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Experimental Investigations into the Effect of Process Parameters on Performance Measures of Sink EDM Process: A Review Year 2011 To 2015 and Future Work

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***Abstract*—Sink Electrical Discharge Machining (Sink EDM) is a one of the important NTM process wherein electrically conductive work pieces are melted, vaporized (thermal erosion) by immersing in a dielectric fluid; tool electrode and work piece between the DC supply two poles either positive or negative and electric discharges takes place produces very high temperature in few micro seconds. It is widely used in defense, aerospace, automotive, micro systems, mould and die making industries. Recently researchers have discovered many ways to improve process parameters for achieving higher MRR, lower TWR and better surface quality. The paper reviews the works carried out from 2011 to till 2015. It reports on the research related to improve performance measures. The primary objective of analysis is to optimize the process parameters with the help of taguchi robust design methodology, design of experiment (DOE), analysis of variance(ANOVA), signal to noise ratio(S/N ratio, analysis of means (ANOM), face centered or rotational central composite design (CCD), scanning electron microscopy (SEM), X ray diffraction (XRD), response surface methodology (RSM), gray relational analysis (GRA), atomic force microscopy (AFM), energy dispersive spectroscopy (EDS), multiple regression analysis (MRA), mass spectrometry, optical microscopy techniques, fractional factorial design(FFD) with CCD and finite element analysis (FEM), etc. In end of the paper suggestions useful for future work has been indicated.**

Keywords: Sink EDM, MRR, TWR, EWR, WR, SR, SF, OC, ROC, TOC, WLT, HAZ, HV

I. INTRODUCTION

Today's industries are facing much challenges problems for machining advanced materials viz. W, Mo, Cb, hard and difficult to cut types. EDM is used to achieve higher MRR with lower TWR, greater SF and surface quality at lesser time with lower machining cost.

II. COMPONENTS, WORKING, PROCESS PARAMETERS AND PERFORMANCE MEASURES

A. IMPORTANT COMPONENTS

EDM consists of: DC Power supply unit; Dielectric fluid reservoir with pump, filter and control valve; Workpiece, work holder, work table; Tool electrode, electrode holder, table; Servo control tool feed mechanism.

B. WORKING PRINCIPLE

The tool and work directly connected between the DC supply two poles either positive or negative; both 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 principle of the process. When supply is given to the circuit, the voltage reaches at about 250 volts and electric discharges takes place between tool and work called spark gap, produces very high temperature in few micro seconds; the material melts, vaporizes and flushed away by the circulation of dielectric fluid.

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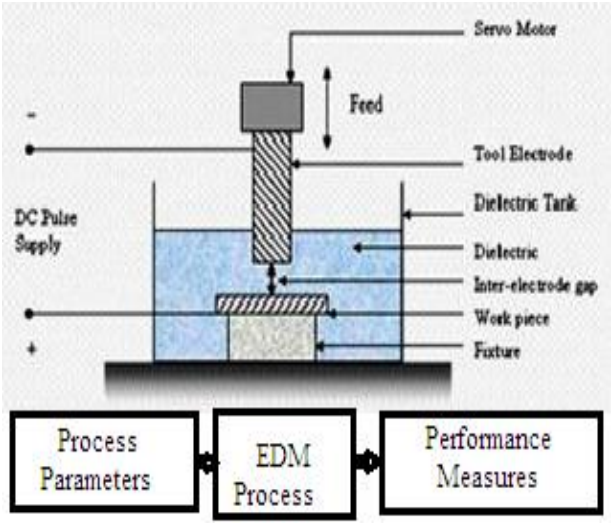

Figure 1: Principle of Die Sink EDM Process

C. *PROCESS PARAMETERS*

Two categories:-1) Electrical – Pulse-on/off times, open circuit voltage, gap voltage, discharge current, peak current, average current, duty factor, discharge energy, electrode polarity, spark gap, pulse frequency, intensity factor, threshold, capacitance, etc.2) Non electrical- Work material, electrode material, electrode shape, electrode size, electrode properties, rotation of tool electrode, dielectric fluid, dielectric type and concentration of powder, flushing system and pressure, servo-head, dielectric level, feed rate, electrode diffusivity coefficient, electrode thermal conductivity and electrode melting point, etc.

D. *PERFORMANCE MEASURES*

Material removal rate (MRR, mm^3/min); electrode wear rate (EWR) or tool wear rate (TWR); wear ratio (WR) or relative wear ratio or volumetric wear ratio; surface roughness (SR) or surface finish (SF); overcut (OC) or radial overcut (ROC) or tool overcut (TOC) or half taper angle or variation of the side overcut; white layer thickness (WLT) or recast layer (RCL); depth of heat-affected zone (HAZ) and micro crack density or micro 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.

S. Prabhu *et al.* (2011) carried out study [1] to optimize input parameters viz. voltage, duration, current with Cu tool having dielectric fluid as multi wall carbon nano tube for machining INCONEL-825 by using taguchi technique, ANOVA, AFM analysis and found that there was an improvement in the SR and surface quality. S.P. Sivapirakasam *et al.* (2011) conducted [2] investigations on the effect of process parameters viz. duration, peak current, level of dielectric above the spark location, flushing pressure with Cu tool on high C high Cr tool steel by using taguchi method, plasma with gas chromatography, mass spectrometry and SEM-XRD techniques. They found that peak current, duration are very important parameters on concentration of breathing zone of aerosol. D. V. Ghewade *et al.* (2011) carried out study [3] on cutting of INCONEL 718 with a Cu tool using taguchi's method and analyzed the effect of each parameter viz. pulse on time, gap voltage, peak current, duty cycle on the machining characteristics and predicted the optimal choice. They found that MRR mainly affected by current and voltage; EWR influenced by duty cycle, pulse on time; duty cycle, peak current have highest effect on ROC; half taper angle mainly influenced by, duty cycle, pulse on time. Promod K. *et al.* (2011) conducted study [4] on modification of surface using specially prepared PM compact tools by depositing a hard layer over the work surface of C-40 plain carbon steel considering process parameters viz. pulse on time, peak current, duty factor, compaction pressure, sintering temperature, composition for determining thickness of the deposited layer, rate of mass transfer, TWR, SR and MH by using L-16 OA taguchi DOE technique, ANOVA, SEM-XRD, optical microscopy techniques. They found that deposited layer of 3 to 785 µm enriched with W and Cu tools with the WC formation and having at the hardest zone micro hardness of 9.81-12.75 GPa was deposited over the work surface. Shabgard M. *et al.* (2011) were carried out study [5] investigating the effect of input parameters viz. current, pulse on time for machining AISI H13 workpiece with round Cu tool by using taguchi, ANOVA, SEM techniques. The study found that higher pulse on time leads to an higher MRR, SR, WLT, depth of HAZ; higher pulse current leads to a sharp higher in the MRR, SR. The TWR lowered by the increase of pulse on time; increases by the higher in pulse current but a slight lower in WLT observed by an increase in current; by constant discharge energy level, higher current with low pulse on time leads to lower WLT, HAZ on work surface. Hao Ning Chiang el at.(2011) conducted study [6] to investigate the side overcut variation, bottom overcut variation, electrode dimensions, spark hole dimensions and machine positioning accuracy considering input parameters Viz. pulse on/off times, voltage, current with square cu tool on AISI D2 and AISI S2 tool steels by ANOVA analysis. They found that coupling effect was an primary factor to estimate the side overcut variation. Horacio T. S. *et al.* (2011) constructed [7] an model of inversion for establishing input parameters viz. pulse on/off times, peak current for predicting output performance characteristics viz. MRR, EWR, SR for machining AISI 1045 steel with prismatic Cu tool by using ANOVA and regression models. Bhola Jha *et al. (*2011) conducted [8] a study on overview of technology and research in electrode design and manufacturing in sinking EDM. He suggested number of ways to improve electrode design and devised various ways of manufacturing for optimizing performance measures and reducing manufacturing time with cost. They also concluded that EDM technology plays important role in design and manufacturing of electrode.

