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Review on Current Research Work in Wire Electrical Discharge Machining

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ABSTRACT

WEDM is a thermo-electrical process which uses electrical spark to erode the work-piece material and is one of the greatest innovation technique which are affecting the tooling and machining industry. This paper includes study of recent research work done in the area of WEDM for various process parameter like(Pulse on time, Pulse off time, Wire feed rate, Peak current, Servo voltage etc) and their affect on performance measures like (Material Removal Rate, Surface Roughness, Surface Integrity, wire lag and inaccuracy etc). Last section of paper includes some suggestion for future research.

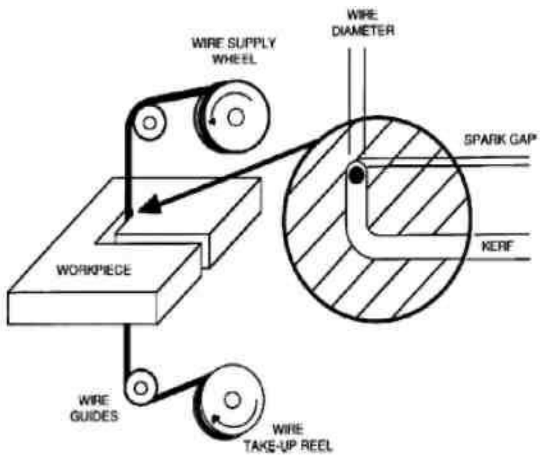
Keywords: *WEDM; Process Parameters; Performance Measures.*

1.0 Introduction

WEDM (Wire Electrical Discharge Machining) is a non-conventional method in which workpiece material is cut using electrical spark between electrode wire and the workpiece. It was first produced in 1969 by Swiss firm Agie. At that time their cutting speed was (21mm/min). In this process a wire spool is used for drawing the wire and is kept straight by high tension and guided by diamond guides. Electrode wire is made of brass wire, zinc wire or composite material from .001 to .014 inch (0.025-0.357mm). High frequency DC pulses are delivered to wire and workpiece, causing spark discharge in the narrow gap. Dielectric is inserted between working area of wire electrode and workpiece to allow cooling action and also allows flushing of debris or the resolidified eroded particles from the gap. Effective flushing is required, otherwise eroded particle in the gap will cause undesirable craters in the wire and workpiece material. With each and every discharge, crater will produced which is termed as defect or flaw. As the flushing condition becomes weak then these flaws tends to become larger & larger, so finally catastrophic failure of wire will takes place and wire will eventually break. Hence this property of wire to resist failure caused by the crater/ crack is called fracture toughness. Lower tensile wires usually have higher fracture strength then the higher tensile wires. Electrical conductivity is to be more , to increase the efficiency of cutting the workpiece material.

WEDM is used for cutting the parts which are difficult to machine by conventional methods. It is used in industry for producing the intricate shapes, complex geometries, where precision work is required & cutting hard materials [1]. This process is used in tool and dies industry. Presently use of WEDM is also in the field of medicine, electronic and automotive, aerospace, defense industries.

Fig 1: Wire Electrical Discharge Machining



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2.0 Introduction

2.1 Process parameter of WEDM

2.1 1 Pulse on time (TON)

During this time actual Electrical discharge occurs between the workpiece and electrode wire (gap) and voltage is also applied along the same. For getting long discharge, large value of ON time must be selected. It is expressed as TON. Higher value of discharge may cause wire breakage.

2.1 2 Pulse off time (TOFF)

During this time no voltage is applied consequently no electric discharge between workpiece and wire electrode takes place. It is expressed as TOFF. Using low value of discharge may cause wire breakage and due to this cutting efficiency also reduces.

2.1 3 Peak current (IP)

It is the maximum amount of current flowing through the circuit during pulse on time. It is expressed in amperage. This parameter actually reveals how much power is used in WEDM. Higher value of peak current is required for roughing operations and cutting rate also increases with increase in peak current. It is represented as IP.

2.1 4 Servo voltage (SV)

This parameter actually controls the movement of the wire i.e. (advancing and retracting). So if SV is applied more, than gap between wire electrode and workpiece will be wider and hence electric spark will be less and machining rate will be low. If SV is less then, gap is less so electric sparks are more then automatically machining/cutting rate will be more. It is expressed in SV

2.1 5 Wire tension

This parameter reveals about the straightness of the electrode wire. That mean's if wire tension is high then wire will remain straight otherwise wire might drag behind or even bent.

