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Investigation of the dielectric for electrical discharge machine of nickel-based superalloy

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Abstract

Over the past two decades, the advancement of metals and alloys with increased difficulty in manufacturing and processing has presented challenges for researchers in the manufacturing sector. This surge in demand is particularly prevalent in technologically advanced industries such as nuclear reactors, automobiles, and aeronautics, necessitating high strength temperature resistant (HSTR) materials with significant strength-to-weight ratios. Materials science scholars are actively engaged in developing materials with enhanced strength, hardness, and durability, which also drives the need for advancements in cutting instrument materials to maintain productivity. Despite recent technological progress, conventional machining methods struggle with processing HSTR alloys, die steels, and complex shapes. Consequently, there is a growing imperative to adopt more recent developments in metal machining, often referred to as unconventional or sophisticated machining processes, where direct energy is utilized instead of conventional tools. Electric Discharge Machining (EDM) is one such process, notable for its ability to achieve precise machining through the use of electrical discharges to erode conductive materials. This paper examines the mechanism, capabilities, advantages, and limitations of EDM, as well as its applications, focusing on the machining of superalloys like Inconel. Additionally, Powder Mixed Electric Discharge Machining (PMEDM) is explored as a hybrid process to enhance machining capabilities and surface quality. The study encompasses experimental investigations on various machining parameters and materials to optimize EDM performance, offering insights for future research in this domain.

Keywords: Electrical discharge machining (EDM), nickel-based superalloys

Introduction

In the past two decades, the development of metals and alloys that are more difficult to manufacture and more difficult to work with has increased at a rapid rate. Researchers in the manufacturing sector are confronted with an increasing number of obstacles as technology advances. Industries that are technologically advanced, including nuclear reactors, automobiles, and aeronautics, have developed a need for high strength temperature resistant (HSTR) materials that possess a significant strength to weight ratio. Scholars specializing in materials science are engaged in the development of materials that possess an array of qualities, including increased strength, hardness, and durability. Additionally, this necessitates the advancement of cutting instrument materials to prevent any hindrance to productivity. A reduction in cutting speed occurs when the hardness of the work material is increased during conventional machining. Moreover, despite recent technological advancements, these machines are still incapable of processing HSTR alloys, die steels, and complex rigid shapes.

Given the gravity of this issue, it is imperative that more recent developments in metal machining be implemented. Thus, the more recent machining process is often referred to as an unconventional machining process or a sophisticated machining process. The unconventional aspect of the term derives from the fact that conventional tools are not employed in the process of metal cutting; rather, direct energy is utilized. The categorization of these contemporary processes is based on the fundamental machining energy utilized.

Process capabilities

When a number of sparks are generated across the surface during the EDM machining process, a number of small cavities are produced and distributed across the surface. The magnitude of the crater formed is proportional to the amount of energy discharged by the explosion. Greater crater formation occurs when the energy is elevated, leading to a substandard surface finish.

Due to the thermal nature of the procedure, material characteristics such as toughness, hardness, and strength have no bearing on the material removal rate (MRR). The MRR is influenced by the frequency of discharge, the energy per discharge, the current, and the voltage. The surface roughness (SR) and MRR increase as the current density rises, whereas they decrease as the spark frequency falls. Additionally, increased MRR causes an uneven cut surface and diminished fatigue properties. In order to achieve an optimal surface finish, it is necessary to remove the recast layer with a distinct surface finish. A comparison of the processing capabilities of unconventional machining techniques is presented in Table-1. It is evident from the table-1 that EDM possesses commendable process capabilities in comparison to CHM and ECM.

Once the off-time is adaptively controlled to achieve complete gap deionization, only then will the pulse ahead be activated. By eliminating arcing automatically, this control enables the process to operate at a higher pulse duty factor while maintaining stable machining conditions.

The absence of direct contact between the instrument and the work piece results in the elimination of mechanical stresses.

