Experimental Investigations into the Effect of Process Parameters on Performance Measures of Sink EDM Process- A Review till the year 2010 and Future Work

Prabhu Basanna Choudri
Associate professor (and PhD Research Scholar, VTU- RRC, VTU Belgaum)
Department of Mechanical Engineering
KLE Society's KLE College of Engineering and Technology, Chikodi-591 201, Belgaum, Karnataka, India

Dr. S. V. Gorabal
Principal
SK and SVMA College of Engg. & Tech., Laxmeshwar-582 116, District- Gadag, Karnataka, India

Abstract- Electrical Discharge Machining (EDM) is a fusion-thermal erosion manufacturing process whereby electrically conductive work material is melted and vaporized by immersing in a dielectric fluid with a series of spark discharges between the tool electrode and work piece created by a DC power supply. It is widely used in automotive, defense, aerospace, micro systems, mould and die making industries to produce die cavities, small deep holes, narrow slots, turbine blades, and intricate shapes and plays an excellent role in the development of least cost products with more reliable quality assurance. In recent years, EDM researchers have explored a number of ways to improve various process parameters for achieving higher MRR with reduction in TWR and improved surface quality. This paper reviews the research work carried out from the beginning to the development of die-sinking EDM till 2010. It reports on the EDM research pertaining to improve performance measures, optimizing the process variables, monitoring and controlling the sparking process, electrode design simplification and manufacture. The main objectives of analysis is to optimize the process parameters of EDM with the help of orthogonal array (OA) taguchi method, design of experiment (DOE) procedure, signal to noise(S/N) ratio, analysis of variance(ANOVA), response surface methodology (RSM), central composite design (CCD), residual grey dynamic model(GM), residual modified grey dynamic model (RGM), non-dominated sorting genetic algorithm (NSGA), multiple regression analysis (MRA), gray relational analysis (GRA), atomic force microscopy (AFM), scanning electron microscopy (SEM), micro hardness testing (MH) techniques etc. In the end of the paper scope for future research work has been outlined.

Keywords: **Die sinker EDM, MRR, TWR, SR, SF, taper, Overcut, WLT, HAZ, HV, Taguchi.**

I. INTRODUCTION

Modern manufacturing industries are facing challenges from these advanced materials viz. W, Mo, Cb, ceramics, composites and super alloys which have high strength, heat resistance, hard and difficult to machine, requiring very high precision and very good surface quality which increases machining cost. And also obtaining complex geometries of the products are time consuming processes. These problems overcome by NTM processes. EDM is employed to achieve higher MRR with reduction in TWR, better SF and greater dimensional accuracy.

II. COMPONENTS, WORKING, PROCESS PARAMETERS AND PERFORMANCE MEASURES

A. IMPORTANT COMPONENTS AND WORKING PRINCIPLE

EDM consists of the following important components- 1) Power supply Unit – It transforms the AC input power supply into the pulse DC required to produce the spark discharge at the machining gap. The DC pulse generator is responsible to supply pulses at a certain voltage and current for specific amount of time. 2) Dielectric fluid reservoir, pumps, filters and control valve – used for supplying the dielectric to the tool and workpiece, electrode and wok material submersed. 3) Workpiece, work holder, tool holder and table –used to hold tool and workpiece firmly so that the vibrations are reduced. Workpiece-all the electrically conductive materials, 4) Tool electrode, tool holder and table -the electrode is the tool that determines the cavity shape to be produced. 5) Servo control mechanism –control the feed of electrode & work material to precisely match the MRR, maintain a constant gap between tool and workpiece.

The tool and work directly connected with DC power supply. The workpiece is made as anode and tool as cathode; both are submerged in the dielectric fluid media. For maintaining the constant spark gap between anode and cathode, a servo feed mechanism is used. Figure 1 shows the schematic diagram of die sink EDM process. When the DC supply is given to the circuit, the voltage reaches at about 250 volts and high spark is produced between tool-workpiece at the spark gap. So that the dielectric breaks down and electrons start to are emit from cathode, the gap is ionized and series of sparks/sec occurring at the gap. This high spark produces very high temperature; the metal melts, vaporizes and flushed away from machining region by the dielectric fluid and when the voltage drops, the dielectric fluid gets deionized.

