INVESTIGATE THE EFFECTIVE PARAMETERS ON TEMPERED HSS IN ELECTRICAL DISCHARGE MACHINING

DISSERTATION-II

Submitted in Partial Fulfillment of the

Requirement for Award of the Degree

Of

MASTER OF TECHNOLOGY

In

MECHANICAL ENGINEERING

By

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2014-2015

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CERTIFICATE

I hereby certify that the work which is being presented in the dissertation-II entitled **"Investigate the effective parameters on tempered HSS in electrical dischcarge machining"** in partial fulfillment of the requirement for the award of degree of **Master of Technology** and submitted in Department of Mechanical Engineering, Lovely Professional University, Punjab is an authentic record of my own work carried out during period of Dissertation-II under the supervision of **Mr. Jasvinder Singh**, **Assistant Professor cum HOD,** Department of Mechanical Engineering, Lovely Professional University, Punjab.

The matter presented in this dissertation-II has not been submitted by me anywhere for the award of any other degree or to any other institute. .

Date: **Sandeep Singh**

This is to certify that the above statement made by the candidate is correct to best of my knowledge.

Date: **Mr. Jasvinder Singh**

Supervisor

The M- Tech Dissertation-II examination of Investigate the effective parameter on tempered HSS in electrical discharge machining, has been held on 14 May, 2015.

Signature of Examiner

Acknowledgement

It is with a feeling of great pleasure that I would like to express my most sincere heartfelt Gratitude to **Mr. Jasvinder Singh**, **Assistant Professor cum HOD, Department of Mechanical Engineering, Lovely Professional University** for their ready and able guidance throughout the Course of my preparing the report. I am greatly indebted to them for his constructive suggestions and criticism from time to time during the course of progress of my work. I am very grateful to **HTM Alloy Industries, Ludhiana** for Providing me the material and allowed me to use their machine for tempering. I am also very thankful to **Lovely Professional University, Phagwara** for allowed me to work on their EDM machine.

I am also thankful to all the staff members of the department of Mechanical Engineering for their inspiration and help.

Sandeep Singh

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List if Abbreviation and Nomenclature

1. EDM	Electrical discharge machining
2. MRR	Material removal rate
3. TWR	Tool wear rate
4. SR	Surface roughness
5. DC	Direct current
6. DRO	Digital read output
7. HSS	High speed steel
8. ANOVA	Analysis of variances

ABSTRACT

Electrical discharge machining (EDM) is extremely important type of machining where accuracy, high surface and complex shape is required. EDM is a type of non-conventional machining and EDM is also a non-contact type machining process, so there is no external force act between workpiece and electrode. In this thesis work, experimentation done on tempered high speed steel of grade M2, M35 and M42 by using copper electrode of 12mm diameter and taking variable parameters like discharge current, pulse on time, pulse off time and optimal parameters for higher material removal rate ,lower tool rate and surface roughness were find out by using Taguchi and ANOVA analysis. After the analysis conclude that which grade of HSS is most suitable for machining with copper electrode. A better experimentation scheme was used to deduce the total number of experiments. Experimentation were conducted with Taguchi's L9 orthogonal array and ANOVA method is used to analyze the outcomes of experimental data.

Keywords: Electrical discharge machining (EDM), MRR, TWR, High speed steel.

CHAPTER1. INTRODUCTION

1.1 ELECTRIC DISCHARGE MACHINING (EDM)

Electric discharge machining (EDM) is one of the most widely used nontraditional process. The shape of the finished work surface is produces as the shape of the electrode tool. When sparks takes place between the tool and work piece, Erosion of metal occurs. During EDM process, tool and work piece is immersed in dielectric fluid and when direct current is supplied then ionization of dielectric fluid occur between the gap of tool and workpiece, which makes the spark stable [1].

Fig1: EDM

Due to the generation of discharge, region is heated to extremely high temperature, as a result small portion of work surface is suddenly melted and removed. Dielectric fluid flushes away the eroded particle also called as chip. In EDM individual discharge remove a metal at very localized points, sparks occur hundreds or thousands of times per second so that a gradual erosion of the entire surface occurs in the area of the gap. Due to high spark temperature melting of the work surface occur as well as it melt the tool also, and creating a small cavity in the surface of the tool which cause cavity produced in the work surface also. This wear ratio ranges sometime 1.0 and 100 slightly above depending upon the combination of work and electrode materials. The EDM process involves a controlled erosion of material which is electrically conductive in nature. This erosion is controlled by continuous spark discharge between the cathode and anode separated by small gap of about 0.01 to 0.50mm known as spark gap. EDM sometime also referred as spark eroding, burning, die sinking, spark machining in manufacturing process [2].

1.2 Working of EDM

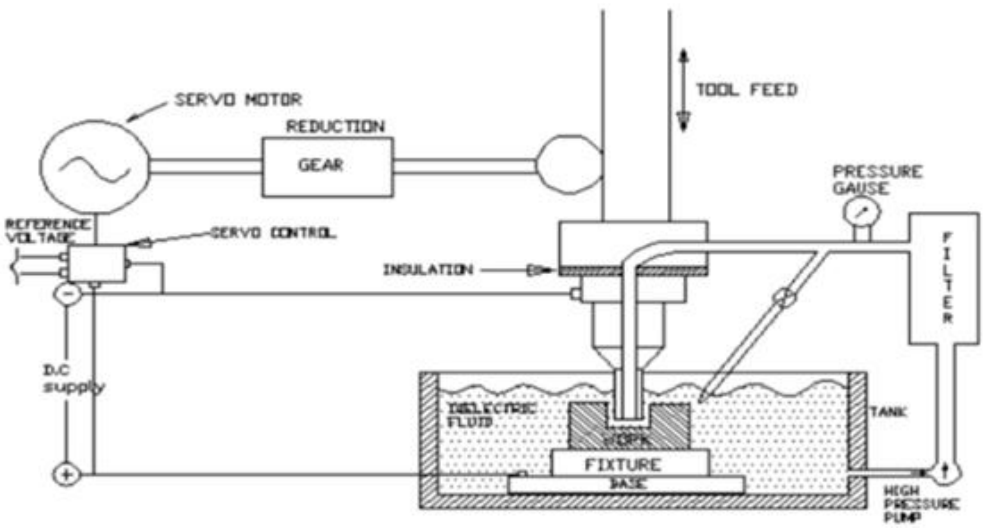

Fig 2: Construction of EDM

1.2.1 Important parts of EDM:

1. Pump.
2. Dielectric Reservoir.
3. DC Power Supply.
4. Numeric Control Unit.
5. Fluid Tank with work holding device.
6. X-Y movable working table.
7. Tool Holder.

1.2.1.1 Pump & Dielectric Reservoir

Fig 3: Dielectric Reservoir and Pump

It is used to circulate and filter the EDM oil during EDM machining.

1.2.1.2 DC Power Supply and Numeric Control Unit

DC Power Supply provide discharge current for the generation of sparks but too much current increase temperature cause damaging of work piece, So NC Unit is used to control such parameters like pulse on time, current etc.

Fig 4: Power Supply

Fig 5: DRO

1.2.1.3 X-Y movable work holding device

This table are used to provide the movement or motion in X and Y direction. Tank with work holding device.Tank is filled with dielectric fluid and it also hold work piece during machining .

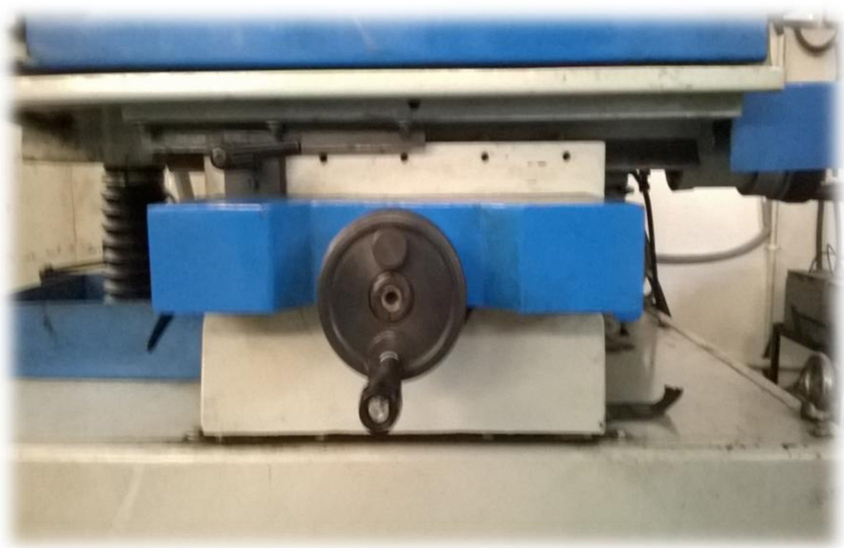

Fig 6: X-Y movable working table

1.2.1.4 Tool Holder

This tool holder is used to clam or hold the electrode in vertical position

Fig 7: Tool Holder

1.2.2 WORKING

In EDM process, when the direct current is supplied a spark is take place between tool and workpiece. When voltage between gap becomes large (more than 250v), the high spark is produced. This spark occur in interval of 10 to 30 microseconds and with a current density of 15-500A per mm^2 approximately. In this process, temperature is increased about 10,000 degcentigrade. At such large temperature, heat is increase which leads that work piece eroded and some of it is vaporized. In this way the metal is removed from the workpiece. The eroded material or devris are carried away by dielectric fluid circulated around it. The metal removal rate depends on the spark gap maintained between the work surface and electrode. If anode and cathode are made of same material, then material removal rate is very high. When the voltage drops to about 12 volts,the spark discharge extinguishes and the dielectric fluid once again becomes deionizer.When voltage drops occur then it leads to collision of plasma channel, which create shock wave which leads to erosion of work piece [3].

