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Multi – Objective Optimization of Wire Electric Discharge Machining Parameters of Plastic Mould Steel - P20+Ni

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ABSTRACT
This study aims to optimize Wire Electrical Discharge Machining (WEDM) parameters for machining P20+Ni plastic mold steel. It examines surface roughness, machining time, and taper angle in relation to pulse on/off time, dielectric pressure, pulse current, wire feed rate, tension, servo voltage, and servo feed rate. Using an Electronica Jobmaster D-Lite machine and Taguchi's L18 orthogonal array, eighteen experimental runs were conducted. Analysis involved signal-to-noise ratio, variance analysis, and Grey Relational Analysis through MINITAB-18. Optimal settings were determined as IP = 2 A, Ton = 20 µs, Toff = 57 µs, WP = 12 Kg/cm2, WF = 2 m/min, WT = 8 Kgf, SV = 18 V, SF = 100 mm/min, confirmed by validation run. This study enhances precision machining, benefiting the manufacturing industry by improving surface modification processes for intricate geometries and high-performance materials. It explores the interplay of electrical and non-electrical factors in WEDM performance and aims to optimize processes through modeling and empirical investigation, contributing to significant enhancements in manufacturing practices in industrial settings.
Keywords - surface roughness, taper angle, machining time, mould steel, wire electrical discharge machining (WEDM), Taguchi optimization method, grey relational analysis.

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I. Introduction

In today's rapidly evolving landscape of technology, design, and manufacturing, the quest for precision and flawlessness in products, services, designs, and technologies is crucial [2]. Manufacturers worldwide are striving to enhance quality, even for intricate geometries, without inflating costs. The current needs of manufacturing industries encompass improved finishing, reduced tolerance, increased production rates, miniaturization, and other critical aspects [6]. The contemporary technological industry has witnessed a growing demand for alloy materials exhibiting superior hardness, high strength, toughness, and impact resistance across diverse fields. Non-conventional machining techniques have emerged to address challenges associated with cutting extremely hard materials to precise dimensions while minimizing material wastage and reducing tool-to-workpiece contact pressures. Among these techniques, Electrical Discharge Machining (EDM) and Wire Electrical Discharge Machining (WEDM) have emerged as highly effective, especially for tough materials. WEDM, characterized by its straightforward control and ability to create intricate designs, has become the preferred choice, revolutionizing various industries including die manufacturing, automotive, tool making, marine, defence, and metalworking.

Wire Electrical Discharge Machining (WEDM) stands out as a cost-effective and advanced machining technology designed to yield superior-grade parts with high quality. It as an electro-thermal technique that leverages heat to remove material. Also known as spark machining [11] or electro-erosion machining [10], it employs high-frequency pulsed direct current (DC) or alternating current (AC) electrical discharges generate sparks, creating plasma channels at extremely high temperatures (8,000 to 10,000 °C) [14], leading to partial or complete evaporation of the workpiece, tool electrode, and dielectric fluid at the discharge site. The maintenance of the sparking gap, the minimum space between the electrode and workpiece, is crucial. The controlled electric spark erosion leads to remove of metal, yielding precise shapes from hard-to-cut materials. The WEDM apparatus encompasses a power supply, dielectric system, wire drive system, and positioning system which utilizes CNC movements to achieve desired profiles or shapes. The increasing use of plastic components in various industries such as automobile, aerospace, and home appliances has bolstered the demand for steel for the manufacture of dies and molds of these components. Steel, notably P20 and P20+Ni mold steel, is favoured for its excellent machinability, polish, wear and corrosion resistance, texturing, and tensile strength. The addition of 1% nickel enhances the properties of P20+Ni, making it suitable for plastic molds, forging dies and a range of applications.

The focus of this study lies on the surface modification of P20+Ni steel through WEDM. The performance of this method hinges on electrical factors such as current, voltage, polarity, on-time, and off-time, alongside non-electrical characteristics like workpiece and tool material, wire tension, wire feed rate, and dielectric fluid pressure. Various metrics, including Metal Removal Rate, Surface Roughness, Kerf Width, Kerf Taper, and Electrode Wear Rate, are significantly influenced by these factors. Achieving peak performance proves challenging due to process complexity and myriad factors. Identifying the relationship between controllable input variables and performance metrics through modelling and optimization techniques presents a viable solution to potential issues arising from incorrectly chosen parameters, thereby ensuring optimal production outcomes.

II. Literature Survey

The literature survey encompasses various studies on Wire Electrical Discharge Machining (WEDM) parameters and performance across different materials such as aluminium (Al), mild steel (MS), etc. Researchers have explored parameters such as fine pulse (IP), pulse on time (TON), pulse off time (TOFF), dielectric pressure (WP), wire feed rate (WF), wire tension (WT), servo voltage (SV), servo feed rate (SF), corner servo (CS), duty factor (DF) and spark gap voltage (SGV) to optimize outcomes like surface roughness (SR), material removal rate (MRR), fatigue life (FL), spark gap width (SGW), wire consumption (WC), machining time (MT), kerf width (KW), electrode wear ratio (EWR), micro-hardness (MH), cutting rate (CR) and dimensional shift (DS) (Table 1). Findings indicate that optimal parameter settings vary depending on the material being machined. Studies also highlight the importance of methodologies like design of Experiments (DOE), Taguchi analysis (TA), analysis of variance (ANOVA), response surface methodology (RSM), and desirability approach (DA), grey relational analysis (GRA) for parameter optimization. Moreover, techniques such as artificial neural networks (ANN), decision tree (DT), genetic algorithm with hybrid functions (GAHF) and AHP-TOPSIS methods contribute to precise parameter selection and performance enhancement. Overall, the literature underscores the complexity of WEDM processes and the significance of tailoring parameters to specific material properties, offering valuable insights for optimizing machining processes across diverse industrial applications.

