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Perspective and Prospects of Wire Electric Discharge Machining (WEDM)

Buragadda Kiran Kumar[1,*] & Vemulapalli Chittaranjan Das[2]

[1]Department of Mechanical Engineering, Acharya Nagarjuna University, Nagarjuna Nagar, Guntur District, Andhra Pradesh 522510, India
[2]Department of Mechanical Engineering, RVR & JC College of Engineering, Chowdavaram, Guntur District, Andhra Pradesh 522019, India
*E-mail: buragaddakirankumar15@gmail.com

Highlights:

- The WEDM process and its industrial applications are outlined.
- WEDM process parameters and performance measures were explored.
- Various techniques for WEDM process optimization are discussed.
- The effects of process parameters on performance measures are summarized.
- The WEDM process parameters that were learned to be optimal are listed.

Abstract: Wire Electric Discharge Machining (WEDM) is a non-traditional machining method that is widely used in the manufacture of aerospace/aircraft and medical equipment for conductive materials. WEDM products are expected to have good dimensional accuracy, surface roughness, and geometry. Many researchers have done experiments on various materials to optimize the process, which has many parameters and response characteristics. This paper provides an overview of the WEDM process on alloy steels in order to understand the impact of input process variables on output responses and optimization techniques for selecting optimal process parameters. This paper also highlights WEDM process trends as well as workpiece materials, wire varieties, wire diameters, and optimization approaches. This work is expected to be useful in initiating further research on WEDM by documenting substantial research works confirming the latest scenario.

Keywords: *optimization techniques; performance parameters; process optimization; process parameters; WEDM.*

1 Introduction

Wire Electric Discharge Machining (WEDM) is a non-traditional machining technique for electrically removing material from any conductive workpiece, regardless of hardness [1,3]. A high frequency pulsed alternating current or a direct current is applied repeatedly through a wire in an insulating dielectric fluid (water) to melt and evaporate the material. The workpiece is positioned on the machine bed and moves on both the X and Y axes simultaneously, according to

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the CNC code's profile. Contact stresses are eliminated since there is no direct contact between the workpiece and the wire. A typical WEDM process is shown in Figure 1[2]. WEDM is used to make tools and dies, as well as medical and military equipment, aerospace, and electrical equipment [4].

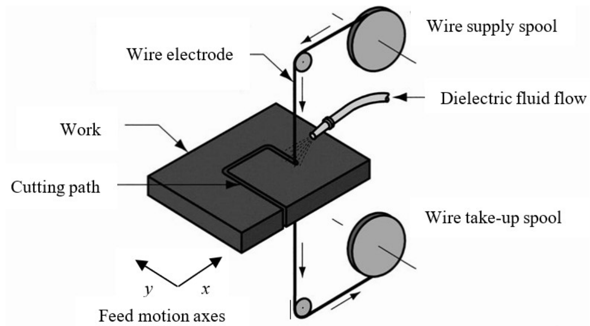

Figure 1 A typical WEDM process.

Electrical, non-electrical, wire electrode, and workpiece parameters are some of the inputs required. For improved performance, choosing the best input settings is critical. With minimum or no subsequent operations, the workpiece can be completed. Figure 2[5] shows the relationship between the input process variables and the output responses in a cause and effect (Fishbone) diagram of WEDM.