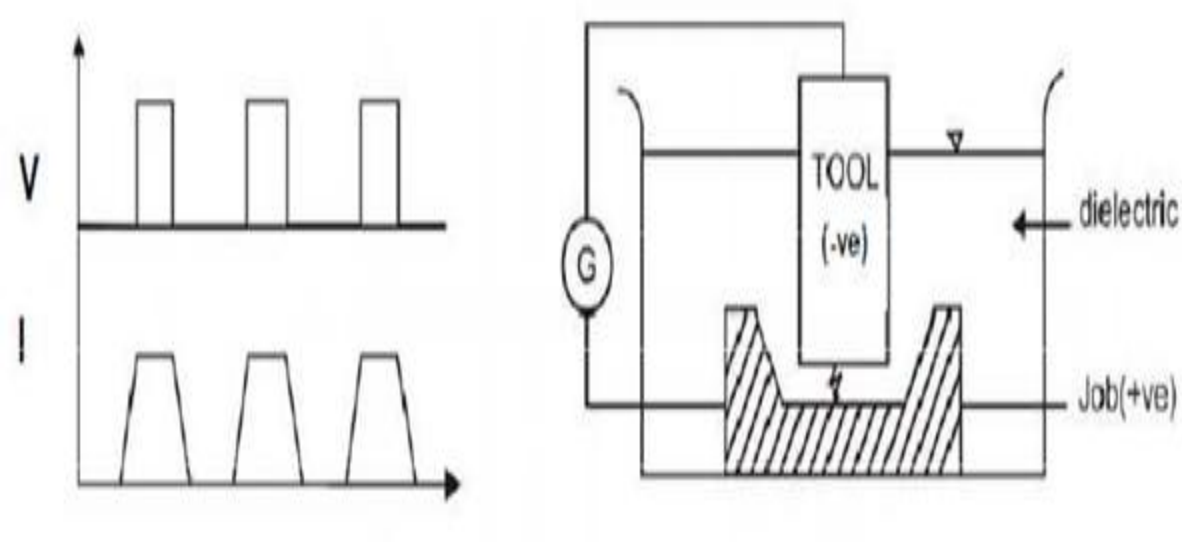

Fig 8: EDM process with cycle

1.3 EDM Principle

It is an non-traditional material removal process which is usedto remove undesired material from the work piece by means of electric current or sparks.EDM is suitable for machining of complex shape and geometry of material. In EDM process sparks is used to remove the undesired material from the work piece and produce a finished part of desired shape.

The material removal processis performed by applying a direct current through the electrode to the workpiece. This removes very tinypieces of metal from the workpiece at a controlled rate [4].

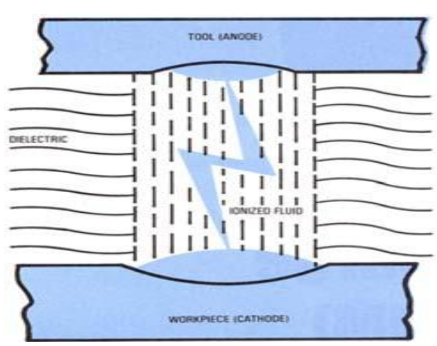

Fig 9: Principle of EDM Process

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1.4 Classification of EDM [3]

EDM are classified as two different types which is discussed below:

1) Die Sinking EDM 2) Wire Cut EDM

1.4.1 Die sinking EDM

In Die Sinking EDM process, electrode and work piece is immersed in dielectric fluid which are connected to main power supply. When the power supply is switched on a discharge current is set up between the electrode and work piece. When electrode to work piece gap is very small then dielectric breakdown occurs in the fluid which leads to generation of sparks as result as erosion of work piece occur.

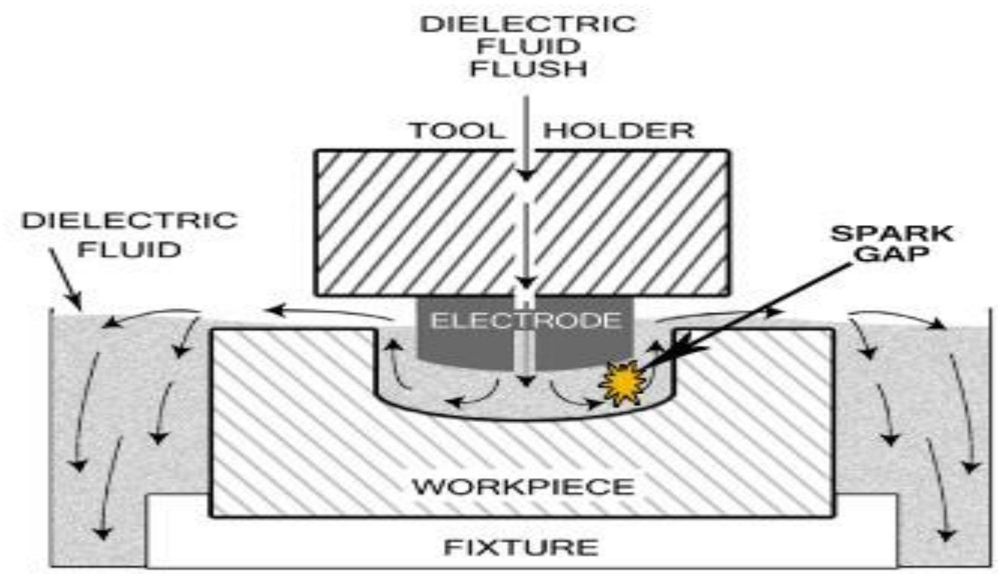

Fig 10: Die-Sinking EDM

1.4.2 Wire Cut EDM

Wire Cut EDM machine is categorized as a type of EDM. Wire Cut EDM use metal wire as a cutting tool with dielectric fluid such as deionized water. When electric spark is provided then heat is generated which allow the metal wire to cut the material into a desired shape or into a final product [3].

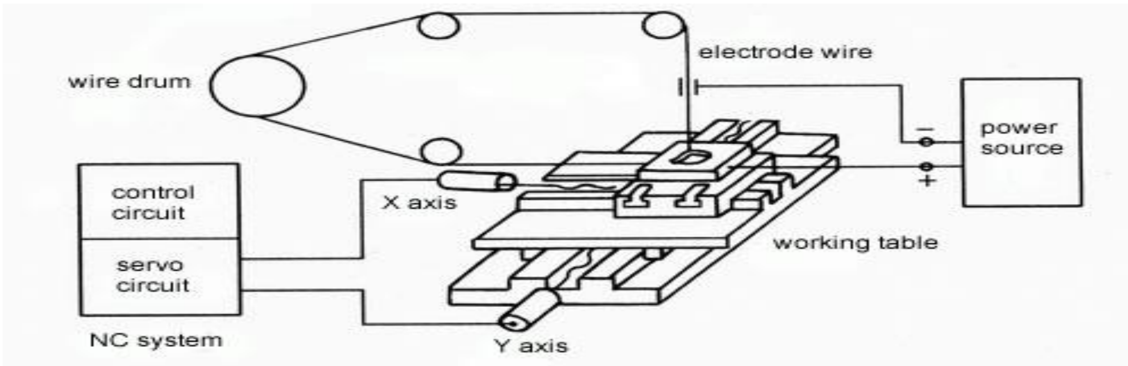

Fig 11: Wire-Cut EDM

1.5 Important parameters of EDM [3]

1. **Spark On-time (Ton):** The duration of time (μs) the current is allowed to flow per cycle..
2. **Spark Off-time (Toff):** The duration of time (μs) between the sparks.
3. **Arc gap:** When discharge current is applied, the spark is generated between the gap of work piece and electrode and this gap is known as Arc gap.
4. **Discharge current (Ip):** Direct current is supplied from power supply into dielectric fluid which is known as discharge current and it directly effect on MRR.
5. **Duty cycle (τ):** Duty cycle is the ratio of pulse on time to the addition of pulse on and pulse off time.

$$\tau = \frac{Ton}{Ton + Toff}$$

6. **Voltage (V):**

   Optimal potential is used for achieving better performance in EDM machining such as 50v or any other.
7. **Over cut:** Over cut is also known as a defect in EDM machining, extra erosion of material at edges occur, noticed after machining.

1.6 Dielectric Fluid

Dielectric is a non-conductive fluid, which is strong dielectric resistance and not breakdown electrically occur too easily [3].

Important function of Dielectric Fluid:

1. Dielectric fluid improves the concentrates of discharge current to a localized region.
2. Dielectric fluid improves the stability of arc as well as act as coolant for electrode and work piece.
3. Dielectric fluidflushes away the removed tiny particles from the material.
4. Dielectric fluid acts as a coolant in EDM process.

1.7 Advantages of EDM [4]

1. EDM process is feasible for machining of all type of conductive material.
2. EDM process is used mostly where requirement of machining of hardened work piece, which is not possible by any other manufacturing process.
3. In EDM process, complex profile also generated because of its XYZ movement.
4. EDM machine consist a NC control system which can produce complex die section with high accuracy
5. EDM is automated machine which allow less interfere of human.
6. In the EDM process, no cutting forces occur.

1.8 Application of EDM

1. EDM process is used for the production of punches, dies etc.
2. EDM process is used for the machining of very hard material such as High Speed Steel.
3. EDM process is used where accurate machining is required such as automobile, aerospace, and electronics areas.
4. EDM machine contains NC control unit which leads to obtain high tolerance limits
5. EDM process is also used in another area like engineering such as medical, R&D areas, Research work.

6. EDM process is also used for drilling micro-holes.

1.9 Heat Treatment

For the better selection of the grade itself, heat treatment of steel is very important. When tool steel is heat treated its property enhances such as wear resistance, resistance to deformation or breaking under loads, and resistance to softening at elevated temperature.