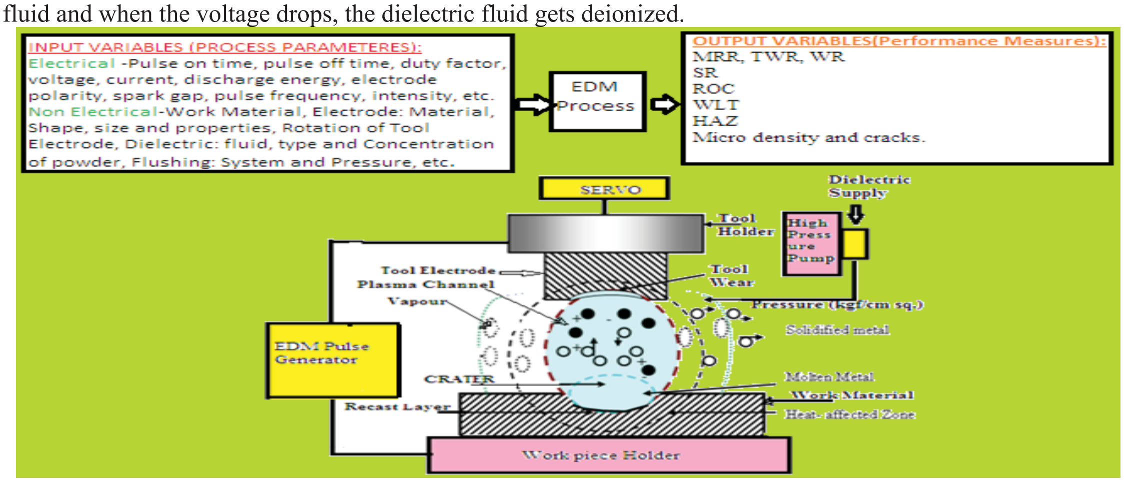

Figure 1: Schematic Diagram of Principle of EDM Process

B. PROCESS PARAMETERS AND PERFORMANCE MEASURES

PROCESS PARAMETERS- The process parameters are used to control the performance measures and they are controllable machining input factors, discover the conditions in which machining is carried out and these conditions will affect the process performance results, which are being measured. Process parameters classified into two categories- one is electrical & the other is non electrical type parameters.

i) Electrical parameters- 1) Pulse on time ($t_{on,}$ μs)-The duration of discharge and time for which current is allowed to flow per cycle. 2) Pulse off time ($t_{off,}$ μs) - The duration of time between each spark, when no discharge exists and the dielectric is allowed to de-ionize and recover its insulating properties. A longer t_{off} improves machining stability as arcing is eliminated.3) Duty Factor ($\tau_{df,}$ %) - Percentage of ratio between pulse duration and total cycle time. $\tau_{df}(\%) = [(t_{on,}\ \mu s)/ (t_{on,}\ \mu s + t_{off,}\ \mu s)]$ X 100. 4) Open Circuit Voltage (V_{oc}, Volts) - The input voltage applied across the tool and workpiece is called Set Voltage or Open Circuit Voltage (V_{oc}). During discharge, V_{oc} drops to the discharge voltage (V_d) and is influenced by the dielectric fluid strength. As V_d varies during t_{on}, its magnitude is expressed as an average discharge voltage (V_{av}). 5) Gap Voltage (V_g, Volts)-two types- open gap and working gap voltages. Open gap voltage can be measured at the spark gap before the spark discharge current begins to flow and working gap voltage can also be measured at the gap during spark current discharge. 6) Discharge Current (I_d, Amps)-The discharge current (I_d) is a measure of amount of electrical charges flowing between tool electrode and work material. As discharge current from an RC-type pulse generator is not constant during ton, the magnitude of discharge current may be expressed as a peak current (I_p) or average discharge current (I_{av}). Peak Current (I_p) is the amount of power used in EDM. Average Current (I_{av}) is a maximum current available for each pulse from the power supply. $I_{av} = \tau_{df}(\%)$ x $I_{p.}$ 7) Discharge energy- This is the electrical energy that is available for material removal and may be stated as input (E_{in}) or measured (E_m) discharge energies. The magnitude of measured discharge energy is calculated from measured t_{on}, V_d and I_d values. 8) Electrode polarity- positive or negative and is chosen based on the requirement of tool wear dominance at a given pulse on time. MRR is higher when tool is connected to positive polarity. 9) Spark Gap (SG, mm) - the maximum distance separates the anode and cathode at which sustainable discharge is possible during the process. Servo mechanism is used to provide a constant gap. It is influenced by the V_{oc} and dielectric fluid strength. 10) Pulse frequency (f_p, KHz)-Pulse Frequency is defined as number of cycles produced at the gap in one second. f_p = 1000/Total Cycle Time (μs)= 1000/(t_{on}, μs + t_{off}, μs). 11) Intensity-It is the different levels of power generated by the generator.

ii) Non Electrical Parameters-1. Work Material- advanced materials which are very hard to cut. 2) Electrode Material- metallic, non-metallic and combination of metallic and non-metallic materials used as a tool materials which have better conductivity, good resistance and wearing capacity. 3) Electrode shape, size and properties- The performance characteristics mainly dependent upon the tool shape. Many electrode shapes such as square, rectangular, hexagonal and cylindrical are used. The conductivity, good resistance and wearing capacity are the desired properties. 4) Rotation of Tool Electrode (R_{etool} , RPM)-The rotational movement of electrode is used to raise the MRR due to the centrifugal force on workpiece. 5) Dielectric fluid, type and concentration of powder - dielectric medium acting as an insulator media which doesn't conduct electricity and used to flush the eroded particles. It cools down region, tool and work material, also provides a high plasma pressure and it also helps in flushing away these eroded particles. Most commonly used dielectric fluids are paraffin, white spirit, deionized water, hydrocarbon fluids, light transformer oil and kerosene. 6) Flushing System and Pressure (F_p, kgf/cm^2)- The process of clearing machining debris from spark discharge gap and supplying fresh dielectric to the spark discharge gap called as flushing. The dielectric fluid must be circulated freely into spark gap for stable machining. Eroded particles should be flushed out at the earliest as possible. There are several methods generally used to flush the gap viz. injection, suction, side, motion and impulse flushing. The method used largely depends on the tool and machined feature dimensions.