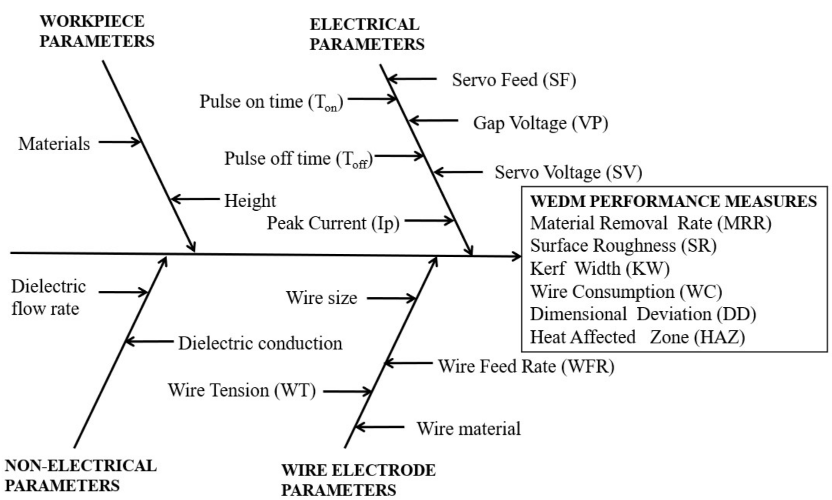

Figure 2 Relation between WEDM input process variables and output responses.

1.1 WEDM Process Parameters and Performance Measures Important Process Parameters in WEDM

Pulse-on time (T_{on}) is the duration of time (in μs) for the current to flow [6]. *Pulse-off time (T_{off}),* known as pulse interval, is the duration of time (in μs) between two simultaneous sparks [6]. The *peak current* or *discharge current (Ip)* is the maximum current (in A) passing through the wire electrode for the pulse [6]. Figure 3[7] shows the relation between the WEDM input parameters.

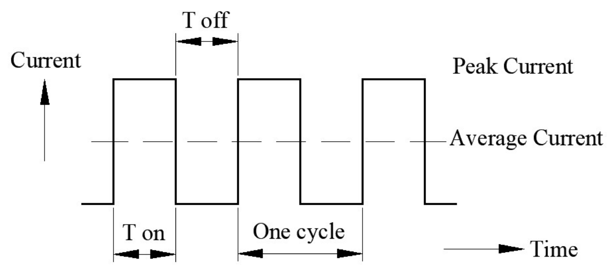

Figure 3 Relation between WEDM input parameters.

The *gap voltage (VP)* is the specific voltage (in V) for the gap between the workpiece material and the wire; it is also known as the open circuit voltage [6]. The *servo voltage (SV)* is used for controlling advances and retractions of the wire. During machining, the mean machining voltage varies depending on the machining state between the workpiece and the electrode [8]. The *servo feed (SF)* specifies the feed rate of the table during machining. Typically, the WEDM machine selects this factor automatically related to the SV [8]. The *wire feed rate (WFR)* is the speed at which the wire travels along the wire guide path. It is fed to generate the sparks [6] and is measured in meters per minute (m/min).

The *wire tension (WT)* is the electrode wire stretching between the upper and lower guides [8] and is expressed in grams (g). *Wire materials* include copper wire, brass wire, coated copper core wire, coated brass core wire, molybdenum wire, coated molybdenum wire, and coated steel core wire [9]. The *wire size* is the diameter of the wire electrode (available in sizes of 0.15, 0.2, 0.25, and 0.3 mm) [9] and depends on the corner accuracy requirement in the workpiece profile.

The *dielectric flow rate (DFR)* is rate of the dielectric fluid's circulation in the tank [8]. The *spark gap* or *overcut* is the distance between the wire electrode and the workpiece during the WEDM process. It decides the *kerf width* (KW) and is expressed in mm [9]. Figure 4[10] shows the spark gap details and related components.

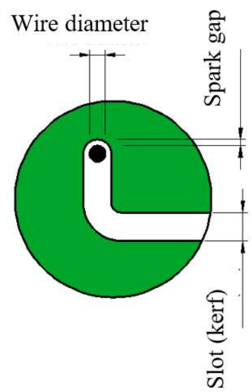

Figure 4 Details of the spark gap in WEDM.

