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EXPERIMENTAL INVESTIGATIONS OF WIRE ELECTRIC DISCHARGE MACHINING ON SUPER ALLOY/METAL COMPOSITES

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ABSTRACT

A specialized thermal machining technique called wire electrical discharge machining (WEDM) can precisely manufacture items with changing hardness or complex shapes that have sharp edges and are very challenging to machine using conventional machining techniques. This useful technology for the WEDM procedure is based on the typical EDM sparking phenomenon and makes use of the commonly used non-contact material removal method. Since the process's inception, WEDM has developed from a straightforward method for creating tools and dies to the best option for creating microscale parts with the highest level of dimensional accuracy and surface finish quality. The WEDM method has endured over time as a competitive and cost-effective machining alternative that can meet the stringent machining specifications imposed by quick product development cycles and rising cost demands. The possibility of wire breakage and bending, however, has severely hindered the process' full potential and decreased the accuracy and efficiency of the WEDM operation. The various approaches to achieve the ultimate WEDM goals of optimizing the numerous process parameters analytically with the complete removal of the wire breakages, while also enhancing the overall machining dependability, have been thoroughly researched .In this paper a significant amount of study has been done on the WEDM process capacity globally over the years. The purpose of this paper is to examine the research on parametric WEDM process variable effects on various output performance measures. The research also explores the potential of using WEDM technology to machine advanced materials and emphasizes several modelling techniques to forecast optimal machining conditions. This research also emphasizes combined technology, which gains from the advantages of both WEDM and traditional methods. The development and potential direction of research in the WEDM process are covered.

Keywords: Wire Electrical Discharge Machining; Wire Tool Electrode; Process Optimization; Modelling Techniques.

I. INTRODUCTION

The non-traditional material removal technique known as wire electrical discharge machining (WEDM) is commonly utilized to create components with complex forms and profiles. It is regarded as a special adaptation of the traditional EDM method, which starts the sparking process using an electrode[1]. To achieve very small corner radii, WEDM uses a constantly traveling wire electrode constructed of thin copper, brass, or tungsten with a diameter of 0.05 to 0.3 mm. The wire is kept in tension using a mechanical tensioning device reducing the tendency of producing inaccurate parts[2]. The WEDM technology eliminates mechanical stresses during machining since the material is degraded ahead of the wire and there is no direct contact between the workpiece and the wire[3]. The WEDM technology also eliminates the geometrical changes that occur during the machining of heat-treated steels and can work with exotic and high strength and temperature resistance (HSTR) materials[4].

At least the traditional version of WEDM does not permit the machining of cavities or blind holes as another limit on application in industrial operations. The WEDM milling procedure is currently being used to partially remove this drawback[5]. Due to the engagement by many researchers and research institutions, study on WEDM has significantly developed in recent decades, and an astonishing number of scientific articles addressing or relevant to such a subject were produced[6].The authors attempted to paint a picture of the current level of scientific and technical knowledge about WEDM and the future development directions in this paper's content using the best data they could find[7].

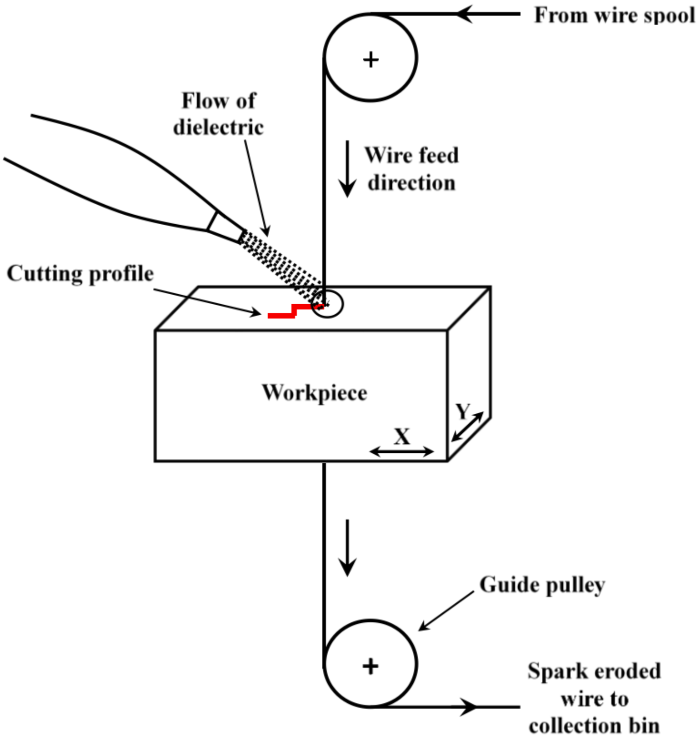

Figure 1. Wire electrical discharge machining Process [4]

Wire EDM (Wire-Cut EDM):

While immersed in a dielectric solution, a thin wire electrode is passed into the workpiece. A spark is formed between the wire and workpiece once it is connected to a high voltage power supply. The spark's heat erodes the workpiece, and the wire is supplied constantly to form a cut. Wire EDM is mostly typically used to carve complicated metal forms[8].