Harpreet Singh *et al.* (2012) conducted a study [9] for investigating the influence of pulse on/off times on machining AISI D3 die steel using Cu, brass tools with

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dielectric as kerosene oil. They found that higher the MRR with higher in pulse off time; lower MRR with higher in pulse on time in case of brass electrode and decrease in Cu electrode. Lei Li *et al.* (2012) conducted study [10] to investigate the influence of methods of flushing and input process parameters with hexagonal shaped Cu bunched electrode for machining S45C carbon steel on performance measures by using experiments and simulations. They found that multi hole inner flushing bunched electrode suffers much greater peak current and results in higher MRR and high. Manish Vishwakarma et al. (2012) were carried out [11] investigation study to determine the process optimal factors viz. pulse on time, input current, duty cycle gap voltage, flushing pressure for machining AISI 4140 grade steel alloy rectangular plates on output responses through RSM using the technique of DOE, ANOVA based on the CCD. They found that higher peak current, duty factor results higher MRR; higher voltage higher MRR, similarly higher capacitance higher MRR; higher spark gap lowers MRR. Renjie Ji *et al.* (2012) conducted [12] investigations on effect of input parameters like electrode polarity, pulse on/off times, peak current, peak voltage and dielectric fluid on output performance measures viz. MRR, SR for ED milling of SiC ceramic with tool as steel-toothed wheel using three kinds of emulsions as the dielectric. Furthermore, the machined surface micro-structure was examined with SEM, XRD and EDS techniques. Ignacio Puertas *et al.* (2012) carried out [13] investigations on optimization of EDM conditions such as pulse duration, intensity, open-circuit voltage duty cycle, and flushing pressure in the processing of hot-pressed B4C and cobalt-bonded WC conductive ceramics with Cu tool on the quality of the manufactured products such as SR, volumetric EW and MRR by using FFD with CCD. S. P. Nipanikar *et al.* (2012) carried out study for optimizing [14] process parameters such as pulse on time, duty cycle, current, gap voltage on output responses on AISI D3 with Cu tool by using taguchi's methodology, ANOVA. They found that higher the peak current higher MRR; MRR not much influenced by duty cycle. Higher the peak current higher EWR; very least influenced by gap voltage, the peak current has maximum effect on ROC and least affected by gap voltage.

Nilesh M. Vohra (2013) was conducted study [15] investigating the optimum cutting parameters viz. pulse on/off times, current, gap voltage on performance measures viz. MRR, TWR, SR for machining SS 304 work piece using Cu, Al and brass tools by using taguchi method in combination on fuzzy logic control. He found that the gap voltage has highest effect on MRR. Jun Li *et al.* (2013) were carried out study [16] investigating modeling and analysis of micro-hole in die-sinking EDM process on Ti-6Al-4V, controlling input parameters like pulse on/off times and discharge current through RSM, DOE, ANOVA, CCD and found that TWR, WLT were much affected by discharge current; some difference unlike the others reported that WLT also affected by pulse off time; WLT can be minimized at lower pulse on time, discharge current and higher pulse off time. P. B. Wagh *et al.* (2013) were carried out [17] study investigating the influence of process parameters viz. pulse on/off times, discharge current, gap voltage on EN31 material with Cu tool through RSM, DOE, ANOVA based on the face CCD matrix. They found that SR much influenced by pulse duration and discharge current; choice of the electrical parameters depends largely on the material combination of the tool and work piece. Raghuraman S. *et al. (*2013) conducted study [18] investigating set of optimal input controllable variables viz. pulse on/off times and current on performance measures viz. MRR, TWR, SR for machining mild steel IS2026 work piece with Cu electrode by using L9 OA taguchi method, S/N ratio and GRA. They found that the taguchi GRA is being effective technique to optimize the machining parameters. D. C. Chen *et al.* (2013) conducted study [19] to find set of optimal input controllable variables viz. pulse on/off times, current and duty cycle for machining A6061-T6 aluminium alloy work material using Cu tool by using taguchi robust design methodology, analysis of means, ANOVA. They found that current and duty cycle factors important to determine the magnitude of SR. A CuZn40 brass alloy specimen is machined using the optimal process parameters and were found to have a lower mean SR than the A6061-T6 aluminium alloy workpiece. A. M. Nikalje *et al.* (2013) conducted study [20] to investigate the effect of input controllable variables viz. discharge current, pulse off time and pulse on time for optimizing performance measures viz. MRR, TWR, relative WR, SR for machining MDN 300 steel with Cu tool by using taguchi method, SEM technique. They found that high pulse on time, high current gave SR with more craters, debris globules and micro cracks than that of lower current and lower pulse on time. Shailendra Kumar Singh *et al.* (2013) were conducted [21] study to optimize input controllable variables viz. current, pulse off time, pulse on time for machining Ti- 6AL- 4V alloy with Cu tool using taguchi robust design methodology, S/N ratio and ANOVA and it shown that SR much affected by followed by pulse off time and least affected by pulse on time; duty cycle influence to increase in TOC initially but late decreased. They found that duty cycle was most important factor influences TOC followed by discharge current, pulse on time; least affected by gap voltage. Shivendra Tiwari (2013) was conducted [22] study investigating set of optimal input controllable variables viz. pulse on/off times, peak current by conducting three sets of trial runs with constant servo-head and positive polarity for Cu tool with commercial grade EDM oil on MS work material for determining MRR and TWR. The discharge current was applied in different steps in positive mode. Singaram Lakshmanan *et al.* (2013) were [23] performed experimental investigation for correlating the process parameters such as current, pulse on/off times, voltage for machining EN 31 tool steel workpiece using Cu tool through RSM using rotatable CCD, ANOVA. They estimated the optimum machining conditions for better MRR. Rao P.S *et al.* (2013) conducted study [24] investigating the influence of process parameters viz. current, voltage, duty cycle, servo for machining AISI 304 stainless steel with rectangular Cu tool by applying mixed factorial DOE's and MRA. They found that MRR influenced by servo, duty cycle, current and voltage; TWR influenced by current, servo and duty cycle; SR influenced by current; MH is influenced by servo in the decreasing order of importance of parameters. Harpreet singh

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et al. (2013) conducted a study [25] on cryogenic and non cryogenic electrode with pulse on/off times as parameter on machining of steel. Cryogenic treatment is used for increasing MRR and lowering TWR and found that TWR is decreased in both cryogenic treated and non cryogenic cu electrodes with increase in pulse on time; increase in pulse off time increases TWR and TWR is very less in cryogenic treated electrode as compared to non cryogenic treated tool. Mohammed S. Rasheed, (2013) carried out study [26] investigating comparison study based on micro-holes produced by micro-EDM with LBM for MRR, surface quality of micro-holes with tungsten and brass electrodes by using taguchi method, ANOVA, SEM and optical microscopy techniques. He found that the performance measures of the processes mainly depends upon the machining parameters; When surface quality is not a criterion, LBM can be used for higher MRR; finally for higher MRR with good SF, the positive features of processes can be used to make hybrid process.