1.2 Performance Measures in WEDM Process

The *material removal rate* (MRR) is a process response that has a significant impact on productivity. The process designer aims to achieve the maximum attainable MRR. Equation 1 is used to calculate the value in mm^3/min.

$$MRR = CS * \text{Kerf Width} * \text{Height of the workpiece} \quad (1)$$

The *surface roughness* (SR) is another important process response, which should be maintained to a minimum for a better surface finish in µm. The *kerf width* or *overcut* is a measure of material removal. It determines the finished part's dimensional accuracy as well as the profile's internal corner radius and will usually be minimized. It is calculated using Equation 2 and determines the wire offset in rough and trim cuts (in mm).

$$KW = \text{Wire diameter} + (2 * \text{Spark Gap}) \quad (2)$$

The *dimensional deviation* (DD) is a measure of the amount of variation in the required dimensions that should be kept to a minimum. The *recast layer* (RL) or *white layer* refers to the WEDMed's surface condition after it has melted and then resolidified or recast back onto the parent material during the WEDM cycle's off-time. The severity of HAZ is influenced by the input parameters employed during the machining process [11]. Process designers prefer HAZ values that are low. Figure 5 [12] depicts the HAZ just below the recast layer.

The *wire consumption* (WC) is an important economic factor. It is the weight difference (in kg) between the spool before and after WEDM.

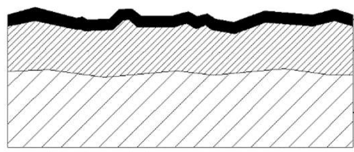

Figure 5 HAZ below the recast layer.

1.3 Optimization of WEDM Process Parameters

Many input process parameters are involved in WEDM. The major objective is to achieve the best parametric combination without compromising performance measures [13]. Trial cuts on expensive materials are either eliminated or reduced due to this parametric optimization. Process parameter optimization results in considerable cost savings as well as reduced material consumption in the process [14]. The optimal combination of multiple input parameters enhances the process's efficiency and safety [15-16].

The system's energy consumption and investment costs decrease as a consequence of optimization [17]. A single-objective or multi-objective optimization technique can be used. To determine the impact of input process parameters on performance measures, several mathematical approaches can be utilized. This study focused on a few of the most often used methods.

1.4 Design of Experiments (DOE) Techniques

Some essential and widely utilized approaches by industrial researchers are: Taguchi's orthogonal array method, Regression Analysis, Particle Swarm Optimization (PSO), Response Surface Methodology (RSM), Central Composite Design (CCD), Grey Relational Analysis (GRA), Feasible-Direction Algorithm, Genetic Algorithm, Fuzzy Clustering, Artificial Neural Network (ANN), Simulated Annealing, Pareto, Artificial Bee Colony (ABC), Tabu-Search Algorithm, Principle Component Analysis, Grey-Fuzzy Logic, etc.

The Section 2 of this article discusses our literature review as well as the researchers' findings. Section 3 provides a summary of the literature review. Finally, in Sections 4 and 5, the study's conclusions and the scope of the research are addressed.

2 Literature Survey

A review of the literature on WEDM processing was carried out, and the findings of studies conducted over the last ten years are presented. Tables 1 and 2 present the types of workpiece materials, electrode materials, optimization approaches, and optimal process parameters that can be used to identify research gaps and initiate future studies.

Table 1 Application of Taguchi approach in WEDM process on various materials.

