International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 5, Issue 4
April 2018

A Review on Research Aspects and Trends in Electrical Discharge Machining (EDM)

Anand Singh[1], Ankit Kumar[1], Sachin Kumar[1], Akshay Kumar[1], Shrikant Vidya[1]
[1] School of Mechanical Engineering, Galgotias University, Uttar Pradesh, India

ABSTRACT

With the advancement of technology and global competition, the manufacturing industries are facing challenges from difficult-to-machine materials like Super alloys, ceramics and composites which require high precision and surface quality thereby increase machining cost. Among various non-traditional machining processes such as Electrical Discharge Machining (EDM), Ultrasonic Machining (USM), Electro-Chemical Machining (ECM) and Laser Machining, EDM has become the most prominent tool due to its salient feature of contactless machining and three dimensional machining irrespective of hardness. Electrical discharge machining (EDM) is a nontraditional machining process which can be used to machine electro-conductive, difficult-to-machine materials, high strength temperature resistant alloys, complex geometries in small batches or even on job-shop basis. Researchers have been exploring the EDM process continuously for many years to provide vast theoretical and experimental concepts. The objective of this paper is to study the different aspects and research trends and developments in EDM. The review begins with the introduction to EDM and its principle, followed by the variants of EDM and then different research trends and developments have been discussed in detail.

Keywords: *EDM, Material Removal Rate (MRR), Tool Wear Ratio (TWR), Surface Roughness*

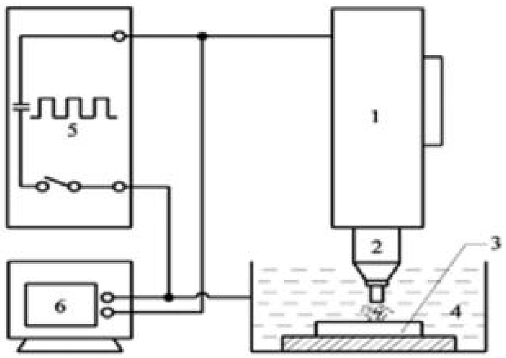
1. INTRODUCTION AND P RINCIPLE OF EDM

Electrical Discharge Machining (EDM) [1] is an electro-thermal non-traditional machining process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark. The main components of EDM include the tool feed servo-controlled unit, which maintains a constant machining gap that ensures the occurrence of active discharges between the two electrodes. The DC pulse generator is responsible for supplying pulses at a certain voltage and current for specific amount of time. The dielectric circulation unit flushes the dielectric fluid into the inter electrode gap after being filtered to remove the machining debris.

In EDM, the metal is removed from the work piece due to erosion caused by rapidly recurring spark discharge taking place between the electrode (tool) and work piece. A small gap of about 5µm is maintained between the tool and work piece by a servo system as shown in figure 1. Both tool and work piece are submerged in a dielectric fluid. Kerosene/EDM oil is a very common type of liquid dielectric used, although, gaseous dielectrics are also used in certain cases. Generally the work piece is made positive and the tool negative. When the voltage across the gap becomes sufficiently high it discharges through the gap in the form of a spark in an interval ranging from 10µs to few hundred µs. Positive ions and electrons are accelerated (as shown in figure 2), producing a discharge channel that becomes conductive. It is just at this point when the spark jumps causing collisions between ions and electrons creating a channel of plasma, a sudden drop of the electric resistance of the previous channel allows that current density reach a very high value producing an increase of ionization and the creation of a powerful magnetic field. The moment spark occurs; sufficient pressure develops between work and tool as a result of which a very high temperature is reached in the range of 8000 to 12,000 °C [2] and at such high pressure and temperature some metal is melted and eroded. Such localized extreme rise in temperature leads to material removal. Material removal occurs due to instant vaporization of

International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 5, Issue 4
April 2018

the material as well as due to melting. The molten metal is not removed completely but only partially. Once the potential difference is withdrawn, the plasma channel no longer sustains. As the plasma channel collapses, it generates a pressure (shock waves), which evacuates the molten material thus forming a crater at the site from where the material got eroded.