Abhishek Gaikwad et al. (2014) conducted [27] research work investigating the influence of process parameters viz. pulse on/off times, current, fluid pressure for machining SS 316 workpiece using Cu electrode with taguchi technique, DOE, ANOVA. They found that increasing pulse off time followed by current increases MRR and is least affected by fluid pressure. EWR decreases with increasing current followed by pulse off time and is least affected by fluid pressure. Vikasa et al. (2014) conducted study [28] investigating the influence and optimization of process parameters viz. pulse on/off times, current, voltage for machining EN19 and EN41 work materials with Cu tool using taguchi method. They found that the discharge current was having larger impact on the MRR. T. Roy et al. (2014) were carried out study [29] investigating the influence of input controllable variables viz. pulse duration, current, duty cycle and voltage based on TOC on SS 304 grade work material through L9 OA taguchi's robust design technique, S/N ratio and ANOVA. They found that TOC decreases initially and then increases by gradual increase of the pulse on time; the duty cycle factor causes an increase in TOC initially but decreases afterwards. They found that TOC affected much by duty cycle followed by current, pulse on time; TOC least influenced by gap voltage. Brajesh Kumar et al. (2014) described [30] optimization of process parameters viz. pulse on time, current, voltage on SR of CFRP composite material with copper tool by using parametric design of Taguchi methodology, S/N ratio, and ANOVA. They found that the discharge current was the most influential factors on the SR. N. Radhika et al. (2014) conducted study [31] investigating on optimization input controllable variables viz. pulse on time, current, pressure for machining aluminium hybrid composites on performance measures by using Taguchi method, S/N ratio and ANOVA. They found that SR much affected by peak current followed by pulse on time, flushing pressure; flushing pressure followed by peak current and pulse on time gave higher MRR and pulse on time followed by peak current, flushing pressure affects much on TWR. N. Annamalai et.al (2014) conducted study [32] on investigation and modeling of input controllable variables viz. current, pulse on/ off times for machining AISI 4340 steel with electrolytic Cu electrode tool by using Box Behnken design of RSM, ANOVA technique. They found that higher peak current much higher the MRR and SR; higher pulse on time higher the MRR and SR; whereas there was no much impact when pulse off time is increased. Viral B. Prajapati et al. (2014) were carried out study [33] of review on optimization of input controllable variables viz. pulse on/off times and current for machining AISI SS 410 work material with Cu electrode and EDM oil as dielectric for improving performance such as MRR, SR using taguchi DOE procedure with full factorial design and ANOVA method. Shashikant et al. (2014) were carried out [34] investigation on optimization of input controllable variables viz. pulse on/off times, current, voltage for machining EN19 workpiece with electrolytic Cu tool by using RSM, ANOVA. They found that pulse off time, current, voltage and the interaction terms were very important where as the pulse on time least effect on MRR. Vishal J Nadpara et al.(2014) were carried out [35] work on optimization of input controllable variables viz. pulse on time, current, duty cycle, voltage and dielectric flow rate; their interactions on performance measures for machining AISI D3 tool steel with graphite tool electrode using Taguchi's experimental design method. They found that the MRR mainly influenced by peak current and very less influenced by duty cycle; peak current influences much on EWR and very least affected by gap voltage. Chandramouli S et al. (2014) conducted [36] investigating the influence and optimization of input controllable variables viz. pulse on/off times, current 0n performance measures viz. MRR, TWR, SR for machining RENE80 nickel super alloy workpiece with aluminum tool electrode by using Taguchi method, ANOVA and revealed that proper selection of input parameters is very important. Shishir M Shrivastava et al. (2014) has studied [37] the influence of input controllable variables viz. pulse on/off times, current, tool shape configurations viz. circular, square, triangular, rectangular, and diamond cross sections of Cu, brass and graphite electrodes on the machining characteristics. This review was based on various studies carried by various researchers. They found that tool electrode with negative polarity gave better machining performance and also observed that pulse on/off times, peak current factors mainly responsible for higher MRR; whereas peak current, pulse on time mainly influence TWR; peak current influences SR; higher MRR with lower TWR achieved by circular tool shape followed by above said other cross sections. Dhirendra nath mishra et al. (2014) were carried out study [38] on EDM containing general introduction, principle of EDM, principles of operation, types of EDM, important parameters of die-sinking EDM, wire cut EDM, major components in wire cut machine, principle of WEDM, important parameters of WEDM, modelling of material removal and product quality, specification on EDM, dielectric fluid- functions, properties, requirements, types, selection, tool materials- characteristics, types, selection, comparison of die-sinker and wire-cut machines, flushing methods, applications of EDM and WEDM, advantages of EDM and WEDM, disadvantages of EDM and WEDM. They concluded that EDM were used effectively for machining of

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complex geometries, process is independent of material properties, can result in high accuracy. Varinder Khurana et al. (2014) were carried out study [39] investigating effect and interaction between input controllable variables viz. pulse on/off times, current, voltage using tubular copper electrode with internal flushing on the response variables viz. MRR, SR of AISI-D2 high-carbon, high-chromium steel through L9 OA Taguchi technique, S/N ratio and ANOVA. They found that individual parameters like discharge current and voltage are more influencing than other factors viz. pulse on/off times. Arumugam Kadirvel ET AL. (2014) were carried out study [40] investigating optimization of the die sinking micro-EDM process parameters viz. voltage, threshold, capacitance, feed rate for multiple performance characteristics such as higher MRR, lower TWR and minimum SR by using L16 OA Taguchi method, S/N ratio, ANOVA and GRA. They found that capacitance and the gap voltage were the most significant controlled factors influencing the performance of the machining process. Sushil Kumar Choudhary et al. (2014) were carried out study [41] on recent advancements in various aspects of EDM that reflect the states of the art in these processes are presented in this review paper. Researcher worked on enhancement of MRR, reduction of TWR; improve Surface Quality by experimental investigation. Various EDM approaches employed for increase of efficiency, use of gas instead of oil electrolyte, powder mixed EDM. The process also plays a important role in automotive, aeronautic industry, optical, medical, Jewelry and making a various mechanical components in manufacturing industries. Abhijeetsinh V Makwana et al. (2014) were carried out [42] detailed literature review and analysis of various process parameters of EDM process by using different electrode shapes on the performance. In this research they used taguchi's method for DOE's with three input parameters and their three levels of experiments with kerosene diluted with water as dielectric. They observed the main influences of input factors on MRR, TWR, SR and cavities. Present paper proposed to select carefully parameters for machining cavities with multiple and intricate shaped electrodes. They found that higher MRR is achieved with the copper. Bharat Raj Bundel et al. (2014) were carried out study [43] investigating TWR in the form of weight and length of electrode was controlling different input controllable variables such as pulse on/off times, current in die-sinking EDM on D-3 die steel (HRC-58) with electrolytic cylindrical Cu tool. They found that the increase in current supply as well as pulse on time and pulse off time increases TWR; decrease in current supply but at particular lower current and pulse on/off times decreases TWR where SF was also good. They found that round copper tool can be used for longer period without redressing.