Table 1: Details of literature

Material	Input parameter	Output parameter	Methodology	Significant parameters	References
Al, MS	TON, TOFF, WF	SR, KW	DOE, TA, ANOVA	Al - TON for longitudinal SR, TOFF for transverse SR, WF for KW MS - IP for longitudinal and transverse SR, TON for KW	[1]
]HARDOX-400 & HARDOX-500	TON, TOFF, IP, WF	MRR	DOE, TA, ANOVA	MRR increases with increase in TON and decrease in TOFF	[2]
Al 2014-T6 alloy	TON, TOFF, IP, WF, WP, WT, SV, SF	SR, MRR	DOE, ANOVA, GAHF	SR - IP, TON MRR - IP, TON, SF	[3]
High carbon high chromium steel	TON, TOFF, IP, WT	SR	DOE, TA, ANOVA	SR – TOFF, followed by WT	[4]
Ti-6Al-4V alloy	TON, TOFF, IP, SV	SR, MRR	AHP-TOPSIS	Optimum parameter setting IP - 20, TON - 105, TOFF – 95, SV - 50	[5]
AISI H11 tool steel	TON, TOFF, WF	SR, MRR, FL	DOE, TA, ANOVA, GRA	TON for SR, MRR, FL	[6]
Inconel-825	TON, TOFF, CS, WF, WP, WT, SV, SF	SR, MRR , SGW	DOE, TA, fuzzy- GRA, ANOVA	TON, followed by CS	[7]
Maraging steel 300	TON, TOFF, IP, WT, SV	SR, WC	DOE, ANOVA	TON, SV, TOFF are the significant parameters. SR can be further reduced by using silver coated brass wire than normal brass wire	[8]
Stainless steel (SS 304 grade)	TON, TOFF, IP	SR, KW	DOE, ANOVA, GRA	TON, followed by IP, TOFF	[9]
Al 6082 T6 alloy	TON, TOFF, IP	MT	DOE, TA	The order of significance of the parameters are IP, TOFF, and TON. Optimized settings for minimum MT are TON - 34ms, TOFF - 6ms, IP – 2.5A	[10]
Al 2024 Alloy	TON, DF, IP, SGV	SR, MRR, EWR	DOE, TA, GRA	Optimized settings are TON - 12µs, DF - 33%, IP -14A, SGV – 80V	[11]
AISI 316L stainless steel	TON, TOFF, IP, SGV, WF	SR, KW	DOE, TA, GRA	WF, TON, IP	[12]
A572-grade 50	TON, TOFF, IP	SR, MH	DOE, TA,	TOFF, followed by TON, IP	[13]

HSLA steel			ANOVA, GRA		
Titanium alloy (Ti–6Al–4V)	TON, TOFF, IP, WF, WP, WT, SV, SGV	CR, SR,	DOE, ANOVA, ANN, DT	SR – TON CR - SV, TOFF	[14]
Nicrofer 5716	TON, TOFF, SV	SR, MRR	DOE, ANOVA, RSM	TON	[15]
Al 6063/ ZrSiO4(p)	TON, TOFF, IP, SV	CR	DOE, ANOVA, RSM	CR increases with increase in TON, IP and decrease in TOFF, SV	[16]
Porous nickel–titanium (Ni40Ti60) alloy	TON, TOFF, IP, SV	CR, DS, SR	DOE, ANOVA, DA	The order of significance of the parameters are, for SR – TON, SV, IP, for CR – TON, SV, IP, for DS – TON, TOFF, IP	[17]
Nitinol, TiNi (Ti50Ni50)	TON, TOFF, WF, SV	SR, MRR	DOE, TA, ANOVA	WF followed by TON, TOFF, SV	[18]
Al-Cu-TiC-Si P/M composite	WP, WT, DF, IP, V	SR, MRR	DOE, TA, ANOVA	DF	[19]
Inconel 718	TON, TOFF, IP, WF, WT, SV	SR, CR	DOE, ANOVA, RSM	The order of significance of the parameters are, for SR – TON, SV for CR – TON, SV, TOFF	[20]

III. Material and Method

A total of eight input parameters and three output parameters were finalized to study the impact of WEDM on P20+Ni steel material. Table 2 lists the input parameters and their levels. These characteristics and levels were chosen based on literature, machine capabilities, and operator experience. Using an orthogonal array for experimental design and statistical analysis is an efficient way to examine the impact of various factors on a process. The Taguchi Design of Experiments (DOE) method was chosen to optimise process parameters because of it is flexible and adaptive approach. Given the presence of seven 3-level parameters and one 2-level parameter (factors), an L18 orthogonal array was chosen to conduct experiments to investigate the impact of WEDM on the machining of P20+Ni material.

