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EFFECT OF GRAPHITE AND COPPER TOOLS ON MRR AND SURFACE ROUGHNESS BY USING MINERAL OIL WHILE MACHINING INCONEL600 ON EDM

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BY

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CERTIFICATE

This is to certify that the dissertation entitled **EFFECT OF GRAPHITE AND COPPER TOOLS ON MRR AND SURFACE ROUGHNESS BY USING MINERAL OIL WHILE MACHINING INCONEL600 ON EDM** is a bonfide work carried out by **G.V.CHAITANYA BHARTH KUMAR,** RollNo:14021D0424, in the CAD/CAM submitted to the Dept of Mechanical Engineering, Jawaharlal Nehru Technological University, Kakinada, in partial fulfillment of the requirements for the award of degree of **MASTER OF TECHNOLOGY** in **CAD/CAM**, from JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY, KAKINADA

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G.V.CHAITANYA BHARATH KUMAR (14021D0424)

ABSTRACT

The correct selection of manufacturing conditions is one of the most important aspects to take into consideration in the majority of manufacturing processes and, particularly, in processes related to Electrical Discharge Machining (EDM). It is a capable of machining geometrically complex or hard material components, that are precise and difficult-to-machine such as heat treated tool steels, composites, super alloys, ceramics, carbides, heat resistant steels etc. being widely used in die and mould making industries, aerospace, aeronautics and nuclear industries.

Inconel 600 is a nickel-chromium alloy with good oxidation resistance at higher temperatures, with good resistance in carburizing and chloride containing environments.

Inconel 600 is a nickel-chromium alloy designed for use from cryogenic to elevated temperatures in the range of 2000 deg F (1093 deg C). The high nickel content of the alloy enables it to retain considerable resistance under reducing conditions and makes it resistant to corrosion by a number of organic and inorganic compounds.

The chromium content of the alloy makes it superior to commercially pure nickel under oxidizing conditions. In strong oxidizing solutions like hot, concentrated nitric acid, 600 has poor resistance. Alloy 600 is relatively un-attacked by the majority of neutral and alkaline salt solutions and is used in some caustic environments. The alloy resists steam and mixtures of steam, air and carbon dioxide.

Alloy 600 is non-magnetic, has excellent mechanical properties and a combination of high strength and good workability and is readily weldable. Inconel 600 exhibits cold forming characteristics normally associated with chromium-nickel stainless steels.

Typical corrosion applications include titanium dioxide production (chloride route), perchlorethylene syntheses, vinyl chloride monomer (VCM), and magnesium chloride. Alloy 600 is used in chemical and food processing, heat treating, phenol condensers, soap manufacture, vegetable and fatty acid vessels and many more.The Electric discharge machining process is finding out the effect of machining parameter such as discharge current, pulse on time and gap voltage on INCONEL 600 work material using square shaped cut tool. A well-designed experimental scheme was used to reduce the total number of experiments. Parts of the experiment were conducted with the L9 orthogonal array based on the Taguchi method. Moreover, the experiments were determined by which factor is most affected by the Responses of Material Removal Rate (MRR) and Surface roughness by using graphite and copper tools.

Table of Contents

List of Figures

List of Tables

CHAPTER- 1

1.1 Background of EDM

The history of EDM Machining Techniques goes as far back as the 1770s when it was discovered by an English Scientist. However, Electrical Discharge Machining was not fully taken advantage of until 1943 when Russian scientists learned how the erosive effects of the technique could be controlled and used for machining purposes. When it was originally observed by Joseph Priestly in 1770, EDM Machining was very imprecise and riddled with failures. Commercially developed in the mid-1970s, wire EDM began to be a viable technique that helped shape the metal working industry we see today. In the mid-1980s.The EDM techniques were transferred to a machine tool. This migration made EDM more widely available and appealing over traditional machining processes. The new concept of manufacturing uses non-conventional energy sources like sound, light, mechanical, chemical, electrical, electrons and ions. With the industrial and technological growth, development of harder and difficult to machine materials, which find wide application in aerospace, nuclear engineering and other industries owing to their high strength to weight ratio, hardness and heat resistance qualities has been witnessed. New developments in the field of material science have led to new engineering metallic materials, composite materials and high tech ceramics having good mechanical properties and thermal characteristics as well as sufficient electrical conductivity so that they can readily be machined by spark erosion. Non-traditional machining has grown out of the need to machine these exotic materials. The machining processes are non-traditional in the sense that they do not employ traditional tools for metal removal and instead they directly use other forms of energy. The problems of high complexity in shape, size and higher demand for product accuracy and surface finish can be solved through non-traditional methods. Currently, non-traditional processes possess virtually unlimited capabilities except for volumetric material removal rates, for which great advances have been made in the past few years to increase the material removal rates. As removal rate increases, the cost effectiveness of operations also increase, stimulating ever greater uses of nontraditional process. The Electrical Discharge Machining process is employed widely for making tools, dies and other precision parts. EDM has been replacing drilling, milling, grinding and other traditional machining operations and is now a well-established machining option in many manufacturing industries throughout the world. And is capable of machining

Geometrically complex or hard material components, that are precise and difficult-to-machine such as heat treated tool steels, composites, super alloys, ceramics, carbides, heat resistant steels etc. being widely used in die and mold making industries, aerospace, aeronautics and nuclear industries. Electric Discharge Machining has also made its presence felt in the new fields such as sports, medical and surgical, instruments, optical, including automotive R&D areas.

1.2 Introduction of EDM

Electrical Discharge Machining (EDM) is a well-known machining technique since more than fifty years. Nowadays it is the most widely-used non-traditional machining process, mainly to produce injection molds and dies, for mass production of very common objects. It can also produce finished parts, such as cutting tools and items with complex shapes. EDM is used in a large number of industrial areas: automotive industry, electronics, domestic appliances, machines, packaging, telecommunications, watches, aeronautic, toys, surgical instruments. The advantages of EDM over traditional methods such as milling or grinding are multiple. Any material that conducts electricity can be machined, whatever its hardness (hardened steel, tungsten carbide, special alloys for aerospace applications, for example). Furthermore, complex cutting geometry, sharp angles and internal corners can be produced. Final surface state with low rugosity (< 100 nm) and precise machining (» 1 ¹m) are other important advantages. Moreover, there is no mechanical stress on the machined piece, no rotation of work piece or tool is necessary, and the machines have a high autonomy. On the other hand, the disadvantages are the relatively low material removal rate (order of 100 mm3/minute), surface modification of the machined work piece ("white layer" and heat affected zone, typical depth » 50 ¹m), and limited size of work piece and tool, for example.

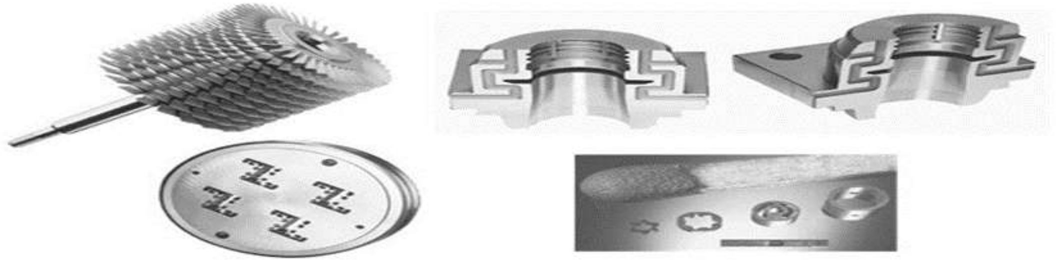


Figure 1.1 Examples of parts machined with EDM: high speed turbine and mold for the screw thread of PET bottles, produced by die-sinking.

1.3 Principle of EDM

In this process the metal is removing from the work piece due to erosion case by rapidly recurring spark discharge taking place between the tool and work piece. Show the mechanical set up and electrical set up and electrical circuit for electro discharge machining. A thin gap about 0.025mm is maintained between the tool and work piece by a servo system shown in fig 1.1. Both tool and work piece are submerged in a dielectric fluid .Kerosene/EDM oil/deionized water is very common type of liquid dielectric although gaseous dielectrics are also used in certain cases.

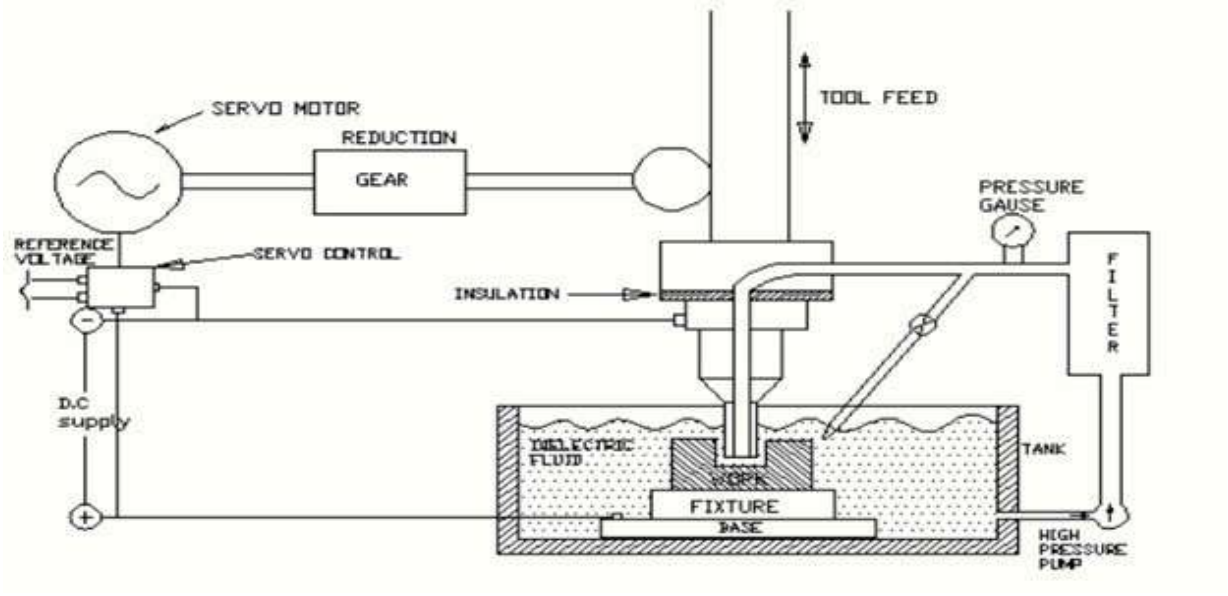


Figure 1.2 Set up of Electric discharge machining

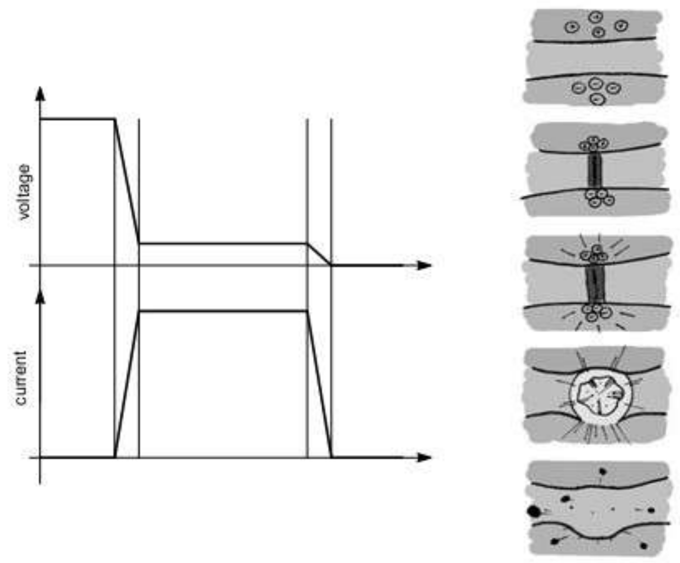
This fig.1.2 is shown the electric setup of the Electric discharge machining. The tool is mead cathode and work piece is anode. When the voltage across the gap becomes sufficiently high it discharges through the gap in the form of the spark in interval of from 10 of micro seconds. And positive ions and electrons are accelerated, producing a discharge channel that becomes conductive. It is just at this point when the spark jumps causing collisions between ions and electrons and creating a channel of plasma. A sudden drop of the electric resistance of the previous channel allows that current density reaches very high values producing an increase of ionization and the creation of a powerful magnetic field. The moment spark occurs sufficiently pressure developed between work and tool as a result of which a very high temperature is reached

And at such high pressure and temperature that some metal is melted and eroded. Such localized extreme rise in temperature leads to material removal. Material removal occurs due to instant vaporization of the material as well as due to melting. The molten metal is not removed completely but only partially.

1.4 Successive steps by which EDM proceeds

The principle of EDM is to use the eroding effect of controlled electric spark discharges on the electrodes. It is thus a thermal erosion process. The sparks are created in a dielectric liquid, generally water or oil, between the work piece and an electrode, which can be considered as the cutting tool. There is no mechanical contact between the electrodes during the whole process. Since erosion is produced by electrical discharges, both electrode and work piece have to be electrically conductive. Thus, the machining process consists in successively removing small volumes of work piece material, molten or vaporized during a discharge. The volume removed by a single spark is small, in the range of 10¡6¡10¡4 mm3, but this basic process is repeated typically 10,000 times per second. Figure 1.3 gives a simple explanation of the erosion process due to a single EDM discharge. First, voltage is applied between the electrodes. This ignition voltage is typically 200 V. The breakdown of the dielectric is initiated by moving the electrode towards the work piece. This will increase the electric field in the gap, until it reaches the necessary value for breakdown. The location of breakdown is generally between the closest points of the electrode and of the work piece, but it will also depend on particles present in the gap. When the breakdown occurs, the voltage falls and a current rises abruptly. The presence of a current is possible at this stage, because the dielectric has been ionized and a plasma channel has been created between the electrodes. The discharge current is then maintained, assuring a continuous bombardment of ions and electrons on the electrodes. This will cause strong heating of the workpiece material (but also of the electrode material), rapidly creating a small molten metal pool at the surface. A small quantity of metal can even be directly vaporized due to the heating. During the discharge, the plasma channel expands. Therefore, the radius of the molten metal pool increases with time.

At the end of the discharge, current and voltage are shut down. The plasma implodes under the pressure imposed by the surrounding dielectric. Consequently, the molten metal pool is strongly sucked up into the dielectric, leaving a small crater at the workpiece surface (typically 1¡500 ¹m in diameter, depending on the current).



(a) Pre-breakdown : Voltage applied between the electrode and the work piece.

(b) Breakdown: dielectric breakdown creation of the plasma channel.

(c) Discharge : Heating, melting and vaporizing of the workpiece.

(d) End of the discharge: plasma implosion removing of the molten metal pool.

(e) Post-discharge: solidifying and flushing of the eroded particles by the dielectric

Figure 1.3 *Principle* of the EDM process

The liquid dielectric plays a crucial role during the whole process: it cools down the electrodes, it guarantees a high plasma pressure and therefore a high removing force on the molten metal when the plasma collapses, it solidifies the molten metal into small spherical particles, and it also flushes away these particles. The post-discharge is in fact a crucial stage, during which the electrode gap is cleaned of the removed particles for the next discharge. If particles stay in the gap, the electrical conductivity of the dielectric liquid increases, leading to a bad control of the process and poor machining quality. To enhance the flushing of particles, the dielectric is generally flowing through the gap. In addition, the electrode movement can be pulsed, typically every second, performing a large retreat movement. This pulsing movement also enhances the cleaning, on a larger scale, by bringing "fresh" dielectric into the gap.

1.5 Classification of EDM process:

Basically, there are two different types of EDM:

1.5.1. Die-sinking

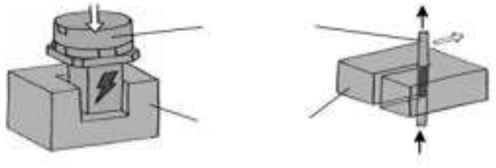
1.5.2. Wire-cut.

1.5.1Die-sinking EDM –

In the Sinker EDM Machining process, two metal parts submerged in an insulating liquid are connected to a source of current which is switched on and off automatically depending on the parameters set on the controller. When the current is switched on, an electric tension is created between the two metal parts. If the two parts are brought together to within a fraction of an inch, the electrical tension is discharged and a spark jumps across. Where it strikes, the metal is heated up so much that it melts. Sinker EDM, also called cavity type EDM or volume EDM consists of an electrode and workpiece submerged in an insulating liquid such as, more typically, oil or, less frequently, other dielectric fluids. The electrode and workpiece are connected to a suitable power supply. The power supply generates an electrical potential between the two parts. As the electrode approaches the workpiece, dielectric breakdown occurs in the fluid, forming a plasma channel, and a small spark jumps. These sparks usually strike one at a time because it is very unlikely that different locations in the inter-electrode space have the identical local electrical characteristics which would enable a spark to occur simultaneously in all such locations. These sparks happen in huge numbers at seemingly random locations between the electrode and the workpiece. As the base metal is eroded, and the spark gap subsequently increased, the electrode is lowered automatically by the machine so that the process can continue uninterrupted. Several hundred thousand sparks occur per second, with the actual duty cycle carefully controlled by the setup parameters.