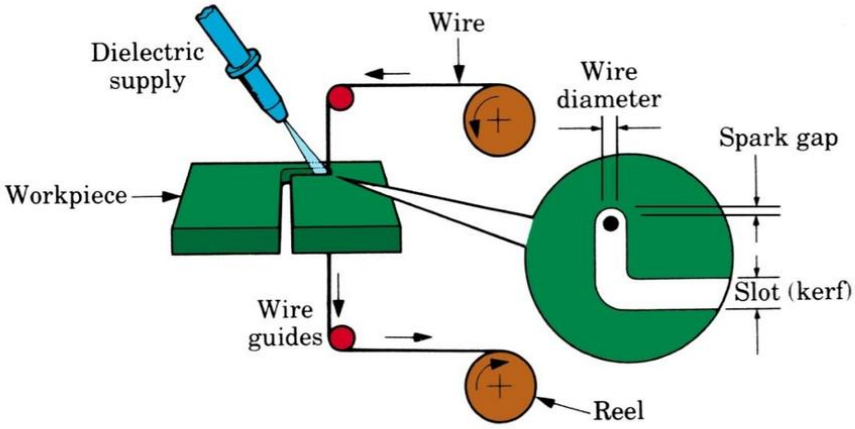

Figure 2. Schematic diagram of EDM process

WEDM Processes

The mechanism of material removal used by WEDM and traditional EDM both rely on the erosion effect created by electrical discharges (sparks). A succession of discrete sparks that happen between the workpiece and the wire and are separated by a stream of gas erode material from the workpiece in WEDM[9].A constant supply of dielectric fluid is provided to the zone for machining. However, the current WEDM procedure is frequently performed on objects that are completely submerged in a dielectric fluid-filled tank. Such a WEDM's submerged technique raises the temperature stabilization and effective flushing, particularly when the workpiece's thickness varies[10]. The WEDM process converts electrical energy that creates a plasma channel between the cathode and anode into thermal energy at temperatures between 8000 and 12,000 ^{o}C or as high as 20,000 ^{o}C, which starts a significant amount of heating and material melting on the surface of each pole[11]. The plasma channel malfunctions when the 20,000–30,000 Hz pulsing direct current power supply is shut off. As a result, the temperature suddenly drops, allowing the circulating dielectric fluid to saturate the plasma channel and remove microscopic debris that contains molten particles that have built up on the pole surfaces[12].

Deionized water is typically used as a working fluid because of its high fluidity, which makes it possible to comparatively easily remove particles loosely attached by the electroerosive process by the action of gravity[13. The potential for an electrolysis process to evolve is a less convenient element. By igniting hydrogen from bubbles created during the electrolysis process, the electrolysis could cause microexplosions, which would be bad for the integrity of the wire and the quality of the machined surface[14].

Evolution of WEDM

In the latter half of the 1960s, WEDM was first introduced to the manufacturing sector. The search for a method to replace the machined electrode used in EDM led to the creation of the procedure[15]. In order to autonomously regulate the shape of the component that would be machined using the WEDM process, D.H. Dule-bohn applied the optical-line follower system in 1974 [16]. As the technique and its possibilities were well recognized by the industry by 1975, its popularity was rising quickly. The introduction of the computer numerical control (CNC) system into WEDM at the tail end of the 1970s was the sole factor that significantly advanced the machining process[17].