Table 2: Process parameters and their levels

Sr. No.	Parameter Name	Symbol	Range	Levels		
				1	2	3
1	Fine pulse (current)	IP	0-2	1	2	-
2	Pulse on time	TON	0-31	12	16	20
3	Pulse off time	TOFF	0-63	50	57	63
4	Dielectric pressure	WP	0-15	10	12	14
5	Wire feed rate	WF	0-15	2	3	4
6	Wire tension	WT	0-15	8	10	12
7	Servo voltage	SV	0-99	18	19	20
8	Servo feed rate	SF	0-999	75	100	125

18 blocks of P20+Ni material, specified as EN ISO4957, Grade 40CrMnNiMo8-6-4, DIN - 1.2738, were machined to the dimensions of 48mm x 49mm x 64mm using milling and surface grinding for the experiments. Eighteen trials were conducted following the order and factor levels specified in Table 4. The machining was carried out with the Electronica Job Master D-Lite (Electronica Hi-tech Machine Tools Pvt. Ltd.). It is a flush-type WEDM machine and includes several key components, such as the wire electrode, worktable, servo control system, power supply system, and dielectric supply system. Deionised water, serving as the dielectric medium, continuously flows through the gaps along the wire, effectively clearing debris caused by erosion. A collection receptacle at the bottom captures and disposes of the debris and eroded wire. The machine uses semi-automatic wire threading technique to continuously feed brass wire of 0.25 mm diameter. Bolts firmly secured the work material to the worktable, eliminating any potential movement between the work material and the wire (Figure 1). A dial calliper was utilized to verify the perpendicularity of the block surface to the table surface when setting the block on the table to assure the precision of the taper angle.

Table 3 : Chemical composition of the workpiece (P20+Ni steel)

ELEMENT	C	Mn	P	S	Si	Cr	Ni	Mo
CONTENT (%)	0.363	1.388	0.0208	0.0038	0.235	1.04	0.909	0.195

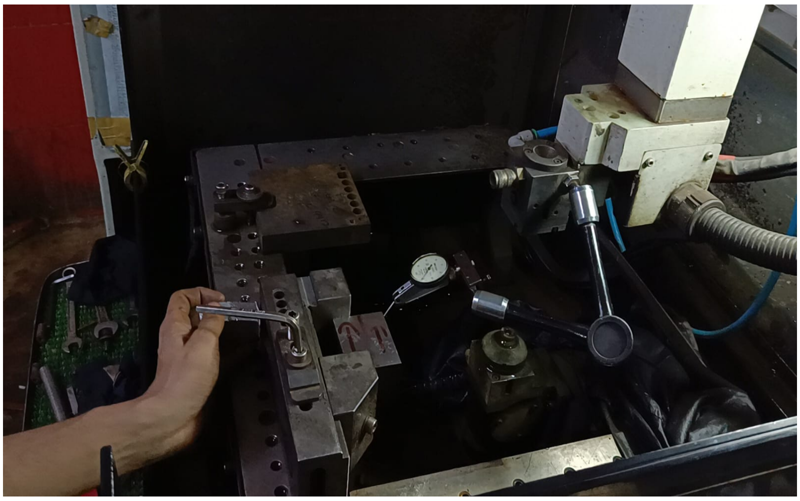

Figure 1: Setup of work piece on WEDM machine.

The surface roughness of the machined samples was measured using a portable Mitutoyo surface roughness tester, model SJ 210. The device was calibrated before measuring the surface roughness of the workpiece. Ra values were recorded at three different surface locations, and the average of these values (Ra) is presented in Table 4. The measurement settings, which were consistent across all measurements, included a speed of 0.25 mm/s, a sampling length of 5, a cut-off wavelength of 0.25 m, and a short wavelength of 2.5 m. The taper angle, representing the variance between the machined feature's upper and lower surfaces, was calculated using the difference in width at the top and bottom of the block divided by its height (Figure 2b). This angle was measured at three distinct planes on the workpiece, as illustrated in Figure 2(a), with subsequent calculations performed to determine the angle. The machining time, defined as the time required to machine the workpiece, was measured in minutes using a stopwatch. Average values of the measured surface roughness, taper angle, and machining time observed during each experimental run are presented in Table 4.

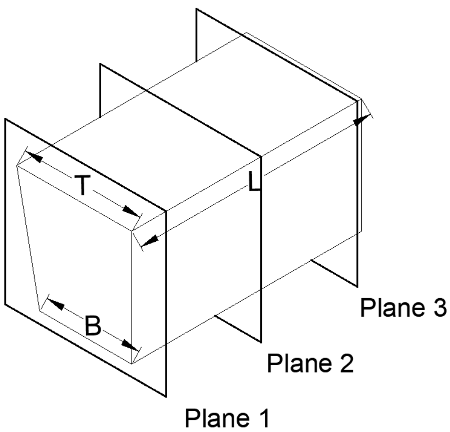

Figure 2(a): Planes for taper angle measurement

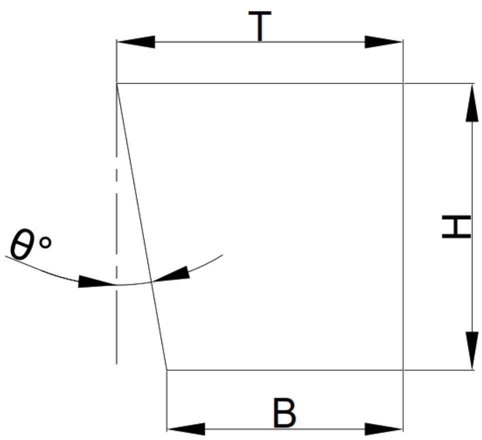

Figure 2(b): Parameters for taper angle calculation

Table 4: Design of Experimentation with L18 orthogonal array and experimental results