2.1 6 Wire speed

This is important factor which tells about the actual speed of wire in WEDM. If speed of wire is more, than consumption of wire will be more and if speed of wire is less then wire breakage can occur.

2.1 7 Dielectric fluid

Dielectric fluid is essential parameter of WEDM. It is used to cool the wire and flush off the resolidified particles from the gap. Commonly used dielectric fluid for WEDM is distilled water oil.

2.2 Performance measure of WEDM

Lot of researchers experimentally tried to use the above different combinations of WEDM process parameters while machining different material such as (HI 1, H12, H13 steel, MMC etc) to improve the performance measures of WEDM like (Cutting speed, Material removal rate, Surface roughness, Kerf width, wire wear ratio, wire lag) so that machining rate, productivity and accuracy of the WEDM can be improved. Hence selection of optimal machining parameters, play important role for obtaining higher cutting speed, better material removal rate, lower dimensional deviation and higher surface finish

2.2 1 Material removal rate

Material removal rate is very important parameter which influences productivity of any process. As MRR [2] increases, the economic benefits of using WEDM will be worthwhile for any firm. This factor depends upon number of input parameters which are associated with WEDM. Lot of research had been done in past to maximize the MRR by different models and approaches.

MRR is normally can be calculated using following equation:

MMR= (Wb - Wa) / (Tm x p) (mm3/sec) (1)

R. A. Kapgate [3] et.al investigates and develops the models using dimensional analysis to determine MRR for triangular, circular, rectangular shape cut on Al/Sic 10% . Experiment was done on SODICK 350W CNC WEDM with brass as electrode wire of size 0.25mm. It was found that, mathematical models were developed for different shapes to help the manufactures to maximize the use of AL/Sicl 10% MMC for higher performance.

H Singh, R. Garg [4] investigates the effect of various process parameters of WEDM on MRR. In their experiment they use Hot die steel (Hll) as workpiece material, brass wire as electrode wire and Electronica sprint cut as WEDM machine. Six input parameters (Pulse on time, Pulse off time, servo volage, peak current, wire feed & wire tension) were examined one by one & keeping other parameter fixed at certain value. It was found that Pulse on time and Peak increases the MRR and wire feed and Wire tension has no significant effect on MRR.

Pujari Rao [5] et.al examines effect of input parameters WEDM on MRR by using Aluminium BIS-24345 alloy as workpiece material. Different levels of input parameters were studied using Taguchi design LI8 orthogonal array. In all 8 input parameter are selected (Pulse on time, Pulse off time, Peak current, flushing pressure of dielectric, wire feed rate, wire tension, spark voltage & servo feed). First table was prepared using orthogonal array then ANOVA (analysis of variance) was done and lastly S/N ratio was used to calculate MRR. After doing all the experiments, it was concluded that Peak current parameter was most significant, Pulse on time, Pulse off time, Spark voltage and Flushing pressure of dielectric are significant factor. While wire feed and wire tension are less significant parameter.

D.SatishKumar [6] et.al investigates performance of WEDM parameter while machining A16063/Sicp composite. In this experiment they had chosen 4 process parameters (Pulse on time, Pulse off time, gap voltage, wire feed).

For this, Sic was mixed as 5%, 10% & 15% in Al using stir casting method and then machining of pure Al 6063 and Al MMC is done. In this design of experiment was used using L9 orthogonal array and after that values are analyzed using ANOVA and response graph. Different results were compared for MRR with selected combinations. Result shows increase in volume percentage of Sic, as MRR starts decreasing. Gap voltage shows more significant influence.

Dr. S. Ganapathy [7] et.al optimizes performance characteristics like MRR using Grey rational analysis. In the experiment Inconnel 718 used as workpiece material and Electronica Eco-cut machine having brass wire (0.25mm) diameter as electrode wire. Overall 6 input parameter were considered and remaining was kept constant. GRA is used with taguchi method to find grey relational coefficient and Grey rational grade. Higher GRA value implies better quality levels.

Singh [8] et.al studies effect of input process parameters of WEDM on MRR while machining steel and using brass as electrode wire. Conclusion drawn was as Pulse on time increases, then MRR increases as Pulse off time increases then MRR decreases and Wire Feed and Wire Tension has no effect on MRR.