Author/ Workpiece material/ Electrode material and Wire diameter/ Equipment	OA	Optimal		Additional Techniques
		Input parameters	Performance measures	
Nayak, *et al*. in [18] **AISI D2 tool steel** Coated Broncocut-W and 0.2 mm AC Progress V2 high precision CNC WEDM (Agie-Charmilles)	L_{27}	Part Thickness, Taper Angle, T_{on}, Ip, Wire Speed, and Wire Tension	Angular error, SR, and CS	TOPSIS
Patro, *et al*. in [19] **D2 Steel** Brass, zinc-coated copper, and annealed copper wires ELECTRONICA	L_{27}	T_{on}, T_{off}, SV, Ip, WFR, and WT	MRR, TWR, SR, KW	GRA
Nayak *et al*. in [20] **D2 tool Steel** Zinc coated Brass wire and 0.25 mm Elektra CNC	L_9	T_{on}, T_{off}, SV, and WFR	Cutting rate, DD, and Corner radius	-
Sinha, *et al*. in [21] **AISI D3 Tool Steel** Zinc coated wire and 0.25 mm -	L_9	T_{on}, T_{off}, Ip, and SV	MRR, SR, and Length of cut	PCA
Sinha, *et al*. in [22] **AISI D3 Tool Steel** Zinc coated wire and 0.25 mm -	L_9	T_{on} = 125 µs, T_{off} = 40 µs, Ip = 210 A, and SV = 15 V	Max. MRR	PCA
Priyadarshini *et al*. in [23] **AISI P20 tool steel** Zinc coated brass wire and 0.20 mm -	L_{16}	Ip, T_{on}, WS, FP, and WFR	CS, KW, MRR, SR, Micro-hardness	-
Choudhuri, *et al*. in [24] **AISI SS316** Uncoated soft brass (CuZn36) and 0.25 mm WEDM (Electronica Sprintcut)	L_{25}	T_{on} = 0.35 µs, T_{off} = 24 µs, Ip = 170 A, SV = 60 V, and WT = 1.2 kg	SR, and Recast Layer	ANN- PSO
Alduroobi, *et al*. in [25] **AISI 1045** Zinc coated copper wire and 0.3 mm CNC WEDM (Elektra)	L_{27}	T_{on}, T_{off}, and SF	Ra, and MRR	ANN

Table 1 Continued. Application of Taguchi approach in WEDM process on various materials.

Author/ Workpiece material/ Electrode material and Wire diameter/ Equipment	OA	Optimal		Additional Techniques
		Input parameters	Performance measures	
Reddy, *et al.* in [26] **Aluminum HE30** Brass wire CNC-WEDM	L_{27}	T_{on} = 112 µs, T_{off} = 61 µs, WT = 780 gm, Ip = 11 A, UF= 10 kg/cm^2, LF= 8 kg/cm^2	MRR = 0.153mm^3/min, SR = 2.861µm, and KW = 0.257mm	GRA
Das, *et al.* in [27] **Al6061** Zinc coated Brass wire and 0.25mm Electronica Sprint cut 734 CNC Wire EDM	L_{16}	T_{on} = 106 µs, T_{off} = 60 µs, I_P = 200 A, and SV = 40 V	SR = 2.4654µm	RSM
Bobbili, *et al.* in [28] **Ballistic grade aluminum alloy** - CNC WEDM from ELECTRONICA	L_{18}	T_{on} = 1.35 µs, T_{off} = 18 µs, Ip = 16 A, and SV = 15 V	MRR, SR, and Gap Current	GRA
Lodhi, *et al.* in [29] **EN41B steel** Molybdenum wire and 0.18 mm EX7732 CNC WEDM	L_9	T_{on}, T_{off}, Ip, and WFR	SR	-
Banerjee, *et al.* in [30] **EN47** Copper wire and 0.25 mm WEDM (JOEMARS WT355)	L_{27}	T_{on} = 8 µs, T_{off} = 8 µs, WFR = 8 mm/min, and SV =50 V	MRR	-
Zakaria, *et al.* in [31] **FeCuSn Hybrid metal material** Brass wire and 0.25 mm Sodick CNC Wirecut EDM, Model: AQ537L	-	T_{on} = 3 µs, T_{off} = 10 µs, Ip = 3 A, and SV = 120 V	SR (without sand polishing)	-
		T_{on} = 15 µs, T_{off} = 10 µs, Ip = 3 A, and SV = 120 V	SR (with sand polishing)	
		T_{on} = 15 µs, T_{off} = 10 µs, and Ip = 3 A	Hardness	

Table 1 Continued. Application of Taguchi approach in WEDM process on various materials.

