Machinability Analysis And Optimization In Wire EDM For Aluminum Alloy 6061: A Review

Mr. Manojkumar Kate[1], Mr Pratik Malpure[2], Mr Rohan Shinde[2], Mr Prajwal Kshirsagar[2], Mr Ajit Misal[2]

Department of Mechanical Engineering , " Nutan Maharashtra Institute of Engineering & Technology", Talegaon ,Pune Maharashtra 410507.

ABSTRACT

Wire Electrical Discharge Machining (EDM) has emerged as a prominent machining process due to its capability to fabricate intricate shapes on conductive materials with high precision. This research focuses on investigating the machinability of Aluminum Alloy 6061 using Wire EDM and optimizing the process parameters to enhance machining efficiency and surface quality. The study begins with a comprehensive analysis of the machinability characteristics of Aluminum Alloy 6061, including its mechanical properties, thermal conductivity, and electrical conductivity. Experimental trials are conducted to evaluate the influence of key process parameters such as pulse-on time, pulse-off time, wire tension, and flushing conditions on material removal rate (MRR), tool wear rate (TWR), and surface roughness. Through systematic experimentation and statistical analysis, optimal process parameters are determined to maximize MRR while minimizing TWR and surface roughness. Advanced techniques such as response surface methodology (RSM) and Taguchi method are employed to establish mathematical models correlating process parameters with machining performance indicators. Furthermore, the study explores the effects of different dielectric fluids, electrode materials, and wire diameters on machining characteristics to identify the most suitable combinations for achieving superior machining outcomes. Additionally, the environmental impact and economic feasibility of the optimized Wire EDM process are assessed. The findings of this research contribute to enhancing the understanding of Wire EDM of Aluminum Alloy 6061 and provide practical insights for optimizing the machining process in industrial applications. By improving machining efficiency and surface quality, the proposed methodology can potentially lead to significant advancements in the manufacturing of precision components using Aluminum Alloy 6061.

Keywords - Wire Electrical Discharge Machining (EDM) ,Aluminum Alloy 6061 ,Optimization , Machining Parameters , Surface Quality

INTRODUCTION

Wire Electrical Discharge Machining (Wire EDM) is an important part of modern manufacturing. Wire EDM is mainly used for machining hard materials and performing high-precision cutting processes. This process is also known as electro-erosion and spark machining. Wire EDM doesn't touch the workpiece, which helps reduce stress and distortion. This method is great for making complicated shapes, sharp corners, and small details. Many industries, like aerospace, automotive, medical, and precision engineering, use Wire EDM to make parts with high accuracy and a smooth finish. Wire EDM helps make manufacturing faster, waste less material, and work more efficiently. The paper focuses on improving the Material

Removal Rate (MRR) in Wire-EDM specifically for aluminium alloy 6061. While many studies have investigated Wire Electrical Discharge Machining (EDM) for materials like titanium alloys, alloy steel, and metal matrix composites, there is limited research on EDM for aluminium alloy. The study seeks to fill this gap and improve the efficiency of Wire-EDM processes for Aluminium alloy 6061

The research aims to improve Wire-EDM productivity by optimizing process parameters and predicting Material Removal Rate (MRR) for different setups. Also, it checks the quality of the surface and looks for any holes or cracks that might happen during cutting. The results of this study can help make Wire-EDM machines work faster and better for making parts from Aluminium alloy 6061. In our investigation of Wire-EDM on 6061 aluminium alloy, we used the Taguchi experimental design method. Pulse on time, pulse off time, voltage, ampere, and wire tension were considered as input parameters, while surface roughness and cutting speed served as output parameters. The important performance is surface roughness (Ra) which determines the surface texture of the workpiece, and it is measured using a precision roughness tester. The main goal of this research work is to minimize surface roughness.

