CHAPTER-1

Introduction and Literature Survey

1.1.Introduction

In the present era, the hard and brittle materials are being used in various manufacturing sectors which have been technologically highly developed. These materials are utilized in the nuclear sector, aerospace, automobile, and multiple Industries because of their hardness, heat resistance and high strength to weight ratio qualities. In addition, other engineering materials such as superalloy, nanoalloy, ceramics and composite materials having excellent mechanical properties are also used in different R&D and production sector. As for as the manufacturing processes are concerned, the non-traditional machining process is one of the suitable technique which is used to machine these materials.

With the rapid growth of Industry, the demand for steel, alloy materials with good mechanical properties are increasing day by day. However, the machining of these materials creates complexity with the conventional machining process. There are different unconventional machining processes such as Electrochemical machining, Ultrasonic machining, Electro-discharge machining are used to machine such materials irrespective of its complicated shape, dimensional accuracy, and high production rate. Among all the nonconventional process, Electro discharge machining is commonly used. Electrical Discharge Machining is a significant process which is broadly applied for the machining of electrically conductive materials regardless of its hardness, strength, etc. In this process, the material erosion occurs through the process of controlled electric spark generation. The non-traditional machining process, i.e., EDM machining requires high energy input to erode unit volume of metal in comparison with the traditional method. The major part of the EDM energy is transformed into heat, which leads to increase the temperature in machining zone and possible thermal damage. This thermal damage on the EDMed surface also affects the surface properties such as hardness and microstructure etc. It also develops fatigue strength and microcrack on the machined surface (Ghosh & Mallik, 1993).

The concept of EDM process was introduced in 1770, and it was first developed by Dr. B.R. Lazarenko and Dr. N.I. Lazarenko in 1943. At that time, they invented the spark generator which was known as Lazarenko circuit. Further, the developed EDM system was applied to the resistance-capacitance type of power supply. Afterward, the modified EDM has been designed with the merge of pulse and solid-state generators. It reduced the difficulties of using weak electrode and the creation of the orbiting systems. Subsequently, the machine was developed using the fewer wire to create cavities. In the year 1980, the computer numerical controlled EDM was invented in USA (Ho & Newman, 2003; Choudhary & Jadoun, 2014). The concept of material removal mechanism of EDM was discussed. When tool and workpiece are immersed in the dielectric medium namely de-ionized water, kerosene or hydrocarbon oil, pulse arc discharges occur in the inter-electrode gap when a potential difference is applied across them. The insulating strength of dielectric medium plays an important role in avoiding the electrolysis effect on tool and workpiece during the EDM process. For precise machining minimum gap of 10-100 μm needs to be maintained, thus for this tool shape is copied with an offset equal to gap size. However, to avoid the short circuit, a certain gap width is necessary. Pulse arc discharge occurred when the high voltage applied in the inter-electrode gap to overcome the breakdown strength of dielectric medium and plasma channel. However, with further progress of pulse duration, the plasma channel develops wider. Discharge occurs at high frequencies in the range of 10^3 to 10^6 Hz for removing small materials from the electrodes. The materials from tool and workpiece are evaporated or ejected in the molten phase when discharge occurs at a single point for every pulse. Due to this small crater is formed on the surface of the sample and electrode. The number of debris particles is formed when materials are removed from the electrodes are cooled and re-solidified in the dielectric medium. These fragments particles are then flushed away by the dielectric medium from the gap between tool and workpiece. Rapidly drop in temperature of plasma and surfaces in contact with plasma were observed after the end of pulse duration. This results in recovery of breakdown strength of dielectric and recombination of electrons and ions. Stable machining is obtained in EDM when subsequently pulse discharge occurs at a place which is spaced adequately far away from the earlier pulse discharge location. Such spot is mainly observed when either the gap is minimum or contains debris particles causing the reduction in breakdown strength of dielectric. The duration of pulse time should be sufficient enough between discharges so that plasma formed by the earlier discharge gets de-ionized and moreover, recovery of breakdown strength of dielectric occurs around the previous discharge location before subsequently voltage is applied. Otherwise overheating and inconsistent removal of specimen occur due to frequent discharge for every pulse at the same location. EDM possesses certain benefits such as higher machining accuracy and attainable surface roughness. However, low material removal rate was observed as compared to other machining processes, the formation of the recast layer and heat affected zone is the limitation of this process. Thus, EDM is mostly utilized in die and mold manufacturing sector for generating complex shapes in difficult to cut materials with high precision (Kunieda. *et al*.,2005)

1.2. Surface Integrity

The surface morphology is associated with various characteristics such as microhardness profile, surface roughness, residual stress geometric, crack density, white layer (WL), and crack density, etc. The morphology of an EDMed surface is becoming progressively more significant to fulfilling the rising anxiety of complicated component performance, durability, and reliability. It plays an important role in industry and manufacturing sector while the inspection of product geometry, roughness, and dimensional accuracy. The measurement of surface integrity is more time taking process with the use of precious apparatus such as microhardness tester, XRD, SEM and surface roughness tester, etc. Therefore, these elements are monitored with the use of a sampling technique. This monitoring strategy may cause the occurrence of an unexpected failure (Guu & Hou, 2007).

There are numerous methods applied for characterization and testing of the machined samples such as optical microscopic study, microhardness test, surface roughness, X-ray diffraction (XRD), Barkhausen Noise (BN) technique, Non-Destructive Testing (NDT), etc. The NDT is used to test the materials, structures, and parts, etc. This technique predicts the strength, quality, and lifespan of the tested sample which are more reliable for the use of industries. It is a time-saving process and does not need to verify. It has many methods namely visual, pressure and leak, penetrate, thermal, radiography, acoustic, magnetic, electrical and electrostatic, electromagnetic induction used in industries because of its impact on the enhancement of productivity, serviceability, safety and identification of materials. (Sorsa, 2012).

X-ray diffraction (XRD) is a widely used destructive method to measure the residual stresses because of its small penetration depth. It is an expensive and time-consuming and follows laboratory method. It cannot be used frequently in Industry environments (Brinksmeier & Tönshoff, 1985). Despite having disadvantages, this technique is used continuously for the fast monitoring of the damaged surface of the machined product. Generally, the damage is observed on a machined product due to severe pressure and thermal loading. This damaged surface of the product supports untimely failure which adversely affects the human life.

Many researchers described a variety of techniques for the analysis of surface integrity following manufacturing operations such as welding, heat treatment, forming, milling, etc.

1.3. Literature Survey

This section contains the major finding and highlighting the limitation of each relevant past work and the importance of present investigation in manufacturing. It also initiates with a critical review of the existing literature on the laboratory-based techniques available for the assessment of the surface integrity of the manufactured component.

Estimation of surface integrity of the material is necessary for both the economic and safety reason. It is extensively received that all the components possess defects at the commence of their service days. Surface assessment is very essential to control reliable structure integrity of components. The reliable performance of components or structures relies on the service quality and in-service degradation during their working condition. The NDT is a promising method for the analysis of service quality and observing the service degradation to keep away formerly failure of the component.

There are numerous NDT techniques which depend on different physical principles. Non-Destructive Testing aims to recognize and categorize the arrangement of defects, stress, microstructure. The information of Non-Destructive Testing gathered from experiments are not only used for assessment of surface integrity but also estimate the life of component or structures. The physical concept of Non Destructive evaluation method and derived parameters are suitable for identification of various defects, stresses and microstructures which were discussed (Raj *et al*., 1995).

It is necessary for a deep understanding of the relationship among the major EDM parameters (voltage, pulse current, pulse on time) and for observing machined surface integrity (surface roughness, microhardness, and residual stress, etc.) to improve the quality of the product.

1.3.1. Effect of Pulse on time (T_{on})

This is period which is set during the machining process in which current is permitted to pass per sequence. It is measured by microsecond (μs). The spark energy generated is reliant on both the pulse current and the pulse on-time. The EDM process removes material by thermal energy. The temperature at the spark is high enough to vaporize the material. Thermal energy is provided by electricity flowing in the inter-electrode gap in the form of a spark. Increasing the current also increases the amount of material removal (Jameson, 2001). The mechanism of phases of electrical discharges in the small gap between tool and electrode was not uniformly interpreted by the various researchers. The researchers stated clearly regarding the different phase in practical EDM machining. Three steps occurred such as ignition; discharge and interval period between discharges in EDM machining at practical applications. The material removal mechanism was grouped at the start of ignition in the evaporation phase, and later expulsion of fused material by immediate boiling was observed at the discharge places. Optimize discharge conditions for stability and efficiency was set by servo controllers. Also, the ignition could be modified by the addition of fine conductive powder in the dielectric fluid (Schumacher, 2004).

Kiyak & Cakır (2007) machined 40CrMnNiMo864 tool steel (AISI P20) with EDM to examine the influence of EDM parameters namely, pulsed current, pulse on time and pulse off time on the surface roughness of workpiece and electrode. It was noticed that pulsed current and pulse on time has an important influence on surface roughness. Better surface finish was noted at a small current, pulse on time and high pulse off time. A similar trend of surface roughness was observed for both workpiece and electrode for the same pulse off time. From the surface quality point, there was a relation between the increase in surface roughness of the specimen and the wear on the electrode (Kiyak & Cakır, 2007; Bergaley & Sharma, 2013). Çaydaş and Hascalik (2007) performed machining of Ti-6Al-4V alloy with the EDM process to analyze the effect of machining parameters on White Layer Thickness (WLT) and Electrode Wear (EW). The Central Composite Rotatable Design (CCRD) based on Response Surface Methodology (RSM) was used for carrying out the experiments. The effect of pulse current was found to be a most influential parameter on WLT and EW; the effect of pulse off time was least significant. The mathematical model was developed to predict the WLT and EW in terms of machining parameters, and the model was found to have congruence with the experimental data.

Kung *et al*. (2009) used aluminium powder mixed in the dielectric fluid in EDM to machine the cobalt-bonded tungsten. This investigation was performed to analyze the effect of the pulse on time, the grain size of powder, pulse current and powder concentration on the performance measure as Material Removal Rate (MRR) and Electrode Wear Ratio (EWR). The second order model was developed to predict the MRR and EWR using RSM. Improvement in machining efficiency was observed with the use of aluminium powder. Higher MRR was noted at more pulse on time, grain size and pulse current; and at optimum powder concentration. While, low EWR was observed at lower pulse on time, grain size and pulse current; and at optimum powder concentration. Syed & Palaniyandi (2012) had been experimentally investigated the effect of polarity on the performance of electrical discharge machining using aluminium fine particles added in distilled water. During the machining of W300 die-steel with a low concentration of powder of 1g/L, the most MRR was obtained at large pulse current of 12A and a reasonable pulse on time of 180µs at positive polarity. The low EWR and low surface roughness values were obtained at smaller values of the peak current of 6A with a pulse on time 240µs and180µs, respectively. However, low EWR was achieved in the positive polarity, and for low surface roughness values, positive polarity should be selected. The experimental results suggested that the polarity showed a significant role in Powder Metallurgy EDM (PMEDM) and distilled water might be utilized as a dielectric in its place of hydrocarbon oil as well as the addition of aluminium powder may also be improved the machining process.

The cemented carbide or hard metal (i.e., 94WC–6Co) had been selected for the die-sinking electrical discharge machining (EDM) as a conductive ceramics. The study focused on modeling procedures of some the parameters of die-sinking EDM. Low values of both intensity and pulse time resulted in the better surface finish in tungsten carbide. The small values of electrode wear could be obtained by using an intensity factor near or greater than its central value and lower than the pulse on time. Increasing intensity and duty cycle increased MRR while it decreased when pulse time was increased (Puertas *et al.*, 2004). The regression model was used to predict the output variables corresponding to three most influencing input parameters for AISI 1045 steel keeping others fixed. Also, more input parameters should be considered taking the dimensional accuracy as the output variable (Sánchez *et al.*, 2011). This study focused on surface roughness variation due to the machining parameters. Because of large discharge energy liberated and enlarging discharge channel, with an increase in discharge duration, the surface roughness showed an increasing trend (Keskin *et al.*, 2006). The study tried to find out the important parameters which were narrated to the die-sinking EDM of B_4C and WC. The different conditions used in the study were low surface roughness (Ra), low EW and high MRR to analyze the differences in the EDM of B_4C and WC (Puertas & Luis, 2012). The effect of discharge energy on different machining characteristics in EDM was studied. The discharge energy could be increased using both pulse duration and power. The inter-electrode gap influenced machining accuracy of EDM greatly when discharge energy was increased. Also, surface roughness increased uniformly due to the effect of discharge power and pulse duration as its direct dependence on the discharge energy (Gostimirovic *et al.*, 2012). Uhlmann & Domingos, (2013) developed and optimized the EDM-technology for EDM of the nickel-based alloy

MAR-M247 for turbine components. This work focused on reducing total time for manufacturing seal slots by EDM. A faster machining process was obtained by using larger feed voltage which improved the inter-electrode gap facilitating the flushing of debris. For producing the cavities in MAR-M247, a less process time-consuming technology was developed keeping the best surface quality. Roy & Kumar (2014) examined the influence of the different process parameters on the surface roughness. This investigation showed the variation of surface roughness for an EN41 material when changed pulse on time, pulse off time, pulse current and voltage. The result showed that the pulse current had a significant effect over surface roughness while the effect of other was very small and could be avoided. The interaction plots also resulted in an insignificant outcome over the surface roughness value. All the results were investigated at 95% confidence level and the investigational data gained was observed near to the predicted value, and hence, the whole work was confirmed.