Rajaneesh [9] et.al investigates performance of WEDM by reinforcing Sic particles in Zn-Al alloys. Above MMC is prepared by liquid metallurgy technique. In this experiment 3 input parameters are varied (Pulse on time, Pulse off time and Peak current) and others were kept constant. It was observed that MMR decreases as percentage of Sic particles increases in composite. Also MMR increases with increase in Pulse on time and Peak current.

Kozak. J [10] et. al. This paper show experimental study on low conductive materials & it was concluded that electrical resistance between work piece & wire electrode vary with change in clamping position this causes change in MRR. For reducing electrical resistance, silver coating technique is applied on work piece surface & as a result of this variation in resistance decreases & MRR increases, so automatically productivity of process is improved.

Kuang-Yuan Kung & Ko-Ta Chiang [11]. In this paper various input parameters are selected to evaluate their effect on MRR. As Pulse on time & Peak current increases then MRR also increases.

Parashar, V [12] et. al. Experiments were performed using Taguchi mixed orthogonal array. Every experiment was performed with process parameters like pulse on time, pulse off time, wire feed, dielectric flushing pressure, gap voltage to statically analyze MRR. ANOVA was used to find variables which affect MRR. Lastly variations of MRR are modeled mathematically using regression model.

Rajurkar and Wang [13] A WEDM sparking frequency monitor was developed to prevent the wire breakage. Further experiments were performed to determine MRR with all process parameters of machine.

Muthuraman V., Ramakrishnan R.et. al [21] Experiments are performed on WC-Co using best combination of input process parameters like (Pulse on time, Pulse off time, Ignition current, Wire feed, Dielectric pressure etc) to get desired output. As values of above parameters increases then MRR automatically increases. There was a little exception for dielectric pressure, as it increases then value of MRR first increases & in the end it decreases.

Dinu Gubencu, Marius Pop-Calimanu [32] Experiment were performed on highly quality composite material AA2124/SiC/25p. It is basically a Aluminum matrix and silicon carbide is reinforced in proportion of 25%. Application of such material is in structural engineering of air craft industry. Bi factorial ANOVA was considered for establishing the effect of thickness of material laminate on material removal rate of material. It was concluded that thickness of laminate does not have significant role on material removal rate of AA2124/SiC/25p.

CD. Shah et al. [34] this paper reflects the optimization of Process Parameters of WEDM during machining Inconel-600 using Response Surface Methodology. Four parameters (Input) were considered (Pulse on time, Pulse off time, Peak Current, Wire feed rate) were chosen to study their effect experimentally on performance response of Material Removal Rate. Taguchi with mixed LI8 array is used for optimization and ANOVA is used for analysis and finally RSM was used to develop surface models for response parameters. Result was shown that effect of Pulse on time, pulse off time and Peak current has significant effect on MRR.

D. Sudhakara et al. [36] This paper deals with optimization of process parameters (Open voltage, Intensity of pulse, Voltage gap, Wire feed, Wire tension) of WEDM with performance response of Material removal rate while machining Powder Metallurgical Cold worked Tool Steel. Experiments were performed on Mitsubishi WEDM and optimum factors are found out using Taguchi method and ANOVA. Pulse on time has significant effect on MRR. Wire feed and Wire tension has almost no effect on material removal rate.

2.2 2 Surface roughness (Ra)

It is also the very important parameter whose value is required to be minimized. It is important to the finish cut of WEDM. To obtain good surface roughness, certain factors need to be controlled and these are electrical parameters, dielectric fluid, workpiece material etc. Researchers suggest that with increase of discharge energy, roughness of WEDMed surfaces also increases. As larger discharge energy will produce larger crater & hence larger value of surface roughness on the workpiece would be formed. So lot of research had been done in past & it was suggested that Pulse on time and Peak current are the factors which most prominently affect the surface roughness. As Pulse on time & Peak current is increased, then surface roughness also increases because large & frequent spark is created along with large current will flow for a longer period of time.

Dr. S. Ganapathy [7] et.al optimizes performance characteristics like Surface Roughness using Grey rational analysis. In this experiment, overall 6 input parameter were considered and remaining were kept constant.

GRA wa used to find grey relational coefficient and Grey rational grade. In the experiment Surface roughness needed to be low, hence it is taken as smaller is better value. Result shows optimal level of condition with reduced surface roughness.

