer oil, paraffin oil, and deionized water. Different types of wires can serve as cutting tools, such as brass wires coated with copper or zinc, annealed brass tools, and abrasive-coated brass tools. Tool diameter typically ranges from 0.1 mm to 3 mm.

The behavior of Inconel 825 was studied by cutting it using a cryogenically treated tool and a normal tool, and it was concluded that a cryogenically treated tool is more advantageous and results in a greater MRR, less surface roughness, and less tool wear than a nontreated tool [1]. An Overcutting, taper angle, and circularity were investigated using micro EDM machining using a standard brass wire, a tin (Sn)-coated tool, and a cryogenically treated brass tool. According to the data, the coated tool outperforms the normally and cryogenically treated tools in terms of overcutting and circularity. Uncoated tools produce better outcomes in terms of the taper angle as compared to treated and regular tools [2]. Inconel 625 machined WEDM with both Zn-coated and cryogenically treated Zn-coated tools. The objective was to optimize the MRR and SR by considering variables like Ton, Toff, WF, WT, and current intensity. The experimentation followed the Taguchi L18 OA design, and ANOVA was utilized to optimize the MRR and SR. The final results indicated that the cryogenically treated zinc-coated tool performed better than the standard zinc-coated tool. By considering Ton, Toff, WF, and spark voltage as input variables [3]. The dimensional variation in M42 HSS on WEDM by machining cryogenically treated brass wires. Shallow cryogenically treated wires yield better results, such as dimensional deviation and enhanced electrical conductivity [4]. The outcome of deeply cryogenically treated tools for machining deep cryogenically treated Ti-6Al-4 V. They evaluated several parameters, including Ton, Toff, the flushing pressure, the WF, the WT, the peak current (IP), and the spark voltage. An L18 OA was utilized for the DOE, and the SR was measured. The outcomes indicated that the IP, Ton, and spark gap voltage significantly influence surface roughness [5]. Experiments were conducted on Nimonic 80A by WEDM. The machined raw material measuring 8 mm × 8 mm × 25 mm with a brass electrode that had a dia. of 0.25 mm. The experiment involved several selected process parameters: WT, Ton, Toff, WF, IP, and gap voltage. The final output showed that pulse durations were the most noteworthy affecting features on MRR. Additionally, the interactions among Ton and Toff, as well as between Ton and IP, contributed more to the Wire Wear Rate (WWR) [6]. The study compared the properties of cryogenically cooled molybdenum wire with those of nontreated molybdenum wire. They analyzed the microstructure, hardness, electrical conductivity, and wear resistance of both types of wire. The results of the investigation revealed that cooling molybdenum wire improved its electrical conductivity, hardness, and wear resistance [7]. Optimization of WEDM parameters to enhance the SR of cryogenically treated AISI D2 tool steel. M.M. Dhobe et al, the experimental work considered some inputs including Ton, Toff, IP, and spark voltage. The results indicated that Toff had the least influence compared with other variables. Owing to its enhanced surface finish, AISI D2 tool steel is suitable for manufacturing punches and dies used in sheet metal applications [8]. The input parameters considered for machining Inconel 825 by a cryogenically treated Cu tool in EDM were IP, Ton, and duty factor. The outcomes focused on surface morphology, white layer thickness, and microstructure. The results indicated that the cryogenically treated copper tool produced fewer defects than did the nontreated tool, resulting in the formation of a thinner white layer [9]. To evaluate MRR, electrode wear, and SR, experiments were conducted on M2 grade HSS. The controlling parameters chosen for the study included the discharge current, Ton, and gap voltage. The results indicated that both the electrode wear rate and the SR were lower when the cryogenically treated tool was used than when the untreated