Author/ Workpiece material/ Electrode material and Wire diameter/ Equipment	OA	Optimal		Additional Techniques
		Input parameters	Performance measures	
Ugrasen, *et al.* in [32] **HCHCr** Molybdenum wire of 0.18 mm CONCORD DK7720C four-axis CNC WEDM	L_{27}	T_{on}, T_{off}, Ip, and Bed Speed	Volumetric MRR, SR, and Accuracy	-
Kulkarni, *et al.* in [33] **HCHCr** Brass wire and 0.25 mm -	L_{25}	T_{on} = 8 µs, T_{off} = 3 µs, WFR = 5 mm/s, WT = 500 g, LF = 5 kg/cm^2, and UF = 6 kg/cm^2	MRR	Grey Wolf Optimizer (GWO) Technique
Prakash, *et al.* in [34] **Hybrid Composite (356/B_4C/Fly Ash)** Brass wire and 0.25 mm ECOCUT-CNC Wire EDM	L_{27}	SV = 30 V, T_{on} = 10 µs, T_{off} = 2 µs, WFR = 6 m/min, and Reinforcement 3%	MRR	-
Deshwal, *et al.* in [35] **H13 die steel** Brass wire and 0.25 mm Elektra Sprintcut 734	L_{16}	T_{on}, T_{off}, WFR, and Ip	SR, and MRR	-
Goyal, *et al.* in [36] **Inconel 625** Zinc coated wire and Cryogenic treated Zinc coated wire and 0.25 mm Four-axis CNC type WEDM (Electronica Spring cut 734)	L_{18}	Cryo-treated wire, Ip = 12 A, T_{on} = 125 µs, T_{off} = 60 µs, WFR = 8 m/min, and WT = 9 N	MRR	-
		Cryo-treated wire, Ip = 14 A, T_{on} = 125 µs, T_{off} = 60 µs, WFR = 6 m/min, and WT =11 N	SR	

Table 1 Continued. Application of Taguchi approach in WEDM process on various materials.

Author/ Workpiece material/ Electrode material and Wire diameter/ Equipment	OA	Optimal		Additional Techniques
		Input parameters	Performance measures	
Kumar, *et al.* in [37] **Inconel 718** Brass wire and 0.20 mm CNC WEDM (AGIE, Switzerland)	L_{27}	WT = 16 N, WS = 154 mm/s, Ip = 20 A, and T_{on} = 30 µs	MRR	SA
		WT = 12 N, WS = 104 mm/s, Ip = 10 A, and T_{on} = 14 µs	SR	
Nayak, *et al*. in [38] **Inconel 718 deep cryo-treated** Cryo treated coated Bronco cut-W and 0.20 mm AC Progress V2 high precision CNC WEDM (Agie-Charmilles)	L_{27}	Part Thickness, Taper angle, T_{on}, Ip, WS, and WT	Angular error, Surface roughness, and Cutting speed	Maximum deviation theory, BPNN, and Levenberg Marquardt Algorithm (LMA)
Ajay, *et al*. in [39] **Inconel 825, Monel 400, Incoloy 800** Cu-Zn master brass wire and 0.25 mm EZEECUT NXG CNC WEDM	L_9	T_{on}, T_{off}, WFR, and Ip	MRR, and SR	-
Tonday, *et al*. in [40] **Inconel 825** Brass wire and 0.25 mm Fanuc ROBOCUT CNC Wire EDM	L_{12}	SV, WT, Flushing Pressure (FP), and T_{on}	MRR, and SR	LRT
Saha, *et al*. in [41] **Nano-structured hardfacing materials** Brass wire and Zinc-coated Brass wire and 0.25 mm 5-axis WT 355 CNC WEDM (Joemars)	L_{25}	T_{on}, T_{off}, SV, WT, and WFR	MRR, SR and Machining time	GRA with PCA
Majumder, *et al.* in [42] **Ni-Ti shape memory alloy** Brass wire and 0.30 mm CNC WEDM (AGIECUT)	L_{27}	Ip = 12 A, T_{on} = 10 µs, WT = 12 N, WS = 150 mm/s, and FP = 6 bar	SR (Ra, Rq, and Rz), and Micro Hardness	GRNN, VIKOR-Fuzzy method

Table 1 Continued. Application of Taguchi approach in WEDM process on various materials.