Exp. No.	IP	T_{ON}	T_{OFF}	WP	WF	WT	SV	SF	Average R_a	Average Taper angle	Machining Time (mins)
1	1	12	50	10	2	8	18	75	1.429	0.104	150
2	1	12	57	12	3	10	19	100	1.337	0.035	223
3	1	12	63	14	4	12	20	125	1.352	0.435	264
4	1	16	50	10	3	10	20	125	1.640	0.18467	103
5	1	16	57	12	4	12	18	75	1.675	0.05767	151
6	1	16	63	14	2	8	19	100	1.297	0.046	175
7	1	20	50	12	2	12	19	125	2.656	0.023	82
8	1	20	57	14	3	8	20	75	2.013	0.004	104
9	1	20	63	10	4	10	18	100	1.874	0.06167	131
10	2	12	50	14	4	10	19	75	1.565	0.13867	100
11	2	12	57	10	2	12	20	100	1.360	0.08467	143
12	2	12	63	12	3	8	18	125	1.310	0.012	215
13	2	16	50	12	4	8	20	100	2.161	0.03867	66
14	2	16	57	14	2	10	18	125	0.842	0.031	155
15	2	16	63	10	3	12	19	75	1.318	0.20367	225
16	2	20	50	14	3	12	18	100	2.121	0.18467	53
17	2	20	57	10	4	8	19	125	2.045	0.181	77
18	2	20	63	12	2	10	20	75	1.601	0.069	130

IV. Impact on Surface Roughness

The experimental outcomes were analysed statistically through MINITAB 19 to assess the impact of WEDM process parameters on machining P20+Ni workpieces. Aiming for reductions in surface roughness, taper angle, and machining time, the smaller-the-better (S/N) ratio characteristic was adopted for the analysis. Figure 3, the main effects plot, illustrates how each parameter affects surface roughness. It reveals that surface roughness diminishes with an increase in fine pulse and pulse off time, but escalates with a rise in pulse on time, wire feed rate, and servo voltage. Initially, increase in dielectric pressure and servo feed rate levels increases surface roughness; however, further increments lead to its reduction. Conversely, increasing wire tension initially reduces surface roughness, but subsequent increases result in greater roughness. ANOVA analysis (Table 5) of the partial factorial experiment data highlighted that pulse on time (44.31%) and pulse off time (21.44%) exert significant influences on surface roughness, whereas servo feed rate (1.24%) impacts it minimally. Table 8 presents the optimal parameter levels to minimize surface roughness.

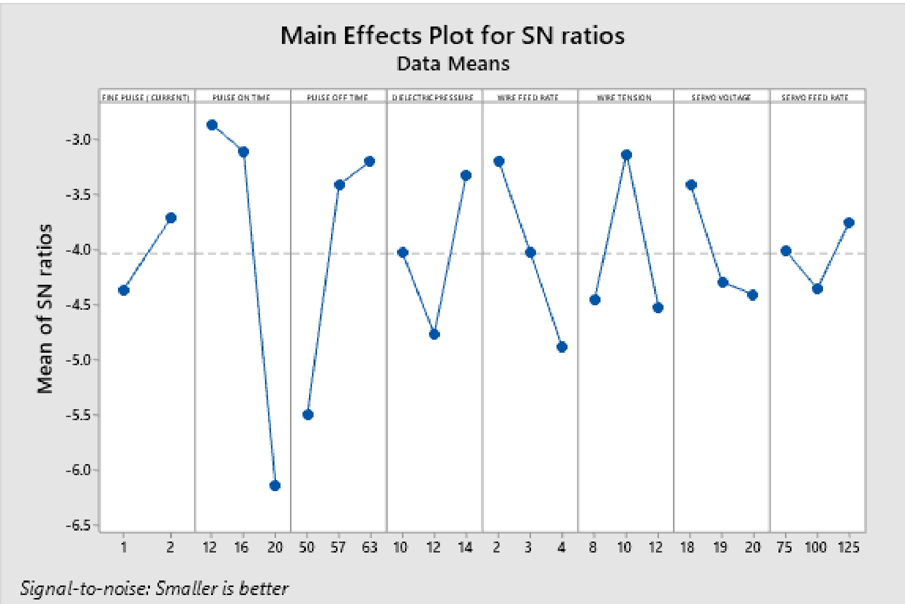

Figure 3: S/N ratio graph of surface roughness

Table 5: ANOVA for S/N ratio – surface roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% contribution
IP	1	1.973	1.973	1.9731	2.24	0.273	2.18
TON	2	40.133	40.133	20.0665	22.83	0.042	44.31

TOFF	2	19.423	19.423	9.7116	11.05	0.083	21.44
WP	2	6.338	6.338	3.169	3.61	0.217	7.00
WF	2	8.75	8.75	4.3751	4.98	0.167	9.66
WT	2	7.456	7.456	3.728	4.24	0.191	8.23
SV	2	3.625	3.625	1.8126	2.06	0.327	4.00
SF	2	1.121	1.121	0.5604	0.64	0.611	1.24
Residual Error	2	1.758	1.758	0.879			
Total	17	90.577					

V. Impact on Taper Angle

The main effects plot, as shown in Figure 4, shows how each parameter affects the taper angle. The taper angle increases with higher fine pulse, wire tension, and servo feed rate, but decreases with longer pulse on time. Initially enhancing the servo voltage prompts an increase, but additional improvements lead to a decrease in the taper angle. An initial rise in wire feed rate, dielectric pressure, and pulse off times leads to a decrease in the taper angle. Subsequent increases in these parameters cause the taper angle to increase. The ANOVA analysis in Table 6 shows that dielectric pressure(23.107%) and wire tension and (19.036%) have a significant impact on taper angle values influence, respectively, whereas servo feed rate does not have a noticeable effect. Table 8 outlines the ideal levels for different parameters to reduce the taper angle.