tool was used [10]. A cold-treated brass tool at -70°C for 24 hours was used for machining a high-strength low-alloy steel (HSLA). The input process parameters included the servo voltage, Toff, Ton, wire tension, and pressure of the deionized water. The primary process outcomes measured were the recast layer thickness and microhardness. Compared with the normal tool, the cold-treated tool led to a thinner recast layer and reduced wire material infusion [11]. The MRR is more in the case of a cryogenic-treated graphite tool when compared with a normal graphite tool when machined Inconel 718 on EDM with a normal graphite and cryogenic-treated graphite tool [12]. The GRA technique was used to evaluate MRR, SR, and kerf width of Nimonic alloy 236 by selecting process parameters, including Ton, Toff, wire feed, and gap voltage. ANOVA was employed to find the parameters that had the most significant influence on the outcomes. With 40 V gap voltage, 8 µs Ton, 16 µs Toff, and 4 m/min wire feed, they achieved 8.238 mm³/min MRR, 2.83 µm SR, and 0.343 mm KW [13]. Optimization of the MRR and surface finish for EN-24 steel using WEDM by focusing on three process variables: Ton, IP, and Toff. The findings revealed that IP had the greater impact on both MRR. The maximum MRR was achieved at an IP of 5A, with a Ton of 20 µsec and Toff of 15 µsec. In contrast, the best SR was obtained at an IP of 1A, with a Ton of 10 µsec and Toff of 5 µsec [14]. A Nimonic alloy 90 was machined by WEDM with Zn-coated brass wire to optimize the MRR and SR. The inputs considered included Ton, servo voltage, and wire tension. Through RSM optimization, they achieved a maximum MRR of 5.3574 mm³/min and minimum surface roughness at a wire tension of 11.962 N, a Ton of 79.785 µs, and a servo voltage of 100 V [15]. A Ti Grade 5-Ti-6Al-4V alloy machined with WEDM to optimize the MRR and SR by taking inputs such as current, Ton, and Toff. The outcomes were optimized using the Taguchi method. ANOVA was employed to assess the contribution of each variable to the outcomes. The optimal conditions for achieving the maximum. MRR and min. SR were determined to be a current of 3A, a Ton of 30 µs, and a Toff of 9 µs [16]. The machining of AISIP20 on WEDM to evaluate several performance metrics: MRR, SR, Tool Wear Rate (TWR), and Kerf width. The input variables examined included Ton, Toff, servo voltage, and IP. The experimentation utilized a Taguchi L27 orthogonal array design. The optimized values achieved were 2.71943 mm³/min for MRR, 3.27194 µm for SR, 0.0208325 kg for wire consumption, and 0.26932 mm for kerf width, at settings of 110 µs for Ton, 60 µs for Toff, 5.1869 V for servo voltage, and 11.00889 A for IP [17]. Analysis of dimensional errors in Al2024/Al2O3/W /W composite material during machining with WEDM by focusing on several input parameters, including wire feed, pulse duration, wire tension, and wire run-off speed. The study found that pulse interval and wire tension significantly influenced both linear and curvature errors. Additionally, pulse duration and wire feed had a considerable impact on vertex angle errors. The research revealed that untreated wire resulted in more voids and craters compared to cryogenically treated wire. A comparative analysis showed that cryogenically treated wire gave better results as compared to untreated wire [18]. By employing kerosene as the dielectric medium and a Cu tool to investigate the EDM of Inconel 625. In order to measure MRR, SR, and TWR as process outcomes, they used the parameters of Ton, Toff, and gap voltage as variables [19]. Anticipated and optimized parameters for NiTi form alloys' WEDM while taking into account input variables like wire feed, servo voltage, IP, Ton, and Toff. Overcut, SR, and vibration are the key Measurable responses. The experiment was conducted using a Taguchi L18 DOE. With the desired parameters being a peak current of 11.5 A, Ton of 125 µs, Toff of 58 µs, servo voltage of 55 V, and a wire feed of 2 mm/min, the ANFIS produced values of 0.113 kHz for vibration, 0.113 µm for surface finish, and 0.0526 µm for overcut [20].