D. SatishKumar [6] et.al investigates performance of WEDM parameter (Surface Roughness) while machining A16063/Sicp composite. Experiment suggested selection of 4 process parameters (Pulse on time, Pulse off time, gap voltage, wire feed). For this, Sic was mixed as 5%, 10% & 15% in different proportions in Aluminium using stir casting method and then machining of pure Al 6063 and Al MMC was done. It was observed that Surface Roughness (Ra) increases with increase in percentage fraction of Sic particles in MMC.

Another conclusion is that, relative importance of process parameters of WEDM influencing Ra, according to the relative importance as percentage of Sic particles increases are Pulse off time, Wire feed, Pulse on time and Voltage.

Rajaneesh [9] et.al investigates performance measure (Surface Roughness) of WEDM by reinforcing Sic particles in Zn-Al alloys. Above MMC was prepared by liquid metallurgy technique. In this experiment 3 input parameters are varied (Pulse on time, Pulse off time and Peak current) and others were kept constant. It was observed that Surface Roughness (Ra) increases as percentage of Sic particles increases in composite. Also with the increase in Pulse on time and Peak current, surface roughness again increases. Another interesting observation come on surface roughness was the bed speed. If bed speed factor was more than surface roughness will be more due to formation of wire feed marks on machined surface.

Mahapatra [14] et. al investigates affects of 6 process parameters on surface roughness and it was observed that Peak current, Pulse duration and Dielectric flow rate are significant in determining surface roughness.

Rao P.S [15] et.al studies and optimize surface roughness using various process parameters like (Peak current, Pulse on time, Wire feed, Wire tension, Flushing pressure etc) and it was concluded that Peak current and Pulse on time are main & important factors affecting surface roughness.

Fuzhu Han [16] et.al investigates influence of process parameters like (Pulse-duration, Discharge current, Polarity effect, Material & dielectric) on Surface Roughness. WEDM machine used was EU64, brass wire with 0.2mm dia & Workpiece was alloy steel (Crl2). It was found that Surface roughness is improved by decreasing both pulse duration and discharge current. Also short duration with high peak value can create better surface roughness. It was also suggested that with reverse polarity machining with proper pulse energy, machined surface roughness can be improved considerably.

M.L Kulkarni [17] et.al investigate effect of processs parameters(Pulse on time, Pulse off time, Wire tension, Wire feed, Servo voltage) on surface roughness. Experiment was performed on Electronica supercut machine and the workpiece on which machining done was AISI D3 steel. Coated brass wire (CuZn50) of 0.25mm dia was used as electrode material. Experimental results were drawn and empirical models were developed for validation and shows good alignment with experimental results. It was concluded that, as the Pulse on time and peak current increases, Surface finish become poor means roughness increases and as Pulse off time and servo voltage increases then Surface finish becomes good.

M M Dhobe [18] et.al investigates the effect of Heat treatment & Machining Parameters like Pulse On time, Pulse Off time, Gap voltage, Peak current on surface roughness on Tool steel AISI D2. Actual experiment was done on Electronica Spring cut WEDM machine. For measuring the roughness Surface roughness Tester was used. Workpiece was manufactured by milling and size was 10x10x50mm. This workpiece was then heat treated by two methods, one was single tempering and other was double tempering. After that parameters was set and experiments were performed. It was observed that with increase in Pulse on time, surface roughness increases for both types of workpieces but value is lower in-case for double tempered workpiece., and with increase in Pulse off time, surface roughness decreases for both pieces, but surface value is lower in double tempered workpiece.

Muthuraman V., Ramakrishnan R.et. al [21] performed experiments on (WC-CO) using different process parameters & to study their effect on surface roughness. It was suggested that with increase in Pulse on time, Wire feed, then value of surface roughness increases but as increase in dielectric pressure takes place then surface roughness starts decreasing.

2.2 3 Surface integrity

There are certain factors which influence the surface integrity and these are tool noise radius, cutting geometry, feed, depth of cut so these factors may be considered as input process parameters. Surface integrity is associated with surface roughness and sub surface damage, microhardness and surface residual stress generated in machined surfaces. Hence for improving surface integrity of WEDM, surface roughness, surface cracks needs to be given consideration.

