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A REVIEW ANALYSIS OF ELECTRICAL-DISCHARGE MACHINING OF VARIOUS NICKEL-BASED SUPERALLOYS

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ABSTRACT

In the current scenario, high accuracy and quality are not only expected but also a minimum of production time. The aim of this review paper is to present the consolidated information on processing of nickel based alloy using Electrical Discharge Machining (EDM) and wire electrical discharge machining process (WEDM) and subsequently identify the research gaps. Electrical Discharge Machining (EDM) is a widely accepted process for machining of Nickel based alloy. This material is important in high-temperature applications; they are also known as heat-resistant material. They are extremely useful in gas turbine, aircraft, nuclear reactors, petrochemical equipment's. Nickel based alloy is the only materials to retain high strength even after continuous exposure to extremely high temperatures. Due to these properties the machining of this material is difficult. New and alternate method of machining propelled research to develop and use new processes of machining which promoted the use of electric discharge machining and wire electric discharge machining process. The process is widely accepted by the researchers to machine the Nickel based alloy. This paper has been concluded by giving some suggestion for future researcher from the literature survey

Keywords: Electrical Discharge Machining (EDM); Nickel based alloy high-temperature

INTRODUCTION

An alloy with the potential to work at a high percent of the melting point is a superalloy or high-performing alloy. A superalloy's many main features are its excellent mechanical strength, thermal cramping resistance, corrosion resistance, and high surface stability. The composition of the crystal is normally face-cantered cubic (FCC) austenitic. For instance, Waspaloy, Pyromet 860, Nimonic, Haynes 230, Hastelloy, Inconel, TMS alloys, Rene alloys, MP98T, Incoloy, Udimet, CMSX single crystal alloys, and TMS alloys are examples of such alloys. The production of superalloys has depended heavily on advances in both chemicals and processes. High-temperature strength development of superalloys is achieved by solid solution and precipitation strengthening. Superalloys achieve high-temperature strength by improving the solid solution and strengthening secondary precipitation, including gamma primary and carbide. Elements such as aluminium and chromium shall have oxidation or corrosion resistance. Superalloys are also cast as a single crystal, which reduces cramp resistance when the grain limits provide strength in low temperatures. In aerospace and marine turbine engines the principal application is for such alloys. In gas turbine blades, Creep is usually the life-limiting factor. Superalloys are the materials that make a lot of engineering technology very high in temperature possible.

Electrical discharge machining (EDM) is a widely recognized contemporary machining technique employed to machine alloys and other exceedingly difficult-to-machine materials (e.g., process hard materials). In EDM, the three most crucial performance metrics are MRR, TWR, and SR. Polarity, Peak current, Ton, Toff, Discharge voltage, and Pulse frequency are machining parameters that have an impact on performance metrics. However, its application is especially pronounced when carving intricate shapes into 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 superalloys possess unique characteristics, such as exceptional surface stability and the capacity to maintain high strength despite prolonged and continuous exposure to extremely high temperatures. In contemporary times, scholars have placed significant emphasis on the enhancement of machining performance in conjunction with purposeful surface treatments. PMEDM, a hybrid manufacturing technique, is implemented to augment the machining process's capabilities in this regard. In this regard, a high level of surface quality is also achieved by altering the surface characteristics of the machined parts via the addition of particulate particles suspended in the dielectric fluid. The history and mechanism of the PMEDM process are described in this article, along with a literature review.

This review contains information regarding the PMEDM process in numerous academic research fields. It begins with an overview of the process founded on the universally acknowledged principle of thermal conduction and then describes several of its applications. The primary emphasis of this article is on the principal research endeavors of PMEDM, encompassing the PMEDM machining characteristics and process optimization in tandem. The proliferation of technological innovations has presented manufacturing scientists with an increasing number of challenges. Automobiles, aeronautics, and nuclear reactors are among the advanced sectors that have increased their demand for HSTR materials with a high 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. In conventional machining procedures, it is a proven fact that an increase in the hardness of the work material causes the MRR to decrease. Currently, tool materials lacking the requisite hardness and strength to cut materials including superalloys, titanium, stainless steel, nimonics, fiber-reinforced composites, ceramics, and satellites are unattainable. Conventional methods continue to pose challenges in the production of intricate shapes from these materials (Pandey and Shan; McGeough 1988).