1.5.2 Wire-cut EDM –

Wire EDM Machining (also known as Spark EDM) is an electro thermal production process in which a thin single-strand metal wire (usually brass) in conjunction with de-ionized water (used to conduct electricity) allows the wire to cut through metal by the use of heat from electrical sparks. a thin single-strand metal wire, usually brass, is fed through the workpiece, submerged in a tank of dielectric fluid, typically deionized water. Wire-cut EDM is typically used to cut plates as thick as 300mm and to make punches, tools, and dies from hard metals that are difficult to machine with other methods. Wire-cutting EDM is commonly used when low residual stresses are desired, because it does not require high cutting forces for removal of material. If the energy/power per pulse is relatively low (as in finishing operations), little change in the mechanical properties of a material is expected due to these low residual stresses, although material that hasn't been stress-relieved can distort in the machining process. Due to the inherent properties of the process, wire EDM can easily machine complex parts and precision components out of hard conductive materials.



(a) die-sinking (b) wire-cutting

Figure 1.4 Main types of EDM: die-sinking and wire-cutting.

1.6 Important parameters of EDM:

(a) Spark On-time (pulse time or Ton): Machining takes place only during the pulse-on time (Ton). When the tool electrode is at negative potential, material removal from the anode (work piece) takes place by bombardment of high energy electrons ejected from the tool surface. At the same time positive ions move towards the cathode. When pulses with small on times are used, material removal by electron bombardment is predominant due to the higher response rate of the less massive electrons. However, when longer pulses are used, energy sharing by the positive ions is predominant and the material removal rate decreases. When the electrode polarities are reversed, longer pulses are found to produce higher MRR. The duration of time (µs) the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on-time. This energy is really controlled by the peak current and the length of the on-time.

(b) Spark Off-time (pause time or Toff): A non-zero pulse off time is a necessary requirement for EDM operation. Discharge between the electrodes leads to ionization of the spark gap. Before another spark can take place, the medium must de-ionize and regain its dielectric strength. This takes some finite time and power must be switched off during this time. Too low values of pulse-off time may lead to short-circuits and arcing. A large value on the other hand increases the overall machining time since no machining can take place during the off-time. The surface roughness is found to depend strongly on the spark frequency. When high frequency sparks are used lower values of Ra are observed. It is so because the energy available in a given amount of time is shared by a larger number of sparks leading to shallower discharge craters. The duration of time (µs) between the sparks (that is to say, on-time). This time allows the molten material to solidify and to be wash out of the arc gap. This parameter is to affect the speed and the stability of the cut. Thus, if the off-time is too short, it will cause sparks to be unstable.

(c) Arc gap (or gap): The Arc gap is distance between the electrode and workpiece during the process of EDM. It may be called as spark gap. Spark gap can be maintained by servo system.

(d) Discharge current (current Ip): The discharge current (Id) is a measure of the power supplied to the discharge gap. A higher current leads to a higher pulse energy and formation of deeper discharge craters. This increases the material removal rate (MRR) and the surface roughness (Ra) value. Similar effect on MRR and Ra is produced when the gap voltage (Vg) is increased.

1.7 Characteristics of EDM:

1.7.1 Advantages of EDM

(a) Any material that is electrically conductive can be cut using the EDM process.

(b) Hardened work pieces can be machined eliminating the deformation caused by heat treatment.

(c) X, Y, and Z axes movements allow for the programming of complex profiles using simple electrode.

(d) Complex dies sections and molds can be produced accurately, faster, and at lower costs. Due to the modern NC control systems on die sinking machines, even more complicated work pieces can be machined.

(e) The high degree of automation and the use of tool and work piece changers allow the machines to work unattended for overnight or during the weekends

(f) Forces are produced by the EDM-process and that, as already mentioned, flushing and hydraulic forces may become large for some work piece geometry. The large cutting forces of the mechanical materials removal processes, however, remain absent.

(g) Thin fragile sections such as webs or fins can be easily machined without deforming the part.

1.7.2 Limitation of EDM –

(a) The need for electrical conductivity – To be able to create discharges, the work piece has to be electrically conductive. Isolators, like plastics, glass and most ceramics, cannot be machined by EDM, although some exception like for example diamond is known. Machining of partial conductors like Si semi-conductors, partially conductive ceramics and even glass is also possible.

(b) Predictability of the gap - The dimensions of the gap are not always easily predictable, especially with intricate work piece geometry. In these cases, the flushing conditions and the contamination state of differ from the specified one. In the case of die-sinking EDM, the tool wear also contributes to a deviation of the desired work piece geometry and it could reduce the achievable accuracy. Intermediate measuring of the work piece or some preliminary tests can often solve the problems.

(c) Low material removal rate- The material removal of the EDM-process is rather low, especially in the case of die-sinking EDM where the total volume of a cavity has to be removed by melting and evaporating the metal. With wire-EDM only the outline of the desired work piece shape has to be machined. Due to the low material removal rate, EDM is principally limited to the production of small series although some specific mass production applications are known.

(d) Optimization of the electrical parameters - The choice of the electrical parameters of the EDM-process depends largely on the material combination of electrode and work piece and EDM manufactures only supply these parameters for a limited amount of material combinations.

1.7.3 Application of EDM –

1. The EDM process is most widely used by the mould-making tool and die industries, but is becoming a common method of making prototype and production parts, especially in the aerospace, automobile and electronics industries in which production quantities are relatively low.

2. It is used to machine extremely hard materials that are difficult to machine like alloys, tool steels, tungsten carbides etc.

3. It is used for forging, extrusion, wire drawing, thread cutting.

4. It is used for drilling of curved holes.

5. It is used for internal thread cutting and helical gear cutting.

It is used for machining sharp edges and corners that cannot be machined effectively by other machining processes.

CHAPTER-2

2.1 LITERATURE SURVEY

C.D. Shah1, J.R.Mevada2, B.C.Khatri3 [1] From the experiments that were conducted on Inconel600 material in Wire Cut EDM and the RSM models developed, the following interesting conclusions were drawn.

1. The effects of Pulse On time, Pulse Off time, Peak Current, Wire Feed rate setting are experimentally investigated in machining of Inconel-600 using CNC Wire-cut EDM process. The level of importance of the machining parameters on the material removal rate is determined by using ANOVA and it is shown that Pulse on, Pulse Off, Pea current are most significant

2. An optimum parametric combination for the maximum material removal rate was obtained by using Signal-to-Noise (S/N) ratio. Improved S/N ratio and conformation test indicated that it is possible to increase material removal rate by using the proposed statistical technique.

D.Vinoth Kumar1, P.Siva Kumar2, B.Kumaragurubharan3, T.Senthil kumar4 [2] Based on the Results and Discussion the following conclusions are drawn in this article,

- A trial was created to work out the numerous machining parameters on electrical discharge Machining of Inconel 600 has been done using copper electrode for performance measures supported by Taguchi-Grey Relational Analysis.
- The optimized input parameter combinations to urge the utmost Material Removal Rate and Tool Wear Rate are Pulse on 500 µs,
- Pulse off 40 µs, Current 4 amps. The experimental results are validated with ANOVA.

1BUTA SINGH, 2MANPREET SINGH [3] This work evaluates the feasibility of machining Inconel600 by electrical discharge machining. Based on the results presented here in, we conclude the following:

a) The suggested optimal machining parameters for material removal rate are: Em (Copper), Ip (15), Pon (120), Vg (35).The parameter with the greatest effect on the material removal rate was peak current and copper electrode showed the highest MRR. while brass electrode showed the the least MRR.

b) The suggested optimal machining parameters for electrode wear rate are: Em (Copper tunsten),IP (9),Pon (120), Vg (40). The significant parameters with the greatest effects on the electrode wear rate were electrode material and peak current. Copper tungsten electrode showed the minimum EWR than other two electrodes.

c) The suggested optimal parameters for surface roughness are: Em (Brass),IP(9),Pon (120), Vg(45). The significant parameters with the greatest effects on the electrode wear rate were electrode material and peak current. Brass electrode showed the minimum SR than other two electrodes

Dattatray Vishnu Wagh1, Prof.D.R.Dolas2 [4] The response surface methodology based on three variables, face centered composite design was used to determine the effect of time (ranging 30-70 min), concentrations of etchant (ranging 300– 700 gm/lit) and temperature (55-65 0C) on the Undercut during the PCM process of Inconel 600 material. The regression analysis, statistical significance and response surface were applied using Design Expert Software for forecasting the responses in all experimental areas. Quadratic models were developed to show a relationship between variables and the responses. Through analysis of the response surfaces derived from the models, role of time was found to have the most significant effect on Undercut. Process optimization was carried out and the experimental values acquired for the Undercut during the PCM process of Inconel 600 material are found to agree satisfactorily with the values predicted by the models. Since experimentally obtained and model predicted values are residual which shows the effectiveness of model, based on the designed experiment. The optimal predicted Undercut 0.0029 mm of Inconel 600 was obtained as Ferric chloride concentration, time and temperature of etching and these were found to be 470.781gm/lit, 32.39 min and 55.276 0C respectively.

D Sudhakara1*, B Venkataramana Naik1 and B Sreenivasulu2. [5] When current increases, the MRR also increases. The higher the current, intensity of spark is increased and results in high metal removal will takes place.

- When the current is increased, surface roughness is also increased. Because due to increase in current, the spark intensity is also increases. So the MRR per minute increases. Finally the surface roughness is increases.
- When current is increases, hardness will decreased. Because due to increase current, the intensity of spark increases. Due high spark intensity the carbon layer will depleted. So that the hardness is decreased.

• When current is increased, the crack length, crack widths are also increased due to the high temperature generation at high currents.

• When duty factor is increases, the MRR is also increases. The higher the duty factor, intensity of spark and machining time is increased and results in high metal removal will takes place. • When the Duty factor is increased, surface roughness is also increased, because due to increase in duty factor, the spark intensity, machining time is also increases. So the MRR per minute increases. Finally the surface roughness is increases.

• When Duty factor is increases, hardness will decreased. Because due to increase Duty factor, the intensity of spark increases. Due high spark intensity, the carbon layer will depleted. So that the hardness is decreased.

When duty factor is increased, the crack length, crack widths are also increased due to the high temperature generation at high duty factors.

• When pulse on time is increases, the MRR is decreased. The higher the pulse on time, intensity of spark is decrease due expansion of plasma channel and results in less metal removal will takes place.

• When the Pulse on time is increased, surface roughness is decreased, because due to increase in pulse on time, the spark intensity is also decreases due to the expansion of plasma channel. So the MRR per minute decreases. Finally the surface roughness is decrease.

• When the Pulse on time is increases, hardness will increased. Because increase in pulse on time, the intensity of spark decreases due to the expansion of plasma channel. Due low spark intensity, the carbon layer will deposited, so that the hardness is increased.

• When pulse on time is increased, the crack length, crack widths are increased due to the low temperature generation at high pulse on time due the expansion of plasma channel.

Balram Jakhar, Puneet Katyal, Vishal Gulati [6] Here Taguchi’s method has been used for single response optimization. And in the present set of study, five control factors have been studied simultaneously to establish the trend of variation of a few important machining criteria with these control factors. From present study, the following conclusions are drawn: 1. The cutting speed (CS) is mostly affected by the peak current, pulse-on time, pulse off-time, and taper angle. The third level of peak current is highly affected the CS. 2. The surface roughness values (SR) are influenced mostly by peak current, pulse-on time, taper angle, pulse off-time, and dielectric flow rate. 3. The comparison of the predicted Surface Roughness and Cutting Speed with the experimental Surface Roughness and Cutting Speed using the optimum process parameters in WEDM has shown a good agreement between the predicted and experimental results but there are error in 0.46% error in cutting speed and 6.02% error in surface roughness respectively.

Wang and Lin [7] discuss the optimization of W/Cu composite martial are used the Taguchi method. W/Cu composites are a type of cooling material highly resistant to heat corrosion produced through powder metallurgy. The Taguchi method and L18 orthogonal array to obtain the polarity, peak current, pulse duration, duty factor, rotary electrode rotational speed, and gap-load voltage in order to explore the material removal rate, electrode wear rate, and surface roughness. The influenced of each variable and optimal processing parameter will be obtained through ANOVA analysis through experimentation to improve the process.

Sudhir Ashok Shardul1, Sachin K. Dahake2 [8] Experimental investigation on wire electrical discharge machining On graphite material has been done using brass wire of 0.25mm. The following conclusions are made

- Based on taguchi optimization optimized input parameter combinations to get the minimum surface roughness are 5A current,7 pulse on time ,30bpulse off time,12 g wire tension. similarly to optimized conditions to get the maximum MRR are 5A current,7 pulse on time, 25 pulse off time, 10g wire tension.
- Increase in the pulse on-time leads to the increase in MRR. With the increase in all input parameter SR increases.
- The Analysis of Variance resulted that the Pulse off time has major influence on the MRR and Wire tension on surface roughness.
- The objectives such as surface roughness and MRR are optimized using a single objective taguchi method
- Eventually, mathematical models were developed using regression analysis for both MRR and SR to establish the relation between process parameters and response characteristics.

Senkathir S, Arun Raj A C, Vaddi Thulasikanth, Manoj Samson R [9] A study on machining Inconel 718 with brass tool electrodes having different bottom shape like Flat and Convex ends using the EDM process is to studied and analyzed the effects of different bottom shape tool electrodes on response in the thermal erosion process. The conclusions of the experimental results could be summarized as follows: The Machining time is decreased while using convex tool electrode over flat tool electrode but the Machining time is increased with increasing in diameter of convex tool electrode. Electrode wear is also reduce when electrode chance from flat to convex thus electrode wear is increase when radius of convex tool electrode increase. The cylindricity factor increases with increase in the radius of curvature of convex tool electrode. Finally, it is observed that the small diameter of convex tool electrode has been achieved lower cylindricity factor. The peak current and pulse off time significantly affects the machining characteristics in the EDM process

Sharanjit Singh*and Arvind Bhardwaj [10] Because of EDM enormous improvement in machining process has been achieved in recent years. The capability of machining intricate parts and difficult to cut material has made EDM as one of the most popular machining processes. The contribution of EDM to industries such as cutting new hard materials make EDM technology remains indispensable. The review of the research trends in EDM in water and EDM with powder additives is presented. In each topic, the development of the methods for the last 25 years is discussed & noticed much work in PMEDM rather than by using water as dielectric fluid as shown in Figure 18. The progress of development in each area is presented using block diagrams Figures19 and 20. EDM in water is introduced for safe and conducive working environment; EDM with powder additives is concerning more on increasing SQ, MRR and tool wear using dielectric oil and EDM modeling is introduced to predict the output parameters which leads towards the development of precise and accurate EDM performance. For each and every method introduced and employed in EDM process, the objectives are the same: to enhance the capability of machining performance, to get better output product, to develop technique to machine new materials and to have better working conditions.

Jinming Zhoua*, Volodymyr Bushlyaa, Ru Lin Pengb, Zhe Chenb, Sten Johanssonb and Jan Eric Stahla [11] Subsurface microstructural alterations and residual stresses caused by machining significantly affect component lifetime and performance by influencing fatigue, creep, and stress corrosion cracking resistance. Assessing the surface quality of a machined part by characterizing subsurface microstructural alterations and residual stresses is essential for ensuring part performance and lifetime in aero-engines and power generators. This comparative study characterizes and analyzes subsurface microstructural alterations and residual stresses in Inconel 718 subjected to high-speed machining with PCBN and whisker-reinforced ceramic cutting tools. Effects of cutting tool materials and microgeometry on subsurface deformation, microstructural alterations, and residual stresses were investigated. Surface and subsurface regions of machined specimens were investigated using X-ray diffraction, electron channeling contrast imaging, and electron back-scatter diffraction to characterize microstructural alterations and measure deformation intensity and depth.

H. L. Eiselstein and D. J. Tillack [12] From an initial plan to develop an alloy for service in critical steam applications evolved a material that is used in a wide range of industries. Alloy 625 is used in the aerospace industry because of its high strength, outstanding fatigue and thermal fatigue resistance, oxidation resistance and excellent weldability and brazeability. The ‘outstanding and versatile corrosion resistance of the alloy under a wide range of temperatures and pressures is a primary reason for its wide acceptance in the chemical processing field. Its resistance to stress cracking and excellent pitting resistance in a wide range of water temperatures have enabled it to be used extensively in nuclear applications. Its choice in sea-water applications is a result of a resistance to pitting and crevice corrosion, high corrosion-fatigue strength, high tensile strength and resistance to chloride-ion stress-corrosion cracking. It is often used as a welding material to join dissimilar metals because of its strength and ductility and its ability to tolerate a considerable amount of dilution from other alloys.