Parameters for Wire EDM

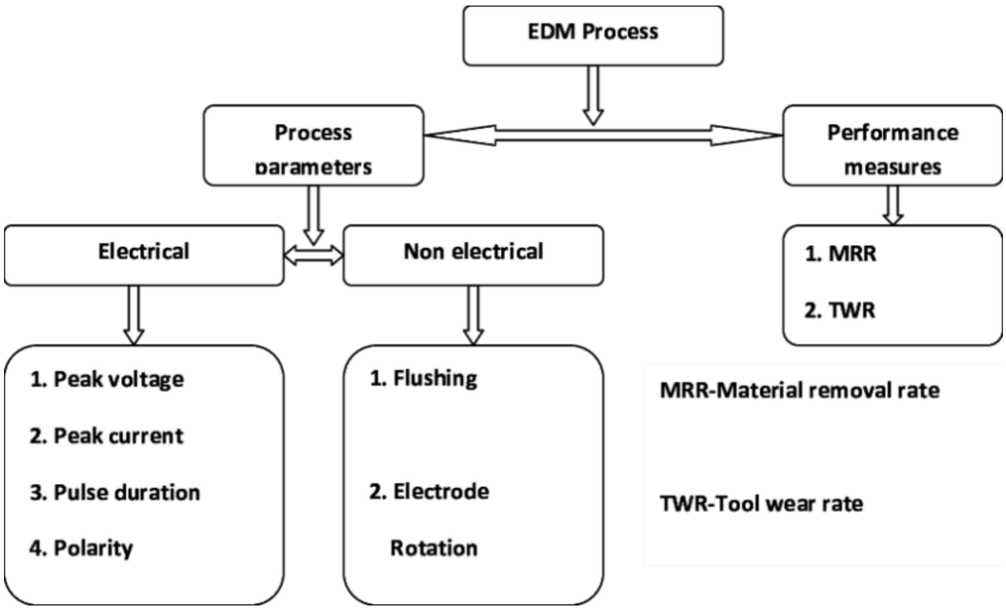

Figure 3. Process parameters and Performance measure of WEDM[4]

The right machining settings must be chosen in order to perform an economical machining operation since Wire EDM is a necessary but expensive procedure. With knowledge of how the machining parameters affect the Wire EDM performance measure, such as surface roughness, the machining parameters can be tuned for optimum machining[4].

II. LITERATURE REVIEW

Akash Nag et al.[5] discussed about the performance of the fabricated hybrid metal matrix composite during the wire-EDM process under different operating conditions. The defect-free fabrication of the material was examined by scanning electron microscope, and the optical microscopic image examined its microstructure. The output response is measured in terms of Metal Removal Rate and Surface Roughness. The analysis part has been done by using the L27 Taguchi's array under the randomly designed experiment trials. The surface topography study of the machined surface was investigated by using 2D and 3D images of the surface obtained by confocal microscope. SEM analysis was performed to analyze the machined morphology for defects induced during machining. The experimental analysis concluded that with an increase in pulse on time and a decrease in pulse off time and gap voltage, surface roughness and material removal rate increases. The SEM results revealed the formation of micro-voids, craters and surface cracks during machining of the workpiece.

K. Raju et al.[6] presented an overview about the optimum parameters opted for better material removal rate with good surface finish. The material for this study was selected as aluminium metal matrix composite fabricated by stir casting method with Al 6061 90 percentage and Boron Carbide 10 percentage as reinforcement. The study was conducted on wire electrical discharge machining machine where the selected parameters are pulse on time, current and pulse off time. Surface roughness and material removal rate was taken as output responses for the study. The X-ray Diffraction test confirms the presence of boron carbide particulate in prepared aluminium composite. The microstructure taken reveals the uniform mixing of boron carbide particulate. The Scanning Electron Microscope analysis was also taken to confirm the uniform mixing of boron carbide particulate with aluminium.

G Ramanan et al.[7] demonstrated that Wire cut discharge Machining is an advanced machining method controlled by a variety of interrelated complex parameters like discharge current, pulse on time, pulse off time and servo speed rate. Any slight variations in one will have an effect on the machining quality measures like surface roughness and material removal rate. In the present work Aluminium 7075 is used as matrix and activated charcoal with different percentage as reinforcement to fabricate metal matrix composites. The specimens are tested for Density, Hardness, Impact Strength and Ultimate tensile Strength. Best chosen samples are used to perform machining process in wire cut electrical discharge machine. 27 trials of experiments based on Response surface methodology are done and the observations are made. The quality of the machined samples is evaluated by the measurement of material removal rate and surface roughness. Results are utilized to develop the grey-fuzzy model. From this technique, the optimum combinations of process parameters are obtained and corresponding values of maximum material removal rate and minimum surface roughness are found out. From ANOVA analysis it is found that servo speed is the significant factor in determining the machining quality. Confirmatory experiments are performed to determine the effectiveness of the approach.

J.Udaya Prakash et al.[8] reported that Aluminium alloy is used as the matrix material for fabrication of hybrid AMCs by stir casting. Hybrid AMCs containing 1.5%, 3% & 4.5% boron carbide of average particle size 63 μm and 1.5%, 3% & 4.5% fly ash of average particle size 12 μm were fabricated. Optical micrographs of the composites show that the reinforcement particles were uniformly distributed in the matrix. WEDM is used to cut conductive materials of any hardness that are difficult or impossible to cut with traditional methods. WEDM is specialized in cutting complex contours or fragile geometries. High material removal rate and good surface finish cannot be achieved simultaneously. This is an important problem and continuous efforts are being made by various researchers all over the world. This research work attempts to develop an appropriate machining strategy for WEDM of hybrid AMCs using 0.25 mm diameter brass wire as the electrode. The five important process parameters such as gap voltage, pulse on time, pulse off time, wire feed and percentage reinforcement are taken as input parameters and material removal rate as the output parameter.

