Effect of Various Dielectric Fluids on Performance of EDM: A Review

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Effect of Various Dielectric Fluids on Performance of EDM: A Review

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Abstract
In electrical discharge machining (EDM), material removal takes place by means of successive electrical discharges occurring between an electrode and a work piece in the presence of dielectric liquid or gas. As dielectric fluid plays very significant role in any electrical discharge machining operation, selection of dielectric medium is an important consideration for EDM performance. It does not only serve to carry away the condensed metal particles from the spark gap region but also has different functions which highly influence the performance of this process. An exhaustive research work had been carried out by different researchers for improvement of performance measures such as material removal rate (MRR), tool wear rate (TWR) and surface roughness of electrical discharge machining using different dielectric fluids like kerosene, deionized water, air, mineral oil, powder mixed dielectric, etc. In the powder mixed EDM process, a suitable material e.g. aluminium, nickel, iron, cobalt, copper, carbon or silicon carbide in the powder form is mixed into the dielectric fluid. This paper reviews the research work carried out to evaluate the effects of different dielectric fluid on performance measures of EDM.

Keywords: *EDM, dielectric fluid, MRR, TWR, surface roughness*

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INTRODUCTION

For making of tool, die and mould from advanced materials such as super alloys, ceramics, and metal matrix composites, electrical discharge machine (EDM) technology is being popular due to precise machining of complex shapes and high surface finish [1]. In the EDM process, material removal takes place due to multiple discharges between work piece and tool electrodes submerged in dielectric fluid. Certain quantity of material gets removed from molten metal due to vaporization and remaining gets resolidified in form of white layer due to cooling effect of dielectric fluid. It is flushed through the spark gap to remove gaseous and solid debris during machining and to maintain the dielectric temperature by acting as coolant also [2]. The dielectric fluid should possess certain characteristics which include: high dielectric strength and quick recovery after break down, effective quenching and flushing ability [3]. Tool wear and material removal rate are affected by the type of dielectric fluid used for flushing [4]. To improve the performance of EDM, dielectric fluid suspended with different powders was attempted by several investigators. Powder mixed electric discharge machining (PMEDM) improves the quality of the electric discharge machined surface and reduces the surface defects [5]. Different dielectric fluids used in EDM are kerosene, water, mineral oil, transformer oil, synthetic oil, dielectric liquid with powder additives, air, oxygen, nitrogen, etc.

EFFECT OF DIFFERENT DIELECTRIC FLUIDS ON PERFORMANCE OF EDM

Various researchers had carried out research work to assess the influence of different dielectric fluids on performance of EDM like material removal rate, electrode wear, surface roughness, overcut, white layer thickness, surface hardness, etc.

EDM in Water

Water can be used as substitute to hydrocarbon oil in EDM. It is more economic, safe and it has less negative influence on environment and health while working with EDM. Hydrocarbon oils are generally used as dielectric fluid in EDM but it has some disadvantages such as harmful gas generation during electrical discharge machining. For more than last 35 years, research is going on in using pure water and water with additives as dielectric fluid in EDM.

Jeswani conducted experiments and concluded that higher MRR and lower wear ratio can be obtained while machining with distilled water compared to kerosene for high pulse energy range [6]. Jilani and Pandey investigated the machining characteristics of different forms of water in EDM of low carbon steel [7]. The tap water showed the best machining rates and copper tools with negative polarities showed the possibility of achieving zero electrode wear in water as dielectric. Micro-hole drilling using water as working fluid was studied by Kagaya *et al.* [8]. High MRR and low TWR were achieved by using tungsten electrode with straight polarity. It is possible to obtain a non-tapered straight micro-hole around 0.1 mm in diameter with a certain anticipative working gap. Masuzawa *et al.* carried out experimental study to check effect of water solutions of organic compounds on machining rate [9]. It was found that great improvement in MRR is achieved by mixing organic compounds in water and the effectiveness increases with increase in the thickness of the solution. Zhang *et al.* compared the characteristics of the recast layer formed in water in oil emulsion, kerosene and de-ionized water dielectric [10]. The recast layer formed in without emulsion dielectric exhibits a greater surface roughness, micro hardness and thickness than that formed in kerosene and de-ionized water dielectrics. Many micro-voids were found within the recast layer formed in water in oil emulsion compared to kerosene and de-ionized water. Figure 1 shows the thickness of the recast layer obtained in different dielectrics and pulse duration.

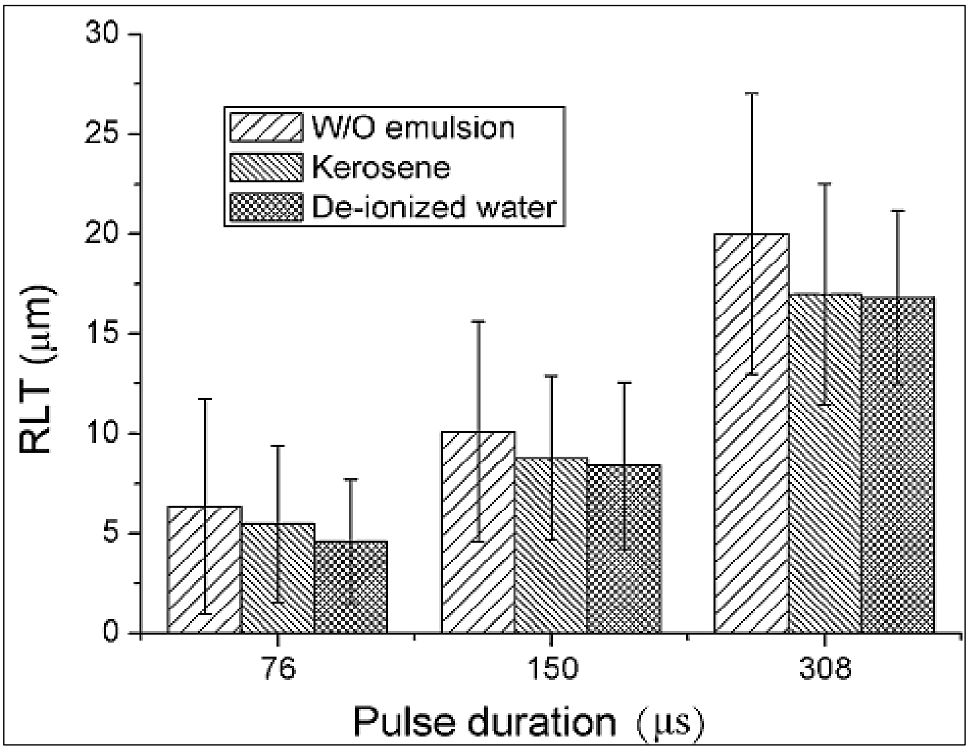

Fig. 1: *Comparing the RLT of Samples Obtained in Different Dielectrics and Pulse Duration. Peak Current=9 A [10].*

Bai and Koo investigated effect of kerosene and distilled water on electrical discharge alloying of superalloy Haynes 230 with Al-Mo composite electrode [11]. They found that the maximum hardness of alloyed layer P-AlMo-Water exceeds that of P-AlMo-Kerosene.

The P-AlMo-Kerosene specimen has the finest surface morphology, the thickest alloyed layer, and the slowest oxidation rate of all EDA specimens. It was also concluded that the surface alloying effect in kerosene is better than that in distilled water. Figure 2 shows the cross sectional hardness profiles of P-AlMo-Water, P-AlMo-Kero and N-AlMo-Kero specimens.

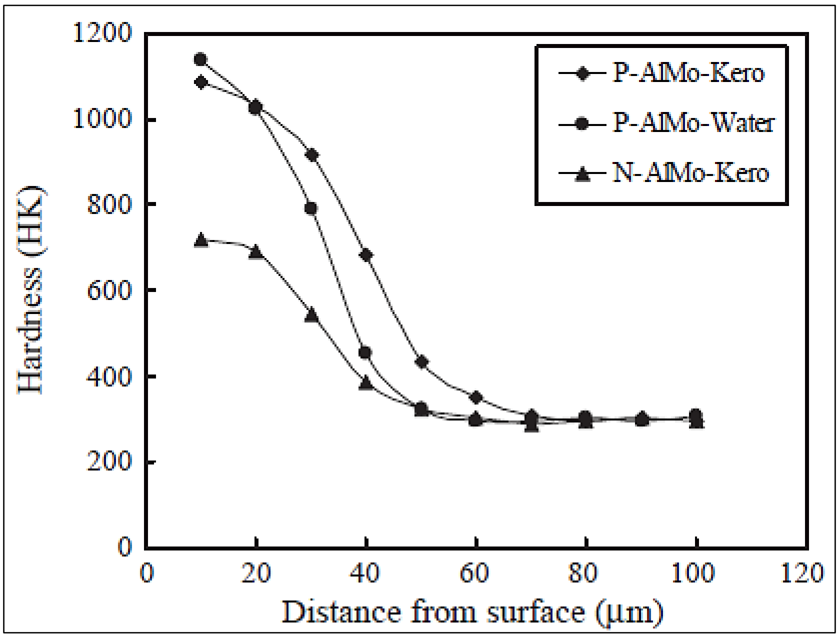

Fig. 2: *Hardness Profiles along the Depth of Cross-Section of Three EDA Specimens [11].*