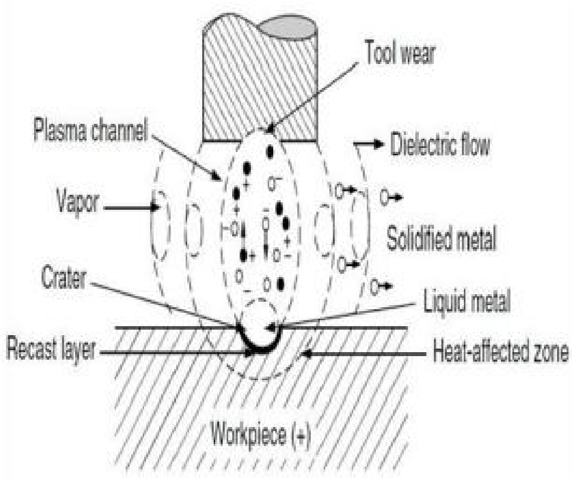


Fig.1: Schematic diagram of the EDM process

1. Servo-control, 2.Electrode, 3.Work piece,
4. Di-electric fluid, 5.Pulse generator, 6.Oscilloscope

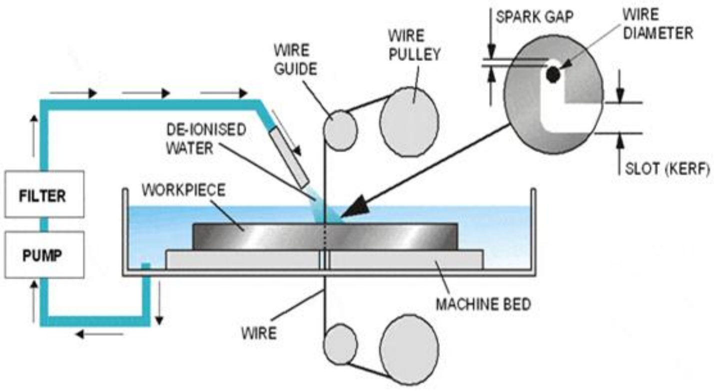
Fig.2: EDM Spark Description

2. VARIANTS OF EDM

Basically, there are two different types of EDM:

(a) Die-sinking EDM: The sinker EDM machining process uses an electrically charged shaped or three-dimensional electrode that is configured to a specific geometry to burn the geometry of the electrode into a metal component. With the negative energy, even the thinnest and hardest steel pieces can be processed. A die sinker EDM is also commonly known as a cavity type EDM or a volume EDM. The sinker EDM process is commonly used in the production of dies and moulds. Two metal parts submerged in an insulating liquid are connected to a source of current which is switched on and off automatically depending on the parameters set on the controller. When the current is switched on, an electric tension is created between the two metal parts. If the two parts are brought together to within a fraction of an inch, the electrical tension is discharged and a spark jumps across. Where it strikes, the metal is heated up so much that it melts. One after the other, sparks are produced and slowly shapes the needed figure for the metal sheet, as dictated by the electrode shape. Several hundred thousand sparks must fly per second before erosion takes place.

(b) Wire-cut EDM: Wire EDM machining is an electro thermal production process in which a thin single-strand metal wire in conjunction with de-ionized water (used to conduct electricity) allows the wire to cut through metal by the use of heat from electrical sparks. Wire-cutting EDM is commonly used when low residual stresses are desired, because it does not require high cutting forces for removal of material. If the energy/power per pulse is relatively low (as in finishing operations), little change in the mechanical properties of a material is expected due to these low residual stresses, although material that hasn't been stress-relieved can distort in the machining process. Due to the inherent properties of the process, wire EDM can easily machine complex parts and precision components out of hard conductive materials. Wire EDM machining works by creating an electrical discharge between the wire or electrode, & the work piece. As the spark jumps across the gap, material is removed from both the work piece & the electrode. To stop the sparking process from shorting out, a non conductive fluid or dielectric is also applied. The waste material is removed by the dielectric, and the process continues.