1.9.1 Annealing

After forging operation High Speed Steel must be completely annealed. Pack annealing in tightly closed container which leads to minimize decarburization. Small amount of charcoal is added to packing material such as dry sand, because it act as insulator for the container. When the steel has attain its annealing temperature range, than work piece held at temperature for 1hr per inch of container thickness and then slowly cooled down in the furnace at a rate not exceeding 20 deg. Celcius per hr until it attain a temperature of 650 deg celcius , after that faster rate of cooling can be done.

1.9.2 Preheating

At 760 deg. Celcius, Austenite starts to form and due to that stress are set up because of transformation, then preheating for hardening above this temperature will decrease the developed stresses. For minimizing thermal shock double preheating is used. Firstly, preheated in one furnace at 540-650 deg. Celcius and then in another at 845-870 deg. Celcius.

1.9.3 Austenitizing

During Austenitizing, heat resistant qualities and cutting ability of High Speed Steel is develop or enhanced depend upon the solution of various complex alloy carbides. Accurate temperature control is required in austenitizing HSS because carbides does not dissolve to an appropriate extent until the High Speed Steel is heated to temperature near the melting point.

1.9.4 Quenching

It is used to hardening tool steels, for better hardening quenching done as rapidly as possible. Mostly, water as a brine solution consisting of 10% NaCl in water is used. Sometime, where fast quenching is required then iced brine solution is used. Cooling rate is depend on work pieces size as well as of quenched medium and small pieces are quenched in oil. Steels of groups A and D will attain maximum hardness by cooling in still air, unless sections are extremely large. High speed steels can be quenched in air, oil or molten salt. Air quenched is used for thin tools and it can be also be quenched in oil from muffle or semi muffle furnaces and in molten` salt from high temperature salt bath, when work piece is equalized in the salt quench, then tool is air cooled. For large cutters heated in a furnace , an interrupted oil quench is often used to minimize quenching strains and prevent cracking .This consists of cooling the cutters in the oil only until they lose color (about 540 ^{o}C) and then cooling them in air. The optimum temperature range for quenching baths consisting of conventional oils is 40 to 60^{o}C, agitation is recommended.

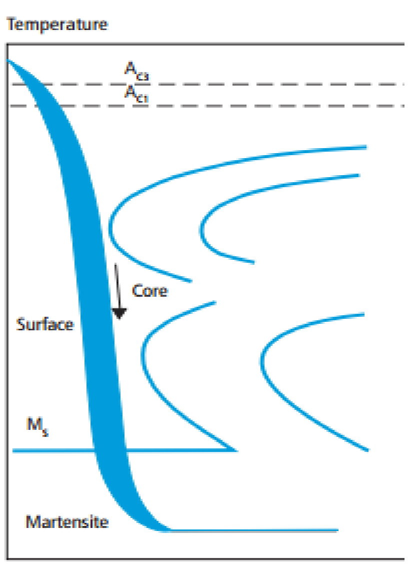

Fig12: TTT graph

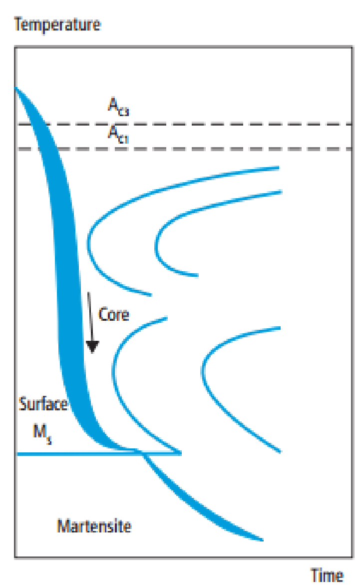

Fig13: Martempering

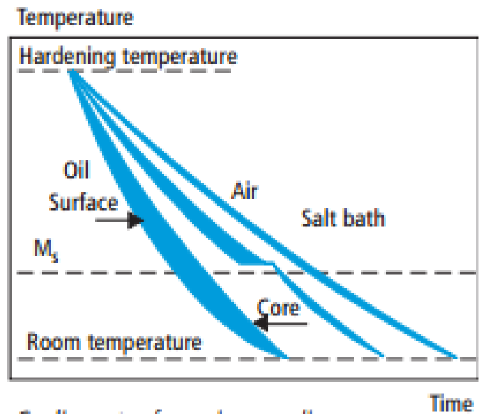

Fig14: Cooling rate

1.9.5 Tempering

In High Speed Steel, hardness is affected by tempering temperature and time, For example, M2 is austenitized at 1220 deg. Celcius. Then secondary hardening of M2 at a temperature above 370 deg. Celcius and this process proceed until temperature upto about 595 deg. Celcius depend upon time. Mostly, tempering process follow these temperature as a practical limits. Optimal temperature is required in tempering to attain desired hardness because low temperature doesn’t initiate secondary hardening process and high temperature produce hardness lower than as desired. At least two separate tempering treatment with in range 540-595 deg. Celcius is provide to High Speed Steel. Holding time during each treatment is 2hr or more at temperature. Tempering ensure the aim to achieve martensitic structure because amount of retaining austenite is vary significantly.

Fig15: Salt bath tempering furnace

Panag et al. [5] worked on EDM to study the optimum parameters of Surface roughness for AISI M2 high speed steel by using Response surface methodology. Authors takes the four significant parameters like current, pulse on time, gap voltage and duty cycle. Authors found that discharge current and duty cycle are more influenced parameters than other like gap voltage and pulse on time.

Singh et al. [6] worked on EDM to study the Investigation of TWR and MRR on High speed steel by using brass and copper electrode. Authors taken the input parameters like pulse off time, peak current, pulse on time and fluid pressure. Authors found that MRR is increased with increase in peak current and pulse off time and MRR is decreased while increasing in pulse on time in case of brass electrode and vice-versa for copper electrode.

Siva et al. [7] worked on Die sinking EDM machine to study the effect of parameters in micro EDM on D2 steel using brass electrode. In this Authors evaluate process performance criteria such as material removal rate, electrode wear rate, over cut and taper angle. An author found that current is most effected parameter for material removal rate, electrode wear rate, taper angle and over cut.

Sharma et al. [8] worked on Die sinking EDM machine to study parameters on AISI-329 using copper and brass rotary electrode during EDM process. In this Author evaluate process performance criteria such as material removal rate and electrode wear rate and taper angle of the hole in AISI 329. Confirmation of the experimental data is done by ANOVA. Authors found that copper electrode improve hole quality and provide good machinability as comparision to brass electrode.

Khan et al. [9] worked on Die sinking EDM machine to study the surface finish of Ti-5AL-2.5Sn during EDM process. In this Authors evaluate process performance criteria such as surface roughness. Authors found that material of electrode effect surface roughness. Authors also found that at low discharge energy, copper-tungsten electrode gives a excellent surface structure as compared to graphite electrode.

Tang and Du [10] worked on Die sinking EDM machine to study effect of tap water on Ti-6Al-4V and parameters optimization during EDM machining. In this Authors evaluate process performance criteria such as material removal rate, electrode wear ratio and surface roughness. Authors found that for Ti-6Al-4V material has high material removal rate when tap water is used.

Majumder [11] worked on Die sinking EDM machine to study parameter optimization of AISI 316ln steel during EDM machining by using fuzzy based multi objective pso. In this Author evaluate process performance criteria such as material removal rate and electrode wear ratio. Author found that optimal process parameter to improve material removal rate and electrode wear ratio by employing multi objective optimization technique.

Nikalje et al. [12] worked on Influence of parameters and optimization of EDM performance measures on MDN 300 steel using Taguchi method. In this Authors evaluated process performance criteria such as material removal rate (MRR), tool wear rate (TWR), relative wear ratio (RWR), and surface roughness (SR) and Selected Parameters which effect EDM performance are Discharge current, pulse on time, and pulse off time. Authors have found that the optimal level of the factors for SR and TWR are same but differs from the optimum levels of the factors for MRR and RWR. Authors found that discharge current, pulse on time, and pulse off time have been found to play significant role in EDM operations. From the result they have found that study of Surface morphological indicates that at higher discharge current and longer pulse on duration gives rougher surface characteristics with more craters, globules of debris, and micro-cracks than that of lower discharge current and lower pulse on duration.

Amorim et al. [13] worked on Performance and Surface Integrity of Ti6Al4VAfter Sinking EDM with Special Graphite Electrodes. Authors investigated the influence of electrical parameters in sinking ED-Machining of Ti6Al4V alloy using special graphite electrodes with particle size of 3, 10, and 15 um. They have found that the best results for material removal rate, workpiece surface roughness and volumetric relative wear were obtained for the graphite electrode of 10 um particle size and negative polarity. The use of a positive electrode, despite the graphite particle size, promoted very low material removal rate due to formation of oxides on the Ti6Al4V workpiece samples. For the finish EDM regimes, the modified layer presents an increased amount of titanium carbide compared to semi-finish and rough regimes. Authors concluded that the EDM regime and the graphite particle size (15, 10, and 3 um) an adequate cost-benefit ratio for EDM of Ti6Al4V is the use of 10um graphite.

Tang and Guo [14] worked on Electrical discharge precision machining parameters optimization investigation on S-03 special stainless steel. In this Authors evaluate process performance criteria such as material removal rate and surface roughness. EDM technology can obtain high precision in processing S-03 material and has been reported in this paper. The effects on MRR and SR of S-03 material by gap voltage, peak discharge current, pulse width, and pulse interval. Authors found that machining performance of the surface roughness decreases from 1.6 to 1.7 μm , which satisfied the demand of the product. Perfectly, the material removal rate increases from 10.5 to 13.3 mm^3/min, it is nearly improved by 27 %.