M. Arunadevi et al.[9] reported that Metal Matrix Composites (MMCs) plays very important role in structural, aerospace and automotive industries, because of their good properties like light weight, high specific strength and good wear resistance. Among various nonconventional machines, wire EDM is widely used in cutting of hard materials with good mechanical properties and high accuracy. The required materials are taken and stir casting process is used in composite fabrication and machining is done using Wire EDM. Increasing the Material Removal Rate (MRR) value and decreasing the Surface Roughness (SR) are the main objectives. There are five input parameters such as pulse-on, voltage; pulse-off, bed speed and current are considered to study the output parameters and to achieve the objectives. Performance analysis of the experimental values is done using Artificial Neural Network (ANN) mathematical model and the model is evaluated using R-square value. Artificial Neural Network model gives better and accurate results compared with linear regression model. In practical situation, it is hard to find the best for all the objectives simultaneously. Pareto optimal solutions are non-dominated solutions when all the objectives are considered. So, in this study, Solution for multi objective optimization is determined based on Pareto optimal optimization.

K. Raju et al.[10] stated that aluminium composite was produced through the two-step stir casting route with the combination of 2% lithium and 10% silicon nitride reinforcements. Experiments were performed using the Taguchi design of experiments to optimize the selected input parameters such as pulse on time, pulse off time, current and wire feed for the response parameter, material removal rate, and surface roughness. An ANOVA-based regression equation with genetic algorithm was used to optimize the input variables. The gray relational grade was also performed to optimize multiple performance characteristics. Taguchi-based optimization analysis results in wire feed as the domination factor for material removal rate and surface roughness. Increased wire feed increases the material removal rate with good surface finish as confirmed from gray relational grade analysis.

D. Vijay Praveen et al.[11] mainly focused on investigating the influence of wire-cut EDM process parameters on material removal rate and surface roughness of Ni–P-coated and un-coated alumina-reinforced composite materials. The stir casting method was used to prepare the composites at weight percentages of 3, 6 and 9. Taguchi's L18 multi-level orthogonal array (2^1 3^6) was adopted to conduct the experimental studies. An optimal combination of the process parameters was obtained by applying Grey relation analysis coupled with principal component analysis. The combined effect of machining performance measures was analyzed using ANOVA to identify the significance of the result. The surface morphology of the machined surface of the optimal set of parameters was presented. Identified optimal parameters were verified by conducting the confirmation tests and the predicted results have been a good agreement with the experimental fndings.

Shyam Lal et al.[12] investigated about the effect of wire electrical discharge machining process parameters like discharge duration, pulse interval time, discharge current and the wire speed on the kerf width while machining newly developed hybrid metal matrix composite (Al7075/ 7.5 % SiC/7.5 % Al_2O_3). The hybrid composite was prepared by inert gas assisted electromagnetic stir-casting process. Taguchi method was used for parameter optimization and the level of importance was determined using analysis of variance. The results show that the discharge current was the most significant parameter that contributed maximum (47.16 %) to the kerf width followed by discharge duration (38.36 %), wire drum speed (5.16 %), and interaction, discharge duration 9 discharge peak current (5.47 %). The pulse interval time had insignificant effect on the kerf width. In confirmation test, the average experimental value of kerf width (228.7 lm) was within an error of 2.56 % of the predicted value at the optimum level of process parameter.

Malik Shadab et al.[13] discussed that Metal matrix composites have become a vital concern for the modern manufacturing companies due to some of their special properties. The presence of reinforcement makes them difficult in machining operations to achieve industrial requirements. Therefore, it is necessary to optimize the machining process parameters to improve output performance in terms of product quality. The overall performance of the wire electrical discharge machining (WEDM) process is influenced by various parameters, such as pulse-on time, pulse-off time, induced current, and wire-feed. WEDM is one of the non-traditional machining processes. During machining of composites, material removal rate, cutting speed, and surface roughness have been considered. The relation between the process parameters and the output responses is developed by using linear regression analysis through Minitab-17. The experiments conducted are dependent on Taguchi L25 orthogonal array. The optimized sets of process parameters are obtained by using teaching and learning-based optimization.