PERFORMANCE MEASURES

An important number of papers have been focused on ways of yielding optimal EDM performance measures of high MRR, low TWR and satisfactory SQ. This section provides a study into each of the performance measures and the methods for their improvement.

1) Material removal rate (MRR, mm^3/min)-Erosion rate of the workpiece and is typically used to measure the speed at which machining is carried out. It is expressed as the volumetric amount of work material removed per unit time, MRR (mm^3/min) = [(Initial weight -Final weight) of workpiece in grams)/[Density of work material in g/mm^3 X time of machining in min.].

2) Tool wear rate (TWR, mm^3/min) - Erosion rate of the tool electrode. It is expressed as the volumetric amount of tool electrode material removed per unit time, TWR (mm^3/min) = [(Initial weight -Final weight) of tool in grams)/ [Density of tool material in g/mm^3 X time of machining in min.].

3)Wear ratio (WR, %)-The ratio of TWR/MRR and is used as a performance measure for measuring pairs of tool-work material combination, since different tool-work material combinations gives rise to different TWR and MRR values. A material combination pair with the lowest Wear Ratio (WR) indicates that the tool-work material combination gives the optimal TWR and MRR condition, WR (%) = TWR/MRR.

4) Average Surface Roughness (SR or SF, Ra, μm) - Surface irregularities on a machined surface. SR is an important output performance which influences the product quality, cost and is measured by surface roughness tester.

5) Over Cut (OC, ROC or taper, mm) - An EDM cavity obtained is always larger than the tool electrode used to machine it. The difference between the electrode size and the cavity (or hole) size is called the overcut.

6) Surface Quality or Surface Integrity (SQ)-The White layer thickness (WLT) or Recast Layer (RCL) is the layer created by molten metal solidifying on the work metal surface. The Heat affected zone (HAZ) - The layer just below the WLT or RCL above parent material. This layer has been subjected to elevated high temperatures that have changed the metallurgical properties of the work metal. Below the HAZ is the parent material and this area is unaffected by process and

7) Micro crack density or hardness (HV).

III. LITERATURE REVIEW

In this review paper, few selected research papers considered and primarily concerned with the different work materials, electrode-materials shape configurations, different machining input parameters and how these affect the performance measures.