Table 1: Process Economy of Conventional and Non-Conventional Machining Processes

Process	Capital investment	Tooling and fixtures	Power requirement	Efficiency	Tool consumption
USM	B	B	B	D	C
AJM	A	B	B	D	B
ECM	E	C	C	B	A
CHM	C	B	D	C	A
EDM	C	D	B	D	D
EBM	D	B	B	E	A
LBM	C	B	A	E	A
PAM	A	B	A	A	A
Conv. machining	A	B	A	A	A

Electric discharge machining (EDM) process

Virtually all EDM devices are composed of a base, a column, and a head, arranged in a vertical C-shape. The column is permanently affixed to the base and serves to support the cranium. The base typically accommodates a coordinate table, which either directly or indirectly supports the work piece. A dielectric reservoir is constructed around the table, featuring an automatic level controller. Additionally, it is outfitted with a safety mechanism that interrupts operation when the temperature surpasses a specified threshold. Nevertheless, proper circulation and purging of the dielectric fluid must be maintained. In order to sustain fluid recirculation, a pump in conjunction with a filter is employed. The schematic diagram of the EDM process is depicted in Figure-1.

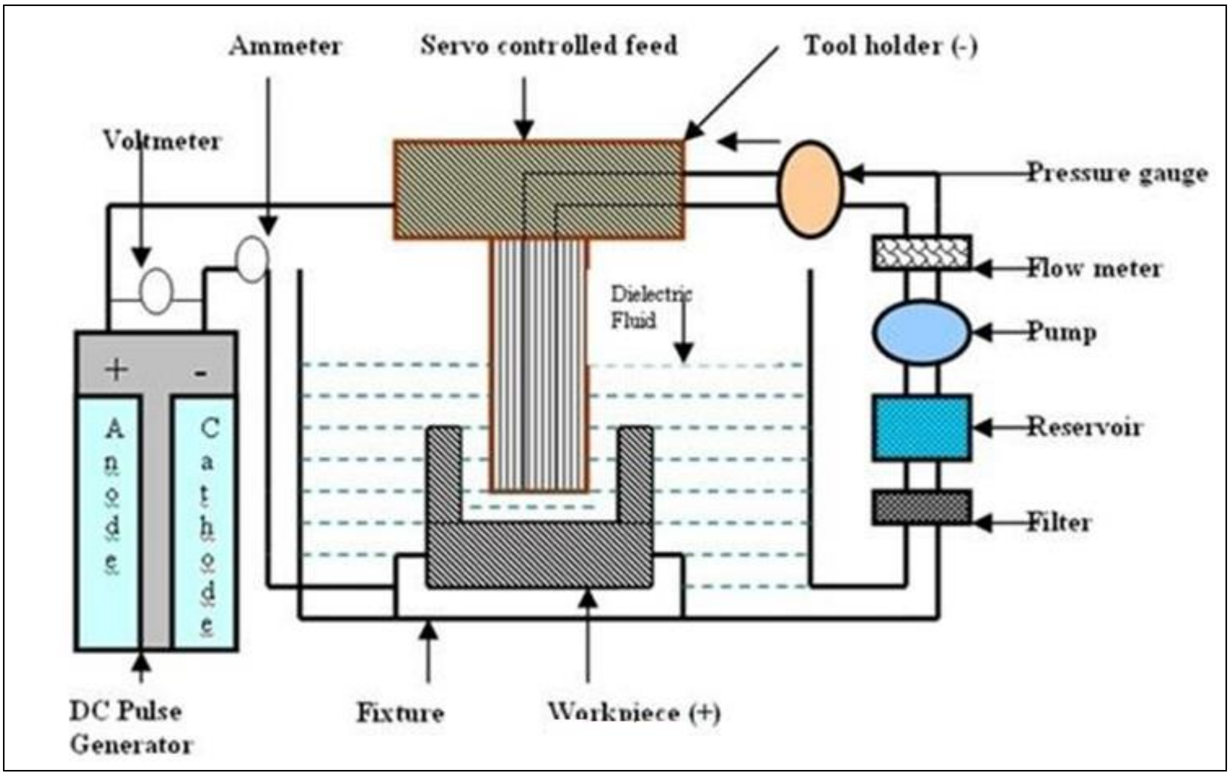

Fig 1: Schematic diagram of EDM experimental setup

Utilizing spark heat energy, it is a thermoelectric procedure that eliminates the substance from the workpiece. Furthermore, this technique is referred to as "non-conventional machining" due to the utilization of spark energy to erode metal rather than relying on chip-forming cutting instruments. In essence, it is a highly precise machining procedure in which electrical discharges are utilized to create features in a workpiece composed of a typically conductive material. EDM consists of two electrodes, one of which is the workpiece, which are partitioned apart by a