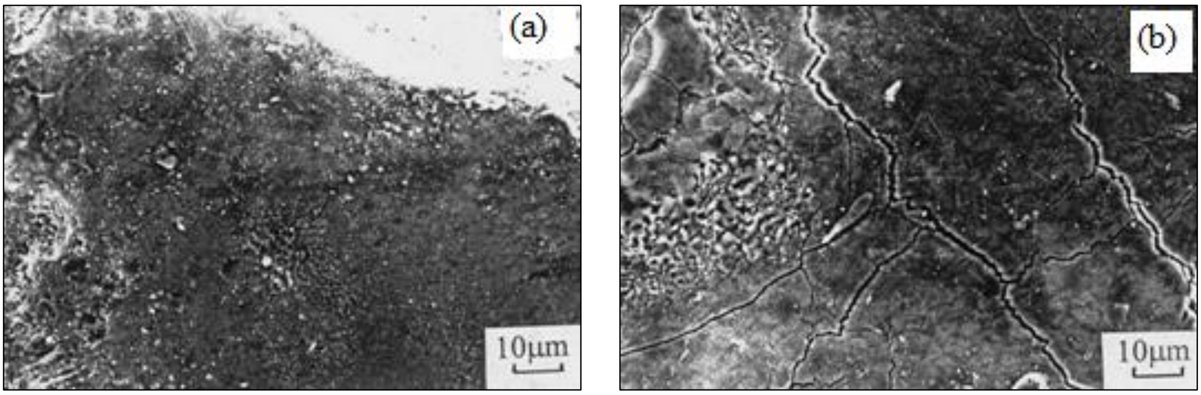

Fig. 3: *SEM Photographs of the Crack Distribution of an EDMed Surface for **(a)** Kerosene and **(b)** Distilled Water [13].*

Micro-slit EDM process along with SiC powder in pure water was investigated by Chow *et al.* [12]. Results showed that the pure water with SiC powder can scatter the discharging energy that improves the surface roughness and also attains a higher MRR simultaneously than that of pure water. Chen *et al*. showed that formation of TiC on work piece, requiring larger discharge energy and carbon deposition on the electrode, causing further retardation of the discharge process lowers the material removal rate in machining of Ti-6A1-4V alloy in kerosene compared to water [13]. More micro cracks were found while using distilled water as the dielectric. Figure 3 shows micrographs of the workpiece surface.

The experimental investigations carried out by Syed and Palaniyandi showed that addition of aluminium metal powder in distilled water results in high MRR, good surface finish, and minimum white layer thickness as compared with pure distilled water [14].

Yan *et al*. evaluated feasibility of surface modification of pure titanium metal by EDM using a dielectric of a urea solution in water [15]. Results indicated that a TiN hard layer forms on workpiece due to migration of nitrogen decomposed from the dielectric which results in good wear resistance of the machined surface after EDM. Experimental study on electrical discharge machining of Ti-6Al-4V in tap water was used by Tang and Du [16]. It was concluded that machining in tap water increases MRR, decreases machining cost and it has no harmful effect on operator and environment. Kibria *et al*. analyzed machining of Ti-6Al-4V alloy for the study of influence of pure and boron carbide mixed kerosene and deionized water dielectrics [17]. Results showed that B_4C mixed kerosene has not remarkable improvement in MRR, but B_4C mixed deionized water has excellent increase in MRR. Tool wear is higher withpure and B_4C mixed deionized water compared to kerosene. Some SEM micrographs of machined microholes using different dielectrics are shown in Figure 4.

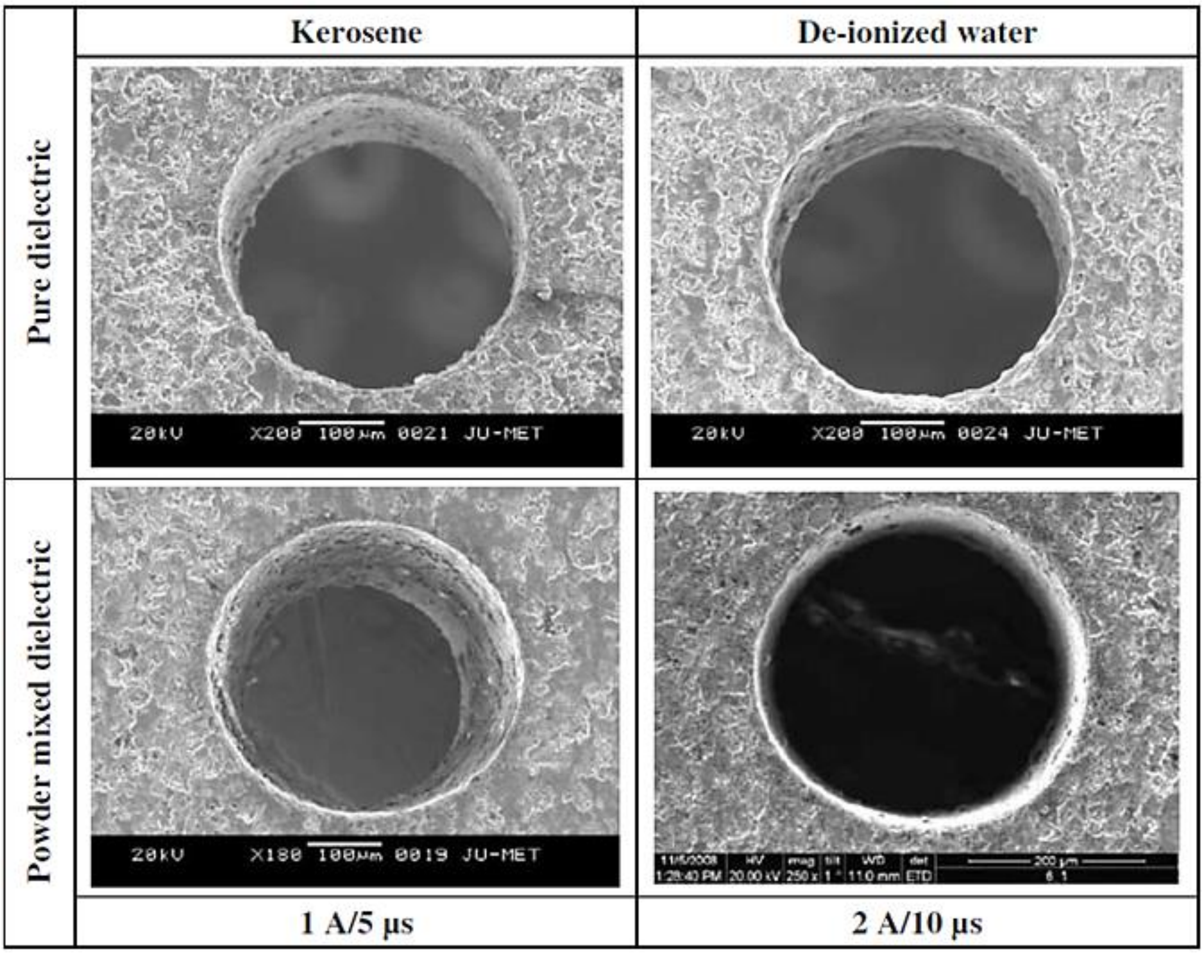

Fig. 4: *SEM Micrographs of Machined Microholes Using Pure and Powder-Mixed Dielectrics [17].*

Syed and Kuppan investigated the effect of aluminium powder mixed distilled water on recast-layer in EDM [18]. It was found that pure distilled water produces dense and high thickness white-layer with fewer cracks on the machined surface as well ashigher concentration of aluminium powder in the distilled water produces thin white-layer consisting of more cracks and voids on the machined surface.

The influence of salt mixed de-ionized water as a dielectric fluid on micro-hole machining was investigated by Shivakoti *et al.* [19]. It was concluded that salt concentration is significant parameter for MRR and TWR as well as insignificant for overcut and taper of hole. Residual stresses and hardness depth in EDM'ed surface of plastic mold steel with de-ionized water as dielectric fluid were examined by Ekmekci *et al*. [20].

The residual stresses induced by EDM on the surface were found to be tensile in nature and varies to compressive in nature below the heat-affected zone. The white layer was found to be much harder than the parent material and a dramatic decrease in micro hardness was observed within the heat-affected zone.

Micro EDM of reaction bonded silicon carbide (RB-SiC) was studied by Liew *et al.* using EDM oil, deionized water, and graphite fiber mixed EDM oil as the dielectric fluids [21]. It was found that when graphite fiber mixed EDM oil was used, higher MRR, better surface finish and smoother surface topography were obtained compared to pure EDM oil and deionized water.

Muniu *et al.* compared performance of EDM using pure distilled water and diatomite powder mixed distilled water [22]. They concluded that addition of 2 g/l diatomite powder into distilled water at peak current of 21 A, duty cycle of 0.5 and pulse frequency of 10 KHz increases MRR by 8% and lowers EWR by 46%, respectively. High MRR was obtained by Konig and Siebers in water-based dielectric due to higher thermal stability and much higher power input under critical conditions [23].

In aqueous media, specific boiling energy is about eight times higher and boiling phenomena occur at a lower temperature level as compared to oil based dielectrics. Kang and Kim found carburization and sharp crack propagation along the grain boundary of specimen after the heat treatment when kerosene was used as dielectric [24]. However, using deionized water as dielectric, the specimen showed oxidation and no crack propagation behavior after heat treatment.

EDM in Powder Mixed Dielectric

Powder mixed electric discharge machining (PMEDM) is a new development in the field of EDM to improve performance characteristics of the process. In this process, different materials in the form of tiny particles are mixed into the dielectric fluid which causes early explosion and hence faster material removal from the workpiece surface. The process becomes more stable with improved machining efficiency due to uniform flushing of debris in wider spark gap. Various qualities of the powder like type of material, particle size and concentration influence the dielectric performance. It was found by Jeswani that the addition of 4 g/l of graphite powder in kerosene increases the MRR by 60% and the wear ratio TWR/MRR reduces by about 28% in EDM with respect to pure kerosene [25].