The problem to be examined can be stated as follows in relation to the description given: In comparison to a standard brass tool, how does CT brass wire affect Nimonic alloy 75 when it is machined using WEDM?

2. Impact of Cryogenically Treated Wire on The WEDM Process Results

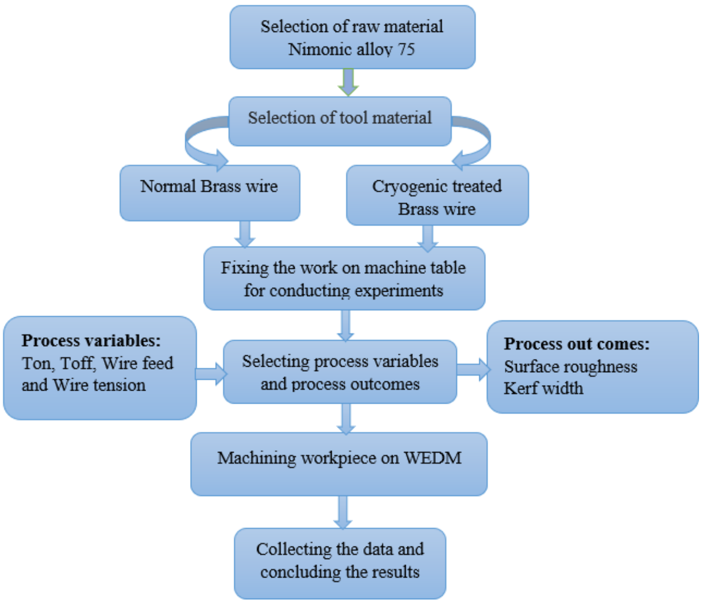


Fig. 1: Flow chart of experimentation

In this experimental study, both cryogenically treated brass tools and untreated brass tools were used for machining Nimonic Alloy 75 materials via WEDM. The diameter of the brass tool was 0.25 mm in both cases. Cryogenic treatment is a process that enhances various mechanical properties of brass wires. The Nimonic Alloy 75 samples were machined using both cryogenically treated and nontreated brass wires.

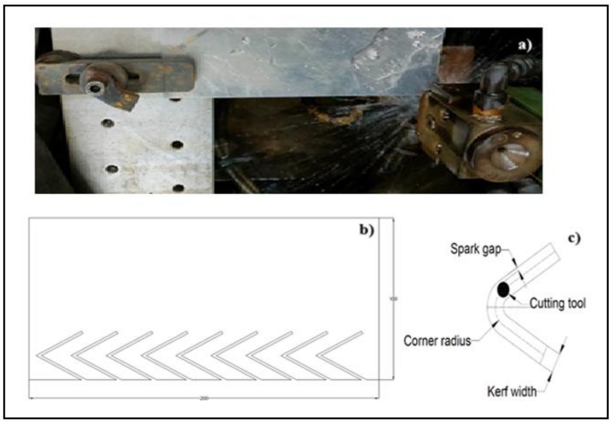


Fig. 2: a) Fixing of Nimonic alloy 75 material on Wire-cut EDM table before machining
b) Machined Nimonic alloy 75 sheet on Wire-cut EDM table after considering various process inputs
c) Detailed view of the slot, which shows kerf width after machining.

Nimonic alloy 75 samples were fixed on the machine table, and machining was conducted after selecting the input parameters for each experiment, as shown in Figure 2.

3. Video Profile Projector

A video profile projector is a precision optical measuring instrument that magnifies and projects a machined profile onto a computer screen. This tool allows for accurate measurement of the profile's dimensions and is commonly used to inspect manufactured components.

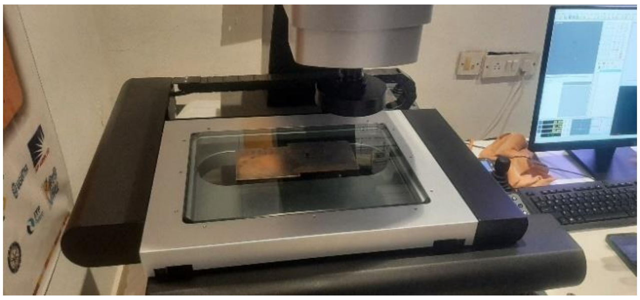


Fig. 3: Measuring kerf width of machined Nimonic alloy 75 sample by Video Profile Projector

The kerf width was inspected with the assistance of a video profile projector. The kerf width refers to the slot made by the cutting tool in the wire-cut EDM process. The machined workpiece was placed on the projector platform, and the kerf width for each slot was measured using the projector, as shown in fig. 3. This investigation revealed that the kerf width is greater when machined with nontreated brass wire than when machined with cryogenically treated wire.