Klocke et al. [15] worked on Die sinking EDM machine for the optimization of material removal rate and electrode wear rate by using different grades of graphite. In this Authors evaluate process performance such as material removal rate and electrode wear rate. Authors found that discharge current effect material removal rate and discharge duration directly affect tool wear rate.

Azizi et al. [16] worked on Surface roughness and cutting forces modeling for optimization of machining condition in finish hard turning of AISI 52100 steel. Authors found that surface roughness increases with the increase of feed rate and almost decreases with the increase of workpiece hardness. ANOVA results show that the feed rate, workpiece hardness and cutting speed affect the surface roughness (Ra) by 83.93%, 10.07% and 5.81% in the finish hard turning process, respectively. Authors also found thrust force is at least 1.06 times higher than the tangential cutting force, while the maximum is 2.62 times higher in the range of 46−62 HRC. Authors found optimum value of machining conditions to produce the lowest surface roughness with minimal cutting forces are in the region of: cutting speed, 170 m/min; feed rate, 0.08 mm/rev; depth of cut, 0.1 mm; and workpiece hardness, 56.51 HRC; with estimated surface roughness of 0.309 μm and cutting forces Fa, Fr and Ft of 26.72 N, 134.01 N and 53.92 N, respectively. The average percentage error obtained by confirmation experiments was determined to be 5.89% and 3.06% for surface roughness (Ra) and cutting forces (Fa, Fr and Ft), respectively; which proves the reliability of the equations established.

Singh [2] worked on Die sinking EDM machine to study the effect of copper chromium and aluminum electrode on EN31. In this Authors evaluate process performance criteria such as material removal rate, electrode wear rate, hardness, depth of cut and over cut. Authors found that brass electrode has a more depth of cut and hardness but copper chromium has a more material removal rate with lower electrode wear.

Rajesh et al. [17] worked on Die sinking EDM machine to study the optimization of EDM process by using genetic algorithm and response surface methodology. In this Authors evaluate process performance criteria such as material removal rate, surface finish. Authors found that the optimal condition obtained by grey analysis for maximizing material removal rate and minimize surface roughness.

Jung and Kwon [18] worked on Die sinking EDM machine to study the optimization of EDM process using grey relation analysis and taguchi method. In this Authors evaluate process performance criteria such as electrode wear and most effect parameters are input voltage and capacitance. Authors found that optimal machining condition for drilling of a micro hole of minimum diameter.

Rao et al. [19] worked on Die sinking EDM machining to study the parameter optimization of AISI 304 during EDM process. In this Authors evaluate process performance criteria such as material removal rate, tool wear rate, surface roughness and hardness. Authors found that material removal rate is increases when current, servo and duty cycle is fixed as high as possible.

Kao et al. [20] worked on Die sinking EDM machine to study the EDM parameters during process of Ti-6Al-4V. In this Authors evaluate process performance criteria such as material removal rate, electrode wear ratio, surface roughness. Authors found that optimal machining condition to decrease 15% EWR, increase 12% MRR, decreases 19% surface roughness.

Pellicer et al. [21] worked on die sinking EDM to study Parameters optimization of EDM process on AISI H13. In this Authors evaluate process performance criteria such as material removal rate, surface roughness, depth, width, slope. Authors found that when discharge current increase than material removal rate increases and surfaces roughness decrease.

Sohani et al. [22] worked on Die sinking EDM machine to study the effect of tool shape as well as size on EDM process. In this Authors evaluate process performance criteria such as material removal rate, tool wear rate. Authors found that circular shape of electrode is very effective to increase material removal rate and decrease tool wear rate.

Gao et al. [23] worked on parameter optimization model in electrical discharge machining process. In this Authors used artificial neural network to provide a relation between input parameters and material removal rate, which adapted Leven berg-Marquardt algorithm and its network architecture was 3-26-1. It shows that the net has better generalization performance, and convergence speed is faster. GA is used to optimize parameters. MRR is improved by using optimized parameters; it is close to experiment result. With the increase of current, MRR can be improved.

Keskin et al. [24] performed an EDM process to carried out parameters effecting surface roughness and selected parameters are power, spark time and pulse time. Authors found that surface roughness increasing with an increase in the discharge duration.

2.2 RESEARCH GAP

From the literature survey research gaps are found, which contribute to the selection of my topic, which is as follows:

1. There are many parameters that affect machining in EDM, but the Researchers have only taken very few parameters at a time.
2. A less amount of research has been done on tempered High Speed Steel.
3. Research has been done on many materials and on AISI M2 with cryogenic treatment but research on HSS (M2, M35 and M42) simultaneously with normal copper electrode is yet to be carried out.

2.3 SCOPE OF THE STUDY

1. High Speed Steel is mainly used in making of dies & punches but in this experiment there is evaluation and comparision the results of Surface roughness, Material removal rate and Tool wear rate which helps in selecting the correct electrode material and parameter for specific type of material.
2. Copper (cu) electrode at specific setting with the correct flushing technique can produce a mirror-like surface finish. This is beneficial is small cavities where it is difficult to polish.
3. If best parameter is known than more Material removal, lower Surface roughness and less Tool wear rate is easily carried out.
4. Well known of best parameters, machining will be less time consuming and also it is beneficial at economic point of view.

2.4 OBJECTIVE OF THE STUDY

In this Thesis work, EDM machining is performed on tempered High Speed Steel (M2, M35 and M42) by using copper (cu) material of electrode. From the literature survey it is known that very few researches has been done on M2, M35 and M42. Researchers has mostly concentrated or experimentation done on M2 by using cryogenic copper electrode on EDM. In this Thesis work it is proposed to Evaluate and Compare the result of Surface Roughness, Material Removal Rate and Tool Wear Rate of High speed steel (M2, M35 and M42) on Electric Discharge Machine by using Copper electrode.

The main objectives are as follows-:

1. Machining of tempered High Speed Steel (M2, M35 and M42) by using copper (cu) electrode of diameter (12mm).
2. To evaluate and compare the Material removal rate, Surface roughness and Tool wear rate on Die- Sink EDM.
3. Analysis is done by using Taguchi and Anova method.

CHAPTER3. METHODOLOGY

3.1 METHODOLOGY FOLLOWED

3.1.1 Description of machine / set up

The experimentation work will be done on EDM machine placed in Advanced machining lab at LPU Phagwara, Punjab. Copper electrode of diameter (12mm) is used in EDM for machining of High Speed Steel (M2, M35 and M42) . EDM Grade oil will be used as a Dielectric Fluid.

3.1.2 PARAMETERS OF EDM [5]

Design parameter, Variable parameter and constant parameter are following ones:

3.1.2.1 Design parameters– Parameters which can be carried out during experimentation.

1. MRR
2. TWR
3. Over cut
4. Surface roughness
5. Residual stress.

3.1.2.2 Variable parameter– There are some variable parameter which can be used during experimentation.

1. Current (Ip)
2. Pulse on time (Ton)
3. Pulse off time (Toff)
4. Tool shape
   - (i) Triangular electrode
   - (ii) Convex electrode
   - (iii) Rectangular electrode
   - (iv) Circular electrode

3.1.2.3 Constant parameter- There are some constant parameter which can be used during experimentation (Voltage, Polarity, Duty cycle, Flushing pressure).

3.1.2.4 Selection of material

Conductive workpiece is only employed in EDM. In this experiment, HIGH SPEED STEEL of grades M2, M35 and M42 is selected which can withstands higher temperatures without losing its hardness. High Speed Steel mostly used in manufacturing of various tools. Nowadays punches and dies are manufactured from High Speed Steel.HSS has many magnificent properties such as high hardness and good toughness. HSS having a less wear of edges as compared to high carbon steel tools. I have brought my work piece tempered M2, M35 and M42 from HTM alloy industry, Giaspura, Ludhiana.

M2 is molybdenum based of High Speed Steel, Nowadays M2 is mostly used type of high-speed steel. M2 contains higher carbon (0.78-0.88).Balanced chemicals analysis of M2 produce a property which are applicable in all general purpose high speed uses. M2 steel is used in practically all applications as specified for T-1 high speed. These applications include punches, dies and mould making of cutting tools.

Table1: Chemical Composition of M2

	C	**Si**	**Mn**	**P**	**S**	**Cr**	**Mo**	**V**	**W**	**Co**	**Ni**
AISI-M2	0.78-0.88	0.20-0.40	0.20-0.40	0.35	0.35	3.75-4.50	4.50-5.50	1.60-2.20	5.50-6.75	0	0

M35 is also molybdenum based High Speed Steel alloy.M35 is not exactly but similar to M2 except that 5% cobalt is added. Cobalt having a property of good heat resistance, so it increases heat resistance property of M35.M35 is also used for punches, dies and cutting tools.M35 is best used in cutting condition where demands of hot hardness are of importance. M35 can be used for cold work applications, where wear resistance is required.M35 gives a good combination of wear resistance and toughness.

Table2: Chemical Composition of M35

	C	Si	Mn	P	S	Cr	Mo	V	W	Co	Ni
AISI-M35	0.85-0.95	0.00-0.40	0.00-0.40	0.35	0.35	3.75-4.50	4.75-5.25	1.75-2.15	6.00-6.75	4.60-5.20	0.00-0.40

M42 is a very hard material and its composition is mainly molybdenum based type of High Speed Steel. M42 is more harden than M2, M35 and it also consist more percentage of cobalt such as 8% more than as compared to M35. M42 is used in making of dies, punches and cutting tools. M42 is mostly used where requirement of hot hardness is necessary i.e where high performance is essential.

Table3: Chemical Composition of M42

	C	Si	Mn	P	S	Cr	Mo	V	W	Co	Ni
AISI-M42	1.05-1.15	0.15-0.65	0.15-0.40	0.35	0.35	3.50-4.25	9.00-10.00	0.95-1.35	1.15-1.85	7.75-8.75	0

3.1.2.5 Selection of Tool material:

The basic characteristics of electrode materials are:-

1) High electrical conductivity.
2) High thermal conductivity.
3) Higher density.
4) High melting point.
5) Easy manufacturability.