Uday A. Dabade [19] tries to improves surface integrity on turned surface of Al/Sicp MMC using GRA. In this experiment Tool noise radius, Feed rate, Cutting speed and Depth of cut were considered as process parameters. 3 level of each process parameter were selected and experiments were performed using L27 orthogonal array as per taguchi method. After this GRC (Grey relation coefficient) and GRG (Grey relational grade) were calculated. Then GRG is analysed using ANOVA (Analysis of variance) to identify significance of individual parameter on particular response. It was concluded that best optimized condition for improving surface integrity on machined surface of composite are; a)Tool radius =0.8mm b) Feed rate= 40mm/min c)Cutting speed = 40m/min d) Depth of cut=0.2mm.

MA Hassan [20] et.al studied the effect on surface integrity of AISI 4140 steel in WEDM. In this experiment surface texture of AISI steel was analysed by Scanning Electron Mcroscopy (SEM). Model of

WEDM was Sodick 200. 200Brass wire of (0.1-0.33mm diameter) was used as electrode material. Taguchi orthogonal array L9 was used to design the experiment. The results were shown that Pulse on duration has major affect in determining surface texture in compared with Pulsed current. It was also observed by SEM and calculations that value of surface roughness, micro voids, cracks increases as the high discharge energy creates larger melting of work surface and due to that deeper formation of crater takes place on work piece surface and hence surface finish of workpiece become poorer.

2.2 4 Kerf width (Cutting width)

It represents the amount of material removed or wasted during machining. Dimensional accuracy of finished part is decided by kerf. It is calculated using the following relation: Kerf width = 2 {Sparking gap} (mm) + wire diameter.

Process parameters mainly on which kerf width of material depends is Pulse on time, pulse of time, Spark voltage, Wire feed [22] & Flushing pressure of dielectric.

V Parashar. et.al [23] analysis kerf width for WEDM of Stainless Steel grade 304L as workpiece material & experiment was done on CNC Ezee cut WEDM machine. It was found that Pulse on time & dielectric flushing pressure has significant effect on kerf width & Pulse of time, wire feed, Gap voltage has less significant.

Gupta, Pardeep. et.al [24] examines effect of process parameters on kerf width by using HSLA as material. It was suggested that kerf width decreases with increase in pulse on time, pulse off time, spark gap voltage and peak current. But kerf width increased with increase in wire tension.

Siba & Sourav [25] studied the behavior of process parameters of wedm for D2 tool steel by applying response surface methodology & developed quadratic models on kerf width.

Thella Babu Rao, A Golapa Krishna [26]. studied kerf width by controlling parameter setting while machining A17075/SiCP MMC. Parameters selected were Pulse on time, Pulse off time & Wire feed. Along with them composite variables of particulate size and volume fraction of SiCp are selected as variables. Then response surface methodology was used to find control variable & minimum kerf was obtained during GA. It was finally concluded that high value of pulse in time increases kerf. Also with increase in particulate size & volume fraction of SiCp kerf width decrease as hardness of material increases Nitin kumar lautre [27] studied the effect of cutting parameters on crater wear depth (wire wear) of brass wire & kerf width on workpiece (T160G12) alloy steel.

For this they used pixel image analysis for analyzing the electrode wire wear on surface roughness through different outlines of image and Taguchi LI8 array along with ANOVA and F test were conducted to study the effect of cutting parameters on crater depth and kerf width. In all 7 Input parameters were considered (Pulse on time, Pulse off time, Wire feed rate, Peak current, Spark gap voltage, Wire tension & Pulse voltage). It was concluded that contribution of Spark voltage, Pulse on time & Wire feed rate are maximum in crater wear width & contribution of Pulse on time, Pulse off time & Wire feed has significant effect on Kerf width.

Thela Babu Rao [28] In their investigation ZC63 magnesium alloy was selected as matrix and particulate silicon carbide was mixed with stir casting method to form ZC63/SiCp and machining was done on five axis CNC-WEDM.

This experiment includes five input parameters were considered like (Particulate size, Volume fraction, Pulse on time, Pulse off time and Wire tension. Principle Component Analysis (PCA) is used as multi-response optimization technique to determine CPC (Composite Principle Component). Then ANOVA was used for validation. It was observed that Pulse on time, particulate size and Wire tension has significant role on overall performance of process.

Gadakh, V.S. [29] This paper examines the application of TOPSIS (Technique of order preference similarity to ideal solution) is used for solving multi-criteria optimization problems in Wire Electrical Discharge Machining.

Result obtained by this technique hold same as the result obtained by past researchers work. Example was discussed by author, in first Muthu Kumar et al. [30] used Incoloy 800 super alloy as work material.