4. Surface Tester

The SR of the components was checked by a Mitutoyo surface testing machine. The jobs were securely fixed in a vice, and the roughness values were evaluated for both cryogenically treated and non-cryogenically treated brass wires, as shown in Figure 4.

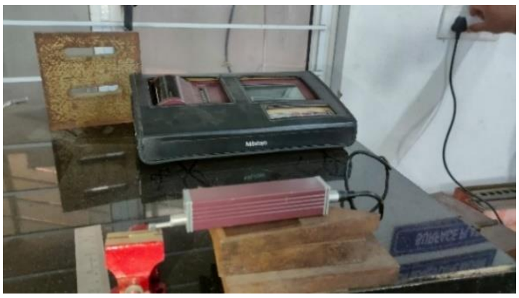


Fig. 4: Measuring Surface roughness of a machined sample of Nimonic alloy 75 by Mitutoyo surface tester

The experimental results demonstrated that the roughness values were lower for the samples machined with cryogenically treated wire. These reduced roughness values are considered for optimization purposes.
Controlling Factor Levels:

Table 1: List of Control Factor Levels

Input factors	Letter	Level 1	Level 2	Level 3
Ton (µs)	A	105	115	125
Toff (µs)	B	40	50	60
Wire Feed rate (mm/minute)	C	3	6	9
Wire Tension (N)	D	4	8	12

5. Results Obtained with The Nontreated and Treated Brass Tools

Table 2: Experimental results of surface roughness (SR), kerf width (KW), with and without cryogenic tools.

Experiment No.	Ton (µsec)	Toff (µsec)	WF (mm/min)	W (N)	With a non-cryogenically treated tool		With cryogenic treated tool	
					Ra (µm)	KW (mm)	Ra (µm)	KW (mm)
1	105	40	3	4	1.98	0.276	1.84	0.256
2	105	50	6	8	1.78	0.282	1.63	0.259
3	105	60	9	12	1.88	0.277	1.83	0.261
4	115	40	6	12	4.28	0.285	3.92	0.263
5	115	50	9	4	4.56	0.283	3.78	0.258
6	115	60	3	8	3.49	0.269	3.19	0.258
7	125	40	9	8	4.84	0.274	3.34	0.272
8	125	50	3	12	4.93	0.281	4.78	0.262
9	125	60	6	4	4.76	0.279	4.41	0.276

5.1 Comparison of The SRs of Cryogenically Treated and Untreated Wires Under Different Parameters

The roughness of the surface is affected by Ton. As the value of Ton increases, the SR also increases for both cryogenically treated and untreated wires. The off-time (Toff) also affects surface roughness. It was also noted that an initial increase in Toff leads to a slight improvement in SR; however, further increases in Toff ultimately result in a decrease in SR.