Based on all characteristics of electrode materials, Copper (cu) electrode having diameter 12mm selected respectively for the experimentation of High Speed Steel. Copper and copper alloys have better EDM wear resistance than brass, but are more difficult to machine than either brass or graphite. It is also more expensive than graphite.

Fig16-Copper electrode

5.1.2.6 Responses to be measured:

i) Material Removal Rate (MRR)

- $MRR = \frac{W_i - W_f}{Time * Density} mm^3/min.$

ii) Tool Wear Rate (TWR)

- $TWR = \frac{W_i - W_f}{Time * Density} mm^3/min.$

iii) Surface Roughness

3.2 Design of Experiment

Taguchi method is used to decrease the number of experiment and create a work plan chart for the further experiments. Taguchi method is very effective method as compared to another DOE method. Taguchi method is economical and time saving technique. In Taguchi method, three factors such as pulse on time, pulse off time and discharge Current are considered to study the influence of output parameters. In this experimentation L9 orthogonal array is considered for further study, L9 orthogonal array is used for the evaluation of effects of input parameters on machining performance (MRR, SR, TWR).

3.2.1 Taguchi's method

Taguchi method decrease the number of experiment and give a optimal and effective parameters which effect process. L9 array is used in this experimentation any by using L9 array process chart is constructed.

The process has three stages:

- System design
- Parameter (measure) design
- Tolerance design

3.2.2 System design

In Taguchi method, concentrate on conceptual level, creativity, and innovation during system design.

3.2.3 Parameter design

In Taguchi method, during parameters design consider that parameters which effect the performance and it allow to choose those parameters which minimize effect on performance requirement in the system. This phenomena sometime known as a Robustification.

3.2.4 Tolerance design

After selecting the optimal parameters and understanding the effect of each parameters on performance then concentrate on reducing and controlling variation in few dimensions.

3.2.5 Analysis of Experiment

When the experimentation is done then Analysis of variance is performed to confirmation of the data collected through experiments. For the validation of the result, confirmation tests is necessary values obtained from the Taguchi Method. From the combination of factors and levels conduct an experiment for the validation process.

In the familiar regression context, the Total sum of squares, can be decomposed as follows,

$$SS_{total} = \sum_{i=1}^{N}(Yi - \bar{y}i)^2$$

The Regression sum of squares,

$$SS_{regression} = \sum_{i=1}^{N} (\hat{Y}i - \bar{y})^2$$

The Error in sum of square,

$$SS_{error} = \sum_{i=1}^{N} e_i^2$$

Total Sum of Square is followed as,

$$SS_{total} = SS_{regression} + SS_{error}$$

Table 4: Anova table

Source	df	SS	MS	F
Regression	p	$SS_{Regression}$	$SS_{Regression/p}$	$\dfrac{SS_{Regression/p}}{SS_{Total/n-1}}$
Error	n-p-1	SS_{Error}	$SS_{Error/n-p-1}$	
Total	n-1	SS_{Total}		

CHAPTER4. RESULT AND DISCUSSION

4.1 Experimentation on AISI M2

L9 array is used in this experimentation any by using L9 array process chart is constructed. Experimentation is performed on AISI M2 and achieved material removal rate, tool wear rate and surface roughness is shown in table below.

Table 5: Design Matrix of L9 Orthogonal Array for machining of M2

I	Ton	Toff	MRR	TWR	SR
15	200	200	3.009	0.791	4.48
15	400	400	30.864	6.510	7.88
15	600	600	31.453	0.710	10.78
20	200	400	5.856	1.906	4.11
20	400	600	22.446	8.116	8.52
20	600	200	0.586	0.013	9.27
25	200	600	1.605	0.928	4.9
25	400	200	36.008	5.580	7.54
25	600	400	72.873	6.200	11.09

4.1.1 Design of Experiment

Analysis is done by using Minitab software is shown below:

4.1.1.1 Material removal rate (MRR)

From the Anova table, it is clear the most effective factor for material removal rate is pulse-on time (1.24) and most significant factor is again pulse-on time for material removal rate is (0.446).

Table6: Anova table for SN ratio of M2 for mrr

SOURCE	DF	Seg SS	Adj SS	Adj MS	F	P
I	2	246	246	123	0.52	0.656
Ton	2	582	582	291	1.24	0.446
Toff	2	352	358.5	179.2	0.76	0.567
Residual		4688	468.8	234.4		

error	2					
Total	8	1655.3				

Table7: Response Table for SN Ratios of M2 for mrr

Level	**I**	**Ton**	**Toff**
1	23.104	9.678	12.022
2	12.581	29.313	27.464
3	24.163	20.857	20.362
Delta	11.582	19.636	15.443
Rank	3	1	2

From the response table, it is found that most effective value of current is 24.163, pulse-on time is 9.678 and pulse-off time is 27.464 for material removal rate.

4.1.1.2 Tool wear rate (TWR)

From the Anova table, it is clear the most effective factor for tool wear rate is pulse on time (1.80) and most significant factor is pulse-on time for tool wear rate is (0.357).

Table 8: Anova table for SN ratio of M2 for twr

SOURCE	**DF**	**Seg SS**	**Adj SS**	**Adj MS**	**F**	**P**
I	2	323.	323.3	161.7	0.62	0.616
Ton	2	3933.9	933.9	467	1.80	0.357
Toff	2	662.7	662.7	331.4	1.28	0.439
Residual error	2	519.6	519.6	259.8		
Total	8	2439.6				

Table9: Response Table for SN Ratios of M2 for twr

Level	I	Ton	Toff
1	-3.759	-0.976	8.216
2	4.587	-16.464	-12.574
3	-10.046	8.222	-4.860
Delta	14.6331	24.686	20.790
Rank	3	1	2

From the response table, it is found that most effective value of current is -10.046, pulse-on time is -0.976 and pulse-off time is -12.574 for tool wear rate.

4.1.1.3 Surface Roughness (SR)

From the Anova table, it is clear the most effective factor for surface roughness is pulse-on time (111.80) and most significant factor is pulse-on time for tool wear rate is (0.357).

Table10: Anova table for SN ratios of M2 for SR

SOURCE	DF	Seg SS	Adj SS	Adj MS	F	P
I	2	0.712	0.712	0.356	0.96	0.511
Ton	2	82.819	82.819	41.409	111.08	0.009
Toff	2	1.687	1.687	0.843	2.26	0.307
Residual error	2	0.745	0.745	0.372		
Total	8	85.964				

Table 11: Response Table for SN Ratios of M2 for SR

Level	I	Ton	Toff
1	-17.20	-13.04	-16.64
2	-16.74	-18.03	-17.04
3	-17.42	-20.30	-17.69
Delta	0.67	7.26	1.05
Rank	3	1	2

From the response table, it is found that most effective value of current is -17.42, pulse-on time is -13.04 and pulse-off time is -17.04 for surface roughness.

4.1.1.4 Main plots for MRR, TWR, SR

4.1.1.4.1 Material removal rate (MRR)

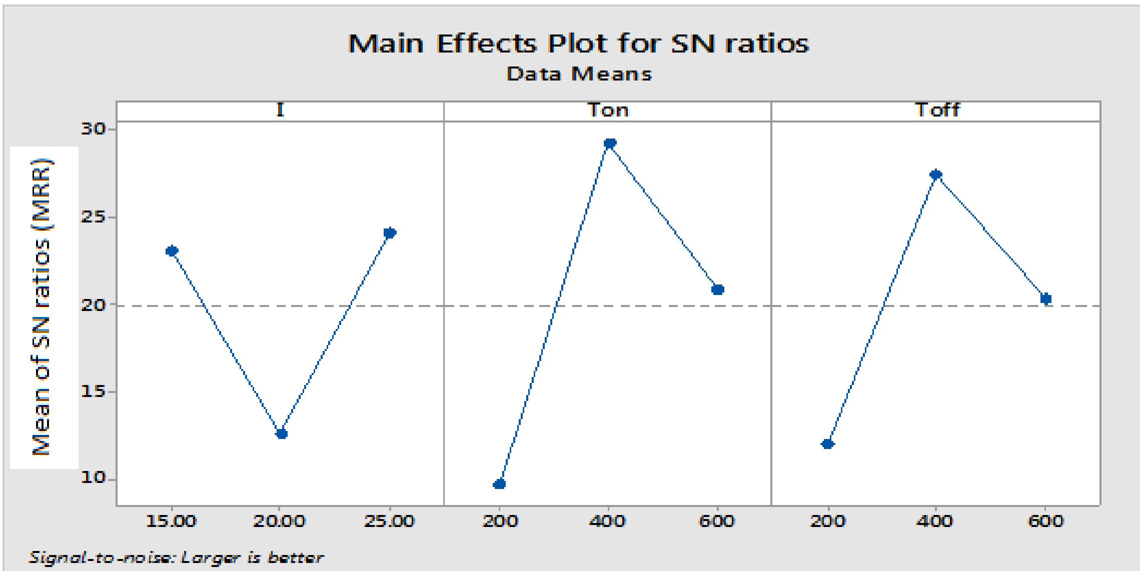

Fig17: MRR of M2

From the figure 17, it is shown that material removal rate is maximum when the value of current is 25amp, pulse on time is 400micro sec. and pulse of time is 400 micro sec. and the material removal rate is minimum when the value of current is 20amp, pulse on time is 200micro sec., pulse off time is 200 micro sec.

