DISSERTATION REPORT ON

EXPERIMENTAL INVESTIGATION AND PARAMETRIC OPTIMIZATION OF DIE STEEL, INCONEL 718 AND NIMONIC 80 IN POWDER MIXED ABRASIVE ELECTRIC DISCHARGE GRINDING PROCESS.

SUBMITTED IN PARTIAL FULFILMENT FOR THE AWARD OF MASTER OF TECHNOLOGY IN PRODUCTION ENGINEERING

BY

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UNDER THE GUIDANCE OF

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CERTIFICATE

This is to certify that the Project report on the topic "Experimental Investigation and Parametric Optimization of Die Steel, Inconel-718, and Nimonic 80-A Super Alloy in Powder Mixed Abrasive Electric Discharge Grinding Process." prepared by Vijay Pratap Singh (2013PPE5095) student of Master of Technology in Production Engineering of Malaviya National Institute of Technology, Jaipur is a bonafide compilation of the candidate's work based on published literature on the topic.

Dated: June 2015

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ABSTRACT

Hybrid machining processes are becoming more popular for machining of hard materials i.e. difficult to machine materials as there are many challenges in machining high strength alloys, composites, and ceramics, etc., and hence a need of developing the hybrid processes and understanding their process capabilities is a major research area in Production engineering. In this work, a hybrid machining process called Powder Mixed Abrasive Electric Discharge Grinding (PMAEDG) has been proposed for machining of Die steel, Inconel 718 and Nimonic 80A. The experiments were carried out on an in-house fabricated PMAEDG set up on Electronica ZNC EDM machine. The bronze bonded diamond grinding wheel attachment was used along with EDM to achieve Electro Discharge Grinding while a separate tank attached to mix abrasive in dielectric fluid.

Performance features of machining different materials in PMAEDG during machining of AISI D3 steel, Inconel 718, and Nimonic 80A have been investigated. The experiments were planned according to Taguchi Experiment Design Methodology and signal to noise (S/N) is used to indicate the functioning of the process. The SiC powder with mean mesh size of 150-170 µm was mixed in dielectric fluid. The wheel speed, powder concentration, current, pulse on time were selected as control machine parameters where as metal cutting rate (MRR) and mean surface roughness (R_a) were selected as output performance parameters. The results indicated that wheel speed, powder concentration, current are the most significant machining parameters in PMAEDG process. In all cases, MRR increases with increase increasing wheel speed increases metal cutting rate as at higher wheel speed more volume of work piece will be abraded by the grinding wheel. Also, MRR increases with current as with increase in current more discharge energy will erode more volume of the work piece. The metal cutting also increases with increase in SiC concentration of 4g/l as initially increase in powder concentration will assist more stable spark channel. There is 3-4 times increase in MRR compared to conventional EDM, and grinding level of surface finish is obtained as the process is Grinding Assisted; with a minimum 2.67 µm surface roughness achieved.

During PMEDDG of Die Steel and Inconel 718, it was found that 6g/lit of power concentration, 1400 rpm wheel speed and 4 amps current results in optimum material removal rate. The most favorable parameters ascertained in PMEDDG on Nimonic 80A are wheel speed of 1400 rpm, powder concentration of 4 g/lit current of 10 amps, and pulse-on-time of 26 µs.

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LIST OF ABBREVIATIONS:

EDM	Electric Discharge Machining
EDDG	Electric Discharge Diamond Grinding
AEDG	Abrasive Electric Discharge Machining
PMEDM	Powder Mixed Electric Discharge Machining
PMAEDG	Powder Mixed Abrasive Electric Discharge Machining
AEDCG	Abrasive Electric Discharge Cut off Grinding
AEDFG	Abrasive Electric Discharge Face Grinding
AEDSG	Abrasive Electric Discharge Surface Grinding
MRR	Material Removal Rate
Ra	Surface Roughness
PMAEDCG	Powder Mixed Abrasive Electric Discharge Cut Off Grinding
PMEDDG	Powder Mixed Electric Discharge Diamond Grinding
AMEDDG	Abrasive Mixed Electric Discharge Diamond Grinding
SEM	Scanning Electron Microscopy

1. Introduction:

1.1 EDM:

Electric Discharge Machining (EDM) is a non formal electrically conductive machining process.EDM is substantially founded machining option for fabricating geometrically coordination compound or hard materials that are highly difficult to machine by ordinary processes. The non adjoin fabricating technique has been continuously developing from a simple tool and die making process to a micro scale application fabricating option drawing a substantial number of research involvements. (Ho & Newman, 2003)

There are basically two types of EDM set ups, the use of Ram and the Wire cut. Each one used to fabricate very small and precise parts as well as large items like automotive Stamping Dies and aircraft body components.

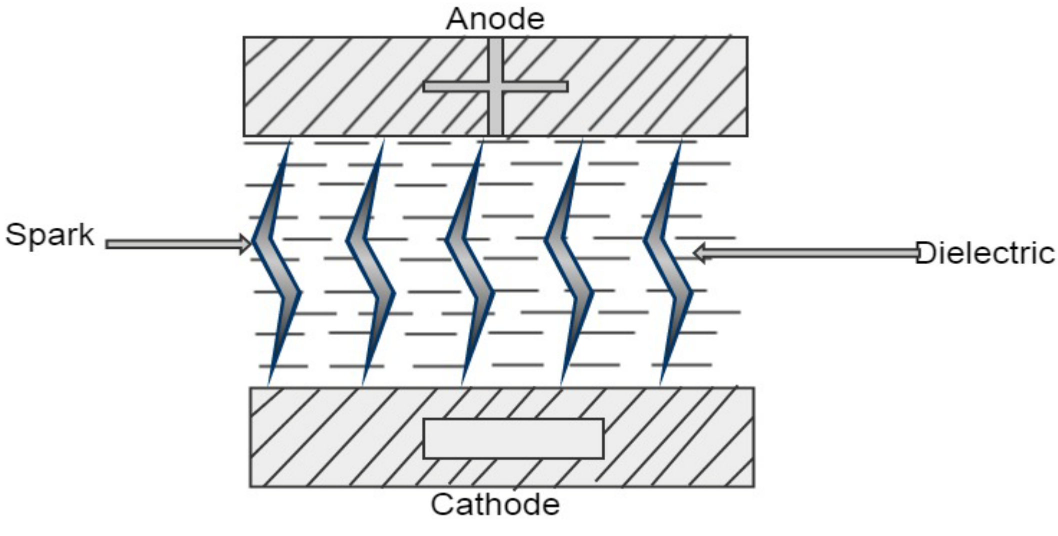


Figure 1.Conventional EDM Process.

Advantages of EDM.

- EDM is a non adjoins process that produces no cutting forces, allowing the production of small and delicate pieces.
- Burr devoid corners are produced.

- Complex shapes and higher up finishes are possible.
- EDM machines with built-in process cognition allow the fabrication of complex parts with least operator interference.

Limitations of EDM.

- Material removal rate is less compared to chip machining.
- Production of Electrode requires time.

1.2 EDDG (Electric Discharge Diamond Grinding).

In order to machine high strength composites, polycrystalline Diamonds (PCD), polycrystalline cubic boron nitride (PCBN), high strength alloys such as nickel alloys like Inconel, Nimonic, Haste, Wasp alloys etc is challenging due to their inbuilt high strength and high toughness properties.

AEDG (Abrasive Electric Discharge Grinding) process, where interactive effect of combination of electrical discharge machining and grinding process is employed to increase machining productivity. The part of conventional grinding and Electro discharge grinding (EDG) to AEDG example shows in Figure 3 and 4.

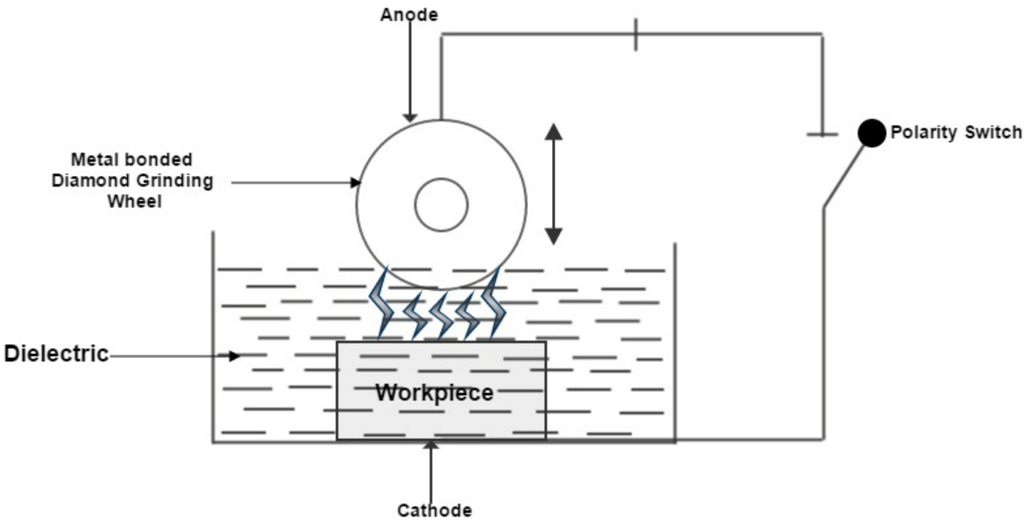


Figure 2:Abrasive Electric Discharge Process.

(Kozak, 2002)In the AEDG process, metallic and Graphite electrode used in Electric Discharge process has been replaced with metallic bonded grinding wheel. Therefore, the material removal is the combined effect of electro erosion and micro cutting process (mechanical effect of abrasives).

Observable gain in performance measures of the AEDG process turns up when fabricating super hard materials, composites, sintered carbides and metal composites. Thus, EDDG is a moderated electro discharge process aided by mechanical grinding. EDM grinding process can be done when tool and work piece gets in contact .Short circuiting may take place when tool and work piece come in contact but due to the Diamond abrasive wheel as diamonds are isolators hence it prevents from short circuiting. Speed of the removal of electrically non-conductive components increased due to abrasion action in the process when machining electrical conductive composites like PCD and PCBN. Protuberances can also be smoothen off by the abrasion process, of the non conductive ingredients, which insulate the inter electrode gap, so that the electro erosion can be accelerated. Simultaneously electrical discharge interactions on the metal bond super abrasive-grinding wheel lead to its self-dressing in AEDG (Abrasive Electric Discharge Grinding) process.

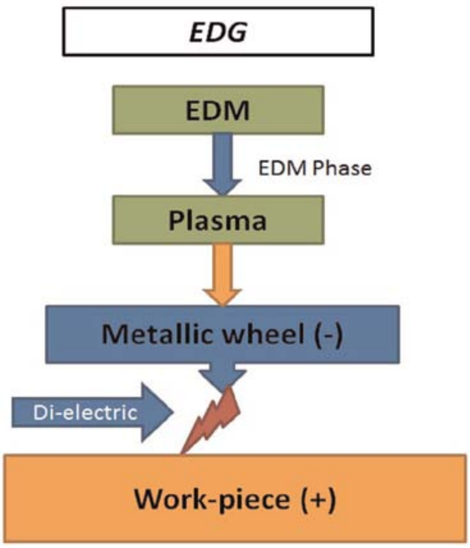


Figure 3.Elements of EDG (Unune & Mali, 2014)

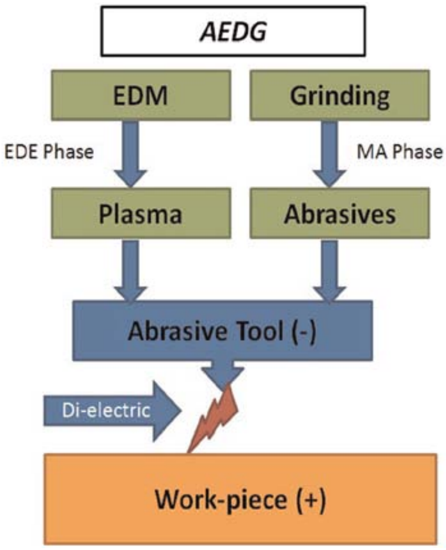


Figure 4.Elements of AEDG (Unune & Mali, 2014)

Advantages of AEDG:

- Improved surface finish with higher material removal rate.