Author/ Workpiece material/ Electrode material and Wire diameter/ Equipment	OA	Optimal		Additional Techniques
		Input parameters	Performance measures	
Sonawane, *et al*. in [43] **Ni-75** Brass wire and 0.25 mm Electroplus Wire EDM	L_{27}	T_{on} = 114 µs, T_{off} = 51 µs, SV = 20 V, Ip = 200 A, WFR = 5m/min, and WT = 2 g	MRR, Overcut, and SR	PCA based utility theory
Chalisgaonkar, *et al*. in [44] **Pure Titanium (CPTi)** Zinc coated and uncoated Brass wire and 0.25 mm Sprintcut (ELPULS-40A DLX) CNC Wire-EDM (Electronica)	L_{18}	T_{on} = 0.5 µm, T_{off} = 26 µm, Ip = 80 A, WFR=8 m/mm, SV = 75 V, Wire offset = 0.11 mm, and Wire type - Zinc coated brass wire	MRR, SR, and WC	Utility concept methodology
Majumder, *et al*. in [45] **Shape Memory Alloy (SMA) nitinol** Brass wire and 0.20 mm AGISCUT PROGRESS WED-003	L_{27}	T_{on} = 12 µs, Ip = 10 A, WFR = 150 mm/s, WT = 12 N, and FP = 8 bar	SR, and MRR	GRNN, FL coupled with MOORA
Ugrasen, *et al*. in [46] **SS304** Molybdenum wire and 0.18 mm CONCORD DK7720C	L_{27}	T_{on}, T_{off}, IP, and Bed Speed	MRR, SR, and Accuracy	-
Saravanan, *et al*. in [47] **Ti Gr 2** Brass wire and 0.20 & 0.25 mm ECOCUT CNC Wire EDM (Electronica)	L_8	SV = 35 V, T_{on} = 8 µs, T_{off} = 17 µs, Ip = 7 A, WT = 1600 N/mm^2, WFR = 45 mm/min, and Wire Diameter = 0.2 mm	MRR, SR, and Corner Accuracy	GRA

Table 1 Continued. Application of Taguchi approach in WEDM process on various materials.

Author/ Workpiece material/ Electrode material and Wire diameter/ Equipment	OA	Optimal		Additional Techniques
		Input parameters	Performance measures	
Rao, *et al.* in [48] **Titanium Grade5 (Ti-6Al-4V)** Brass Wire and 0.25 mm ELEKTRA SPRINTCUT 734 Wire EDM	L_{25}	T_{on} = 128 µs, T_{off} = 48 µs, Ip = 220 A, WT = 6 kgf, and SV = 30 V	Volume MRR	LRT
		T_{on} = 112 µs, T_{off} = 60 µs, Ip = 150 A, WT = 6 kgf, and SV = 70 V	SR	
Sneha, *et al.* in [49] **Ti-6Al-4V** Brass wire and 0.25 mm SODICK Q300L WEDM	L_{27}	T_{on}, Ip, and WS	MRR, SR, and KW	LRT
Prasad, *et al.* in [50] **Ti-6Al-4V Alloy** Brass Wire and 0.25 mm Electronica Maxicut-E	L_9	Ip =20 A, T_{on} = 125 µs, T_{off} =75 µs, and SV = 50 V	MRR	-
		Ip = 10 A, T_{on} = 105 µs, T_{off} = 85 µs, and SV = 40 V	SR	
Nain, *et al.* in [51] **Udimet-L605** Brass wire and 0.25 mm Electronica sprint cut CNC Wire EDM	L_{27}	T_{on} = 122 µs, T_{off} = 38 µs, Ip = 130 A, WFR = 11 m/min, WT = 6 m/min, and SV = 36 V	MRR, and SR	Support Vector Machine algorithm, Non-linear and multilinear regression, GRA

The works mentioned in Table 1 used the Taguchi technique (orthogonal array) from L8 to L27 as design of experiment (DOE) in optimization of the process parameters (i.e., 4 to 7) for single or multiple performance measures, from which it is evident that T_{on} is most significant in process parameters.