Measuring surface roughness is an important quality control step that can greatly affect how well a product works and how long it lasts. For example, in mechanical parts, if the surface is very rough, it can cause more friction, faster wearing out, and the part breaking early. On the other hand, if the surface is too smooth, it might not keep enough lubrication, which could also make it wear out faster because of more friction. The study aimed to understand the effect of pulse on time and wire tension on the material removal rate and surface finish, as well as to analyse the impact of pulse on time on surface roughness. The researchers also wanted to see how changing the pulse on time affected the surface roughness. The study wanted to see how 6061 aluminium behaves during wire EDM which is widely used in various industries. By understanding the different input parameters, the study aims to provide insights for improving the accuracy and surface finish of the workpiece in Wire-EDM machining.

LITERATURE REVIEW

This study involves the effect of parameters such as I, ton, toff on machining of 4 wt. % to 8 wt. % SiCp—Al6061 alloy by wire-EDM. These parameters are optimized to improve the MRR. The model from statistical data generated is useful for predicting the MRR for different settings of the process parameters. The optimized settings can be used to improve the productivity by increasing the MRR while machining of Al6061-SiCp (up to 8 wt. %) alloy by wire-EDM industries. The following conclusions are getting based on the results obtained.[1]
The study investigates the impact of parameters on kerf width and surface roughness in machining operations, employing Taguchi optimization. By optimizing factors like pulse on time (Ton), pulse off time (Toff), servo voltage (SV), and wire tension (WT), the research aims to achieve desired outcomes in kerf width and surface roughness. These parameters are crucial in minimizing kerf width and enhancing surface quality during cutting processes. The utilization of Taguchi optimization enables the determination of optimal input combinations for achieving desired machining results, contributing to improved efficiency and quality in manufacturing operations. [2]
In wire EDM (Electrical Discharge Machining), the optimization of parameters like Ton (pulse on time), Toff (pulse off time), SV (servo voltage), and WT (wire tension) is crucial for achieving desired outcomes such as minimizing kerf width and surface roughness. Higher wire tension leads to reduced surface roughness due to steadier machining, while longer pulse on times increase wear on the wire electrode. Conversely, higher tension decreases wear. Additionally, progressive wear of the wire electrode results in tapered slots, with the taper increasing alongside electrode wear. These findings underscore the intricate interplay of parameters in wire EDM and highlight the importance of precise parameter optimization for optimal machining results.[3]
This study investigates the optimization of wire-EDM parameters for machining SiCp—Al6061 alloy, focusing on Material Removal Rate (MRR) enhancement. Significant influences of current, pulse parameters, wire speed, and voltage on MRR are noted, with optimum settings identified. Although SiCp addition up to 8% shows minimal impact on MRR, surface quality is affected by the formation of craters and recast layers. A statistical model with a 73.65% average R^2 is developed for MRR prediction within specified operating ranges. Additionally, the model demonstrates minimum and average prediction errors of 4.45% and 20.46%, respectively. Future directions suggest exploring advanced optimization methods to further refine prediction accuracy in wire-EDM processes.[4]

EXPERIMENT

I. Machine Details

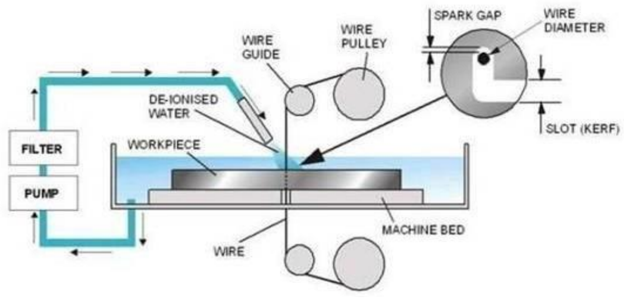

Fig No -1 Wire EDM setup

Wire Electrical Discharge Machining (Wire EDM) is a precision machining process utilized for cutting conductive materials with high accuracy. In this method, a thin, electrically conductive wire is used as an electrode to create precise cuts in the workpiece. The wire is guided along a programmed path, typically controlled by computer numerical control (CNC) systems. During machining, a series of electrical discharges, or sparks, occur between the wire electrode and the workpiece, eroding material to form desired shapes. Wire EDM is widely used in industries requiring intricate and precise parts, such as aerospace, automotive, and medical device manufacturing. It offers advantages like minimal tool wear, high accuracy, and the ability to cut complex shapes without inducing mechanical stresses. Additionally, the process is suitable for a wide range of materials, including metals, alloys, and even some non-conductive materials when combined with special techniques like wire threading or flushing with dielectric fluid. Overall, Wire EDM stands as a versatile and efficient machining solution for producing intricate components with high precision.