Lee *et al*., (2004) reported the residual stress in SKD11 tool steel during hole drilling through the EDM process. Hole-drilling induced stress could be reduced by using small pulse-on time, and large pulse current and the cracks appearance could also be avoided. The White Layer (WL) showed more stress state because of phase change and quenching effect and the higher chromium content in the WL than the base material.

From the balanced investigation of models which considered an Artificial Neural Network (ANN) and two neuro-fuzzy systems for the evaluation of MRR, TWR, and overcut of steel in EDM. It was summarised that the MRR, TWR, and G showed a linear relationship with the discharge current in machining. The average calculated errors for MRR were lower 6%. The average overcut was also less than 7.2%. On the other hand, the median predicted errors for TWR were in the range of 14–16%. The simulated results showed proper validation with experimental results (Pradhan & Biswas, 2010). All the responses indicated a linear relation with current, but different relations with pulse-on time because the frequency of spark occurrence decreased when the pulse-on time was improved. The results showed that high MRR was obtained when machining was done with straight (positive) polarity as compared to those with negative polarity. The Lexicographic Goal Programming (LGP) could be used as a powerful tool for optimization of multiple responses because the optimal solution obtained using LGP matched with experimental results. With straight polarity, maximum MRR was obtained by using high current and low pulse on-time while for upper surface finish, the smaller pulse current and pulse-on time should be used. trials conducted with negative polarity showed similar results for finish machining. If TWR was higher precedence as balanced to MRR, then low current and an average pulse on-time should be maintained. The current and pulse on-time were significant in determining the Recast layer (RCL) thickness, but these were profoundly affected by pulse on-time. The pattern of irregular distribution of reinforced particles worsen the properties of the EDMed surface; hence, due to least existence of reinforced particles in RCL, it was desirable to remove particles (Sidhu *et al*., 2013). The modeling of surface modification trend by EDM using ANN was described. Acceptable conformity between the trial and proposed model results were attained using this type of network. The effect of different process parameters on material transfer rate and layer thickness had been presented in this work (Patowari *et al*., 2010). The deviation of tool edge wear and MRR, TWR, with the varying input process parameters were studied in sinking EDM. The study revealed that on increasing pulse current, MRR and TWR were improved. The high-pressure dielectric flushing pressure did not show any significant influence on TWR and RW. It was also noticed that the tremendous value of the pulse on time, pulse current and dielectric flushing pressure improved the inner and outer edge radii (Cogun & Akaslan, 2002).

Kunieda *et al*. (1997) performed the EDM in gas and compared this gas EDM with traditional EDM using dielectric fluids. It was found that eroded materials flowed by the large-velocity gas flow did not contact the tool surfaces and were flushed out of the gap. Also to prevent the reattachment of the removed material to the electrode surfaces, a thin walled pipe was used as tool electrode. The EWR was practically nothing for every pulse duration and increased the concentration of oxygen in gas EDM. When more heat generation by oxidation of electrode materials in air, then MRR was also improved. The 3D machining with a Numerical Control (NC) tool path could be performed with the help of uniform high-velocity air flow. The generated machine surface would be exactly as the tool wear value was small. Kunieda *et al*. (1999) performed the reverse simulation of die-sinking EDM considering various factors like tool wear, gap width distribution, curved tool surface, and fragments particle concentration, that every element influence each other during the process. The forward simulation helped to regain new shape of both electrodes in EDM. The similar algorithm as used in the forward simulation was accepted for reverse simulation method. Çaydaş & Hascalik (2008) modeled the EW and WLT using the EDM process and investigated it through RSM. It was found that the most significant parameter influencing the both EW and WLT was pulse current. There was no significant influence of pulse off time on both responses. It was also found that RSM could successfully model the EW and WLT and it was a more efficient way for acquiring information for any system with the least number of experiments.

While EDM of Gamma Titanium Aluminide with fine graphite, it was reported that surface roughness did not show any effect with pulse interval time. The WLT increased with pulse interval time. The duty factor was independent of surface roughness. But the average WLT slightly decreased with an increment of duty cycle due to less energy density in an inter electrode gap (Klocke *et al*., 2015). Gostimirovic *et al*., (2012) studied the influence of discharge energy on EDM responses in the machining process. The found that capability of EDM frankly dependent on the power and duration of the discharge energy. Also, the MRR enhanced with improvement in discharge energy. But to get maximum MRR there should be optimum discharge energy, and to obtain optimal pulse duration the MRR should increase with the increase of the discharge power (pulse current). With the rise in spark energy, either through pulse duration or discharge power, the inter-electrode gap space exercises superior effect on the EDM accuracy. Guu and Huo (2007) analyzed the impact of pulse current and pulse on time on surface characteristics on EDMed Fe-Mn-Al alloy using atomic force microscopy technique. The surface characteristics namely surface roughness, microhardness, micro-void, and micro-cracks were considered for analysis. The ridged surface, micro-cracks, micro-voids and damage layers on workpiece surface were observed on machining with EDM process. The pulse on duration had more dominating effect as compared to pulsed current on the surface texture. More quantity of micro-voids, damage layer, and depth of micro-cracks was observed with increased in pulsed current and pulse-on duration. The model for surface roughness, microhardness, micro-cracks, micro-voids, and damage layer was analyzed using regression analysis. No significant difference was observed in microhardness of machined and unmachined surface of the workpiece.

1.3.2. Effect of Pulse off time (T_{off})

While EDM was performed with different tool shape, it was observed that longer pulse on-time was non-linear relation with MRR. It caused more chopping on the gap time duration, creating short. It also investigated that MRR linearly improved with pulse off-time as correct flushing of debris, but TWR decreases linearly due to increase in the tool area. Among all these tool shapes, a circular tool was preferred due to its high MRR and low tool wear (Sohani *et al*., 2009). Lakshmanan *et al*. (2013) used the RSM method for modeling of EDM of EN31 tool steel and also checked the model for its adequacy so to compare the process parameters with the responses for MRR. The second-order response models had also been confirmed with Analysis of Variance (ANOVA). They also tried to assess the optimal machining setting to generate the greatest probable response within investigational constraints. With the help of this study researchers and industries could develop a robust and reliable knowledge base and can also predict the MRR without experimenting with EDM process for EN31 tool steel.

Kiyak & Cakır (2007) examined the machining parameters on surface roughness in EDM of tool steel. The settings taken for this study were pulse current, pulse on time and pulse pause time. The tool steel used in the study was 40CrMnNiMo864 tool steel. They found that rough EDM application used one-fourth of the produced power with 16A of current, 6µs of pulse time and 3µs of pulse pause time as machine power. For finish machining, the power should be one-half of power at 8A of current and 6µs of pulse time and 3µs of pulse pause time. There was always observed the wearing of electrode surface during the EDM process. Because of pulsed current density, electrode surface quality decreased with increase in surface roughness of machined workpiece. The tendency of surface roughness on both were same for the similar pulse pause time.

The induced stress in drilling EDM was more sensitive to pulse current and pulse duration. This induced stress decreased because of the improvement of pulse-off length to a particular limit; after that, it was not affected with pulse-off length (Lee *et al*., 2004). An actual pulse-off time was linearly increased with active erosion area. The small erosion area changed the range of the discharge channel, erosion area, and the pulse frequency. The actual pulse off-time maintained non-linear relation with normal material erosion, but it also increased with a pulse on time. The tool wear rate improved with an increment of pulse off time and current, but it decreased with the increase of pulse on time. The surface roughness enhanced with the improvement of current and pulse on time, but it decreased with the increase of pulse off time. On the contrary, the MRR was directly related with an increase in peak current, spark energy, pulse on time (Reddy, 2016).

1.3.3. Effect of Pulse current (I_p)

This is the current permitted to per cycle in the machining process. For the machining of Inconel 718 alloy, a model was proposed which showed that both the increased value of pulse current and duty cycle improved MRR. The electrode wear revealed the non-linear relationship with the pulse on time resulted decreased in spark energy. The surface roughness improved parallel with current intensity and pulse time led to large craters (Daneshmand *et al*., 2013). While the comparative investigation of Ultrasonic Assisted Cryogenically Cooled EDM (UACEDM) and conventional EDM, it was noticed that the UACEDM provided lower EW and surface roughness and more MRR than conventional EDM. Conventional EDM provided high EWR, MRR and surface roughness with increased in pulse current than the UACEDM due to the formation of recast layer (Srivastava & Pandey, 2012). While EDM of special stainless steel, it was noticed that the improvement of only spark energy resulted in a higher value of MRR and surface roughness. In the EDM process, the other parameters are I_p, pulse interval, V_g and pulse width. As per the requirement of product surface finish and MRR, the surface roughness could be reduced from 1.6 to 1.7μm, and MRR improved from 10.5 to 13.3 mm^3/min (Tang & Guo, 2014). The mathematical modeling was proposed during EDM of tungsten carbide-cobalt composite, and multi-objective optimization of process parameters was done using the concept of desirability function. The effects of input process parameters namely pulse current, pulse on time, duty cycle and gap voltage were analyzed on the MRR, TWR. The obtained results were verified experimentally after performing confirmation tests; this ensured the feasibility and effectiveness of the adopted approach. The higher MRR could be obtained with a selection of greater pulse current intensities and duty cycle whereas lower surface roughness could be attained by setting a short pulse duration (Assarzadeh & Ghoreishi, 2013). The machining of D2 and H13 tool steel was performed using EDM process. It was observed that formation of cracks could be avoided within the specific range of voltage and pulse current along with pulse duration. Based on the experimental study, a comparative study of surface roughness, White Layer Thickness (WLT) and crack formation was done between the D2 and H13 tool steel. The surface roughness and WLT improved with increases of pulse current and pulse on duration (Lee & Tai, 2003). The dimensions of the random overlapping surface crater as well as the density and penetration depth of the cracks in the recast layer incremented with the spark energy. Based on spark energy and the primary state of the steels, several heat affected zones were observed. X-ray diffraction (XRD) was used to determine the high residual stress of tensile nature. Network cracks formation were resulted in high tensile stresses, exceeding the fracture strength of the material (Rebelo *et al*., 1998). The effect of major EDM parameters on the surface texture. 3D surface measurement and 3D surface characterization were analysed, and it was observed that pulse current was a most affecting factor for surface texture. On the other hand, the effect of pulse current and its equation on 3D surface roughness was minimal. It was found that the surface parameters were more sensitive to the process variables (Ramasawmy & Blunt, 2004). During the EDM of DIN 1.2080 and DIN 1.2379 using two special graphite such as Dura graphite 11 and Poco graphite EDMC-3, it was noticed surface roughness showed linear relation with pulse current due to more quantity of melted and suspended particle in the inter-electrode gap. The unfavourable erosion quality of Dura graphite 11 promoted surface roughness upon DIN1.2080 specimen. It was also noticed that lowering of the pulse current results elimination of microcracks formation because of high thermal gradient (Younis *et al*., 2015). During EDM process with new generator, when pulses current applied in both polarities but with a certain ratio, then better EDM results were obtained. This new generator could handle the generation of these pulses, regarding surface, amplitudes, and duration. These parameters could be separately picked and modified for both polarities. Experiments were performed to compare the performance and machining results with the current situation (Giandomenico *et al*., 2016).

The effect of pulsed current and electrode material on MRR, TW, surface roughness and diameter overcut in corrosion resistant steel viz. 316L and 17-4 PH during EDM were analyzed. Using various tool materials namely copper, Cu-W and graphite, it resulted that more MRR was attained with copper whereas Cu-W generated low tool wear, flat surface roughness and excellent dimensional accuracy. It was found that the MRR, electrode wear, and surface roughness improved with pulsed current during EDM. The favourable machining parameters for each material were then satisfied by using S/N ratio of the relative emission rate (Gopalakannan & Senthilvelan, 2012). The small value of pulse-on duration and a tremendous amount of pulse current reduced the induced stress. It was also observed that the high-stress concentration on the WL due to the presence of high chromium content (Lee *et al*., 2004).