4.1.1.4.2 Tool wear rate (TWR)

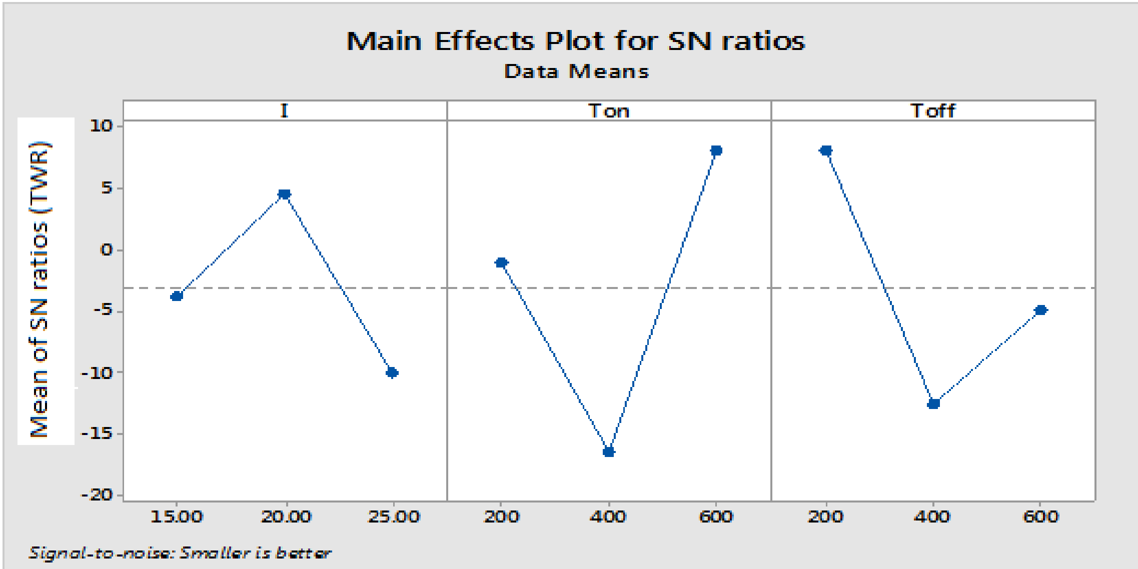

Fig18: TWR of M2

From the figure 18, it is shown that Tool wear rate is maximum when the value of current is 20amp, pulse on time is 600micro sec. and pulse of time is 200 micro sec. and the Tool wear rate is minimum when the value of current is 25amp, pulse on time is 400micro sec., pulse off time is 400 micro sec.

4.1.1.4.3 Surface roughness (SR)

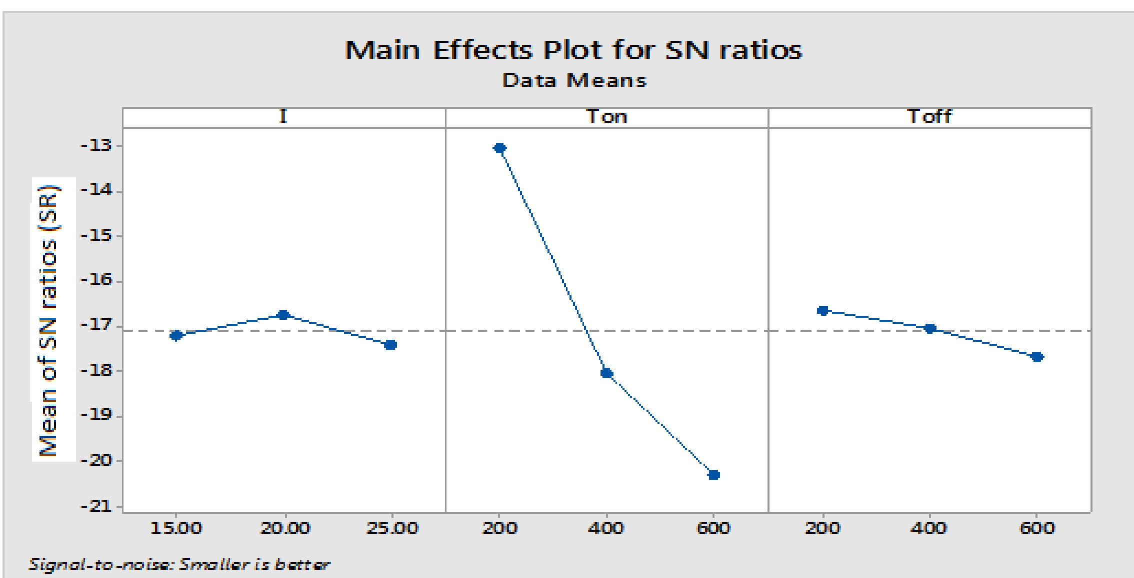

Fig19: SR of M2

From the figure 19, it is shown that Surface roughness is maximum when the value of current is 20amp, pulse on time is 200micro sec. and pulse of time is 200 micro sec. and the Surface roughness is minimum when the value of current is 20amp, pulse on time is 600micro sec., pulse off time is 600 micro sec.

4.2 Experimentation on AISI M35

L9 array is used in this experimentation any by using L9 array process chart is constructed. Experimentation is performed on AISI M2 and achieved material removal rate, tool wear rate and surface roughness is shown in table below.

Table12: Design Matrix of L9 Orthogonal Array for machining of M35

I	Ton	Toff	MRR	TWR	SR
15	200	200	3.164	65.616	4.31
15	400	400	6.510	64.97034	7.94
15	600	600	18.538	171.7572	10.45
20	200	400	2.527	94.88175	5.79
20	400	600	18.696	430.7692	9.55
20	600	200	1.484	3.812766	13.38
25	200	600	2.333	105.8268	4.52
25	400	200	0.863	1.099387	15.38
25	600	400	45.167	145.6911	10.21

4.2.1 Design of Experiment

Analysis is done by using Minitab software is shown below:

4.2.1.1 Material removal rate (MRR)

From the Anova table, it is clear the most effective factor for material removal rate is pulse-off time (1.36) and most significant factor is pulse-off time for material removal rate is (0.424).

Table13: Anova for SN ratio of M35 for mrr

SOURCE	DF	Seg SS	Adj SS	Adj MS	F	P
I	2	41.90	41.90	20.95	0.12	0.891
Ton	2	223.97	223.97	111.98	0.66	0.604
Toff	2	462.76	462.76	231.38	1.36	0.424
Residual error	2	341.22	341.22	170.61		
Total	8	1069.84				

Table14: Response Table for SN Ratios of M35 for mrr

Level	I	Ton	Toff
1	17.213	8.473	4.053
2	12.306	13.477	19.141
3	13.060	20.629	19.385
Delta	4.907	12.156	15.332
Rank	3	2	1

From the response table, it is found that most effective value of current is 13.060, pulse-on time is 13.477 and pulse-off time is 4.053 for material removal rate.

4.2.1.2 Tool wear rate (TWR)

From the Anova table, it is clear the most effective factor for tool wear rate is pulse-off time (3.17) and most significant factor is pulse-off time for tool wear rate is (0.240).

Table 15: Anova table for SN ratio of M35 for twr

SOURCE	DF	Seg SS	Adj SS	Adj MS	F	P
I	2	180.2	180.2	90.10	0.39	0.720
Ton	2	120.7	120.7	60.37	0.26	0.793
Toff	2	1469.9	1469.9	734.96	3.17	0.240

Residual error	2	463.4	463.4	231.71		
Total	8	2234.3				

Table16: Response Table for SN Ratios of M35 for twr

Level	**I**	**Ton**	**Toff**
1	-39.10	-38.79	-16.26-39.69
2	-34.62	--29.92	-45.96
3	-28.19	-33.20	29.70
Delta	10.90	8.87	
Rank	2	3	1

From the response table, it is found that most effective value of current is -34.62, pulse-on time is -33.20 and pulse-off time is -16.26-39.69 for tool wear rate.

4.2.1.3 Surface Roughness (SR)

From the Anova table, it is clear the most effective factor for surface roughness is pulse-on time (10.98) and most significant factor is pulse-on time for tool wear rate is (0.083).

Table17: Anova table for SN ratios of M35 for SR

SOURCE	**DF**	**Seg SS**	**Adj SS**	**Adj MS**	**F**	**P**
I	2	8.384	8.384	4.192	0.92	0.521
Ton	2	100.087	100.087	50.044	10.98	0.083
Toff	2	7.240	7.240	3.620	0.79	0.557
Residual error	2	9.116	9.116	4.558		
Total	8	124.827				

Table 18: Response Table for SN Ratios of M35 for SR

Level	I	Ton	Toff
1	-17.02	-13.68	-19.65
2	-19.13	-20.45	-17.81
3	-19.01	-21.03	-17.70
Delta	2.10	7.35	1.96
Rank	2	1	3

From the response table, it is found that most effective value of current is -19.13, pulse-on time is -13.68 and pulse-off time is -17.70 for surface roughness.