1.3 AEDG Orientations:

In Abrasive electric discharge grinding process the grinding can be performed in three different orientations.

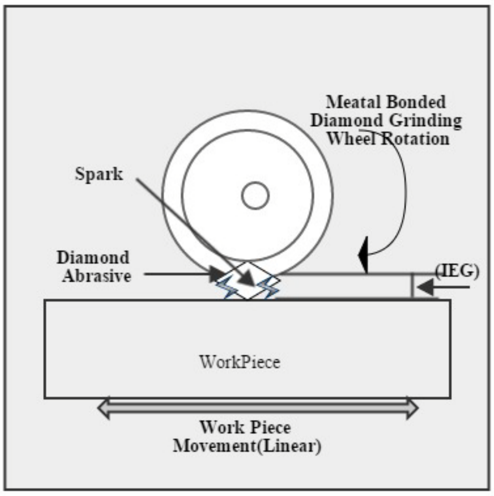


Figure 5.AEDSG (Abrasive Electric Discharge Surface Grinding)

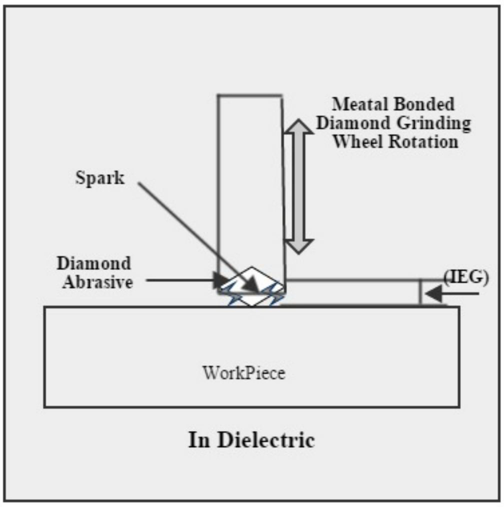


Figure 6.AEDCG (Abrasive Electric Discharge Cut off Grinding)

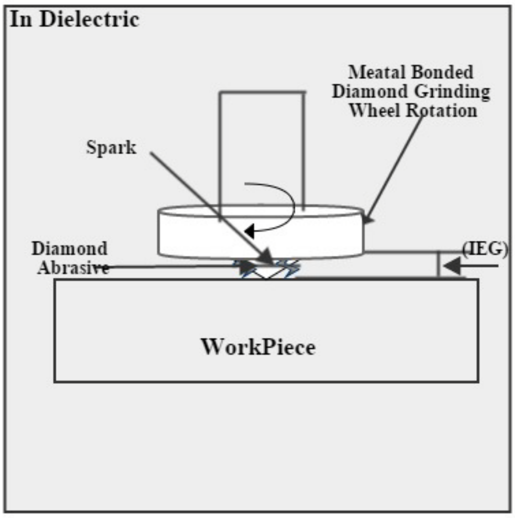


Figure 7.AEDFG(Abrasive Electric Discharge Face Grinding).

2. PMAEDG (Powder Mixed Abrasive Electric Discharge Grinding)

Powder Mixed Abrasive Electric Discharge Grinding is used to overcome the limitations of current EDM machines coping with delicate surface finish over large process area. Indeed this is the reason for manual polishing of mould cavities machined by EDM. Recently PMEDM focus of an acute research work in order to subdue these technological performance barriers. (Erden & Bilgin, 1980) First studied the characteristics of powder mixing in the dielectric medium. Both studied the effect of various powders like copper, aluminium, graphite, silicon carbide and found that in mixing the abrasive powders in the dielectric reduces the ignition time and the strength of the dielectric hence the abrasive erodes the material and hence Material cutting rate increases (Kansal, Singh, & kumar, 2007) described that a desirable mixing of powder is an advanced process for improving the performance characteristics of EDM process. Abrasive Powder Mixed Electric Discharge Machining has a unlike working mechanics from the formal EDM. In PMEDM process, a desirable material in the powder form is blended into the dielectric tank. Meliorate circulation of the powder mixed dielectric, a stirring system is employed. Constant recirculation is required in PMEDM process so that the powder is blended completely in the dielectric. Hence a modified circulation system is required. Setup consists of a transparent bath like container, called machining tank. It is placed in the work tank of EDM and the machining is performed in this container. In order to hold the work-piece, a work-piece fixture assembly is placed in it. Dielectric fluid is filled in the machining tank. Stirring system was integrated in order to avoid particle ensconcing. A pump was installed for the better circulation so that dielectric flushes the debris completely. Stirrer assembly and pump are placed in the same tank in which the metal cutting is performed. Order to ensure the complete suspension of powder in the discharge gap the distance between powder mixed dielectric suction point and nozzle outlet is kept as short as possible (25 cm) in. Aluminium, chromium, graphite, silicon, copper or silicon carbide, are the Powders that can be added into the dielectric fluid etc. (Kansal, Singh, & kumar, 2007)**. T**he thermo physical properties of SiC and Aluminium abrasive is

Table 1 Thermo physical properties of various additives. (Wong, Lim, Rahuman, & Tee, 1998).

Powder	Density(gcm−3)	Thermal conductivity (Wcm−1∘C−1)	Electrical resistivity (μΩcm)	Melting point (∘C)	Specific heat (calg−1∘C−1)
Al	2.75	2.30	2.46	665	0.215
SiC	3.21	1.0-5.0	$1x10^9$	2987	0.18

Powder particles accumulate in between spark gap. When a voltage of 80–415V pulsating DC is used among the work piece and the electrode fronting each other with a inter electrode gap of 20–50 µm, 90-110 V/m electric field is produced. Abrasive particles get accelerated and energised and behaves in a zigzag motion. These abrasive powder particles get charged and accelerated and become conductors which when come in contact with the flow channel i.e. between work piece and electrode encourages the breakdown in the gap and the spark gap between work piece and tool increases. Chain like structures are formed when the abrasive powder particles come nearer to each other under the influence of the sparking area.

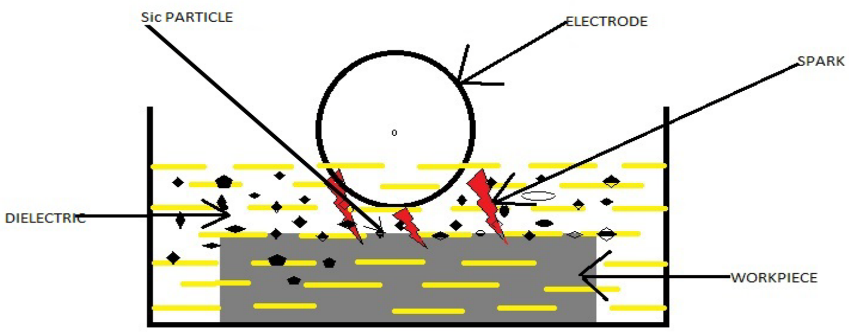


Figure 8: Principle of powder mixed EDM.

When current flow starts the intermeshing of the abrasives powder occurs it forms a bridging area and a chain like structure is formed by the powder particles between the tool and the work piece due to this insulating strength of the dielectric decreases. As the main characteristic of dielectric is to form a channel which provides the spark to happen between anode and cathode and due to this circuit shorts down and sparks occurs before. Thus the continuous series of sparks starts between tool and work piece. Frequency of the sparks increase tremendously and the metal erodes much faster than the usual rate which consequently increases the metal removal rate. The abrasive powders mixed in the dielectric is uniformly distributed in dielectric channel and the frequency of the sparks reduced and starts to occur in a uniform and channelized way due to that uniform sparking of the abrasive powder particles the crater wear is of less density. Hence the surface roughness of the work piece improves in comparison of normal Electric Discharge Machining.

Advantages of PMEDM:

- Provides the best surface finish in comparison of normal EDM process.
- Mirror like surface finish can be obtained in certain conditions.
- Reduces the extra expenditure which occurs in finishing process after machining upto a certain level.

Limitations of PMEDM:

- Process occurs at slow phase at industry level.
- Machining mechanism is still not completely understood.

2.1 Applications

EDM and Hybrid manufacturing has numerous applications i.e. why it has incorporated due to its several important parameters uses and functionality in comparison with basic machining processes.

Some of the applications of AEDG hybrid manufacturing are as follows.

- Turbines
- Motors in Rockets.
- Applications in Space craft’s parts.
- Automobile parts and accessories.

3. Literature Review:

The research work carried out by various researchers involving AEDG and PMEDM is tabulated in table 2.

Table 2: Various works carried out in AEDG and PMEDM:

Reference No	Method	Work piece/Powder used	Process parameters	Remarks
(Assarzadeh & Ghoreishi, 2013)	PMEDM	Aluminium oxide in Kerosene Dielectric	Pulse on time, Discharge current, Source voltage	Surface roughness is influenced mostly by Discharge current. Increasing voltage alone and Current and Pulse on Time keeping constant MRR slowly decreases.
(Bhattacharya, Batish, Singh, & Singla, 2012)	PMEDM	Die Steels EN31,H11,HCHCr	Metal cutting rate, wear of the tool and surface roughness	Aluminium powder and copper electrode.
(Ekmekci & Ersöz, 2012)	PMEDM	SiC Powder	PC, Pulse on time, Discharge Current, Type of Dielectric	Surface modifications occur after the sparks stop due to the powder present in the dielectric.
(Furutani, Sato, & Suzuki, 2009)	PMEDM	WC powder used	Powder concentration, Pulse on Time	Discharge energy over the pulse duration of 10µs is the major criterion for the material removal.
(Kumar, 2014)	PMEDM	AISI D2 Steel	CNTs concentration and peak current	CNTs concentration has a strong interaction with peak current in MRR results. The interaction of pulse duration with peak current is significant

				for MRR, but its contribution is not considerable.
(Kung, Horng, & Chang, 2009)	PMEDM	WC-Co/Aluminium Powder	Current, Pulse on Time, Powder Concentration	Concentration of aluminium powder increases the metal removal rate
(Kumar, Choudhary, & Singh, 2014)	EDSG	AluminumComposite by Composite Tool Electrode	Wheel Speed, Polarity, current, Pulse on time, pulse off time	Abrasive particles increases MRR and white recast layer and resoled layer decreases
(Pecas & Henriques, 2008)	PMEDM	Silicon Powder	Powder concentration Flushing flow rate	Crater area decrease with the increase in SiC powder, white-layer thickness and surface roughness.
(Prihandana, et al., 2014)	PMEDM	Molybdenum Di Oxide/ Inconel 718	Powder Concentration and Current	5 g/l concentration was the best powder size of Quality Micro holes and maximum MRR.
(Srivastava & Dubey, 2013)	EDDG	Al/SiC MMC	MRR and WWR	Both performances, MRR and WWR, have simultaneously been improved by 76.80% and31.85%, respectively.
(Singh, Kumar, & Kumar, 2014)	PMEDM	AA6061/10%SiC composite	Discharge current, pulse on/off and Gap Voltage	Tungsten Powder in PMEDM resulted in 48.32% increases in MRR

Further to the table 2: The following paragraphs are enumerated the work done so far related to AEDG and PMEDM.