dielectric liquid, which is commonly deionized water or oil. A current flows across the dielectric when the field strength between the two electrodes reaches a sufficient level, resulting in the removal of material from both electrodes. The instantaneous current flow between the electrodes generates particles that are subsequently removed by the fluid. By repeating this process, a precisely manipulated feature can be eroded that would be unattainable using conventional machining techniques.

Mechanism for Metal Removal

Figure presents a schematic representation of the metal removal mechanism, whereas Figure depicts the motion of the particulates comprising the tool and the work material, respectively. Both the instrument and the workpiece are submerged in the dielectric fluid during this procedure. Dielectric fluids include deionized water minerals, petroleum oil, and others. By facilitating the clearance of the inter-electrode gap, dielectric fluid aids in the cooling of both the workpiece and tool-electrode, as well as the concentration of spark energy within a narrow region situated between the two components.

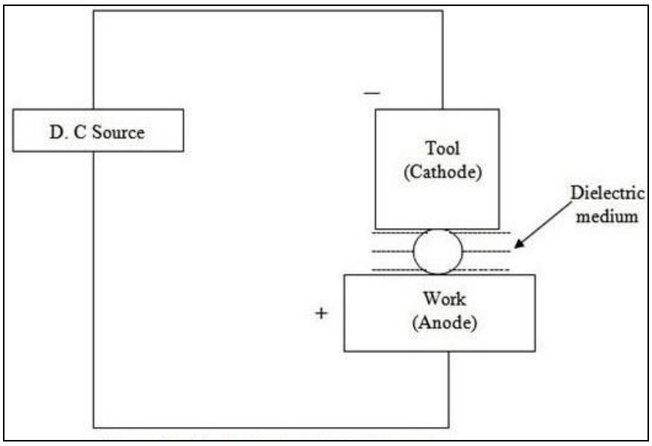

Fig 2: Mechanism of Model Removal

When voltage is supplied to the tool electrodes, a potential intensity of electric field accumulates across them in accordance with a predetermined value. As illustrated in Figure-2, this causes individual electrons to detach from the cathode surface and be compelled to move towards the anode due to the field force. Figure-3 illustrates the motion of particles comprising the work material and the tool. While traversing the inter-electrode distance, electrons encounter neutral dielectric molecules through collisions. The detachment of electrons from these substances results in ionization.