Further requirements, such as increased output, reduced tolerance values, and improved surface quality, present greater challenges in the machining process of these materials, according to Jain (2012). The creation of holes, specifically holes with a contour or without a chamfer, is an additional domain that requires substantial investigation at this time.

In response to these demands, Weller (1984) states that an alternative category of machining procedures called non-conventional machining procedures has been created. Conversely, the energy is employed in its direct form to eliminate the material from the workpiece. The versatility of the recently developed machining processes is dictated by the characteristics of the work material, including but not limited to electrical and thermal conductivity, melting point, and electrochemical equivalent. The implementation of these procedures is progressively becoming customary and widespread in manufacturing facilities.

Kumar et al. (2010) state that EDM is a singular non-conventional machining process and is suitable for the machining of geometric forms with complex shapes. According to Tasi and Wang (2001), the material erosion mechanism in EDM operates on the thermoelectric model. This model posits that thermal energy is generated as a result of a sequence of electrical discharges that transpire between the electrode and the workpiece. A plasma channel is produced by McGeough and Rasmussen (1982), which raises the temperature to 2,00000C, causing the workpiece and tool to dissolve and evaporate. Zhang et al. (1997) found that re-solidification occurs when high temperatures are generated, resulting in the formation of a recast layer on the machined surface.

According to Ekmekci and Erden (2004), the erosion and corrosion resistance of the EDM surface is slowed by the microcracks present in the layer formed on the machined surface. Foteyey (1997) observed that when the pulse is deactivated, the plasma channel undergoes a breakdown process, resulting in the discharge of molten materials from both electrodes as detritus through the dielectric fluid. A series of craters are formed on the machining surface, resulting in an irregular surface.

Talla et al. (2016) state that despite the potential to machine virtually any electrically conductive material, EDM is restricted to a small number of industries due to the low output and surface quality of machined components. In recent years, scholars have developed novel alterations to EDM with the aim of enhancing its functionality.

According to Gudur et al. (2014), in PMEDM, an appropriate material is finely powdered into the EDM oil, resulting in a more refined surface finish and a quicker milling rate than with conventional EDM, i.e. without powder mixed dielectric. The insulating strength of the dielectric fluid is diminished by the electrically conductive additive particles, resulting in a more static process that alters the machining rate and surface polish. Mitsubishi initially devised a two-tank system for EDM.

The larger tank contains conventional EDM oil, whereas the smaller tank is filled with a mixture of granules and dielectric. Following the conclusion of the initial operation in the larger tank, the tool head was transferred to the smaller tank in order to carry out the machining procedures. Nevertheless, for PMEDM to be widely utilized in industry, its mechanism and the effect of various particle characteristics on performance metrics must be comprehensively comprehended.

TECHNOLOGY OF POWDER MIXED EDM

This section describes the fundamental machining process utilized by PMEDM. Zhao et al. (2002) state that the machining mechanism of PMEDM differs from that of conventional EDM.

In PMEDM, as described by Kansal et al. (2005), a suitable conductive powder is incorporated into the EDM oil in a separate vessel. A stirring mechanism is employed to facilitate the movement of particulate material within the EDM oil. To ensure that powder in the dielectric fluid is continuously reused, a modified circulation system (Figure-1) is implemented.