- (Agarwal & Modi, 2013) Studied the effect of powder concentration in Powder mixed abrasive electric discharge process and saw the effects of wheel speed, concentration of the powder, current and pulse on time on material removal rate and surface finish of the work piece with the effect of flushing and observed experimentally that material cutting rate increases and surface roughness decreases.
- (Agarwal & Yadava, 2013) studied the Electric Diamond grinding process in surface mode and obtained that grinding speed and concentration of the powder is the main factors considered for the increased material removal are and decreased surface roughness .they used a 10 % weighted aluminium composite with Sic powder as abrasive in dielectric is used.
- (Assarzadeh & Ghoreishi, 2013)Studied that Pulse on time, Discharge current, Source voltage are the major important parameters in Material removal rate. Surface roughness is influenced majorly by current. It can also be said that by increasing voltage alone and Current and Pulse on Time keeping constant MRR slowly decreases.
- (Furutani, Sato, & Suzuki, 2009) Studied that discharge energy over the pulse duration of 10µs is the major criterion for the material removal.
- (Kumar, 2014)Studied the improvement in surface roughness and MRR is obtained at the CNT (Carbon Nano tubes) concentration of 4 g/l mixed into the dielectric fluid. The experimental result indicates that the CNTs concentration and peak current are the most influential variables. It indicates that concentration of added CNTs and peak current is the most influential parameters on MRR and SR (Surface Roughness). The addition of appropriate amount of CNTs (4 g/l) into the dielectric fluid of EDN significance improves the MRR by 80% and lowers the SR by 67%.The CNTs concentration has a strong interaction with peak current in MRR results. The pulse duration has a significant effect on both MRR and SR. Here, its contribution is small. The interaction of pulse duration with peak current is significant for MRR, but its contribution is not appreciable.
- (Kumar, Choudhary, & Singh, 2014) studied various parameters in machining in abrasive powder mixed electric discharge machining .they studied the effect of the

concentration of the powder, grit size and abrasive particles size, effect of the current and pulse on time and duty factor and resulted that the resolidified layer decreases and ,material removal rate increases with the increase of the powder and current density followed by duty factor, and DF(Duty factor) also affects the surface roughness of the work piece in ,machining in PMEDM

- (Kung, Horng, & Chang, 2009) studied the effect of aluminium powder mixed in dielectric ,they deduced that the output of the machine increaeses when abrasice aluminim powder is blended in appropraite quantity.they also deduced that materail removal rate and wear of the tool incraeses up to a ceratin quantity of the powder added in the deielectric but when the quantity incraeses the maximim limit the removal rate and wear of the tool startaed decreasing.current also helps i invraesing the removal of the material upto some extent but too high current will lead to grater surface roughness of the workpiece due to high crater wear.
- (Pecas & Henriques, 2008) studied the quantity of SIC powder which gives the maximum material removal rate is 2-4 g/l and flushing of the debris is also an important parameters in the metal removal rate because if the metal which is removed cooled suddenly due to the dielectric it becomes solid and again comes in the cutting process but the use of abrasive does not let the metal to resolidify and it erodes the material. They also studied that if the discharge energy is too low it cannot help in eliminating the surface roughness even if Sic powder is mixed. The mixed Sic powder helps in reducing the crater wear thickness of the white recast layer and the depth of the crater wear.
- (Prihandana, et al., 2014) Studied the influence of Molybdenum Di- sulphide (MoS_2) powder in the Dielectric fluid on the performance of Micro –EDM on Inconel 718 with focus in obtaining Quality Micro holes. The most important deduction has been observed that Molybdenum Di- sulphide (MoS_2) powder of 50 nm size with 5 g/l concentration was the best powder size of Quality Micro holes and maximum MRR.
- (Singh, Kumar, & Kumar, 2014)Used tungsten powder in dielectric fluid in powder-mixed electrical discharge machining in comparison with the machining in Simple EDM machine and they deduced improvement in surface finish and reduction in recast layer thickness with PMEDM with the EDM machining.
- (Yadav & Yadava, 2013)Studied the performance (EAHM)process i.e. the use of abrasive in Hybrid process which uses has been tested on hybrid aluminium-silicon

carbide-graphite (Al/SiC/Gr) composite in terms of material removal rate(MRR) and average surface roughened (Ra). The effects of pulse current, pulse duration, pulse interval and wheel speed on MRR and Ra has been experimentally investigated that it gives about 7 times higher MRR as compared to stationary wheel electrode and about 2 times more MRR as compared to rotating wheel. The surface finish obtained with EAHM process is much better as compared to the surface finish obtained with stationary and rotating electrodes. The range of input parameters as current (3-15 A), pulse duration (60-120 μs), pulse interval (15-90 μs) and wheel speed (700-1300 RPM) are the best parameters for machining of the aluminium/silicon and graphite composite. Longer pulse on-time is required for melting the matrix material which covers the ceramic particles and also surrounding the ceramic particles. Flushing efficiency of dielectric has been enhanced due to the transfer of kinetic energy of the wheel in the dielectric fluid.

- (Yadav & Yadava, 2014) studied the effect of current and pulse on time and deduced that 3-15 A is the optimal current parameter setting in which material removal rate increase and the average surface roughness decreases and after the given current limit the MRR and surface roughness decreases because of the solidification of the molten metal on the work piece surface, they also studied that the Pulse on time also increase the material removal rate up to 10-100 micro seconds after that material removal rate decreases due to the cooling effect of the dielectric medium. In order to achieve high material removal rate they preferred that high grinding speed is good and it also reduces the surface roughness of the work piece.

3.1 Research Gap:

- PMAEDG of materials like Inconel, Die Steels, Haste Alloys, Wasp Alloys, Conducting Ceramics, and Super Alloys has not been done and their study is still a major research domain.
- Modelling and Multi objective optimization of process parameters on PMEDDCG has not been done for these materials.
- In PMAEDG the study of Surface Morphology and presence and effect of white recast layer thickness of machined work piece is still an area for research interest. The influence of current, wheel speed, and pulse duration and duty factor is still to studied for these super alloys and difficult to machine materials.

3.2 Objectives:

1. Automation is to be done in PMAEDG setup to make its X axis automated in ZNC EDM and self reciprocating in order to work in Surface Grinding mode.
2. To carry out individual experiments on each material for finding the optimum parameters and levels, of different materials in PMEDDG.i.e.
    - Die Steel
    - Inconel 718
    - Nimonic 80A
3. Parametric optimization of materials Die Steel, Inconel Alloy, Nimonic 80 A in PMEDDG.

4. Experimental Set up and Methodology:

4.1 ENC 35 ZNC Electric Discharge Machine

The experiments were conducted on an ENC 35 EDM, (model – ZNC 50 X 30, die sinking type, made by Electronica Machine Tool LTD. Pune) to work on AEDG.

Technical Specification:

Electrical data:

Following are the electrical data of the ZNC EDM machine.

Type	: ENC 35
Supply	: 415V, 3 phases, 50 Hz
Mains voltage tolerance	: +/- 10 %
Connected load	: 3 KVA
Power factor	: @ 0.8

Working parameters:

Following are the working parameters in which maximum current for which this EDM machine will work is 35 A.

Machining current max (amps)	: 35 A
Bi pulse current	: 3 amps
Open gap output voltage	: 200 V dc +/- 5%
Current range selection	: In step of one amp
Bi pulse current selection	: 0-3 amp in step of one amp
Pulse on duration	: 2 to 1050 microseconds

4.2 Wensar Electronic Balance.

Weighing machine is used to measure weight of work piece during machining operation which in turn gives MRR.

Model	HPB310
Capacity	310gm
Readability	0.001gm
Repeatability	0.001gm
Linearity	0.002gm
Pan size	90mm dia.
Response time	3-4sec
Calibration	Automatic external
Tare range	Full
Operating temperature	15^0C to 35^0C
Housing dimension	195x275x406mm
Weight approx.	6.7kg
Make	Wensar
Power supply	AC Adaptor 220V, 50-60 Hz
Data output	RS232C

4.3 Digital Tachometer:

Tachometer (model: KM 2241) is used to measures the rotation speed of a shaft or disk. The device displays the revolutions per minute (RPM) on a calibrated digital displays.

Display	:	5 digits 18 mm (0.6") LCD
Accuracy	:	± (0.05% + 1 digit)
Sampling Time	:	0.5 s (over 120RPM)
Range Select	:	Auto –Ranging
Memory	:	Last value, Max.Value, Min.value
Power Consumption	:	Approx 55mA
Time Base	:	6 MHz Quartz crystal
Detecting Distance	:	50 mm to 500 mm
Measuring range	:	PHOTO TACH 2.5 TO 99999 RPM
Contact Tach 0.5TO 19,999 RPM Surface Speed (m/min) 0.05 TO 1,999.9 (m/ min).		

4.4 Requirement of System:

- 3- phase stabilized power supply
- Proper earthing.
- Regular keeping of machine tool and control parameters

- Filtering of EDM oil

All the experiments were performed on ENC 35 EDM Machine (model – ZNC 50 X 30, die sinking type, made by Electronica Machine Tool LTD. Pune) with self designed and fabricated in surface grinding mode. This setup consists mainly of

4.4.1 Bronze-Diamond Abrasive Grinding Wheel with following specifications.

Diamond with bronze bonded abrasive grinding wheel is used as an electrode in PMAEDG process in this in house fabricated set up with the following specifications are:

Diamond wheel Diameter	100 mm
Thickness	10 mm
Abrasive used	Diamond
Bore Diameter	32 mm
Bonding Material	Bronze
Concentration	75%
Grit Size	80/100
Depth of Indentation	3 mm

4.4.2 Direct current motor:

A permanent magnet direct current motor (PMDC) of 2 HP and 4000 rpm is used to drive the grinding wheel. The PMDC motor speed can be controlled through a direct current drive.

Figure 9 shows the schematic diagram of an fabricated of an fabricated PMAEDG set up.