K M Tsai *et al.* (2001) carried out **[1]** dimensional analysis for SF of different work materials like AISI EK-2, D2, AISI H13 in EDM based on relevant process parameters viz. peak current, pulse duration, polarity, main power voltage, servo standard voltage using Cu, Graphite (ISEM-8), Ag-W tool materials using taguchi method and found that SF is dependent on work and tool materials. **P J Wang *et al.* (2001)** carried out **[2]** dimensional analysis for MRR and TWR in EDM based on work materials like AISI EK2, D2, H13 controlling relevant process parameters viz. peak current, discharge time, quiescent time, polarity of tool, servo standard voltage, main power voltage, temperature of dielectric fluid using Cu, Graphite(ISEM-8), Ag-W tools using taguchi method and found that MRR, TWR is dependent on work and tool materials. **Puertas I. *et al.* (2003)** were carried out **[3]** a proposal for modeling technological parameters on F-1110 steel for determining surface quality and dimensional precision by taking into account operation conditions such as current intensity, pulse on/off times, gap, dielectric fluid, penetration speed, etc. using Cu tool by using taguchi DOE to select the optimum manufacturing conditions. **Puertas I. *et al.* (2004)** have carried out **[4]** a study of the behavior of SR, TWR and MRR parameters for ceramic material of hot pressed boron carbide by taking into account level of intensity of the generator, pulse time and duty cycle as design factors in die-sinking EDM process by using taguchi DOE and ANOVA techniques. **P. M. George *et al.* (2004)** having **[5]** the purpose to determine the optimal setting of the EDM process parameters like pulse current, gap voltage and pulse-on-time while machining C–C composites using Cu tool by using taguchi method and found that the EWR reduces substantially at lowest values, while the MRR increases drastically at highest values of the parameters setting. **Puertas I. *et al.* (2004)** carried out study **[6]** on the influence of the factors of intensity, pulse time and duty cycle using copper tool electrode in EDM to determine MRR, TWR, EW, SR for ceramic composite such as 94WC–6Co by using taguchi method, DOE, ANOVA and found that intensity and pulse time factors were the most important in case of SR, intensity factor was again influential in case of TWR, intensity factor followed by duty cycle, pulse time in case of MRR. **P. Narender Singh *et al.* (2004)** were conducted study **[7]** investigating the effect of pulse on time, current and pressure on MRR, TWR, taper, ROC and SR on EDM of Al- with 10% SiCp as cast MMC reinforcement with brass tool having jet flushing of kerosene as dielectric fluid by using L27 OA taguchi method, ANOVA to establish optimal levels for maximizing the response and SEM analysis was done to study the surface characteristics. **F. L. Amorim et al. (2004)** were carried out study **[8]** investigating rough, finish machining conditions and thermally affected zones on C17200 alloy by varying pulse duration and the peak discharge current keeping duty factor constant for Cu and W-Cur as electrodes by using SEM and found that values of MRR for CuBe C17200 alloy are lower than of steel workpieces and RCL, HAZ zones, HV increases with increase of discharge current and pulse duration. **K.L. Wu *et al*. (2005)** conducted **[9]** study to investigate the effect of surfactant and Al powders added in the dielectric on the surface status of the SKD-61 steel workpiece under different machining parameters like electrode polarity, peak current, pulse duration, open circuit voltage, gap voltage, surfactant concentration with solid round Cu tool by taguchi method adopting 3 dielectrics. The SR status of SKD steel has improved up to 60% as compared to that EDMed under pure dielectric with high SR. **Y.H. Guu (2005)** has carried out an AFM study **[10]** of the surface nano-morphology, SR and micro-crack of EDM on AISI D2 tool steel by considering parameters like pulsed current, voltage, pulse-on/pulse-off durations with kerosene as dielectric and negative polarity Cu tool and revealed that a higher discharge energy results in a poorer SR. The SR and depth of the micro cracks were proportional to the power input. **Y.C. Lin *et al.*(2006)** conducted **[11]** study to investigate the effects of EDM parameters like polarity, peak-current, auxiliary current, voltage, pulse duration, servo reference in machining of SKH 57 HSS with Cu tool using taguchi method. They found that MRR increases with peak current. **H.K. Kansal, et al. (2006)** conducted **[12]** an investigation into the optimization of the powder mixed EDM process parameters viz. peak current, pulse duration, duty cycle and concentration of silicon powder added into the dielectric fluid with Cu tool on H-11die steel using taguchi method with multiple performance characteristics viz. MRR, SR, TWR and found that peak current and concentration of the silicon powder suspended into dielectric fluid were most significant parameters on overall utility value. **Yusuf Keskin et al. (2006)** conducted **[13]** study for determination of the effects of machining parameters such as power, pulse time, and spark time on steel work material with Cu tool in EDM by using DOE based taguchi method, MRA and found that SR has an increasing trend with an increase in the discharge duration. **Ali Ozgedik et al (2006)** conducted study **[14]** of investigations on the variations of geometrical tool