Input parameters were Gap voltage, Pulse on time, Pulse off time and Wire feed. Optimization of Multi performance characteristics like MRR, kerf was done using TOPSIS.

Kuriachen Basil et al. [31] This research investigates the effect of voltage, dielectric pressure, pulse on time and pulse off time on spark gap while machining Ti6A14V (Super alloy).

For this brass wire having 0.25mm dia is used as wire electrode and machining of super alloy is done on Electronic ultra cut machine.

It was found that Pulse on time and Pulse off time has more impact on spark gap.

The value of spark gap obtained was 0.040407mm (minimum). It was also concluded that improper setting of Pulse on time and Pulse off time can cause wire breakage. Sanjeev kr.

Garg et al. [33] This paper studied the effect of process parameters of Wire EDM during machining of Al/ Zr02 (p).

Input parameters considered were Dielectric conductivity, Pulse width, Time between pulses, Max. Feed rate, Servo control Reference mean voltage, Short Pulse time, Wire feed rate, Wire Tension and Injection Pressure.

Robofil-290CNC WEDM having brass coated wire with diameter 250um was used.

For optimization Taguchi L36 mixed orthogonal array was used.. It was shown that significant parameters for spark gap are Pulse width, Time between pulses, Servo control mean reference voltage, Wire feed rate, Wire tension and Injection Pressure. S. Sivanaga et al.

[35] This paper reveals the chosen of best process parameter of WEDM while machining 18-4-1 grade speed steel (HSS) of different thickness from 5mm to 80mm.

Experiments were done on work piece by varying power input and condition of best power value with stable machining and high cutting speed is recognized.

Then all performance measures are evaluated like surface roughness, Material removal rate, Spark gap etc. Experiments were repeated with all different thickness of work piece material.

Later on mathematical correlation was developed with software.

Finally this correlation and parameter evaluated are studied to choose best process parameter.

3.0 Comparative Table Showing Different Work of Researchers

S. No.	Material Machined	Input Parameters	Output Parameters	Technique Used	Effect on Output Parameters	Author &Year
1)	Hot Die steel (H11)	Pulse on time Pulse off time Servo voltage Peak current Wire feed & Wire tension	MRR	Design of Experiments	Pulse on time & Peak Current increases the MRR and wire feed and Wire tension has no significant effect.	H.Singh R.Garg 2009
2)	Aluminium BIS-24345 alloy	Pulse on time Pulse off time Peak current flushing pressure wire feed rate wire tension spark voltage servo feed	MRR	Taguchi & Anova (Analysis of Variance)	Pulse on time, Pulse off time, Spark voltage and Flushing pressure are significant factor. While wire feed and wire tension are less significant parameter.	Pujari Rao et.al 2010
3	Zn-Al alloys & reinforcing Si particles	Pulse on time, Pulse off time Peak current	MRR	liquid metallurgy technique for reinforcing Si particles.	MMR decreases as percentage of Sic particles increases in composite.	Rajanesh
4)	Stainless steel Grade 304L	Pulse on time, Pulse off time, Wire feed Flushing pressure Gap voltage	MRR	Taguchi & Anova (Analysis of Variance)	Pulse on time & Wire feed has significant effect	Parashar, V.
5)	WC-Co	Pulse on time Pulse off time Ignition current Wire feed Dielectric pressure	MRR	Design of Experiment	Increasing the parameters increases MRR. But for Dielectric pressure, MRR first increases then decreases	Muthuraman V., Ramakrishnan R.et. al
6)	Al6063/Sic_p composite	Pulse on time, Pulse off time, gap voltage, wire feed	Surface Roughness	Stir casting method	Pulse off time. Wire feed. Pulse on time and Voltage also increases the R_a with their increase.	D.SatishKumar [6]et.al
7)	Zn-Al alloys	Pulse on time. Pulse off time and Peak current	Surface Roughness	liquid metallurgy technique for reinforcing Si particles.	Pulse on time and Peak current , increases then R_a increase. Bed speed factor is more than surface roughness will be more.	Rajaneesh
8)	Alloy steel (Cr12)	Pulse-duration, Discharge current, Polarity effect, Material & dielectric	Surface Roughness	Pulse generator Method	Surface roughness is improved by decreasing both pulse duration and discharge current.	Fuzhu Han
9)	AISI D_3 steel	Pulse on time, Pulse off time, Wire tension, Wire feed, Servo voltage	Surface Roughness	Design of Experiment	Pulse on time and peak current increases, R_a increases & as Pulse off time and servo voltage increases then R_a decreases.	M.L Kulkarni
10)	AISI D_2 steel	Pulse On time, Pulse Off time, Gap voltage, Peak current	Surface Roughness	Design of experiment	With increase in Pulse on time, surface roughness increases & increase in Pulse off time, surface roughness decreases.	M M Dhobe
11)	Al/Sic_p	Noise radius, Feed rate, Cutting speed & Depth of cut	Surface Integrity	Taguchi & ANOVA	Optimized condition for improving surface integrity are; a)Tool radius =0.8mm b) Feed rate= 40mm/min c)Cutting speed = 40m/min d) Depth of cut=0.2mm.	Uday A. Dabade
12)	AISI 4140 steel	Pulse on duration & Pulsed current.	Surface Integrity	Taguchi Method.	Pulse on duration has major affect on surface texture in compared with	MA Hassan