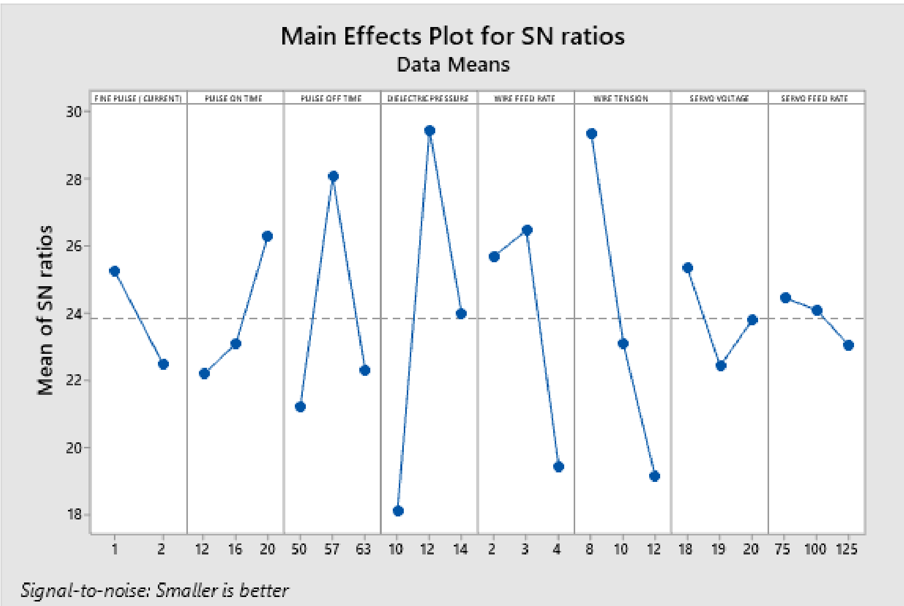

Figure 4: S/N ratio graph of taper angle

Table 6: ANOVA for S/N ratio – taper angle

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% contribution
IP	1	35.05	35.052	35.052	0.14	0.744	2.106
T ON	2	55.86	55.863	27.932	0.11	0.899	3.356
T OFF	2	163.20	163.197	81.598	0.33	0.753	9.806
WP	2	384.56	384.556	192.278	0.77	0.564	23.107
WF	2	178.39	178.390	89.195	0.36	0.736	10.719
WT	2	316.80	316.804	158.402	0.64	0.611	19.036
SV	2	25.37	25.372	12.686	0.05	0.952	1.524
SF	2	6.50	6.502	3.251	0.01	0.987	0.390
Residual Error	2	498.46	498.457	249.229			

Total	17	1664.19					

VI. Impact on Machining Time

The main effect plot (Figure 5) illustrates the impact of each parameter on the duration of machining. It shows that the machining time decreases when the fine pulse, pulse on time, dielectric pressure, and wire feed rate increase. Extending the pulse off time will result in a longer machining time. Initially, raising the servo feed rate reduces machining time, but future increases in the feed rate lead to longer machining times. The analysis of variance (Table 7) shows that pulse off time (48.47%) and pulse on time (36.06%) significantly impact machining time values. Dielectric pressure and servo voltage have minimal effects on machining time, accounting for only 0.2% and 0.63% respectively. Table 8 displays the optimal levels of different factors to reduce machining time.