As versatile and impressive as alloy 625 is, one of the truly amazing facts about its development history is that it was the seed for the development of alloy 718, the most successful age-hardenable nickel alloy ever developed. Numerous other spin-off alloy compositions have been, and continue to be, developed. But even after over 30 years of existence, alloy 625 is still very much alive.

2.1 Objective of the present work

From the research papers in this classification, it is observed that few works has been reported on EDM on the material INCONEL625, INCONEL718, and various alloy materials. Study on EDM for INCONEL600 Work piece using Copper and Graphite Tools were taken as project.

The objective of the present work is an attempt to finding feasibility of machining nickel-chromium alloy using square shaped electrolytic copper electrode and graphite with dielectric mineral oil. Analyzing the responses MRR and Surface roughness for machining parameters selected such as discharge current, pulse on time, and gap voltage using Taguchi design approach for tools.

CHAPTER- 3

3.1 Dielectric Medium in EDM

3.1.1 Functions of dielectric

Dielectric fluid plays an important role in the EDM process. Because of a high dielectric strength, the dielectric medium prevents premature discharge between the electrodes until a low discharge gap is established between them. Continuous dielectric flow in the discharge gap helps in carrying away the debris formed during the discharge and ensures a proper flushing. Also, dielectric medium cools the machining zone by carrying away excess heat from the tool electrode and the work piece.

3.1.2 Properties of dielectric

The most important properties of dielectric are its dielectric strength, viscosity, thermal conductivity and thermal capacity. Dielectric strength characterizes the fluid’s ability to maintain high resistivity before spark discharge and the ability to recover rapidly after the discharge. High dielectric strength leads to a lower discharge gap which in turn leads to a low gap resistance. Hence, high discharge currents may flow leading to a higher material removal rate. Also, fluids with high dielectric strength need lower time for the recovery of dielectric strength.

Thus, low pulse-off times are sufficient. This not only improves the MRR but also provides better cutting efficiency because of a reduced probability of arcing. Liquids with low viscosity generally provide better accuracies because of a better flow ability of the oil leading to improved flushing. Also, the sideward expansion of the discharge plasma channel is restricted by high viscosity fluids. This focuses the discharge energy over a small region and leads to a deeper crater which reduces the surface finish. Dielectric fluids with high thermal conductivity and thermal heat capacity can easily carry away excess heat from the discharge spot and lead to a lower thermal damage.

3.1.3 Types of dielectric

Selection of dielectric medium is an important consideration for EDM performance. Mineral oils are commonly used as the dielectric medium for die sinking EDM operations. Mineral oils exhibiting high dielectric strength and a low viscosity are preferred because of their higher performance. For safety reasons oils with a high flash point are usually used. Kerosene is one such oil which is used commonly for EDM. Water based dielectrics are used almost extensively for wire EDM operations. Water has a high specific heat capacity which leads to a better cooling effect required for wire cut operations. To prevent chemical reactions, deionized water is used in such applications.

Table 3.1: Comparison of electrical, thermal and mechanical properties of mineral oil, deionized water and air

Properties	Dielectric Strength	Dynamic Viscosity	Thermal Conductivity	Specific Heat Capacity
Medium	(MV/m)	(g/m-s)	(W/m-K)	(J/g-K)
Mineral oil (Grade 2)	0.6	96	0.1	1966

In comparison to mineral oils and water, air has the lowest dielectric strength, viscosity, thermal conductivity and thermal capacity as shown in Table 3.1. A low viscosity air medium favors higher cutting accuracy and better surface finish. However, low dielectric constant suggests a lower MRR with air medium. Low thermal capacity and thermal conductivity suggests higher thermal damage of work piece. However, for a complete analysis of the thermal damage an opposing effect caused by the expansion of plasma channel due to low viscosity must also be accounted. Thus, overall it seems that using air as dielectric may be a better alternative for improving some of the process performance such as surface finish and accuracy at the expense of the MRR.

3.2 Over view On Tool Material

Electrode material should be such that it would not undergo much tool wear when it is impinged by positive ions. Thus the localized temperature rise has to be less by tailoring or properly choosing its properties or even when temperature increases, there would be less melting. Further, the tool should be easily workable as intricate shaped geometric features are machined in EDM. Thus the basic characteristics of electrode materials are:

- High electrical conductivity – electrons are cold emitted more easily and there is less bulk electrical heating

- High thermal conductivity – for the same heat load, the local temperature rise would be less due to faster heat conducted to the bulk of the tool and thus less tool wear

- Higher density – for the same heat load and same tool wear by weight there would be less volume removal or tool wear and thus less dimensional loss or inaccuracy

- High melting point – high melting point leads to less tool wear due to less tool material melting for the same heat load

- Easy manufacturability

- Cost – cheap

The followings are the different electrode materials which are used commonly in the industry:

- Graphite

- Electrolytic oxygen free copper

- Tellurium copper – 99% Cu + 0.5% tellurium

- Brass

Electrolytic oxygen free copper is taken as tool material for carrying out present experiments.

3.3 Specification of Work Material

Inconel 600 is a *nickel-chromium* super alloy that is resistant to steam at high temperatures and sea water as well as to caustic and salt solutions. A solid solution alloy (Inconel 600) that can only hardened by cold working. Inconel 600 exhibits characteristics like high strength , toughness , good weldability and good corrosion resistance. Alloy 600 is non magnetic at room temperature.

Chemical Composition

Chemical Composition Limits								
Weight %	Ni	C	Mn	S	Si	Cr	Fe	Cu
ALLOY 600	**72**	**0.15**	**1**	**0.015**	**0.5**	**14.0-17.0**	**6.0-10.0**	**0.5**

Mechanical Properties – Inconel 600

Yield strength (0.2% Offset)		**Tensile Strength**		**Elongation (%)**
psi	**MPa**	**psi**	**MPa**	**45**
45000	310	95000	60	

Physical properties - Inconel 600

Density	8497 g/cm^3
Melting point	1370-1425 ℃

Characterstics of Inconel 600

- Resistant to seawater and steam at high temperatures
- Excellent resistance to rapidly flowing brackish water or seawater
- Excellent resistance to stress corrosion cracking in most freshwaters
- Particularly resistant to hydrochloric and hydrofluoric acids when they are de-aerated
- Presents the desirable combination of high strength and good weldability under wide range of temperatures
- Excellent resistance to neutral and alkaline salt
- Resistance to chloride induced stress corrosion cracking
- Resistant under reducing conditions, makes it resistant to corrosion by organic and inorganic compounds
- High resistance to alkalis
- It is non magnetic ,has excellent mechanical properties
- designed for service temperatures from cryogenic to evevated temperatures in the range of 2000 F

Applications

- Marine engineering
- Chemical and hydrocarbon processing equipment
- Gasoline and freshwater tanks
- Crude petroleum stills
- De-aerating heaters
- Boiler feed water heaters and other heat exchangers
- Valves, pumps, shafts, fittings, and fasteners
- Industrial heat exchangers
- Chlorinated solvents
- Crude oil distillation towers

3.4 Taguchi Design of Experiments

The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan who maintained that variation. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. The Taguchi method is best used when there is an intermediate number of a variable (3 to 50), few interactions between variables, and when only a few variables contribute significantly.

Analysis of variance on the collected data from the Taguchi design of experiments can be used to select new parameter values to optimize the performance characteristic. The data from the arrays can be analyzed by plotting the data and performing a visual analysis, ANOVA, bin yield and Fisher's exact test, or Chi-squared test to test significance.

Philosophy of the Taguchi Method

1. Quality should be designed into a product, not inspected into it. Quality is designed into a process through system design, parameter design, and tolerance design. Parameter design, which will be the focus of this article, is performed by determining what process parameters most affect the product and then designing them to give a specified target quality of product. Quality "inspected into" a product means that the product is produced at random quality levels and those too far from the mean are simply thrown out.

2. Quality is best achieved by minimizing the deviation from a target. The product should be designed so that it is immune to uncontrollable environmental factors. In other words, the signal (product quality) to noise (uncontrollable factors) ratio should be high.

3. The cost of quality should be measured as a function of deviation from the standard and the losses should be measured system wide. This is the concept of the loss function, or the overall loss incurred upon the customer and society from a product of poor quality. Because the producer is also a member of society and because customer dissatisfaction will discourage future patronage, this cost to customer and society will come back to the producer.

Taguchi Method Design of Experiments

The general steps involved in the Taguchi Method are as follows:

1. Define the process objective, or more specifically, a target value for a performance measure of the process. This may be a flow rate, temperature, etc. The target of a process may also be a minimum or maximum; for example, the goal may be to maximize the output flow rate. The deviation in the performance characteristic from the target value is used to define the loss function for the process.

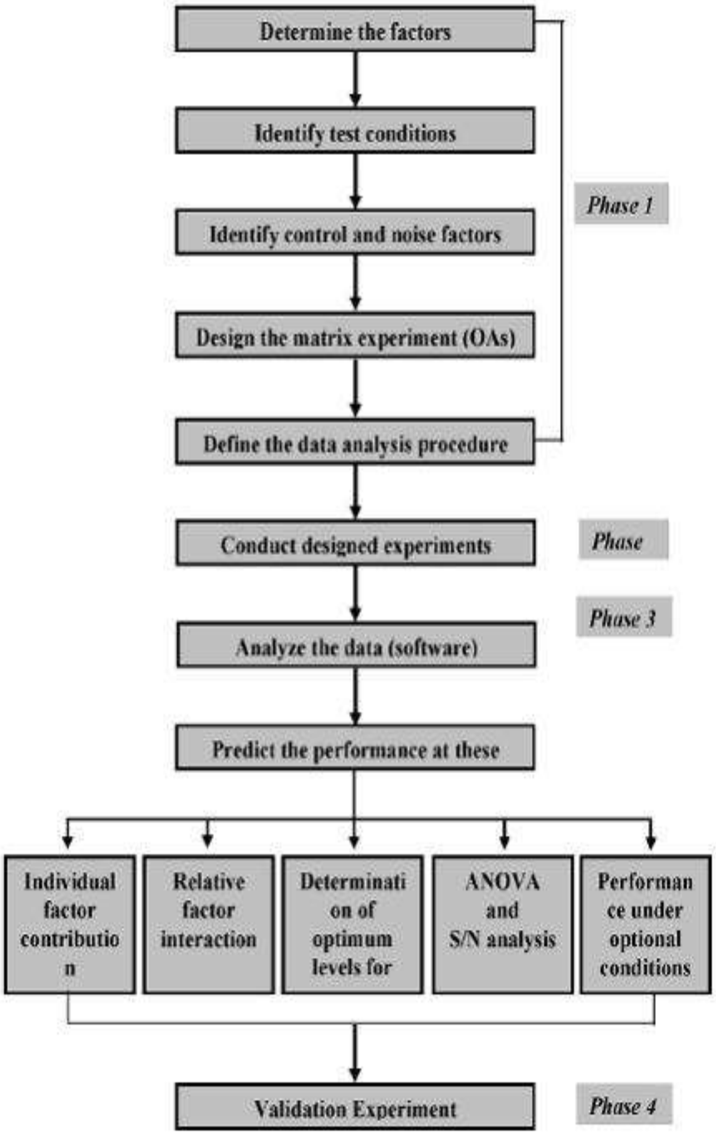
2. Determine the design parameters affecting the process. Parameters are variables within the process that affect the performance measure such as temperatures, pressures, etc. that can be easily controlled. The number of levels that the parameters should be varied at must be specified. For example, a temperature might be varied to a low and high value of 40 C and 80 C. Increasing the number of levels to vary a parameter at increases the number of experiments to be conducted.

3. Create orthogonal arrays for the parameter design indicating the number of and conditions for each experiment. The selection of orthogonal arrays is based on the number of parameters and the levels of variation for each parameter, and will be expounded below.

4. Conduct the experiments indicated in the completed array to collect data on the effect on the performance measure.

5. Complete data analysis to determine the effect of the different parameters on the performance measure.

Table 3.2 Steps in Taguchi method



From Taguchi design for three factors and three levels we will get L9 Orthogonal Array(OA). Hence experiments are conducted based on L9 OA.

3.5 Surface Finish Measurement

Handy Surf Instrument: Handy surf instrument is widely used to measure the shape or form of components.

Figure 3.1 Measuring surface roughness by using HANDYSURF

Introduction:

Many components are manufactured today with tolerances in fractions of a micron. Quality control for such parts requires not only an instrument with sufficient accuracy, but also careful operation in a controlled environment.

The areas to be considered include:

- Capability of the instrument
- The measuring environment
- The component and its set-up
- Data acquisition and analysis

The measuring system:

Performance of a profiling instrument depends on the optimal balance of a number of features; the most important of which are gauge linearity, datum straightness, gauge resolution and noise floor. Poor performance in any one of these areas will produce a poor result, however good the others may be.

A good assessment of an instrument is to measure an inclined glass flat. Any deviation from a straight line indicates inaccuracies of the form measurement capability of the system.

It is vitally important to obtain a good calibration prior to the measurement to set the gain and linearity of the gauge. The quality of the calibration arte fact is also important because any errors will be passed through to the measurement results on the actual component.

The ease and speed of the Handy surf calibration offers significant benefits; accurate calibrations can be made as frequently as necessary, with excellent repeatability between operators.

The measurement environment:

The instrument should be isolated from physical factors that are likely to affect the measurement, the most obvious being vibration and temperature change. Positioning your Instrument in the glare of an outside window facing a busy road is not usually good practice.

Air movement can also considerably affects results. In particular instruments should be used for optimum results.

Also remember that changing the stylus will upset the physical conditions of the instrument system by introducing both a mechanical stimulus (changing the stylus) and a heat source (the operator) close to the extremely sensitive gauge.

Setting up the Component:

Having ensured that the instrument is ready, attention needs to be given to setting up the component. For example, it is important to correctly level and crest (where appropriate) the component and to take the measurement as symmetrical about the gauge centre as possible. In that way the same part of the gauge range (the central and most linear part) is being used across the component.

Measurement uncertainty is influenced by the nature of the work piece itself. Indeed it must be noted that one of the main contributors to uncertainty is the component itself, where surface texture and other imperfections such as dirt or damage caused by mishandling can affect the overall form measurement.

Summary:

The measurement of form requires careful consideration from the outset if measurements are to be repeatable and have a low uncertainty. Attention must be paid to all aspects of the assessment, from choosing the right instrument and right location through component set-up and control of the analysis conditions.

Principle:

A profile measurement device is usually based on a tactile measurement principle. The surface is measured by moving a stylus across the surface. As the stylus moves up and down along the surface, a transducer converts these movements into a signal which is then transformed into a roughness number and usually a visually displayed profile. Multiple profiles can often be combined to form a surface representation.

Surface roughness values are measured for different approach angles at a particular parameter.

Measuring different positions:

The small and light Handy surf E-35A measures not only flat, horizontal, but also vertical and Overhead surfaces. In addition, the traversing unit can be separated from the display unit and used with optional holding devices for more flexible operation.

The experiments are designed and conducted based on L_9 (3^3) orthogonal array.

Surface finish, MRR are measured and tabulated.

3.6 Experimental Setup

In order to carry out the experimentations it is needed to fix a set of input and response parameters which are observed and measured throughout the experimentations.

3.6.1 Input parameters

There are a large number of input parameters or design factors that can be changed and experimented but in this experiment it is proposed to consider Peak Current, Pulse On Time, and Gap Voltage as the input parameters as these parameters are most widespread in EDM research. Pulse off time is made constant throughout the process.

3.6.2 Response parameters

The response parameters that are proposed to be measured and optimized here are material removal rate (MRR), Surface roughness.

3.6.3 Process variables and their limits

The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L9 Orthogonal Array (OA) design have been selected. In the present experimental study, three levels and three parameters such as Peak current, Ton and Gap voltage have been considered as process variables. The process variables are listed in Table below.