S. Barman et al. (2015) were carried out [44] investigation on surface quality, shape, size and elemental characterization of blind micro-holes in micro EDM by adopting a destructive method having high aspect ratio. They also studied deformation of electrodes and tool profiles. Avdesh Chandra Dixit et al. (2015) carried out study [45] investigating the influence of input controllable variables viz. pulse on/off times, current, pressure while machining of AISI D3 material fitted with a Cu electrode by using Taguchi method and was found that the peak current influenced much on MRR, other factors have very less effect; peak current and pulse on time infulenced much on TWR and, fluid pressure has no effect it. J Jeevamalar et al. (2015) were carried out [46] review study on die sinking EDM parameters and concluded that machining done on steel materials, EN series, Ti-6AL-4V, S45C, SiC, B4C, WC-Co, Al2O3+Ti and Inconel 718. Copper often used as a tool in various shapes and also found that pulse on/off times, voltage and current were the primary electrical parameters; dielectric fluid, flushing pressure, electrode rotation are the non electrical parameters which were considered in EDM. Acc. to them most of the much work carried out to improve the performance measures viz. MRR, TWR, WR and SF and many research works have been carried out by using optimization techniques like, RSM, ANNOVA, Taguchi, SEM, CCD, GRA and MRA. Bai Shao et al. (2015) were carried out [47] investigation on electro- thermal modelling of the crater formation incorporating realistic machining conditions in micro-EDM. They applied input controllable variables viz. pulse on time, pulse energy distribution fraction and pulse energy with model and solved by using the FEM. They found that pulse energy distributed to the anode, and to the cathode, average error of the crater radius and of the cater volume. Sharma et al. (2015) were carried out [48] study to investigate the WR of SKD11 steel material in titanium abrasives mixed EDM process considering input factors viz. pulse on time, peak current, gap voltage, polarity, concentration of abrasive with Cu electrode tool plus dielectric fluid as EDM oil by using L18 OA Taguchi method, ANOVA technique. They found that WR is less at positive polarity in comparison of negative polarity, pulse on time decreases the WR and increases the MRR and also enhances the productivity of SKD11 steel material and the addition of abrasives particles in EDM oil has also put the effect on wear ratio of material. M. A. Md Ali et al. (2015) were carried out [49] study to investigate the performance of copper, copper tungsten, graphite and brass electrodes on performance measures for machining aluminium alloy LM6 (Al-Sil2) considering process parameters viz. voltage, pulse on/off times, peak current by using L9 OA Taguchi technique and ANOVA. They found that graphite electrode produces the highest MRR with low SR as compare to others electrodes. Meanwhile, copper generates high SR and low EWR with copper tungsten. Brass tool shown low ability to withstand of spark energy that produced highest EWR. Thus, it showed that output quality of material characteristics of workpiece mainly influenced by thermal conductivity and melting point of electrode materials. Dr. Sanjeev Saini et. al. (2015) were conducted [50] investigating optimization of input controllable variables viz. pulse on/off times, discharge current on EN31, DS P20 and HCHC D2 workpieces with U-shaped copper cathode tools of dia. 8mm and 10mm having side flushing by using Taguchi strategy, S/N ratio and ANOVA to identify the optimum cutting parameters and found that different combinations of input controllable variables were needed to have greater MRR and better SF. Amoljit S. Gill et al. (2015) were carried out [51] study to investigate the phenomenon of H11 hot die steel surface

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alloying by considering six input parameters using copper-tungsten tool by using L18 OA Taguchi method, DOE, ANOVA, SEM-XRD and EDS to achieve the high SF and MH. They found the on the machined surface by XRD technique, there was a formation of cementite and tungsten carbide. Surinder et al (2015) were carried study [52] investigating WR of EN-8 steel with copper too in abrasive mixed sinking EDM process by choosing the process factors such as pulse on time, current, polarity, voltage and concentration of titanium abrasives in EDM oil using Taguchi method, S/N ratio, ANOVA and found that WR at positive polarity is less than the WR at negative polarity, high peak current decreases the WR, gap voltage increases WR decreases and pulse on time, abrasives concentration produce very little effect on WR. F. Kolahan et al. (2015) were carried out [53] investigations to optimize input controllable variables viz. pulse on/off times, current, duty factor, voltage for machining AISI 2312 hot work steel alloy by using L36 OA Taguchi method, S/N ratio, ANOVA and GRA. The three performance characteristics are combined into a single objective using GRA to minimize TWR and SR and maximize MRR. Ahmed Raza Khan et al. (2015) were carried out [54] work investigating influence of different types of electrode materials on quality of blind holes machined in AISI P20 work material in term of SR, diameter error and axial error considering three current conditions, i.e., 5 amp, 8 amp and 10 amp via die sinker EDM process and found that graphite as an electrode provides the most suitable values overall for most of the stated performance measures among all the electrodes. Copper provides the best SF for closely followed by graphite; graphite was the best electrode material for dimensional accuracy and provides the least values of the errors. M. Priyadarshini et al. (2015) conducted study [55] investigating the parametric optimization of EDM for machining Ti-6Al-4V alloy with copper electrode for desired responses using L25 OA Taguchi method, ANOVA and GRA. They found that for achieving higher MRR and greater SF, various combinations of optimal input controllable variables were needed. Sumit Raj et al. (2015) were carried out [56] investigations on optimization and prediction of MRR in die sinking EDM of EN45 steel tool work material considering input controllable variables viz. pulse on/off time, current and voltage using L27 OA Taguchi method, ANOVA. They found that more significant factor for MRR were peak current and pulse off time. Goran Mijuskovic et al. (2015) carried out [57] study investigating the effect of input controllable variables viz. width of cut, depth of cut and feed on deflection of tool in micro milling of graphite electrodes using measuring technique laser-based one. The results showed that RSM of deflection of tool used to determine the process behavior across a useful cutting conditions range. S. Bharathi Raja et al. (2015) carried out [58] study investigating the optimization of input controllable variables viz. pulse on time, current on performance measures viz.SR, machining time for machining hardened die steel by using taguchi' method, firefly algorithm with development of mathematical model. They predicted the values of actual machining time and SR. F. Zhang et al. (2015) were carried out [59] study investigating the time integration effect of the expanding spark for anode erosion with water as dielectric by developing FEM based thermal model for predicting craters and MRR. They found the very nearer agreement with experimental results. G. K. Bosea et al. (2015) were carried out [60] study investigating effect of input controllable variables viz. pulse on/off times, current, spark gap on MRR, SR, OC using Cu tool of square shaped for machining of AISI H13 tool steel with lateral flushing by using Taguchi methodology, ANOVA, S/N ratio, GRA. They focused with multi criteria decision making and found that gap current influenced much on MRR; pulse on time pulse on time influenced much on SR. Kulkarni et al. (2015) were carried out project [61] to investigate the effect of input controllable variables viz. pulse on/off times, current for machining of Al-SiC MMC work material with copper-tungsten tool by using RSM approach, CCD and ANOVA. They found that MRR mainly influenced by pulse on time and current; TWR mainly influenced by pulse off time and current. M.H. Joudiv et al. (2015) were carried out [62] study investigating effect of thermal diffusivity coefficient of tool material on TWR in the EDM process using copper alloy, copper-iron alloy, aluminum alloy and graphite as tools and AISI H13 as work piece by using Levenberg–Marquardt technique. They found that increase of thermal diffusivity of tool material decreases TWR; tool electrodes with low thermal diffusivity coefficient, increase of current, increase of pulse on-time significantly increased TWR. L. Selvarajan et al. (2015) were carried out [63] study on optimization of input controllable variables viz. pulse on/off times, current, spark gap, pressure on MRR, EWR, circularity, cylindricity, and perpendicularity for machining inter-metallic base MoSi2-SiC composites with copper tool by using L18 OA Taguchi methodology, ANOVA and GRA. They found that accuracy and precision mainly influenced by pulse on time, current, dielectric pressure. Banh Tien Long et al. (2015) were carried out [64] investigating the effect of varying concentrations of titanium powder by keeping constant input controllable variables viz. pulse time, current, voltage on MRR, SR and topography surface while machining H13 steel in powder mixed EDM with graphite electrode in rough machining by using Taguchi method, ANOVA, SEM, EDS and XRD techniques. The results revealed that the concentration of Ti powder has a high influence on MRR, SR and topography surface. Mona A. Younis et al. (2015) were carried out [65] study investigating the effect of electrode materials viz. Dura graphite 11 and Poco graphite EDMC-3 to avoid resulting residual stresses, SR and cracks resulted during EDM on DIN 1.2080 and DIN 1.2379 tool steels by choosing different machining methods such as ''rough, medium, and soft'' using Taguchi methodology, ANOVA, SEM, EDS, XRD techniques. They found that the Dura graphite 11 upon DIN 1.2379 exhibits more surface cracks, POCO Graphite EDMC-3 electrode results higher residual stresses. Harshit K. Dave et al. (2015) were carried out [66] study on influence of input controllable variables viz. pulse on/off times, current, gap voltage, tool electrode scanning speed, aspect ratio while cutting of micro-slots by using Taguchi's method, DOE, ANOVA. They found that over-cut mainly influenced by current; TWR mainly influenced by scanning speed of tool electrode. Jyoti Bhaghi, et al. (2015) were