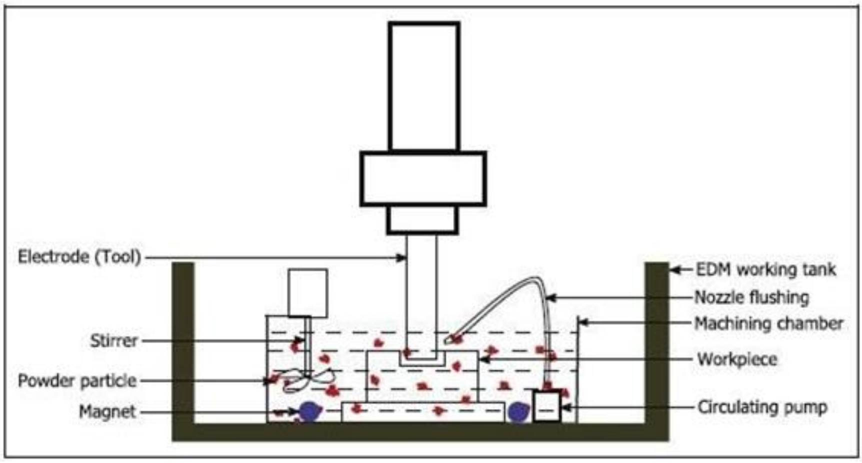

Figure-1 : Schematic Diagram of PMEDM Experimental Setup

It comprises an individual vessel known as the machining tank. It is introduced into the EDM's main tank, while the machining takes place in the machining tank. In order for the workpiece to be supported, a workpiece fixture assembly is inserted. A stirring mechanism is employed to facilitate the movement of particulate material within the EDM oil. A diminutive dielectric circulation pump was implemented to ensure that the powder-mixed dielectric fluid in the discharge gap was circulated appropriately. During machining, both the pump and the stirrer assembly are contained in the same vessel.

Zhao et al. (2002) found that powder particles in IEG become energized and move with ions and electrons during the initial discharge. The electric field accelerates charged particles, which in turn conduct current. When these energized particles collide with dielectric molecules, additional ions and electrons are produced. As a result, PMEDM generates a greater quantity of electric charges than conventional EDM.

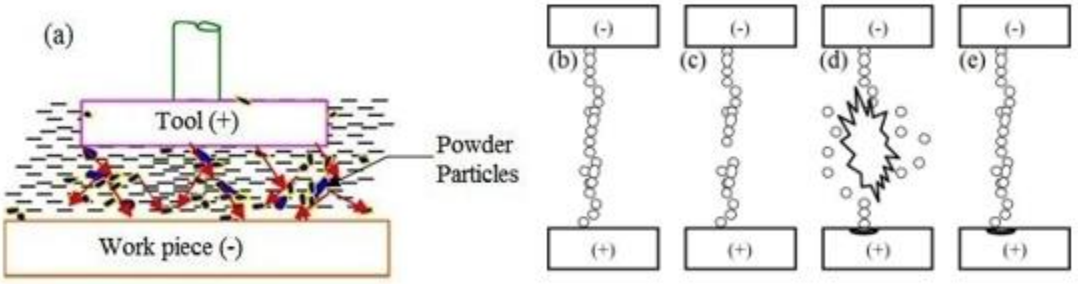

Figure-2 : Illustrates the powder blended EDM principle. (b) Formation of a bridge, (c) Initiation of sparks, (d) Explosion resulting in the motion of zigzag particles, and (e) Re-bridging.

The charged particles increase the spark gap between the instrument and the workpiece by promoting gap breakdown. Within this region, the particles coalesce in proximity to one another and produce chain-like configurations between the two electrodes. The interlocking of the various powder particles takes place in the direction of the current flow. Chain formation facilitates the bridging of the discharge gap that exists between the two electrodes.

ENLARGEMENT OF THE DISCHARGE GAP

The dimensions of the discharge gap between the workpiece and the electrode are predominantly determined by the powder particles' electrical and physical properties.

Prihandana et al. (2011) and Zhao et al. (2005) found that the presence of free electrons in electrically conductive powder particles decreases the overall resistance of the dielectric at high temperatures.