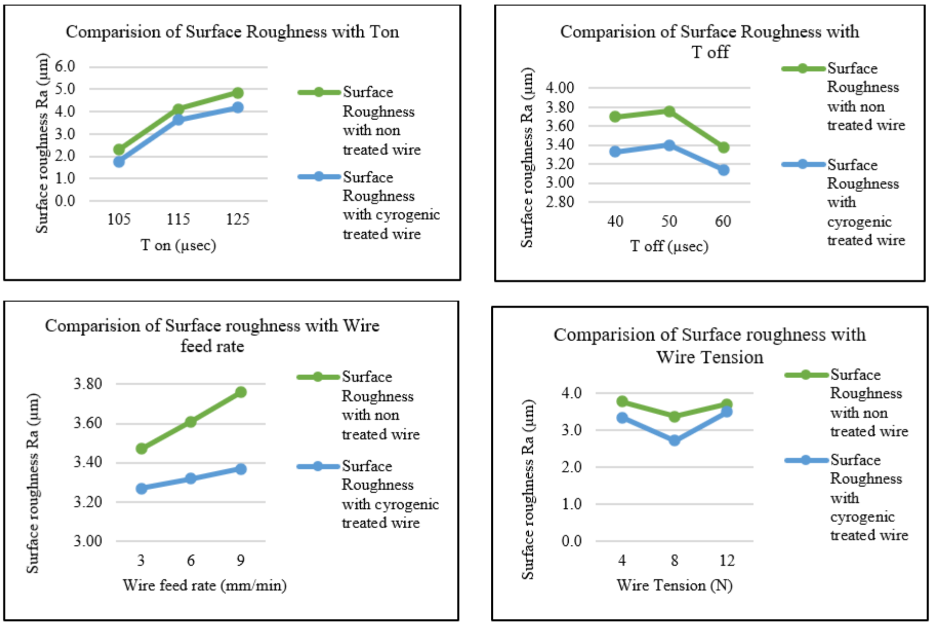


Fig. 5: Comparison of SR between cryogenically treated wire and untreated wire under different parameters

The SR increased with increasing wire feed rate for both cryogenically treated and untreated wires, as illustrated in the graph. Additionally, while the SR decreased with an initial increase in wire tension, it began to increase again with further increases in wire tension.

5.2 Comparison of Kerf Width between Cryogenically Treated and Untreated Wires Under Different Parameters

The kerf width increases with increasing Ton for both cryogenically treated and untreated wires, as shown in the graph. Additionally, the kerf width decreases with increasing pulse-off time; however, as Toff increases, the kerf width gradually increases.

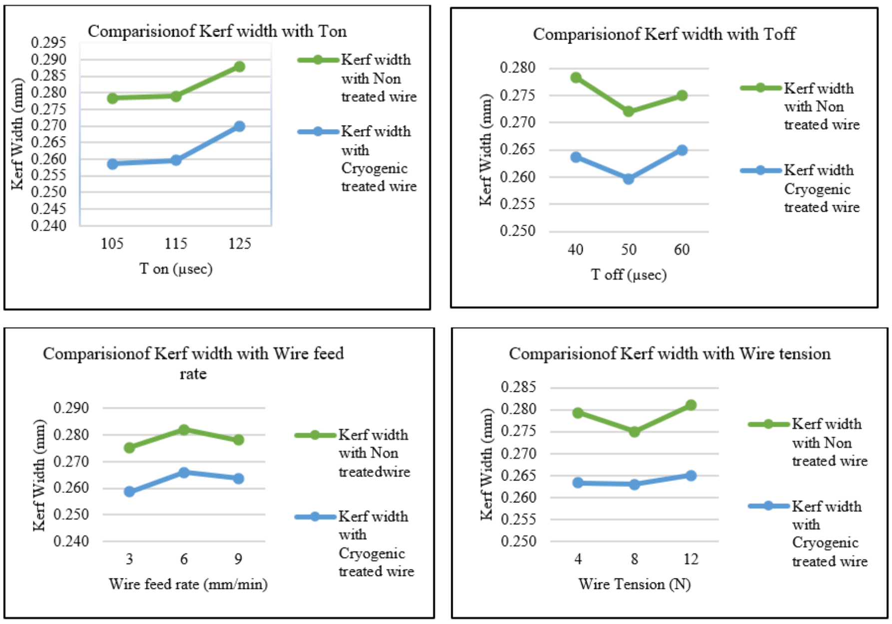


Fig. 6: Comparison of kerf width between cryogenically treated and untreated wires under different parameters

The WF influences the width of the kerf. For both types of wire, an increase in the WF results in a wider kerf. However, after reaching a certain point, further increases in the WF can lead to a slight reduction in the KW. Additionally, the kerf width has an impact on the wire tension. As the WT increases, the kerf width decreases, but with further increases in the WT, the kerf width slightly increases.

6. Results and Discussions

The experimental results indicate that the SR and KW are superior when cryogenically treated tools are used than when nontreated tools are used. Therefore, the outcomes achieved with the cryogenically treated tool were analyzed via ANOVA.