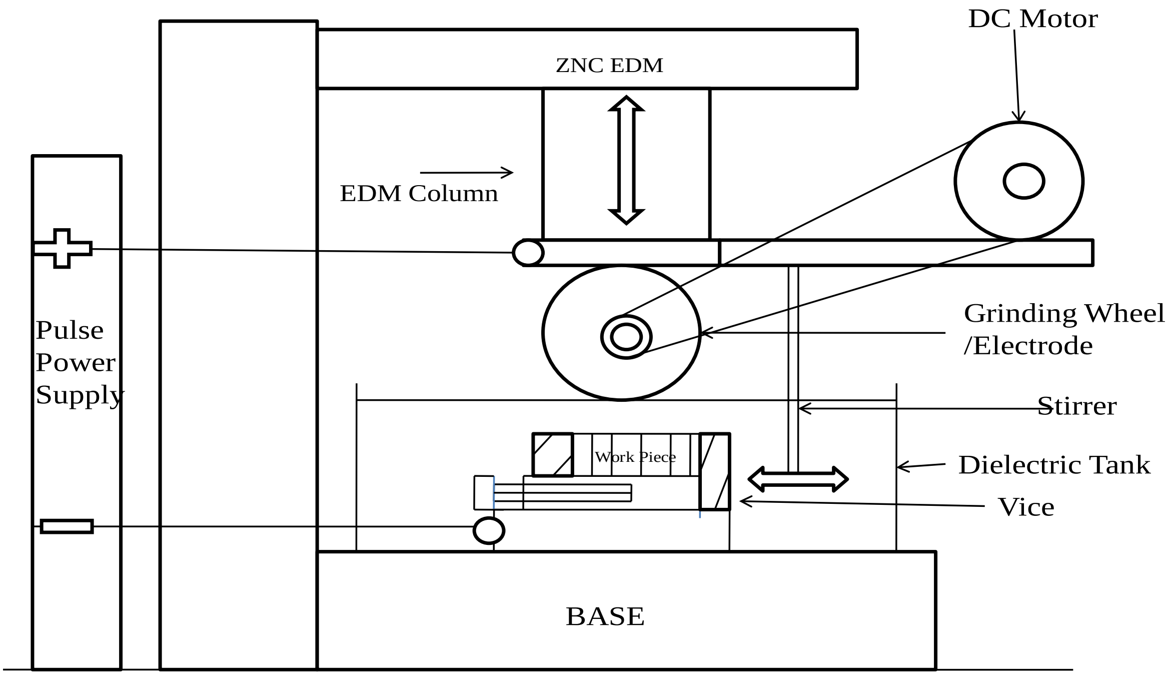


Figure 9. In House Fabricated PMAEDG Set up.

4.4.3 Alternating current reversible synchronous motor:

The relative motion between the diamond abrasive wheel and the work piece is achieved by reciprocating the machine table through an automatic feed arrangement. For this purpose alternating current reversible synchronous motor is attached with machine table lead screw through special attachment. This synchronous motor is controlled with 2 way control switches.

4.4.4 Shaft:

The function of the shaft is to rotate the grinding wheel and is itself rotating. So its design requires some of the input parameters like material, diameter, RPM, motor power. Keeping all the input factors 19 mm shaft diameter, EN 24 as shaft material and bearing whose ISI No. 1203 is selected.

4.4.5 V-belt:

The V shaped belt (13 mm x 9 mm) is used to transmit power from driver to driven pulley. The V belt has trapezoidal cross section so that it remains in touch with the side of the pulley to avoid slip.

Figure 10. ZNC EDM machine with PMAEDG set up and Automated X axis.

4.5 Automation of X axis:

Motion control of ZNC EDM machine X axis is required to done because in normal surface grinding mode in PMAEDG process the X axis of the machine should reciprocate for the process .Firstly In house fabricated set up uses servo motor and manually the polarity of the motor has to be changed but due to the automation the polarity changes automatically.

4.5.1 Component required.

Following are the component used for setup,

- NXP8051 (any 8051 can be used)
- ULN 2803
- Relay 250AC/10-20Amp using 12 volt
- Limit Switches 2 no.
- 7805 IC (to step down 12 volt to 5 volt)
- Resisters (1K,10 Ohm,10 K)
- Capacitors (10µ,30p,470µ,1µ)
- 12 volt DC supply
- Push button
- LED's
- Crystal oscillator 10Hz

4.5.2 Software Used:

Keil micro vision and ***flash magic***for burning in micro controller.

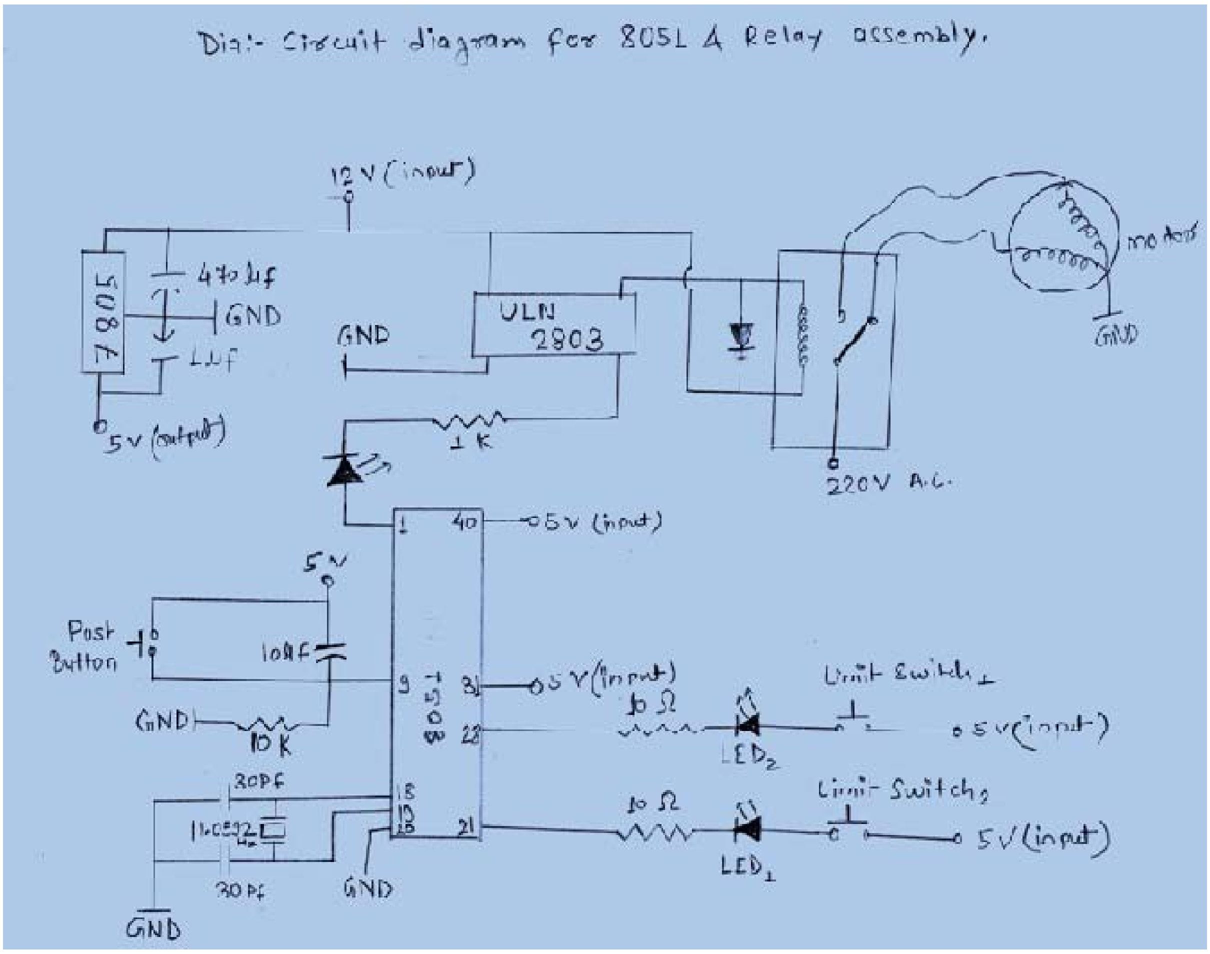
4.5.3 Code used in 8051

```
#include<reg51.h>
sbit a=P1^0;

sbit a1=P2^0;
sbit b1=P2^1;

void main()
{
P1=0x00;
P2=0x00;
while(1)
{
if(a1==1)
{  a=1;  }
if(b1==1)
{a=0;  }
}  }
```

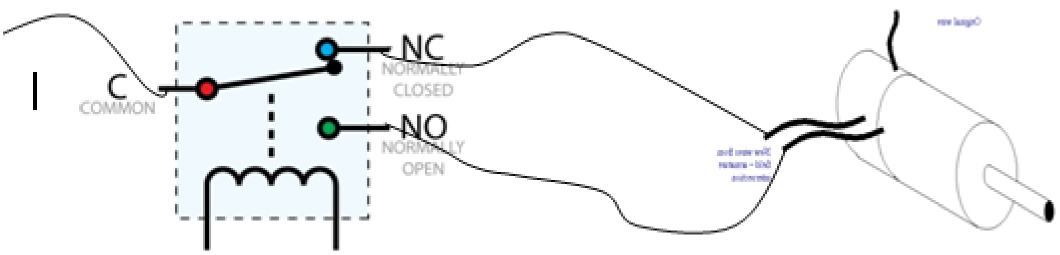
4.5.4 Construction Diagram:



4.5.5 Working Theories:

Working of relay and motor-

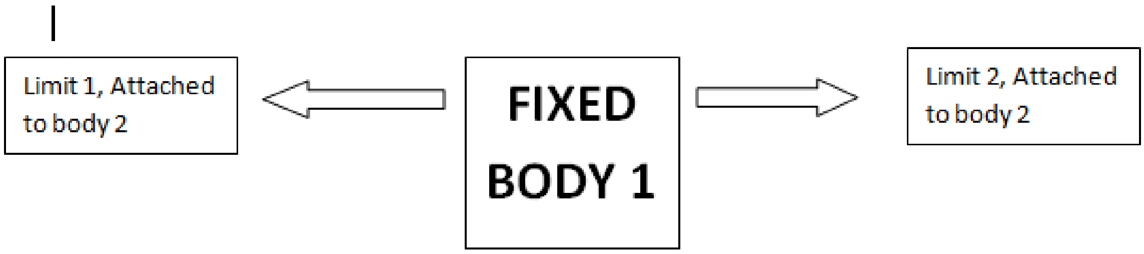
8051 microcontroller is generally used for controlling sensors and small components. Here we are using it for controlling of relay which uses 12 volt to activate and deactivate. We have motor(240 volt AC) that requires three wire to control polarities and relay can operate it well.



In above diagram wire connected to C supplies the 240 volt to motor which is transferred to two different winding of motor to change the direction of rotation; the third wire of motor is ground. From above diagram we can see that at OFF state of relay supply goes to first winding and at ON state supply goes to second winding which controls the motion of motor.

Working of limit switches:

From below diagram we can see that there are two limit switches which supplies 5 volt to microcontroller as a signal that body has reached to its limit. Now after getting this signal microcontroller changes the state of relay so that polarity of motor can be changed also corresponding direction of motion.



Code used in KEIL MICROVISION:

This code uses pin (P1^0) as output signal to relay and (P2^0 & 7) for input signal for limit switches. So when limit switch 1 sends 5 volts to **P2^0** then microcontroller activates the relay using pin **P1^0** and when limit switch 2 sends the 5 volts to **P2^7** then microcontroller deactivates the relay using the pin **P1^0.**

5. Experimental Methodology and Parametric Design:

5.1 Performance measures are:

5.1.1 Material removal rate (MRR):

The material removal rate is volumetric material removal rate which is found out by the formula.

$$\text{MRR (mg / minute)} = \frac{Weight\ of\ workpiece\ \ before\ \ machining - after\ \ machining}{time\ \ (t)} \text{x1000}$$

$$\text{MRR (mm3 / minute)} = \frac{Weight\ of\ workpiece\ \ before\ \ machining - after\ \ machining}{time\ \ (t) X\ \rho} \text{x1000}$$

Where t= time of machining

ρ= density of the material

5.1.2 Average surface roughness (Ra):

Arithmetic average roughness of the deviations of the roughness profile from the central line along the measurement. Surface roughness, often shortened to roughness, is a component of surface texture.