K. Ravi Kumar et al.[14] stated that Wire electrical discharge machining is a broadly recognized unconventional machining process capable of accurately manufacturing rigid components with compound contours. Peak current, pulse-on time, pulse-off time, wire feed rate and filler percentage were used as variables to study the material removal rate and surface roughness. Analysis of variance technique is used to study the effect on material removal rate and surface roughness. Material removal rate is primarily influenced by filler % followed by peak current, pulse-off time, feed rate and pulse-on time, respectively. Surface roughness is highly influenced by peak current followed by filler %, pulse-off time, pulse-on time and feed rate respectively. Desirability-based multi-objective optimization was employed to optimize the process parameters.

S. Dinesh Kumar et al.[15] demonstrated that Metal Matrix Composite was produced using stir casting route and the mechanical properties of the composites were studied. The microstructure and elemental verification were done by using Scanning Electron Microscope (SEM) and Energy Dispersive X-Ray Spectroscopy (EDS). Among the various non-traditional machining processes, Wire Electrical Discharge Machining (WEDM) is an important process for machining MMCs. The objective of this work is to investigate the effect of Peak current (I), Pulse On-Time (Ton), Pulse Off Time (Toff) and Wire feed rate (WF) on the combined objective of maximum Metal Removal Rate (MRR) and minimum Surface Roughness (SR) during machining of hybrid composite using

Taguchi based Grey Relational Analysis (GRA). Results show that, maximum MRR and minimum SR can be achieved for the peak current (11 A), Pulse On-Time (112 μs), Pulse Off Time (45 μs) and Wire feed rate (7 m/min).

Devaraju Aruri et al.[16] stated that hybrid metal matrix composites are important materials used in marine, automobile, aerospace, structural, and entertainment fields because of their exceptional mechanical and physical properties such as lightweight, high strength, corrosion resistance, and elastic modulus. The effect of EDM input factors like current (Ip), pulse on time (Ton), pulse off time (Toff), and voltage (V) on the output factors such as material removal rate (MRR), surface roughness (Ra) and electrode wear rate (EWR) are studied. A response surface methodology (RSM) is employed for planning and the design of experimental layout and also to find output factors of EDM to acquire the maximum MRR, minimum SR, and TWR. The ANOVA result measures the most significant process parameters and their levels for performance factors. The final results are noted that Ip and Toff are more significant factors and, Ton and V is less significant.

Rm Sakthi Sadhasivam et al.[17] stated that Aluminium Matrix Composites are the most hopeful alternatives to many industrial and structural applications because of their good parental and inbuilt mechanical properties. This work deals with the machining of stir castAl6061 matrix reinforced with 6 wt% zinc oxide particle sample by Wire cut Electro Discharge Machining and investigate the effects of input factors such as pulse on time, wire feed rate and voltage over the responses metal removal rate (MRR) and surface roughness. Wire EDM machining is carried out with a varying pulse on time (4–6 ls), Voltage (50–80 V) and wire feed rate (2–6 m/min). By using TOPSIS approach, the optimal machining parameters are recommended. The optimized results suggest that higher MRR and lower surface roughness were accomplished with the combination of pulse on time, voltage and wire feed rate at 6 ls, 50 V and 4 m/min respectively.

V. Kavimani et al.[18] discussed about the examination and investigation on the impacts of Wire Electric Discharge Machining (WEDM) parameter on Material removal rate (MRR) and surface roughness (Ra) for the newly developed Magnesium metal matrix composite. Two material parameters (namely reinforcement wt.%, SiC doping %) and three machining parameters (viz. Pulse-On Time (P-ON), Pulse-Off Time (P-OFF), and Wire Feed Rate (WFD)) have been selected to study their effects on the desired output responses (MRR and Ra). The output response variables like MRR and Ra are then analyzed using Taguchi coupled Grey relation analysis. The general belief in any such investigations is that increase in P-ON increases MRR and the same has been revisited through this exhaustive study.

S. Suresh Kumar et al.[19] stated that aluminum based composites are widely used in various engineering applications. Though the processing of these materials is easy, it requires advanced machining techniques to cut the same as it becomes harder after the addition of ceramic reinforcements. The Wire Electrical Discharge Machining (WEDM) process is employed for cutting of Al-SiC-B4C hybrid metal matrix composites with the varying machining conditions. The machining factors, namely current (12A-20A), pulse on time (100μs-120μs), the wire feed rate (6mm/min – 10 mm/min) and the content of B4C (weigt percentage) in the composite are considered for the performance evaluation. A Response Surface Methodology (RSM), the multi-objective optimization technique is adopted for determining the influence of parameters on the machining features like kerf width and cutting speed.