The experimental work, referred to as the design of experiments, was conducted on a sheet of Nimonic alloy 75 using both cryogenically treated and untreated brass wires. The study followed the L-9 OA Taguchi method. The outcomes evaluated included SR and kerf width while considering process variables such as Toff, Ton, WF, and WT to optimize the results.

a. Factors Influencing Surface Roughness

Table 3: Response Table for S/N Ratios- SR

Level	Ton	Toff	WF	WT
1	-4.93	-9.212	-9.654	-9.912
2	-11.164	-9.794	-9.666	-8.265
3	-12.317	-9.405	-9.091	-10.234
Delta	7.388	0.582	0.575	1.97
Rank	1	3	4	2

Table 4: ANOVA for SR

Source	DF	Adj SS	Adj MS	% Contribution
Ton	2	9.579	4.78948	86.88
Toff	2	0.2083	0.10414	1.89
WF	2	0.198	0.09901	1.8
WT	2	1.0404	0.52021	9.44
Total	8	11.0257		100

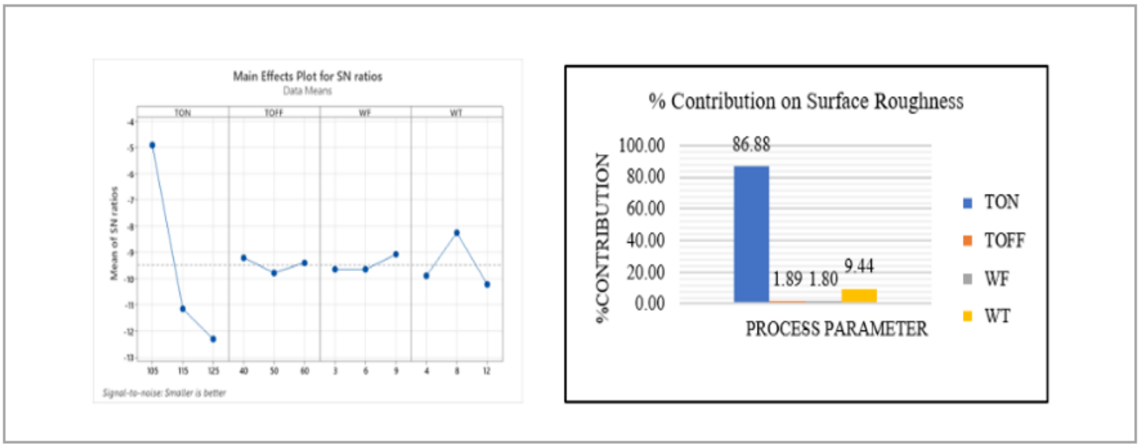


Fig. 7: S/N ratios of surface roughness on Nimonic Alloy 75 using a CT brass wire and the % contribution to surface roughness

From the graph showing the main effects of the SN ratios of the SRs, the combination A3B2C1D3 matches Taguchi's orthogonal array. This combination indicates that the optimized value of surface roughness is 4.78 µm.
Analysis shows Ton is the most influential factor (86.88%) affecting SR, while WF has the least influence.

b. Factors Influencing Kerf Width

Table 5: Response Table for S/N Ratios- KW

Level	Ton	Toff	WF	WT
1	11.75	11.58	11.75	11.59
2	11.71	11.71	11.51	11.6
3	11.37	11.54	11.58	11.63
Delta	0.37	0.17	0.24	0.04
Rank	1	3	2	4

Table 6: ANOVA for KW

Source	DF	Adj SS	Adj MS	% Contribution
Ton	2	0.000236	0.000118	63.78
Toff	2	0.000046	0.000023	12.43
WF	2	0.000084	0.000042	22.7
WT	2	0.000004	0.000001	1.08
Total	8	0.00037		100

According to the graph displaying the effects of the S/N ratios of kerf width, the combination A3B3C2D1 corresponds to Taguchi's orthogonal array. From this combination, the optimized value of the kerf width is 0.276 mm.