Table 2 Application of various techniques (other than Taguchi) adopted in the optimization of WEDM process.

Author/ Workpiece material/ Electrode material and Wire diameter/ Equipment	Technique	Optimal		Additional Techniques
		Input parameters	Performance measures	
Singh, *et al*. in [52] **AA 6063** Brass Wire and 0.25 mm -	3^k Full factorial design	T_{on}, T_{off}, Ip, and SV	MRR	ANN
Ramanan, *et al.* in [53] **AA7075 PAC composite** - -	RSM	Ip = 1500 A, T_{on} = 15 µs, T_{off} = 75 µs, and Servo Speed = 50 rpm	SR, and MRR	Grey – Fuzzy Technique
Kumar, *et al*. in [54] **Al-SiC composite with 0,5,10 wt% of B_4C** Brass Wire and 0.25 mm Electronica Sprint Cut model	GRA	Ip = 12 A, T_{on} = 100 µs, WFR = 6 m/min, and 5 wt% of B_4C	KW, and SR	-
Patel, *et al*. in [55] **EN31 alloys steel** Brass wire and 0.25 mm -	AHP	T_{on} = 125 µs, T_{off} = 45 µs, Flushing Pressure = 14 kgf/cm^2, WT = 900 gms, SV = 20 V, and WFR = 8 m/min	MRR = 8.4936 mm^3/min, SR = 3.5320 µm, and KW = 0.2611mm	MOORA
Thomas, *et al*. in [56] **Tool Steel EN31** Zinc coated wire SPRINTCUT WEDM	RSM	T_{on}, T_{off}, WT, and Ip	MRR	Central Composite Rotatable Design (CCRD)
Choudhuri, *et al.* in [57] **H21 tool steel** Soft brass wire, and 0.25 mm ELEKTRA SPRINTCUT CNC WEDM	RSM	T_{on} = 0.5 µs, T_{off} = 9.5 µs, Ip = 160 A, SV = 50 V, and WT = 1.4 kg	SR, and WC	Fuzzy-PSO algorithms
Sen, *et al*. in [58] **Maraging steel 300** Brass wire and 0.25 mm Electronica CNC Wire cut EDM	RSM Central composite design	T_{on}, T_{off}, Ip, WT, and SV	CS, SR, and WC	BPNN, FL, and Teaching Learning Based Optimization Algorithm (TLBO)

Table 2 Continued. Application of various techniques (other than Taguchi) adopted in the optimization of WEDM process.

Author/ Workpiece material/ Electrode material and Wire diameter/ Equipment	Technique	Optimal		Additional Techniques
		Input parameters	Performance measures	
Priyadarshini, *et al.* in [59] **P20 Tool Steel** - Electronica ecocut EIPULS 15	-	T_{on} = 130 µs, T_{off} = 23 µs, SV = 40V, and Ip = 12A	MRR	-
		T_{on} = 130 µs, T_{off} = 3 µs, SV = 20V, and Ip = 11A	KW	
Soundararajan, *et al*. in [60] **Squeeze cast A413 alloy** Zinc coated brass wire and 0.25 mm ELEKTRA SPRINTCUT 734 Wire EDM	RSM	T_{on} = 1.15 µs, T_{off} = 20 µs, and Ip = 160A	MRR = 23.515mm^3/min, and SR = 2.302 µm	Desirability Function Approach
Arikatla, *et al*. in [61] **Titanium Alloy (Ti-6Al-4V)** Brass wire and 0.30 mm ULTRACUT S1 Four Axis Wire Cut EDM (Electronica)	RSM	T_{on}, T_{off}, SV, Ip, and WT	KW, MRR, and SR	-
Raj, *et al*. in [62] **Titanium alloy (Ti6Al4V)** Brass wire and 0.25 mm Charmilles Wire-EDM	RSM	T_{on} = 1 µs, T_{off} = 17 µs, and WFR = 3.85 mm/min	MRR, and SR	Box-Benkhen approach, and Desirability Function
Zhu, *et al.* in [63] **Tool Steel G Cr 15** Brass Wire and 0.20 mm Makino U32j	Single factor experim ent	T_{on} = 1.5 µm, T_{off} = 1.5 µm, Ip =12 A, Spindle speed = 300 rpm, and Radial infeed	MRR	-