The breakdown voltage of kerosene reduced 30% at a spark gap of 50 µm and 4 g/l graphite addition in kerosene which resulted in high discharge frequency and hence high MRR. Due to high process stability, highly concentrated aqueous glycerine solution proved to have the most suitable characteristics in terms of material removal, tool wear behaviour and surface quality when working with long pulse durations, high pulse duty factors and discharge currents [26].

Pecas and Henriques employed a new approach of using silicon powder-mixed dielectric to study the performance improvement of conventional EDM [27]. Results showed reduction in operating time required to attain a specific surface quality, and generation of mirror-like surfaces by decreasing of the surface roughness.

It was also found that the average surface roughness depends on the area and varies from 0.09 to 0.57 µm for the electrode area range of 1 to 64 cm^2. Figure 5 shows surface textures for 32 and 64 cm^2 electrode area machined with and without using silicon powder in dielectric.

Wu *et al*. reported that addition of span 20 increases conductivity of kerosene and hence improves machining efficiency due to a shorter delay time of electrical discharge [28]. Selection of proper process parameters can improve MRR by 40–80% without deterioration of surface roughness. Recast layer thickness for different additives is shown in Figure 6.

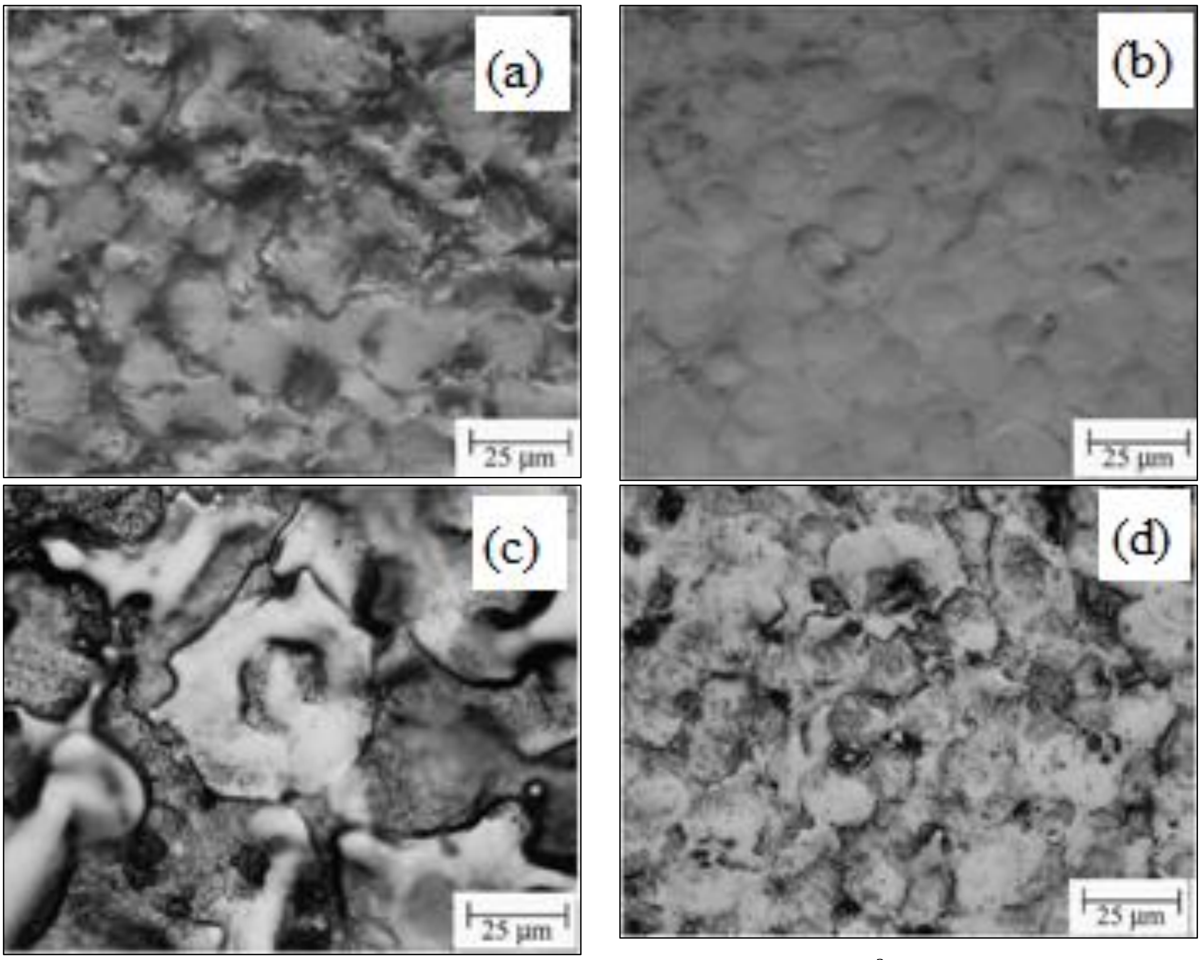

Fig. 5: *Surface Textures Obtained for an Electrode Area of 32 cm*^{2} ***(a)*** *Kerosene and,* ***(b)*** *Kerosene+2 g/l Silicon Powder, and for an Electrode Area of 64 cm*^{2}*,* ***(c)*** *Kerosene and,* ***(d)*** *Kerosene+2 g/l Silicon Powder [27].*

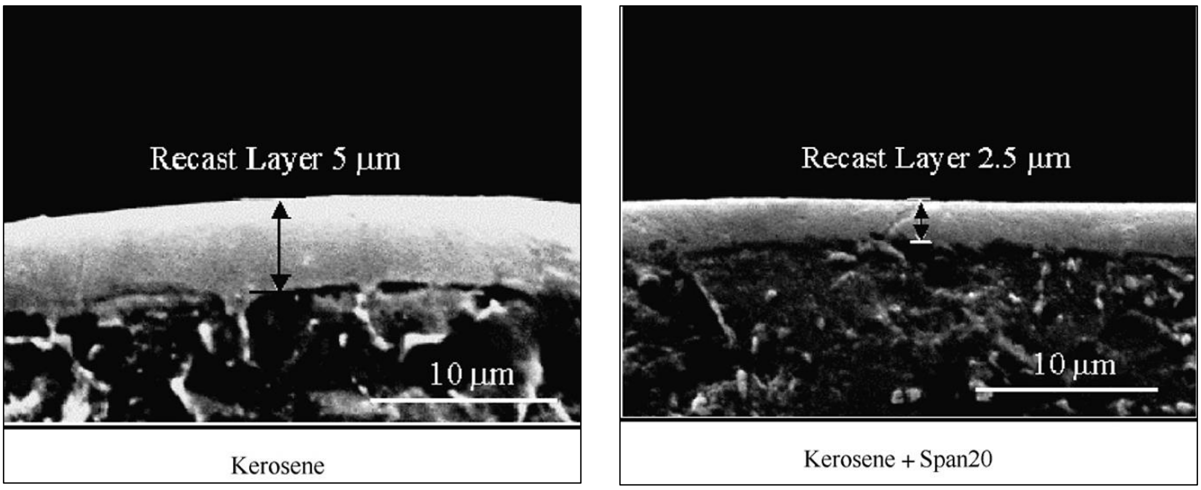

Fig. 6: *SEM Micrographs of Machined Recasted Layer on Various Dielectric [28].*

During investigation, Wu *et al*. found that thinner recast layer can be achieved using dielectric mixed with aluminum powder and surfactant while 60% improvement in the surface roughness of the workpiece was obtained as compared to pure kerosene [29]. Prihandana *et al*. showed that micro-EDM with suspended micro-MoS_2 powder in dielectric fluid accelerates sparking frequency during EDM process which results in higher

MRR [30]. Yih-fong and Fu-chen investigated effect of various powder additives in dielectric on surface quality of SKD-11 [31]. It was found that the smallest particles generate the best surface finish and the thickest recast layer. Among the additives, Al powder produces the best surface finish and the thinnest recast layer in the workpiece. The presence of silicon particles increases the gap distance between electrodes and promotes the occurrence of multiple discharges in one input pulse. The discharge energy is mainly used for the metal melting all over the crater area which increases MRR and the surface tends to be smooth and more homogeneous [32–33]. A study of the near-mirror-finish phenomenon in EDM by addition of different fine powders into dielectric fluid was carried out by Wong *et al.* [34]. The powder-mixed dielectric EDM showed shorter machining time, more uniform dispersion of the electrical discharges, and stable machining. Graphite and silicon powders generated fine to glossy finish surfaces even at relatively high pulse currents of up to 2 A. Hu *et al*. found that aluminium powder mixed dielectric decreases surface roughness by about 31.5% and increases hardness as well as wear resistance by almost 40 and 100% in SiCp/Al composite respectively compared to conventional EDM [35]. Hence, it can be used in machining of metal matrix composites. The comparison of micro-hardness for SiCp/Al and ASP-23 is shown in Figure 7.

