

Review Article

Study on Optimization of WEDM Process Parameters on Stainless Steel

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Stainless steel is a material which has high corrosive resistance and oxidation resistance at high temperature with the combination of chromium, nickel, and niobium as a primary constituent. This material which is difficult to machine with complex shape is taken by using wire cut electric discharge machining. Wire electrical discharge machining is a nontraditional process widely taken for cutting and machining for complex shapes. This review paper involves wire cut EDM optimization parameters. Pulse interval, pulse duration, wire feed, voltage, and mean current are the operational parameters. The Taguchi orthogonal array method, analysis of variance (ANOVA), and grey relation analysis (GRA) methods are taken for different kinds of machining various kinds of materials, and different kinds of result with best material removal rate (MRR) and surface roughness (SR) are analyzed. This work suggests the most influencing process parameters and best optimization method for various steel materials.

1. Introduction

The harder materials are preferred for the engineering jobs to increase the service of the components by modifying the surface features to advance the hardness and the abrasion resistance properties. The austenitic stainless steels are preferred for the increasing strength and for higher corrosion resistance but it is very hard to machining in the conventional process. To overcome this problem, the nonconventional machining process is introduced for complex cut processing. Among the nonconventional machining process, the less heat affected zone with more accuracy of machining can be obtained from the WEDM process. This WEDM has widely used to cut hard and complicated to machine. This can be able to machine the high corrosion resistant materials

like super alloys in the application of aerospace, marine, and high temperature application. Sahiti and Reddy [1] and Bharathi [2] have made an analysis for Incoloy 800 alloy and SS304. By using Taguchi's method, the output process parameters like kerf width, MRR, and SR are analyzed. ANOVA is executed to recognizing inputs like wire feed rate, pulse off time, voltage, pulse on time, and the output response parameters like kerf, MRR, and SR [1, 2].

Melting of material is created by electric sparks which is taken as T_{on} and T_{off} is the pulse off time provided for the removal of molten particles from machining one. The spark machining gap is maintained by feed rate of wire (WF), and servo voltage (SV) points out the feeding rate of wire electrode into the zone of machining. The above mentioned parameters are secondary whereas peak current (I_p) and

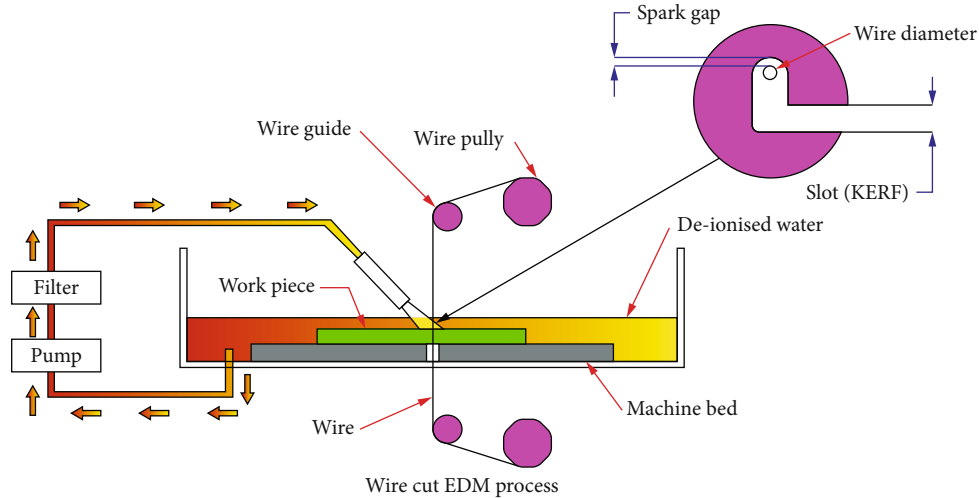


FIGURE 1: Wire cut EDM process.

pulse peak voltage (V_p) are the primary factors which influence the result of WEDM as follows: kerf width, SR, MRR, and recast layer thickness [3, 4]. Among the newest nontraditional manufacturing process machining, difficult-to-machine materials and delicate geometries that traditional machining methods cannot handle can be done by WEDM. The most efficient and cost-effective process is shown in Figure 1.

WEDM uses a wire electrode that moves longitudinally during machining and is directed by two distinct guide wires above and below the work piece [5]. Brass or coated steel wires are common wire electrodes, although tungsten or molybdenum wires are preferred for thin wires with ϕ 0.05–0.3 mm [6]. The work piece is degraded ahead of the wire during the machining process, so there is no direct contact between the work piece and the wire [7]. A mechanical tensioning mechanism is used to keep the wire in place. The melting and vaporization of material from the sample are caused by discharge between electrode and work piece [8]. Each electrical spark's heat believed to be between 15,000 and 21,000 degrees Fahrenheit and erodes a little quantity of material from the sample depicted in Figure 1 [9].