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carried out [67] review studies on influence of input controllable variables on various performance measures. They found that there are a number of process parameters which must be selected correctly for obtaining sound products. S. Chakraborty et al. (2015) were carried out [68] a literature review on use of dielectric fluids, their effects. They found that utilizing the removal phenomenon with dielectric; working dielectric fluid played a very major role affecting MRR and properties of the machined surface by choosing the right dielectric fluid is critical for successful operations. T. Muthuramalingam et al. (2015) were carried out [69] the study and discussed about having an overview of the EDM process, modeling, effect of input controllable variables viz. electrical parameters, pulse shape, discharge energy on MRR, SR, TWR. They also discussed about controlling the electrical process parameters and empirical relationships between and optimization of process parameters. From the review results, they found that the electrical parameters can improve process effectiveness. Dignesh Thesiya et al. (2015) were carried out [70] study investigating the influence of input controllable variables viz. pulse on/ off times, peak current, servo voltage on performance measures viz. HAZ, RLT while machining of titanium alloy Ti-6Al-4V using copper, graphite electrodes with positive polarity through L18 OA Taguchi technique of DOE, SEM. They found that gap voltage and peak current are also responsible for RCL formation to some extent. In Titanium alloy (Ti-6Al-4V), higher SR and less RCL were found during low voltage and peak current while machining using Cu tool; this condition is vice-versa for graphite tool. Makwana A.V. *et al*. (2015) carried out [71] study investigating the influence of input controllable variables viz. pulse on/off times, current with various tool electrode shape configurations on machining AISI 316 stainless steel workpiece with pure Cu electrode by using L9 OA based on the Taguchi method, DOE, ANOVA, SEM. They found that greater MRR greater MRR possible only by pulse on time, current, optimum tool shapes; lower EWR and better SR is circular followed by rectangular, triangular sections. Harmanpreet et al. (2015) were carried out [72] study for the optimization and improvement of various input controllable variables viz. pulse on time, pulse off time, current, spark gap, duty cycle by using Taguchi method. They worked for minimizing TWR, SR; maximizing MRR. Review revealed that metal cutting by EDM and WEDM is generally assessed on the basis of MRR, TWR, SR; some of the important factors that influence the machining characteristics were pulse on time, pulse off time, duty cycle, dielectric flushing pressure, peak current, voltage.

IV. CONCLUSION AND SUGGESTIONS

CONCLUSION

The review of research trends has been taken for last 5 years till the year 2015. From the above reviews conclude that,

- Most of the EDM work that has been carried on Steel materials(C-40, MS IS2026, MDN 300 steel,SKD11, DSP20, H13, AISI -D2,D3, S2,1045 steel, 4140, SS 304, SS316 ,SS410, 4340, 2312),EN series (EN19, 31, 41, 45), Ti-6AL-4V, S45C, SiC, B4C, WC-Co, Al2O3+Ti, Al-Sil2, A6061-T6 aluminium alloy, CuZn40, Inconel-718, 825, CFRP composite material, RENE80 nickel super alloy, hybrid Al-SiC MMC, MoSi2-SiC composites.

- Graphite, brass, copper (prismatic, round, square hexagonal, tubular, U shaped), copper alloy, copper-iron alloy, aluminium, aluminum alloy, tungsten, gun metal, copper-tungsten, silver- tungsten, cryogenic and non cryogenic treated, Al-Cu-Si-TiC powder metallurgy Composite used as a tool materials, copper is often used in various shapes and found cylindrical as good one.

- Pulse on/off times, pulse/peak currents, voltage are the primary electrical parameters and dielectric fluid (kerosene, commercial grade EDM oil, emulsions, carbon nano tube), pressure, tool rotation are the non electrical parameters which are considered and very few have considered parameters like electrode polarity, electrode shape configuration(square, triangular, rectangular, and diamond cross sections) intensity factor, ,duty cycle, servo-head, dielectric level, composition, compaction pressure, sintering temperature, spark gap, threshold, capacitance, feed rate, electrode diffusivity coefficient, thermal conductivity and melting point of electrode.

- Most of the researches carried out to improve performances measure viz. MRR, TWR, EWR, Volumetric EW, relative WR, SR, SF and very few for OC (overcut), TOC (tool overcut), ROC, dimensional precision, surface quality, RCL or WLT, depth of HAZ, micro cracks or HV, half taper angle, mass transfer rate and variation of the side overcut.