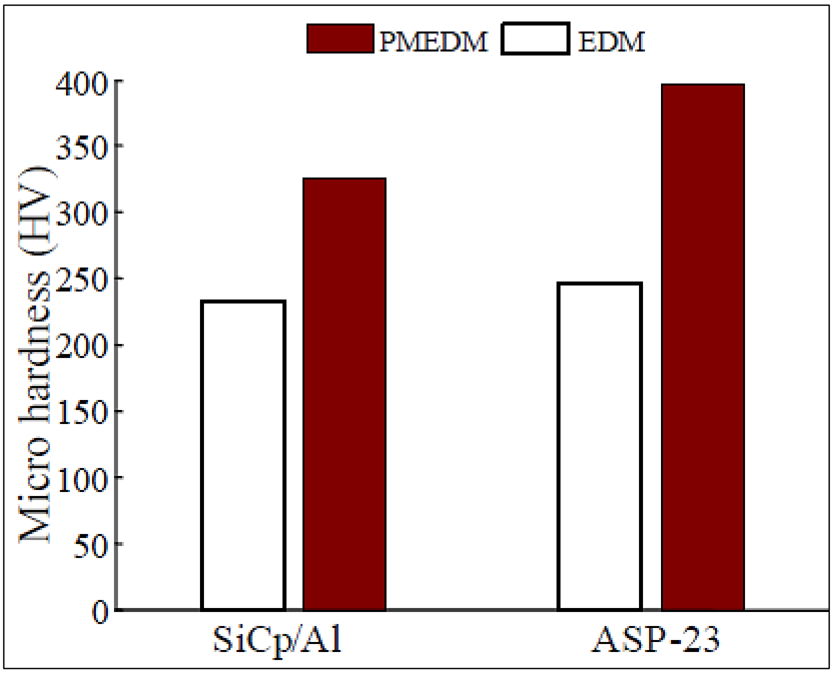

Fig. 7: *Micro Hardness Comparison [35].*

Ojha *et al.* established optimum process conditions for PMEDM using the RSM method with chromium powder and result showed increasing trend of MRR and decreasing trend of TWR with increase in powder concentration [36]. Additive powder mixed EDM of Nickel based Super Alloy 718 was carried out by Kumar *et al*. [37]. From the experimental study, it was found that addition of graphite powder enhances machining rate significantly. At best parametric setting, machining rate is improved by 26.85% with 12 g/l of fine graphite powder.

Padhee *et al*. optimized process parameters of PMEDM with silicon powder mixed dielectric [38]. It was observed that powder-mixed dielectric significantly reduces surface heterogeneity and hence increases process robustness. So, it contributes well particularly when a high-quality surface is a requirement. Ali *et al*. found that the silicon carbide powder in dielectric fluid splits the single spark into no. of small sparks which create small craters and hence reduces the surface roughness [39]. The concentration of SiC powder above 20 g/l leads to increase in surface roughness.

Yan *et al.* demonstrated surface modification of SKD61 by addition of Al and Cr powder into kerosene and showed that the MRR and TWR decrease with high pulse duration [40]. The corrosion resistance and hardness of machined surface improves by addition of the mixture (Al+Cr) into kerosene. Variation of surface roughness with different dielectric fluid is shown in Figure 8.

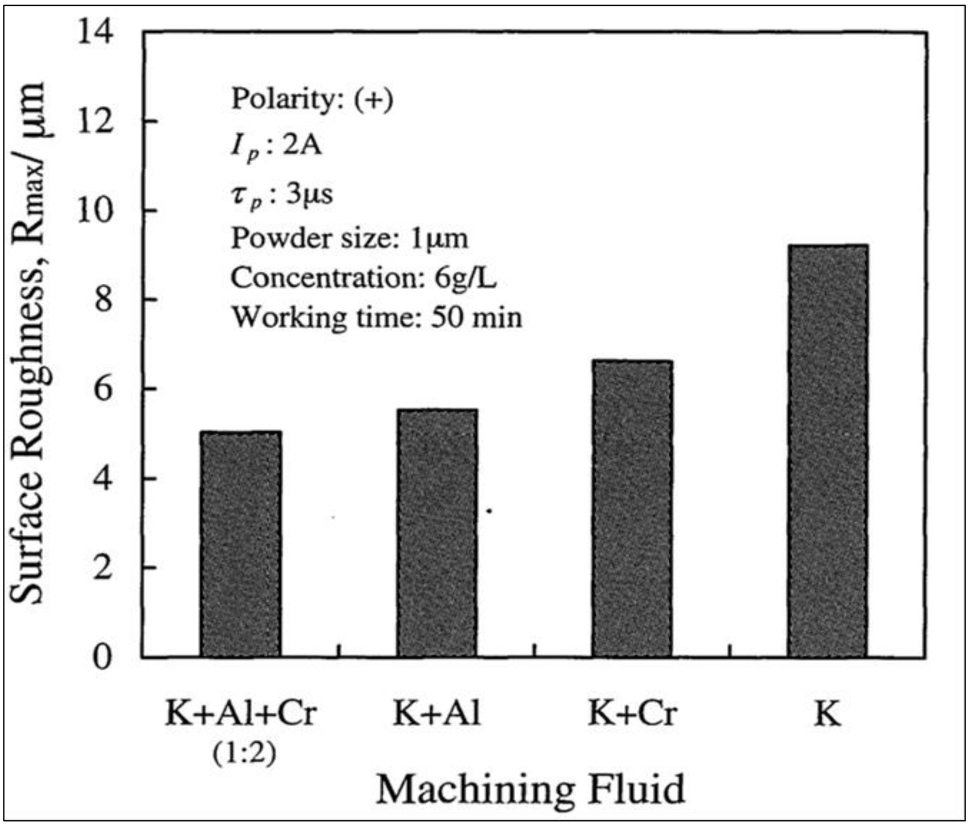

Fig. 8: *Influence of Various Dielectrics on Surface Roughness [40].*

Prihandana *et al*. found significant reduction of machining time, increase in accuracy and reduction of microcracks on the workpiece surface while machining with dielectric fluid having suspension of nanographite powder with a particle size of 55 nm [41]. Khan *et al.* conducted experiments for surface modification using EDM with TiC and Al_2O_3 addition into kerosene and showed that carbon deposition on work surface makes surface more hard using TiC powder compared to Al_2O_3 powder [42]. TiC powder mixed dielectric gave smoother surface, while Al_2O_3 powder gave higher thickness of recast layer. Ojha *et al*. described the effect of dielectric mixed with nickel powder on the MRR and TWR. It was shown that the kerosene with increased suspended micro nickel powder increases MRR but it has no dominant effect on TWR [43]. It was observed by Prakash and Kumar that powder mixed electric discharge machining had significant effect on the tool wear rate [44]. The tool wear rate is higher with copper as an additive and less when graphite is used in kerosene; means tool life increases with the addition of graphite powder in the dielectric medium. Kumar and Singh found that the transfer of manganese and carbon from the plasma channel to the work surface in the form of manganese carbide improves microhardness by 73% and prevents micro-cracks formation after electrical discharge machining with manganese powder mixed dielectric [45]. Jahan *et al.* investigated the feasibility of improving surface characteristics of cemented tungsten carbide in the micro-EDM using graphite nano-powder-mixed dielectric [46]. In both sinking and milling micro-EDM, smooth and glossy surface finish was found due to uniform distribution of sparking among powder particles. Figure 9 shows variation of MRR, EWR, and surface roughness with graphite powder concentration in dielectric.

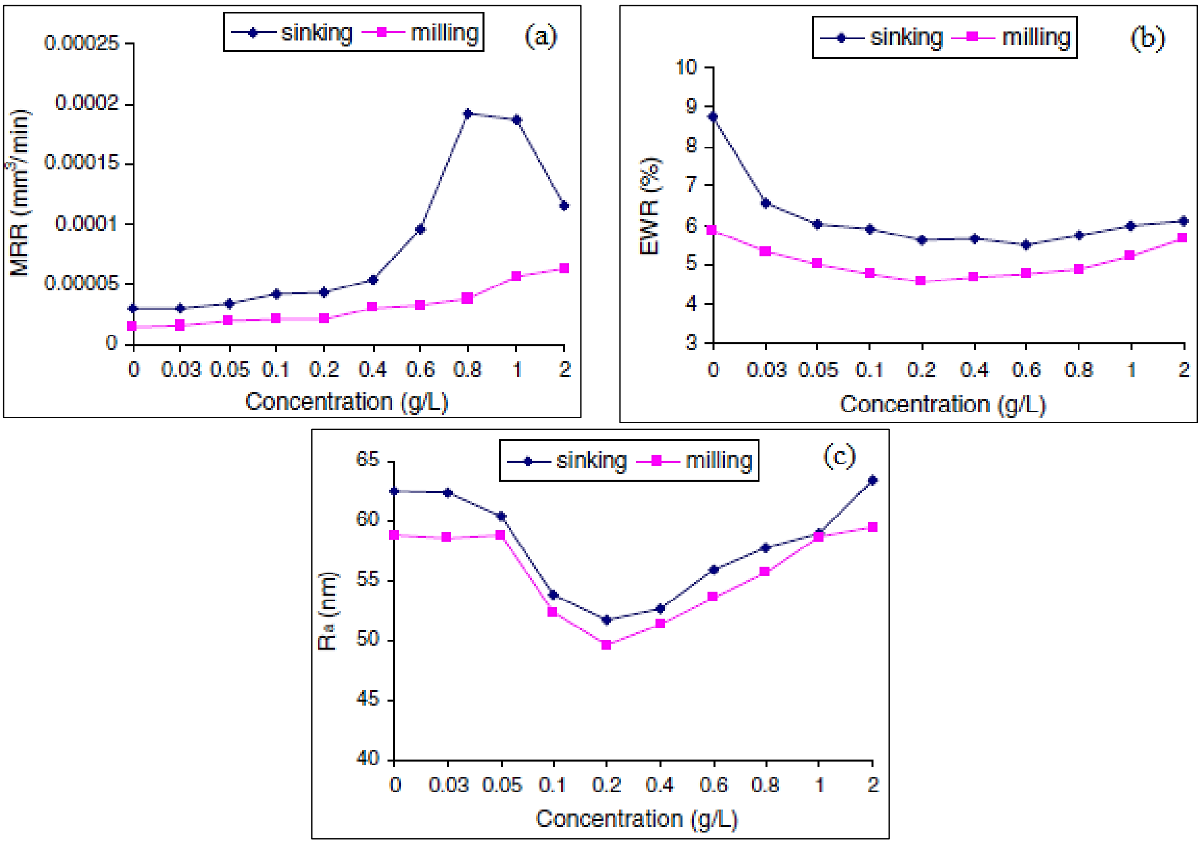

***Fig. 9:** Variation of **(a)** MRR, **(b)** EWR and **(c)** Ra with Graphite Powder Concentration in Dielectric [46].*