2. Experimental Methods

2.1. Material Selection. For the machining control parameter in the WEDM process, the authors used a variety of materials. The Taguchi method was used to analyse a block of D2 steel with ϕ 0.25 mm (zinc coated) copper wire using the L27 orthogonal array [10]. For SS304 of $100 \times 25 \times 10$ mm size with 0.25 mm diameter diffused brass wire, experimental analysis utilising ANOVA is used [11]. For the examination of SS 15-5 pH martensitic, precipitation hardening stainless steel of $100 \times 40 \times 10$ mm with 0.15 mm zinc-coated brass wire, the Taguchi method of orthogonal array L9 design was used [12]. For SS 316L of $20 \times 10 \times 10$ mm size with ϕ 0.25 mm (zinc coated) copper wire, grey relational analysis using ANOVA was expected [13]. Taguchi orthogonal array design utilised for super alloys

TABLE 1: Input process parameter ranges for WEDM.

Sl. no	Parameters	Units	Range
1	Pulse duration (T_{on})	μs	100-120
2	Pulse interval (T_{off})	μs	30-45
3	Wire feed (WF)	mm/s	4-12
4	Mean current (I)	A	20-50
5	Voltage (V)	V	90-150

of Incoloy types with brass wire diameters of 0.25 mm and wire feed rates of 420 mm/s [14].

2.2. Selection of Process Parameters. The input parameters were chosen to be pulse duration, pulse interval, mean current, voltage in V, and wire feed [15]. Surface texture (Ra), MRR, kerf breadth, straightness, perpendicularity gives output response from several method of studies [16]. It is noted that the following parameters have been changed to find the above results with the various ranges in Table 1.

3. Optimization Methods

There are different types of methods available for conducting the experiments as follows: Taguchi method, ANOVA, and grey relation analysis. Let us see the above methods one by one.

3.1. Taguchi Method. It is the most potent design tool for manipulative quality systems [17]. This provides an effective, simple method for optimising the concert, superiority, and budget [18]. Process parameter adjustment is a vital stage for attaining the excellence without raising costs [19]. Taguchi technique uses a particular design of orthogonal arrays with a minimal number of experiments to solve conventional process parameter design [20].

3.2. ANOVA. The analysis of variance (ANOVA) was used to determine significant and insignificant factors using the S/N and raw data [21]. Plotting the signal-to-noise data

TABLE 2: Experimental analysis of WEDM process with various techniques.

S. no	Material used	Methods conducted	Process parameters	Output	Authors/reference
1	SKD61 alloy	Taguchi method, ANOVA	T_{on} , T_{off} , WFR	SF, MRR	Kumar and Singh [29]
2	DC53 die steel	ANOVA, Taguchi method	V , I , T_{on} , T_{off}	SF, MRR	Kanlayasiri and Boonmum [30]
3	EN34 steel	Taguchi method, ANOVA	T_{on} , T_{off} , WFR	MRR, S/N ratio	Mohammad Taha and Bose [31, 32]
4	SS304	Taguchi method, orthogonal array	T_{on} , T_{off} , V , I	MRR	Ragunath and Vignesh [33]
5	SS316	Taguchi method	T_{on} , T_{off} , I	MRR, SR S/N ratio	Ramesh Babu and Subhair [34]
6	Ti-6Al-4V super alloy	Taguchi L-18 mixed orthogonal array	T_{on} , I , dielectric flushing pressure	MRR, TWR, overcut, and taper	Parmeswara and Sarcar [35]
7	Nimonic 80A	Taguchi method, ANOVA	T_{on} , T_{off} , WFR (wire offset)	MRR, SR	Goswami and Kumar [36]
8	Inconel 625	ANOVA, Taguchi method	T_{off} , WFR, T_{on}	SF, MRR	Goyal [37]
9	HCHCR	Taguchi process and GRA	T_{on} , T_{off} , V , I , WFR	MRR, SF	Patel et al. [38]
10	Inconel 718	Taguchi L-9 orthogonal array	T_{on} , T_{off} , I	MRR, SR, S/N ratio	Ramakrishnan and Karunamoorthy [39]
11	Monel 400	Taguchi method, ANOVA	T_{on} , T_{off} , V , I , WFR	MRR	Rajyalakshmi [40]
12	Nitinol (superelastic shape-memory alloy)	Heat-transfer search algorithm	T_{on} , T_{off} , I	MRR, SF	Chaudhari et al. [41]
13	Ti-6Al-4V (grade 5)	Taguchi orthogonal array	T_{on} , T_{off} , I , wire offset	Overcut in convex and concave profile, corner radius	Muhammad Umar Farooq and Muhammad Asad Ali [42]
14	Shape memory alloy (Ni 55.8 Ti)	NSGA-II, Taguchi	T_{on} , T_{off} , I , wire offset	MRR, SF	Magabe et al. [43]
15	Inconel 718	Discharge experiment design	V , I , dielectric pressure, pulse width, pulse interval, wire speed	MRR, SF	Chen and Zhou [44]
16	Hybrid Al-MMC (AA6061)	Taguchi method, ANOVA	T_{on} , T_{off} , WFR	MRR, SF	Kumar and Grover [45]
17	Composites of aluminium Al-SiC-B4C	RSM	T_{on} , T_{off} , V , I , WFR, B4C content	Kerf width, cutting speed	Suresh Kumar and Erdemir [46]
18	Steel SKD11	NSGA-II, hybrid method of RSM	T_{on} , T_{off} , WFR	SR, MRR, S/N ratio	Zhang et al. [47]
19	Ti50Ni45Co5 shape memory alloys	PCA, GRA technique	T_{on} , T_{off} , V	MRR, SF	Soni et al. [48]
20	EN31 alloys steel	AHP and MOORA	T_{on} , T_{off} , V , I , WFR, dielectric flushing pressure	Kerf width, MRR, SF	Patel and Kalpesh [49]