- Many research works have been taken by the optimization techniques like Taguchi, DOE, S/N ratio, RSM, ANNOVA, CCD, SEM, XRD, CCD, GRA, Micro Crack by AFM technique, XRD,EDS, regression models, Multiple Regression analysis (MRA), mass spectrometry, optical microscopy techniques, analysis of means , fractional factorial design (FFD) and FEM.

SUGGESTIONS 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:

- The experimental investigation of optimal machining parameters for hot die steels viz. H11, H13 is very essential, it is one advanced material used in applications of extreme loads and response characteristics.

- Urgent need to recognize important cutting conditions viz. pulse on/off times, duty factor, current, voltage, electrode polarity, spark gap, and other machining parameters like electrode material/shape/size/properties, dielectric fluid, dielectric type, flushing system and pressure, etc must be selected for optimizing performance measures viz maximizing MRR, SF and minimizing TWR, WR, Over Cut, WLT, HAZ, MV. Now here is a need to carry out systematically research work

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by the techniques like one factor at a time (OFAT) approach, Taguchi's methodology, SEM-EDS, XRD, Micro Crack by AFM, RSM with CCD, GRA, Single response process parameters optimization using RSM and desirability function, Multi-objective process parameters optimization using desirability function in conjunction with RSM and using Taguchi's technique with utility concept. The efforts should be made to investigate experimentally the influence of input controllable variables on performance measures especially with a cryogenic cutting environment and the weightages to be assigned to various characteristics in models of multi-response optimization should be based upon requirements of industries.

V. REFERENCES

[1] S. Prabhu and B.K. Vinayagam, "AFM surface investigation of INCONEL 825 with multi wall carbon nano tube in electrical discharge machining process using Taguchi analysis", Archives of Civil and Mechanical Engineering , 11(1), PP: 149-170, 2011.

[2] S.P. Sivapirakasam, Jose Mathew and M. Surianarayanan, "Constituent analysis of aerosol generated from die sinking electrical discharge machining process", The Institution of Chemical Engineers (Elsevier), 89(2), Pages: 141–150, 2011.

[3] D.V.Ghewade and S.R.Nipanikar, "Experimental study of electro discharge machining for INCONEL material", JERS, Vol.2, Issue 1, pp-107-112, E-ISSN 0976-7916, 2011.

[4] Promod K. Patowari, Partha Saha and P. K. Mishra, "Taguchi analysis of surface modification technique using W-Cu powder metallurgy sintered tools in EDM and characterization of the deposited layer", Int J Adv Manuf Technol, 54(5-8), PP: 593–604, 2011.

[5] Shabgard M., Mirsadegh Seyedzavvar, Samad Nadimi Bavil Oliaei, "Influence of Input Parameters on the Characteristics of the EDM Process", Journal of Mechanical Engineering, 57(9), PP: 689-696, 2011.

[6] Hao Ning Chiang and J. J. Junz Wang (2011); "An analysis of overcut variation and coupling effects of dimensional variable in EDM process", Int J Adv Manuf Technol, 55(9), PP: 935-943, 2011.

[7] Horacio T. Sanchez, Manuel Estrems and Felix Faura, "Development of an inversion model for establishing EDM input parameters to satisfy material removal rate, electrode wear ratio and surface roughness", Int J Adv Manuf Technol, 57(1) PP: 189-201, 2011.

[8] Bhola Jha, K.Ram and Mohan Rao, "An overview of technology and research in electrode design and manufacturing in sinking electrical discharge machining". Journal of Engineering Science and Technology Review, 4 (2), PP: 118-130, 2011.

[9] Harpreet Singh and Amandeep Singh, "Effect of Pulse On/Pulse Off Time On Machining Of AISI D3 Die Steel Using Copper And Brass Electrode In EDM", International Journal of Engineering and Science, 1(9), PP: 19-22, ISSN: 2278-4721, 2012.

[10] Lei Li, Lin Gu, Xuecheng Xi and Wansheng Zhao, "Influence of flushing on performance of EDM with bunched electrode", Int J Adv Manuf Technol, 58(1), PP: 187-194, 2012.

[11] Manish Vishwakarma, V.K.Khare and Vishal Parashar, "Response surface approach for optimization of Sinker Electric Discharge Machine process parameters on AISI 4140 alloy steel", IJERA, 2(4), PP: 185-189, ISSN: 2248-9622, 2012.

[12] Renjie Ji, Yonghong Liu , Y. Zhang, B. Cai, Jianmin Ma and X. Li, "Influence of dielectric and machining parameters on the process performance for electric discharge milling of SiC ceramic", Int J Adv Manuf Technol ,59(1), PP: 127-136, 2012.

[13] Ignacio Puertas and Carmelo J. Luis, "Optimization of EDM conditions in the manufacturing process of B_4C and WC-Co conductive ceramics, Int J Adv Manuf Technol, 59(5), PP: 575-582, 2012.

[14] S. R. Nipanikar , "Parameter Optimization of Electro Discharge Machining of AISI D3 Steel Material by Using Taguchi Method", Journal of Engineering Research and Studies (JERS) 3(3), PP: 7-10, ISSN: 0976-7916, 2012.

[15] Nilesh M. Vohra (2013); "Optimization of Cutting Parameter in EDM using Taguchi Method", International Journal of Scientific Research (IJSR) 2(1), PP: 90-95, ISSN: 2277-8179.

[16] Jun Li, S. Shi1 and S. Zhao, "Modeling and Analysis of Micro-hole in Die-sinking EDM Process through Response Surface Method based on the CCD", Int J of Signal Processing, Image Processing and Pattern Recognition, 6(6), PP: 351-364, 2013.

[17] P. B. Wagh, Dr. R. R. Deshmukh and R. D. Gurav, "Optimization for Surface Roughness in Edm for En31 Material by Response Surface Methodology", Indian Journal of Applied Research, 3(10), 2013, ISSN - 2249-555X, 2013.

[18] Raghuraman S, Thiruppathi K, Panneerselvam T and Santosh S, "Optimization of EDM parameters using taguchi method and GRA for mild steel IS2026", Int J of Innovative Research in Science, Engineering and Technology, 2(7), ISSN: 2319-8753, 2013.

[19] D.C. Chen, J.J. Jhang and M.W. Guo, "Application of Taguchi Design Method to Optimize the Electric Discharge Machining", Journal of Achievements in Materials and Manufacturing Engineering (JAMME) 57(2), PP: 76-82, 2013.

[20] A. M. Nikalje , A. Kumar and K. V. Sai Srinadh, "Influence of parameters and optimization of EDM performance measures on MDN 300 steel using Taguchi method", Int J Adv Manuf Technol, 69(1), PP: 41-49, 2013.

[21] Shailendra Kumar Singh and Narinder Kumar, "Optimizing the EDM Parameters to Improve the Surface Roughness of Titanium Alloy (Ti-6AL-4V)", International Journal of Emerging Science and Engineering (IJESE), ISSN: 2319–6378, 1(10), 2013.