Table 3.3 Process Variables and their limits

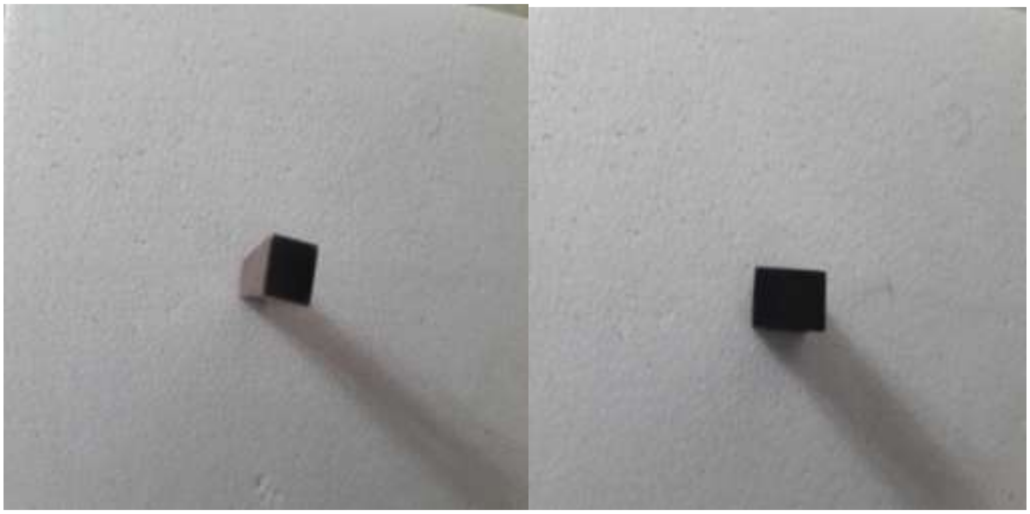
Controllable factors	Level 1	Level 2	Level 3
Peak current(Amp)	3	6	9
Ton(Micro secs)	45	90	200
Gap voltage(Volts)	40	45	50

3.6.4 Equipment used

Fig.3.2 EDM Equipment

SPECIFICATIONS OF MACHINE TOOL (EDM X 3040)	UNITS	X 3040
TABLE DIMENSION	MM	600 x 400
WORK TANK DIMENSION	MM	900 x 550 x 375
X TRAVEL	MM	400
Y TRAVEL	MM	275
Z TRAVEL	MM	220
BACK SLIDE TRAVEL	MM	200

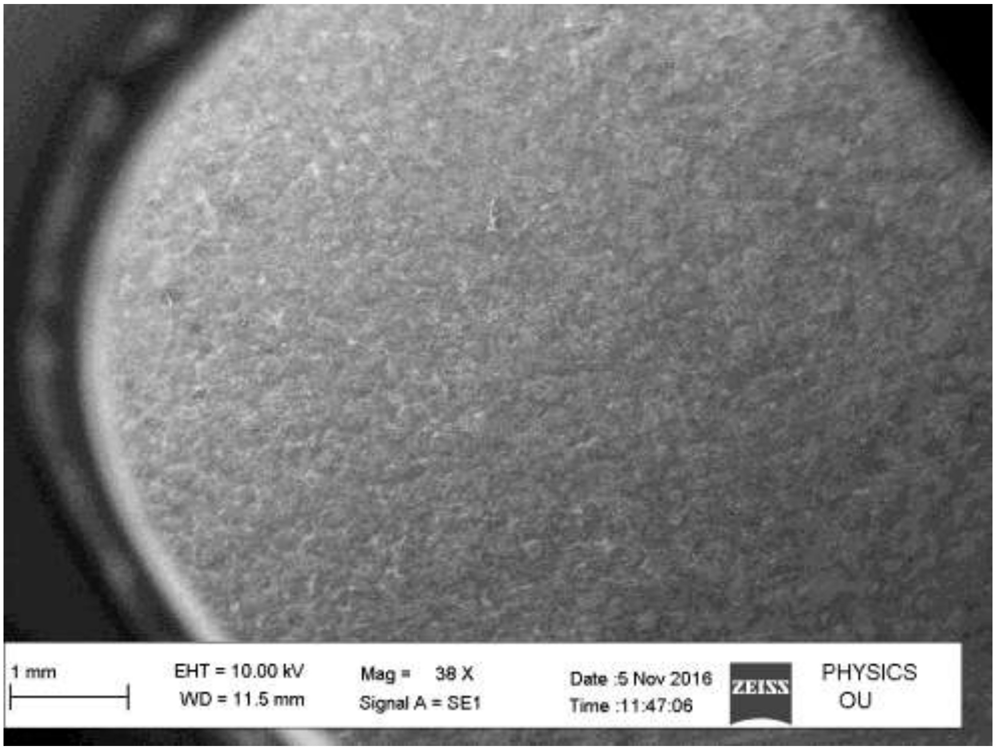
MAX. TABLE LOADING	KGS	600
DI-ELECTRIC CAPACITY	LTS	300
NORMAL CURRENT	AMPS	50
SPECIFICATIONS OF POWER SUPPLY	UNITS	P50
MAX. CURRENT	AMPS	50
MAX. OPEN CKT. VOLTAGE	VOLTS	75-80
MATERIAL CU	MM^3/MIN	300
REMOVAL RATE GR		350
SURFACE FINISH	CLA MICRON	0.8
POWER CONSUMPTION	KW	3
PULSE ON/OFF TIME		IN 10 STEPS

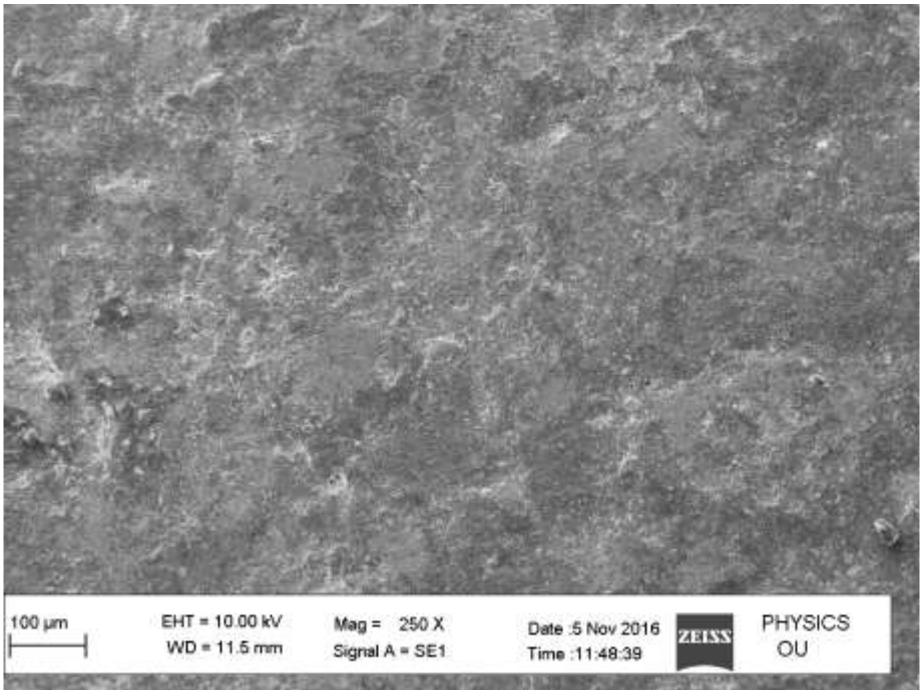


Copper and graphite tools after machining inconel600 workpiece

Fig 3.3 copper tool after machining inconel600 workpiece

SEM IMAGES OF COPPER TOOL

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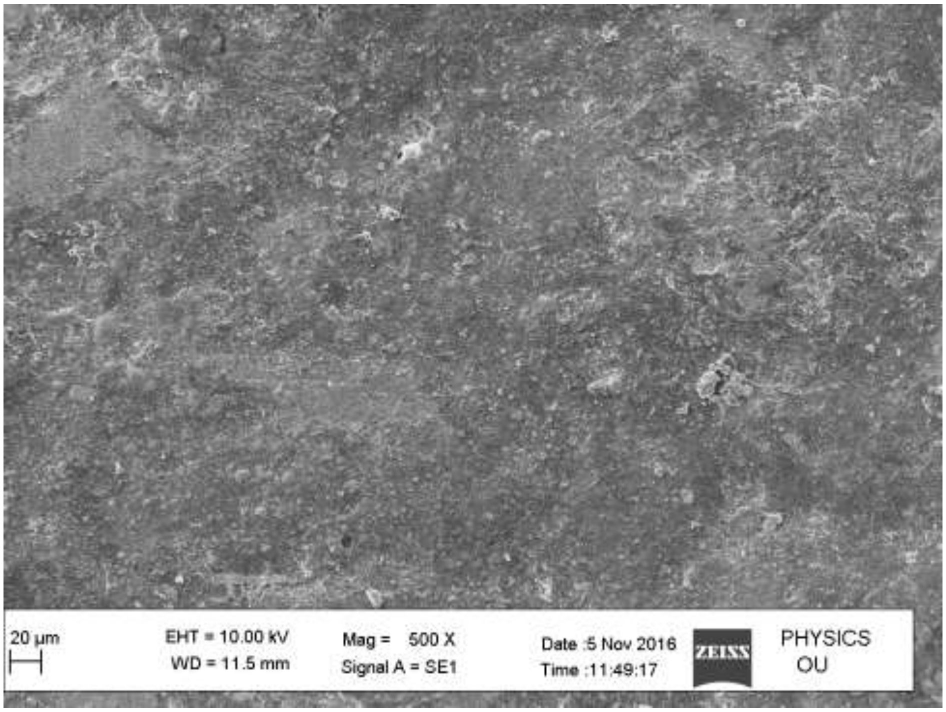
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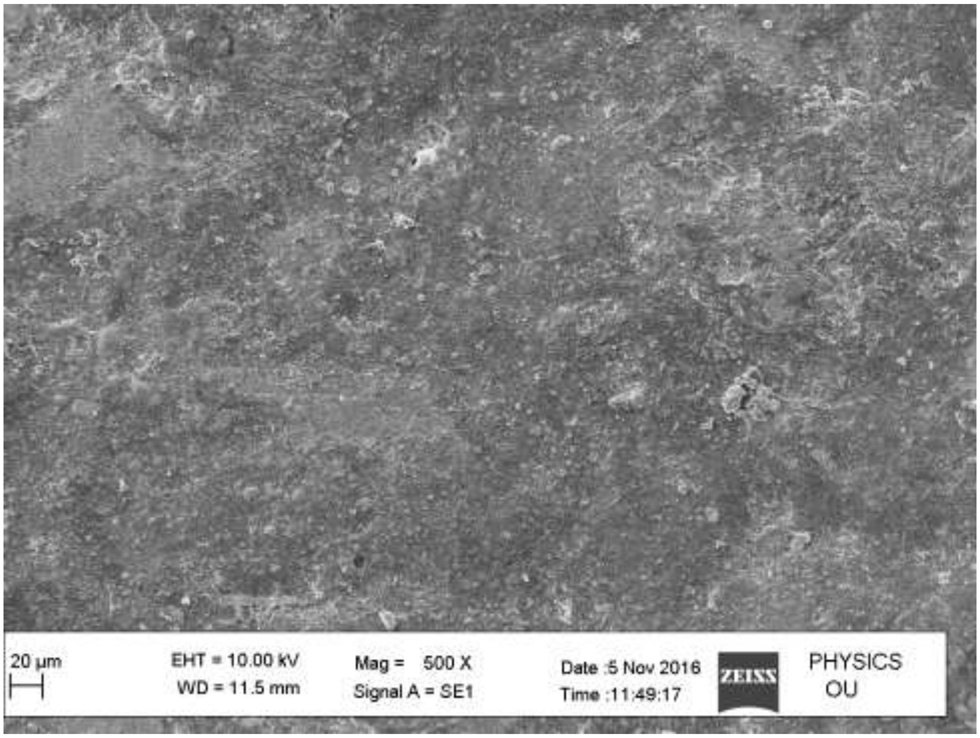
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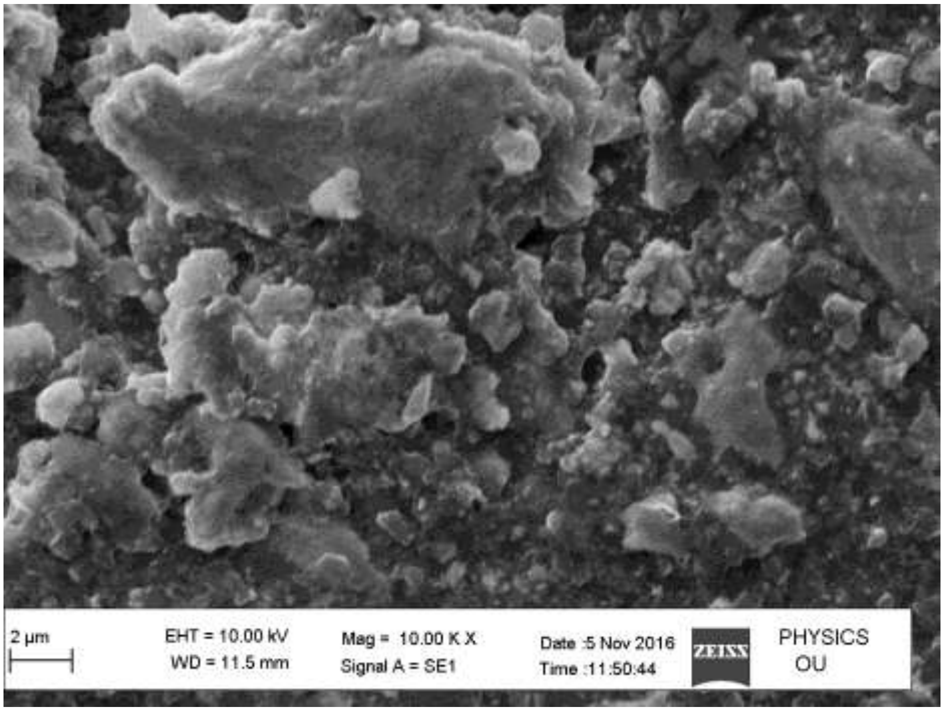
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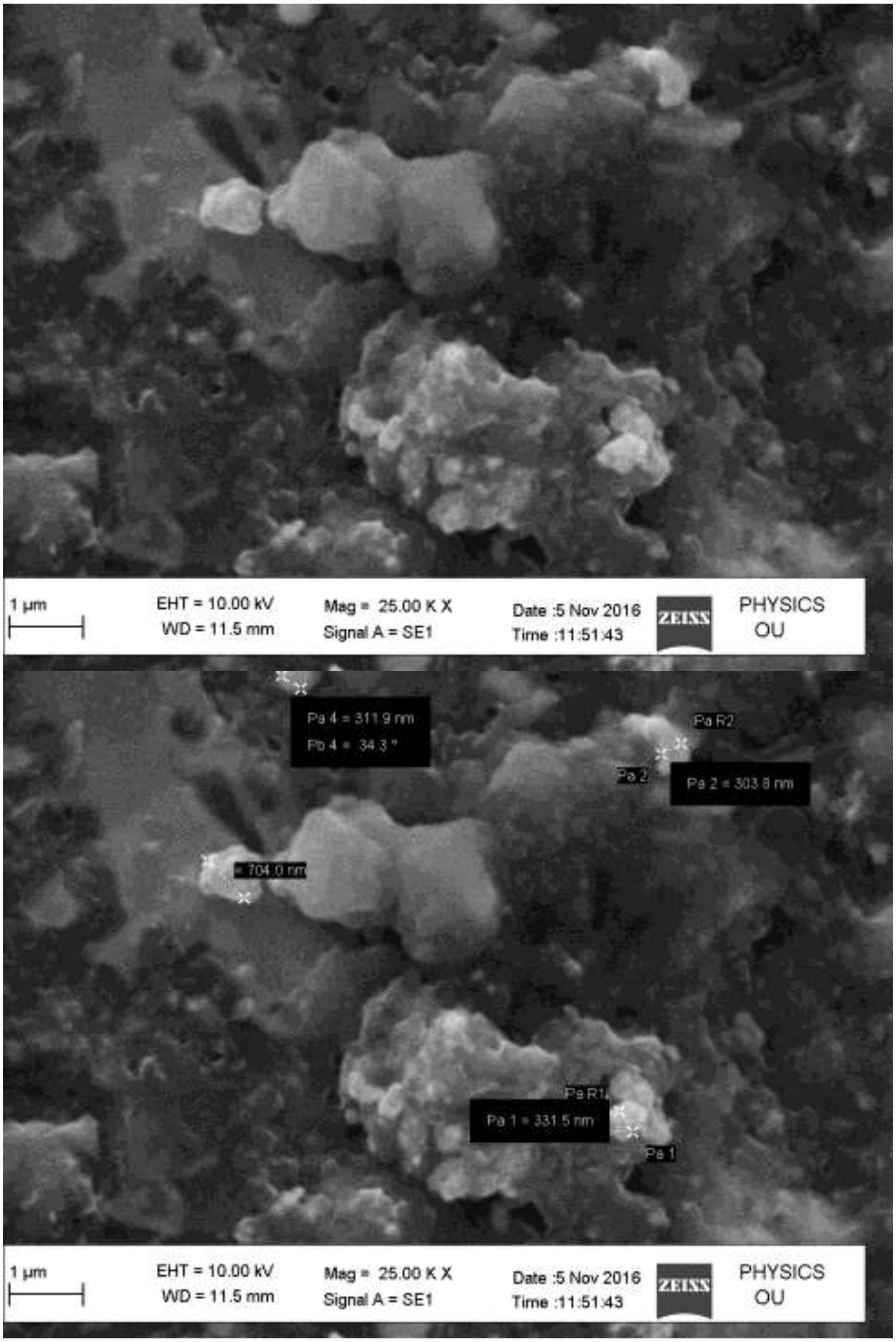
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Pa R2
Pa 2
Pa 2 = 303.8 nm
= 704.0 nm
Pa R1
Pa 1 = 331.5 nm
Pa 1
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Project 1