The combined Ultrasonic Machine (USM) assisted EDM offered a significant advantage as compared with conventional EDM in the form of MRR, relative electrode wear (REW), surface roughness and a machined hole on magnesium alloy using titanium carbide particle in the dielectric fluid. The combined USM assisted EDM had more MRR, surface roughness, related electrode wear with raise the pulse current. The surface modification, as well as wear resistance in combined EDM, were comparatively more than conventional EDM because of titanium carbide particle (Chen & Lin, 2009). The aerosol emission rate and the MRR from a die sinking EDM process were experimentally investigated. The performance on three types of workpieces material viz. tool steel, mild steel, and aluminium by adopting Taguchi methodology for experimental design for suggesting an appropriate process for green manufacturing was discussed. It was found that there was a close relation between aerosol emission profile and material profile of workpiece materials and also significant variation in emission rate for comparing the emission for a variety of process parameters and combinations of both electrodes. The aluminium showed more relative emission rate with low pulse current because of its low melting point and high heat conductivity. Whereas the mild steel and tool, steel showed small improvement of relative emission rate with pulse current as raised of vaporization of the melted sample. It was also noticed that aerosol emission was inversely proportional to die electric level. It was pointed out that increment in dielectric level decreased MRR (Thiyagarajan *et al*., 2014). The influence of machining characteristics and surface modifications in low carbon steels during the EDM process using semi sintered electrodes were summarised. The machining characteristics such as MRR, Surface Deposition Rate (SDR) and Electrode Wear Rate (EWR) were included for analysis. Also with that effect of semi sintered electrodes on the surface modifications were evaluated by Electron Probe Micro Analyzer (EPMA), microhardness and corrosion resistance tests. The experimental results ensured the feasibility of process and also the natural formation of a modified layer on the machined surface (Chen *et al*., 2008). A combined hybrid ANN along with Genetic Algorithm (GA) model was utilized to optimize the machining process. This model considered different peak current and voltage and its effect on surface roughness (Rangajanardhaa & Rao, 2009). It was observed in the most cases that MRR showed a linear relationship with both peak current and pulse on time. The material removal is calculated as per Eq.1.1

$$MRR\left(\frac{mm^3}{min}\right) = \left(\frac{W_i - W_f}{7.8t}\right) \times 100 \qquad (1.1)$$

where W_i and W_f are the weight of specimen before and after the machining.

t represents machining time. The density of steel is 7.8 gm/cc.

It was also reported that the increase of pulse off time did not show much effect on both MRR and surface roughness (Annamalai *et al*., 2014). A proposed mathematical model revealed that the surface roughness enhanced with increment in pulse current. The improvement of WLT was observed as the rise of peak current due to improper flushing of molten metal. The average WLT increased with a pulse on duration results more stress (Bhattacharyya *et al*., 2007).The advantages of the linear motor into EDM die sinker based on Z- map method was explained. The current model was developed to calculate the minimum gap distance for sparks and to find the possibility of spark generation between the surface of the electrode and workpiece. The experiment was performed to study the relation between pulse current and pulse duration on the Ra and EDM conditions and to confirm the efficiency of the developed geometric model by predicting final machined surface topography (Zhao *et al*., 2004).

On the other hand, EDM of Inconel 718 with a copper electrode, it was noted that MRR improved with pulse current up to a certain point which led to an increase in spark energy. After that, it started decreasing due to high ignition delay. The copper electrode revealed less EWR due to longer pulse duration and more carbon deposited on the electrode surface. But pulse duration linearly increased with a surface roughness (Ahmad & Lajis, 2013). A small and lightweight synchronous converter equipped with EDM changed the frequency, duty cycle, and polarity. The surface finish was more excellent in case of the lighter frequency bipolar operating mode (Baizán *et al*., 2014). The current showed more influence on crater dimension than pulse on time. An empirical inconsistency regression investigation of these data generated average WLT.

$$AWLT\ (mm) = 148.5(I)^{0.4}(t)^{0.25} \tag{1.2}$$

This Average White Layer Thickness ($AWLT$) is calculated in Eq.1.2

$AWLT$ is measured in mm, *I* denote pulse current (A), and *t* is pulse on-time (µs). The thickness of the white layer relies on a single spark which was uniform in nature (Lee & Tai, 2003). The optimum response parameter (Electrode Wear) of EDM for die steel with electrolytic copper electrode was investigated. It was found that on increasing in pulse on-time and pulse off-time the EW (in terms decreased as a reduction of weight of the tool). On reducing the supply current, the EW decreases. It was observed that cylindrical copper electrode could be used for longer life of electrode without any redressing (Bundel, 2015). The thermal spalling method which was used for shaping of high melting point ceramics by EDM was studied. An expanding circular heat source created by enlargement of plasma was supposed which was acting on the surface. Also, it was found that thermally induced compressive stresses did the material removal by spalling through heating-up periods and tensile stresses in cooling-down periods. The spalling developed flakes with a thickness which was compared to the pulse duration. The outcomes were validated by the trial data on which large chips had the most significant depth and hardly any quenched spherical droplets of titanium of machined sample. This thickness and droplet were also predicted by the model (Gadalla & Bozkurt, 1992). The effects of the pulsed current of EDM on MRR, depth of cut, overcut, TW and hardness of EN31 steel was experimentally investigated. The electrodes were copper chromium and brass material. The workpiece was machined on EDM with varying pulsed current at positive polarity. From this experiment, it was found that depth of cut was better for copper chromium electrode as compared to brass and depth of reduction increased with increase in pulsed current for brass electrode while remained same for copper chromium electrode. Hardness and over cut was better for the brass electrode. The TW was less for copper chromium electrode, and MRR was more for copper chromium electrode at all values of pulsed current (Singh *et al.*, 2012). While the machining characteristics using a different shape of current impulse were discussed, It was noted that the use of rectangular current pulse always resulted in the more MRR and relative wear ratio due to maximum starting current and shortest current. Whereas trapezoidal current impulse decreased the relative wear ratio and MRR. The trapezoidal pulse form was preferred for machining of high melting point material like tungsten carbide (Tsai & Lu, 2007).

1.3.4. Effect of Voltage (V)

It is the potential supplied per cycle in the EDM process. In EDM process using water as dielectric, the material removal and thermal shock damage of machined surface were investigated. From this experiment, it was noticed that the improvement of MRR took place due to rise in pulse current and working voltage. But it decreased with the increase in pulse on time. The thermal shock induced cracks and lost grains in the machined surface. These cracks and grains damaged and reduced the strength of the product. It was also noted that the ceramic sample showed good damage tolerance capacity and higher Weibull modulus over brittle ceramic (Hu *et al.*, 2008). In this work, the performance characteristics in the EDM process of Al_2O_3+TiC mixed ceramic was modeled and investigated. The pulse current and duty factor (η) significantly affected the MRR. The value of MRR showed a nonlinear trend with the pulse on time. On increasing the current, duty factor and clear discharge voltage, the MRR increased. The EWR quickly decreased, on increasing pulse on time and after some time, EWR stabilizes. EWR declined on increased pulse current, but EWR expanded on increased duty factor and a clear discharge voltage (Chiang, 2008).

The EW and MRR of aluminium and mild steel using copper and brass electrodes on EDM was investigated. It was observed that the wear on electrodes was more along their cross-section compared to that along with its length. On increased the current and voltage, the EW increased. The wear in copper electrode was less as compared to brass electrodes because of higher thermal conductivity and melting point of copper. In machining of mild steel, the electrode wear was more as compared to that of aluminium because of the higher thermal conductivity of aluminium. The wear ratio increased on increasing the current and gap voltage. The highest wear ratio was obtained for EDM of steel with the brass tool, and highest MRR was obtained during machining of aluminium using a brass electrode (Khan, 2008).

1.3.5. Types of dielectric fluid and flushing

The EDM parameters for roughness were modeled by evolutionary programming method. In this model, different materials as electrode were used and with varying parameters of machining of EDM on powder metal was investigated. A model was developed, and mathematical relationship was established among process parameters and surface roughness with the help of GEP and artificial intelligence. It was found that the powder particle generates slighter unevenness as compare to all tool steels with similar parameters. The experimental result was very close to model predicted value for tungsten and graphite electrodes (Salman & Kayacan, 2008). A work for progress in polishing performance of traditional EDM with powder-mixed-EDM was studied. By using silicon particles in the dielectric fluid, crater diameter, crater depth, and the WLT were decreased. On increased the silicon content in the liquid, the crater dimension reduced slightly. Short-circuiting raised for a higher concentration of powder that caused the structure of deep valleys in a matrix completed by even discharge craters. The performance of the polishing regimes was affected by the dielectric flow rate when the silicon fine particles were used, while in conventional

EDM dielectric, the flushing flow rate did not show the effect in the number of abnormal discharges. It was also found that the dielectric flow rate minimizes the surface roughness for every tool area but high flow rates, there was no positive result observed in the surface morphology. Using small flow rate, abnormal discharging occurred in the roughing and finishing regime (Peças & Henriques, 2008).

Tzeng & Lee, (2001) identified the use of PMEDM process to machine the EN31, H11, and die steel metals. An appropriate relation was found in between tool and powder which were used in a dielectric medium. Although the tool separately did not show any influence on material erosion both tool and particles in dielectric fluid showed considerably affect on material erosion. The surface roughness was extensively influenced by process parameters, types of tool and sample and powder. EN31 revealed the highest MRR among all samples for same process parameters. The combination of copper and aluminium particles in PMEDM process enhanced the MRR. The fine graphite particles showed smaller MRR and better surface finish on EDMed sample. The die steel needed more pulse current and pulse on time for machining purpose. Therefore, die steel showed better surface finish with the combination of copper and graphite powder in the EDM process. The H11steel resulted in smaller MRR as compared to EN31 steel but large than die steel for same process parameters. A model using RSM as well as investigation of the resolidified layer of spheroid graphite cast iron was presented. It was observed that the layer thickness improved with the increment of amount and area fraction of graphite elements, while it reduced with the larger diameter of the graphite particle. The continuous ridges were exhibited on the rapidly re-solidified layer on the EDM surface. The ridges density increased with increasing the amount, and area fraction of graphite elements and more ridge densities helped the quantity of discharge density (Chiang *et al*., 2007). The EDM of titanium alloy with cryogenic cooling resulted in the reduction in EWR. titanium alloy, with and without liquid nitrogen by copper tools, was machined on EDM. It was also observed that the liquid nitrogen reduced the temperature of the copper tool so minimized its melting and vaporization. The cooling effect of liquid nitrogen enhanced the electrical and thermal conductivities of copper. Due to an increase in thermal conductivity, more heat transmitted from the copper tool reduces its wear. The investigational results showed that for any of the values of the machining parameters, there was a reduction in EW and better surface finish (Abdulkareem *et al.*, 2009). A combined machining method using electrorheological (ER) fluids for EDM had been developed. From this performance, it was noted that the machining process could also be carried out in the ER fluid. On increasing concentration of starch and aluminium, the discharge frequency, the pulse number decreased at a constant period. On adding more starch and aluminium powders, the discharge efficiency decreased other than more polishing process time. Without the use of abrasive Al_2O_3 as the working fluid, using ER fluid of starch particle, improved the roughness a little. On increasing the abrasive in the ER fluid surely showed the polishing effect to increased the surface roughness. It was also revealed that the roughness by using the ER fluid with aluminium powder of 0.3μm was increased to Ra 0.06μm for discharge capacitance of 0.01μF, and no crater was noticed (Tsai *et al.*, 2008). The effect of a dielectric of urea solution in water on modifying the surface of titanium was investigated. It was found that on mixing urea into distilled water, MRR and EWR increased with enhancement of peak current while MRR and EWR decreased on increasing pulse duration. On adding urea in the dielectric, the surface roughness worsens with a higher in pulse current. The higher value of pulse current generates more discharge energy and high impulsive force which was acted so removed more molten material and generated deeper and larger discharge craters. The surface modification of clean titanium metals was straightforward and no need for particular equipment as required in other conventional methods (Yan *et al.*, 2005). In this experimental, the EDM of CK45 steel with Al–Cu–Si–TiC composite tool which was prepared by powder metallurgy (P/M) technique was investigated. The composite P/M tool offered more achievement in the MRR, TWR, and microhardness of the machined component. The pulse current was observed as an essential parameter affecting both MRR and TWR, while dielectric flushing pressure did not show any influence on MRR and TWR. The sensitivity of the composite tool for pulse current and pulse on time was noticed more as compared to the conventional electrode. In case of multi-response optimization, it was found that the higher MRR and lower TWR were obtained at the setting of the peak current of 6A, flushing pressure of 1.2 MPa, and pulse on-time of 182μs and TiC percentage 18% (El-Taweel, 2009). The influence of the good finishing process parameters on microholes in abrasive fluid machining (AFM) was investigated. Micro-holes on stainless steel and titanium alloy plate was fabricated using a deep drilling machine of EDM before AFM. The AFM process was used to enhance the surface finish and shape precision of micro-holes which was machined with EDM. The machining time most significantly affected the MRR during AFM process. The optimal abrasive grain size of 20μm was used to achieve high MRR in the EDM process (Lin *et al.*, 2007). The probability of nitriding steel machined by sinking EDM was demonstrated. The dielectric medium consist of urea and deionized water resulted in the surface hardening of steel specimen. In this study, it was revealed that the urea content did not affect the surface morphology of the EDMed surface. Nitrogen concentration reduced with the distance from the machined surface. The average thickness of the nitride layer was found 23μm. Due to high temperatures and small discharge periods engaged in the process, the nitriding mechanism was guessed to be particular to EDM (Santos *et al.*, 2016). The tool electrode wear ratio using the spectroscopic measurement of the vapour density of the tool was discussed. The deposition of the thicker carbon layer on copper anode lowers the copper density, i.e. the carbon layer shielded the copper anode wear. The evaporation rate was drastically high rate soon after the dielectric breakdown on using copper as an anode. On using copper as a cathode, evaporation of copper was smaller than when used as anode due to more discharge power distribution at the anode (Kunieda & Kobayashi, 2004). The utilize of a steel-toothed wheel as the instrument tool to machine silicon carbide ceramic by electric discharge milling was investigated. The procedure demonstrated high MRR. Moreover, utilizing a water-based emulsion as a dielectric fluid, the hazardous gas isn't produced amid machining, and it demonstrated a decent working ecological practice. The smaller pulse span and pulse interim, high voltage, pulse current, and positive tool polarities were reasonable for electro-discharge processing of the silicon carbide ceramic. The material from the tool can exchange to the silicon carbide workpiece, and a blend response happened amid electro discharge processing of the ceramic (Ji *et al.*, 2012). The target of this experimental work was to optimize the process parameters during the EDM of carbon-carbon composites. The process factors influencing EW rate and MRR, as indicated by their relative significance, are V_g, I_p, and T_{on}, individually. The pulse on time was insignificant. The optimal EDM setting for terminal wear rate, with average decreased of 89.28% from the current average estimate of 0.056 mg/min, was pulse current (1A), pulse on time (150µs) and gap voltage (20V). While the equivalent for MRR, with an increment of 116.67% from the current mean estimate of 0.09mm^3/min, was pulse current (9A), pulse on time (750µs) and gap voltage (100V). The optimal states for the two reaction capacities were unique. It demonstrated that process parameters maintained their optimum levels have a remarkable enhancement in the response functions, which might be verified by the extra tests (George *et al.*, 2004). A unique thermal model which was fitted for simulating discharge superposition and showing machined surfaces was investigated. The model created machined surfaces by figuring temperature fields inside the workpiece utilizing a finite difference based methodology and considering the effect of following releases. In light of the proposed thermal model, reverse assurance of attributes of the release was performed. For the considered erosion system discharge process was described by a plasma channel diameter of 255µm, the power transmission to the sample of 18.8% of the aggregate pulse energy and a material discharge efficiency of 29.4%, alluded to the aggregate sum of melted material. It would be conceivable to discover estimations of the characteristics of the discharge, and consequently accumulate exceptionally accommodating data. When performing re-enactments utilizing the optimal information esteems the mistake in the expectation of surface complete which was under 6% and the error in the forecast of MRR was lower than 3% (Izquierdo *et al.*, 2009). During the Electro Discharge Abrasive Drilling (EDAD) of tungsten carbide P20 and mold steel HPM 50 using metal matrix composite rotator electrode, it was reported that the MRR and front gap showed linear relation with the current. The machining of composites using uncoated SiCp electrode results lowered tensile strength than that of machining of composites with electroless copper plated silicon carbide electrode. The EDAD using rotating composite electrodes showed lower MRR than pure wire. Overall, the Electro-discharge Abrasive Drilling (EDAD) showed better MRR and SR than EDM (Shu *et al.*, 2006).