4.2.1.4 Main plots for MRR, TWR, SR

4.2.1.4.1 Material removal rate (MRR)

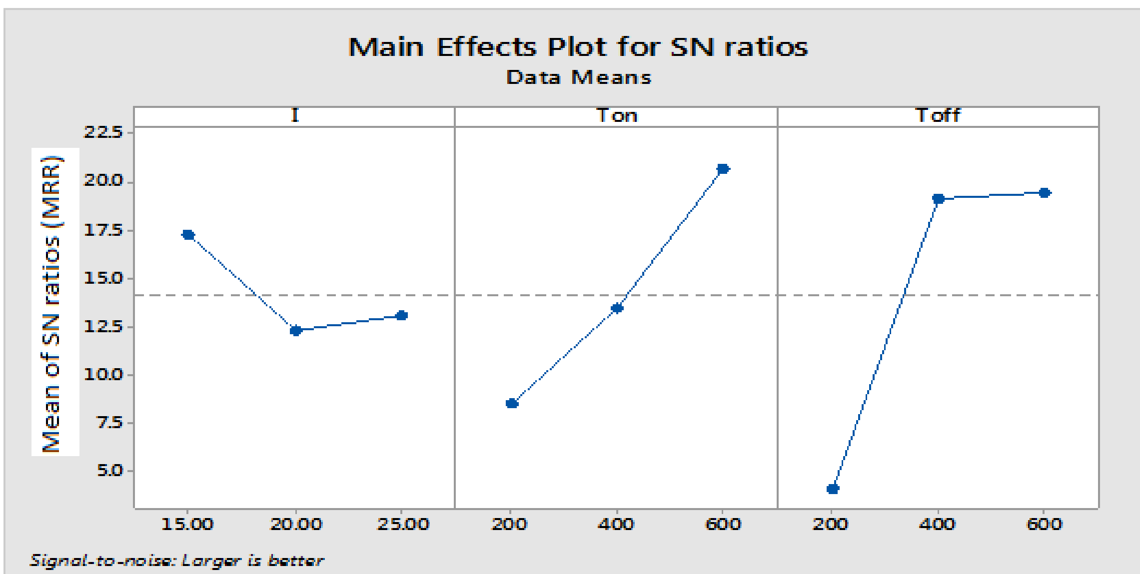

Fig20: MRR of M35

From the figure 20, it is shown that material removal rate is maximum when the value of current is 15amp, pulse on time is 600 micro sec. and pulse of time is 600 micro sec. and the material removal rate is minimum when the value of current is 20amp, pulse on time is 200micro sec., pulse off time is 200 micro sec.

4.2.1.4.2 Tool wear rate (TWR)

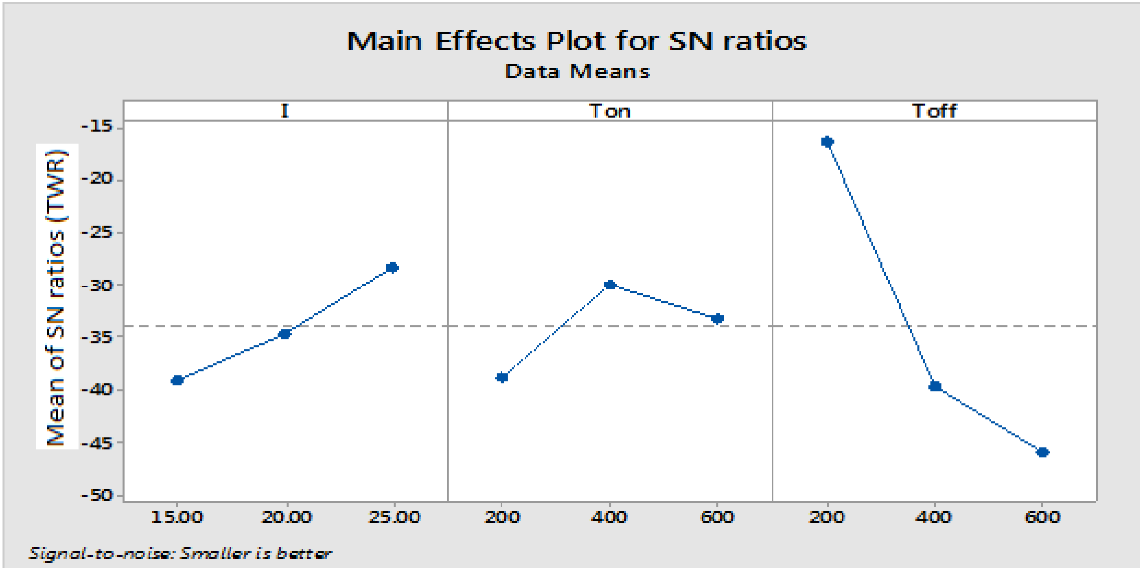

Fig21: TWR of M35

From the figure 21, it is shown that Tool wear rate is maximum when the value of current is 25amp, pulse on time is 400micro sec. and pulse of time is 200 micro sec. and the Tool wear rate is minimum when the value of current is 15amp, pulse on time is 200micro sec., pulse off time is 600 micro sec.

4.2.1.4.3 Surface roughness (SR)

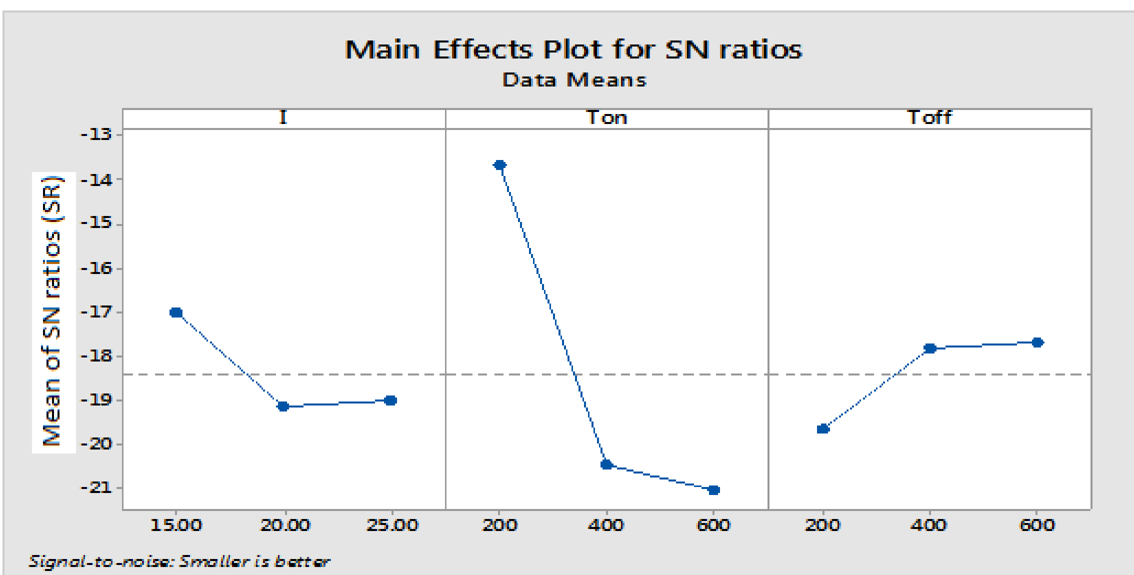

Fig22: SR of M35

From the figure ,it is shown that Surface roughness is maximum when the value of current is 15amp, pulse on time is 200micro sec. and pulse of time is 600 micro sec. and the Surface roughness is minimum when the value of current is 20amp, pulse on time is 600micro sec., pulse off time is 200 micro sec.

4.3 Experimentation on AISI M42

Table19: Design Matrix of L9 Orthogonal Array for machining of M42

I	Ton	Toff	MRR	TWR	SR
15	200	200	1.422	26.224	7.07
15	400	400	19.230	236.307	8.21
15	600	600	19.459	32.820	11.92
20	200	400	3.522	110.163	4.49
20	400	600	24.771	710.243	7.09
20	600	200	43.191	145.691	11.41
25	200	600	39.335	1503.776	4.28
25	400	200	0.650	2.795	14.18
25	600	400	44.014	252.314	13.06

4.3.1 Design of Experiment

Analysis is done by using Minitab software is shown below:

4.3.1.1 Material removal rate (MRR)

From the Anova table, it is clear the most effective factor for material removal rate is pulse-off time (0.92) and most significant factor is again pulse-off time for material removal rate is (0.522).

Table20: Anova for SN ratio of M42 for mrr

SOURCE	DF	Seg SS	Adj SS	Adj MS	F	P
I	2	49.04	49.04	24.52	0.09	0.918
Ton	2	423.19	423.19	211.60	0.77	0.564
Toff	2	502.96	502.96	251.48	0.92	0.522
Residual error	2	548.40	548.40	274.20		
Total	8	1523.59				

Table21: Response Table for SN Ratios of M42 for mrr

Level	I	Ton	Toff
1	18.18	15.30	10.68
2	23.84	16.61	23.16
3	20.34	30.45	28.52
Delta	5.67	15.16	17.84
Rank	3	2	1

From the response table, it is found that most effective value of current is 20.34, pulse-on time is 16.61 and pulse-off time is 10.68 for material removal rate.

4.3.1.2 Tool wear rate (TWR)

From the Anova table, it is clear the most effective factor for tool wear rate is pulse-off time (0.94) and most significant factor is pulse-off time for tool wear rate is (0.515).

Table 22: Anova table for SN ratio of M42 for twr

SOURCE	DF	Seg SS	Adj SS	Adj MS	F	P
I	2	206.02	206.02	103.01	0.21	0.826
Ton	2	62.76	62.76	31.38	0.06	0.940
Toff	2	918.68	918.68	459.34	0.94	0.515
Residual error	2	976.05	976.05	488.03		
Total	8	2163.50				

Table23: Response Table for SN Ratios of M42 for twr

Level	I	Ton	Toff
1	-35.39	-44.25	-26.86
2	-47.05	-37.81	-45.45
3	-40.17	-40.54	-50.30
Delta	11.66	6.44	23.44
Rank	2	3	1

From the response table, it is found that most effective value of current is -47.05, pulse-on time is -40.54 and pulse-off time is -26.86 for tool wear rate.

4.3.1.3 Surface Roughness (SR)

From the Anova table, it is clear the most effective factor for surface roughness is pulse-on time (15.56) and most significant factor is pulse-on time for tool wear rate is (0.060).