Tzeng and Lee found that the particle concentration, the particle size, the particle density, the electrical resistivity, and the thermal conductivity of powders are important characteristics that considerably affect the machining performance in the EDM process [47]. Under the same particle concentration, the smallest suspended particle size led to the greatest MRR and, thus, the lowest TWR. Among the investigated additives (Al, Cr, Cu, SiC), chromium powder produced the greatest MRR and the lowest TWR.

The effects of diatomite, aluminium and copper powders and their concentrations in distilled water on MRR and EWR were investigated by Muniu *et al*. [48]. MRR for copper, aluminium and diatomite powder increases to maximum and then decreases with further increase in powder concentration. At optimum machining condition of 6 g/l concentration, MRR increased by 32, 44 and 7% while EWR decreased by 14, 23 and 12% for diatomite, aluminium and copper, respectively. Increase in MRR, decrease in the TWR and improvement in the surface roughness of the workpiece was reported by Ming and He using conductive and inorganic powder mixed dielectric [49]. Erden and Bilgin investigated the effect of suspended powder particles (Al, Cu, Fe, and carbon) in kerosene on the machinability of mild steel [50]. The machining rate was found to increase with powder particle concentration as it increases the breakdown characteristics of the dielectric fluid. An excessive powder concentration causes the machining unstable and difficult due to the occurrence of short-circuiting. A comparative study has been carried out for EDM of 6061Al/Al2O3p/20p work specimens by Singh *et al.* using pure dielectric fluid and silicon carbide (SiC) abrasive powder suspended dielectric fluid to evaluate surface roughness [51].

The results were analyzed using Lenth's method and it was found that particle size, particle concentration and pulse current are the most significant parameters that affect the surface characteristics. Pec found that powder mixed dielectric helps in reduction of surface roughness, crater diameter and depth as well as the white-layer thickness [52]. Moreover, it was found that powder mixed-dielectric reduces the sensitivity of the surface quality measures to the electrode area. Powder-mixed dielectric also reduces surface heterogeneity which increases process robustness. When large electrode areas are involved with high-quality surface requirement, it contributes well to the performance of the EDM process.

EDM in Gas

In dry EDM, air or gas is used as a dielectric to reduce environment pollution and health hazards caused by hydrocarbon oils. Generally, tubular type tool electrode is used through which high-pressure gas or air is supplied at the gap between tool and workpiece. The air or gas is used to remove the debris from the gap and to cool the inter electrode gap. Kunieda and Yoshida showed that the tool wear ratio is almost zero for any pulse duration for EDM in air and hence the machined shape is very precise [53]. The material removal rate is improved as the concentration of oxygen in air is increased due to heat generation caused by oxidation of the electrode materials. Figure 10 shows comparison of MRR with different dielectric fluids.

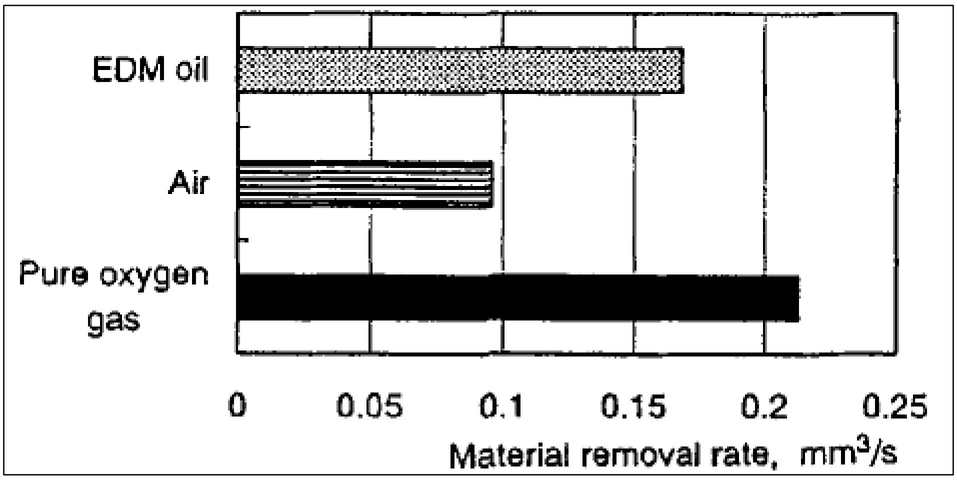

Fig. 10: *Influence of Various Dielectrics on the Material Removal Rate [53].*

Kunieda and Furuoya employed a new method of EDM in water based dielectric with supply of oxygen, argon and nitrogen gas into the discharge gap [54]. It was found that the material removal increases with supply of oxygen compared to conventional EDM due to the enlarged volume of discharged crater and increase in discharge frequency. It was also found that too much oxygen is harmful to the stability of discharges as well as nitrogen and argon is not effective for increasing MRR. Govindan and Joshi evaluated dry electrical discharge drilling by providing shielding to the sparking region [55].

High MRR was observed in dry EDM as compared to the conventional liquid dielectric EDM while micro-cracks were found due to entrapped gases on the machined surface. A new method of ultrasonic vibration assisted EDM in gas was proposed by Zhang *et al.* [56]. The MRR in pure oxygen was twice as compared to air due to heat generation by oxidation of the steel resulting in higher machining efficiency. The MRR of UEDM in gas was found much higher compared to that of EDM in gas and dielectric liquid. Curodeau *et al*. suggested the hybrid electrical discharge polishing (HEDP) process in air using a thermoplastic composite electrode to perform automated polishing of tool steel cavity [57]. It was demonstrated that the HEDP process can be used to reduce a 44 μm Ra surface finish down to a 36 μm Ra with three electrodes forming iterations using constant EDM settings.

Yu *et al*. compared machining characteristics between dry EDM milling, oil EDM milling and oil die sinking EDM for three-dimensional machining of cemented carbide [58]. Dry EDM milling showed higher machining speed and lower electrode wear ratio than oil EDM milling. It was also found that dry EDM milling is most advantageous to three-dimensional milling of cemented carbide considering the total machining time and cost. Machining time for different process is shown in Figure 11.

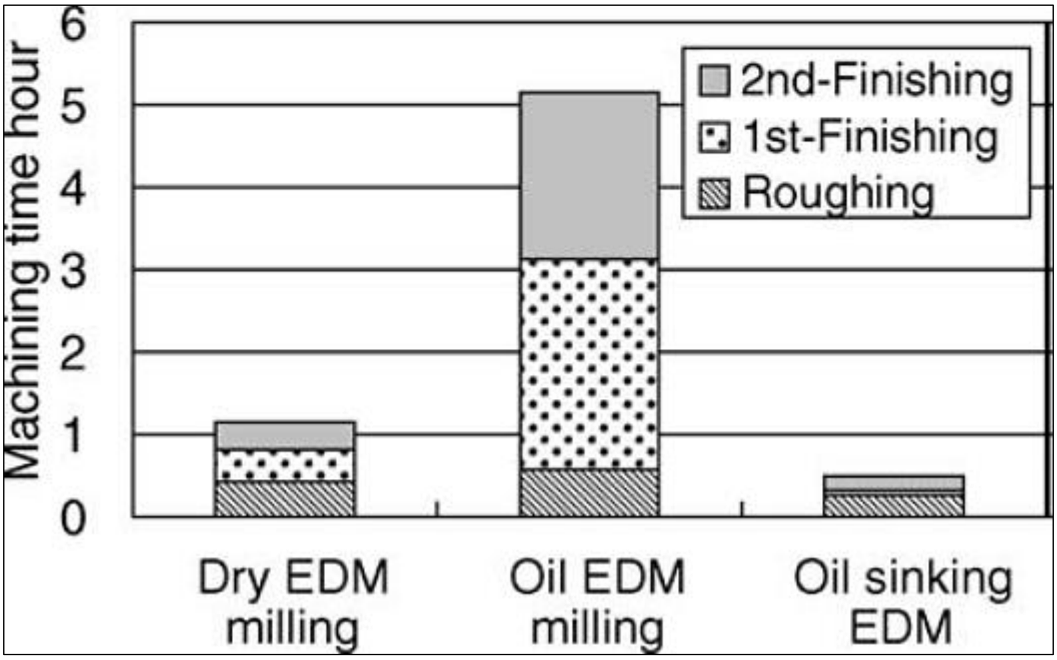

Fig. 11: *Machining Time for Different Process [58].*

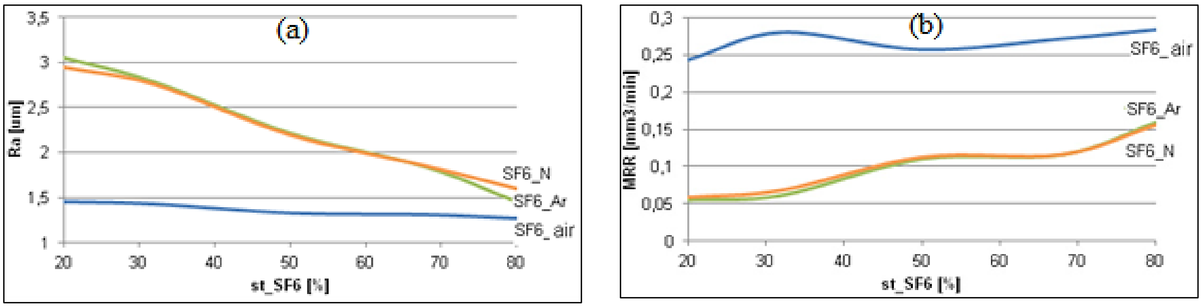

Fig. 12: *Surface Roughness **(a)** and MRR **(b)** vs. Concentration of SF_6 in the Gas Mixture [59].*