TABLE 3: Optimal process parameters for various research.

T_{on} (μ s)	T_{off} (μ s)	WF (mm/min)	Voltage (V)	Current (I)	Reference
10	10	6	20	215	Kumar and Singh [29]
125	52	8	15	220	Mohammad Taha and Bose [31]
10	5	10	25	200	Ragunath and Vignesh [33]
9	8	12	22	210	Ramesh Babu and Subhair [34]
118	45	5	30	110	Chen and Zhou [44]
10	4	7	60	205	Ramakrishnan and Karunamoorthy [39]

and raw data for the response curves (primary effect) reveals the parametric impacts on the response characteristics [22]. The ideal values of important process parameters in terms of mean response characteristics were determined by examining the ANOVA table and response curves [23].

3.3. Grey Relational Analysis (GRA). Dr. Deng J.L. et al. introduced the grey theory, which covers grey modelling prediction [24]. Numerous analysis can be done by GRA related to performance [25]. The grey relation analysis transforms the optimization of complex numerous performance variables into the single GRA optimization [26].

3.4. Optimizing the Process Variables. Table 2 depicts many types of research analyses used to conclude the best value for the process parameters of wire EDM. It is challenging to identify the right parameter through a series of experiments [27]. A large number of tests are carried out, and the best combination of machining parameters is chosen for the materials using the Taguchi orthogonal array and the ANOVA table. The analysis is carried out by several authors utilising analytical and statistical approaches. The MRR, kerf width, and surface roughness are S/N ratio-based metrics of process performance [28].

Table 2 shows the various experimental analysis by various researchers.

4. Result and Discussion

It was proposed in this review paper work to investigate various factors like T_{on} , T_{off} , V , I , and WFR dielectric flushing pressure used for wire EDM by various methods of analysis so as to maximise MRR and minimise surface roughness [50]. Signal to Noise ratio is used to craft one of the best feasible parametric sequences for the severe MRR. The reference articles listed in Table 3 conducted several observations.

4.1. Material Removal Rate. Greater energy is delivered by longer pulse on time and results more heat energy generation on that time. As the pulse on time grows, the rate of material removal and wire wear increases, while the surface polish drops [51]. Cutting speed can be increased by reducing pulse off time. The wire advances and retracts are controlled by servo voltage, which functions as a reference voltage. As the SV grows, the gap between the workpiece and the wire expands, limiting the amount of sparks, stabilising the electric discharge, and slowing the cutting rate [52]. The mean gap narrows when the SV is reduced, leading in increase electric sparks and a higher rate of machining

which leads to breakage of wire. In discharge machining, the amount of power used is termed as peak current denoted in amps [53]. Cutting speed can be increased by shortening the duration between pulses. The servo voltage, which also serves as a reference voltage, controls how far the wire advances and retracts. MRR rises in direct proportion to peak current [54].