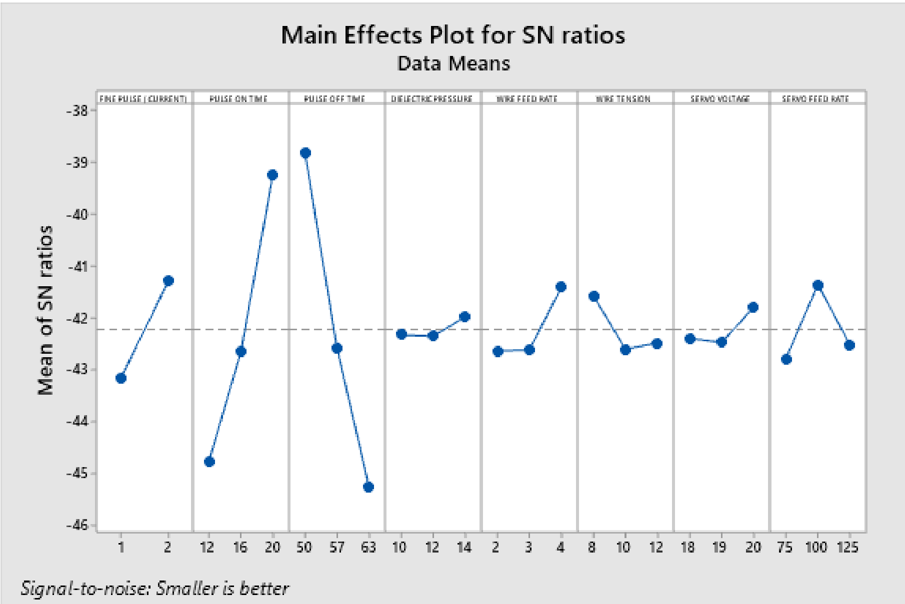

Figure 5: S/N ratio graph of machining time

Table7: ANOVA for S/N ratio – machining time

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**% contribution**
IP	1	16.223	16.223	16.2233	6.36	0.128	6.2476
TON	2	93.624	93.624	46.8120	18.35	0.052	36.06
TOFF	2	125.848	125.848	62.9239	24.67	0.039	48.47
WP	2	0.514	0.514	0.2568	0.10	0.909	0.2
WF	2	5.952	5.952	2.9761	1.17	0.461	2.29
WT	2	3.777	3.777	1.8886	0.74	0.575	1.45
SV	2	1.647	1.647	0.8233	0.32	0.756	0.63
SF	2	6.981	6.981	3.4903	1.37	0.422	2.69
Residual Error	2	5.101	5.101	2.5505			
Total	17	259.666					

Table 8: Summary of optimum parameters levels

Sr. No.	Parameter name	Parameter levels for optimum		
		Surface roughness	**Taper angle**	**Machining time**
1	IP (A)	2	1	2
2	TON (µs)	12	20	20
3	TOFF (µs)	63	57	50
4	WP (Kg/cm^2)	14	12	14
5	WF (m/min)	2	3	4
6	WT (Kgf)	10	8	8
7	SV (V)	18	18	20
8	SF (mm/min)	125	75	100

VII. Grey Relational Grade Analysis (GRA)

GRA is used for comparing and analysing the relationships between multiple factors in a system where there is limited or incomplete information. It addresses the challenge of multiple responses, by transforming it into a single response problem. The process of performing GRA involves a specific sequence that focuses on determining the rank of the grade using data acquired from experimental observations. To perform the GRA analysis, the experimental response data was initially normalised using smaller the better characteristic, resulting in values that were scaled within the range of 0 to 1. The grey relational coefficient was then calculated and the grey relational grade was computed by providing equal weightage to all three output responses. The values obtained from the Grey Relational Analysis (GRA) process are presented in Table 9.

To achieve an optimal combination of surface roughness, taper angle, and machining time, grey relational analysis recommends increasing the fine pulse and pulse on time while decreasing the wire feed rate, wire tension, and servo voltage (Figure 6). An increase in pulse off time, dielectric pressure, and servo feed rate initially increases the the GRA scores, but further increases will however lower them. ANOVA analysis (Table 11), utilized to assess the individual impact of each parameter on the GRA score, ranks the parameters and their contribution in the following decreasing order: pulse off time (19.83%), wire tension (17.66%), wire feed rate (13.31%), dielectric pressure (12.17%), pulse on time (8.91%), servo voltage (6.28%), fine pulse (5.59%), and servo feed rate (4.30%). The optimal parameter levels to maximize the GRA score are provided in Table 10.

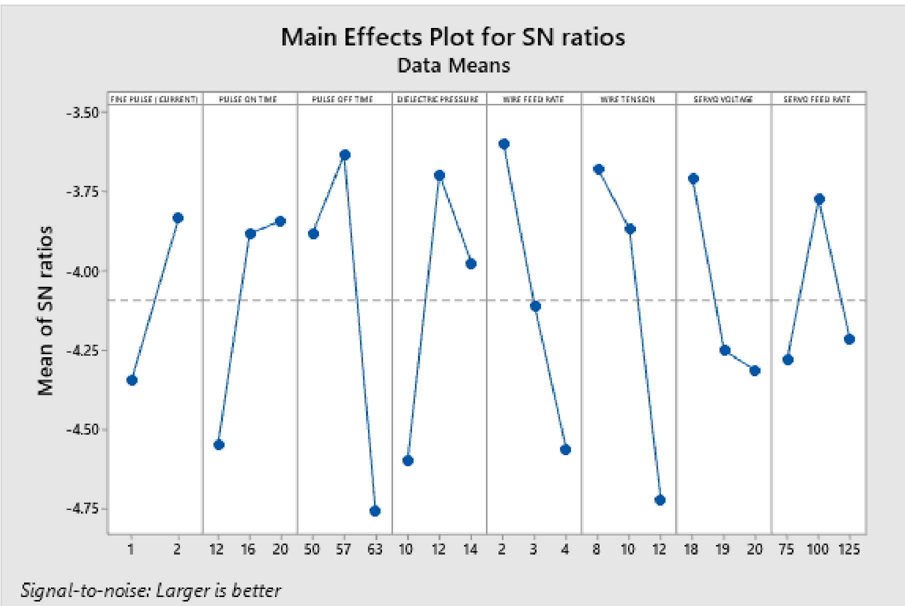

Figure 6: S/N ratio graph of GRA grades

				SMALLER THE BETTER			DEVITATION SEQUENCE			GR COEFFICIENT			GR GRADE
Exp no	SR	TA	MT	Normalised SR	Normalised TA	Normalised MT	SR	TA	MT	SR	TA	MT	