Y.K. Lok et al.[20] discussed about processing of two advanced ceramics using Wire-Cut Electrical Discharge Machining (EDM) which is evolving as one of the promising method for the processing advanced ceramics. Two types of advanced ceramics, Sialon and AI203-TiC, were machined successfully by the Wire-Cut EDM process. The machining performance in terms of material removal rate and surface finish were compared under different cutting conditions. The extent of the surface damage resulting from this thermal machining process were evaluated further by the flexural strength data obtained from three-point and four-point-quarter bend test methods. The results showed that the Wire-Cut EDM process is a viable material processing method for the machining of advanced ceramics, but work have to be carried out to further study the ways and means of improving the surface finish and surface integrity of the machined ceramics.

Nagarajan Lenin et al.[21] reported that wire electrical discharge machining (WEDM) of aluminum (LM25) reinforced with fly ash and boron carbide (B4C) hybrid composites was performed to investigate the influence of reinforcement wt% and machining parameters on the performance characteristics. The hybrid composite specimens were fabricated through the stir casting process by varying the wt% of reinforcements from 3 to 9. In the machinability studies, the WEDM process control parameters such as gap voltage, pulse-on time, pulse-off time, and wire feed were varied to analyze their effects on machining performance including volume removal rate and surface roughness. The WEDM experiments were planned and conducted through the L27 orthogonal array approach of the Taguchi methodology, and the corresponding volume removal rate and surface roughness were measured.

Thanikodi Sathish et al.[22] reported that Wire Cut Electric Discharge Machining (WCEDM) is a novel method for machining different materials with application of electrical energy by the movement of wire electrode. For this work, an AZ61 magnesium alloy with reinforcement of boron carbide and silicon carbide in different percentage levels was used and a plate was formed through stir casting technique. The process parameters of the stir casting process are namely reinforcement %, stirring speed, time of stirring, and process temperature. The specimens were removed from the casted AZ61 magnesium alloy composites through the Wire Cut Electric Discharge Machining (WCEDM) process, the material removal rate and surface roughness vales were carried out creatively. L 16 orthogonal array (OA) was used for this work to find the material removal rate (MRR) and surface roughness.

Deepak Doreswamy et al.[23] stated that the mechanical, physical and interfacial properties of aluminum alloys are improved by reinforcing the silicon carbide particles (SiCp). Machinability of such alloys by traditional methods is challenging due to higher tool wear and surface roughness. The objective of research is to investigate the machinability of SiCp reinforced Al6061 composite by Wire-Electrical Discharge Machining (wire-EDM). The effect of wire-EDM parameters namely current (I), pulse-on time (Ton), wire-speed (Ws), voltage (Iv) and pulse-off time (Toff) on material removal rate (MRR) is investigated and their settings are optimized for achieving the high MRR. The experiments are designed by using Taguchi L16 orthogonal arrays. The MRR obtained at different experiments are analyzed using statistical tools.

P. Sivaprakasam et al.[24] discussed the effect of WEDM process parameters on the material removal rate (MRR) and surface roughness (SR) responses when machining hybrid composites (Al-Si12/boron carbide/fly ash) using the Taguchi technique. Fly ash and boron carbide (B4C) particles were used for reinforcement (3%, 6%, and 9% by weight), and aluminium alloy (Al-Si12) was used as a matrix material. ANOVA was used to find out the importance of machining factors that affect the quality features of the WEDM process, as well as the relative role of input parameters in determining the WEDM process' responses. The greatest impact on the response is finalised by the signal-to-noise (S/N) ratio response analysis. As the pulse on time and reinforcement increases, MRR also increases. As the gap voltage, wire feed, and pulse off time decrease, it increases. SR is increased by increasing the gap voltage, pulse on time, and pulse off time, wire feed, and reinforcement.

Dora Siva Prasad et al.[25] discussed the effect of different Wire electrical discharge machining (WEDM) process parameters on the damping behavior of A356.2 aluminum alloy is investigated. In the present investigation pulse on time (TON), pulse off time (TOFF) and peak current (IP) which are considered to be the most significant process parameters from the previous studies are varied using one factor at a time approach, to study the effect on damping behavior of A356.2 aluminum alloy. Damping experiments are performed on a dynamic mechanical analyzer (DMA 8000) at constant strain under dual cantilever mode over a frequency range of 1 to 100 Hz at room temperature. The scanning electron microscope was used for characterization of the wire EDMed samples.