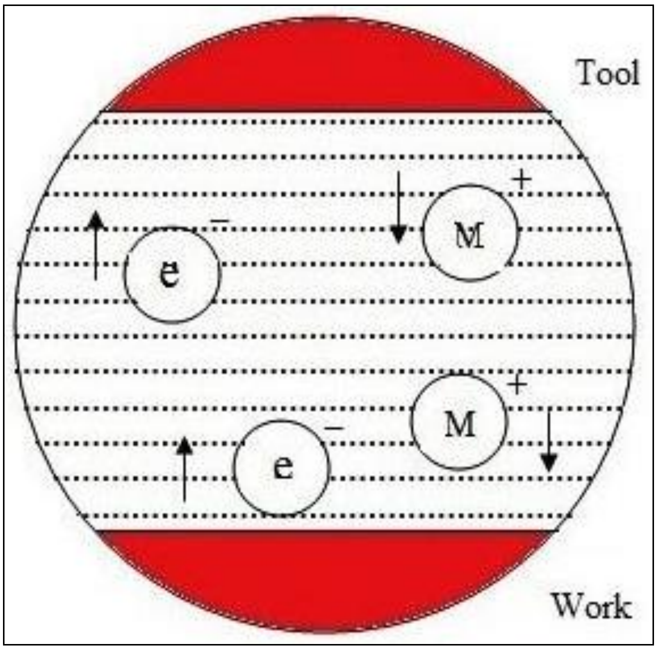

Fig 3: Movement of tool and work material particles

Ionization eventually results in the formation of a narrow channel characterized by continuous conductivity. A momentary discharge results from the substantial passage of electrons along the channel to the anode when this occurs. The spark energy induces a localized increase in temperature between 8000 and 12,000 degrees Celsius, or as high as 20,000 degrees Celsius, which results in the melting or simultaneous vaporization of material at the surface of each pole. The explosive pressure of the gaseous products in the discharge disperses the metal in the form of liquid droplets into the area surrounding the electrodes. The consequence of this is the development of a minor depression at the location where the work piece is expelled.

The rate of material removal is contingent upon the subsequent variables

- The velocity and stability are influenced by the off-time and peak amperage or spark intensity.
- The length of the on-time
- Duty cycle: the proportion of on-time operations in relation to the total cycle time. -Gap distance: a narrower gap corresponds to a slowing material removal rate but improves accuracy.

Applications of EDM

EDM is a thermoelectric procedure that removes material from the workpiece using spark heat energy. Furthermore, this technique is referred to as "non-conventional machining" due to the utilization of spark energy to erode metal rather than relying on chip-forming cutting instruments. It has supplanted the conventional machining processes that are prevalent across numerous industries. In the aerospace, automotive, mold, tool, and die manufacturing sectors, EDM is extensively employed. Hard carbides and heat-treated steels, which are challenging to manufacture materials utilized in the space industry, are among the many areas where EDM is being implemented.

Examples of item-shaped EDM applications include

- Fixtures, gauges, and dies.
- Tools for calibrating. Tools for cutting.
- Mold dies for plastics.
- Producing forging dies, including those for forging connecting rods, etc.
- Carbide shaping tool and templates.
- In the automotive, aerospace, and electronics sectors, where quantities produced are comparatively modest.
- Within the medical industry, such as hardware, surgical screws, fasteners, and jaw reamers utilized in dental implants, as well as support apparatuses for the knee, shoulder, and hip joints.
- Components for the aerospace and aircraft industries, including turbine blades, gyroscopes, satellite structural elements, jet engine blade sets, turbine diffusers, missile fin deployment actuator housing, and aircraft airframes. Components for the automotive industry, including fuel metering valves, engine mountings, gears, and rear housing systems.
- Because EDM is a non-contact machining technique, it is ideally suited for fabricating delicate components that cannot withstand the duress of machining. Parts such as agitators for laundry machines, electronic components, and printer parts are compatible with these profiles.
- Typical uses include cam wheels, watch components, collets, and keyways.

Advantages of EDM

Electrical discharge machining (EDM) is becoming an increasingly popular technique for machining precision components. It is a well-established supplementary technique to conventional manufacturing methods such as Swiss turning and milling, and is particularly suitable for fabricating mechanical components, gears, and quick-turn prototypes that are geometrically intricate and require high precision. The primary benefits of EDM are

- It facilitates the production of intricate designs that would be challenging to produce using traditional cutting instruments.
- Machining of exceptionally rigid and rare materials to immaculate tolerances in order to fabricate mechanical components requiring high precision.
- undergoing machining without the use of burrs.
- The procedure is deemed complete when polishing is no longer necessary.
- Weak materials can be machined without undergoing any deformation due to the absence of direct tool-workpiece contact.
- Because there is no direct contact between the tool and the work material, no forces are applied during the machining process; consequently, no residual stresses are produced.
- Suitable for use with any material exhibiting a moderate level of electrical conductivity.
- Molds, complex die sections, and rapid, cost-effective production are all that are required.
- Smooth surface finishes are achievable.
- Very small workpieces for which excessive tool pressure with a conventional cutting tool could severely injure the component.

Limitations of EDM

- In the course of machining, generate a firm recast layer.
- Fine fractures may be present on the surface as a result of thermal stresses.
- Machine-generated fume has the potential to be toxic.
- Generated a zone that was thin, brittle, and susceptible to heat.
- Slow material removal rate, limiting the process's economic viability to materials that are exceptionally difficult to manufacture and extremely hard.
- In order to optimize production costs, the specified surface texture should not be excessively fine.
- Capable of machining only conductive materials.