A thermal model had been created for the assurance of the MRR and the average surface roughness accomplished as a function of the procedure parameters. A theoretical thermal model was planned for the recreation of the EDM process. The

MRR and average surface roughness could be resolved with an average deviation of 8.2% and 6.1%, individually. The variances were credited to the suppositions presented amid the improvement of the model, i.e., the disregard of the recast layer's development and the presumption that the idle time was irrelevantly contrasted with the discharge time (Salonitis *et al*., 2009). An improvement of a thermo physical model to bite the powder EDM process utilizing limited component technique (FEM) was reported. The discharge voltage was a vital procedure parameter, which oversees the thermal transition connected on the electrode surface. The MRR was revealed to increment with the discharge voltage. Larger estimations of discharge voltage increment the transition thickness which created more prominent material removal and the tool wear. More important opinions of discharge voltages were prescribed for roughing application. The cavity shapes anticipated by our model were observed to be more practical and near to the exploratory outcomes when contrasted and those announced before by the logical investigations. The computed MRR (mm^3/min) is shown in Eq. 1.3

$$MRR\left(\frac{mm^3}{\min}\right) = \left(\frac{60\times C_{VT}}{t_{on}\times t_{off}}\right) \tag{1.3}$$

Where C_{VT} is the material eroded per discharge pulse, t_{on} pulse on time and t_{off} is pulse off-time. The results predicted by their model were validated with the trial data. The created thermo-physical model could be utilized to complete broad parametric examinations to comprehend the EDM procedure execution without going for real tests. The model could be used related to Artificial Intelligence (AI) instruments and streamlining strategies to acquire process conditions for optimal EDM execution (Joshi & Pande, 2010).

The copper electrode was utilized in EDM of tool steel with the goal of deciding conceivable relationship among pulse current, MRR, and EW. It was presumed that the most excellent execution was given by a tool with a diameter of 20 mm at pulse current (6.5A). This arrangement provided the most astounding MRR and the least wear rate. The MRR and EW relied upon electrode diameter and flow. At current setting at 3.5A, the material erosion diminished directly from the littler electrode distance across (9.5mm) to the larger electrode diameter (Haron *et al*., 2001). The effectiveness of EDM for silicon single crystals was enhanced by diminishing the contact resistance between the silicon single crystal and electric metal feeder. To reduce the contact resistance, the correcting contact between the silicon wafer and metal was altered into an ohmic contact. On account of the p-type silicon, the contact surface of the silicon wafer was plated with aluminium by vacuum evaporation, and aluminium was doped into silicon by the diffusion procedure. To achieve an ohmic contact between the n-type silicon and metal, Sb–Au was utilized instead of aluminium. Exploratory outcomes demonstrated that the machining rate could be enhanced significantly by changing the correcting contact into an ohmic one. The correction nature at the interface between the circular segment plasma and silicon wafer was likewise affirmed. In the machining, the p-type silicon, release happened just when the extremity of the p-type silicon was sure. In actuality, for the n-type silicon, the machining rate was more when the extremity of the n-type silicon was negative (Kunieda & Ojima, 2000).

The multi-start EDM was recently created to get higher removal rates and lower energy utilization contrasted and traditional EDM. In multi-start EDM, one release happens in the hole between one tool and the sample, and another version occurred in the meantime in the rift between the other tool and example. To adjust the removal rates in both gaps, the extremity of the beat generator was changed adaptively to level the hole voltages estimated at both gaps. The MRR and energy effectiveness of Multi-start EDM were impressively larger than those of regular EDM. The tool wear proportion of multi-start EDM was lower than the number-crunching mean of the tool wear proportions of the single positive tool electrode and single negative tool electrode of regular EDM. There was no unique distinction in surface roughness between multi-start EDM and regular EDM (Kunieda & Muto, 2000). The effect of ultrasonic vibration of the tool in electrical-release machining of established tungsten carbide could be condensed as pursues Ultrasonic vibration of the instrument gave pressure variety bringing about improved flushing state and less demanding ionization of the start hole. The MRR of the ultrasonic helped electro-release machining was appeared to be up to four times more than the MRR of the conventional EDM for little pulse lengths and low release flows. The ultrasonic helped EDM permanently diminished arcing, short out and open circuit beats and diminished the start postpone time, along these lines expanding the number of ordinary pulses and average pulse energy. The tool wear proportion of the ultrasonic helped EDM was more than the tool wear proportion of conventional EDM. The surface roughness estimated of the ultrasonic helped EDM was marginally more significant than the SR estimated for ultrasonic EDM. The ultrasonic helped EDM was handy for machining of metallic composite materials with a high level of carbon content and distinctive component composition with various melting points (Abdullah & Shabgard, 2008).

EDM selecting optimum process parameters could machine aluminum-based composites, to be specific, release current, pulse on time and flushing pressure the viability of processes like MRR and EWR could be progressed. An attentive examination concerning the surface of the EDMed sample after the machining proposed that ceramic particles were not melted amid the procedure and expulsion of material happened because of matrix melting and ceramic molecule haul out from there on. This resulted in the decreased MRR with the expanded TiC content in the composite material. The MRR and tool wear rates were affected by the pulse current. Flushing pressure assumed a vital job in proceeding with the procedure and enhancing the MRR at higher pulse current and pulse time levels (Senthilkumar & Omprakash, 2011). The after effects of pertaining smaller-frequency vibration demonstrated that the vast majority of the MRR got from the machining with small-vibration were higher than in machining without vibration, particularly at a setting of frequency 600 Hz and amplitude of 0.75µm. The MRR demonstrated an expansion of about 23%. The use of smaller-frequency wave has made a more continuous and brief separation between the electrode and specimen. It likewise upgrades the flushing effect and enhanced dielectric diffusion in an inter-electrode gap. The resulted SR and TWR estimated from the EDM process with no vibration were higher than in EDM process with low-frequency vibration. In this way, the use of low-frequency vibration could be utilized to build the MRR and reduced the SR and TWR (Prihandana *et al*., 2011).
The cutting of Austempered Ductile Iron (ADI) material by EDM-sawing was appeared to be a smart strategy. A semi-empirical articulation was recommended to develop the optimal MRR, EWR and SR zone for different crest flows or pulse duration under various conditions. EDM-sawing with a pitch tool could give a surmised steady machining rate and a little profundity effect by the EDM working procedure contrasted with not utilizing a pitch tool. EDM-sawing with a six-pitch

electrode at a $2.5X10^4 ms^{-1}$ responding development was confirmed from the observed outcomes to accomplish a more material erosion rate and a low SR than those got with no utilization of a pitch electrode (Wang *et al*., 1999). From the comparative study of various EDM models namely Snoeys, Van Dijck, Beck, Jilani, and DiBitonto, it was reported that DiBitonto model showed energy collection from 0.33 to 952mj and produced the closeness of 1.2-46.1 in terms of MRR. This MRR was good agreement with experimental data as compared to another model. The discussed disk heat source model could be used for the improvement of heat flux and energy fraction (Yeo *et al*., 2008).

The EDM material removal components had been contemplated for three industrially accessible composite fired materials. ZrO_2-based, Si_3N_4-based and Al_2O_3-based ceramic materials, with increments of electrical conductive stages like TiN and TiCN, had been contemplated in detail. This attempt brought up that other than the average EDM material removal components, for example, melting/dissipation and spalling, different systems could happen, for example, the oxidation and decay of the base material. The last mainly happened in wire EDM of Si_3N_4–TiN when utilizing de-ionized water. Additional, the spalling effect was ended up being unequivocally identified with the arrancrystalent of breaks. The breaks on itself depends, among different elements like thermal conductivity of the material, softening point and quality, on the breaking toughness of the article. In this regard, spalling was not perceived in the EDM of ZrO_2–TiN which has a more significant fracture durability esteem, contrasted with the other examined materials (Lauwers *et al*.,2004). The consequences of this exploration demonstrated that the MRR and the workpiece SR were specifically reliant on the workpiece hardness. This was exhibited by the mathematical models utilized in the experiment. The consequences of this examination demonstrated that the MRR was subject to the workpiece hardness and its collaborations with the particular case of the cooperation between the workpiece hardness and the crash cycle. The MRR was anticipated with the common blunder of 1.06%. It was additionally exhibited that workpiece surface roughness was reliant on the workpiece hardness and other parameters. The added substance display predicted the workpiece surface roughness esteemed with the common blunder of 0.4%. All in all, this learning exhibited that the electrical release machining process wasn't just affected by the thermal properties of the workpiece yet also by its hardness (Liu *et al*., 2009; Marafona & Araujo, 2009).

With the end goal of the creation of a miniaturized scale gas turbine impeller, an inside and out an examination of the EDM of Si_3N_4–TiN utilizing different pulse shapes was exhibited. Iso-enthusiastic and unwinding resulted in various machining practices on MRR and TW. Using sinking EDM, iso-vigorous pulses could generally offer even surface with smaller machining time yet high TW and debased flexural quality. In opposite, utilizing unwinding beats gave less TW and fulfilling machining speed, however, left a rougher, frothy and permeable best surface layer with no imperfection into mass material. The distinction in the surface was identified with the happening material removal systems (softening, decay and oxidation), which were to a great extent affected by pulse compose and its related pulse parameters (mainly beat length). By taking favourable circumstances of the distinctions in machining exhibitions utilizing diverse release pulse shapes, an EDM machining technique was created where roughing depended on an unwinding compose pulse and completing dependent on an iso-lively pulse compose. The established system had effectively been connected to machine a small scale gas turbine impeller, for which a decent machining time, excellent surface quality and geometry exactness was acquired (Liu et al., 2009). The ZrB_2–Cu composite tool had been created for EDM ponder. The ends dependent on the different exploratory outcomes were condensed beneath. The ZrB_2– 40 wt.% Cu composite device demonstrated more MRR with reduction tool removal rate over ultrasonic copper tool. The average surface roughness of hardware surfaces and diameter overcut created on the sample were observed to be more for ZrB_2–40 wt.% Cu composite tool than copper device. The EDMed surface of hardware demonstrated nearness of agglomeration of the exceptional molecule, porosity, and so forth. There was a noteworthy measure of mass transfer between the electrodes. The ZrC was shaped on the composite tool surface while held austenite was seen on the workpiece surface. The copper tool surface showed the advancement of favoured introduction amid the EDM (Khanra *et al*., 2007). The target of this examination was to explore the effect of EDM input parameters on the qualities of the EDM process. Achievability of the EDM process for tempered steel 316l by utilizing copper impregnated graphite tool had been demonstrated. All setting chosen for the trial, pulse current, pulse on time and pulse off time were critical variables. The servo voltage did not have essential effects to the EDM reactions in response surface methodology. Numerical models created to foresee the different machining attributes are measurably legitimate. The quadratic models were acquired and noteworthy for MRR, EWR, and SR. The dimensional accuracy reaction fitted for first request display or straight condition. The edge error got from all responses considered in this exploration work which were altogether acknowledged as the outcomes inside estimated interim and below than 15 %.