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EDS IMAGES OF COPPER TOOL

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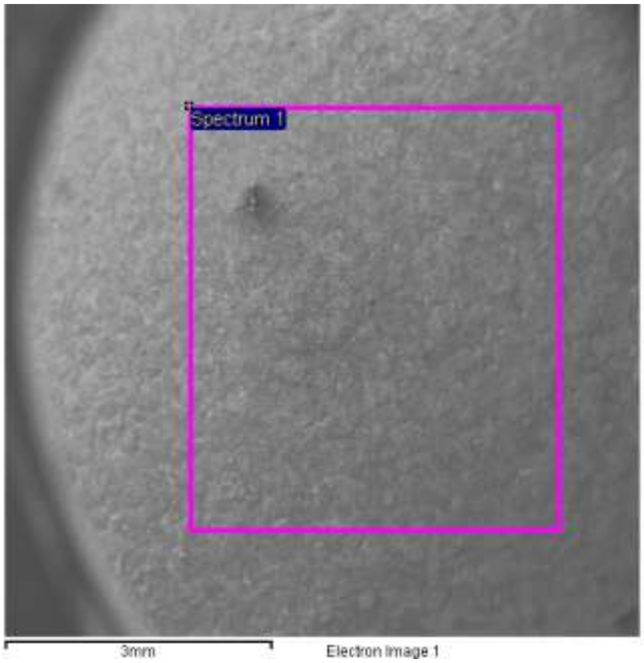
Ni Ni 1-Jun-1999 12:00 AM
Cu Cu 1-Jun-1999 12:00 AM



Element	Weight %	Atomic %
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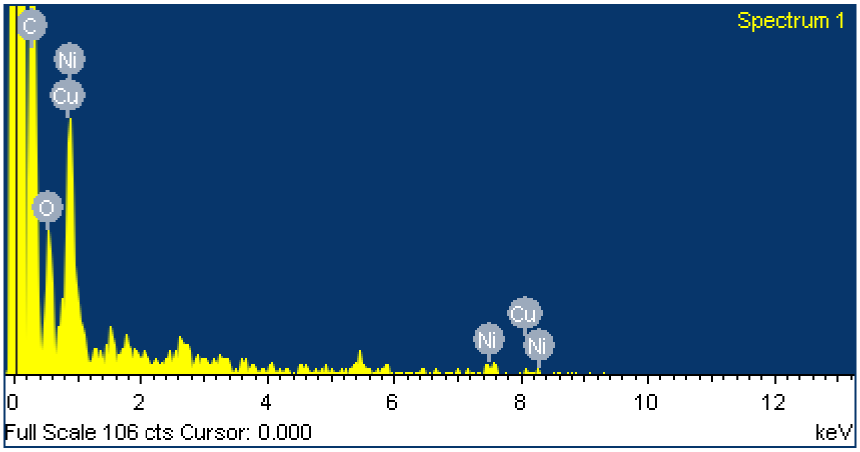
O K	10.84	10.18
Ni L	20.07	5.14
Cu L	1.79	0.42
Totals		100.00



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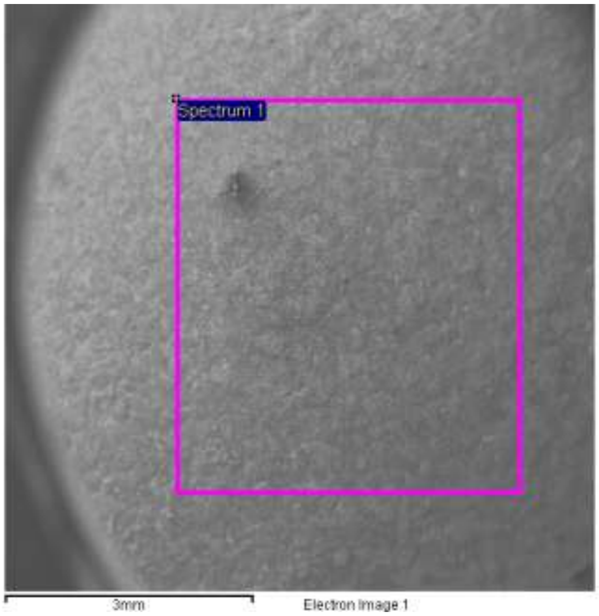

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Ni Ni 1-Jun-1999 12:00 AM
Cu Cu 1-Jun-1999 12:00 AM

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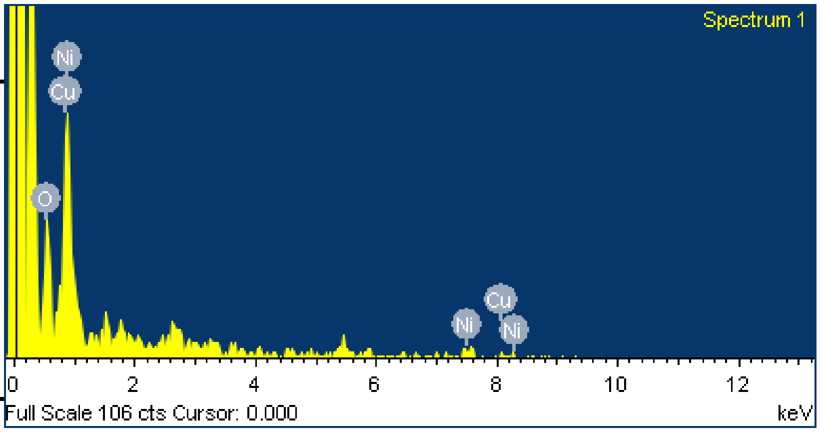
Ni L	66.11	39.50
Cu L	8.42	4.65
Totals	100.00	



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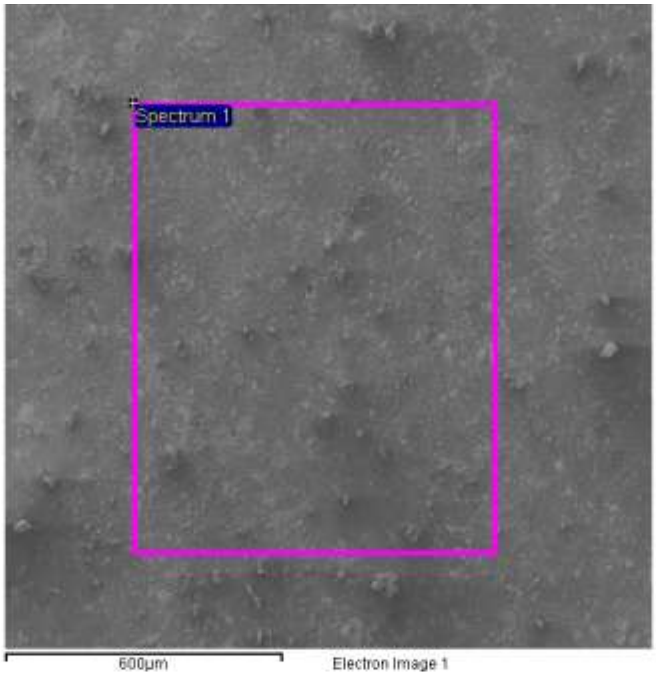

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O SiO2 1-Jun-1999 12:00 AM
Ni Ni 1-Jun-1999 12:00 AM

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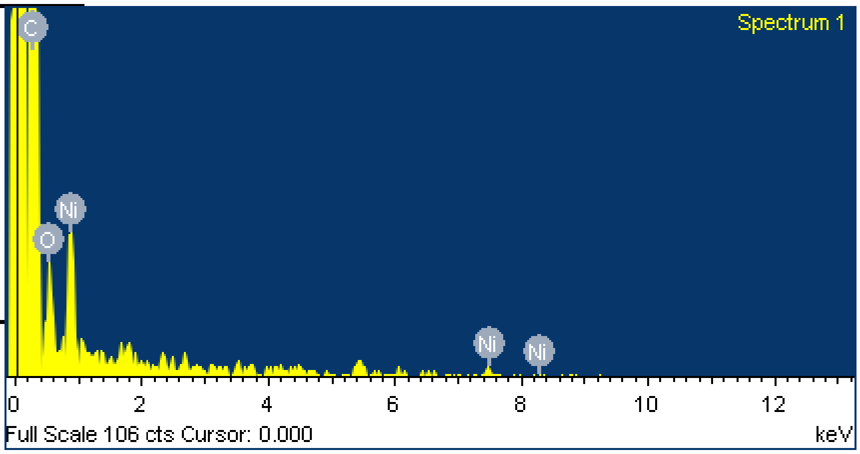
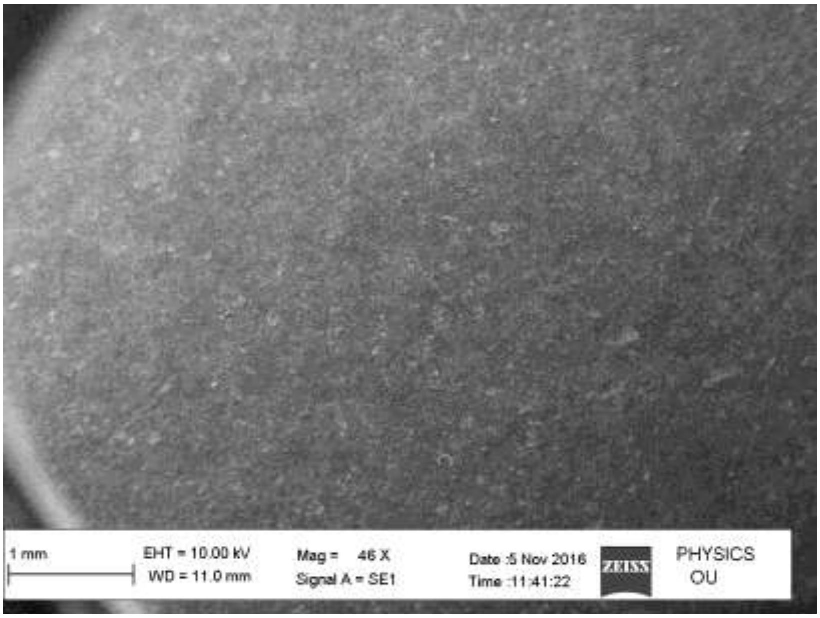
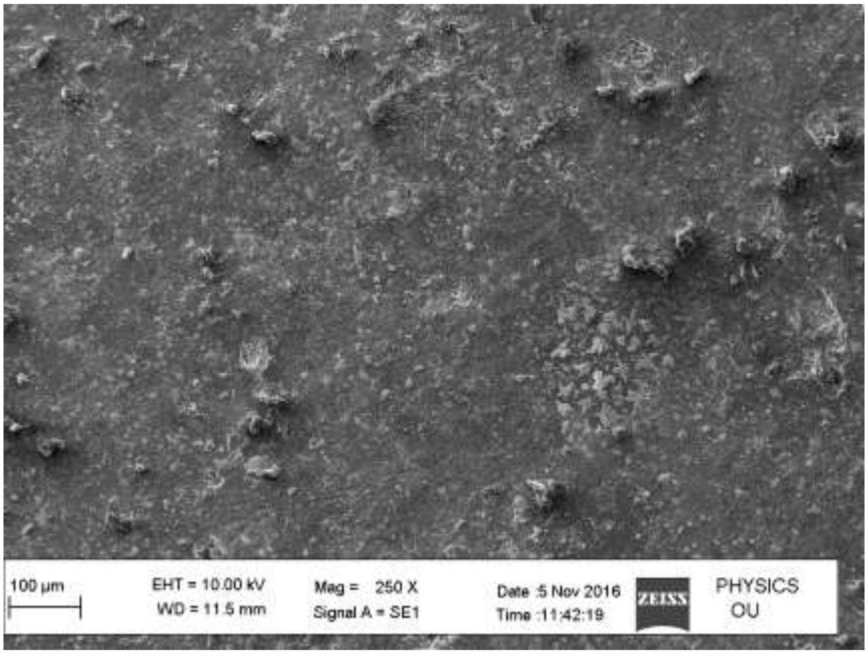
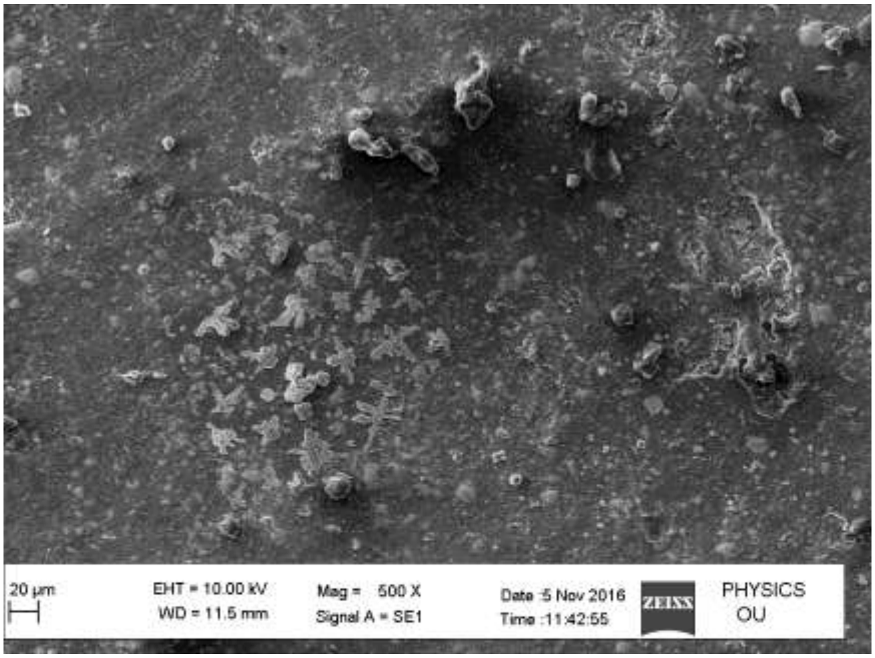
O K	6.46	5.57
Ni L	14.09	3.31
Totals	100.00	