Powder mixed electric discharge machining (PMEDM)

The EDM process is effective for machining electrically conductive materials of any type, irrespective of their hardness, strength, or durability. The primary disadvantages of this machining method are its low MRR and subpar surface finish, which prevent its widespread application in the manufacturing sector. Furthermore, its application becomes especially pronounced when intricate designs are to be created on extremely rigid materials, such as superalloys, with precise dimensions and geometry. Superalloys have found widespread implementation in various sectors, including but not limited to gas turbines, submarines, nuclear reactors, rocket engines, and petroleum facilities. The exceptional surface stability and ability of superalloys to retain high strength even after prolonged and continuous exposure to extremely high temperatures are among their novel characteristics. In contemporary times, scholars have placed significant emphasis on the enhancement of machining performance in conjunction with purposeful surface treatments. PMEDM is a hybrid manufacturing process that is implemented to augment the machining process's capabilities in this regard. In this regard, the dielectric fluid's supplemented powder particles also alter the surface properties of the machined components, thereby enhancing their surface quality.

PMEDM is comprised of a distinct tank measuring (1100×980×1000) mm in size, which is positioned within the primary tank of EDM. A distinct vessel is utilized for machining, which is refilled with dielectric fluid. In order to prevent particles from accumulating, a stirrer mechanism is implemented. A diminutive dielectric circulation pump is implemented to ensure that the powder-mixed dielectric fluid is adequately circulating within the discharge gap. During machining, both the pump and the stirrer assembly are contained in the same vessel. To guarantee that all powder is completely suspended in the discharge gap, the distance between the suction point and the nozzle outflow is minimized even further. The detritus particles were segregated from the dielectric fluid through the application of magnetic forces. In order to segregate the particles of detritus, two magnets are positioned at the machining tank's base. The space between sparks is occupied by powder particles. An electric current is generated when a voltage is applied between the electrode and the workpiece with a minimum distance of 25–50 µm between them.

Super alloys

The designation "superalloy" is bestowed upon alloys characterized by exceptional resistance to oxidation and high-temperature strength. The development of superalloys has been motivated by the requirement for a category of lightweight and durable materials in the production of aircraft engines and airframes. Superalloys are utilized at a greater percentage of their actual melting point than any other category of metallurgical materials that are widely available for purchase. They are the materials that have enabled a significant portion of our extremely high-temperature engineering technology, as well as the cutting edge of aircraft engines.

Through the 1980s, contemporary superalloys emerged. Aluminum, titanium, tantalum, and niobium are incorporated into the superalloys of the first generation so as to enhance the γ' volume fraction. For the purpose of strengthening the alloy, γ' phase is employed. Superalloys of the initial iteration consist of PWA1480, René N4, and SRR99, among others. With the introduction of single crystal solidification techniques for superalloys, which eliminate grain boundaries wholly from a casting, the volume fraction of γ' precipitates increased to approximately 50–70%. In order to enhance the thermal capabilities, superalloys of the second and third generations were formed by incorporating 3% and 6% (Re) rhenium by weight, respectively. Re exhibits a low diffusion rate and tends to partition into the γ phase matrix, resulting in a 30 °C reduction in diffusion and a 60 °C increase in service temperatures for superalloys of the second and third generations, respectively. Moreover, the tendency of Re to facilitate the development of brittle TCP phases has prompted the reduction of Co, W, Mo, and specifically Cr.

Cr content has been substantially diminished in more recent iterations of Ni-based superalloys; nevertheless, this reduction in Cr also results in a decline in oxidation resistance. Presently, sophisticated coating techniques are employed to compensate for the oxidation resistance loss that results from the reduction in Cr content. Superalloys of the second generation consist of PWA1484, CMSX-4, and René N5. Alloys of the third generation consist of René N6 and CMSX-10.