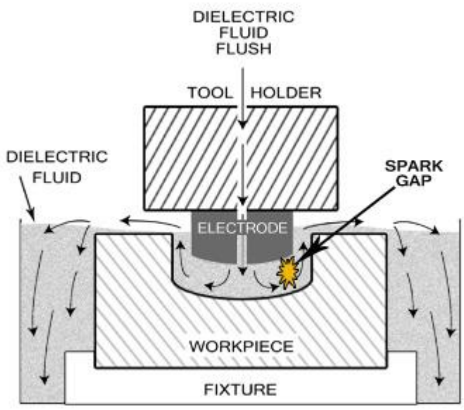


Fig.3: Die-Sinking EDM Mechanism [3]

Fig.2: Wire-cut EDM Schematic [4]

3. RESEARCH ASPECTS, TRENDS AMD DEVELOPMENTS IN EDM

3.1 Material Removal Mechanism

Wang et al. [5] analyzed electrode material removal process in EDM using short pulse and applying heat conduction, plasma theory and elasticity mechanics. Authors reported that the material removal process of EDM can be quantitative analyzed by using the theory of thermal conduction and electrostatic force. A thermodynamic model of electrode material removal under single spark was established. The results of infinite element numerical simulation and experiments confirmed the model. Another material removal model of electrostatic force for super short pulse EDM was discussed and established. This research can forecast the electrode wear to a certain extent and therefore improve the machining precision.

Lauwers et al. [6] studied the EDM material removal mechanisms for ZrO2- based, Si3N4-based and Al2O3-based ceramic materials, with additions of electrical conductive phases like TiN and TiCN. This study pointed out that besides the typical EDM material removal mechanisms, such as melting/evaporation and spalling, other mechanisms can occur such as the oxidation and decomposition of the base material. The latter especially occurs in wire EDM of Si3N4–TiN when using de-ionized water. Further, the spalling effect proved to be strongly related to the formation of cracks. The formation of cracks itself depends on other factors like thermal conductivity of the material, melting point and strength and the fracture toughness of the material. In this respect, spalling was not recognized in the machining of ZrO2–TiN which has a higher fracture toughness value, compared to the other investigated materials. *Singh et al. [7]* proposed a thermo-electric model to calculate the electrostatic force on the surface of the cathode and the stress distribution inside the metal during a discharge. They reported that the surface stress acts as a point force and can be extended to any kind of discharge. The model based on the experimental results for short pulses revealed that the electrostatic forces are the major cause of metal removal for short pulses and melting is the dominant phenomenon for long pulses. This model also explained the reason for constant crater depth with varying discharge duration.

3.2 Plasma Characteristics

Panda Deepak Kumar [8] provided a close form solution in computing thermal stress components developed under a single spark in EDM. The nature of the thermal stresses showed significant resemblance with the results obtained from finite element based model reported earlier. The present analytical model provided simpler mathematical expressions to compute thermal stress components. The results obtained substantiate the damaging nature of thermal stresses developed during EDM. After a spark, significant magnitude of stress developed around the crater extending from the top surface to about more than twice the crater depth, which was in excess of the ultimate stress. Further, it was reported that the pulse duration, power, and plasma channel radius are the prime factors, which influences the temperature developed under the spark and values of thermal stresses. Higher heat flux, and longer pulse duration were found to be the cause of relatively higher thermal damage in EDM. From the nature and magnitude of the stress developed, it was inferred both experimentally and theoretically that a network of crack initiates from the top edge of the crater and propagates towards the bottom of the crater surface. Also, damaged layer in adjoining area of overlapping craters can be minimized by controlling the surface roughness. The damaged layer was found to encircle the crater up to a significant depth relative to crater depth, which needs to be removed to yield damage free surface.

Natsu et al. [9] observed the arc plasma with a high-speed video camera and showed that the expansion of the arc plasma in the EDM process completed within only a few microseconds after dielectric breakdown. On the basis of observations, a new model of EDM arc plasma expansion, called first-stage-expansion model was proposed and verified experimentally by the measurement results of plasma temperature. It was found from the computed discharge crater that the first-stage expansion-model was closer to the actual EDM process than the conventional model.

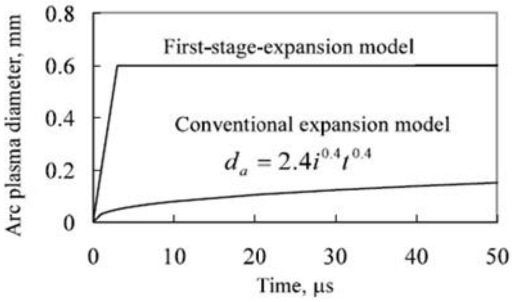


Fig.3: Expansion of arc plasma for two models

Pandey et al. [10] presented the computational analysis of plasma channel size as a function of pulse-on duration in EDM and also suggested a method for evaluating the thickness of the resolidified layer. They proposed two-dimensional disc heat source model and concluded that this model can be modified adequately for the time-dependence of plasma channel diameter in EDM. Due to this consideration, the results as well as the correspondence between theoretical and experimental data improved. The proposed heat source model also enabled to obtain the heat affected zone thickness due to a single spark with a fair degree of accuracy and a good correlation between the analytical and experimental values. This model also helped in the estimation of extent of thermal damage of the electrode material during EDM.