The goal of this examination was to explore the effect of EDM input parameters on the depth of cut should set no less than 5mm rather than 3mm before getting more exact information particularly for electrode pressure. Workpiece surface trustworthiness, for example, recast layer, thermally influenced zone, microstructure and smaller scale splits ought to be explored likewise for better comprehension of EDM marvel. With the end goal to get an optimal situation for EWR and SR, it was recommended that appropriate screening of scope of parameters ought to be completed. Others factors affecting EDM machining reactions, for example, fly flushing, a dielectric liquid, and so forth ought to be examined (Sharif *et al*., 2015). The trial thinks about for the most part spotlights to research the effect on EDM process performed utilizing electromagnetic attractive field setup. The use of electro-attractive field indicated exceptional increment in the MRR by 25.7% over traditional EDM. The chart esteemed for MRR uncovers that, by the utilization of attractive field force from low (0.4T) to medium (0.8T), the MRR increments from $78.25X10^{-3}$ to $89.207X10^{-3}$ (mm^3/min), yet in the event that the attractive field power achieves high (1.2T) at that point it declined to $85.3031X10^{-3}$(mm^3/min). The patterns demonstrated that surface roughness increments with current and pulse on time, yet with increment in the pulse of the time, it wasn't abundantly influenced. The pattern esteemed for surface roughness uncovers that, by the use of attractive field power from low (0.4T) to medium (0.8T), the surface roughness diminished from 3.9202 (μm) to 3.3429 (μm), yet on the off chance that the attractive field force achieves high (1.2T) at that point it increments to 4.1517 (μm). Expansive size of released holes was seen at first glance machined by conventional EDM, while the measure of holes diminished because of the use of electromagnetic field (Naidu, 2014). The effects of rotational tool and EDM input parameters incorporate; pulse on time, pulse momentum, pulse off time and voltage, on yield parameters, for example, MRR, surface roughness, and TWR were explored for NiTi composite with using the copper tool and deionized water as a dielectric. The tool electrode insurgency was considered as 200 rpm. The yield parameters of rotational and conventional start were noted. Consequences of this examination showed that paying little mind to the rotational device, the most critical and compelling parameters in MRR were pulsed current and pulse on time. At the point when the pulse current and pulse on time increment, the start energy improved and subsequently, MRR increments too. The MRR for NiTi combination in the rotational start was not as much as the customary start. The principle reasons for diminishing the MRR in rotational start were diminishing the dielectric resistance because of hardware turn, and expanding the machining hole and also upgrading the plasma channel width. As indicated by the consequences of exploring the surface roughness in the rotational and customary start, it had been cleared that by expanding the pulse current and pulse on time, surface roughness increments. Electro release cavities of rotational start were less because of electrical bend persistent development and the surface roughness in the rotational start was not as much as the normal start. Notwithstanding instrument revolution, by expanding the pulse current and voltage, TWR increments. The tool electrode turn was directed to change more thermals to outside from the hole between tool electrode and workpiece. In other words, diminishing the electro-discharge limit on the tool electrode surface, so the MRR in the rotational start was not as much as the normal start. Subsequently, tool turn with 200 rpm was directed to diminishing the MRR and enhancement of surface roughness and TWR (Daneshmand *et al*., 2013). The implementation of piezo-unit in more temperature materials which was then situated at 0 Hz to 1000Hz and amplitudes from 0μm to16μm was discussed. These piezo actuators and charge enhancers were selected from the market. The planned piezo unit for EDM process could be utilized viably in a blend with the fitting handling innovation to acquire lifted material erosion and diminished tool EW. The relative tool EW diminished up to 21%. The MRR was enhanced by 11%. Large vibration frequencies and lower amplitudes raised the EDM efficiency. These upgrades lie on the enhanced flushing situation, which prompted the enhancement of process steadiness. It was expected, the number of circular electrical

segments could be decreased narrating the longitudinal vibration of the electrodes. The TW was pointed in these trials, implying that the longitudinal vibration could affect decidedly the tool wear amid the EDM of deep holes. A multi-step innovation could be tried later on further enhancement of material erosion and EW (Uhlmann & Domingos, 2013b). This examination demonstrated the conceivable productivities, TW and surface characteristics in handling γTi aluminides with the assistance of EDM. The graphite electrodes utilized which had a thin front surface. The pits were like those utilized for seal spaces in turbine sharp edges. The γTi aluminides had unique machinability by EDM forms dissimilarity with average titanium compounds.
The tool wear had been distinguished to be below 2%. The MRR was seemed similar in both nickel compounds and titanium-based alloy. Geometric exactness experiences tool wear on the device edges and could be streamlined particularly by utilizing new tools for completing advances and utilizing planetary disintegration completing methodologies (Klocke *et al*., 2014).

With the end goal to increase new bits of knowledge in electrical discharge machining process (the dust sinking EDM, wire EDM, EDM penetrating variations), particularly in meso-smaller scale sinking EDM (region:10mm^2-0.1mm^2), rapid imaging (up to 500'000fps) of the procedure was joined with electrical process motions in a period synchronized way, for semi-genuine disintegration conditions. The procedure understanding determined by connecting the visual and electrical data of the flashes and hole area alongside the release cavities empower next level of versatile process control in high accuracy EDM (Maradia *et al*., 2013). It was noticed that the tool wear measurement of graphite was difficult because of its porous nature and more weight. The trials revealed that the material should be electrical conductivity which was used for the EDM process. The increment of electrode mass was narrated by a huge drop of the sample material at the edges of the tool with the setting of certain parameters (Klocke *et al*., 2013). Then the artificial bee colony algorithm was used in the EDM process to achieve optimal MRR and SR. The MRR enhanced with a decrease in pulse off time because of the narrow plasma channel and less amount of spark energy absorb by specimen. The MRR decreases with voltage due to more gap width which is resulted in less energy transfer to the machined surface. Remarkably increase of pulse current due to the formation of the more massive crater on the EDMed surface offered more surface roughness (Das *et al*., 2014).

Taguchi dynamic approach integrated with model had been introduced in the development of robust EDM to improve the machining precision and accuracy optimization EDM process. While a powder mixed rapid EDM method was used for machining purpose, It was found that powder particles did not show any significant effect on machining accuracy (Tzeng, 2008). There had been established a good agreement of machining time in both experimentation and industrial application. This machining time estimation depended on the reference value (Lauwers *et al*., 2010).

Multi-stage planetary EDM was an effective alternative used in finishing operations to reduce machining time and electrode costs. Various strategies could be employed keeping the amount of material to be removed into perspective. The roughness values could be increased by changing the work time, often resulting in increased machining time. The technique used should be altered by including the compensations concerning EW and thermal deformations, for both in the workpiece and tool. This results in the possibility of getting dimension tolerances within 0.01mm. It was probably to calculate thermally induced distortions on both electrodes (Sanchez *et al*., 2002). The application of EDM in the surface variation of steel by employing particularly prepared P/M tools was discussed. In this comprehensive preliminary investigation, a wide range of material transfer rate was obtained in various parametric situations. The sizeable average layer thickness was observed on the EDMed surface. The observed surface roughness on the machined specimen was 3 µm to 15µm. At a specific parameter, there was a better drop of material erosion was found. The layer was consist of tungsten and its carbides, along with iron and copper. This layer showed more hardness than the parent material. In the vicinity of the hardest zone, the microhardness varies in the range of 9.81-12.75 Gpa. It yielded an average SR of 10µm which was much more than the adequate limits. Otherwise, this value could be reduced by surface grinding of the deposited layer and hence, a soft surface could be obtained (Patowari *et al*., 2011). Three variants of microstructures-equiaxed, bi-modal and coarse lamellar were obtained using titanium alloy. The EDM had a high peak current (29A) was carried out for imposing SR and surface modification on the machined sample.

The Scanning Electron Microscope study revealed a martensitic surface layer and subsurface heat affected zone on EDMed specimen. An EDX measurement also revealed the carbon enrichment on the EDMed surface. Rotating bending fatigue tests of samples showed that fatigue performance was deficient and independent mainly on microstructure. The bi-modal microstructure depicted a little superior large cycle fatigue presentation. Further, this test could be progressed through an appropriate heat treatment process (Stráský *et al*., 2011). Three variants of electrode materials viz. copper, graphite and tungsten carbide were taken for investigating the influence of electrode material on quality of blind holes machined using sinking EDM. Three current conditions, i.e., 5amp, 8amp, and 10amp were taken for investigating on workpiece AISI p20 whereas surface roughness, axial error and diameter error are picked as the dimensions quality. The copper yielded the best surface finish for blind holes among the electrode variants nearly followed by graphite. The graphite proved the best electrode material for dimensional accuracy. The graphite yielded the least values of the diameter (axial error, diameter error) .The graphite as an electrode was the most suitable tool by stated performance among all the variants of electrodes (Khan *et al*., 2015).

The results depicted that the value of the surface roughness was expressed mostly by the pulsed current and duty cycle. A brass alloy sample was machined by optimum parameters and was noticed the low mean surface roughness in comparison to the A6061-T6 workpiece. The optimum parameters established using the Taguchi design methodology have great applicability to the EDM machining about aluminum and brass alloys (Chen *et al*., 2013).

In order to seek the EDM of MDN 300 steel, Taguchi optimization method was used for experimentation. The obtained results showed that pulse current, pulse on time and pulse off time plays a vital role in the EDM process. Further, it was observed that the optimum levels of the factors for surface roughness and lower pulse tool wear rate are same. While it was different for material removing rate and relative wear ratio, the ANOVA notified that pulse current was more prominent parameter than pulse on time for MRR and TWR; while pulse on time was more critical than pulse current, relative wear ratio and surface roughness. On the contrary, the pulse of time was less significant among all performance characteristic considered. The EDMed surface investigation showed that at higher pulse current and large pulse duration provided a rough surface with more craters, and debris as compared to smaller pulse current and smaller pulse on duration (Nikalje *et al*., 2013).

The wire brushing process was an appropriate finishing method for EDM of components. This method showed the variation of residual stresses from tensile to compressive. It stabilized the crack networks formation on machined surface and improved the endurance limits of parts. The realized progress of this method was the same to those parts which were prepared by the shot penning method. These crack networks were removed by polishing and wire brushing process of the samples which were collected by EDM. In this case, the realized improvements were approximately 70% and 75% as compared with the EDM condition for polishing and wire brushing. It became probable due to polishing mitigates entirely the branches of cracks obtained by the machining process and introduces compressive residual stresses to EDMed sample planes that were magnified by the use of the wire brushing (Ghanem *et al*., 2011). Numerical investigations and experimental metallurgical studies confirmed that the movement of anodic tungsten carbide, to the surface of the machined sample. The tungsten carbide coated tools showed better wear resistance yet under the excessive pressure as well as temperature situations faced in the metal cutting process. 25% to 60% enhancement in abrasive wear resistance and 20% to 50% decrease in cutting forces were noticed with tungsten carbide coated tools (Shunmugam *et al*., 1994).

It was observed that the defects on the machined surface due to thermal stress. It was also noted that silicon layer deposition on the alloyed layer increased the thickness of the alloyed layer (Stambekova *et al*., 2012). The EW was obtained from the bombardment of either electron or positive ion. A positive electrode, the electrode wear produced due to the attack of electrons. On the other hand, at the negative electrode, the electrode wear was created due to the bombardment of positive ions. When negative or positive ions collide on the electrode surface, it generated heat. Again, this heat melts and vaporize the electrode material, and material erosion took place. This removal of material is known as electrode wear (Jameson, 2001).

In the EDM process, Taguchi methodology was used to ease the discovery of EDM parameters of input and improvement in the electrode wear ratio. The magnitude of interaction could be used safely in a robust design. The orthogonal array was used to provide countermeasure. The knowledge of product which showed the relations of EDM process parameter with effect on EDM response provided the black layer composition. This composition contributes to changes in thermal conductivity of copper tungsten tool which further added to the improvement in the electrode wear ratio (Marafona, 2009).

An electro plastic effect, generated by large density current was used to progress the formability of bulk material by a new embossing process. The process experiment and FEM simulation analyzed the electrically assisted embossing method and the conventional method. This simulation was verified by a comparison between experimental and simulation result. The inferences drawn from this result was an increment in the plastic deformation of workpiece and reduction in residual stress. Additionally, this result highlighted the feasibility and advantages of embossing process of electrical resistance (Mai *et al*., 2013). This attempt stated that after specific cycle dielectric alters into waste was found to be a significant crisis which led to economic as well as economic impact. The samples which were collected from the company for the estimation of total waste were machined using EDM activities. So results came out to be very alarming in term of pollution condition. This inference could be used by the manufacturer of dielectric to manufacture environmental friendly dielectric. Dry EDM and EDM with water were considered to be another alternating method (Abbas *et al*., 2012).