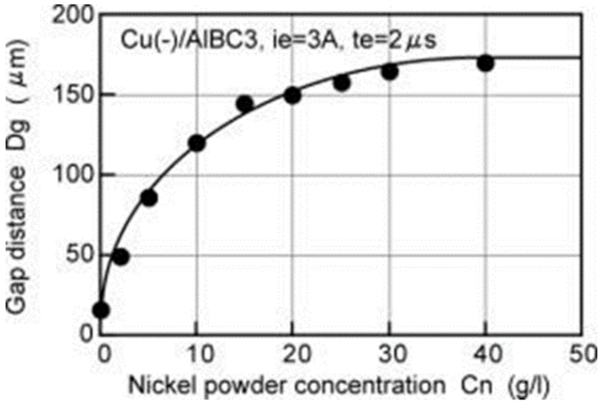

Figure-3 : Variations of Gap Distance with Nickel Powder Concentration in Machining Fluid

Chow et al. (2000) investigated the efficacy of EDM in micro-slit machining titanium alloy using powder additives of aluminum and SiC in EDM oil. They concluded that by increasing the gap distance with powder additives, the MRR was improved and a superior surface polish was produced. Enhanced conductivity facilitates the generation of sparks over greater distances, consequently leading to an expansion of the discharge gap.The influence of particle size on the discharge separation is also significant (Figure-2). In the absence of a powder additive in the EDM oil, the discharge gap is below 30 μm. However, the inclusion of the powder additive significantly increases the gap. The gap distance exhibited a continuous variation in response to the nickel powder concentration, and it grew exponentially as the nickel powder concentration increased to approximately 15 g/l (Figure-3).

INFLUENCE OF POWDER PROPERTIES ON MACHINING CHARACTERISTICS

According to Kansal et al. (2005), the effect of powder particles on EDM performance appears to be complex. An excessive amount of powder particles in the dielectric can lead to ineffective and unstable operation, whereas the absence of powder particles may result in arching. The efficacy of the EDM procedure utilizing powder particles is contingent upon various factors, including the additives utilized, the size and concentration of the particles, and their characteristics such as electrical resistivity, thermal conductivity, and density. As a result, the choice of particle material for dielectric in EDM has a significant impact on a variety of process performance metrics.

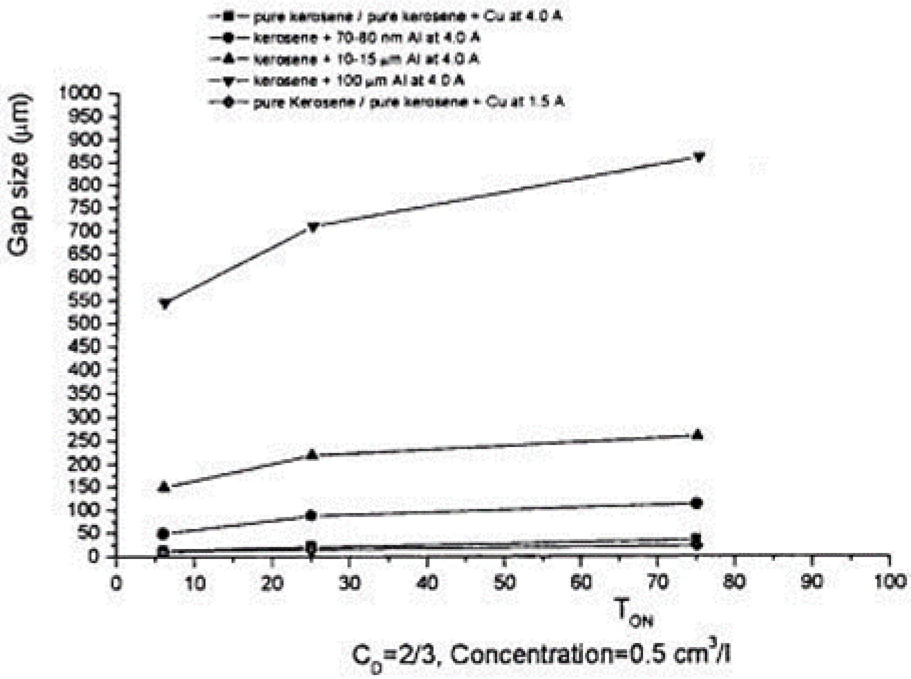

Figure-4 : The effects of the particle size of additives in kerosene on the gap size