5.2 Taguchi Method:

Dr. Genichi Taguchi developed an optimisation technique for the engineering experimentation problems in order to robust design approach. Taguchi methods used simple approach to minimise the experiments with the help of mathematical formulation. He has developed an unparalleled method of improvement in quality which is far better than usual methods. His development towards quality improving and robust design method is independent of various um important variations of nature, machine and other factors.

Taguchi method can be applied for various functions some of them are as follows:

- Design of experiments

- Design of process parameters and Brainstorming the quality characteristics.
- Analysis of the designed results.
- Confirmation of the designed test using optimal process parameters.

Design of experiments through Taguchi methodology:

For designing experiments from Taguchi method first we have to select the input parameters this is also known as Factorial design.

The factors are which are independent or which defines the functionality and performance of the system.

- Controlled inputs
- Influencing performance parameters.
- Inputs included whose study is to be done for understanding of the process.

Procedure of Taguchi Methodology:

Phase: 1.Select the Experiment design Matrix and perform the experiments.

Phase: 2.Calculate the factor effects.

Phase: 3.Selection of Optimum level of factors.

Phase: 4.Develop the Additive model of factor levels.

Phase: 5.Use ANOVA analysis for coefficient equations and further analysis.

In this thesis the design of experiments are carried out by MINI TAB 14

Static problems:

When our output is the required optimal factor we termed the problem as static problem. A process depends on various parameters hence every parameters has to be optimised which involves the finding of the best levels. Here P diagram explains the best level value.

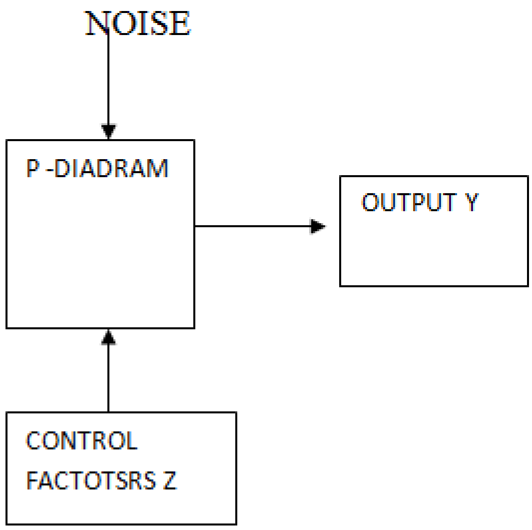


Figure 11: Process Diagram for Taguchi

The process is said to ROBUST when we minimise the variations of the output even when noise is present in the output levels.

5.2.1 Signal to Noise (S/N) Ratio:

There are three forms of *signal to noise* (S/N) ratio that are of common interest for optimization of static problems.

5.2.2 Smaller-the-better:

This is expressed as;

$$n = -10 \ \mathrm{Log}_{10} \ [\text{average of sum of squares of actual measured data}]$$

For difference in measured and ideal use.

$$n = -10 \ \mathrm{Log}_{10} \ [\text{average of sum of squares of } \{ \text{actual measured} - \text{ideal} \}]$$

5.2.3 Larger-the-better:

This is expressed as

N =- 10 Log 10[mean of sum of squares of reciprocal of measured Data]

This is often converted to *smaller-the-better* by taking the reciprocal of the measured data and next, taking the S/N ratio as in the *smaller-the-better* case.

5.2.4 Nominal-the-best:

This is expressed as

$$\mathbf{n = -10\ Log_{10}\ [\frac{square of mean}{variance}]}$$

This case arises when a specified value is the most desired, meaning that neither a smaller nor a larger value is desired.

5.3Experimentation Performed:

5.3.1 PMAEDG of Die Steel:

Experiments are carried out in an in house fabricated Powder Mixed Abrasive Electric Discharge Grinding Machine of AISI D3 die steel. Total of 9 experiments are performed by design of experiments through Taguchi Methodology. In table 5, 3 machining parameters and their levels are selected and then experiments are performed.

Table 3: Machining Parameters and their Levels for AISI D3 Die Steel.

Input Parameters	**Level 1**	**Level 2**	**Level 3**	**Units**
Powder Concentration (PC)	0	3	6	gm/ltr
Wheel Speed (WS)	1000	1200	1400	Rpm
Current (C)	2	4	6	Amp

Table 6 shows the performed Experiments and with the Taguchi L9design of Experiments.

Table 4: Taguchi L9 Experimental Table with Response Variable for AISI D3 Die Steel.

Expt. No.	PC (gm/lit)	WS (rpm)	C (amp)
1	0	1000	2
2	0	1200	4
3	0	1400	6
4	3	1000	4
5	3	1200	6
6	3	1400	2
7	6	1000	6
8	6	1200	2
9	6	1400	4

5.3.2 PMAEDCG of Inconel 718:

Experiments are carried out in an in house fabricated Powder Mixed Abrasive Electric Discharge Grinding Machine of Inconel 718. Total of 9 experiments are performed by design of experiments through Taguchi Methodology. In table 7, 3 machining parameters and their levels are selected and then experiments are performed.

Table 5: Machining Parameters and their levels for Inconel 718.

Input Parameters	Level 1	Level 2	Level 3	Units
Powder Concentration (PC)	0	3	6	gm/lit
Wheel Speed (WS)	1000	1200	1400	Rpm
Current (C)	2	4	6	Amp

Table 8 shows the Experiments and Response Variable of Inconel 718 with different parameters settings.

Table 6.Taguchi L9 Experimental Table with Response Variable for Inconel 718.

Expt. No.	**PC (gm/lit)**	**WS (rpm)**	**C (amp)**
1	0	1000	2
2	0	1200	4
3	0	1400	6
4	3	1000	4
5	3	1200	6
6	3	1400	2
7	6	1000	6
8	6	1200	2
9	6	1400	4

5.3.3 PMAEDCG of Nimonic 80A:

Experiments are carried out in an In house fabricated Powder Mixed Abrasive Electric Discharge Grinding Set up. Total of 25 experiments are performed by design of experiments through Taguchi Methodology. In table 9, 4 machining parameters and their 5 levels are selected and then experiments are performed.

Table 7: Experimental input parameter and their levels for Nimonic 80.

Input factor’s		**Symbol**	**Level**				
Description	**Unit**		**1**	**2**	**3**	**4**	**5**
Wheel speed	rpm	A	600	800	1000	1200	1400
Powder Concentration	g/lit	B	0	2	4	6	8
Current	A	C	4	6	8	10	12
Pulse-on-time	µs	D	17	20	23	26	29

5.3.4 PM-EDDCG of Nimonic 80A using L25 array @ 5 min m/c time, Duty Factor 0.67.

In this experiment Powder Mixed Electric Discharge Diamond Cut off Grinding of Nimonic 80 is done using Taguchi L25 algorithm array. In this experiments 4 machining parameters and 5 levels selected and 25 experiments are performed with Powder concentration, wheel speed, current and Pulse on Time is selected with constant time of 5 min is selected and duty factor for every experiments is 0.7.

Table 8: Experimental observations during PMEDDG of Nimonic 80A.

Expt. No.	**Factor levels**			
	A	**B**	**C**	**D**
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3

Expt. No.	Factor levels			
	A	B	C	D
4	1	4	4	4
5	1	5	5	5
6	2	1	2	3
7	2	2	3	4
8	2	3	4	5
9	2	4	5	1
10	2	5	1	2
11	3	1	3	5
12	3	2	4	1
13	3	3	5	2
14	3	4	1	3
15	3	5	2	4
16	4	1	4	2
17	4	2	5	3
18	4	3	1	4
19	4	4	2	5
20	4	5	3	1
21	5	1	5	4
22	5	2	1	5
23	5	3	2	1
24	5	4	3	2
25	5	5	4	3

6. Results and Discussion:

In this project work as three different materials are selected for their parametric study. Results of each material are described individually so as to clearly understand the factors which are responsible in machining in PMAEDCG process.

6.1 Analysis of Signal to Noise(S/N) Ratio for AISI D3 Die Steel.

ANOVA Analysis is used to determine the optimum parameters of the machining of AISI D3 die steels in PMAEDG process. 24.781 S/N ratio is the best suited condition for MRR in L9 orthogonal array in Table 10. Powder concentration of 6 gm/lit, the wheel speed of 1400 rpm, and the current of 4 amps were obtained for the best MRR value. Fig. 12 shows the main effect plot for S/N ratios. From this figure, it can be seen that MRR increases with increase in powder concentration and wheel speed. Table 10 shows the average S/N ratio value. The different values of S/N ratio between maximum and minimum are (main effect) also presented in Table 10. The Table 3 also shows that powder concentration and wheel speed are most significant machining parameters while current having less significance on MRR. It can be seen that the level 3 of powder concentration and wheel speed while level 2 of current gives the optimum machining condition.

Following results of MRR and S/N ratios for AISI D3 Die steel are obtained from the experiments performed in Table 6 experiments results shows increase in material removal rate with the increase in wheel speed.

S.No	**MRR (mm^3/min)**	**S/N ration for MRR (db)**
1.	5.545	14.8773
2.	5.897	15.4127
3.	9.999	19.9987
4.	5.859	15.3569
5.	7.860	17.9089
6.	10.631	20.5313
7.	11.202	20.9860

8.	12.975	22.2625
9.	17.341	24.7813

Main effects of SN ratios for AISI D3 Die Steel are shown in figure 12 and the parameters as powder concentration; wheel speed and current are studied and show that in PMAEDG process Powder helps in material removal rate up to some extent and after that it reduces the MRR.

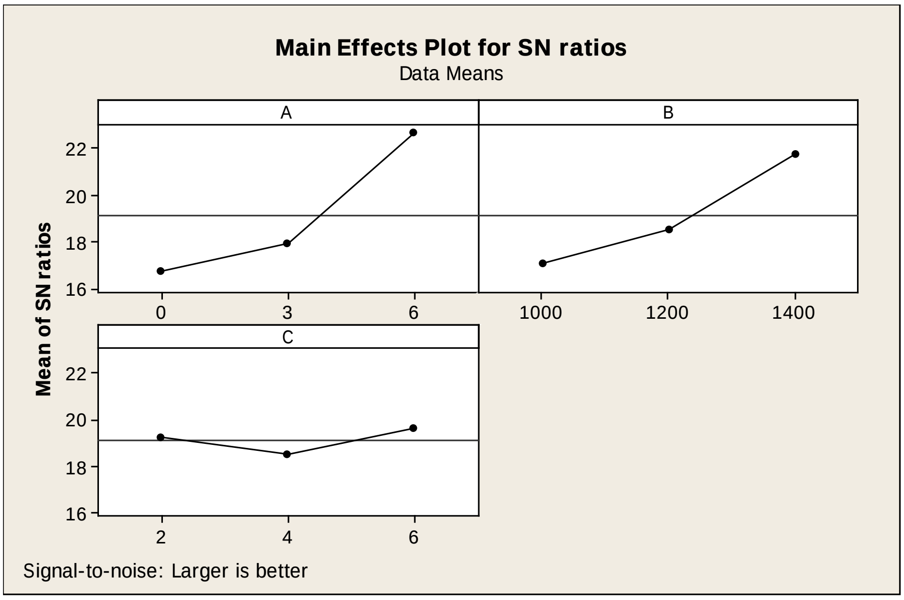


Figure 12:Main Effect Plot for S/N Ratios.

Table 11 is SN ratio table for factor levels. In this table the importance of powder concentration, wheel speed and current is described with their performance rank in machining of AISI D3 die steel.

Table 9: S/N ratio of MRR for factor levels.