These alloy groups are utilized due to their exceptional resistance to corrosion and high temperature tolerance. Nickel-based superalloys comprise balanced alloying elements, including but not limited to titanium, aluminum, and cobalt. Predominantly constituents that are achieved through meticulously regulated solidification processes to ensure an ideal direction of solidification. At 1000 °C, the strength of these components may surpass that of standard steel at ambient temperature. They are vital in the most elevated temperatures of gas turbines, which are utilized in aircraft and power generation. Utilizing casting technologies, forged turbine blade components were introduced in the 1950s. This procedure substantially enhanced the material's purity, decreased the number of defects, and increased its strength and temperature resistance.

Inconel material, specifically nickel-based superalloys, finds extensive application in heat exchangers, reactor vessels, and seawater piping.

- Orthopaedic applications, including prostheses and implants.
- Components of aircraft engines and airframes.
- Wheelchairs, handrails, buildings, structures, and monuments, fish breeding cages, marine chemical components, and condenser ducting.
- Titanium finds application in cardiac valves.
- The Apollo capsules and numerous space shuttle components are composed primarily of pure titanium.
- The metal is utilized in the fabrication of automobile accessories, sports equipment, portable computers, and engine components.

Scope of the work

The work material for this study consists of two grades of Inconel, Inconel-600 and Inconel-800. Three distinct electrode materials-copper (Cu), copper-chromium (Cu-Cr), and graphite (Gr)-have been chosen to facilitate the machining of these grades of Inconel. In addition to the dielectric fluid, three different varieties of powder particles-tungsten carbide, boron carbide, and cobalt-were combined in order to examine the enhancements in the responses. As a dielectric fluid, die-sinking EDM technology makes greater use of petroleum oil that is commercially available. However, the most significant issue is air pollution.

Table 2: Chemical Analyses (%) of Work Materials and Electrode Materials

Elements	Inconel-800	Inconel-600	Copper	Copper- chromium
Ni	Base material	Base material	0.0083	0.0104
Fe	39.5	7.78	0.109	0.0319
Cu	< 0.75	0.5	99.7	98.4
Si	< 1	0.5	< 0.0050	< 0.0050
Ni	Base material	Base material	0.0083	1.36
Cr	20.5	14.56	0.0061	< 0.0020
Al	-	-	< 0.0020	< 0.0020
S	< 0.015	0.015	< 0.0020	< 0.0050
Bi Sb	-	-	< 0.0050	0.0072
Zn	-	-	< 0.0050	< 0.0050
Pb	-	-	0.0148	0.0118
Sn	-	-	0.0206	-
C	-	-	0.0356	< 0.0050
Mn	-	< 0.15	-	0.006
		< 1.0	0.005	

As a result, FERROLAC 3M EDM oil was utilized as the dielectric fluid in the present investigation. The investigation of the machining characteristics of Inconel material has focused on tool wear rate (TWR), MRR, and SR. For the pilot experiments, the peak current (Ip), pulse on-time (Ton), and pulse off-time (Toff) machine input parameters were chosen. Table-2 contains a comprehensive chemical analysis of Inconel work materials as well as three distinct types of tool-electrode materials.

Conclusion

The work material for this study consists of two grades of Inconel, Inconel-600 and Inconel-800. Three distinct electrode materials-copper (Cu), copper-chromium (Cu-Cr), and graphite (Gr)-have been chosen to facilitate the machining of these grades of Inconel. In addition to the dielectric fluid, three different varieties of powder particles-tungsten carbide, boron carbide, and cobalt-were combined in order to examine the enhancements in the responses. As a dielectric fluid, die-sinking EDM technology makes greater use of petroleum oil that is commercially available.

However, the most significant issue is air pollution.
Following this, preliminary pilot experiments were conducted to examine the EDM process using a copper electrode for machining Inconel material. The selection of various machining conditions, including their corresponding ranges and levels, was determined by the outcomes of a pilot study. For the execution and design of experiments, the Box-Behnken approach of response surface methodology (RSM) and Taguchi methodology were utilized. Numerous experimental situations employ the Taguchi technique, which establishes a set of orthogonal arrays and provides a standardized method for analyzing the results.