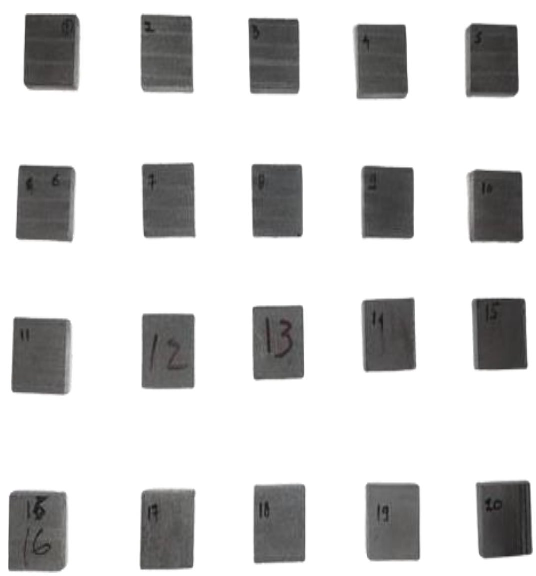

Fig No -2 Work piece samples

II. EDM Components and Features

1. Worktable: The worktable provides the platform on which the workpiece is securely mounted during the machining process. It may have linear or rotary motion capabilities to facilitate the movement of the workpiece during machining.

2. Wire EDM Power Supply: The power supply generates the high-frequency electrical pulses required for the EDM process. It controls the intensity, duration, and frequency of the electrical discharges between the wire electrode and the workpiece.

3. Wire Feed Mechanism: The wire feed mechanism advances the thin metallic wire electrode continuously during the machining process. It ensures a constant feed rate and maintains tension in the wire to ensure accurate cutting.

4. Wire Guide System: The wire guide system guides the wire electrode from the wire spool to the workpiece with precision. It consists of pulleys, rollers, and guides that prevent the wire from bending or deviating from its intended path.

5. Dielectric Reservoir and Pump: Wire EDM machining is conducted in a dielectric fluid, typically deionized water or specialized EDM oils. The dielectric fluid serves multiple purposes, including flushing away debris, cooling the workpiece and electrode, and facilitating the electrical discharge process. The reservoir stores the dielectric fluid, while the pump circulates it through the machining zone.

6. Control System: The control system comprises a computerized interface that allows the operator to input machining parameters such as wire feed rate, voltage, and pulse duration. It monitors and regulates various aspects of the machining process in real-time, ensuring accuracy and consistency.

7. Machining Head: The machining head houses the wire electrode and the nozzle through which the dielectric fluid is delivered to the machining zone. It may have vertical and horizontal movement capabilities for precise positioning of the wire electrode relative to the workpiece.

8. CNC (Computer Numerical Control) System: Many modern Wire EDM machines are equipped with CNC systems, which enable automated operation and programmable control of the machining process. CNC functionality allows for the creation of complex part geometries with high precision and repeatability.

III. Optimizing Process Parameters

1. Pulse-On Time (Ton) and Pulse-Off Time (Toff):
- Ton determines the duration of the electrical discharge, affecting material removal rate.
- Toff controls the interval between successive pulses, allowing for flushing and cooling, influencing surface roughness.
- Optimization involves finding the right balance between Ton and Toff to maximize material removal rate while minimizing surface roughness.

2. Peak Current (Ip) and Voltage (V):
- Ip and V determine the intensity of the electrical discharge, affecting material removal rate and surface roughness.
- Higher Ip and V generally lead to increased material removal rate but may also result in higher surface roughness.
- Optimization involves adjusting Ip and V to achieve the desired balance between material removal rate and surface roughness.