SEM IMAGES OF GRAPHITE TOOL



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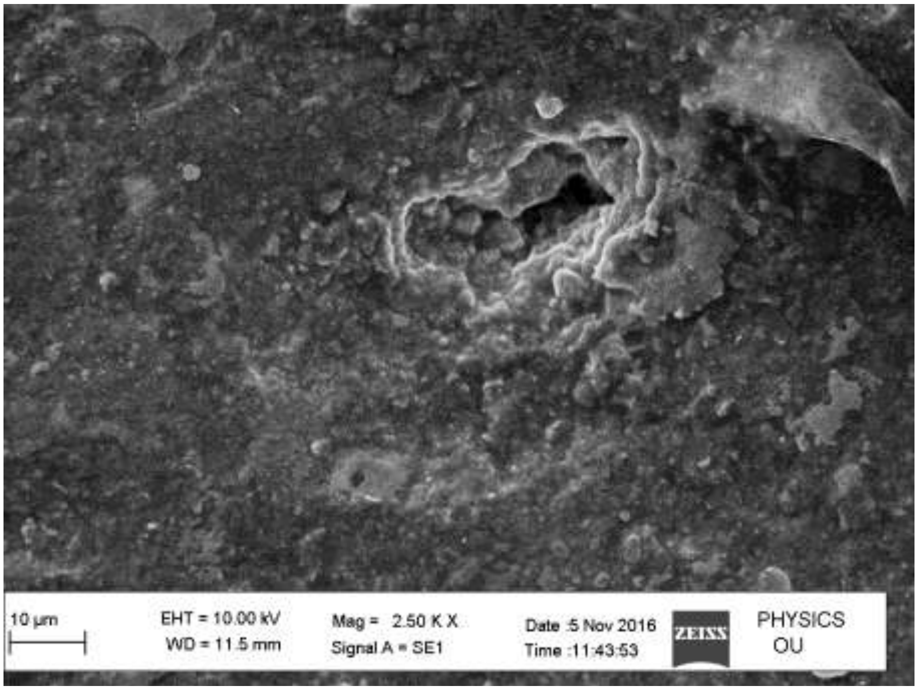
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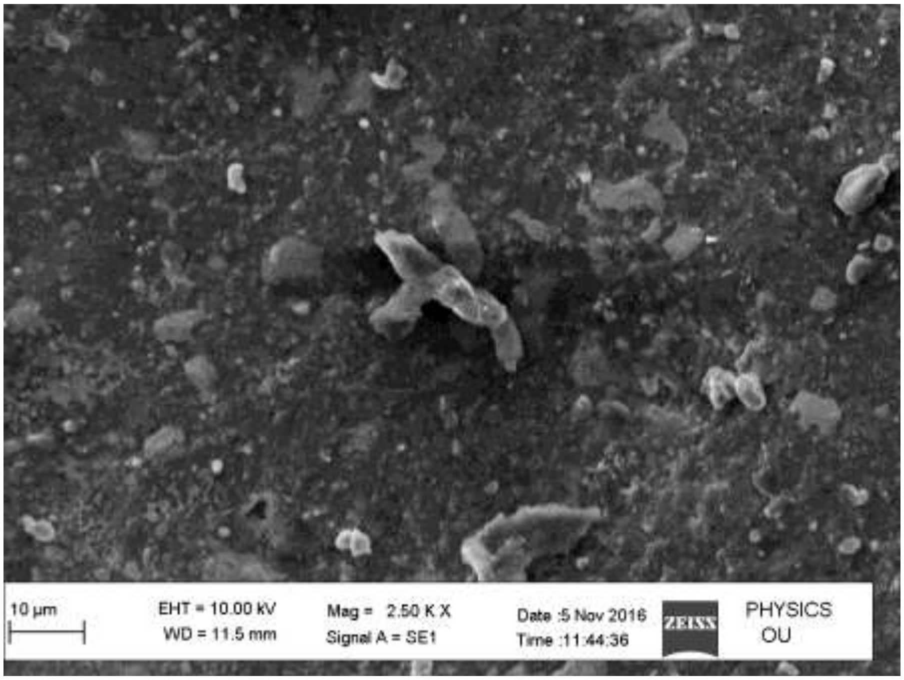
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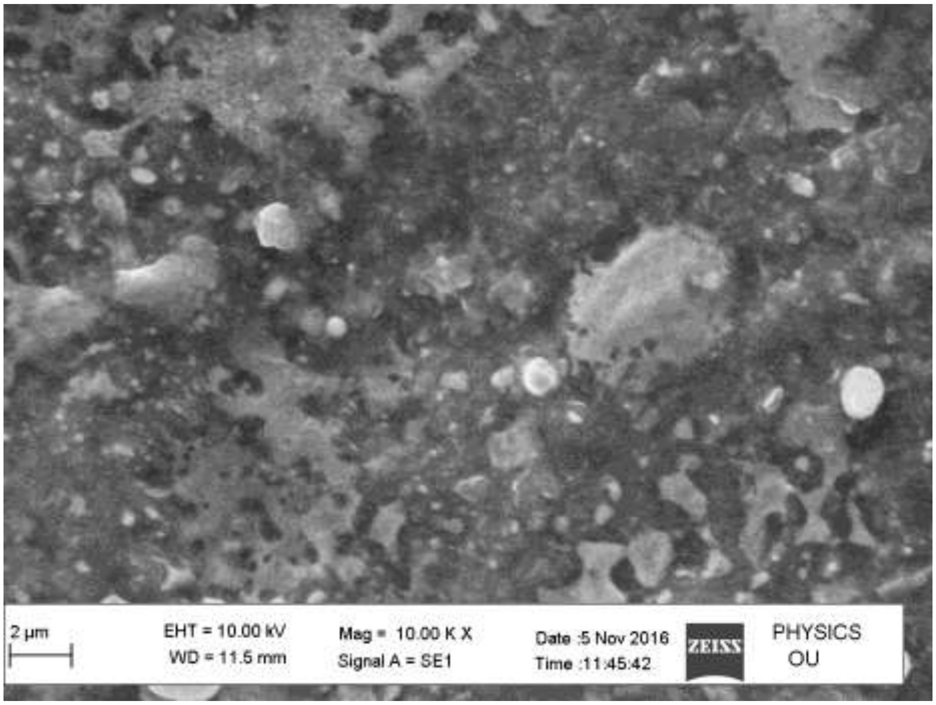
Time :11:44:36
ZEISS
PHYSICS
OU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Mag = 10.00 K X
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PHYSICS
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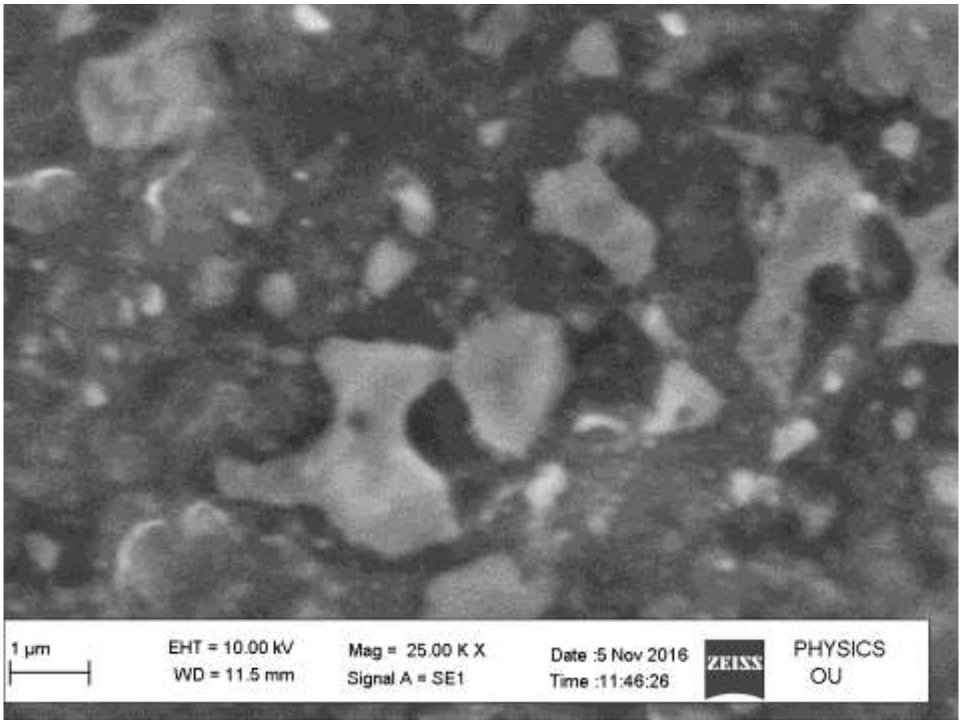


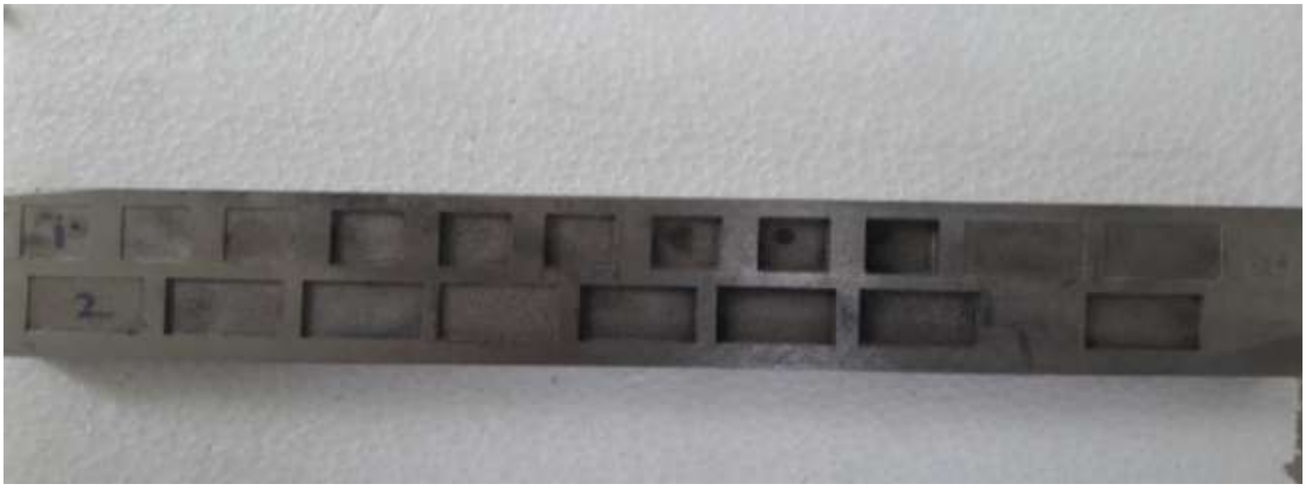
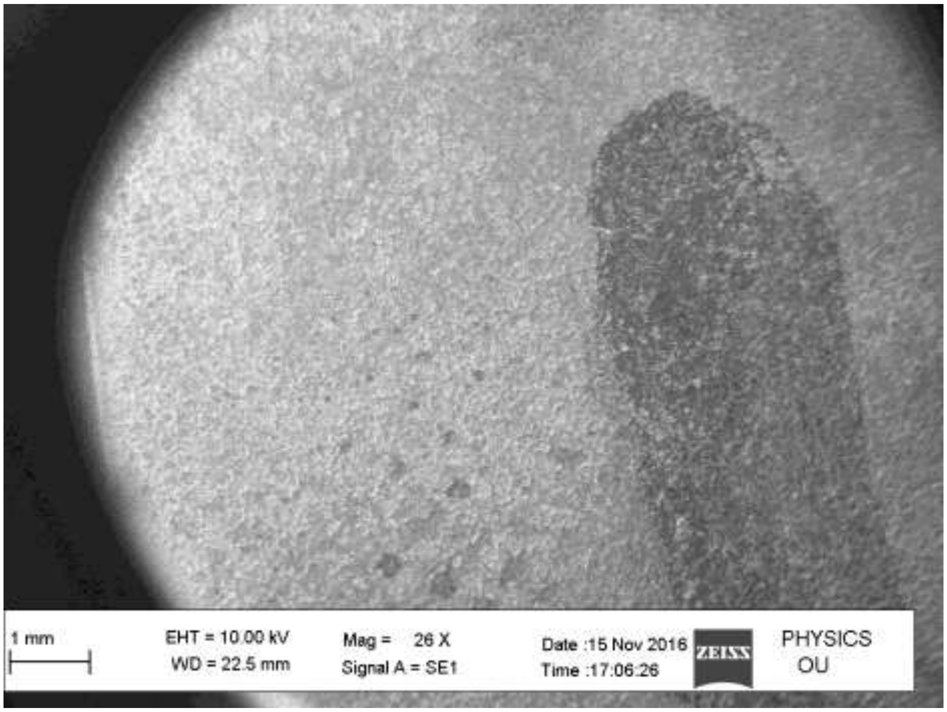


Fig 3.4 Inconel600 work piece after machining with Copper and Graphite Tool

SEM IMAGES OF INCONEL 600 WORK PIECE USING COPPER TOOL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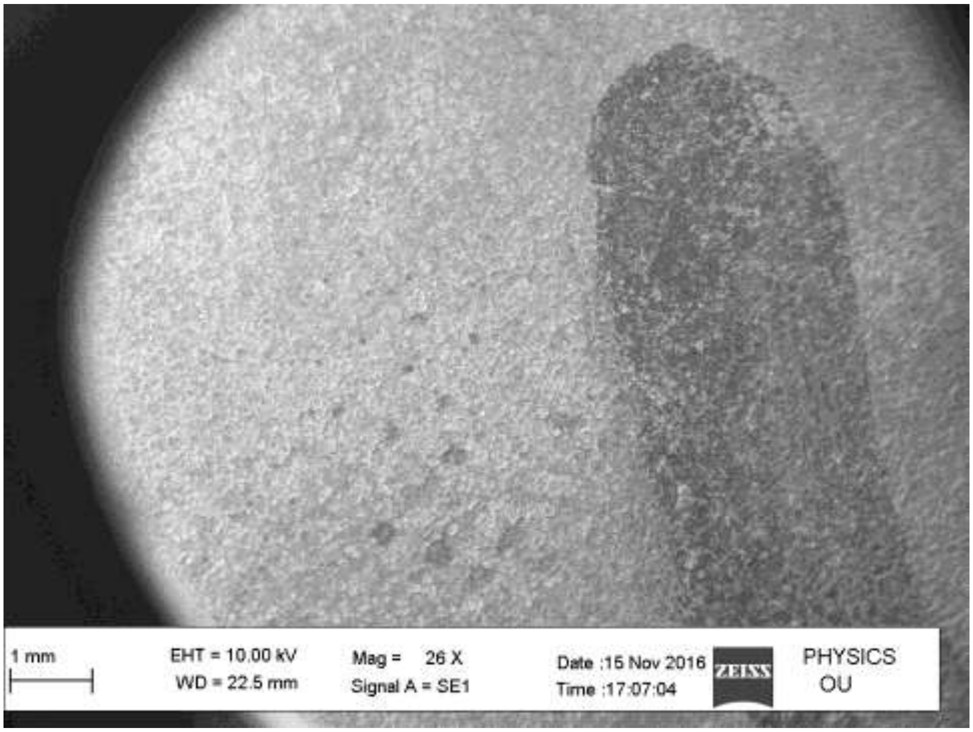
ZEISS
PHYSICS
OU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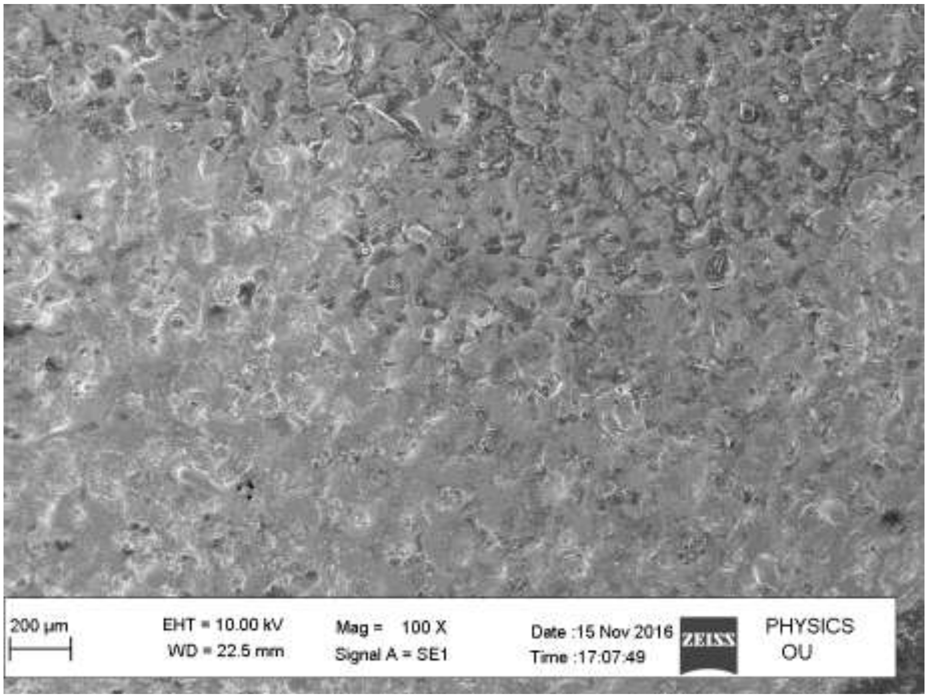
ZEISS
PHYSICS
OU