The improvement in the machinery efficiency and the reduction in TWR was made by shutting off harmful pulses. Further increase in the machinery efficiency could be done by sweep pulses in which TWR which was higher as compared to the above method. The quality of small drill was better in shutting off bad vibrations as compared to regular pulses. The shutting off harmful pulses and sweep pulses could be used to obtain high aspect ratio small holes (Jiang *et al*., 2012). When multihole electrode like copper and chromium used in EDM, it was found that the hardness of machined specimen was more for aluminium as compared to copper chromium electrode. The copper chromium electrode generated less electrode wear and good MRR as compared to aluminium electrode (Singh, 2012).

Hardness is one of the most significant measurement of EDMed products in a die manufacturing industry. Usually, more hardness and excellent impact resistance were needed on the surface of machined products (Abdullah *et al*., 2009). The wire EDM using the concept of RSM, it was confirmed that the WL depth enhanced with a higher value of pulse on time in the first cut. However, it decreased with pulse time in trim cutting. The WL depth also felled down with a lower value of wire tool offset in trim cutting. Also, the WL depth showed the nonlinear improvement cutting speed in trim cutting (Puri & Bhattacharyya, 2005).

The WL was observed on the EDMed surface in the machining process. This experiment deals with this WL in the following dimension such as the effect of sample material, a variety of dielectric fluid, metallographic phase of this layer and electrode material. The material used in the test is Impax C35 and Armco. The carbon content observed of white layer of the EDMed surface are more in oil dielectric as compared to the base metal. The C35 EDMed sample in water contains (about 50 %) a lesser amount of carbon as compared to the base material. The carbon formed iron carbides in the WL. The WL was the composition of dendritic structures (Kruth *et al*., 1995).

The black layer characteristic and electrode wear ratio in EDM was studied. The major constituents of the black layer were carbon and iron. The equivalent carbon contains vanadium, molybdenum, and chromium and carbon from the cracked oil carbon. Also, it was noticed that electrode wear ratio decreased on increasing the percentage of equivalent carbon. The equivalent carbon varied on the electrode surface in machining. The equivalent carbon which was smaller at the start of machining compare to end of machining on EDM, and it showed the formation of the black layer. The patterned black layer decreased the TWR (Marafona, 2007).

A semi-empirical approach was used for studying the residual stresses in EDM. The layer removal technique which was used to measure the residual stress profile. In this method, the stress was considered as the function of depth near the surface developed by die sinking EDM. High tensile residual stresses generated in EDM and enhanced from the surface and reach to the highest value (equal to the around the ultimate tensile strength). The residual stress decreased suddenly for low values of compressive (Ekmekci et al., 2006). A gage method was used for measuring the residual stress in EDM hole drilling. It was found that as the relative stability coefficient of the discharge duty ratio was reduced, the recast layer thickness and induced stress both increased. This coefficient of the discharge duty ratio should be more significant than 0.99 for measuring residual stress in a specimen by strain gage method. On using the hollow tool, the elimination of debris and dirtied dielectric in the machining area was improved and consequently the relative stability coefficient of the discharge duty ratio increased, and the hole-drilled induced stress decreased. On expanding the pulse off time, the hole drilling induced stress decreased (Lee & Liu, 2009). When machining was done with hydrocarbon-based dielectric liquid, it resulted into saturated surface independent of tool electrode material. When machining which was done with de-ionized water dielectric liquid, it resulted into the formation of austenite phase which was affected by the supply of carbon from tool electrode. The increase in non-homogeneities on material surface led to the rise in the white layer (Ekmekci, 2007)

Finite element model was proposed by incorporating random discharge to investigate the residual stress in the EDM process,. This similar profile was seen in local in-plane residual stress. The same characteristic of residual stress which was seen in the subsurface of the machined specimen. The maximum residual stress was noticed in the subsurface as a substitute of the top surface. Lower tensile residual stress was achieved due to lower spark energy (Liu & Guo, 2016). The measured stress observed on Al2014 T6 alloy surface was tensile nature. With the increment in cutting speed, residual stress and surface roughness value also increased. The formation of the intermetallic phase was done with the help of generated spark energy. The result comes out to be 405.6MPa which were a smaller amount as compared to the ultimate tensile strength of the material (Rao *et al*., 2016).

1.4. The need of fast and Non-Destructive Technique.

The residual stress measurement offers many advantages in industry and research and development. This residual stress measurement mainly falls into four categories: Neutron Diffraction, Hole drilling, X-ray diffraction, and Barkhausen Noise (BN) method. There is numerous technique are implemented to determine and monitor residual stress in fabrication and industrial field. Barkhausen Noise one of the new technology used to measure stresses of magnetized ferromagnetic material. In this method, generated noise in the material is responsible for stress field measurement. But it is restricted to use only for ferromagnetic material.

For the measurement of residual stress in crystalline material, an X-ray technique is used, and it is compared with other residual stress measurement techniques. In the XRD technique, the manual stress measurement is performed using powder X-ray diffractometer.

Non-Destructive Technique has many advantages in industrial applications. These are broadly classified into four categories namely increase productivity, increase serviceability, safety and identification of materials. The productivity increases due to the prevention of waste materials, workforce, maintain better and more uniform quality, lower operating and product cost. An increase in serviceability is obtained by preventing the malfunctioning and breakdown of the equipment while safety contribution is associated with prevention of accidents. The detection of material helps to identify the difference in chemical composition and physical and metallurgical properties. There are a wide variety of Non-Destructive Testing methods were used for the measurement of residual stress. These are divided into various categories namely visual, pressure and leak, penetration, thermal, radiography, acoustic, magnetic, electrician, electrostatic and electromagnetic induction, etc (Sorsa, 2012).

1.4.1. XRD technique

The X-ray diffraction is one of the essential methods used to measure the residual stress of the components. It also provided necessary information about the components for the analysis of surface integrity. XRD technique integrated with Gaussian curve method was used to measure the residual stress on the minor region of the polycrystalline materials. It depended on the transfer of position for the changed profile which was direct relation with stress. This XRD and Gaussian curve method also used to measurement of hardness of sample (Kurita, 1987). The XRD technique was used for the measurement of residual stress of butt weld joints of steel tube. For the removal of residual stress, the steel tube was considered for the heat treatment process. The XRD was used to remove the residual stress welded tube at 988 K for 30 minutes. After the measurement of the Barkhausen Noise signal, it was observed the similar BN activity was found in both in parent metal and Heat Affected Zone (Bhattacharya D K, 1992c).

The X-ray Diffraction method was used for residual stress measurement during explosion welding of blast cladded AL-6XN super austenitic stainless steel and composite plates. After the welding of composite bimetal plates, an annealing process was performed at 600 °C for 30 min for stress relief. Therefore, the materials were analyzed for measurement of residual stress in both welded and heat treated conditions. Also, The cladded edge revealed a curvy structure, more bonding strength in the welding area. The hardness deviation which was noticed at the cladding interface mostly affected by strain hardening (Varavallo *et al*., 2014). From the application point of view, XRD had numerous advantages during residual stress measurement. The XRD was implemented to calculate the residual stress because of its development as well as a wide range of practice. Also, it also facilitated regular non-destructive surface measurement in an altered condition. Besides, the XRD was little penetration depth of X-ray for the determination of stress gradient which took place on the component. Residual stress was measured in the various manufacturing process such as deformation, grinding, machining, rolling, EDM, turning, milling, shaping, etc (Brinksmeier *et al*., 1982).

In spite of the numerous benefits of XRD, there were several problems were observed in this method while evaluating the residual stress. While This XRD was used to detects relative peak position; the obtained results were undisturbed by peak splitting, unequal surroundings, intensity deviation and scatter of X-ray. Furthermore, it is an extension as well as the time-consuming technique. It is a laboratory technique (Brinksmeier & Tönshoff, 1985).

1.4.2. Barkhausen Noise Technique

The microstructure of ferromagnetic material is characterized by area, identified as the magnetic domain. An adjacent domain which exhibited different magnetization direction in the magnetized specimen. It is possible to identify a particular area, called domain boundary or domain wall, where the changes in direction occur. Weiss initially examined the existence of magnetic domains in a ferromagnetic metal in the year 1907. The prime investigational confirmation of the existence of magnetic domains was provided in 1919 by Professor H.G. Barkhausen. From the magnetized sample, it was found that the changes in the direction of the magnetic domains occurred in shocks, which in turn alter the global magnetization of the material. This modification in magnetization generated voltage shocks in the measuring coil. A measuring coil detected these induced voltage shocks, amplified and led them to a loudspeaker. The speaker recorded the induced internal magnetization by shocks in the ferromagnetic material. Later than researchers represented this voltage influenced noise as Barkhausen Noise. An appropriate relationship was established between Magnetic Barkhausen Noise method and conventional methods like XRD, cutting, drilling etc. (Gauthier *et al*.,1998).

In the year1977, Tito was the early researcher started use of Barkhausen Noise technique to assess residual stress. When the sample is placed in the magnetic field, and it magnetized, the magnetization of the domain which is horizontal with magnetic field enhances and the magnetization of domains which are vertical to magnetization reduced. In the same way, Titto discussed the influence of both tensile as well as compressive stress on Barkhausen Noise. While tensile stress was applied to the sample, the domains by parallel magnetization to tensile stress path raised with the expense of the former domains, repeatedly acquiring the totality available volume. On the other hand, the domains with vertical magnetization to compressive stress path increased and eventually cancelled out the former domains. While a similar type of variation was noticed in domain arrangements with the effect of the stress and the magnetic field, the cumulative effect caused elevated levels of Barkhausen Noise. In another case, the stress and the magnetic field caused clashing the effect on wall progress which resulted in a decrease in the level of Barkhausen Noise (BD, 1972; Tiitto, 1977; Desvaux *et al*., 2004).

The Barkhausen Noise signal was influenced by material structure, hardness, grain shape, and residual stress. Hence, it could be affectively used for material characterization. The relative investigation of the magnetic characteristics of steel with together Barkhausen Noise and eddy current techniques, showed that improvement of the grain boundary density resulted in a reduction in permeability and normalized impedance output of eddy current test. The observed increase of martensite of dual phase steel led to enhancement in Barkhausen Noise because of higher the dislocation density and internal stress in the ferrite phase. Both techniques were responsive to identify and observe a microstructural modification of steels (Ghanei *et al*; 2014). The relation between the rms value of the Barkhausen Noise with the residual stress as the function conversed for mild steel. The practical changes in the rms value of Barkhausen Noise amplitude took place as high strain state. The variation of the rms value of Barkhausen Noise signal depended on the direction of the primary easy axis of magnetization of the sample. The plastic deformation initiation promoted in the improvement of the angular anisotropy of Barkhausen Noise. The Barkhausen Noise analysis which was occurred in multi-direction of sample consistently helped to estimate fatigue damage (Lindgren & Lepistö, 2003a). The modification of potential differential in electromagnetic yoke was also utilized to analyze the microhardness. Also, for the movement of the magnetic domain wall through the hard magnetic layer, higher magnetic field strength was required whereas lower magnetic field strength was needed in the soft phase. The applied in the electromagnetic field enhanced the intensity of the height of the peak in the Magnetic Barkhausen Noise (MBN) signal. However, it had a smaller influence on the height of the low filed peak. The MBN signals parameters should be used to remove the inconsistency of results (Blaow & Shaw, 2014). The cold rolled steel showed an increase of Barkhausen Noise activity with the appliance of stress.

The MBN energy angular dependence revealed that improvement of the anisotropy of the MBN activity. The jump energy distribution was angular dependence as well as dependent on the anisotropic nature of the Barkhausen Noise activity (Capo-Sanchez *et al*., 2007). A model was used to assess residual stress and hardness of case-hardened steel with the use of Barkhausen Noise measurement. This proposed model considers the combination of feature generation, selection and model recognition as well as justification steps. The selected features are based on a simple forward-selection algorithm. All over the analysis, this model helped to ensure the results are reasonable and useful for future predictions. The predicted models were compared with an external validation data. This proposed models showed the better effect which supported to calculate the material properties (Sorsa *et al*; 2012).

A successful examination for both elastic and plastic deformation effects on Barkhausen Noise signals was performed. The linear and angular Barkhausen Noise measurements on mild steel plates go through changing of uniaxial elastic and plastic deformation up to 40% strain. The elastic strain effects on the Barkhausen Noise energy was large significant as compared to plastic strain effects. The MBN energy increment resulted in the improvement in elastic strain in specimen because of its work hardening (Stefanita *et al*., 2000). In another work, the Barkhausen Noise energy increased with tensile stress in the elastic range. This energy remained stable in the permanent deformation range up to 4% strain as the combined influence of variation of magnetic domain sizes and increased in the number of preferred domain walls. The Barkhausen Noise method was a proper technique to sense micro yielding (Stefanita *et al*; 2000).