[22] Shivendra Tiwari (4/2013); "Optimization of Electrical Discharge Machining (EDM) with Respect to Tool Wear Rate", International Journal of Science, Engineering and Technology Research (IJSETR), 2(4), ISSN: 2278-7798, 2013.

[23] Singaram Lakshmanan and Mahesh Kumar, "Optimization of EDM parameters using Response Surface Methodology for EN31 Tool Steel Machining", Int Journal of Engineering Science and Innovative Technology (IJESIT) 2(5), ISSN: 2319-5967, 2013.

[24] Rao P.S., Kumar J.S, Reddy K., Reddy B.S., "Parametric Study of Electric Discharge Machining of AISI 304 Stainless Steel", International Journal of Engineering Science and Technology, 2(8), PP: 3535-3550, 2013.

[25] Harpreet singh, Amandeep singh, "Effect of Pulse on / Pulse off on Machining of Steel Using Cryogenic Treated Copper Electrode", International Journal of Engineering Research and Development, 5(12), PP: 29-34, 2013

[26] Mohammed Sarvar Rasheed, "Comparison of Micro-Holes Produced By Micro-EDM with Laser Machining", International Journal of Science and Modern Engineering (IJISME), 1(3), ISSN: 2319-6386, 2013.

[27] Abhishek Gaikwad, A. Tiwari, A. Kumar, D. Singh, "Effect Of EDM parameters in Obtaining Maximum MRR And Minimum EWR By Machining SS 316 Using Cu Electrode", Int J of Mechanical Engg and Technology, 5(6), PP: 101-109, ISSN 0976 – 6340, 2014.

[28] Vikas, Shashikant, A.K.Roy and K. Kumar, "Effect and Optimization of Machine Process Parameters on MRR for EN19 & EN41 materials using Taguchi"' 2nd Int Conference on Innovations in Automation and Mechatronics Engg, ICIAME 2014, 14, 204 – 210.

[29] T.Roy, R.K.Dutta, "Study of the Effect of EDM Parameters based on Tool Overcut using Stainless Steel (SS 304 Grade)", International Journal of Engineering Trends and Technology (IJETT), 13, ISSN: 2231-5381, Number 5 – Jul 2014.

[30] Brajesh Kumar Lodhi, Deepak Verma, Rahul Shukla, "Optimization of machining parameters in EDM of CFRP composite using Taguchi technique", Int Jof Mech Engg and Technol (IJMET), 5(10), PP:70-77, ISSN 0976 – 6340,10/2014.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 01, January-2016

[31] N. Radhika, Sudhamshu, A.R. and Kishore Chandran, G., "Optimization of electrical discharge machining parameters of aluminium hybrid composites using Taguchi method", Journal of Engg Sc and Technology, Taylor's University, 9(4),Pages 502-512, 2014.
[32] N. Annamalai, V. Sivaramakrishnan, N.Baskar, "Investigation and Modeling of Electrical Discharge Machining Process Parameters for AISI 4340 steel", International Journal of Engineering and Technology, 5(6), PP: 4761-4770, ISSN: 0975-4024, 2014.
[33] Viral B. Prajapati, H.G. Rajput, "A Review on Optimization of Process Parameters for Improving Performance in Electrical Discharge Machining", Int. Journal of Engineering Research and Applications, 4(2), Ver.1, PP: 331-336, ISSN: 2248-9622, 2014.
[34] Shashikant, Apurba K Roy, K. Kumar, "Optimization of machine process parameters on material removal rate in EDM for EN19 material using RSM", IOSR-J of Mechanical and Civil Engg, e-ISSN: 2278-1684, p-ISSN: 2320-334X PP 24-28, (ICAET-2014).
[35] Vishal J Nadpara, "Optimization of EDM Process Parameters Using Taguchi Method with Graphite Electrode", International Journal of Engineering Trends and Technology (IJETT), 7(2),PP: 48-51, ISSN: 2231-5381, 2014.
[36] Chandramouli S, Shrinivas Balraj U and Eswaraiah K., "Optimization of Electric Discharge Machining Process Parameters Using Taguchi Method", International Journal of Advance Mechanical Engineering (IJAME), 4(4), PP: 425-434, ISSN: 2250-3234, 2014.
[37] Shishir M Shrivastava, Dr. A.K.Sarathe, "Influence of Process Parameters and Electrode Shape Configuration on Material Removal Rate, Surface Roughness And Electrode Wear In Die Sinking EDM: A Review", IJETAE, 4(4), ISSN 2250-2459, 2014.
[38] Dhirendra nath mishra, Aarti Bhatia,Vaibhav rana, "Study on Electro Discharge Machining (EDM)", The International Journal Of Engineering And Science, 3(2), PP: 24-35, 2014.
[39] Varinder Khurana, H.S. Sodhi, A. Singh Sandhu, "The Effect of Die Sinking Process Parameters on Surface roughness of D2 Steel Using Taguchi"s Method", ISO 9001:2008 Certified Int. J of Inno. Research in Engg & Multidisciplinary Physical Sciences, 2(3), 2014.
[40] Arumugam Kadirvel, P Hariharan, "Optimization of the die-sinking micro-EDM process for multiple performance characteristics using the Taguchi-Based Grey Relational Analysis", Materials and technology, 48(1), 27–32, ISSN 1580-2949, 2014.
[41] Sushil Kumar Choudhary, Dr. R.S Jadoun, "Current Advanced Research Development of Electric Discharge Machining (EDM): A Review", International Journal of Research in Advent Technology, 2(3) March 2014,E-ISSN: 2321-9637, 2014.
[42] Abhijeetsinh V Makwana, Kapil S Banker, "An Electrode Shape Configuration on the Performance of Die Sinking EDM: A Review", Int. Journal of Engineering Research and Applications www.ijera.com ISSN: 2248-9622, 4(11),Ver.5, pp.117-122, 2014.
[43] Bharat Raj Bundel, "Experimental Study of Electrode Wear in Die-Sinking EDM using Cylindrical Copper Electrode", International Journal of Engineering Research & Technology, Vol. 3 Issue 10, October- 2014, ISSN: 2278-0181, 2014.
[44] S. Barman, N. Hanumaiah, A. B. Puri, "Investigation on shape, size, surface quality and elemental characterization of high-aspect-ratio blind micro holes in die sinking micro EDM", Int J of Advanced Manufacturing Technology, 76(1), pp 115-126, 01/2015.
[45] Avdesh Chandra Dixit, Amit Kumar, R K Singh, R Bajpai, "An Experimental Study of MRR and EWR of High Carbon-High Chromium Steel (AISI D3) In EDM Process Using Cu Tool Electrode", IJIRAE, ISSN: 2349-2163 Issue 1, Vol.2, 01/2015.
[46] J Jeevamalar and S Ramabalan, "DIE SINKING EDM PROCESS PARAMETERS:A REVIEW", Int. J. Mech. Eng. & Rob. Res., ISSN 2278 – 0149, Vol. 4, No. 1, January 2015, www.ijmerr.com.
[47] Bai Shao and K. P. Rajurkar, "Modelling of the crater formation in micro-EDM", Procedia CIRP, 33 (2015) 376 – 381, 2015.
[48] Vinal Sharma, Harvinder Lal Paramjit Singh, "Study of Wear Ratio of SKD11 Steel in Titanium Abrasives Mixed Electrical Discharge Machining", International Journal of Emerging Research in Management &Technology, ISSN: 2278-9359, 4(7), 2015.
[49] M. A. Md Ali, S. Laily, B. Manshoor, N. I. Syahrian, "Performance of Copper, Copper Tungsten, Graphite and Brass Electrode on MRR, EWR and SR of Aluminium LM6 in EDM Die Sinking", J of Advanced Research in Applied Mechanics, 6(1), pp: 30-36, 2015.
[50] Dr. Sanjeev Saini, Varun Singla, Jaspreet Singh, "Optimization Of Machining Parameters In EDM Of High Speed Steel By Using U Shape Electrode", Int J of Engineering & Science Research, Vol-5, Issue-7, pp: 906-908, ISSN 2277-2685, 01/2015.
[51] Amoljit S. Gill, S Kumar, "Surface alloying of H11 die steel by tungsten using EDM process", IJAMT, 78(9), pp 1585-1593, 2015.
[52] Surinder Pal Singh, Harvinder Lal, Paramjit Singh, "Wear Ratio of EN8 Steel and Copper Electrode in Sinking EDM with Titanium Abrasives Suspended Dielectric Fluid", IJERMT, ISSN: 2278-9359 (Volume-4, Issue-7), 07/2015.
[53] Farhad Kolahan, Masoud Azadi Moghaddam, "The Use of Taguchi Method with Grey Relational Analysis to optimize the EDM Process Parameters with Multiple Quality Characteristics", Int J of Sc and Technol (ISI), 22(2), pp: 530-538, 05/2015.
[54] Ahmed Raza Khan, Muhammad Awais Ahmad, Nauman Munir and Z R Butt, "Influence of electrode material on quality of blind holes machined via electric discharge machine (die sinker)", Int. J. Engg. Res. & Sci. & Tech. 4(2), ISSN 2319-5991, 05/2015.
[55] Manisha Priyadarshini, Kamal Pal, "Grey-taguchi Based Optimization of EDM Process for Titanium Alloy", Materials Today: Proceedings, 2(4-5), pp: 2472–2481, 4th Int Conference on Materials Processing and Characterization (Elsevier Ltd.), 09/2015.
[56] Sumit Raj, Kaushik Kumar, "Optimization and Prediction of Material Removing Rate in Die Sinking EDM of EN45 Steel Tool", Materials Today: Proceedings, 2(4-5), Pages 2346–2352, 4th Int Conference on Materials Processing and Characterization, Sept.2015.
[57] Goran Mijuskovic, Peter Krajnik, Janez Kopac, "Analysis of tool deflection in micro milling of graphite electrodes", The International Journal of Advanced Manufacturing Technology, 76(1), pp 209-217, 01/2015.
[58] S. Bharathi Raja, C. V. Srinivas Pramod, K. Vamshee Krishna, Arvind Ragunathan, Somalaraju Vinesh, "Optimization of EDM parameters on hardened die steel using Firefly Algorithm", Engineering with Computers, Vol 31, Issue 1, pp 1-9,01/ 2015.
[59] Fawang Zhang, Lin Gu , Jing Hu, Wansheng Zhao, "A new thermal model considering TIE of the expanding spark for anode erosion process of EDM in water", The Int J of Advanced Manufacturing Technology, pp 1-10, First online: 14 June 2015.
[60] G. K. Bosea and K. K. Mahapatrab, "Multi criteria decision making of machining parameters for Die Sinking EDM Process", International Journal of Industrial Engineering Computations, 6 (2015) 241–252, 2015.
[61] S. C. Kulkarni, H. K. Amarnath, and Kiran B. Menasagi, "Some investigations into the sinker type EDM of hybrid Al-SiC MMC using RSM approach", Int. J. Adv. Res. Sci. Technol. Volume 4, Issue 5, pp.459-463, ISSN 2319 – 1783, 2015.
[62] M.H. Joudiv, Sarand, M.R. Shabgard, "Investigation of the effect of thermal diffusivity coefficient of tool material on electrode-tool wear in the EDM process", Archives of Civil and Mechanical Engineering, Vol 15, Issue 4, Pages 806–821, 09/2015.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 01, January-2016