3.3 Process Performance and Optimization

Puertas el. al. [11] investigated the influence of intensity, pulse-on-time and pulse-off time on process performance criteria such as surface quality and dimensional precision. Authors concluded that the factor of intensity has the most influence on the surface roughness and also found that there is a strong interaction between the intensity (I) and the pulse on time. Authors advised to work with high intensity values and low pulse on time.

Guu Y.H. [12] reported that higher discharge energy results in a poorer surface structure when the atomic force microscopy (AFM) study of the surface morphology, surface roughness and micro-crack of AISI D2 tool steel machined by EDM process was done. He stated that low discharge energy should be used to avoid excessive machined damage. The surface roughness and the depth of the micro cracks were proportional to the power input. The AFM technique can be successfully applied to obtain a three-dimensional image with a nanometer scale and to evaluate the depth of the micro-cracks formed on the EDM surface. It is suggested that the EDM components should be polished down to at least the maximum depth of the micro-cracks prior to use.

Guu et al. [13] presented a novel rotary electrical discharge machining (EDM) cutting process for a hard-to-machine cylindrical work piece. Experiment was carried on using AISI D2 tool steel as work piece and copper as electrode material with a view to analyze the effects of machining parameters such as pulsed current, pulse-on-time and work piece rotation on MRR and surface roughness and their comparison with those of conventional EDM without work piece rotation. Experimental results revealed that debris particles in the gap increased the discharge instability in conventional EDM. On the other hand, the centrifugal force in rotary EDM improved gap flushing and machining efficiency. The MRR in rotary EDM was found to be up to twice that of conventional EDM and the value of surface roughness decreased with increasing rotation speed. They also concluded that the specimen rotation can reduce the formation of micro voids and defects on machined surface and hence, EDM of axial-symmetrical die is improved by this technique.

Anish et. al. [14] presented quadratic models for the machining rate, surface roughness and dimensional deviation to correlate the dominant machining parameters: pulse on time, pulse off time, peak current, spark gap voltage, wire feed & tension in wire EDM process for pure titanium. An experimental plan of the Box-Behnken based on RSM has been employed to perform the experiments and reported that the most significant parameters are pulse on time, pulse off time, peak current & spark gap voltage and also finalized that the machining rate, surface roughness and dimensional deviations were fairly well fitted with the experimental results with 95% confidence level.

Nikalje et. al. [15] investigated the influence of process parameters such as discharge current, pulse-on-time and pulse-off-time for process performance criteria such as MRR, Tool Wear Ratio (TWR), Relative Wear Ratio (RWR) and surface roughness. The MDN 300 steel was used as work piece material and copper as electrode. The Taguchi method was utilized for optimization. It was found that the optimal levels of the factors for SR and TWR are same but differs from the optimum levels of the factors for MRR and RWR. From ANOVA, discharge current is more significant than pulse on time for MRR and TWR; whereas pulse on time is more significant than discharge current for RWR and SR. on the other hand, pulse off time is less significant for all performance characteristics considered.

K.M. Patel et.al. [16] derived quadratic mathematical model to represent the process behaviour of EDM. Experiments were conducted with four process parameters viz. discharge current, pulse on time, duty cycle and gap voltage and to relate them with process response surface roughness (SR). Experiment was performed with AL2/SiCW/TiC ceramic composite as work piece. Response surface method has been employed for prediction of process response for various combinations of factor setting. The significance of machining parameters selected has been established using analysis of variance. The surface roughness prediction model has been optimized using a trust region method. It was concluded that Pulse-on time is found to be the dominant parameter influencing surface roughness (SR) and it was also observed that an increase in discharge current increases the SR. The confirmation test showed that developed models can predict the SR accurately within95% confidence interval.