					Pulsed current	
13)	Stainless Steel grade 304L	Pulse on time, dielectric flushing pressure Pulse of time, wire feed, Gap voltage.	Kerf-Width	Taguchi L_{32} Array & ANOVA	Pulse on time & dielectric flushing pressure has significant effect on kerf width & Pulse of time, wire feed, Gap voltage has less significant.	V Parashar, et.al
14)	HSLA	Pulse on time, pulse off time, spark gap voltage, peak current & wire tension.	Kerf-Width	Taguchi Method	kerf width decreases with increase in pulse on time, pulse off time, spark gap voltage and peak current. & increases with increase in wire tension.	Gupta, Pardeep, et.al
15)	$Al7075/SiC_P$	Pulse on time, Pulse off time & Wire feed	Kerf-Width	Response surface methodology	High value of Pulse in time increases kerf width.	Thella Babu Rao, A Golapa Krishna
16)	TI60G12 steel	Pulse on time, Pulse off time, Wire feed rate, Peak current, Spark voltage, Wire tension.	Kerf Width	Pixel based image analysis & Taguchi	Pulse on time, Pulse off time & Wire feed has significant effect on Kerf width.	Nitin Kumar Lautre
17)	$ZC63/SiC_p$	Pulse on time, Pulse off time, Particulate size, Volume fraction, Wire tension.	Kerf Width	Principle Component Analysis (PCA) and ANOVA	Pulse on time, Particulate size, Wire tension are significant	Thella Babhu Rao, A. Gopala Krishna
18)	Ti6Al4V (Super alloy)	Voltage, Dielectric pressure, Pulse on time Pulse off time	Spark gap	ANOVA	Pulse on time and Pulse off time has more impact on spark gap	Kuriachen Basil et al.
19)	$Al/ZrO_{2(p)}$	Dielectric conductivity, Pulse width, Max. feed rate, Servo control Reference mean voltage, Short Pulse time, Wire feed rate, Wire Tension and Injection Pressure	Spark gap	Taguchi	Significant parameters for spark gap are Pulsewidth, Servo-control mean reference voltage, Wire feed rate, Wire tension, Injection Pressure.	Sanjeev Kr. Garg et al.

4.0 Conclusion

Wedm is a excellent non-conventional machining process, which is used to cut small and complex parts with closer dimensional accuracy. Proper Selection and optimization of process parameter of WEDM is very important to increase the productivity and improving the economical benefits.

From Literature Survey

- It is revealed from different research that on increasing Pulse on time & Peak current, MRR increases but at the same time Surtace roughness ot workpiece also increases, it is a point of concern.
- It is observed by experimental results that on increasing Pulse off time & Servo-voltage surface finish become better. Wire Feed & Wire Tension has not significant effect on MRR and Surface roughness.
- More experimental work is required to produce a workpiece which is having good surface finish, this can be done by setting low pulsed current & small pulse on duration.
- It is also shown from research that Pulse on time, Dielectric pressure has significant effect on the kerf width.
- From research it is also examined that if, SiC (Silicon carbide) is used as composite material with any Metal to form Metal matrix composite materials (MMC). With increase of percentage of Sic particle in matrix, then MRR and surface roughness of piece will be more. Hence path of electrode wire which erodes the workpiece material is hindered. So result of above is that, wire shall not be able to penetrate the desired depth for which it was programmed.

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