1	1.429	0.104	150	0.677	0.768	0.540	0.323	0.232	0.460	0.607	0.683	0.521	0.604
2	1.337	0.035	223	0.727	0.928	0.194	0.273	0.072	0.806	0.647	0.874	0.383	0.635
3	1.352	0.435	264	0.719	0.000	0.000	0.281	1.000	1.000	0.640	0.333	0.333	0.436
4	1.640	0.185	103	0.560	0.581	0.763	0.440	0.419	0.237	0.532	0.544	0.678	0.585
5	1.675	0.058	151	0.541	0.875	0.536	0.459	0.125	0.464	0.521	0.801	0.518	0.613
6	1.297	0.046	175	0.749	0.903	0.422	0.251	0.097	0.578	0.666	0.837	0.464	0.656
7	2.656	0.023	82	0.000	0.956	0.863	1.000	0.044	0.137	0.333	0.919	0.784	0.679
8	2.013	0.004	104	0.354	1.000	0.758	0.646	0.000	0.242	0.436	1.000	0.674	0.704
9	1.874	0.062	131	0.431	0.866	0.630	0.569	0.134	0.370	0.468	0.789	0.575	0.611
10	1.565	0.139	100	0.602	0.688	0.777	0.398	0.312	0.223	0.557	0.615	0.692	0.621
11	1.360	0.085	143	0.715	0.813	0.573	0.285	0.187	0.427	0.637	0.728	0.540	0.635
12	1.310	0.012	215	0.742	0.981	0.232	0.258	0.019	0.768	0.660	0.964	0.394	0.673
13	2.161	0.039	66	0.273	0.920	0.938	0.727	0.080	0.062	0.408	0.861	0.890	0.720
14	0.842	0.031	155	1.000	0.937	0.517	0.000	0.063	0.483	1.000	0.889	0.508	0.799
15	1.318	0.204	225	0.738	0.537	0.185	0.262	0.463	0.815	0.656	0.519	0.380	0.518
16	2.121	0.185	53	0.295	0.581	1.000	0.705	0.419	0.000	0.415	0.544	1.000	0.653
17	2.045	0.181	77	0.337	0.589	0.886	0.663	0.411	0.114	0.430	0.549	0.815	0.598
18	1.601	0.069	130	0.582	0.849	0.635	0.418	0.151	0.365	0.545	0.768	0.578	0.630

Table 9: Grey relational co-efficients and grades

Table 10: Optimal combination – GRA

PARAMETER	IP	TON	TOFF	WP	WF	WT	SV	SF
Input Values	2	20	57	12	2	8	18	100

Table 11: ANOVA for S/N ratio – GRA

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% contribution
IP	1	1.1789	1.1789	1.1789	0.91	0.440	5.482
T ON	2	1.8633	1.8633	0.9316	0.72	0.581	8.665
T OFF	2	4.1518	4.1518	2.0759	1.60	0.384	19.307
WP	2	2.6999	2.6999	1.3500	1.04	0.489	12.555
WF	2	2.8948	2.8948	1.4474	1.12	0.472	13.461
WT	2	3.7862	3.7862	1.8931	1.46	0.406	17.607
SV	2	1.3872	1.3872	0.6936	0.54	0.651	6.451
SF	2	0.9555	0.9555	0.4778	0.37	0.730	4.443
Residual Error	2	2.5869	2.5869	1.2934			
Total	17	21.5044					

VIII. Conclusions

This study investigated the impact of wire electrical discharge machining (WEDM) on P20+Ni steel material using a brass wire of 0.25mm diameter, focusing on optimizing surface roughness, taper angle, and machining time. Utilizing Taguchi Optimization and Grey relational analysis (GRA), the study identified optimized input parameter combinations for minimizing the targeted machining characteristics, detailed in Tables 8 and 10 respectively. ANOVA analysis indicates that pulse on time, off time, and dielectric pressure significantly influence surface roughness, machining time, and taper angle, respectively. Similarly, GRA highlighted the importance of pulse off time, wire tension, wire feed rate, and dielectric pressure in achieving optimal combination of surface roughness, taper angle, and machining time. The confirmatory runs showed improved machining performance with surface roughness = 1.678 µm, taper angle = 0.004^{o}, machining time = 66 mins and Grey relational grade = 0.804 indicating the successful optimization. In order to extend the study further, higher-order orthogonal arrays may be employed for a deeper analysis of parameter interactions. The study may be further expanded to incorporating more process inputs and performance criteria are to broaden the understanding of WEDM processes and outcomes. The results of this study can provide industries with insights into optimizing WEDM processes for P20+Ni steel, enhancing machining efficiency, leading to improved product quality and reduced production costs.

References

[1]. S. Tilekar, S. S. Das, and P. K. Patowari, "Process Parameter Optimization of Wire EDM on Aluminum and Mild Steel by Using Taguchi Method," Procedia Materials Science, vol. 5, pp. 2577–2584, 2014, doi: 10.1016/j.mspro.2014.07.518.

[2]. V. KALAVATHI and R. K. BHUYAN, "OPTIMIZATION OF PROCESS PARAMETERS IN WEDM PROCESS ON TWO WORKPIECES OF MATERIALS HARDOX-400 AND HARDOX-500," International Journal of Mechanical and Production Engineering Research and Development, vol. 8, no. 4, pp. 71–82, 2018.