Tzeng and Chen [17] developed a robust, versatile, and high speed EDM process by applying fuzzy logic along with Taguchi orthogonal experiment. Fuzzy system was used to capture the uncertainty and vagueness to establish relationships between the machining precision and accuracy for determining the effect of each parameter on the design of robust EDM process. The optimal process conditions for the high-speed EDM process were determined from fuzzy inference process. Analysis of Variance (ANOVA) was further applied to identify factor pulse time, duty cycle, and peak value of discharge current as the most important parameters, which accounted for about 81.5% of the deviation.

Kansal et al. [18] applied response surface methodology (RSM) model to identify relationship of response parameters for a range of specific values in terms of independent input factors. ANOVA was further employed to identify the significant factors. Peak current and concentration of silicon powder were identified as the two most important factors affecting MRR and SR.

Arooj et al. [19] performed experiments on die sinking EDM machine with varying electric current values to determine its effect on surface morphology in the case of aluminum alloy. The operating parameters in EDM, i.e., “current”, “voltage”, “on time” and “off time” are directly related with the white layer formation, its thickness, morphology and roughness. Machining of Al 6061 T6 cylinders was done and the characteristics of material removal rate versus current are determined for different current values. An attempt was made to relate the globule formation on the machined surface, with the machining current. Scanning electron microscopy, optical microscopy and material composition study were performed through energy dispersive spectrography. It was reported that the white layer thickness, globule diameter and inter-globule distance increases with the increase in electric current.

ZhanBo et al. [20] studied the feasibility of 3D surface machining by dry EDM to analyze the effect of depth of cut and gas pressure, pulse duration and pulse interval and the rotational speed of the tool electrode. The result reported that optimum combination of depth of cut and gas pressure at a pulse duration of 25 mm leads to maximum MRR and minimum tool wear. The tool wear increases moderately with the increase in the rotational speed.

Zhang et al. [21] presented a theoretical model for estimating the roughness of the finished surface. Experiments were carried out using AISI 1045 steel as work piece material and copper as the electrode. The study reported that the roughness of finished surface increases with an increase in the discharge voltage, discharge current and pulse duration.

Guu et al. [22] reported that the EDM process causes a ridged surface and induces machining damage in the surface layer, and increases the surface roughness. The surface characteristics caused by EDM were analyzed by means of the atomic force microscopy (AFM) technique and an empirical model of Fe-Mn-Al alloy was proposed based on the experimental data. A qualitative energy dispersive spectroscopic analyzer was used to measure the chemical composition of the specimen and surface hardness was determined with a micro hardness tester. The conclusions stated are as follows:

- The AFM technique can be successfully applied to obtain a three-dimensional image with a nanometer scale.
- The higher discharge energy caused more frequent melting expulsions, leading to the formation of a deeper and larger crater on the surface of the work piece, and resulted in a poorer surface finish.
- The effect of the magnitude of the pulse-on duration on the surface texture of the specimen is more significant than the pulsed current.
- The depth of micro cracks, micro-voids and machined damage increase with an increase in the amount of pulsed current and pulse-on duration.
- The chemical compositions of the machined surface differed from the initial materials due to the diffusion of the electrode material. There was no significant difference between the hardness of the EDM surface and the hardness of the non-EDM work piece.

4. CONCLUSIONS AND FUTURE SCOPE

The research in this area over the past two decades reveals that EDM performance is generally evaluated on the basis of TWR, RWR and SR. The performance is affected by discharge current, pulse on time, pulse off time, arc gap, duty cycle, servo voltage, rotational speed and flushing pressure. The review paper works on identifying parameters for optimization and also suitable techniques for EDM mechanism. Still, researchers and scientists are carrying out their studies to improve the machining performance to the higher extent by implementing newer techniques, different machining conditions, different work materials, different electrodes and selecting optimum parameters. Based on the previous researches, it is concluded that there is still a scope of research in finding the undebatable mechanism of material removal in EDM. The shape and volume of craters formed, the quantity of metals removed from work piece electrode and wear amount of tool electrode is greatly influenced by the diameter of arc plasma and its temporal change. Therefore, investigation of EDM arc plasma characteristics is important to understand the machining phenomena and improve the machining performance.

5. REFERENCES

[1] Hassan Abdel-Gawad El-Hofy, "Advance Machining Processes – Nontraditional and Hybrid Machining Processes" McGraw-Hill, 2005.