Table24: Anova table for SN ratios of M42 for SR

SOURCE	**DF**	**Seg SS**	**Adj SS**	**Adj MS**	**F**	**P**
I	2	8.761	8.761	4.380	1.56	0.391
Ton	2	87.555	87.555	43.777	15.56	0.060
Toff	2	18.046	18.046	9.023	3.21	0.238
Residual error	2	5.628	5.628	2.814		
Total	8	119.98				

Table 25: Response Table for SN Ratios of M42 for SR

Level	**I**	**Ton**	**Toff**
1	-18.93	-14.22	-20.39
2	-17.07	-19.44	-17.88
3	-19.33	-21.66	-17.06
Delta	2.26	7.44	3.33
Rank	3	1	2

From the response table, it is found that most effective value of current is -19.33, pulse-on time is -14.22 and pulse-off time is -17.88 for surface roughness.

4.3.1.4 Main plots for MRR, TWR, SR

4.3.1.4.1 Material removal rate (MRR)

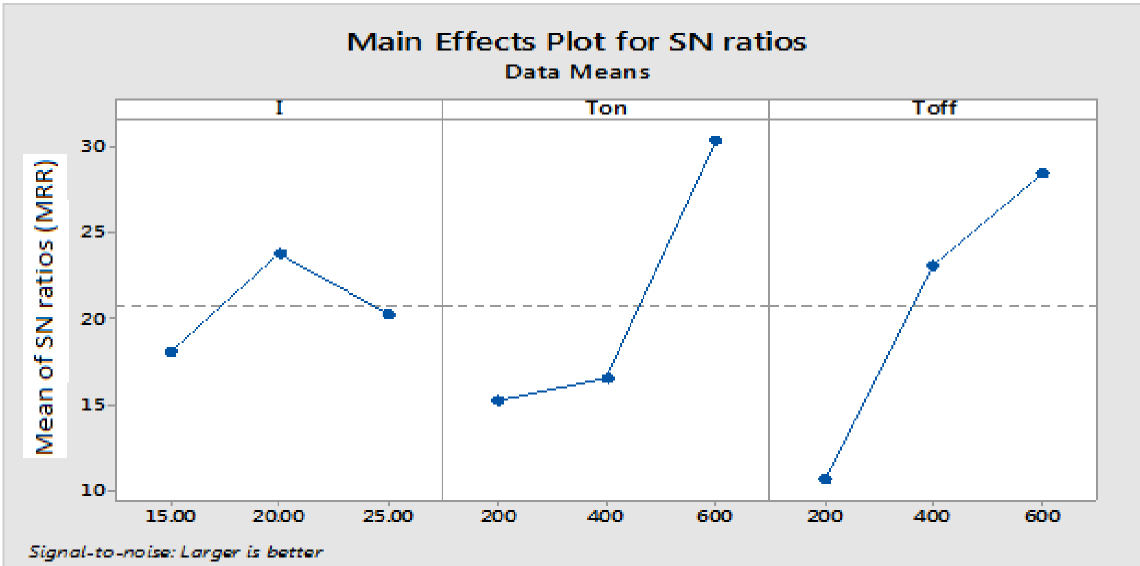

Fig23: MRR of M42

From the figure ,it is shown that material removal rate is maximum when the value of current is 20amp, pulse on time is 600micro sec. and pulse of time is 600 micro sec. and the material removal rate is minimum when the value of current is 15amp, pulse on time is 200micro sec., pulse off time is 200 micro sec.

4.3.1.4.1 Tool wear rate (TWR)

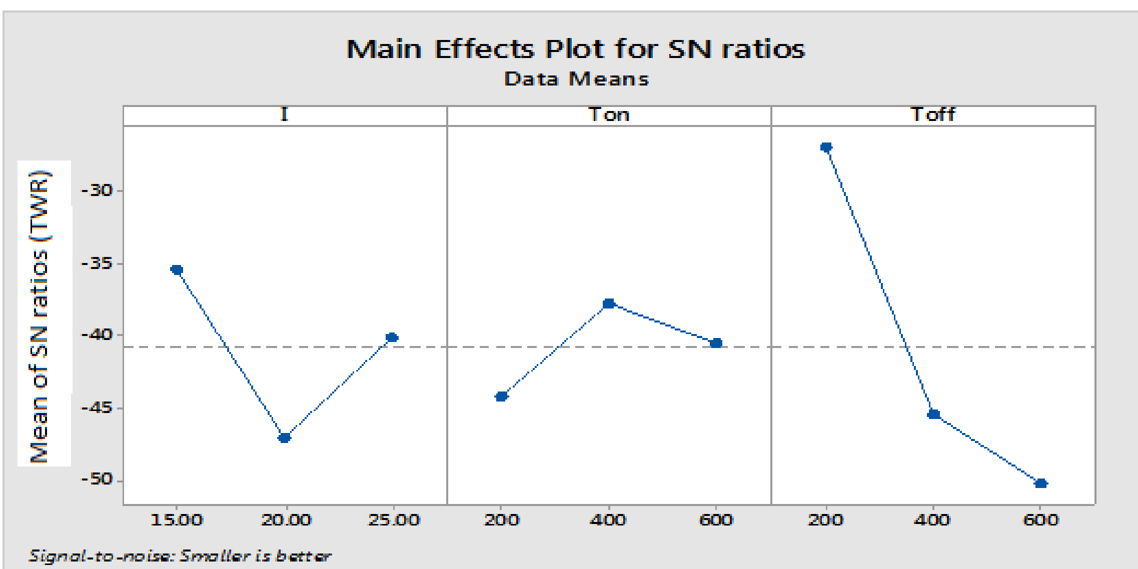

Fig24: TWR of M42

From the figure ,it is shown that Tool wear rate is maximum when the value of current is 15amp, pulse on time is 400micro sec. and pulse of time is 200 micro sec. and the Tool wear rate is minimum when the value of current is 20amp, pulse on time is 200micro sec., pulse off time is 600 micro sec.

4.3.1.4.3 Surface roughness (SR)

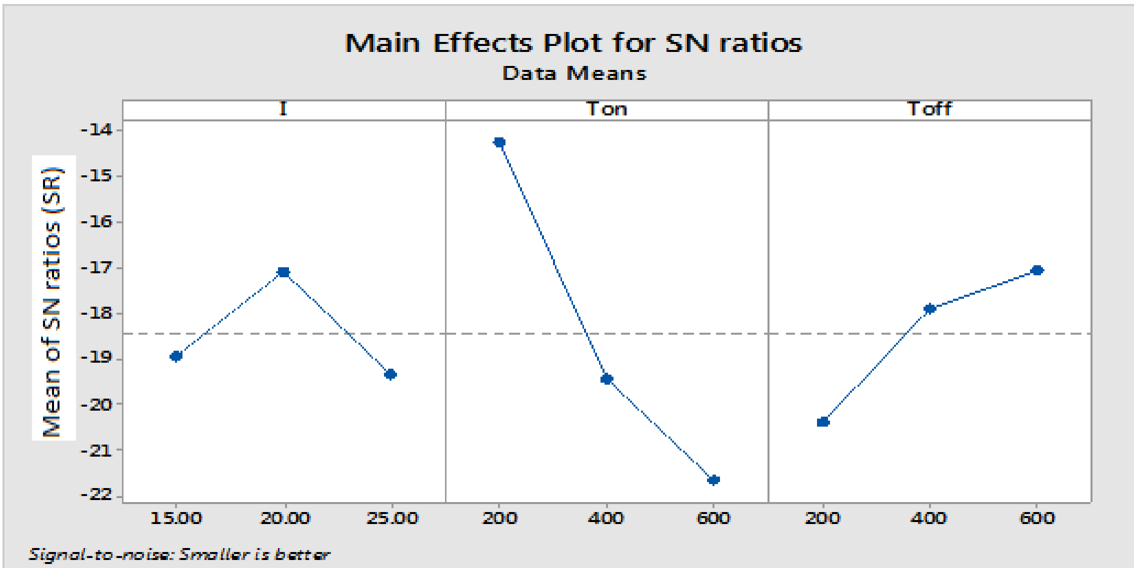

Fig25: SR of M42

From the figure ,it is shown that Surface roughness is maximum when the value of current is 20amp, pulse on time is 200micro sec. and pulse of time is 600 micro sec. and the Surface roughness is minimum when the value of current is 25amp, pulse on time is 600micro sec., pulse off time is 200 micro sec.

CHAPTER5. CONCLUSION

From the above data, it is clearly seen that discharge current and pulse on time has the most effected parameter in Electrical discharge machining on high speed steel of grade M2, M35 and M42. From the minitab software we are able to find optimum parameters for higher material removal rate, lower tool wear rate and lower surface roughness on high speed steel. Higher removal rate is achieved on material M2 when current is 25amp, pulse on time is 600 micro sec. and pulse off time is 400 micro sec. and lower tool wear is achieved again on material M2 when current is 20amp, pulse on time is 600 micro sec. and pulse off time is 200 micro sec. and better surface finish achieved during machining of M2 when current is 20amp, pulse on time is 200 micro sec. and pulse off time is 400 micro sec. So, machining of material M2 is more pronounced and gives better results than M35 and M42 while using Copper electrode. From the date it is known that discharge current and pulse-on time has more affected parameters in electrical discharge machining. When current increases leads to increase in material removal rate, tool wear rate and surface roughness. When pulse-on time increase also increase material removal rate, surface roughness but decreases tool wear rate.

CHAPTER6. FUTURE OF SCOPE

There are many grade of high speed steel available, some of them are molybdenum based and some of tungsten based on which electrical discharge machining is yet to carried out. Electrical discharge machining can be yet to performed with a composition of different class of high speed steel. Electrical discharge machining is very vast manufacturing process, different types of result can be obtained by changing parameters and material which will helpful for accurate machining ,time saving as well as cost saving for the required job. Machining of high speed steel with composition of different electrode is not performed, so machining with composite electrode can give a drastic better result as compared to Copper. Complex shape of die which is made up of high speed steel can be easily machined with accuracy by carrying out experimentation and found optimal parameters for specific grade of materials and electrodes.

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