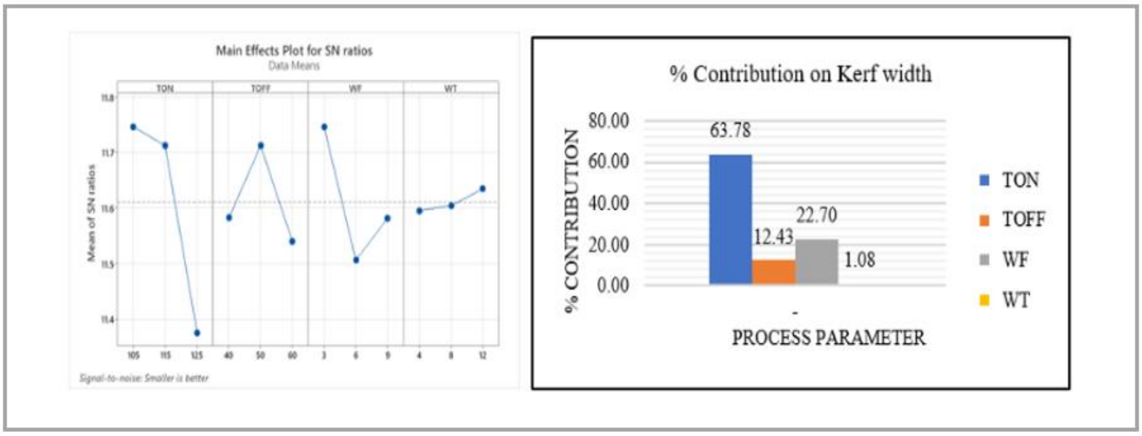


Fig. 8: S/N ratios of Kerf width on Nimonic Alloy 75 by the cryogenically treated brass tool and percentage contribution.

The graph indicates that the most influential parameter is Ton, accounting for 63.78% of the variance, followed by the wire feed rate. In comparison, Toff and wire tension have a lesser impact, with wire tension having the least influence on kerf width.
The microstructures of machined components made of Nimonic alloy 75 display debris and micro-holes, as illustrated in Figure 9.

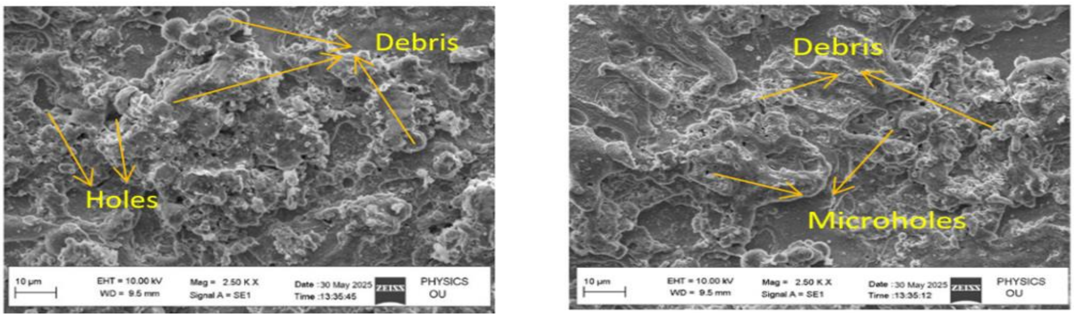
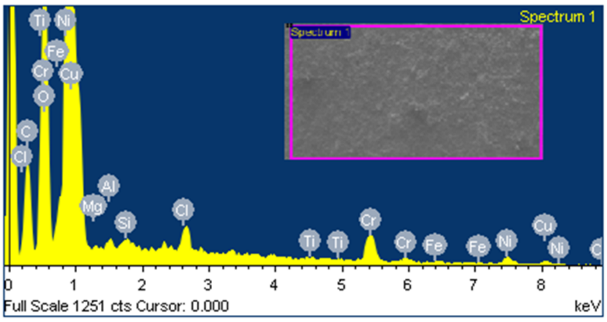


Fig. 9: Microstructure of Nimonic alloy 75 with non-treated and cryogenically treated brass wires

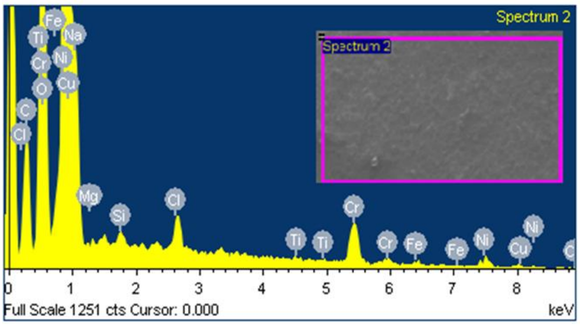
The Energy Dispersive Spectroscopy (EDS) results for machined sample number 4 are shown below, detailing various elements and their respective weight percentages before and after machining, as depicted in Figure 10.