References

1. Abbas NM, Solomon DG, Bahari MF. A review on current research trends in electrical discharge machining (EDM). International Journal of Machine Tools and Manufacture. 2017;47(7–8):1214–1228.
2. Chow HM, Yan BH, Huang FY, Hung JC. Study of added powder in kerosene for the micro-slit machining of titanium alloy using electro-discharge machining. Journal of Materials Processing Technology. 2000;101:95-103.
3. Ekmekci B, Erden A. Remarks on surface integrity of electric discharge machined surfaces: A state of art review. Paper presented at 11th International Conference on Machine Design and Production, Antalya, Turkey; c2014. p. 411–428.
4. Jabbaripour B, Sadeghi MH, Shabgard MR. Investigating surface roughness, material removal rate and corrosion resistance in PMEDM of r-TiAl intermetallic. Journal of Manufacturing Process. 2013;15(1):158-166.
5. Kansal HK, Singh S, Kumar P. Parametric optimization of powder mixed electrical discharge machining by response surface methodology. Journal of Materials Processing Technology. 2005;169(3):427-436.
6. Klocke F, Lung D, Antonoglou G, Thomaidis D. The effects of powder suspended dielectrics on the thermal influenced zone by electro-discharge machining with small discharge energies. Journal of Materials Processing Technology. 2004;149:191-197.
7. Kumar A, Maheshwari S, Sharma C, Beri N. Performance Evaluation of Silicon Additive in Electrical Discharge Machining of EN 24 Steel Based on Taguchi Method. Journal of Mechanical Engineering. 2009;60(5–6):298-304.
8. Kumar A, Maheshwari S, Sharma C, Beri N. Research Developments in Additives Mixed Electrical Discharge Machining (AEDM): A State of Art Review. Material of Manufacturing Process. 2019;25:1166-1180.
9. Kumar H, Davim JP. Role of powder in the machining of Al-10%Sicp metal matrix composites by powder mixed electric discharge machining. Journal of Compos Material. 2011;45(2):133-151.
10. Padhee S, Nayak N, Panda SK. Multi-objective parametric optimization of powder mixed electro discharge machining using response surface methodology and non-dominated sorting genetic algorithm. Sadhana. 2012;37(2):223-240.
11. Pandey PC, Shan HS. Modern machining processes. 27th edition, Tata McGraw- Hill Publishing Company Limited. New Delhi; c2005, ISBN 0-07-096553-6.
12. Pecas P, Henriques E. Electrical discharge machining using simple and powder- mixed dielectric: The effect of the electrode area in the surface roughness and topography. Journal of Materials Processing Technology. 2008;200(1–3):250–258.
13. Pecas P, Henriques E. Influence of silicon powder-mixed dielectric on conventional electrical discharge machining. International Journal of Machine Tools & Manufacture. 2003;43(14):1465-1471.
14. Prihandana GS, Mahardika M, Hamdi M. Accuracy improvement in nano graphite powder-suspended dielectric fluid for electrical discharge machining processes. International Journal of Advanced Manufacturing and Technology. 2018;56(1–4):143-149.
15. Talla G, Gangopadhayay S, Biswas CK. State of the art in powder-mixed electric discharge machining: A review. Journal of Engineering Manufacture; c2016. p. 1-16.
16. Uno Y, Okada A, Cetin S. Surface Modification of ED Med Surface with Powder Mixed Fluid, 2nd International Conference on Design and Production of Dies and Molds; c2001
17. Yan BH, Lin YC, Huang FY, Wang CH. Surface modification of SKD 61 during EDM with metal powder in the dielectric. Materials Transactions. 2001;42:2597-2604.
18. Zhang JH, Lee TC, Lau WS, Ai X. Spark erosion with ultrasonic frequency. Journal of Materials Processing Technology. 1997;68(1):83-88.
19. Zhao FL, Lu ZZ, Wang H. Research on effecting mechanism of particles in powder-mixed EDM. Dalian Ligong Daxue Xuebao/Journal of Dalian University and Technology. 2005;45(5):668-671.
20. Zhao WS, Meng QG, Wang ZL. The application of research on powder mixed EDM in rough machining. Journal of Materials Processing Technology. 2002;129(1-3):30-33.