4.2. Surface Roughness. It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. Rough surface makes large variance while smooth one makes minimal [55]. Surface roughness of the machined surfaces was measured using a portable surface roughness over five to six machined surfaces [56].

Kumar and Singh [29] infer that selection of an optimal combination of WEDM parameters for proper machining of Skd 61 alloy will lead to achieve better surface finish. Mohammad Taha and Bose [31] conclude for EN34 steel that with the value of T_{on} 10 μ s, T_{off} 11 μ s, and wire feed ratio 7 mm/min for huge MRR and infer that signal to noise ratio is directionally proportional to MRR.

With the help of the Minitab software, Ramesh Babu and Subhair [34] examined the data by signal to noise ratios and L9 array and concluded that optimal input parameter for the SS316 with greatest MRR with voltage 23 V, T_{on} 9 s, and T_{off} 6 s. Muhammad Umar Farooq and Muhammad Asad Ali [42] present the results of Ti-6Al-4V for minimising undercut and overcut in profile curvature as SV of 80 V, T_{off} of 42 ms, and WS of 7 mm/s are found to be the optimal process parameters, as well as T_{on} of 9 ms and 7 ms for concave and convex profile production.

According to the grey relational analysis, the optimal process parameters for the MRR, kerf width, and surface roughness are T_{on} 13 s and T_{off} 5 s at level 3 and at level 2 servo voltage 59 volts [16]. Supply voltage to be applied to the gap stipulates the size of electric discharge. When voltage gap rises, so does the peak current, resulting in a greater MRR. The dielectric flow rate is the rate at which the dielectric fluid is circulated which makes efficient machining. As the wire feed rate increases, so will the consumption of wire and the expense of machining. Breakage of wire occurs when cutting at a high speed with a low speed of wire. Increasing tension of wire dramatically improves accuracy, cutting speed within a set of parameters. The discharge current was shown to be the most effective on the surface roughness, followed by pulse duration [15]. According to a report on WEDM, the SR increases if T_{on} , V , I and reduces if T_{off} increases [19]. The various L9 and L27 orthogonal arrays

of Taguchi approaches are used on the austenitic stainless steels for finding the best processing inputs and the optimal values for optimization technique like GA [27, 28]. The genetic algorithm is adopted for cutting the SS347 using laser beam machining, and the parametric optimization is adopted to find the best model [57]. The TOPSIS approach was used for the turning process to find the optimum result.

Most research concentrated on a little bit of process components on a single time to design and optimise a variety of responses, according to the literature, which could result in inaccurate results for the taken process due to lot of process parameters. Furthermore, individual response modelling and optimization have been prioritised by the majority of academics. Multiobjective optimization with good results has a lot of potential. The majority of the researchers worked on tungsten carbide, tool steels, and titanium alloys with little concentration on alloys of nickel and alloys of super structure being mentioned. As a result, research on WEDM over nickel-based alloys and stainless steel offers potential [58, 59]. The investigations on nontraditional machining, Taguchi method, and grey relational analysis can be carried out to find the best optimum solutions [60–63].

5. Conclusion

The manufacturing procedures for machining the materials that are tough to machine and complicated geometries are not easily processed in traditional machining methods. WEDM is a highly accurate process that produces great accuracy and a high surface polish. As the pulse on time is increased, more energy is created, resulting in increased wire wear and MRR. Cutting speed can be increased by shortening the duration between pulses. By widening the distance between the workpiece and the wire, the MRR is lowered. The MRR is directly related to the peak current and increases as the peak current increases. As the gap voltage rises, so does the peak current, leading in greater MRR values. Within a specific range, increasing wire tension dramatically improves cutting speed and accuracy. We infer that the input parameters of T_{on} , T_{off} , V , I , WF , WT , and dielectric flushing pressure have a significant impact on the MRR and surface topography based on the review of different authors about the investigation of various materials on WEDM. It is critical to focus on the input parameter in order to achieve good product quality. To simplify the procedure parameter range selection, greater focusing of multiobjective functions and decision-making algorithms is required. Steel, composites, titanium alloys, aluminium alloys, Monel, Inconel materials, and low-grade stainless steels are employed in the majority of studies. In the future, higher-grade austenitic stainless steels, superaustenitic stainless steels, and nickel-based alloys can be researched using various sets of process parameters to identify the best optimal solutions.

Data Availability

The data used to support the findings of this study are included in the article. Should further data or information

be required, these are available from the corresponding author upon request.

Disclosure

This study was performed as a part of the Employment Hawassa University, Ethiopia.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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