In their study, Tzeng and Chen (2005) examined the effects of chromium, aluminum, silicon carbide, and copper powders on SKD-11 steel. The results indicated that aluminum powder yielded the most favorable surface characteristics, followed by chromium. Conversely, copper powder produced the least desirable surface characteristics. The efficacy was greatly influenced by the properties of powder additives, including density, thermal conductivity, and electrical resistivity. Consequently, the evaluation of particle properties and their potential correlation with EDM attributes is critical. This section provides a comprehensive review of the published research literature concerning the application of additive particles incorporated into the dielectric fluid of EDM in order to enhance the surface integrity and machining characteristics of machined surfaces.

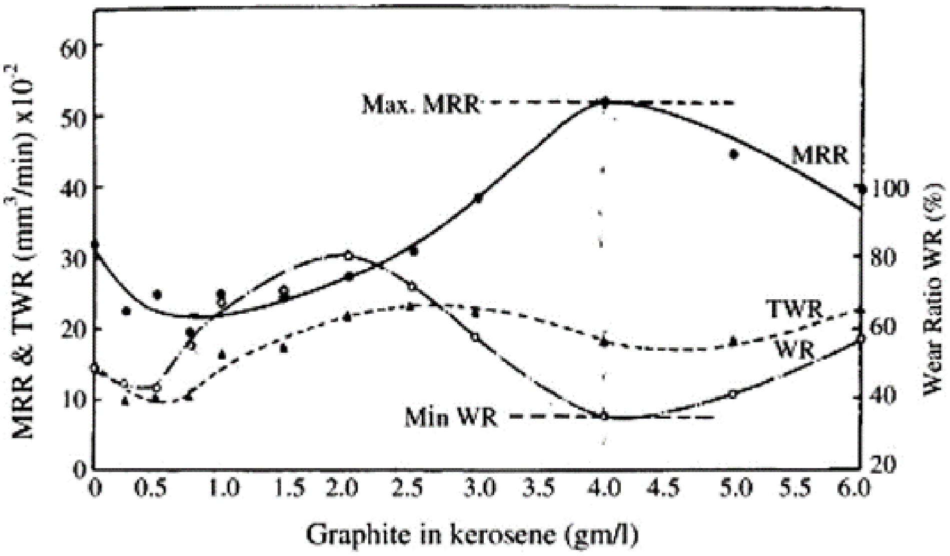

Figure-5 : Effect of graphite powder addition into kerosene on MRR, TW, and Wear rate