3. Wire Tension and Feed Rate:
- Wire tension affects wire stability and accuracy, influencing machining precision and surface finish.
- Feed rate determines the speed at which the wire electrode advances, impacting material removal rate and surface roughness.
- Optimization involves fine-tuning wire tension and feed rate to achieve optimal machining performance without compromising surface quality.

IV. Chemical Composition of Aluminum alloy 6061

Element	Percentage (%)
Aluminum (Al)	97.9 - 98.9
Magnesium (Mg)	0.6 - 1.2
Silicon (Si)	0.4 - 0.8
Iron (Fe)	0 - 0.7
Copper (Cu)	0.15 - 0.4
Zinc (Zn)	0 - 0.25
Titanium (Ti)	0 - 0.15
Manganese (Mn)	0 - 0.15
Chromium (Cr)	0.04 - 0.35
Others	0 - 0.05

REFERENCE

1. Devkumar ,V. Sreedhar ,E., Prabakaran M. P. Optimization of machining parameters on AL 6061 alloy using response surface methodology. *International Journal of Applied Research 2015; 1(7): 01-04.*
2. Elatharasan, G., Senthil Kuma, V. S. An experimental analysis and optimization of process parameter on friction stir welding of AA 6061-T6 aluminum alloy using RSM. *Procedia Engineering 64 (2013) 1227 – 1234*
3. .Monica , v., Lakshmikanth , g., Lathicashree , s., Senthilkumar , n., Muniappan ,a. & Deepanraj, b. an experimental analysis and optimization of heat treatment parameters of al6061 alloy for improved mechanical properties.*International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN(P): 2249–6890; ISSN(E): 2249–8001 Vol. 9, Special Issue, Aug 2019, 46-59 © TJPRC Pvt. Ltd.*
4. Akinwande, A,A, et.al. Microstructure, Process Optimization, and Strength Response Modelling of Green-Aluminium-6061 Composite as Automobile Material. *Ceramics 2023, 6, 386–415.*

5. Adediran, A, A., et.al. Modeling and optimization of Green-Al 6061 prepared from environmentally source materials. *Heliyon 9 (2023) e18474.*

6. .Mandal, K.,Sarkar, S.,Mitra, S.,Bose, D. Analysis of Wire-EDM Input Parameters on Kerf Width and Surface Integrity for Al 6061 Alloy. *Innovation in Materials Science and Engineering Proceedings of ICEMIT 2017, Volume 2*

7. Mythili, T. and Thanigaivelan R. Optimization of wire EDM process parameters on Al6061/Al2O3 composite and its surface integrity studies. *Bulletin of the polish academy of sciences technical sciences, vol. 68, no. 6, 2020*.

8. Pramanik, A., Basak, A. K., Islam, M. N., Littlefair, G. Electrical discharge machining of 6061 aluminium alloy. *Trans. Nonferrous Met. Soc. China 25(2015) 2866−2874*

9. Doreswamy ,D., et.al. Optimization and Modeling of Material Removal Rate in Wire-EDM of Silicon Particle Reinforced Al6061 Composite. *Materials 2021, 14, 6420.*

10. Rawat, R. K. & Saif , M. Investigation of aluminum alloy 6061 in Wire-EDM regarding surface roughness and material removal rate by adopting optimization techniques. *Journal of Mechanical Engineering and Sciences Vol. 17, Issue 1 (2023)*

11. Tiwari, S. & Saif, M . Optimization of Wire-cut EDM of Aluminum alloy 6061 using Taguchi's approach for maximizing MRR. *JETIR August 2020, Volume 7, Issue 8*

12. Kandpal, B. C., Kumar, J & Singh, H. Optimization and characterization of EDM of AA 6061/10%Al2O3 AMMC using Taguchi's approach and utility concept. *Production & Manufacturing Research, 2017 VOL. 5, NO. 1, 351–370*

13. Meenakshi, S, Dr.Baraniraj , A ., Dr. Jamuna, R .,Dr. Lavanya , D ., Kavitha.K , Harihara, S. Optimization of Process Parameter for Aluminium Alloy 6061 and 7075 Processed in Wire-Cut EDM. *International Journal of Research Publication and Reviews, Vol 4, no 1, pp 523-529, January 2023*