wear characteristics such as edge and front wear and machining performance outputs such as MRR, TWR, relative wear and SR with varying machining parameters like discharge currents, pulse durations, different dielectric flushing conditions (injection, suction and static) on 1040 steel workpieces with Cu tool and found that machining parameters and flushing conditions had a huge considerable effect. **T C Chang et al. (2006)** conducted **[15]** study to investigate the effects of EDM parameters viz. pulse-on/off times, open discharge voltage on machining amount, reaming amount, SR, electrode corner loss and MRR for machining SKD-61 hot working mould steel with Cu tool of same size and different shapes by using DOE based taguchi method, ANOVA and found that optimal set of factors obtained has conducive effects and credibility. **H.K. Kansal et al. (2006)** were carried out study **[16]** investigating the optimization of the powder mixed EDM process parameters viz. peak current, pulse duration, duty cycle and concentration of Si powder added into dielectric fluid with Cu tool on H-11 steel using taguchi method. A modified powder mixed dielectric circulation system developed and results indicated significantly improved performance (MRR, SR) of powder mixed EDM over EDM. **H.K. Kansal, *et al.* (2006)** presented a paper **[17]** having a tutorial introduction, comprehensive history and review of research work conducted in the area of powder mixed EDM. They discussed the machining mechanisms, observations, applications, current issues and stated that powder mixed EDM improves the MRR and SF. Moreover, the machined surface develops greater resistance to corrosion and abrasion. **Ko-Ta Chiang *et al.* (2007)** conducted study **[18]** to fit and predict the performance characteristics such as MRR, SR and EWR of an Al2O3+30%TiC ceramic material with Cu tool using GM (1,1), RGM(1,3) during EDM by controlling input parameters like voltage, current, pulse duration and found that RGM(1,3) model gave better performance measures with a greater predicting accuracy. **Jose Carvalho Ferreira (2007)** conducted **[19]** an study for the application of a planetary EDM process on H13 tool steel with Cu-W electrodes by correlating operating parameters such as open-circuit voltage, discharge voltage, peak discharge current, pulse-on duration, duty factor and dielectric flushing pressure to determine MRR, TWR, SR, WLT, and HAZ. They analyzed that negative polarity Cu-W electrodes are suitable for planetary EDM. The Cu-W electrode's low MRR and low TWR allows the machining of EDM cavity surfaces with an exact geometry and a mirror like good surface micro-finishing**. Fred L. Amorim *et al.* (2007)** carried study **[20]** on the behavior of graphite and Cu electrodes on EDM of AISI P20 tool steel. They found that the best results for MRR were reached with negative graphite electrodes; graphite and Cu tools shown similar results of MRR with lowest values of volumetric relative wear were achieved for positive polarity. The best SR was obtained for Cu electrodes under negative polarity. **Yih-Fong Tzeng *et al.* (2007)** carried out study **[21]** to investigate the effect of high speed EDM machining parameters like open circuit voltage, pulse duration, duty cycle, peak current, power concentration, electrode regular distance for optimization of SF on SKD11 workpiece with copper tool by using fuzzy logic analysis coupled with taguchi method, ANOVA and found that targeted multiple performance measures are notably improved to achieve more desirable levels. **H. K. Kansal *et al.* (2007)** conducted study **[22]** to investigate the effect of EDM process parameters viz. peak current, pulse on time, pulse off time, gain, nozzle flushing pressure and concentration of silicon powder mixing into kerosene dielectric on AISI D2 die steel with Cu tool by using taguchi method (ANOVA) and found that SR decreases with increase in concentration of powder. The combination of high peak current and high concentration yields more MRR and smaller SR. **D. Kanagarajan *et al.* (2008)** carried out **[23]** research work to study the influence of EDM process parameters such as pulse current, pulse on time, electrode rotation, flushing pressure with cylindrical solid Cu tool on tungsten carbide and cobalt composites for evaluating MRR and SF produced using NSGA-II to optimize the processing conditions. **Ko-Ta Chiang (2008)** conducted study **[24]** on modeling and analysis of the effects of EDM parameters such as pulse on time, discharge current, duty factor, open discharge voltage on MRR, EWR and SR for machining Al_2O_3+TiC mixed ceramic workpiece with Cu tool by using RSM, CCD, ANOVA and found that discharge current, duty factor were main two significant factors on the value of MRR. **P. Kuppan *et al.* (2008)** carried out **[25]** investigation to study the influence of EDM process parameters such as pulse on time, peak current, duty factor and electrode speed in deep hole drilling of Inconel 718 workpiece with electrolytic Cu tube tool electrode by using CCD procedure, RSM and desirability function approach for optimizing parameters and found that MRR is much influenced by peak current, duty factor and electrode rotation, whereas SR is strongly influenced by peak current and pulse on time. **T. A. El-Taweel (2009)** conducted study **[26]** to investigate the relationship of EDM process parameters like pulse on time, peak current, titanium carbide percent, dielectric flushing pressure on CK45 steel with Al–Cu–Si–TiC novel tool electrode to evaluate performance measures such as max.MRR and min.TWR by using CCD, RSM , ANNOVA, composite desirability. They found that novel electrodes more sensitive to peak current and pulse on time than conventional ones. **K. Salonitis *et al.