[63] L. Selvarajan, C. Sathiya Narayanan and R. Jeyapaul, "Optimization of Process Parameters to Improve Form and Orientation Tolerances in EDM of $MoSi_2$-SiC Composites", Materials and Manufacturing Processes, 30:8, 954-960, ISSN: 1042-6914, 2015.
[64] Banh Tien Long, Ngo Cuong, Nguyen Huu Phan, Hoang Anh Toan and Pichai Janmanee, "Enhanced Material Removal Rate and Surface Quality of H13 Steel in EDM With Graphite Electrode in Rough Machining", IJSET, 4(2), pp : 104-109 01, 02/2015.
[65] Mona A. Younis, Mohamed S. Abbas, Mostafa A. Gouda, Fouad H. Mahmoud, Sayed A. Abd Allah, "Effect of electrode material on electrical discharge machining of tool steel surface", Ain Shams Engineering Journal, 6, 977–986, 2015.
[66] Harshit K. Dave, Vishal J. Mathai, Mukul K. Mayanak, Harit K. Raval, Keyur P. Desai, "Study on effect of process parameters on overcut and tool wear rate during micro-electro-discharge slotting process", IJAMT, pp 1-12, First online: 25 July 2015.
[67] Jyoti Bhaghi, Manjeet Bohat, V. P. S. Kalsi, Sunil Dhingra, "A Review on Effect of EDM Parameters on Die Sinking EDM", Trends in Mechanical Engineering and Technology, 5(1), pp: 26–30, 2015.
[68] S. Chakraborty, V. Dey, S.K. Ghosh, "A review on the use of dielectric fluids and their effects in electrical discharge machining characteristics", Precision Engineering, Vol. 40, Pages 1–6, ISSN: 0141-6359, 2015.
[69] T. Muthuramalingam, B. Mohan, "A review on influence of electrical process parameters in EDM process", Archives of Civil and Mechanical Engineering, Volume 15, Issue 1, Pages 87–94, 2015.
[70] Dignesh Thesiya, Avadhoot Rajurkar and Sagar Patel, "Heat Affected Zone and Recast Layer Of Ti-6Al-4V Alloy in the EDM Process through Scanning Electron Microscopy (SEM)", J of Manufacturing Technology Research, 6(1-2), ISSN: 1943-8095, 2015.
[71] Abhijeetsinh V Makwana, Kapil S Banker, "An Experimental Investigation on AISI 316 Stainless Steel for Tool Profile Change in Die Sinking EDM Using DOE", Sch. J. Eng. Tech., 3(4B), pp: 447-462, ISSN 2321-435X (Online) ISSN 2347-9523 (Print), 2015.
[72] Harmanpreet, Manpreet Singh, Bipendeep, "Optimization of EDM process parameters using Taguchi Method: A review", IJRET, Volume: 04 Issue: 04 | Apr-2015, eISSN: 2319-1163, pISSN: 2321-7308, 2015.