[2] http://www.header.com/capabilities/conventional-edm

[3] www.engineeringclicks.com/wire-edm/

[4] Singh J., Kumar V. "Investigation on the Material Removal Mechanism and the Thermal Aspects in the Electrical Discharge Machining Process", IJET, Vol-2, 2012.

[5] Wang Z.L., J.Z. Cui J.Z., X.F. Liu X.F., Zhao W.S. "Mechanism of Electrode Material Removal in Short Pulse Time Electric Discharge Machining" ,Materials Science Forum, 2004, Vols. 471-472 pp.784-789.

[6] Lauwers B., Kruth J.P., Liu W., Eeraerts W., Schacht B., Bleys P. "Investigation of material removal mechanisms in EDM of composite ceramic materials", J. Mater. Process. Technol., 2004, 149 pp.347–352.

[7] Singh A., Ghosh A., "A thermo-electric model of material removal during electric discharge machining", International Journal of machine tools and manufacture, 1999, 39 pp. 669-682.

[8] Panda D. K. "Study of thermal stresses induced surface damage under growing plasma channel in electro discharge machining", J. Mater.Process.Technol., 2007.

[9] Natsu W., Shimoyamada M., Kunieda M. "Study on Expansion Process of EDM Arc Plasma", JSME Int. J., Series C, 2006, Vol.49, No.2.

[10] Pandey P.C., Jilani S.T. "Plasma channel growth and the resolidified layer in EDM", Precision Engineering, 1986, Vol.8, No.2.

[11] Puertas, I., Lusis, C.J., 2003, "A study on the machining parameters optimization of electrical discharge machining‖, Journal of materials processing technology", 2003, 521-526.

[12] Guu Y.H. "AFM surface imaging of AISI D2 tool steel machined by the EDM process", Applied Surface Science, 2005, 242 pp.245–250.

[13] Guu Y.H., Hocheng H. "Effects of work piece rotation on machinability during electrical discharge machining", Materials and Manufacturing processes, 2001, 16(1) pp.91-101.

[14] Kumar, Anish, Kumar, Vinod, Kumar, Jatinder, "Prediction of Surface Roughness in Wire Electric Discharge Machining (WEDM) Process based on Response Surface Methodology", International Journal of Engineering & Technology, 2012, 2(4):708-719.

[15] Nikalje, A. M., Kumar, A., Sai Srinadh, K. V., "Influence of Parameters and Optimization of EDM Performance Measures on MDN 300 Steel using Taguchi Method", International Journal of Advance Manufacturing Technology, 2013, 69:41-49.

[16] Patel, K.M., Panday, Pulak M., Rao, P. Venkateswara, "Determination of an Optimum Parametric Combination Using a Surface Roughness Prediction Model for EDM of Al2O3/SiCw/TiC Ceramic Composite", Journal of Materials and Manufacturing Processes, 2009, 24:675-682.

[17] Tzeng, Y. and Chen, F., "Multi-objective optimisation of high-speed electrical discharge machining process using a Taguchi fuzzy-based approach", Materials & Design, 2007, Vol. 28, No. 4, pp.1159–1168.

[18] Kansal, H.K., Singh, S. and Kumar, P., "Parametric optimization of powder mixed electrical discharge machining by response surface methodology", Journal of Materials Processing Technology, 2005, Vol. 169, No. 3, pp.427–436.

[19] Arooj S., Shah M., Sadiq S., S. H. I., Khushnood S., "Effect of Current in the EDM Machining of Aluminum 6061 T6 and its Effect on the Surface Morphology", Arab J Sci Eng, 2014, 39:4187–4199.

[20] Zhanbo Yu Z., Tahasaki J., Nakajima N., Sano S., Karatok., Kunieda M., "Feasibility of 3-D Surface Machining by Dry EDM", International Journal of Electrical Machining, 2005, 10: 15-20.

[21] Zhang Q.H., Zhang J.H., Ren S.F., Niu Z.W., Ai X., "A theoretical model of surface roughness in ultrasonic vibration assisted electrical discharge machining in gas", International Journal of Manufacturing Technology and Management 7, 2005, 381–390.

[22] Guu Y.H., Hou M.T., "Effect of machining parameters on surface textures in EDM of Fe-Mn-Al alloy", Materials Science and Engineering A, 2007, 466 pp. 61– 67.