200 µm
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WD = 22.5 mm
Mag = 100 X
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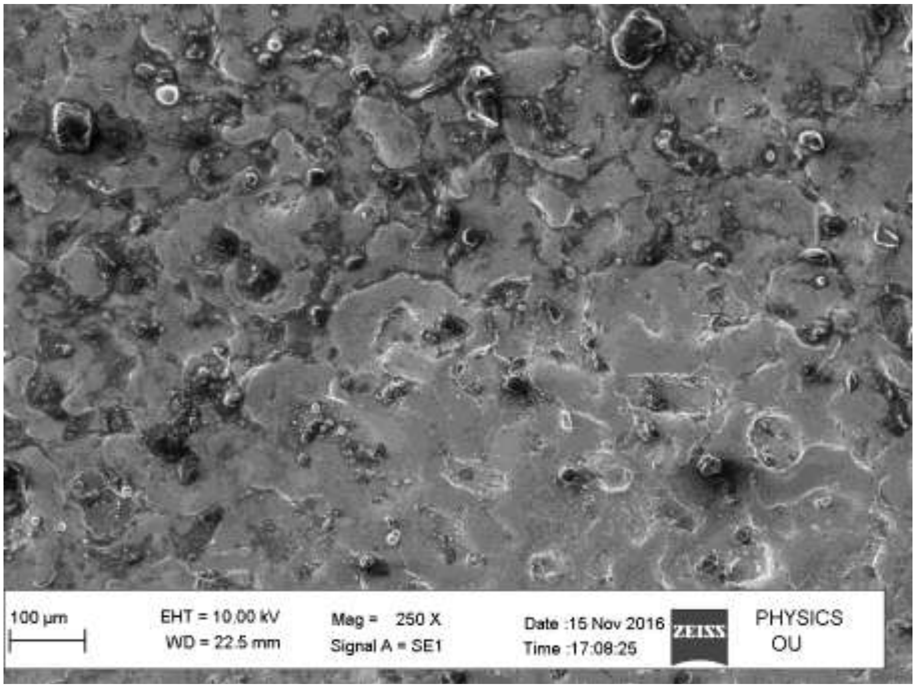
ZEISS
PHYSICS
OU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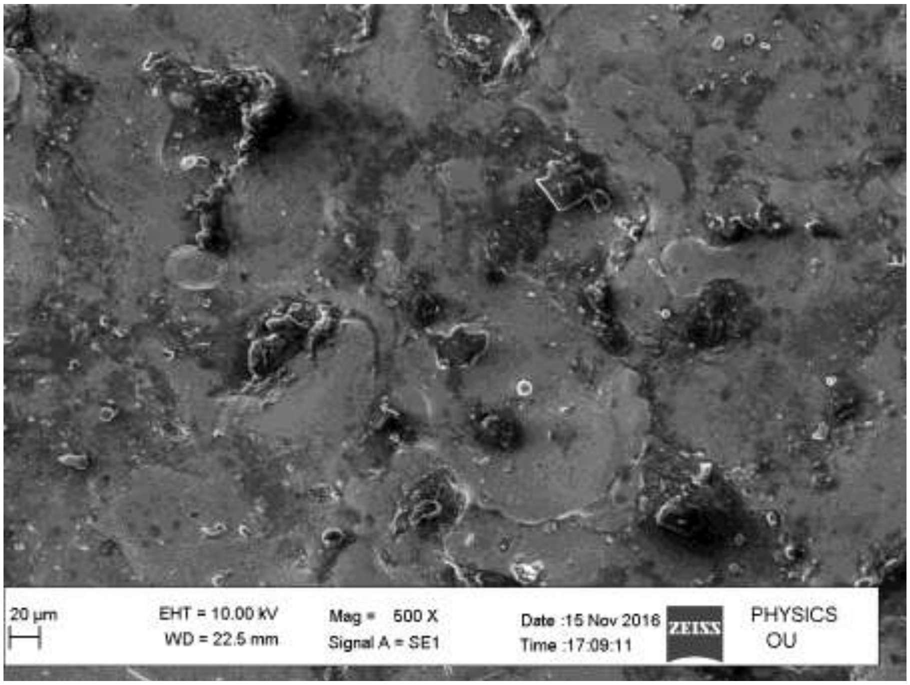
ZEISS
PHYSICS
OU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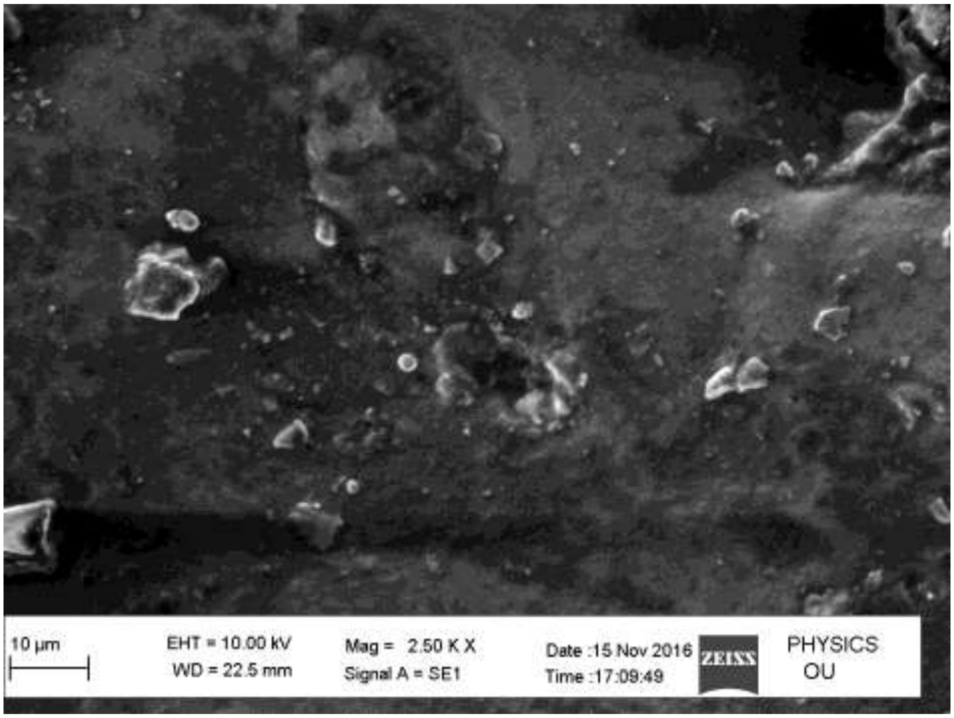
ZEISS
PHYSICS
OU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Mag = 2.50 K X
Signal A = SE1
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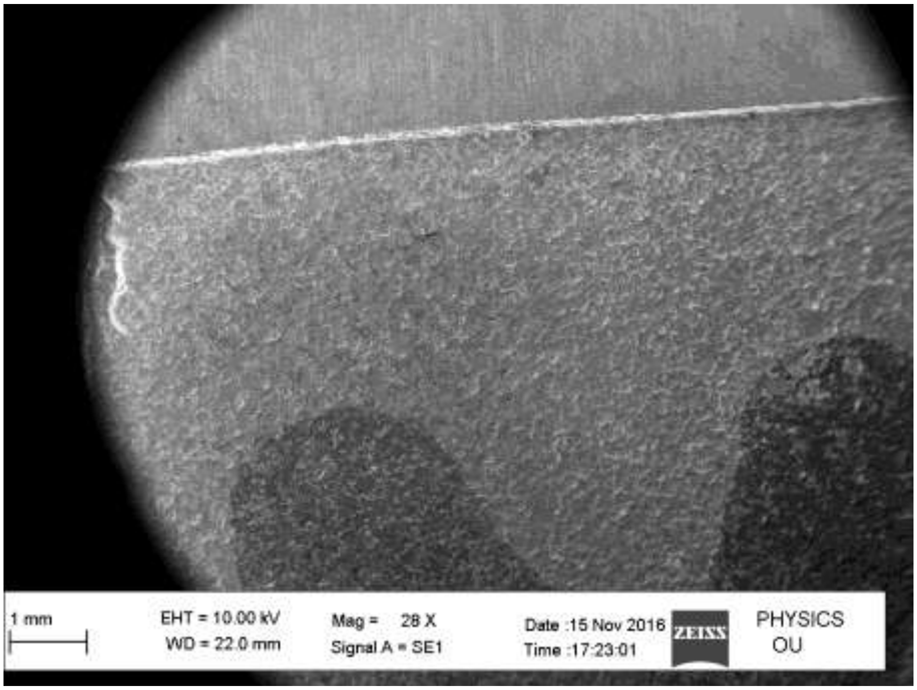
ZEISS
PHYSICS
OU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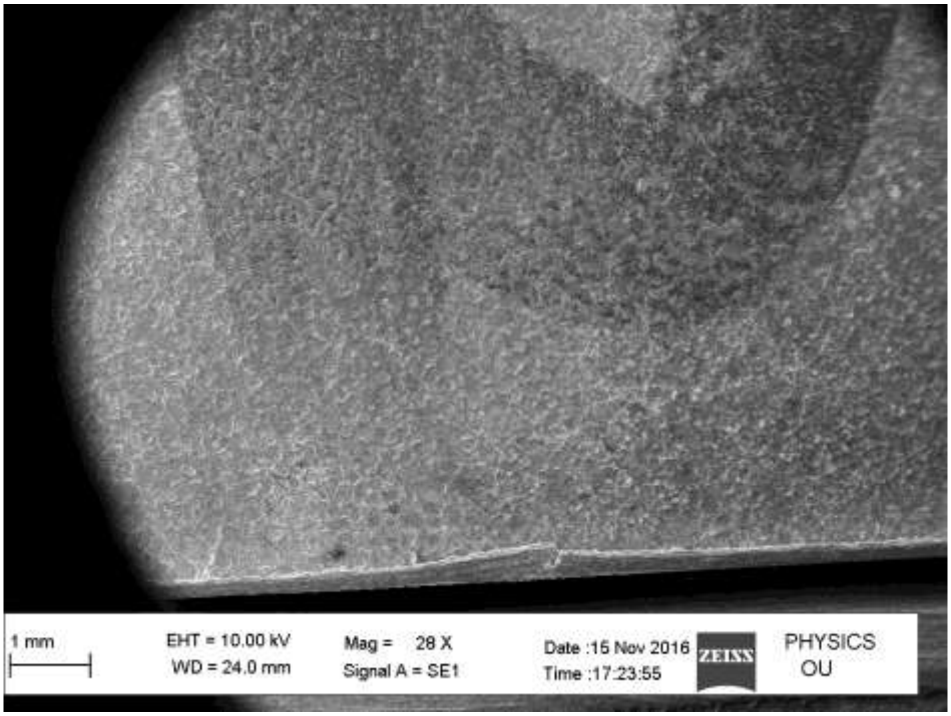
ZEISS
PHYSICS
OU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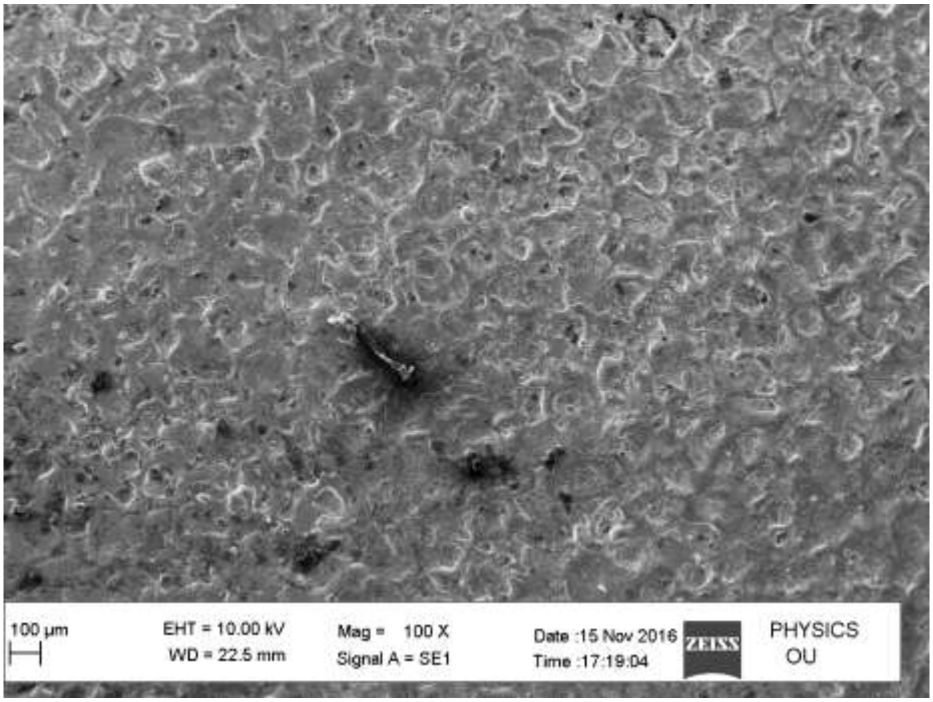
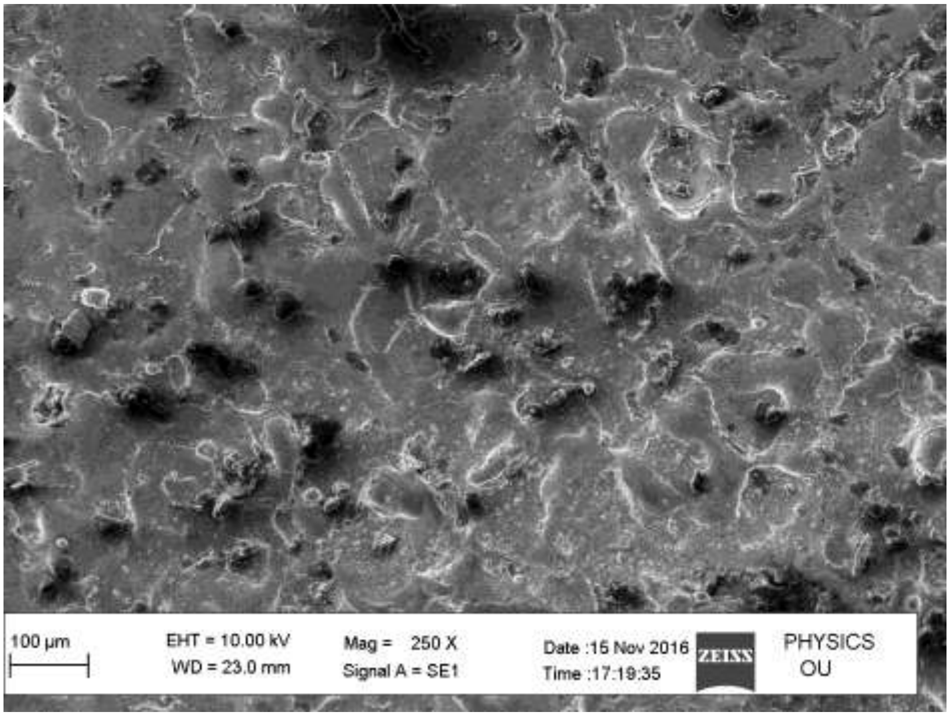
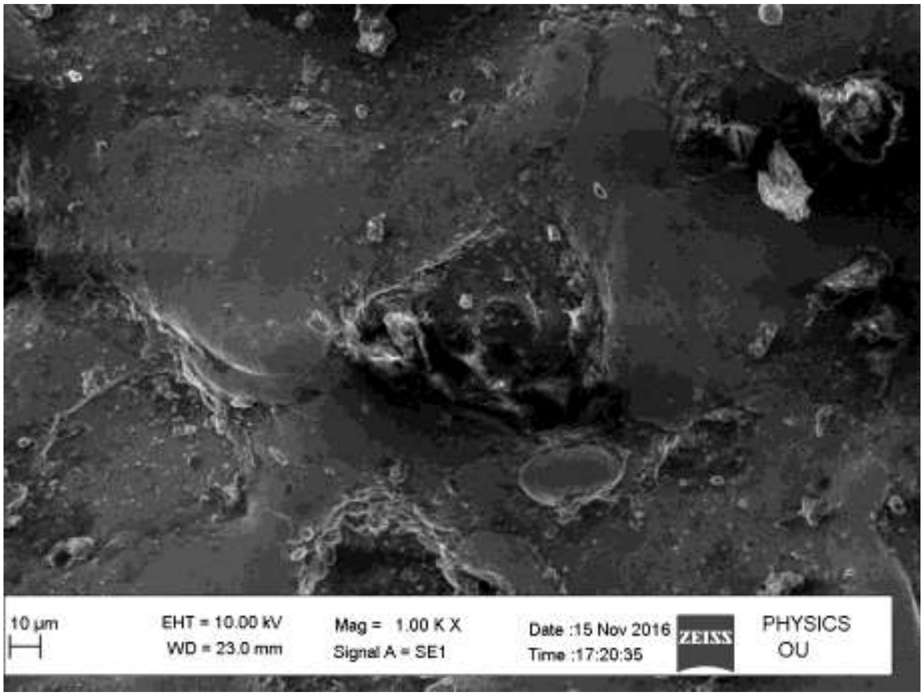
ZEISS
PHYSICS
OU