Skrabalak *et al*. presented performance characteristics of the dry EDM process, using compressed air, argon (Ar), nitrogen (N_2), sulfur hexafluoride (SF6) and their mixtures as dielectric medium [59]. The EDM milling process conducted in air and SF6 is very effective method of machining and it is more precise than EDM milling in kerosene due to the negligible tool wear ratio. Presence (20% and more) of SF6 in gas significantly improved the surface quality and MRR as shown in Figure 12. Roth *et al*. tested different gases for checking stability of the dry EDM process [60]. They suggested that the different physical properties of oxidized particles and their capability to reattach on the work piece play a major role in enhancing MRR and the flushing efficiency of the process. Figure 13 shows comparison of sparking, arcing, shorts and ignition delay times for different flushing gases. Liqing and Yingjie demonstrated the feasibility of the two approaches, namely oxygen-mixed dry EDM and dry EDM with cryogenically cooled work pieces [61]. Oxygen-mixed dry EDM was shown to improve MRR more than 200% over non-oxygen results at chosen experimental conditions. The MRR was improved approximately 30–50%, and SR approximately 1–10%, as compared to uncooled pieces. Figure 14 shows surface topology of cooled and uncooled workpiece.

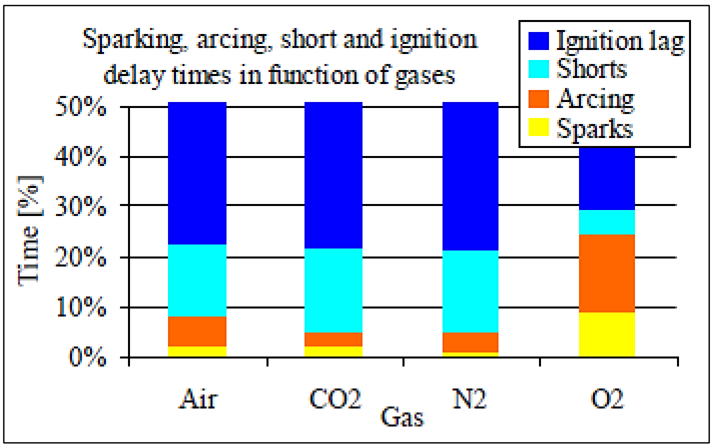

Fig. 13: *Sparking, Arcing, Shorts and Ignition Delay Times for Different Flushing Gases [60].*

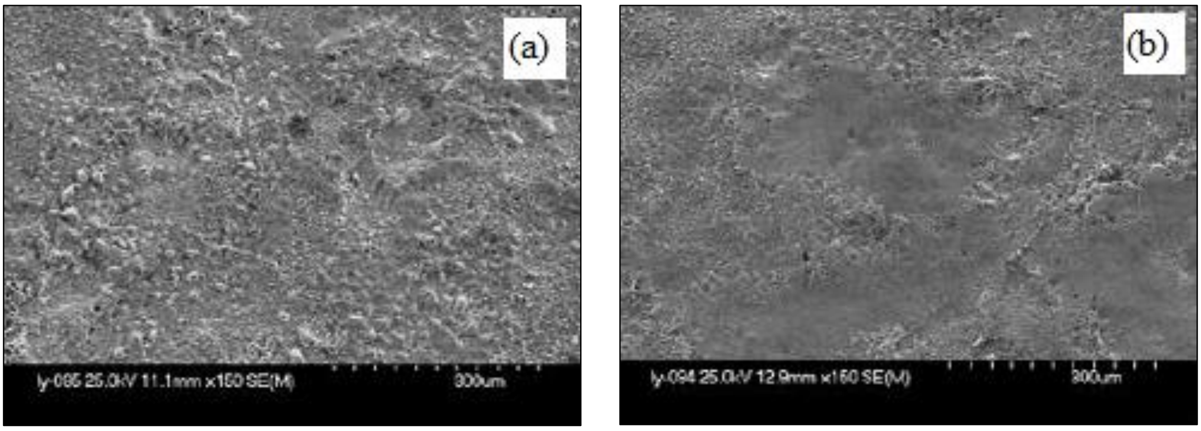

Fig. 14: *Surface Topography Comparison of* ***(a)*** *Uncooled and* ***(b)*** *Cooled Work Pieces as Cathodes at Peak Current of 29 A [61].*

A comparative study between the dry and wet nano-electro machining has been presented by Jahan *et al.* [62]. It was reported that the material removal mechanism of wet nano-EM is associated with field emission-assisted mass in nano-confined liquid dielectric, whereas, dry nano-EM is associated with field-induced evaporation of material. The dry nano-EM showed several advantages over wet nano-EM in terms of dimensional accuracy of the nanoscale features, repeatability and machining performance.

Tao *et al.* investigated the dry and near-dry EDM milling for roughing and finishing operations [63]. Near-dry EDM exhibited the advantage of good machining stability and surface finish under low discharge energy input. Lower pulse duration and lower discharge current were identified as key factors for improving the surface finish in near-dry EDM. Nitrogen and helium gases could prevent the electrolysis and yield better surface finish in near-dry EDM. Figure 15 shows comparison of MRR and surface roughness for different dielectric fluids.

Skrabalak and Kozak conducted experiments to study feasibility of dry EDM process in the field of micro-machining [64]. Better surface roughness and geometry of machined cavity was achieved when two channel electrode was used as compared to single hole electrode. The crucial problem during machining was the evacuation of machined material particles out from the working gap as particles get attached to the electrode. Kunieda *et al*. found that by supplying uniform high-velocity air flow into gap between electrodes, a 3D shape could be machined very precisely and MRR was improved by increasing concentration of oxygen in air [65]. Kao *et al.* investigated the near dry EDM process using mixture of water and air as the dielectric fluid [66]. In near dry EDM, higher MRR, sharper cutting edge, and less debris depositions were observed compared to dry EDM while increase in electrode wear was observed due to higher thermal load. Compared to wet EDM, near dry EDM has higher MRR at low discharge energy. Xu *et al*. proposed ultrasonic vibration assisted EDM in gas medium and discussed five types of cemented carbide material removal mechanisms, which are melting or evaporation, spalling, oxidation, the force of high-pressure gas and ultrasonic vibration affection [67]. They found that the microcracks depend not only on electrical discharge parameters, but also on properties of cemented carbide, such as melting point, thermal conductivity, fracture toughness, etc. Zhan Bo *et al.* studied the feasibility of 3D surface machining by dry EDM. In dry EDM, tool electrode wear ratio was about 1/3 smaller, and the profile accuracy was excellent compared to oil EDM but MRR was not much improved [68]. A study was conducted on ultrasonic-assisted electrical discharge machining (UEDM) in gas medium by Zhang *et al.* to improve its efficiency. The experiment results indicate that material removal rate in UEDM is nearly twice as much as EDM in gas and less than that of conventional EDM [69]. Kunieda *et al*. introduced high speed 3D milling in dry EDM. Due to thermally activated chemical reaction between the gas and workpiece material, the MRR increased when the discharge power density goes beyond certain limit [70]. The maximum MRR found was almost equal to that of high speed milling on a milling machine.