Nithin Raj et al.[26] discussed about the optimal process parameter during machining and to study its influence on material removal rate (MRR) and surface roughness (Ra). The experiments were conducted on L9 orthogonal array by varying process parameters such as pulse on time (TON-115,120,125 µs), peak current (IP-100, 150, 200A) and wire feed rate (WF-2, 3, 4 mm/min). The trend of TON for MRR increased initially and then decreased, whereas for Ra, the trend is increasing. The relationship of IP and MRR initially decreased and then increased, whereas for Ra decreased steadily. The trend for WF was found to be linearly increasing for both MRR and Ra. Analysis of variance and S/N ratio revealed that the WF(98.19%) was the most significant parameter influencing MRR followed by TON and IP. TON(74.63%) was the most significant parameter influencing Ra followed by IP and WF.

Ashish Kumar Srivastava et al.[27] discussed the development of the metal matrix composite by mechanical stirring. Aluminium 6063 is reinforced by 5% of SiC (30 mm in size). The objective of this work is to examine the mechanical characterization of fabricated material (tensile strength and hardness). Further the study moves to evaluate the machinability behaviour of produced MMC using EDM. The result shows the produced MMC has improved hardness and tensile strength. The machining results indicate that all the process parameters have significant effect on material removal rate. It has been improved by 37.5% by using the optimum condition of process parameters.

Johny James.S et al.[28] stated that Hybrid metal matrix composites are advanced materials used for light weight high strength applications in aerospace and automobile sector. Among the various techniques employed in fabricating hybrid metal matrix composites stir casting technique is simple and economical. The metal matrix choice was Aluminium 6061and the reinforcements are Zirconium di oxide (ZrO2) and Aluminium oxide (Al2O3) respectively. The composite comprises of 90% of aluminium 6061, 5% of ZrO2 and 5% of Al2O3 which was restricted to 10 weight percentage in order to prevent cluster formation and to reduce weight. The average size of the reinforcing particle was 55-65 microns in order to attain good bonding with metal matrix. The developed composite casting was cut using wire EDM and test specimens were prepared. The various test consist of, micro graph study, tensile strength test, micro hardness test wear test and corrosion behaviour test.

III. MATERIALS AND METHODS

This section provides the details of specimen preparation and experimental set up used for the investigation, settings of wire-EDM process parameters, design of experiments, measurement of the response parameter and optimization methodology.

Experimental Set Up and Specimen Details

Figure[4] shows the details of experimental facility used in the present work. The experiments are performed using a 2-axis (X-320 mm, Y-400 mm) computer numerically controlled wire-EDM made by Concord wire-EDM, Bangalore, India (Model: DK7732). Zinc Coated wire (diameter: 0.16 mm) is used tool electrode during the experiments. Mixture of soft water and gel is used as dielectric fluid. The resolution of the controller is 0.001 mm. The Mg & Zn particle (size: 170 μm) reinforced Al-6061 alloy is prepared by stir-casting. The matrix material is liquefied at a temperature of 850 ∘C in a crucible and the reinforcing particles (5%,10%,15% and 30% by weight) are added to molten metal and distributed uniformly in the matrix by mechanical stirrer. The liquefied metal is transferred to pre-heated (at 200 ∘C) mold and then cooled to room temperature. General composition of Al6061 composite is shown in Table

Figure 4. Working of Wire EDM

Design of Experiment

Algorithmic Approach

In this work, the optimal input process parameters to simultaneously minimize the SR and maximize the VRR were identified using the Grass-Hooper optimization (GHO) algorithm. Because of the following characteristics of the GHO algorithm, as stated by Mirjalili et al.[29] and Saremi et al.[30], it was selected in this work.

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(a) Grasshoppers can effectively identify the assured areas of the available search space.

(b) The global search by the grasshoppers is carried out by the large-scale and unexpected changes in the preliminary steps of optimization.

(c) The exploitation of search space is permitted due to the local movement of grasshoppers in the final steps of optimization.

(d) The gradual balance of exploration and exploitation is used to find the precise approximation of the global optimum.

(e) The improvement of the average fitness of grasshoppers is used to enhance the initial random population.

(f) The approximation of the global optimum is very accurate relative to the number of iterations. Furthermore, the effectiveness of the GHO algorithm in this work was compared with the particle swarm optimization (PSO) [31] and moth-flame optimization (MFO) [31] algorithms. The pseudo-code for all the algorithms are given in Figure [5].