* (2009)** conducted research work **[27]** focusing efforts by thermal modeling on optimizing the die sinking EDM process parameters like voltage, current, spark duration, idling time with rectangular Cu tool on St-37 steel. They found that increase of the discharge current, arc voltage or spark duration results in higher MRR and coarser surfaces, decrease of idling time increases the MRR with the additional advantage of achieving slightly better SR values. **Amir Abdullah *et al.* (2009)** carried out studies **[28]** on the effects of copper tool electrode when machining with and without ultrasonic vibration under different machining conditions taking into account open circuit voltage of cemented tungsten carbide-10%Co in the EDM process to determine SR by SEM, MH. They found that SEM, MH testing with ultrasonic-assisted EDM applicability in improving surface integrity. **Yan-Cherng Lin *et al.* (2009)** conducted **[29]** an investigation to optimize the magnetic-force-assisted EDM process parameters such as polarity, peak current, auxiliary current, pulse duration, high-voltage, no-load voltage, servo ref. voltage with Cu tool electrode on SKD-61 steel for determining MRR, EWR, SR using L18 OA based on taguchi method, GRA, ANOVA. They determined optimal combination levels of machining parameters to establish higher efficiency, higher precision, and higher SF to meet the demand of modern industrial applications. **M. S. Sohani *et al*. (2009) carried out** study **[30]** to investigate the effect of tool shapes such as triangular, square, rectangular, and circular (Cu, brass and graphite) with size factor consideration along with other process parameters like pulse on/off-times, discharge current and tool area on MRR, TWR in sink EDM process by using RSM, CCD. They found that circular shape tool is best for higher MRR and lower TWR followed by triangular, rectangular, and square cross sections. On MRR and TWR, the interaction effect of discharge current, pulse on time is highly significant and pulse off time, tool area are statistically significant. **Ahsan Ali Khan *et al.* (2009)** conducted **[31]** a review of study of electrode shape configuration viz. round, square, triangular, diamond of constant c/s areas on MRR, EWR, WR, SR of die sink EDM for MS workpiece using Cu tool with different discharge currents. They investigated the effects of the machining parameters on the machining characteristics. **Mohd Amri Lajis *et al.* (2009)** carried out study **[32]** to predict the optimal choice for EDM parameters such as peak current, voltage, pulse duration, interval time for cutting of tungsten carbide ceramic with graphite electrode by using taguchi methodology. They found that peak current significantly affects EWR and SR, while the pulse duration mainly affects the MRR. **P. Govindan *et al.* (2010)** conducted study **[33]** on characterization of MRR, TWR, over size and compositional variation across the machined cross-sections by controlling process parameters such as pulse off time, discharge current, gap voltage, electrode speed, gas pressure, radial clearance shield in dry ED drilling on SS 304 workpiece with Cu tool by using L27 OA taguchi method, SEM-EDS technique. They found that gap voltage, discharge current, electrode rotational speed significantly influence MRR. However, other two factors were statistically significant. **K. Ponappa et al. (2010)** conducted study **[34]** to evaluate drilled-hole quality such as reduced taper, better SF in EDM by controlling process parameters like pulse on/off times, gap voltage, servo speed with brass hollow tubular tool on machining of microwave-sintered magnesium nano composites using taguchi method and SEM techniques. They found that pulse on time and the servo speed that affect drilled-hole quality. **J. Y. Kao *et al.* (2010)** carried out EDM process parameter **[35]** optimization such as discharge current, open voltage, pulse duration and duty factor with round Cu tool on Ti–6Al–4V alloy workpiece by using taguchi method, GRA. They found that the optimized process parameters simultaneously leading to a lower EWR, higher MRR and better SR. **Yonghong Liu *et al. (*2010)** conducted study to **[36]** investigate the effects of composition and concentration of emulsifier on the emulsion property considering EDM process parameters such as pulse on/off times, peak voltage, peak current on performance measures for machining AISI 1045 steel with Cu tool by using SEM analysis. They found that emulsion-1 and -2 used shown higher MRR, lower SR. EWR in emulsion-1 is lower and emulsion-2 is higher than in kerosene. **Choudhary *et al.* (2010)** carried out study **[37]** investigating analysis and evaluation of HAZ in EDM process of EN-31 die steel with Cu, brass and graphite electrodes with kerosene as dielectric fluid considering process parameters such as peak current, pulse duration, and gap voltage by using SEM and optical microscopy. They found that Cu tool shown good response towards MRR, whereas brass gave superior SF compared to other tools and HAZ is much deeper in the specimen when machined by graphite electrode as compared to other tools.