The authors used several optimization techniques other than Taguchi on various materials to find the optimal process parameters to obtain desired performance measures, as shown in Table 2. It is also apparent that T_{on}, T_{off}, Ip and SV are significant input parameters in the WEDM process.

3 Summary of Literature Review

The consolidated contributions of the researchers from the last ten years were separated as presented in Figure 6. It depicts the number of times each performance measured was selected for investigation. It clearly shows that both MRR and SR are significant objectives to be achieved for high accuracy and high production.

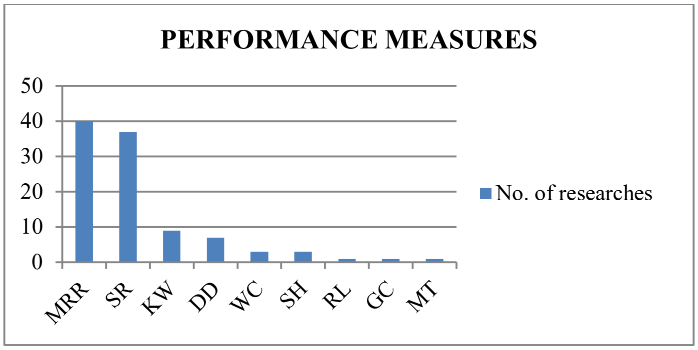

Figure 6 Performance measures selection.

The majority of studies show that pulse on time is the most important process parameter for all performance measures. The next important process parameters are pulse off time, peak current, and servo voltage. The process is least affected by wire feed rate, wire tension, and dielectric flow rate. Table 3 lists the pulse on time, pulse off time, peak current, and servo voltage requirements for each WEDM performance measure.

Table 3 Effects of input process parameters on performance measures in WEDM.

Performance measure	Required effect	Pulse on time	Pulse off time	Peak current	Servo Voltage
Material Removal Rate	↑	↑	↓	↑	↑
Surface Roughness	↓	↓	↑	↓	↓
Kerf Width	↓	↓	↓	↓	↓
Recast Layer Thickness	↓	↓	↑	↓	↓
Wire Consumption	↓	↑	↓	↓	↑
Micro Hardness	↑	↑	↓	↑	↑

4 Conclusion

Wire Electric Discharge Machining (WEDM) is a non-traditional machining technology for processing difficult-to-cut materials and complicated shapes with high accuracy and surface quality. The purpose of this article was to provide an overview of the WEDM process related to various materials to better understand the influence of process parameters on performance measures. The objective of this study was to identify the optimum processing conditions for maximum utilization of the WEDM capabilities, which have also been reviewed and outlined. Tool steels (AISI D3, EN31, HCHCr, H21), Inconel 718, Inconel 825, hybrid composites, Udimet-L605, SMA were all widely utilized in WEDM in previous studies. This review also assists in determining research gaps to improve WEDM performance on innovative materials. WEDM is increasingly being used in die manufacturing industries (which employ hot die steels such as H11, H13, P20 steels, etc.) since the components produced require little or no subsequent operations.

5 Future Research

Based on the findings of the review, further research can be conducted on the following aspects:

1. Controlling the recast layer thickness as well as MRR and SR in the WEDM process reduces the cost of fabricating hot die steel mould elements.
2. More research is needed to enhance the dimensional accuracy of profiles on thicker work materials, particularly when coated wire electrodes are used.
3. Much attention needs to be paid to wire electrode breakage, stress concentration, and the hardness of the work material after machining.
4. Studies are needed on various types of dielectric fluids, flushing nozzles and their impact on cutting speed, and other workpiece quality characteristics.

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