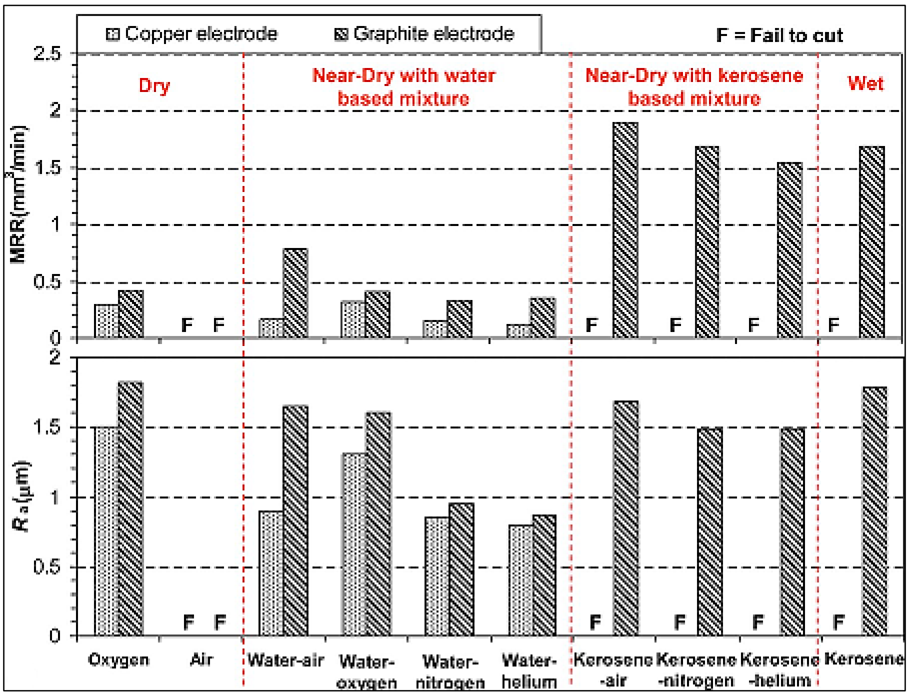

Fig. 15: *MRR and Ra Results of Different Dielectric Fluids for Copper and Graphite Electrode Materials at Low Discharge Energy Input [63].*

CONCLUSION

The selection of dielectric fluid for EDM is a critical task as it has a great effect on performance, economics and environmental impact of process. For more than last 30 years, different researchers are working on improvement of EDM performance in terms of MRR, electrode wear, surface finish, dimensional accuracy, etc. using different dielectric fluids like distilled/deionized water, water with additives, powder mixed dielectric, air, oxygen, nitrogen, etc. However, many issues are still needed to be investigated before this research can be commercially viable in the industries. The review of the research in EDM with different dielectric fluid and variations like ultrasonic vibration, cryogenic cooling, etc. is presented here. There are extensive literatures available which confirm superiority of hydrocarbon oils over deionized/distilled water in EDM applications. However, in some situations, pure water gives good result compared to hydrocarbon oils. Some authors have investigated the feasibility of water as dielectric in EDM and found the possibility of achieving zero electrode wear in special condition. Better performance was obtained by organic compound mixed water for roughing and finishing operations. In case of distilled water, surface finish/integrity is generally poor than that of hydrocarbon oils as higher concentration of micro cracks and voids are formed. As water based dielectrics are economic and environment friendly, they must be investigated further as an option of hydrocarbon oil for performance improvement of EDM with different additives and for machining of materials like composites and carbides.

The effect of adding different powder like graphite, Fe, Cu, Ni, Al, Cr, Co, Si, SiC, TiC, etc. with different grain sizes in dielectric was investigated by many researchers and they found great improvement in surface finish. More literature is found on aluminium powder suspended dielectric as it performs well for improving MRR as well as the surface finish. Complex nature of powder mixed EDM and certain limitations like high cost, environmental issues, dielectric disposal, etc. limited its use in industry. So, more research is needed for powder mixed EDM in terms of using important alloying elements such as manganese, molybdenum, vanadium, etc. in form of powder for machining of materials which have not been tried yet. Effect of size, shape and concentration of powder particles on performance of EDM can be also investigated.

The literature shows that dry EDM can be substitute of hydrocarbon oil based EDM due to low cost, simple operation and no pollution. Some authors have investigated feasibility of dry EDM for 3D surface machining and found excellent profile accuracy and less tool electrode wear ratio compared to oil EDM. Most of the research work was done using air and oxygen as dielectric fluid for improvement of MRR. So, there is a scope of research in dry EDM by using other gaseous dielectrics like argon, helium, nitrogen, etc. for performance variables such as micro hardness, surface integrity, geometrical accuracy, etc. Dry EDM can be developed as precise process for drilling of micro holes.

REFERENCES

1. Banker KS, Parmar SP, Parekh BC. Review to Performance Improvement of Die Sinking EDM Using Powder Mixed Dielectric Fluid. *Int J Res Mod Eng Emerg Technol*. 2013; 1(3): 57–62p.
2. Singh S, Bhardwaj A. Review to EDM by Using Water and Powder-Mixed Dielectric Fluid. *J Min Mater Characterization Eng*. 2011; 10(2): 199–230p.
3. Makenzi MM, Ikua BW. A Review of Flushing Techniques Used in Electrical Discharge Machining. *Proceedings of the 2012 Mechanical Engineering Conference on Sustainable Research and Innovation*, Kenya. 2012; 155–61p.
4. Wong YS, Lim LC, Lee LC. Effects of Flushing on Electro-Discharge Machined Surfaces. *J Mater Process Technol*. 1995; 48(1–4): 299–305p.
5. Syed KH, Palaniyandi K. Performance of Electrical Discharge Machining Using Aluminium Powder Suspended Distilled Water. *Turkish J Eng Env Sci*. 2012; 36: 195–207p.
6. Jeswani ML. Electrical Discharge Machining in Distilled Water. *Wear*. 1981; 72: 81–8p.
7. Jilani ST, Pandey PC. Experimental Investigations into the Performance of Water as Dielectric in EDM. *Int J Mach Tool Design Res*. 1984; 24: 31–43p.
8. Kagaya K, Oishi Y, Yada K. Micro-Electro Discharge Machining Using Water as a Working Fluid-I: Micro-Hole Drilling. *Precision Eng*. 1986; 8(3): 157–62p.
9. Masuzawa T, Tanaka K, Nakamura Y. Water-Based Dielectric Solution for EDM. *Annals CIRP*. 1983; 32(1): 119–22p.
10. Zhang Y, Liu Y, Ji R, *et al*. Study of the Recast Layer of a Surface Machined by Sinking electrical Discharge Machining Using Water-in-Oil Emulsion as Dielectric. *Appl Surf Sci*. 2011; 257: 5989–97p.
11. Bai CY, Koo CH. Effects of Kerosene or Distilled Water as Dielectric on Electrical Discharge Alloying of Superalloy Haynes 230 with Al-Mo Composite Electrode. *Surf Co Technol*. 2006; 200: 4127–35p.

12. Chow HM, Yang LD, Lin CT, *et al*. The Use of SiC Powder in Water as Dielectric for Micro-Slit EDM Machining. *J Mater Process Technol.* 2008; 195: 160–70p.
13. Chen SL, Yan BH, Huang FY. Influence of Kerosene and Distilled Water as Dielectrics on the Electric Discharge Machining Characteristics of Ti-6A1-4V. *J Mater Process Technol*. 1999; 87: 107–11p.
14. Syed KH, Palaniyandi K. Performance of Electrical Discharge Machining Using Aluminium Powder Suspended Distilled Water. *Turkish J Eng Env Sci*. 2012; 36: 195–207p.
15. Yan BH, Tsai HC, Huang FY. The Effect in EDM of a Dielectric of a Urea Solution in Water on Modifying the Surface of Titanium. *Int J Mach Tools Manuf*. 2005; 45: 194–200p.
16. Tang L, Du YT. Experimental Study on Green Electrical Discharge Machining in Tap Water of Ti-6Al-4V and Parameters Optimization. *Int J Adv Manuf Technol*. 2014; 70: 469–75p.
17. Kibria G, Sarkar BR, Pradhan BB, *et al.* Comparative Study of Different Dielectrics for Micro-EDM Performance during Microhole Machining of Ti-6Al-4V Alloy. *Int J Adv Manuf Technol*. 2010; 48: 557–70p.
18. Syed KH, Kuppan P. Studies on Recast-Layer in EDM using Aluminium Powder Mixed Distilled Water Dielectric Fluid. *Int J Eng Technol.* 2013; 5(2): 1775–80p.
19. Shivakoti I, Kibria G, Diyaley S, *et al*. Multi-Objective Optimization and Analysis of Electrical Discharge Machining Process during Micro-Hole Machining of D3Die Steel Employing Salt Mixed De-Ionized Water Dielectric. *J Comput Appl Res Mech Eng*. 2013; 3(1): 27–39p.
20. Ekmekci B, Elkoca O, Tekkaya AE, *et al.* A Residual Stress State and Hardness Depth in Electric Discharge Machining: De-Ionized Water as Dielectric Liquid. *Mach Sci Technol.* 2005; 9: 39–61p.
21. Liew PJ, Yan J, Masaki T, *et al*. Effect of Different Dielectric Fluids on Micro EDM of Low Conductivity Ceramic Material RB-SiC. *Adv Mater Res*. 2012; 565: 529–34p.
22. Muniu JM, Ikua BW, Nyaanga DM, *et al*. Applicability of Diatomite Powder-Mixed Dielectric Fluid in Electrical Discharge Machining Processes. *Int J Pure Appl Sci Technol*. 2013; 19(1): 19–36p.
23. Konig W, Siebers FJ. Influence of the Working Medium on the Removal Process in EDM Sinking. *American Society of Mechanical Engineers (ASME),* Production Engineering Division (PED). 1993; 64: 649–58p.
24. Kang SH, Kim DE. Effect of Electrical Discharge Machining Process on Crack Susceptibility of Nickel Based Heat Resistant Alloy. *Mater Sci Technol.* 2005; 21: 817–23p.
25. Jeswani ML. Effect of the Addition of Graphite Powder to Kerosene used as the Dielectric Fluid in Electrical Discharge Machining. *Wear*. 1981; 70: 133–39p.
26. Konig W, Jorres L. Aqueous Solutions of Organic Compounds as Dielectrics for EDM Sinking. *ClRP Annals*. 1987; 36(1): 105–9p.
27. Pecas P, Henriques E. Influence of Silicon Powder-Mixed Dielectric on Conventional Electrical Discharge Machining. *Int J Mach Tools Manuf.* 2003; 43: 1465–71p.
28. Wu KL, Yan BH, Lee JW, *et al*. Study on the Characteristics of Electrical Discharge Machining using Dielectric with Surfactant. *J Mater Process Technol.* 2009; 209: 3783–9p.
29. Wu KL, Yan BH, Huang FY, *et al*. Improvement of Surface Finish on SKD Steel using Electro-Discharge Machining with Aluminum and Surfactant Added Dielectric. *Int J Mach Tools Manuf.* 2005; 45: 1195–201p.
30. Prihandana GS, Mahardika M, Hamdi M, *et al.* Effect of Micro-Powder Suspension and Ultrasonic Vibration of Dielectric Fluid in Micro-EDM Processes-Taguchi Approach. *Int J Mach Tools Manuf.* 2009; 49: 1035–41p.
31. Tzeng YF, Chen FC. Investigation into Some Surface Characteristics of Electrical Discharge Machined SKD-11 using Powder-Suspension Dielectric Oil. *J Mater Process Technol.* 2005; 170: 385–91p.