IV. CONCLUSION AND SUGGESTIONS FOR FUTURE WORK

CONCLUSION-The review of research trends has been taken for last 10 years till the year 2010. From the above reviews conclude that,

1. Most of the EDM work that has been carried on steel materials, EN series, Ti-6AL-4V, B4C, 94WC–6Co, WC-Co, Al2O3+TiC, CuBe C17200 alloy and Inconel 718.
2. Graphite, brass, copper, Cu-W, Ag-W used as a tool materials, copper is often used in various shapes and found cylindrical as good one.
3. Pulse on/off times, peak current, voltage are the primary electrical parameters and dielectric fluid, flushing pressure, electrode rotation are the non electrical parameters which are considered and very few have considered parameters like polarity and property of the material , intensity factor, ,duty cycle, gain, electrode rotation, idling time,, tool area, radial clearance shield.
4. Most of the research work that has been carried out for improving the performances on EDM are measured in terms of MRR, TWR, EWR, EW, SR, SF, taper and very few for overcut, dimensional precision, surface quality, RCL, HAZ, depth of the micro cracks and HV.
5. Many research works have been taken by the optimization techniques like Taguchi, DOE, ANOVA, CCD, MRA, RSM, SEM, GRA, optical microscopy and MH testing techniques.

SUGGESTIONS MAY PROVE USEFUL FOR FUTURE WORK-There is an urgent need to work on effect of process parameters on performance measures by keeping into consideration the following problems:

1. The investigation of optimal machining parameters for H-11, H-13 is very essential, hot die steel is one advanced material which can be used in applications of extreme loads and response characteristics are not only dependent on the machining parameters but also on materials of the work part.
2. Need to recognize cutting conditions such as: pulse on time, pulse off time, duty factor, current, voltage, discharge energy, electrode polarity, spark gap, and other machining parameters like electrode material/shape/size/properties, rotation of tool electrode, dielectric fluid, dielectric type, flushing system and pressure, etc should be selected to optimize the economics of machining operations in terms of performance measures such as MRR, TWR, WR, SF, Over Cut, RCL, depth of HAZ and hardness as assessed by productivity, total manufacturing cost per component or other suitable criterion. Now here is a need to carry out systematically research work by the techniques like one factor at a time approach, Taguchi methodology, SEM-EDS, XXRD, Micro Crack by AFM, RSM with CCD, GRA, Single response optimization of the process parameters using RSM and desirability function, Multi-objective optimization of the process parameters (using desirability function in conjunction with RSM and using Taguchi's technique with utility concept).
3. The effects of machining parameters on WLT, HAZ, HV and overcut should be investigated, efforts should be made to investigate the effects of process parameters on performance measures in a cryogenic cutting environment and the weightages to be assigned to various characteristics in multi response optimization models should be based upon requirements of industries.

REFERENCES

[1] Kuo-Ming Tsai and Pei-Jen Wang, "Semi-empirical model of surface finish of work in EDM", *Int J of Machine Tools & Manufacture, 41, 1455–1477*, 2001.

[2] P J Wang and Kuo- Ming Tsai, "Semi-empirical model on work removal and tool wear in electrical discharge machining", *J Mat Process Technol, 114, 1-17, 2001.*

[3] Puertas I. and C. J. Luis, "A Study of Optimization of Machining Parameters for EDM", *J Mat Process Technol, 143(1), 521-526, 12/2003.*

[4] Puertas I. and C. J. Luis (2004); "A Study of Optimization of Machining Parameters for EDM of Boron Carbide", *Materials and Manufacturing Processes, 19(6), 1041-1070, 2004.*

[5] P. M. George, B. K. Raghunath, L. M. Manocha and A. M. Warrier, "EDM of carbon–carbon composite- A Taguchi approach", *J Mat Process Technol, 145(1), 66-71, 2004.*

[6] Puertas I., Luis C.J. and Alvarez L, "Analysis of the influence of EDM parameters on surface quality, MRR and EW of WC-Co", *J Mat Process Technol, 153-154, PP: 1026-1032, 2004.*

[7] P. Narender Singh, Raghukandan, K., Rathinasabapathi, M. And Pai, B.C., "EDM of Al-10%SiCP as-cast metal matrix composites", *J Mat Process Technol, 155-156, PP: 1653-1657, 2004.*

[8] F. L. Amorim and W. L. Weingaertner, "Die-Sinking EDM of a High-Strength Copper-Based Alloy for Injection Molds", *J. of the Braz. Soc. of Mech. Sci. & Eng., 26(2), PP: 137-144 (ABCM), 2004.*

[9] Kun Ling Wu, Biing Hwa Yan, Fuang Yuan Huang and Shin Chang Chen, "Improvement of surface finish on SKD steel using EDM with Al and surfactant added dielectric", *Int J of Machine Tools & Manufacture, 45, 1195–1201, 2005.*

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

[11] Y.C. Lin, C.H. Cheng, B.L. Su and L.R Hwang, "Machining Characteristics and Optimization of Machining Parameters of SKH 57 High-Speed Steel Using EDM Based on Taguchi Method", *Mat. And Manuf. Processes, 21(8), PP: 922-929, 2006.*

[12] H K Kansal, S Singh and P Kumar, "Performance parameters optimization (multi-characteristics) of powder mixed EDM through Taguchi's method and utility concept", *Indian J of Engg & Mat. Sciences, Vol. 13, pp. 209-216, 2006.*

[13] Yusuf Keskin, H.S. Halkac and M. Kizil, "An experimental study for determination of the effects of machining parameters on surface roughness in EDM", *Int J Adv Manuf Technol, 28(11), PP: 1118-1121, 2006.*

[14] Ali Ozgedik and Can Cogun, "An experimental investigation of tool wear in electric discharge machining", *Int J Adv Manuf Technol, 27(5), PP: 488–500, 2006.*

[15] T C Chang, F-C Tsai and Jiuan-Hung Ke, "Data mining and Taguchi method combination applied to the selection of discharge factors and the best interactive factor combination under multiple quality properties", *Int J Adv Manuf Technol, 31(1), PP: 164-174, 2006.*

[16] H.K. Kansal, S. Singh, and P. Kumar, "Performance Parameters Optimization of Powder Mixed EDM by Taguchi Method", *West Indian J. of Engg, 29(1), PP: 81-94, 14P, 2006.*

[17] H.K. Kansal, S. Singh and P. Kumar, "Technology and research developments in powder mixed EDM", *J Mat Process Technol, 184(1–3), Pages 32–41, Dec. 2006.*

[18] Ko-Ta Chiang and Fu-Ping Chang, "Applying grey forecasting method for fitting and predicting the performance characteristics of an electro-conductive ceramic (Al_2O_3+30%TiC) during EDM", *Int J Adv Manuf Technol, 33(5-6), PP: 480-488, 2007.*