Level	PC	WS	C
1	7.147	7.535	9.717

2	8.117	8.911	9.699
3	13.839	12.657	9.687
Delta	6.693	5.121	0.03
Rank	1	2	3

6.1.1 ANOVA analysis (AISI D3 Die Steel).

Powder concentration, wheel speed and current on material removal rate (MRR) was analysed by ANOVA. The ANOVA analysis shows that powder concentration is most significant factor affecting MRR followed by wheel speed. While current have very less effect of MRR.

Table 10: ANOVA for MRR AISI D3 Die Steel.

Source	Degree of freedom (DF)	Sum of squares (SS)	Mean of squares (MS)	F Ratio	P Value	PCR (%)
PC	2	58.848	29.424	600.29	0.002	61.59
WS	2	34.691	17.346	353.88	0.003	36.30
C	2	1.907	0.954	19.45	0.049	1.9
Error	2	0.098	0.049			
Total	8	95.544				

6.1.2 Regression Equation for Machining Rate for AISI D3 Die Steel:

In terms of actual factors, the final empirical relationship between machining rate (response characteristic) and input process parameters of AISI D3 Die Steel can be expressed by the following second-order polynomial in Equation 1.

MRR=-8.98017+1.11539PC+0.0128042WS-0.0075C...Equation 1

The coefficients of the process parameters in Eq. (1) have been computed by Mini Tab 14 software after analysis of the data shown in Table 6.

6.2 Result and Discussion of PMAEDG of Inconel 718

6.2.1 Analysis of Signal-to-Noise(S/N) Ratio for Inconel 718:

S/N ratios of MRR are presented in Table 12 obtained from Taguchi method which is best for see the variations in the experimental design. The S/N ratio should have a maximum value to obtain optimum machining conditions.

24.371 S/N ratio is the optimum condition for MRR Table 12. Powder concentration of 6 gm/lit, the wheel speed of 1400 rpm, and the current of 4 amps were obtained for the best MRR value. Fig. 13 shows the main effect plot for S/N ratios. From this figure, it can be seen that MRR increases with increase in powder concentration and wheel speed. Table 12 shows the average values of S/N ratio for every factor. The different values of S/N ratio between maximum and minimum are (main effect) also presented in Table 12. Table 12 also shows that powder concentration and wheel speed are most significant machining parameters while current having less significance on MRR. It can be seen that the level 3 of each factor viz. powder concentration, wheel speed and current gives the optimum machining condition.

From Table 8 the results of MRR and SN ratio of MRR of Inconel 718 are obtained.

S.No	**MRR (mm^3/min)**	**S/N ration for MRR (db)**
1.	4.745	13.524
2.	5.097	14.146
3.	9.199	19.274
4.	5.059	14.082
5.	7.060	16.977
6.	9.831	19.852
7.	10.402	20.342
8.	12.175	21.710
9.	16.541	24.371

Main effects of SN ratios of Inconel 718 are shown in Figure 12 and the parameters as powder concentration, wheel speed and current has been studied.

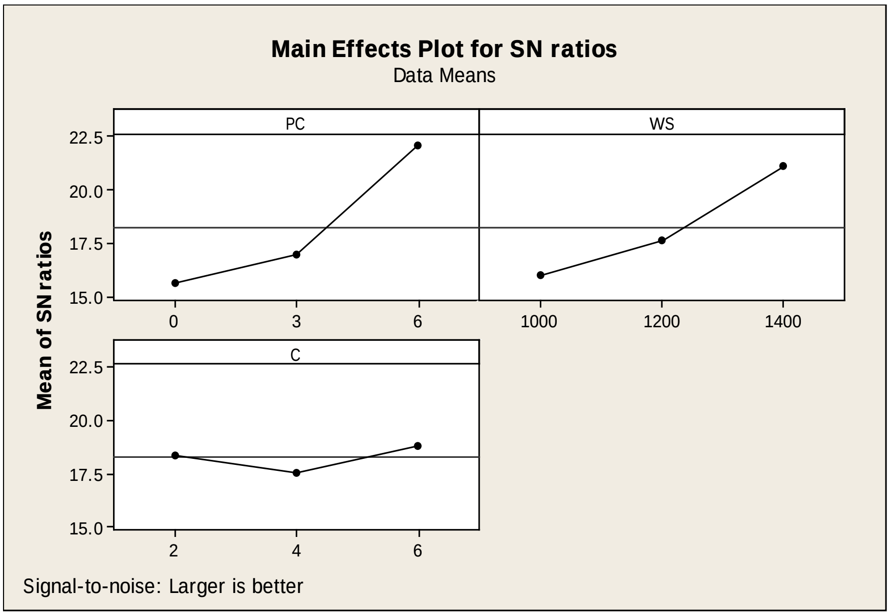


Figure 13:Main Effects Plot for SN ratios.

SN ratio of MRR for Factor levels is shown in table 13 and the contribution of process parameters are shown.

Table 11: S/N Ratio of MRR for Factor levels.

Level	**PC**	**WS**	**C**
1	15.65	15.98	18.36
2	16.97	17.61	17.53
3	22.14	21.17	18.86
Delta	6.49	5.18	1.33
Rank	1	2	3

In Table 14 ANOVA analysis is done to see the effects of powder concentration, wheel speed and current on material removal rate (MRR). In the analysis, the percentage distributions of each control factor were used to measure the corresponding effects on the quality characteristics.

Table 12: ANOVA analysis

Source	Degree of freedom (DF)	Sum of squares (SS)	Mean of squares (MS)	F Ratio	P Value	PCR (%)
PC	2	70.645	35.322	751.84	0.001	61.110
WS	2	42.152	21.076	448.6	0.002	36.463
C	2	2.712	1.356	28.86	0.033	2.346
Error	2	0.094	0.047	-	-	0.081
Total	8	115.602	-	-	-	

6.2.2 ANOVA Analysis of Inconel 718:

ANOVA analysis of Inconel 718 is carried out with 95% of confidence level. ANOVA values belonging to experimental results for S/N ratios for MRR are shown in Tables 13. ANOVA analysis shows that 61.110 % is the contribution of Concentration of Powder in MRR followed by 36.463% of the Wheel speed contribution in MRR and a mere of 2.346% of current. The ANOVA analysis shows that powder concentration is most significant factor affecting MRR followed by wheel speed. While current have very less effect of MRR.The less value of F shows that critical region is less and the experiments are best fitted in the MRR model.

6.2.3 Regression Equation for Inconel 718:

In terms of actual factors, the final empirical relationship between machining rate (response characteristic) and input process parameters of Inconel 718 can be expressed by the following second-order polynomial in Equation 2.

MRR=-9.77945+1.11546PC+0.0128033WS-0.00748167C.......................................Equation 2

The coefficients of the process parameters in Eq. (2) have been computed by Mini Tab 14 software after analysis of the data shown in Table 8.

6.3 Result and Discussion of PMAEDG of Nimonic 80 A:

6.3.1 Analysis of Variance (ANOVA)

The machining control variables having significant effect on MRR and their percentage contribution were determined using analysis of variance (ANOVA). The signal-to-noise ratio used to indicate better performance. A higher MRR signifies better performance of process, hence, higher is better (HB) is selected for determining best possible combination of machining characteristics. For HB the loss function (L) which denotes the deviation between the desired and actual value for measured results $\boldsymbol{y_i}$of n iterative trials is given by:

$$L_{HB} = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2} \tag{1}$$

The S/N ratio η_{ij} for i^{th} response characteristic in j^{th} experiments can be given by:

$$\eta_{ij} = -10\log(L_{ij}) \tag{2}$$

The higher value of η better is the performance of the process. By using above equations the S/N ratio values for each run of experiments mentioned in Table 15 was determined and tabulated in Table 16. The optimum machining parameters determined are wheel speed of 1400 rpm (Level 5), powder concentration of 4 g/lit (Level 3), current of 10 amps (Level 4), and pulse-on-time of 26 µs (Level 4).

From Table 10 the MRR have been obtained from the experiments performed for Nimonic 80.

S.No	**MRR (mm^3/min)**
1	5.518926
2	10.18315
3	11.13187
4	13.33333

5	10.96459
6	7.106227
7	9.52381
8	15.21368
9	11.13553
10	7.838828
11	9.59707
12	11.47741
13	12.02564
14	8.131868
15	11.81929
16	12.74725
17	12.28327
18	12.40537
S.No	**MRR**
19	12.11233
20	12.08791
21	16.11477
22	12.83517
23	17.01832
24	15.26007
25	16.89621

Table 13: S/N values for material removal rate.

Machining parameters	Mean n by factor level (dB)					Delta	Rank
	Level 1	Level 2	Level 3	Level 4	Level 5		
A	19.84	19.81	20.42	21.82	23.83*	4.02	1
B	19.55	20.98	22.53*	21.39	21.27	2.98	3
C	18.99	20.99	21.09	22.8*	21.85	3.81	2
D	20.65	21.08	20.5	21.91*	21.58	1.41	4

* Optimum level

Figure 14 shows the effect of control factors on MRR. It can be seen from figure 14 that, MRR increases with increase in wheel speed. Thus it can be seen that at large wheel speed more number of diamond abrasive particles will cause faster abrasion of work-piece. The MRR initially increases with increase in powder concentration up to 4g/lit and then decreases with further increase in powder concentration. The addition of powder in dielectric will assists to bridge the inter electrode gap resulting in increase in MRR. Due to the bridging effect, multiple discharges within single pulse will be generated resulting increase in discharge frequency. Thus, rapid sparks will erode work-piece at faster rate. But, after an optimum powder concentration the MRR is decreases as high concentration of powder will attribute to discharge interference. It is also seen that with increase in discharge current the MRR increases initially up-to 10 amps of current. More volume of work-piece will be melted and softened at higher discharge energies due to high currents. However, after more than 10 amps current, then molten metal resolidifies on the work-piece surface lowering the MRR. It is seen that pulse-on-time does not have significant effect on MRR in AMEDDG.

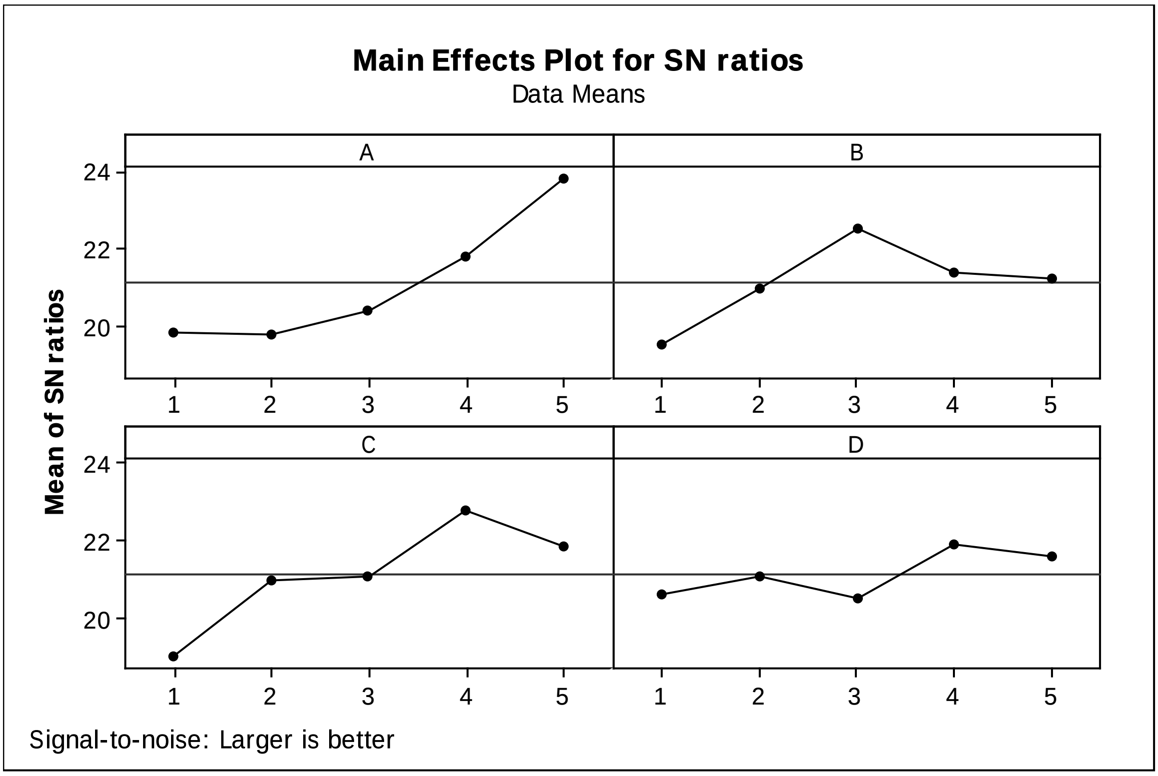


Figure 14. Main Effects plot for SN ratios.