Sometimes, the stress measurement were validated for mild steel by Barkhausen Noise technique and rotation of magnetization method. Therefore, the rotation of magnetization method was preferable as compared to Barkhausen Noise method because of various inbuilt limitation related with Barkhausen Noise method. To measure stress, the mild steel samples were subjected to bending stress. The primary use of Barkhausen Noise method was continued until there was no such specific theory was developed (Langman, 1987). The variation of various contents (i.e., Cr, Si) had significant effect of rms value of Barkhausen Noise. It was found that the lower quantity of silicon content in the magnetized sample decreases the rms value whereas more amount of chromium decreased the rms value of the magnetized sample (Degmova *et al*., 2007). The result obtained from the pulsating fatigue test on the notched steel sample establish a good correlation of the magnetic parameters and fatigue life. It was observed that the confined plastic strain was an important parameter for the prediction of sample life. The hysteresis loop amplitude was responsive to repeated plastic strain. The hysteresis load loop amplitude estimation revealed the bilinear relationship with failure cyclic number led to expect fatigue life of samples (Donzella & Granzotto, 1994). During the measurement of the Barkhausen Noise of Inconel-600 sheet in a rotating magnetic field, it was observed that the limited stress amplitude of every life fraction could be determined using the Barkhausen Noise method. Barkhausen Noise with rotating magnetic field applied to analyze the bending fatigue (Enokizono *et al*., 1996). Both MBN and Metal Magnetic Memory (MMM) were used to measurement of residual stress. From the comparative study of Barkhausen Noise and Metal Magnetic Memory (MMM) experimenting on low carbon steel, it was observed that the Barkhausen Noise dependent on time changing magnetic field created by the excitation coil.

On the other hand, the MMM was affected by earth varying magnetic field. The MMM was desirable method over Barkhausen Noise for its improved recognition capability for characterization of a sample. The MMM method was used because of proper the defect analysis and characterize the sample (Wang *et al*., 2010).

1.4.3. Microstructure and Microhardness

The U-type electromagnet and solenoid which were attached with sample were used in the study of Barkhausen Noise signal. During magnetization, dual peak revealed smallest Magnetic Barkhausen Noise signal at coercivity point, and single peak showed maximum Magnetic Barkhausen Noise signal at coercivity point. Also, it was found that the rms voltage increased with enhancement in the distance among two peaks. For the analysis of the microstructure, the standard mode of magnetization was utilized with Magnetic Barkhausen Noise as a de-magnetization factor (Bhattacharya & Vaidyanathan, 1997).

The magnetized steel showed that the hardness decreased with an increment of the depth of the tested sample. The Barkhausen Noise signal amplitude improved with tempering. Linear relations were observed between tempering and the Barkhausen Noise peak height. The more-frequency part revealed the relations between domain wall mechanism and near-surface region while small-frequency part showed the relationship between the dominant mechanism of the domain wall and subsurface region. The Barkhausen Noise peak vs. hardness at altered depth improved with tempering. The more the Barkhausen Noise resulted in lesser the hardness as the progress of the domain wall by softening of the microstructure (Moorthy *et al*., 2003). In recent time, the Barkhausen Noise technique was successfully applied for estimation of the surface integrity of the rigid milled specimen. The Barkhausen events were a combination of block wall movement and WLT of near-surface got after by HAZ. The WL formation eliminated weak Barkhausen Noise because of compressive stress and microstructure interaction with block wall (Neslušan *et al*., 2015). From the comparative study of the surface layer of carburized steel with induction-hardened steel by Barkhausen Noise method, this was confirmed that the carburized steel showed double overlapping peaks in the Barkhausen Noise profile. On the contrary, induction-hardened sample revealed a single peak in the Barkhausen Noise profile. The induction hardened sample also demonstrated the minor effect on the surface layer elimination. This variant on the microstructure explained the small impact on peak position (Blaow *et al*., 2006).

The reliable performance of components relies on the service quality and degradation in working condition. There is various Non-Destructive Testing technique being used which are based on multiple physical principles. Non-Destructive Testing aims to detect and characterize the anomalies such as defects, stress, microstructure. The non-destructive testing gathered information from experiments with design parameters which are used for estimation of surface integrity and life estimation of tested parts. The physical concept of the non-destructive evaluation method and the derived parameter are suitable for assessing defects, stresses, and microstructures (Sorsa, 2012). While the comparative study was established between the Barkhausen Noise and eddy current method, it was observed that the increasing grain boundary density decreases in permeability and normalized impedance output of the eddy current test. The improvement of martensite of dual phase steel led to enhance the Barkhausen Noise signal. This increment of Barkhausen Noise signal happens because of the higher value of the dislocation density and internal stress. The Barkhausen Noise jumps showed a nonlinear relation with grain size due to the higher grain boundary density. Both Barkhausen Noise and eddy current are responsive techniques to identify and examine microstructural alternations of steels (Ghanei *et al*., 2014).

Now a day's Barkhausen Noise and Acoustic Barkhausen Noise (ABN) are implemented for characterization changed microstructure of plain carbon steel. The existence of cementite precipitates in the tested sample improved the MBN and ABN peak height in ferrite type constituents. A smaller ABN was observed in pearlite because of non-preferred domain walls in the trans lamellar magnetic microstructure (Saquet *et al*., 1999). Both Magnetic Acoustic Emission (MAE) and MBN were used for characterization of heat-treated steel under the plastically deformed state. The plastic strain increased with increment in hardness which led to reduce in MAE and MBN.

Furthermore, it was expressed that residual stress measurement by both XRD and MBN were quite similar (O'Sullivan *et al*.,2004). The MBN technique is a quick and consistent procedure which was implemented for the measurement of residual stress and microstructure on welded steel plates. Both MBN-stress calibration set-up along with a residual stress measuring method was built up. The developed MBN set up was used for different measurement purpose. Furthermore, The obtained MBN results from welding process were validated with the hole-drilling method. If the calibration process with the influence of microstructure were proper, then MBN would be uniquely capable of NDT, rapid and correct calculation of residual stresses in the welded plates. The MBN was also used for the characterization of the specimen (Yelbay *et al*., 2010).

While iron-carbon binary alloy was characterized using Barkhausen Noise method, it was revealed that the voltage felled down with the grain size because of some bloch walls and pinning points. The examined rms value was not similar in tension and compression of the tested sample due to the magnetostriction phenomena. The intragranular precipitation developed separate magnetic fields led to the improvement of the numeral of jumps. It also decreased the pinning point resulted in the development of the amplitude of the Barkhausen Noise signal. Whereas, the magnitude of Barkhausen Noise signal decreased and pinning point increased for cementite precipitate phase (Gatelier-Rothea *et al*. 1998).

Similarly, Barkhausen Noise voltage signals method was used to study microstructure, microhardness and residual stress of steel. The enhancement of the combined frequency spectrum increased with the case depth of the sample. Also, the highest deepness recognition of micromagnetic parameters was found with the sample at maximum microhardness and smallest possible relative permeability (Žerovnik & Grum, 2009).

While Magnetic Barkhausen Emission (MBE) was studied on tempered ferrite steel, it was observed that the presence of carbide in workpiece decreased the MBE. The MBE peak height raised with the advancement of tempering time. Also, it was identified that a reduction in dislocation density and coarsening of grains resulted in enlargement of the mean free path of domain wall displacement. The decline of peak height led to reducing the creep strength (Moorthy *et al.*1998). When the domain wall and the grain boundary were discussed in pure iron and silicon steel, The linear relationship was found between grain boundary of Barkhausen Noise and the miss-orientation angle of nearest grains. The effect of interaction between small-angle boundaries and domain walls was relatively slighter as compared to large-angle boundaries and domain wall. The magnetic domains represented assisted in handling the magnetic properties in ferromagnetic materials (Yamaura *et al.*, 2001).

While the relationship of the hardness measurement was discussed for both conventional mechanical measurements and Barkhausen Noise testing method, this study concluded that the Barkhausen Noise was a non destructive reliable method to certify the widespread and immediate technique for estimation of hardness on steel pipe for oil and gas market (Trillon *et al.*, 2012).

1.4.4. Residual stress

Residual stresses are the stresses existed in the body which is free from external load. It was observed that on the machined surface due to inhomogeneous plastic strains. The tensile residual stress was harmful as diminish of fatigue strength and corrosion resistance. Whereas, the compressive residual stresses were beneficial for an increment of fatigue strength and corrosion resistance. Recently, numerous NDT technique namely XRD, Magnetic Barkhausen Noise, and Ultrasonic method, etc. are utilized for the measurement of residual stress. The distribution of bending stress was investigated by Barkhausen Noise energy in steel pipe. Also, the average energy linearly enhances with bending stress as raise in numeral and volume of selected domains on the outer surface of the pipe (Mandal 1997).

While the Magnetic Barkhausen Effects (MBE) and the Magnetic Acoustic Emission (MAE) hysteresis loops using magnetized alloy steel were investigated. It was confirmed that the Mechanical Magnetic Acoustic Emission (MMAE) intensity showed large amplitude events with the help of the tensile stress. Both MBE and MMAE intensity improved the as large rate of the magnetic field (Augustyniak, 1999). The Magnetic Flux Leakage (MFL) was utilized to investigate stress. The MFL signals were responsive to corrosion pits which were found in the pipe wall and to exterior stresses produced mostly by the line pressure. The MBN calculation had been performed to investigate the stress variation in the path of the bulk magnetic easy axis and directional anisotropies of the pipe wall. This concept assisted one in explaining the stress reliant MFL results. The stress studied in the pipe led to change the MFL signals as its movement in the route of the natural magnetic axis of the sample (Mandal *et al*., 1997). For the analysis of the magnetized tempered sample, it was pointed out that the domain wall movement faces two obstacles namely grain boundary and interface between the matrix or second phase precipitate and inclusion. To overcome this obstacle, some mean values of critical field strength for grain boundary (Hgb) and second phase precipitate were considered. When these two mean values of the critical field are close together, the single peak occurs. On the contrary, if two mean values of the critical field were broadly separated, then two peak behaviour occurred (Moorthy *et al*., 1997).

The Barkhausen Noise emission method was implemented for the measurement of residual stress of ground case carburized steel. The variation of frequencies was measured on samples through case-depth of 0.55 and 0.8mm. The significant frequency of Magnetic Barkhausen emission showed a single peak whereas smaller frequency showed two peaks. The first peak was not influenced by grinding damages. On the other hand, the second peak revealed a nonlinear, and it also specified the variation of microstructure and residual stresses. The small and large frequencies compared with residual stress depth profile. The significant frequency showed the variation of residual surface stress up to a depth of 10µm. While small frequency indicated the alternation of residual stress beneath the surface (Moorthy *et al*.,2005). The variant of residual stress occurred in the depth route due to the grinding of the tested sample. The stress was analyzed on near-surface and subsurface stresses of case-carburized and tempered EN36 steel. The significant, as well as small frequency Magnetic Barkhausen Emission, were measured on a sample with case-depth of

0.95mm. The significant frequency revealed a single peak, and low frequency confirmed two peaks. The various types of frequency analysis revealed the improvement in Magnetic Barkhausen Emission using tension and reduced in Magnetic Barkhausen Emission with compression. The critical frequency measurement did not show variation because of pre-stress. The small frequency Barkhausen emission profile, the primary peak enhanced and the second peak felled down with increment in pre-stress. The peak height of high frequency reduced by an increase in pre-stress under compressive stress. The first peak of the small frequency reduced with improvement in pre-stress level. But, the second peak of the small frequency MBE shape decremented by 10% at a pre-stress. The high-frequency Magnetic Barkhausen Emission resulted in the variation of residual surface stress. But this high-frequency did not reveal any variation of residual stress at depths 420 mm below the surface (Moorthy *et al*., 2006). The BE technique was also applied for the measurement of the surface damage of the grounded steel. A variety of surface damages were observed in ground steel using variant coolant flow rate. At a specific quarter flow rate, it was found that there was a temper burn on the surface of ground steel. This temper burn took place due to the formation of softer layer surface results weak wear resistance (Gupta *et al*., 1997). The amplitude of Barkhausen Noise signal profile effectively signified the residual stress redistribution in the near-surface and subsurface area as the controlled plastic deformation. The MBE method was utilized to assess the average residual stress in the near-surface and subsurface regions with previous calibrations (Moorthy *et al*., 2004). The Barkhausen Emission signal improved with an increment of several unpinning events of Domain Walls (DWs). For the small grain heat-treated sample, the Barkhausen Emission signal improved with tension. Whereas for significant grain heat-treated sample, Barkhausen Emission signal reduces with tensile stress as the development of new DWs led to enhancing the numeral of unpinning events (Ng *et al*., 2003).

For the measurement of Barkhausen Noise activity over the specific rate of plastic deformation inside mild steel, it summarized that Barkhausen Noise activity showed a strong deviation in the applied stress measurement route. The induced plastic deformation affects the Barkhausen Noise activity. This activity was attained from dislocation and domain wall interface (Dhar *et al*.,2001). While the influence of affected stress on Barkhausen Noise and hysteresis loop were studied, the highest amplitude of Barkhausen Noise raised and it reduced for considerable stress as compared to the stress at boundary condition as the influence of the magnetic field and applied stress. Furthermore, the high amplitude of Barkhausen Noise voltage, greatest magnetic induction, and differential susceptibility value, were smaller for first grain sample and movement of domain walls while these values were large for coarse grain sample (Anglada-Rivera *et al*., 2001).