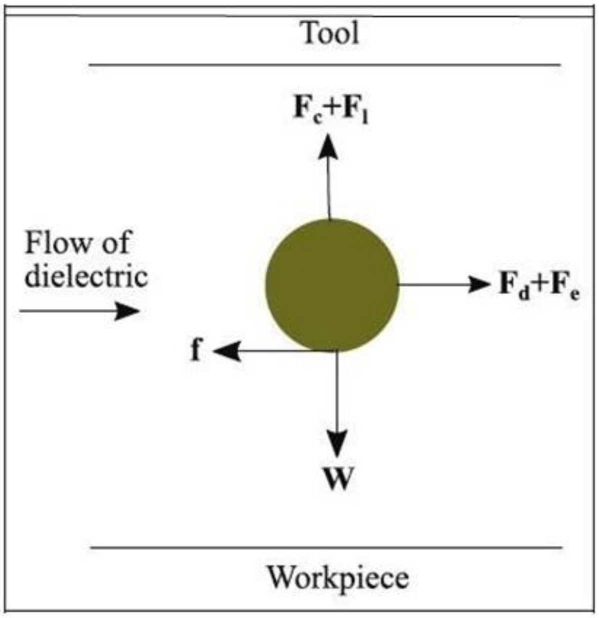

Figure-6 : Different forces acting on the powder particles

Jeswani (1981) reported that the machining stability was enhanced by 60% and 15%, respectively, with the addition of 4 g of fine graphite powder per liter to the EDM lubricant. Approximately 28% was saved in wear rate (WR) (Figure 2.5). The observed outcome was ascribed to an expansion of the discharge gap and a decrease in the dielectric fluid's strength. Electrical conductivity of abrasive powder particles decreases the insulating strength of dielectric fluid, thereby increasing MRR (Furutani et al. 2001; Kansal et al. 2007).
A compilation of commonly employed particulate materials in PMEDM, accompanied by their respective properties, is displayed in Table-1.

Table-1
Properties of Powder Particles as Additives

Powder additives	Density (g/cm^3)	Electrical resistivity (μΩ cm)	Thermal conductivity (W/m K)	Meltingpoint (0^0C)	Specific heat (Calg^{-0}C^{-1})
Aluminum (Al)	2.7	2.89	236	660	0.215
Alumina (Al_2O_3)	3.98	103	25.1	2072	_
Boron carbide (B_4C)	2.52	5.5× 10^5	27.9	2645	_
CNTs	2	50	4000	2800	_
Chromium (Cr)	7.16	2.6	95	1875	0.11
Copper (Cu)	8.96	1.71	401	1084	0.096
Graphite (C)	1.26	103	3000	4550	0.17-0.20
Molybdenum disulfide	5.06	106	138	2610	0.06
Nickel (Ni)	8.91	9.5	94	1453	0.105
Silicon (Si)	2.33	2325	168	1410	0.17
Silicon Carbide (SiC)	3.22	1013	300	2987	0.18
Titanium (Ti)	4.72	47	22	1670	0.14
Tungsten (W)	19.25	5.3	182	3410	0.031

Additionally, according to Tzeng and Lee (2001), a reduced density decreases the quantity of powder particulates that settle to the tank's bottom, thereby reducing the powder quantity requirement. Additionally, lighter particulates induce minor explosions when they strike the molten metal.

Ultimate surface quality was achieved by Wu et al. (2005) through the combination of Al powder and a surfactant (polyoxyethylene-20-sorbitan monooleate) in the dielectric of EDM. By acting as a steric barrier, the surfactant prevented the powder particles from aggregating. According to the findings of Wu et al. (2007), the addition of surfactant alone could decrease the thickness of the recast layer by increasing the dielectric's overall conductivity. Behzad (2012) conducted experiments on γ-TiAl through the blending of various particles in the dielectric fluid of EDM, including aluminum, chrome, silicon carbide, graphite, and iron. Aluminum has the most significant impact on performance characteristics, according to the findings, followed by silicon carbide, graphite, and iron.