The relative significance of control factors on MRR was examined using ANOVA. The results of ANOVA at 95% confidence level for performance factors are tabulated in Table 16. From the results of ANOVA, the wheel speed (S) was seen to be the major factor influencing the MRR and contribute 52.23% on MRR, followed by current (C) which contributes 27.17% on MRR, followed by powder concentration which contributes 14.45% on MRR; whereas pulse-on-time (D) have less significance on the MRR of Nimonic 80A during AMEDDG process. The large value of determination coefficient (R^2=97.42%) indicates that only less than 2.58 % of the total variations in MRR are not clarified by model. The large value of the adjusted determination coefficient (adjusted R^2=92.26%) assures significance of the model.

Table 16 shows relative significance of control factors on MRR was examined using ANOVA. The results of ANOVA at 95% confidence level for performance factors are tabulated in this table.

Table 14.ANOVA results for MRR model of Nimonic 80.

Source	Degree of freedom(df)	Sum of squares(SS)	Mean square(MS)	F value	p-value probability>F	Percentage Contribution
A	4	107.385	26.846	40.48	0.000	52.239
B	4	29.718	07.429	11.20	0.002	14.456
C	4	55.859	13.965	21.06	0.000	27.173
D	4	07.294	01.824	02.75	0.104	03.5483
Residual Error	8	05.306	00.663			
Total	24	205.562				
Standard deviation 0.8144			R^2 = 97.42%			
			Adjusted R^2=92.26%			

6.3.2 Regression Equation for MRR of Nimonic 80A:

In terms of actual factors, the final empirical relationship between machining rate (response characteristic) and input process parameters of Nimonic 80A can be expressed by the following second-order polynomial in Equation 3.

MRR =-0.816793 + 0.00648034 W + 0.207155 PC + 0.430159 C + 0.0807407 POT.......Equation 3

The coefficients of the process parameters in Eq. (3) have been computed by Mini Tab 14 software after analysis of the data shown in Table 8.

6.4 Surface Topography and Results:

Surface topography is precise detailed study of the surface features of a region. In the below figures Scanning Electron Microscopy images are shown and detailed study of the machining is described in order to understand that whether after machining any secondary finishing operation is required after machining in PMAEDG .in PMAEDG process as we know grinding wheel is used in removal of the material .hence it is obvious to get a surface finish of grinding level.

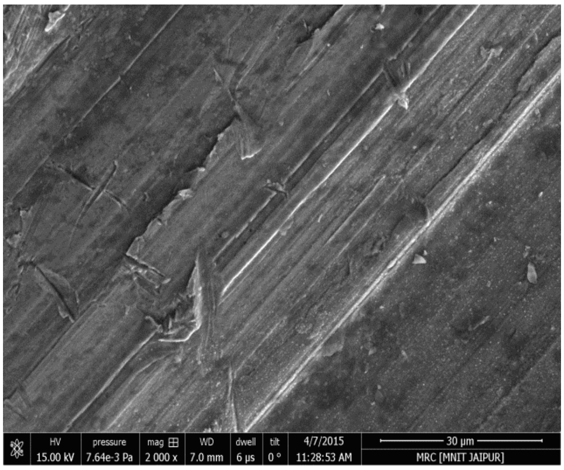


Figure 15. SEM image of NIMONIC 80A

Wheel speed 600rpm,

PC 0 g/l,

Current 4 Amp,

Pulse on Time 17µs

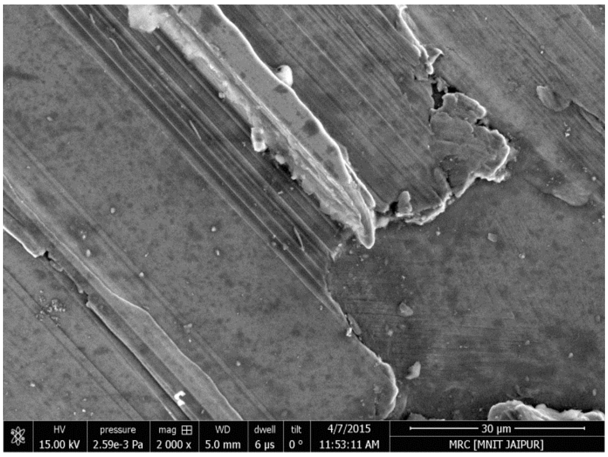


Figure 16. SEM image of NIMONIC 80A

Wheel speed 1000rpm

PC 4 g/l

Current 12 Amp

Pulse on Time 29µs

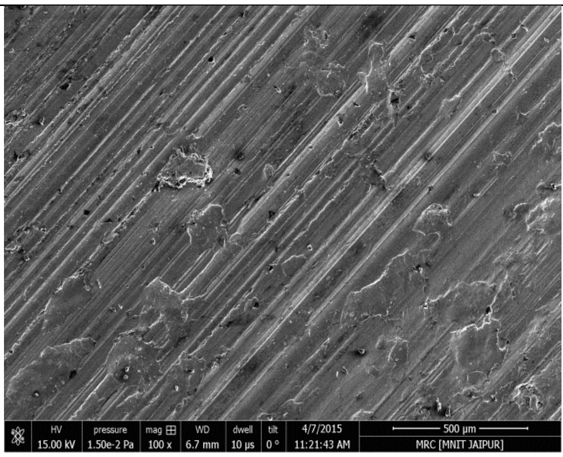


Figure17 SEM image of NIMONIC 80A

Wheel speed 600rpm,
PC 0 g/lit,
Current 4 Amp,
Pulse on Time 17µs

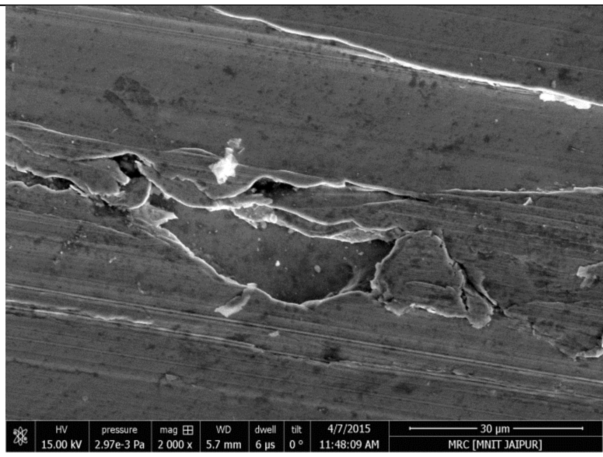


Figure 18 SEM image of NIMONIC 80A

Wheel speed 1000rpm
PC 2 g/lit,
Current 10 Amp
Pulse on Time 17µs

- Figure 15 shows Wheel marks are more due to low rpm. Crater Wear is small due to low current. Presence of White Recast layer
- Figure 16 Wheel marks on the PMAEDG surface are less in comparison to low wheel rpm PMAEDG surface. Crater Wear is high and bigger than Fig 15 due to high current. Recast layer is reduced with improved surface finish.
- Higher the wheel rpm lower the surface roughness in the Figure 17 the rpm is 600 hence the roughness is more
- Pulse Time also contributes in the surface roughness but in very less amount.
- Current is the second prime factor in MRR but in Surface Roughness it shows that increasing the Current leads to higher MRR due to Large Crater formation which increases the Roughness of the Surface.
- In the figure 18 rpm is 1000 rpm which shows less stray marks and improved surface finish with respect to 600 rpm surface.
- Pulse on time is same in both the case shows the minimal effect on the surfaces.

6.5 Surface Roughness Results and Analysis:

In the Experiments performed in PMAEDG process, the main parameters which is taken in consideration is MRR (material removal rate) and Ra i.e. Surface roughness and we had calculated the MRR .Here in the Table 17 Experiments are designed with Taguchi and L25 is used with the same parameters as used in the experimentation of MRR.

Table 15: Surface Roughness values After Experimentation of Nimonic 80.

A(Wheel Speed)	**B(PC)**	**C(Current)**	**D(P_{on})**
600	0	4	17
600	2	6	20
600	4	8	23
600	6	10	26
600	8	12	29
800	0	6	23
800	2	8	26
800	4	10	29
800	6	12	17
800	8	4	20
1000	0	8	29
1000	2	10	17
1000	4	12	20
1000	6	4	23
1000	8	6	26
1200	0	10	20
1200	2	12	23
1200	4	4	26
1200	6	6	29
1200	8	8	17
1400	0	12	26
1400	2	4	29
1400	4	6	17
1400	6	8	20

1400	8	10	23

6.5.1 Analysis of Signal to Noise(S/N) Ratio of Nimonic 80.

S/N ratios of Ra are presented in Table 17. The S/N ratio should have a maximum value to obtain optimum machining conditions.

5.29 S/N ratio value is the maximum value which is the highest R_a in Table 17. Wheel Speed of1400rpm and the PC of 4g/l, are the most suitable conditions obtained for the best Ra value. Fig. 20 shows the main effect plot for S/N ratios. From this figure, it can be seen that Ra increases with increase in wheel speed. Table 19 shows the average of S/N values of each factor levels. The different values of S/N ratio between maximum and minimum are (main effect) also presented in Table 19. The Table 18 also shows wheel speed followed by Powder Concentration pulse on time and current are most significant Surface Roughness parameters.

From Table 17 following are the results of surface roughness obtained when measured from High Precision Taylor Hobson Surface Roughness measuring machine.

S.No	**SR(μm)**
1.	3.78
2.	4.30
3.	4.45
4.	4.84
5.	5.19
6.	5.78
7.	4.91
8.	5.29
9.	4.53
10.	4.51
11.	4.49

12.	3.11
13.	3.63
14.	3.78
15.	3.95
16.	3.01
17.	3.06
18.	3.71
19.	3.92
20.	4.12
21.	3.64
22.	3.60
23.	3.58
24	2.82
25.	2.70

Table 18 is the Response table for means for the analysis of Surface roughness values in MINI TAB 14 in order to get the results of means of roughness of the surface after machining.

Table 16. Response Table For Means.