32. 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. *J Mater Process Technol*. 2008; 200: 250–8p.
33. Kansal HK, Singh S, Kumar P. Parametric Optimization of Powder Mixed Electrical Discharge Machining by Response Surface Methodology. *J Mater Process Technol*. 2005; 169: 427–36p.
34. Wong YS, Lim LC, Rahuman I, *et al*. Near-Mirror-Finish Phenomenon in EDM using Powder-Mixed Dielectric. *J Mater Process Technol*. 1998; 79: 30–40p.
35. Hu FQ, Cao FY, Song BY, *et al*. Surface Properties of SiCp/Al Composite by Powder-Mixed EDM. *The Seventeenth CIRP Conference on Electro Physical and Chemical Machining (ISEM), Procedia CIRP*. 2013; 6: 101–6p.
36. Ojha K, Garg RK, Singh KK. Experimental Investigation and Modeling of PMEDM Process with Chromium Powder Suspended Dielectric. *Int J Appl Sci Eng*. 2011; 9(2): 65–81p.
37. Kumar A, Maheshwari S, Sharma C, *et al*. Realizing Potential of Graphite Powder in Enhancing Machining Rate in AEDM of Nickel Based Super Alloy 718. *AMAE Int. J. Prod Ind Eng*. 2010; 01(01): 48–51p.
38. Padhee S, Nayak N, Panda SK, *et al*. Multi-Objective Parametric Optimization of Powder Mixed Electro-Discharge Machining using Response Surface Methodology and Non-Dominated Sorting Genetic Algorithm. *Sadhana*. 2012; 37(2): 223–40p.
39. Ali MY, Atiqah N, Erniyati. Silicon Carbide Powder Mixed Micro Electro Discharge Milling of Titanium Alloy. *Int J Mech Mater Eng*. 2011; 6(3): 338–42p.
40. Yan BH, Lin YC, Huang FY, *et al*. Surface Modification of SKD61 during EDM with Metal Powder in the Dielectric. *Mater T*. 2001; 42(12): 2597–604p.
41. Prihandana GS, Mahardika M, Hamdi M, et al. Accuracy Improvement in NanographitePowder-Suspended Dielectric Fluid for Micro-Electrical Discharge Machining Processes. *Int J Adv Manuf Technol*. 2011; 56: 143–9p.
42. Khan AA, Ndaliman MB, Zain ZM, *et al*. Surface Modification using Electric Discharge Machining (EDM) with Powder Addition. *Appl Mech Mater*. 2012; (110–116): 725–33p.
43. Ojha K, Garg RK, Singh KK. The Effect of Nickel Micro Powder Suspended Dielectric on EDM Performance Measure of EN-19 Steel. *J Eng Appl Sci*. 2011; 6(1): 27–37p.
44. Parkash V, Kumar D. Effect of Powder Mixed Dielectric Medium on Tool Wear Rate in EDM. *Int J Sci Res*. 2013; 2(2): 107–9p.
45. Kumar S, Singh R. Investigating Surface Properties of OHNS Die Steel after Electrical Discharge Machining with Manganese Powder Mixed in the Dielectric. *Int J Adv Manuf Technol*. 2010; 50: 625–33p.
46. Jahan MP, Rahman M, Wong YS. Study on the Nano-Powder-Mixed Sinking and Milling Micro-EDM of WC-Co. *Int J Adv Manuf Technol*. 2011; 53: 167–80p.
47. Tzeng YF, Lee CY. Effects of Powder Characteristics on Electro-discharge Machining Efficiency. *Int J Adv Manuf Technol*. 2001; 17: 586–92p.
48. Muniu JM, Ikua BW, Nyaanga DM, *et al*. Study on Effects of Powder-Mixed Dielectric Fluids on Electrical Discharge Machining Processes. *Int J Eng Res Technol*. 2013; 2(10): 2449–56p.
49. Ming QY, He LY. Powder-Suspension Dielectric Fluid for EDM. *J Mater Process Technol*. 1995; 52: 44–54p.
50. Erden A, Bilgin S. Role of Impurities in Electric Discharge Machining. *In Proceedings of 21st International Machine Tool Design and Research Conference,* Macmillan, London. 1980; 345–50p.
51. Singh S, Maheshwari S, Pandey PC, *et al*. Effect of Sic Powder Suspended Dielectric Fluid on the Surface Finish of 6061Al/Al2O3P/20p Composites in Electric Discharge Machining. *Int J Machining Machinability Mater*. 2008; 4(2/3): 252–74p.
52. Pec P. Electrical Discharge Machining using Simple and Powder-Mixed Dielectric: The Effect of the Electrode Area in the Surface Roughness and Topography. *J Mater Process Technol*. 2008; 200: 250–8p.

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53. Kunieda M, Yoshida M. Electrical Discharge Machining in Gas. *CIRP Annals*. 1997; 46(1): 143–6p.
54. Kunieda M, Furuoya S. Improvement of EDM Efficiency by Supplying Oxygen Gas into Gap. *CIRP Annals*. 1991; 4(7): 215–8p.
55. Govindan P, Joshi SS. Experimental Characterization of Material Removal in Dry Electrical Discharge Drilling. *Int J Mach Tools Manuf*. 2010; 50: 431–43p.
56. Zhang QH, Zhang JH, Deng JX, *et al*. Ultrasonic Vibration Electrical Discharge Machining in Gas. *J Mater Process Technol*. 2002; 129: 135–8p.
57. Curodeau A, Richard M, Villeneuve LF. Molds Surface Finishing with New EDM Process in Air with Thermoplastic Composite Electrodes. *J Mater Process Technol*. 2004; 149: 278–83p.
58. ZhanBo Y, Takahashi J, Kunieda M. Dry Electrical Discharge Machining of Cemented Carbide. *J Mater Process Technol*. 2004; 149: 353–7p.
59. Skrabalak G, Kozak J, Zybura M. Optimization of Dry EDM Milling Process. *The Seventeenth CIRP Conference on Electro Physical and Chemical Machining (ISEM), Procedia CIRP*. 2013; 6: 332–7p.
60. Roth R, Kuster F, Wegener K. Influence of Oxidizing Gas on the Stability of Dry Electrical Discharge Machining Process. *The Seventeenth CIRP Conference on Electro Physical and Chemical Machining (ISEM), Procedia CIRP*. 2013; 6: 338–43p.
61. Liqing L, Yingjie S. Study of Dry EDM with Oxygen-Mixed and Cryogenic Cooling Approaches. *The Seventeenth CIRP Conference on Electro Physical and Chemical Machining (ISEM), Procedia CIRP*. 2013; 6: 344–50p.
62. Jahan MP, Virwani KR, Rajurkar KP, *et al*. A Comparative Study of the Dry and Wet Nano-Scale Electro-Machining. *The Seventeenth CIRP Conference on Electro Physical and Chemical Machining (ISEM), Procedia CIRP*. 2013; 6: 626–31p.
63. Tao J, Shih AJ, Ni J. Experimental Study of the Dry and Near-Dry Electrical Discharge Milling Processes. *J Manuf Sci Eng*. 2008; 130: 011002–1p.
64. Skrabalak G, Kozak J. Study on Dry Electrical Discharge Machining. *Proceedings of the World Congress on Engineering*, London, UK. 2010.
65. Yoshida M, Kunieda M. Study on Mechanism for Minute Tool Electrode Wear in Dry EDM. *J Jpn Soc Precision Eng*. 1999; 65: 689–93p.
66. Kao CC, Tao J, Shih AJ. Near Dry Electrical Discharge Machining. *Int J Mach Tools Manuf*. 2007; 47: 2273–81p.
67. Xu MG, Zhang JH, Li Y, *et al*. Material Removal Mechanisms of Cemented Carbides Machined by Ultrasonic Vibration Assisted EDM in Gas Medium. *J Mater Process Technol*. 2009; 209: 1742–6p.
68. Zhanbo Y, Takahashi J, Nakajima N, *et al*. Feasibility of 3-D Surface Machining by Dry EDM. *Int J Electr Machining*. 2005; 10: 15–20.
69. Zhang QH, Du R, Zhang JH, *et al*. An Investigation of Ultrasonic-Assisted Electrical Discharge Machining in Gas. *Int J Mach Tools Manuf*. 2006; 46: 1582–8p.
70. Kunieda M, Miyoshi Y, Takaya T, *et al*. High Speed 3D Milling by Dry EDM. *CIRP Annals-Manuf Technol*. 2003; 52: 147–50p.

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