(a) Pseudo-code for GHO

```
Initialize the swarm Xi (i = 1,2,3,....,n)
Initialize Cmax, Cmin and itemax
Calculate the fitness of each agent
T = the best search agent
While (i/< itemax)
        update C
        For each search agent
                Normalize the distance between the
                grasshoppers
                Update the position of current search agent
                Bring the current search agent back
                if it goes outside the boundaries
        End for
        Update T if there is a better solution
        i = i + 1
End While
Return
```

(b) Pseudo-code for PSO

```
P = Particle Initialization ();
For i=1 to itrmax
        For each particle p in P do
                fp = f(p);
                If fp is better than f(pBest);
                        pBest = p;
                end
        end
        gBest = best p in P
        For each particle p in P do
                v = v + c1 *rand*(pBest – p) + c2 *rand*(gBest-P);
                p = p+v;
        end
end
```

(c) Pseudo-code for MFO

```
Initialize the parameters for Moth-flame
Initialize Moth position Mi randomly
For each i = 1 : n do
Calculate the fitness function fi
End For
While (iteration ≤ max_iteration) do
        Update the position of Mi
        Calculate the no. of flames
        Evaluate the fitness function fi
        If (iteration==1) then
                F = sort (M)
                        OF = sort (OM)
Else
                F = sort (Mt-1, Mt)
                OF = sort (Mt-1, Mt)
End if
        For each i = 1 : n do
                For each j = 1 : d do
                        Update the values of r and t
                        Calculate the value of D w.r.t. corresponding Moth
                        Update M(i,j) w.r.t. corresponding Moth
                End For
        End For
End While
Print the best solution
```

Figure 5. Pseudo-code (a)GHO,(b)PSO,(c)MFO

Measurement and Calculation of Output Responses

The selected process control factors were varied based on three levels, and machining experiments were carried out using the WEDM process. Each parameter had an impact on output responses such as VRR and SR. The output responses VRR and SR were measured as per the following procedure. The calculation of the VRR value is expressed in Equation (1).

$$VRR = CS \times W \times T \quad (1)$$

where CS is the cutting speed in mm/min; W is the width of the cut in mm; and T is the thickness of the workpiece in mm.

SR is the irregularity in the machined surface. The average value of the heights of all peaks and valleys on the machined surface was measured as SR. This was measured using the Mitutoyo Surface Roughness Tester. The experimental design for conducting the machinability study as per the L27 orthogonal array.

Optimization of Material Removal Rate

The experimental results were analyzed by statistical method called Analysis of variance (ANOVA) to identify the effect of Wire-EDM parameters namely current, pulse-on and pulse-off time, wire speed and voltage on

MRR. Significant process parameters are identified by conducting F-Test at confidence level of 95%. Further, the average MRR obtained at different settings (Level) is determined. The optimum conditions which generate the high MRR is established based on the levels which produce highest MRR corresponding to each process parameters of the study. The MRR at optimized condition is computed using Equations (2)–(5) [38]. Finally, a statistical model is developed using regression analysis to establish to predict the MRR.

neff = n 1 + DF (2)

T = ∑ MRR n (3)

MRROptimum = MRR[$A_3B_3C_1D_3E_2$] − 4 × T (4)

Confidence interval = ±(s F(α, DFerror) × MSerror /ne f f)½

IV. CONCLUSION

A technique of using electrical discharge machining is wire electrical discharge machining. In WEDM, a moving wire along its axis was used to reduce the impact of tool electrode wear. This wire typically unwinds from one storage roller and is wound on another roller. The creation and growth of numerical control subsystems have greatly aided the spread of the WEDM process. The WEDM process is currently the subject of a flurry of study that is being conducted from a variety of angles. A quick statistical study showed the high level of interest in scientific investigation, application, and WEDM process optimization. The overall goals of the research were to increase the potential applications of WEDM and enhance the efficiency of the WEDM procedures. As a result, some research has sought to enhance the WEDM system's many components. It is noted that WEDM processes are evolving. In an effort to use the WEDM process with a variety of materials, including those with very poor electrical conductivity, workpieces constructed of these materials were machined. The identification and characterization of input components' actions in the WEDM process has been the topic of numerous research studies. The productivity of the process, the precision and roughness of the machined surfaces, the thickness of the heat-affected zone, the wear on the tool electrode, and the kerf width were all taken into consideration as output metrics. Efforts to optimize the WEDM process were made after gaining a better understanding of the impact that the process input elements had on the values of the output parameters. Although monocriterial optimization was attempted, multicriteria optimization techniques were more frequently used. Modern mathematical techniques were used to create mathematical models for both the investigation of the impact of input elements on the values of output parameters and the research to optimize the WEDM process. The literature review revealed a marked rise in the quantity of papers published in recent years that address problems with the WEDM process. In the upcoming years, it is anticipated that this tendency will continue. According to consensus, future efforts will focus on examining the viability of utilizing new WEDM iterations as well as on applying this method to the machining of newly discovered materials. Additional attempts to improve the WEDM processes are also anticipated, along with brand-new specifications unique to the Industry 4.0 phase.

V. REFERENCES

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