Level	**A**	**B**	**C**	**D**
1	4.512	4.140	3.876	3.824
2	5.004	3.796	4.306	3.654
3	3.792	4.132	4.158	3.954
4	3.564	3.978	3.790	4.210
5	3.268	4.094	4.010	4.498
Delta	1.736	0.344	0.516	0.844
Rank	1	4	3	2

Figure 19 shows the Main effect plot of Means obtained from the measurement of Surface roughness means from table 18 through analysis from MINI TAB 14.

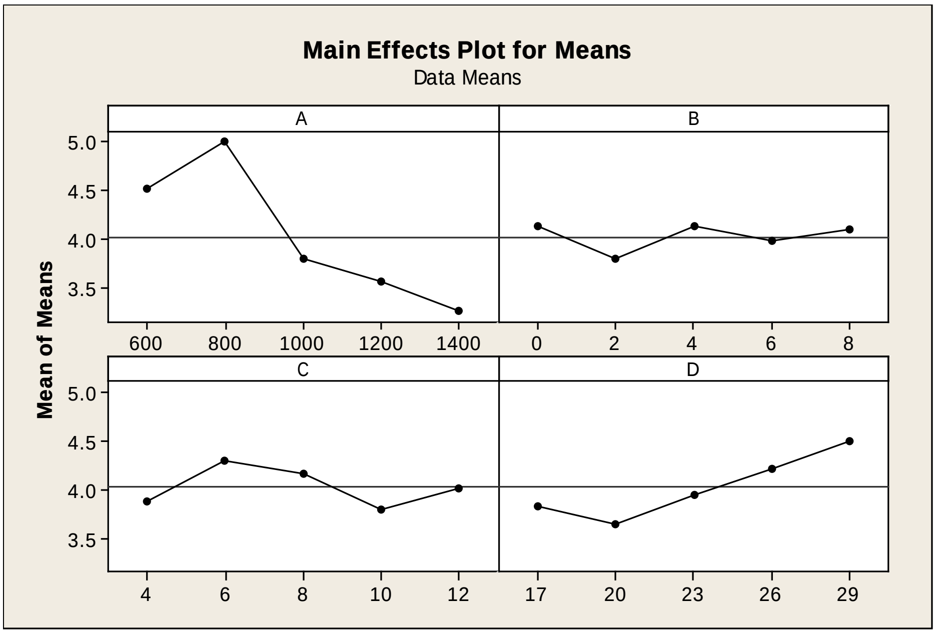


Figure 19. Main Effect Plot for Means.

Figure 20 shows the Mean effect plot for SN ratios i.e. Signal to Noise ratios of Nimonic 80 surface roughness values .in the analysis smaller is better is taken because we want that surface roughness minimum values is best for the work piece.

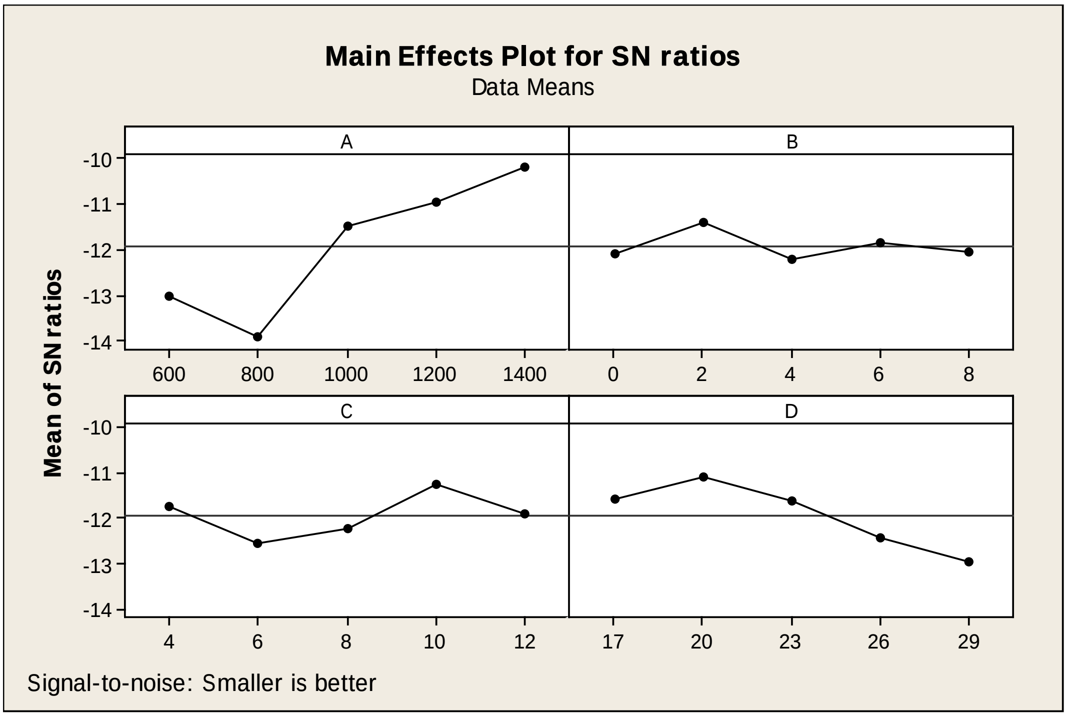


Figure 20. Main Effect Plot for SN Ratios.

Table 19 shows the ANOVA analysis of Surface roughness model of Nimonic 80 .analysis is done in MINI TAB 14. In the analysis the importance and contribution of the process parameters are shown and also the percentage contribution of each and every parameters is shown in the surface roughness after machining.

Table 17 ANOVA Results for Ra Model of Nimonic 80.

Variation source	Degree of freedom(df)	Sum of squares(SS)	Mean square(MS)	F value	P	PCR (%)
A	4	10.1771	2.5443	11.92	0.002	66.16
B	4	0.4202	0.1051	0.49	0.743	2.73
C	4	0.8713	0.2178	1.02	0.452	5.66
D	4	2.2050	0.5512	2.58	0.118	14.35
Residual Error	8	1.7080	0.2135			
Total	24	15.3816				
Standard deviation 0.462066			R^2 = 88.90%			
			Adjusted R^2=66.69%			

6.5.2 Analysis of Variance (ANOVA):

ANOVA analysis is used to determine the effects of various process parameters and their percentage contribution. The coefficient of determination shows that the value of factors taken in experimentations is under our expected range except 12.10 % of factors. The experiments are carried out by 90% confidence level. The Adjusted coefficient of determination shows that surface roughness is a factor which is not only depends on wheel speed and concentration of powder but also other factors like flushing rate and dielectric flow. The ANOVA analysis shows that Wheel Speed is most significant factor affecting Ra followed by Abrasive concentration in Dielectric, while frequency of current and Discharge have very less effect of Ra. In the ANOVA analysis it is clarly shows that powde concentration, pulse on time are most influencing parameters on surface roughness with 66.16% and 14 % respectively.

6.5.3 Regression Equation of Surface Roughness (R_a) of Nimonic 80.

In terms of actual factors, the final empirical relationship between Surface Roughness (response characteristic) and input process parameters of Nimonic 80 can be expressed by the following second-order polynomial in Equation 4.

R_a = 4.61 - 0.00196 W + 0.0045 PC - 0.0124 C + 0.0635 POT..Equation 4

The coefficients of the process parameters in Eq. (4) have been computed by Mini Tab 14 software after analysis of the data shown in Table 17.

7. Conclusion:

7.1 Conclusion for PMAEDCG of AISI D3 Die Steel.

Powder mixed electro discharge diamond grinding of AISI D3 die steel is reported in this study. Taguchi-L9 orthogonal design is used for study the effects of Abrasive powder mixed in dielectric fluid in electric Discharge Diamond Grinding process. Three machining input parameters were selected to analyze process performance and it has found that material removal rate increases with increase in powder concentration and wheel speed. Out of The relative significance of control factors on MRR was examined using ANOVA. The results of ANOVA at 95% confidence level for performance factors are tabulated in selected parameter levels, 6g/lit of power concentration, 1400 rpm wheel speed and 4 amps current results in optimum material removal rate according to Taguchi analysis.

7.2 Conclusion of PMAEDG of Inconel 718.

Powder mixed electro discharge diamond grinding of Inconel-718 is reported in this study. Taguchi-L9 orthogonal design is used for study the effects of Abrasive powder mixed in dielectric fluid in electric Discharge Diamond Grinding process. Three machining input parameters were selected to analyze process performance and it has found that powder concentration and wheel speed significantly improves the material removal rate. Out of selected parameter levels, 6g/lit of power concentration, 1400 rpm wheel speed and 6 amps current results in optimum material removal rate.

7.3 Conclusion of PMAEDG of Nimonic 80A.

This work proposes a new hybrid machining process called as AMEDDG. The performance of proposed AMEDDG process has been experimentally investigated for machining of Nimonic 80A. The effects of various input machining parameters viz. wheel speed; powder concentration, current, and pulse-on-time on MRR have been investigated and following conclusions have been withdrawn:

7.3.1 Material Removal Rate. (MRR)

MRR increases with increase in wheel speed as at higher wheel speeds more number of particles abrades more volume of work-piece.MRR initially increases with increase of powder concentration up to 4gm/lit due to addition of powder in dielectric assists bridging inter electrode gap. Afterwards, further addition of power in dielectric attributes to discharge interference decreasing MRR. At increased current increased discharge energy removed more work-piece material due to melting. However, after 10 amps the MRR decreases due to molten material resolidifies on work-piece. The wheel speed, current and powder concentration were found to be significant parameters in PMAEDG contributing 52.239%, 14.456% and 14.456% respectively on MRR. The optimum parameters determined in PMAEDG on Nimonic 80A are wheel speed of 1400 rpm, powder concentration of 4 g/lit current of 10 amps, and pulse-on-time of 26 µs in machining of Nimonic 80 in PMAEDG process.

7.3.2 Surface Roughness. (R_a)

In the Experiments performed on Die Steels, Inconel 718 and Nimonic 80 in PMAEDCG process, SiC powder was used in order to see whether the changes happen in Surface roughness and MRR. The results shows that MRR increased and Surface roughness decreased .The results of surface roughness on PMAEDCG of Nimonic 80 had been studied and observed that with the increase in powder concentration up to 4 to 6 g/ltr with a constant decrease in Surface roughness when increasing the rpm of the grinding wheel. It is obvious that in grinding process Surface finish is improved but in this process it helps in increasing the MRR also and observed that at 1400 rpm highest surface finish is obtained. It has also been seen that current is the primary factor for high surface roughness as current is increased the crater wear is more which increases the roughness of the surface.

Appendix-I: Publications:

[1] Unune Deepak, Singh Vijay, & Singh Mali (2015) “Powder Mixed Electro Discharge Diamond Grinding of Inconel 718” at the International Conference on Advance Research& Innovation in Engineering and Technology,(ICARIET)15,ARYA Institute of Engineering and Technology,Jaipur3-4th March.

[2] Deepak Rajendra Unune, Vijay Pratap Singh, Harlal Singh Mali (2015) “Experimental Investigation of Abrasive Mixed Electro Discharge Diamond Grinding of Nimonic 80 Alloy.” *Materials Science and Manufacturing Processes*. Communicated on 15 May 2015.

[3] Deepak Rajendra Unune, Vijay Pratap Singh, Harlal Singh Mali (2015) “Machining Performance of Abrasive Mixed Surface Electric Discharge Diamond Grinding of Inconel 718 using Response Surface Methodology.” *Materials Science and Manufacturing Processes*. (Taylor and Francis) communicated on 15 May 2015.

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