[19] Jose Carvalho Ferreira, "A study of die helical thread cavity surface finish made by Cu-W electrodes with planetary EDM", *Int J Adv Manuf Technol, 34(11-12), PP: 1120-1132, 2007.*

[20] Fred L. Amorim and W L Weingaertner, "The Behavior of Graphite and Copper Electrodes on the Finish Die- Sinking EDM of AISI P20 Tool Steel", *J. of the Braz. Soc. of Mech. Sci. & Eng., 24(4), PP: 367-368 (ABCM), 2007.*

[21] Yih-Fong Tzeng and F C Chen, "Multi-objective optimization of high-speed EDM process using a Taguchi fuzzy-based approach", *Materials and Design, 28(4), PP: 1159-1168, 2007.*

[22] H.K. Kansal, S. Singh, and P. Kumar, "Effect of Silicon Powder Mixed EDM on Machining Rate of AISI D2 Die Steel", *J. of Manuf. Processes, 9(1), Pages: 13–22, 2007.*

[23] D. Kanagarajan and R. Karthikeyan and J. Paulo Davim,
o C:\Users\Naveen\Downloads\profile\Kayaroganam_Palanikumar"Optimization of EDM characteristics of WC/Co composites using NSGA-II",
Int J Adv Manuf Technol, 36(11), PP: 1124-1132, 2008.

[24] Ko-Ta Chiang, "Modeling and analysis of the effects of machining parameters on the performance characteristics in the EDM process of Al_2O_3+TiC mixed ceramic", *Int J Adv Manuf Technol, 37(5), PP: 523-533, 2008.*

[25] P. Kuppan, A. Rajadurai and S. Narayanan, "Influence of EDM process parameters in deep hole drilling of Inconel 718", *Int J Adv Manuf Technol, 38(1-2), PP: 74–84, 2008.*

[26] T. A. El-Taweel, "Multi-response optimization of EDM with Al–Cu–Si–TiC P/M composite electrode", *Int J Adv Manuf Technol, 44(1-2), PP: 100-113, 2009.*

[27] K. Salonitis A. Stournaras, P. Stavropoulos and G. Chryssolouris, "Thermal modeling of the material removal rate and surface roughness for die-sinking EDM", *Int J Adv Manuf Technol, 40(3-4), PP: 316-323, 2009.*

[28] Amir Abdullah Mohammad R. Shabgard, Atanas Ivanov Mohammad and Taghi Shervani-Tabar, "Effect of ultrasonic-assisted EDM on the surface integrity of WC-Co", *Int J Adv Manuf Technol, 41(3), PP: 268-280, 2009.*

[29] Yen-Cherng Lin, Yuan-feng Chen, Der-An wang and Ho-Shiun lee, "Optimization of machining parameters using magnetic-force-assisted EDM based on gray relational analysis", *Int J Adv Manuf Technol, 42(11), PP: 1052-1064, 2009.*

[30] M S Sohani, V. N. Gaitonde, B. Siddeswarappa and A. S. Deshpande, "Investigations into the effect of tool shapes with size factor consideration in sink EDM process", *Int J Adv Manuf Technol, 45, PP:1131-1145, 2009.*

[31] Ahsan Ali Khan, Mohammad Yeakub Ali and Md. Mohafizul Haque, "A study of electrode shape configuration on the performance of Die Sinking EDM", *Int. J. of Mech.and Materials Engg, 4(1), PP: 19 -23, 2009.*

[32] Mohd Amri Lajis, H.C.D. Mohd Radzi and A.K.M. Nurul Amin, "The Implementation of Taguchi Method on EDM Process of Tungsten Carbide", *European Journal of Scientific Research, 26(4), PP: 609-617, ISSN 1450-216X, 2009.*

[33] P. Govindan and Suhas S. Joshi, "Experimental characterization of material removal in dry ED drilling", *Int. J. of Machine Tools & Manufacture, 50, PP: 431–443, 2010.*

[34] K. Ponappa, S. Aravindan , P. V. Rao, J. Ramkumar and M. Gupta, "The effect of process parameters on machining of magnesium nano alumina composites through EDM", *Int J Adv Manuf Technol, 46(9), PP: 1035-1042, 2010.*

[35] J. Y. Kao, C. C. Tsao, S. S. Wang and C. Y. Hsu, "Optimization of the EDM parameters on machining Ti–6Al–4V with multiple quality characteristics", *Int J Adv Manuf Technol, 47(1), PP: 395-402, 2010.*

[36] Yonghong Liu, Renjie Ji, Yanzhen Zhang and Haifeng Zhang, "Investigation of emulsion for die sinking EDM", *Int J Adv Manuf*

Technol, 47, PP: 403-409, 2010.
[37] Rajesh Choudhary, H Kumar and R K Garg, "Analysis and evaluation of heat affected zones in EDM of EN-31 die steel", *Indian J. of Engg & Mat. Sciences, 17, PP: 91-98, 2010.*