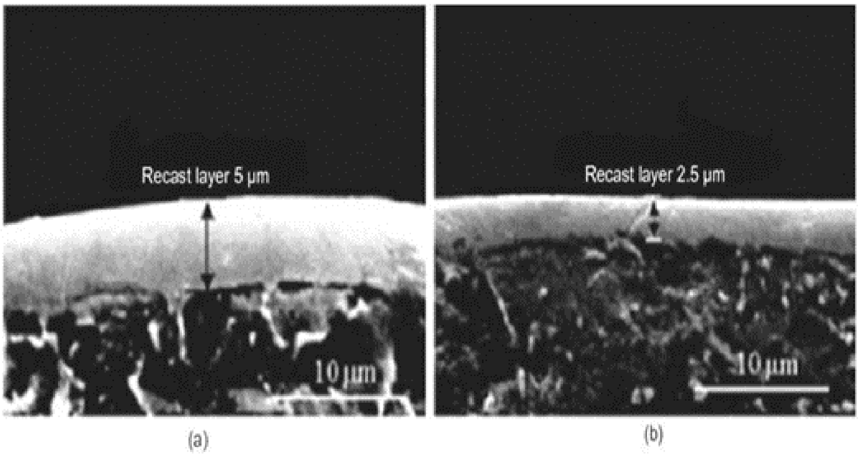

Figure-7 : SEM Micrographs of Recast Layer Using (A) Kerosene (B) Kerosene + Span20 as Dielectrics

The phenomenon of mirror finish is compared by Wong et al. (1998) using various materials such as silicon, graphite, pulverized glass, aluminum, molybdenum sulphide, and silicon carbide, each with a distinct grain size. It was reported that aluminum powder imparts a mirror-like surface to SK-51 workpieces in comparison to other workpieces, and it was suggested that for optimal results, the powder concentration and workpiece materials should be optimized .

INFLUENCE OF MACHINING PARAMETERS ON CHARACTERISTICS OF PMEDM

Batish and Bhattacharya (2012); Bhattacharya and Batish (2012) state that the PMEDM process is profoundly impacted by the diverse and particular properties of dielectric, particle, tool, and workpiece materials, in addition to other machining parameters.

Electrical parameters such as pulse frequency, duty cycle, pulse on time, current, and voltage, as well as material properties of the electrode, workpiece, and dielectric fluid including melting point, thermal conductivity, specific heat, and discharge gap, are the primary determinants of the machining characteristics of EDM, according to Lee and Li (2001).

In their investigation of micro-EDM processes, Prihandana et al. (2009) assessed the four machining input parameters—dielectric fluid, micro-powder concentration, electrode, and workpiece—and determined that response parameters are enhanced by combining micro-powder with dielectric fluid. Mohanty et al. (2014) and Ming et al. (1995) examined and optimized the input parameters for EDM on Inconel 718. Based on their findings, they concluded that the critical parameters affecting the machinability of Inconel 718 are the current and tone.

In their investigation, Kolli and Kumar (2015) employed the Taguchi method to examine the impact of five input parameters on MRR and SR. Based on their findings, they concluded that the feed rate and pulse duration have a substantial influence on MRR and SR. As a result, establishing a correlation between these variables and hybridizing it to improve the quality of machined surfaces has emerged as a significant area of research. In their study, Kumar et al. (2012) assessed the efficacy of PMEDM machining on Inconel-718. The researchers investigated the impact of various input variables, including polarity, tool material, peak current, duty cycle, gap voltage, and powder particulates, on the overall machining efficiency. The TWR and attrition ratio are enhanced when graphite powder particles are mixed with dielectric fluid, according to experimental findings. The fish bone diagram (Figure 2.11), which illustrates the outcome in the form of PMEDM performance parameters, depicts the numerous process parameters. The subsequent section examines the impact of critical process parameters on the machining properties of the PMEDM process.

CONCLUSION

In this review paper, we show a state-of-the-art assessment of EDM research developments in nickel-based superalloys such as Waspaloyincluding research gaps and future directions for research. Because of the preceding conclusions, it appears that there is a substantial scope of in-depth investigations of Ni-based superalloys in ED machining. Hence, scientist and researchers should focus their sustained endeavor on ED machining of important grades of Ni-based superalloys. Optimisation of various EDM parameters, application of nanoparticles mixed dielectric, micro-EDM and hybrid EDM are a few emerging areas where still huge untapped research potential exists. Further, modelling and simulation work pertaining to various aspects of EDM must be explored to reduce the high cost and time associated with actual experiments. Such results can be used to validate and create a roadmap for the ED machining of various Ni-based superalloys. Micro-EDM needs more attention to augment the responses' accuracy and precision, especially in ED machining of various Ni-based superalloy

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