Element	Before weight %	After Weight %	Difference %
Ti K	0.25	1.44	1.19
Ni L	73.36	28.42	-44.94
Cu L	0.5	14.33	13.83
Mn K	1	0.24	-0.76
C K	0.08	7.49	7.41
O K	0	15.28	15.28
Si K	1.06	0.56	-0.5
Ti K	0.31	1.58	1.27
Cr L	17.44	27.15	9.71
Fe L	6	3.51	-2.49
Total	100	100	0

Fig. 10: EDS Result of sample No.4

Similarly, the EDS results for machined sample number 6 are presented below, with various elements and weight percentages before and after machining illustrated in Figure 11.



Element	Before weight %	After Weight %	Difference %
Ti K	0.22	0.63	0.41
Ni L	74.04	39.42	-34.62
Cu L	0.71	10.76	10.05
Mn K	1	0.55	-0.45
C K	0.08	7.63	7.55
O K	0	12.51	12.51
Si K	1.05	0.62	-0.43
Ti K	0.2	0.31	0.11
Cr L	17.7	23.15	5.45
Fe L	5	4.42	-0.58
Total	100	100	0

Fig. 11: EDS Result of sample No.6

From the data in both graphs, we concluded that the amount of nickel (Ni) was reduced due to continuous flushing during the machining process. Additionally, there was an observed increase in copper (Cu) content, likely resulting from the heat-induced transfer from the brass wire during machining. The percentage of chromium (Cr) also increased significantly, attributed to inadequate flushing during the machining operation.

Cryogenic treatment enhances the metallurgical properties of brass, such as grain refinement and stress relief, and improves mechanical properties, including hardness, electrical conductivity, and wear resistance. When brass is cryogenically treated, its wear resistance is greatly enhanced due to the hardness increase and microstructure refinement. After the cryogenic process, the brass wire's microstructure is refined, and it is noted that the alpha grains are evenly distributed throughout the beta-phase matrix. Compared to regular brass wire, treated brass can produce a superior surface polish, which can be very helpful for machining operations on WEDM.

From the experimental investigation, the optimized parameters resulted in an increased MRR and improved surface finish. The CT of brass wire reduces defects such as micro-holes and micro-cracks on the machined samples. Greater dimensional accuracy can be attained, allowing high-precision components to be machined and reducing the need for reworking. As a result, this process is more economical for manufacturing industries.

6.1 Future Scope

Using the cryogenic technique, various work materials and tools may be treated, and other output responses, including MRR, tool wear rate, and cutting speed, can be determined. Based on the requirement, different cryogenic treatments, such as shallow and deep cryogenic techniques, can be adopted by following different cryogenic timings on various materials.

7. Conclusion

1. The SR value is predominantly influenced by the on-time (Ton). The roughness is greater for work samples machined with nontreated brass wires than for those machined with cryogenically treated brass wires. Additionally, the overall surface roughness value decreases as the off-time (Toff) value increases for both types of wire.
2. Both kerf widths were significantly affected by Ton. As the Ton value increases, both kerf widths increase as well. These measurements are greater when nontreated wires are used than when cryogenically treated wires are used.
3. The investigation revealed that better results are achieved with cryogenically treated wires than with nontreated wires in terms of optimizing SR and KW.
4. From the experimental study, the optimized surface roughness value obtained after machining with a cryogenically treated brass wire on Nimonic alloy 75 was 4.78 µm, which was achieved at a Ton of 125 µsec, a Toff of 50 µs, a WF of 3 mm/minute, and a WT of 12 N.
5. The optimized kerf width is 0.276 mm after machining with a cryogenically treated brass wire on Nimonic alloy 75, which is obtained at a Ton of 125 µsec, a Toff of 60 µsec, a WF of 6 mm/minute, and a WT of 4 N.
6. Microstructures of machined components of Nimonic alloy 75 show that debris and micro holes are smaller when using CT brass wire compared to NCT brass wire.

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