[3]. P. S. Rao, K. Ramji, and B. Satyanarayana, "Experimental Investigation and Optimization of Wire EDM Parameters for Surface Roughness, MRR and White Layer in Machining of Aluminium Alloy," Procedia Materials Science, vol. 5, pp. 2197–2206, 2014, doi: 10.1016/j.mspro.2014.07.426.

[4]. A. Bhatia, S. Kumar, and P. Kumar, "A Study to Achieve Minimum Surface Roughness in Wire EDM," Procedia Materials Science, vol. 5, pp. 2560–2566, 2014, doi: 10.1016/j.mspro.2014.07.509.

[5]. A. Ram Prasad, K. Ramji, and R. B. Kumar, "Study of wire-electrical discharge machining parameters of titanium alloy by using taguchi method," International Journal of Engineering & Technology, vol. 7, no. 2.8, pp. 10–12, 2018.

[6]. M. Vignesh and R. Ramanujam, "Response optimisation in wire electrical discharge machining of AISI H11 tool steel using Taguchi – GRA approach," 2018.

[7]. G. Rajyalakshmi and P. V. Ramaiah, "Application of Taguchi, Fuzzy-Grey Relational Analysis for Process Parameters Optimization of WEDM on Inconel-825," Indian J Sci Technol, vol. 8, no. 35, Dec. 2015, doi: 10.17485/ijst/2015/v8i35/50946.

[8]. R. Sen, B. Choudhuri, J. D. Barma, and P. Chakraborti, "Study the impact of process parameters and electrode material on wire electric discharge machining performances," in Materials Today: Proceedings, Elsevier Ltd, 2018, pp. 7552–7560. doi: 10.1016/j.matpr.2017.11.427.

[9]. Z. A. Khan, A. N. Siddiquee, N. Z. Khan, U. Khan, and G. A. Quadir, "Multi Response Optimization of Wire Electrical Discharge Machining Process Parameters Using Taguchi based Grey Relational Analysis," Procedia Materials Science, vol. 6, pp. 1683–1695, 2014, doi: 10.1016/j.mspro.2014.07.154.

[10]. M. Fakkir Mohamed and K. Lenin, "Experimental investigation on wire electrical discharge machining parameters for aluminium 6082 T6 alloy using Taguchi design," in Materials Today: Proceedings, Elsevier Ltd, 2020, pp. 434–437. doi: 10.1016/j.matpr.2020.07.699.

[11]. J. Phimoolchat and A. Muttamara, "Multi-objective optimization of electrical discharge machining parameters for 2024 aluminum alloy using grey-taguchi method," in Materials Science Forum, Trans Tech Publications Ltd, 2020, pp. 55–60. doi: 10.4028/www.scientific.net/MSF.998.55.

[12]. J. kumar, T. Soota, and S. K. Rajput, "Optimization and measurement of kerf width and surface roughness of AISI 316L," Forces in Mechanics, vol. 6, Feb. 2022, doi: 10.1016/j.finmec.2022.100071.

[13]. N. Z. Khan, Z. A. Khan, A. N. Siddiquee, and A. K. Chanda, "Investigations on the effect of wire EDM process parameters on surface integrity of HSLA: a multi-performance characteristics optimization," Prod Manuf Res, vol. 2, no. 1, pp. 501–518, Jan. 2014, doi: 10.1080/21693277.2014.931261.

[14]. S. Kuriakose, K. Mohan, and M. S. Shunmugam, "Data mining applied to wire-EDM process," J Mater Process Technol, vol. 142, no. 1, pp. 182–189, Nov. 2003, doi: 10.1016/S0924-0136(03)00596-X.

[15]. R. Maurya, R. K. Porwal, and V. Kumar, "Experimental investigation & modelling of wire EDM process during machining of Nicrofer 5716," in Materials Today: Proceedings, Elsevier Ltd, 2019, pp. 1184–1190. doi: 10.1016/j.matpr.2020.02.239.

[16]. A. Sharma, M. P. Garg, and K. K. Goyal, "Prediction of Optimal Conditions for WEDM of Al 6063/ ZrSiO 4(p) MMC," Procedia Materials Science, vol. 6, pp. 1024–1033, 2014, doi: 10.1016/j.mspro.2014.07.173.

[17]. N. Sharma, T. Raj, and K. K. Jangra, "Parameter optimization and experimental study on wire electrical discharge machining of porous Ni40Ti60 alloy," Proc Inst Mech Eng B J Eng Manuf, vol. 231, no. 6, pp. 956–970, May 2017, doi: 10.1177/0954405415577710.

[18]. V. N. Kulkarni, V. N. Gaitonde, V. Aiholi, and V. Hadimani, "Multi performance characteristics optimization in wire electric discharge machining of nitinol superelastic alloy," in Materials Today: Proceedings, Elsevier Ltd, 2018, pp. 18857–18866. doi: 10.1016/j.matpr.2018.06.233.

[19]. T. Ali El-Taweel, "Parametric study and optimisation of wire electrical discharge machining of Al-Cu-TiC-Si P/M composite," 2006.

[20]. V. Aggarwal, S. S. Khangura, and R. K. Garg, "Parametric modeling and optimization for wire electrical discharge machining of Inconel 718 using response surface methodology," International Journal of Advanced Manufacturing Technology, vol. 79, no. 1–4, pp. 31–47, Jul. 2015, doi: 10.1007/s00170-015-6797-8.