In recently manufacturing sector, an integrated laser method and Barkhausen Noise technique were used for the measurement of the yield of different gear teeth sample. The laser temperature profile of the ground surface was consistent in a parallel processing direction. The laser method influenced the residual stress in two measured directions. The rms value was showed a linear trend with residual stress and hardness. The steel sample surface was affected by the laser beam absorption. Various surface conditions namely sandblasting and grinding of the sample had been performed on the specimen surface. The sandblasting surface generated a similar dull appearance for the laser practice while ground sample showed a drastic change in the surface temperature measurements. The ground surface showed a laser temperature distribution profile which was more uniform. The rms value also noted a direct relationship with both the residual surface as well as surface hardness (Santa-aho *et al*., 2012).

The Barkhausen Noise amplitude decreased in the loaded path and increased in the transverse direction. In both directions, pre-strain improved linearly with the stress and Barkhausen Noise. This Barkhausen Noise was used for estimation of the residual stress. The saturated tensile stress of the Barkhausen Noise was calculated in the loaded direction (Lindgren & Lepistö, 2001). The probable variation in the rms value of Barkhausen Noise amplitude took place in the specimen as its high strain condition. The narrow heating created more considerable macro stresses which were parallel to the heated line direction. An appropriate variation was observed between the rms value of the Barkhausen Noise amplitude and total stress in the ferrite phase. The pulse height distribution variation helped to change the rms value with induced stress. The Barkhausen Noise is a potential technique to predict the residual stress of the ferrite phase of duplex stainless steel. A correlation of the residual stress was established in ferrite and austenite phase (Lindgren & Lepistö, 2003b).

The pre-strain in the austenite phase of the specimen was tensile whereas this pre-strain in the ferrite phase showed compressive nature. The Barkhausen Noise increased in every calculating direction because of increment of the tensile inter phase micro-stresses and decreased with the macroscopic compressive stresses. The prestraining improved the amplitude of the Barkhausen Noise in the entire direction because of the decreased of macroscopic compressive residual stress and initiation of tensile stresses in the ferrite phase. The Barkhausen Noise enhanced in transverse direction due to compressive strain and reduced in the transverse direction because of tensile strain. The prestrained samples showed more stress sensitive to the Barkhausen Noise signal than the unstrained sample, especially at compressive stress (Lindgren & Lepistö, 2004).

The Barkhausen Noise measurement was carried out for the study of changed magnetic properties of both the hardened steel and the soft base material core. The residual stress distribution on the surface layer decreased the compressive stress, and it changed regularly into tensile residual stress in depth which was equal to layer thickness. For the measurement of Barkhausen Noise, the small magnetizing frequencies were preferred than the conventional high frequency because of its more penetration of magnetic field to the ferromagnetic specimen. But the penetration depth was maximum because of the eddy current damping. During the Barkhausen Noise measurement case-depth sample, the apparatus was used in experimentation to collect data from Magnetizing Voltage Sweeps (MVS). This MVS were studied and evaluated with conventional means. The XRD method was also utilized to measure the residual stress of the tested surface. While the destructive characterization was implemented to check the real hardening depth of the tested specimens, It was noticed that the MVSs was more reliable for the estimation of the case-depth values than the previous studies in addition, the ratio of the most magnificent MVS slopes at changed frequencies showed the case-depth values resulted in superior results (Santa-aho *et al*., 2012).

The effect of Barkhausen Noise was also determined the fatigue damage growth and residual fatigue life of steel using cyclic load. The Barkhausen Noise peak value depended on the induced voltage. While the applied stress value was small as compared to the fatigue limit, the Barkhausen Noise signal remained almost stable. Afterward, the applied stress value was more as compared to fatigue limit, Barkhausen Noise signal changed (Tomita *et al*., 1996). The correlations were observed for the residual stresses obtained from Barkhausen Noise method and traditional cutting and sectioning, hole drilling and XRD method. This relation showed good agreement in both ways the non- destructive method which was used to measure residual surface stress quite precisely to ± 25MPa as proper calibration was carried out. The MBN read head probe provides a large spatial resolution of residual stress variations (Gauthier *et al*., 1998).

The increment of tensile residual stress decreased the progression of the walls which led to an improvement of Barkhausen Noise signal amplitude. The higher quantity of carbon content decreased the amplitude of Barkhausen Noise signal. The Barkhausen Noise signal was raised by tempering and decreased with the hardness of the sample. The BN is an efficient technique to detect thermal damages on the surface of the specimen. The BN method was depended on the condition of heat treatments, materials, and manufacturing processes (Karpuschewski *et al*.,2011). While Barkhausen Noise response of Armco iron was validated with low carbon steel in plastic deformation, this was concluded that stress at the Barkhausen Noise calculation increased at tensile load and decreased at compressive load. While the material was in tensile stress which was parallel to the direction of the magnetic axis, it increased the Barkhausen Noise signal where, in compressive stress, the Barkhausen Noise signal decreased. Furthermore, more dislocation cell and dislocation tangles formed more plastic strain in low carbon steel than the pure iron. (Kleber & Vincent, 2004).

The residual stresses were analyzed by eddy currents, Barkhausen Noise, hysteresis loop with the use of tensile stress on different steel specimen. The residual stress measurement observed from destructive, and NDT was correlated and implemented for analysis. The measurements by the magnetic techniques were taken in the critical zone (Zergoug *et al*., 2007). The properties of the hysteresis loop such as coercivity, remanence, and permeability were correlated with stress under pre-strain condition. Characteristic of the plastically deformed sample based on hysteresis loop and stress could be estimated with Barkhausen Noise method. The coercive field showed the linear behaviour with prestressing, while the other magnetic properties all showed inversely and monotonous activities with prestress. The elastic compression in the direction of the applied field caused a decrement in permeability, and it created an improvement in the range of magnetostriction whereas in tension it is in reverse nature. It was observed that residual stresses did not change consistently with the increase in prestressing. The total pinning of domain wall and number of pinning sites continues to increase with an increase in prestressing (Makar & Tanner, 2000). The Barkhausen Noise with more amplitudes was combined with tensile stresses whereas Barkhausen Noise with low amplitude was combined with compressive stresses. The smaller compressive stress yielded low Barkhausen Noise value whereas tensile stress generated more value of Barkhausen Noise (Barton & Kusenberger, 1974). Barkhausen Noise measurements were utilized for the measurement of the residual stress and amplitude on crankshaft steels. While comparing the material properties of two steel, it was confirmed that enhancement in ductility raised the chip builds up in the grinding wheel. This chip build-up and the high grinding temperature raised the hazard for the deep layer and converted the residual stresses in the direction of tensile resulted in varying the Barkhausen Noise analysis (Doverbo, 2012).

The influence of flexible deformation and employed stress were examined for the induction-hardened steel. The Barkhausen Noise showed linearly trend with tension. The Barkhausen Noise was more sensitive to stress in over tempering sample as compared to standard tempering sample. The peak height of Barkhausen Noise signal was more significant for over tempering sample as compared to a standard tempering sample. The Barkhausen Noise revealed thin hysteresis loop for stressed tensile sample whereas it was widened for the compressively stressed sample (Blaow *et al.*, 2007). Both peak width and position of Barkhausen Noise signal increment were noticed in compression, and at the initial point both were decreased with tension, Whereas, the peak height and skewness decreased with compression and initially increased with tension (Stewart *et al.*, 2004).

The surface density which was observed in magnetized poles developed nucleation energy in polycrystalline materials. The generated energy of the domains of opposed magnetization helped to analyze grain-boundary, lamellar-precipitate, and a domain-wall-surface tension. These determined parameters resulted in coercive force in polycrystalline materials (Goodenough, 1954). The assessment of residual stresses was performed by combined Barkhausen Noise method and relaxation method. The relevant study throughout the thickness calculated of the specimen revealed that the micromagnetic technique was appropriate for the estimation of residual stresses. This method showed a real-time variant of residual stresses in a thin surface layer of the sample (Grum *et al*., 2000).

The Barkhausen Noise signal raised in the direction of applied tensile stress whereas it decreased in the direction of compressive stress as drop-in hysteresis. The degree of Irreversible Differential Permeability (μ_{IDP}) in small field area increased in the employment of tensile stress. Moreover, it decreased in the use of compressive stress. The advancement of the preferred domain wall vicinity was found because of tensile stress while it decreased as compressive stress (Krause *et al*., 1994). Throughout the evaluation of surface integrity using a new move for processing the reply of Barkhausen Noise signal oversample with the weak micromagnetic response, There was a straight relation between Barkhausen Noise constraint namely count and event with residual stresses (Vashista & Paul, 2011). The peak position of Barkhausen Noise signal improved with enhanced tensile residual stress till yield strength of component, then it decreased. The grain elongation along with residual stress of grounded medium carbon steel increased with enhancement in the down feed. The full width half maximum, the peak position of Barkhausen Noise signal, derived remnance and hysteresis loop region was insensible to the applied stress. There was no alteration observed of phase and microstructure in the grounded sample. The irrelevant variation of hysteresis loop region with residual stress as the choice of a changed range of frequency. But residual stress had an insignificant effect on coercivity (Vashista & Paul, 2009). The material erosion mechanism of low carbon steel using a grit blasting process was studied carefully. This grit blasting process was based on two mechanisms, such as micro cutting and indentation was discussed. The grit blast generated micro fracture on the surface of the specimen. Both XRD and BN methods were used to determine the residual stress of the grit blasted surface. Both techniques showed the linear trend between the Barkhausen Noise signal and the compressive residual stress of grit blasted sample. The Grit blasting surface produced compressive residual stress. This stress enhanced with blasting pressure and blasting angle. The grit blasting process also generates nano-structured surface (Chander *et al*., 2009).

Magnetic Barkhausen Noise (MBN) was related to the magnetization of reversal mechanisms and microstructure in the magnetized sample. While characterization of electrical steel specimens under the application of Magnetic Barkhausen Noise method. This MBN technique was extended in three different laboratories. It was found Magnetic Barkhausen Noise improved with strain and it reduced with a smaller size of grain (Ktena *et al*., 2014). When various low carbon and high carbon steel specimen were tested with high and low frequency for the analysis of Magnetic Barkhausen Noise profile, it was noticed that high-frequency study for Barkhausen Noise profile showed single peak because of low applied magnetic field strength. On the other hand, low-frequency analysis of Barkhausen Noise showed two peaks as large magnetization range (Vashista & Moorthy, 2015). The magnetic Barkhausen Noise method was preferred to calibrate the microstructure of bearing manufactured in wind power station. It was selected because Magnetic Barkhausen Noise showed two beaks as heterogeneity of carbide distribution during the grinding process. The MBN technique integrated with other method was used to monitor the thermally induced damage in grinding process case-hardened surfaces. The MBN signal could be measured in the form of HAZ thickness, dislocation density, microhardness profile. The MBN showed two peaks because of the non-homogeneity of the carbide distribution. The MBN was initiated due to carbides resistance adjacent to elevated temperatures which were generated by grinding heat (Neslušan *et al*., 2017). The surface damage of the milled sample was investigated using Barkhausen Noise technique. For measurement of Barkhausen Noise signal, both low frequency along the laboratory method and high frequency using Roll scan device were used in the experiment. While the BN signal was measured in the feeding direction, the BN profiles revealed a second high-field peak attributed to an induced hardened surface layer. This hardened was also called white layer. The Hall sensors provided the consistent result with the organized waveform on the magnetized surface. Depending on the high BN activity. The latest magnetic parameters were implemented for the non-destructive estimation of the WL creation (Stupakov *et al*., 2016). For the measurement of residual stress in the welded specimen, both BN and XRD techniques were used. From accuracy and reliability point of view, the steel specimens were tested under compressive and tensile stresses. Furthermore, the Barkhausen Noise were compared with residual stress values. From this comparative study, it was observed that the difference between the two techniques was inside acceptable restrictions. Therefore, the Magnetic Barkhausen Noise method was preferred (Vourna *et al*., 2015).

1.5. Objectives

A literature survey indicates that surface integrity in EDM is critically dependent on the choice of process parameters, EDM environment, workpiece, electrode, and dielectric fluid. The surface integrity can be improved by the use of suitable EDM process parameters and wires. Analysis of the literature survey indicates that there is a gap in some of the areas. There has not been a much systematic study of the effect of process parameters on Barkhausen Noise parameters upon EDM. None of the studies attempted applicability of Barkhausen Noise in the assessment of surface integrity upon EDM. The applicability of Barkhausen Noise to assess the state of residual stress has not been critically examined with simultaneously change in surface roughness, microstructure, microhardness, white layer, crack density, etc. But so far, no investigation has been reported which compare the XRD parameters, especially residual stress, microhardness with same Barkhausen Noise parameters.

The objective of this research work is to study the effect of process parameters (voltage, current, and pulse on time) on surface integrity aspects, i.e., residual stress, surface roughness, microhardness profile, WLT, crack density and white layer with particular emphasis on the applicability of Barkhausen Noise technique.

Thus, the detailed objectives of the present work are:

(a) To experimentally investigate the role of different EDM parameters on different machinability indices (with particular emphasis on surface integrity) while electro-discharge machining of die steel using the design of the experiment.

(b) To analyze the correlation between different process parameters and surface integrity aspects under reverse and straight polarity condition.

(c) To experimentally study the effects of process parameters on micromagnetic response upon EDM for both polarity condition.

(d) To develop a possible correlation between Barkhausen Noise parameters and residual stress.

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