SEM IMAGES OF INCONEL WORK PIECE USING GRAPHITE TOOL



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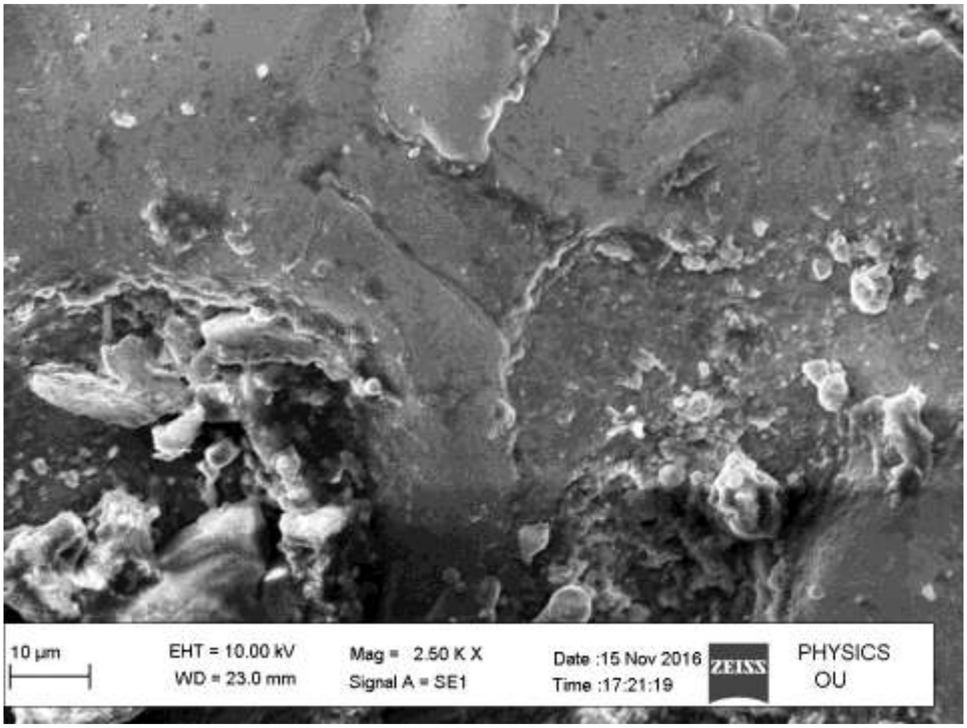
PHYSICS
OU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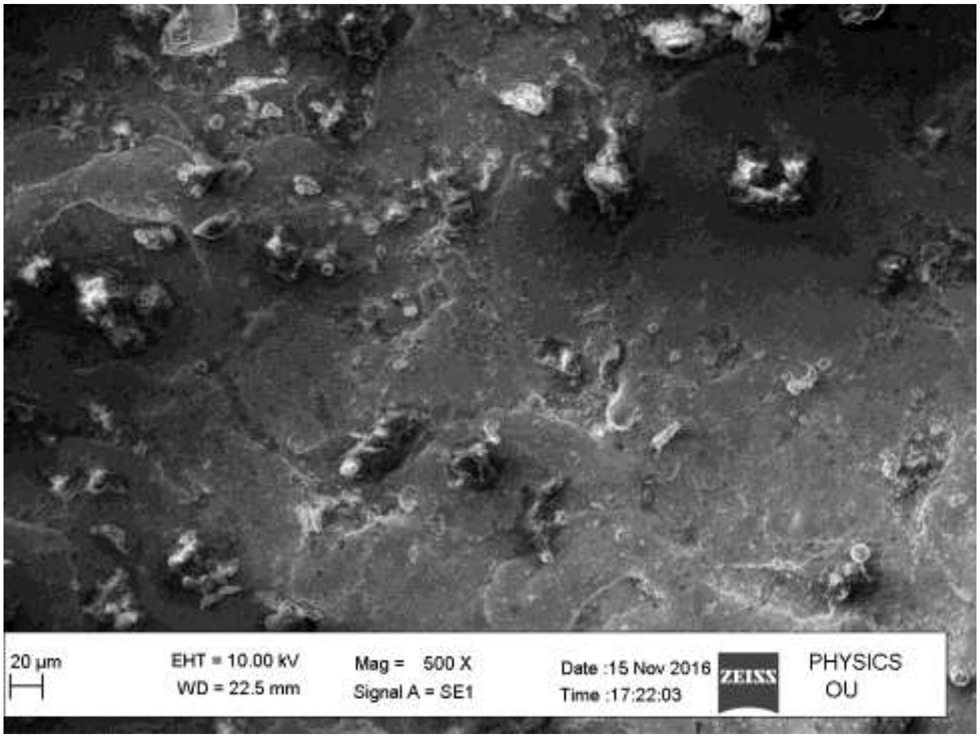
ZEISS
PHYSICS
OU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ZEISS
PHYSICS
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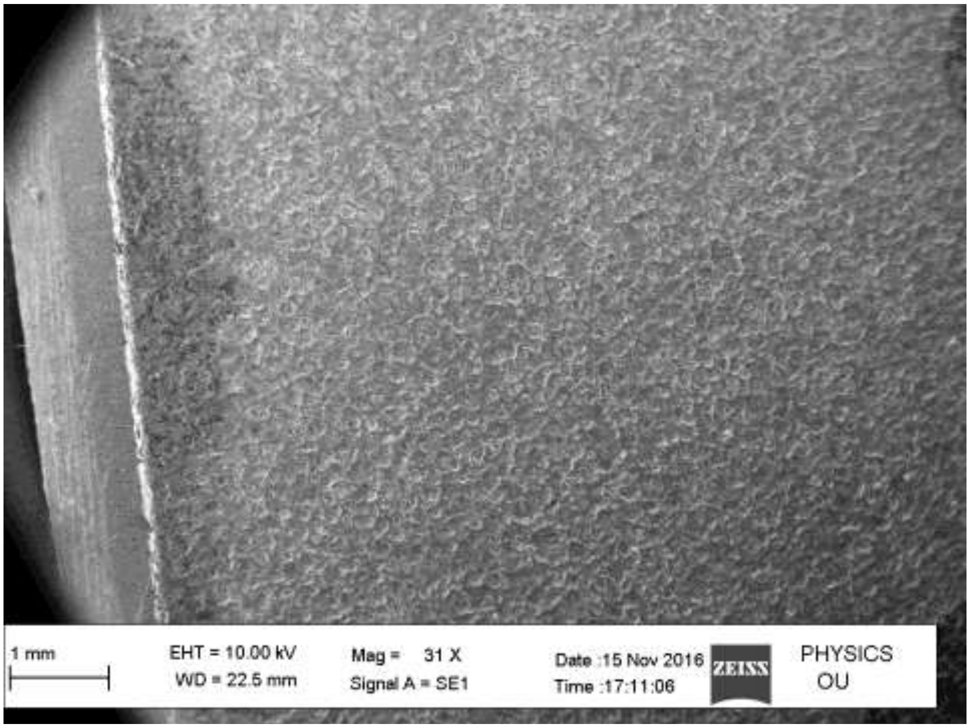
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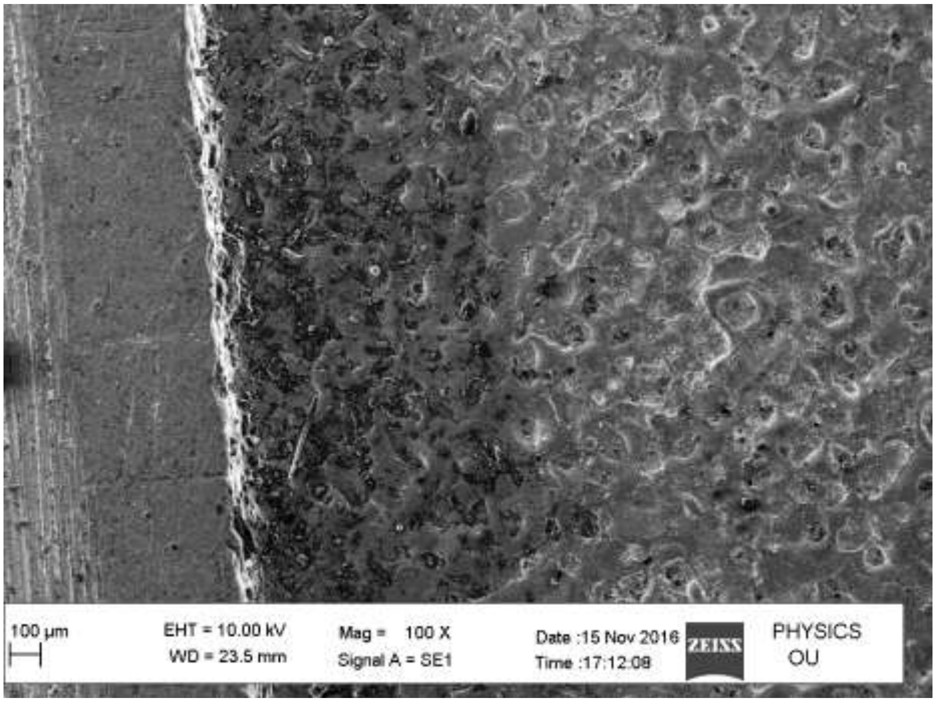
ZEISS
PHYSICS
OU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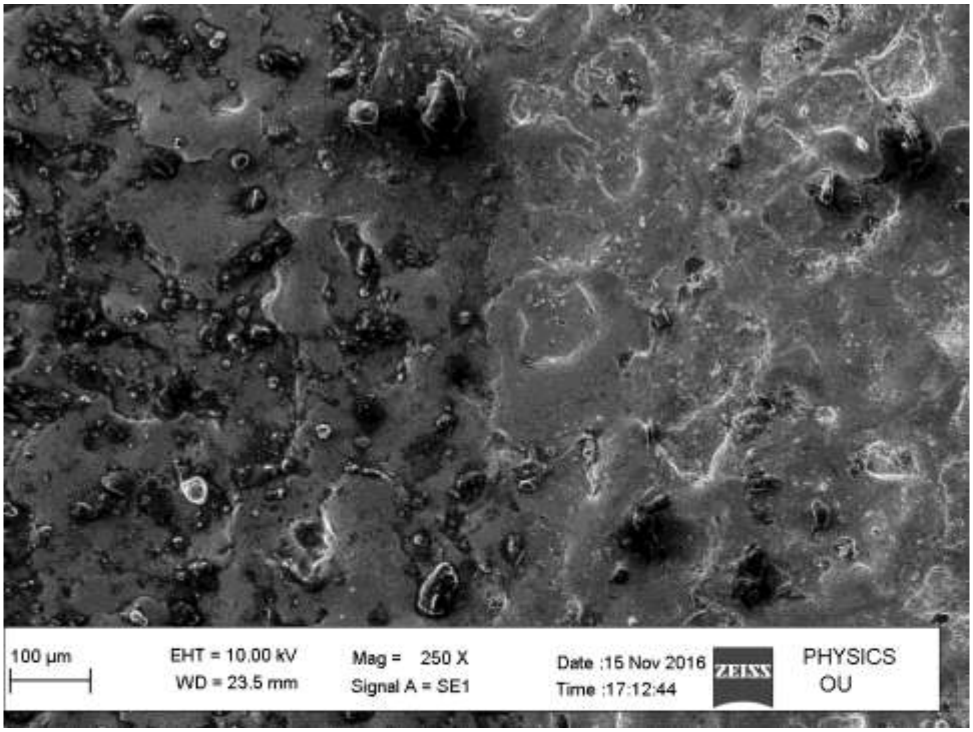
ZEISS
PHYSICS
OU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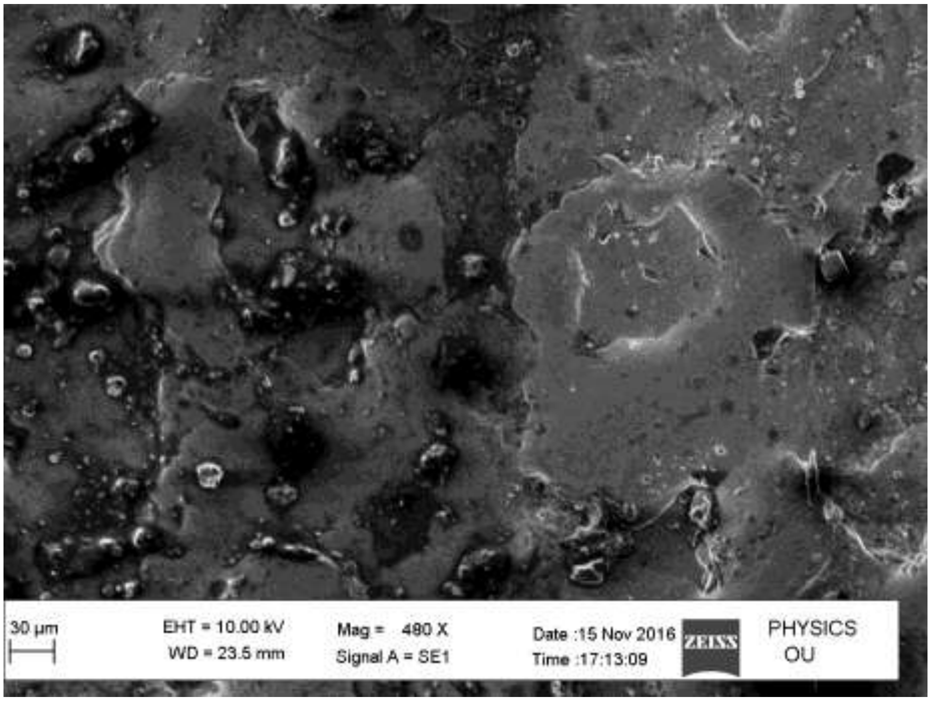
ZEISS
PHYSICS
OU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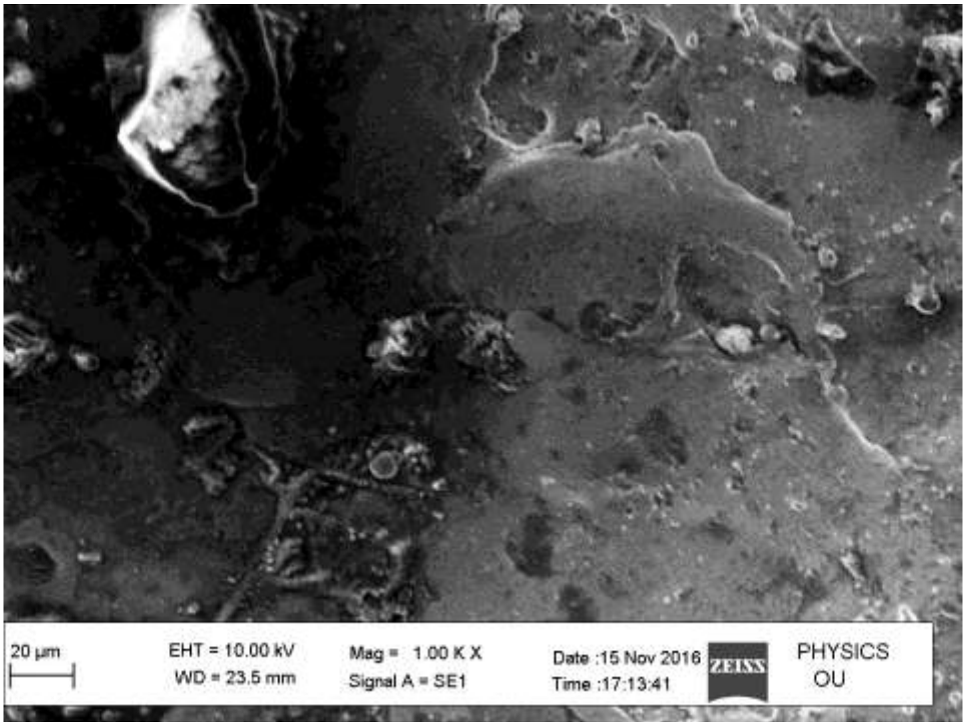
ZEISS
PHYSICS
OU


20 µm
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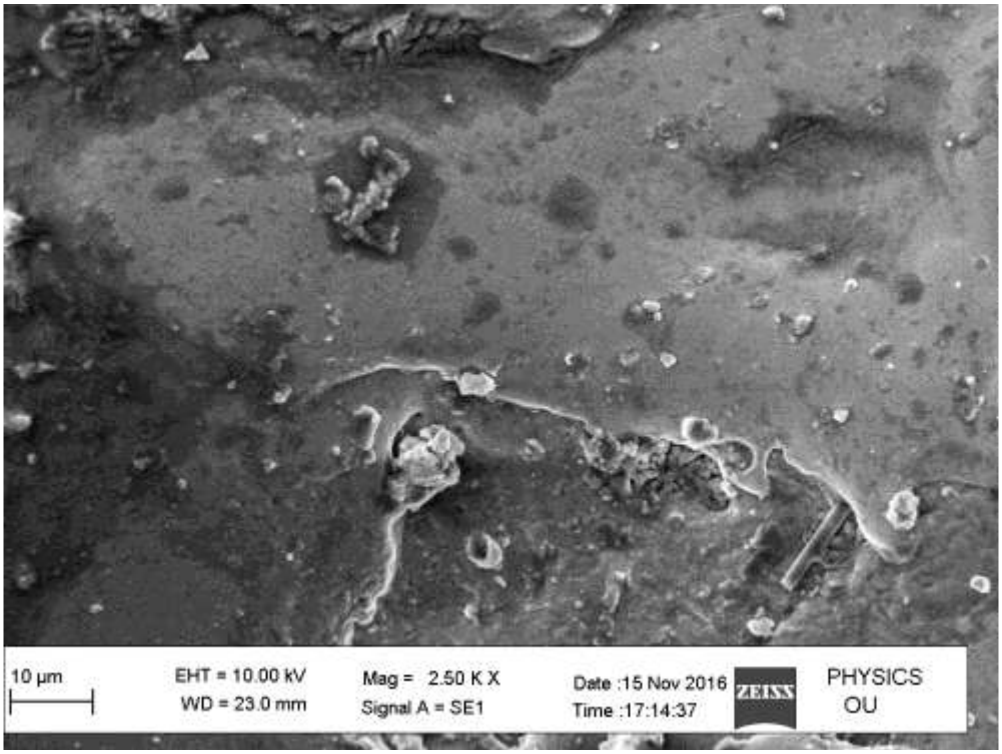
WD = 23.5 mm
Mag = 1.00 K X
Signal A = SE1
Date :15 Nov 2016
Time :17:13:41
ZEISS
PHYSICS
OU


10 µm
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ZEISS
PHYSICS
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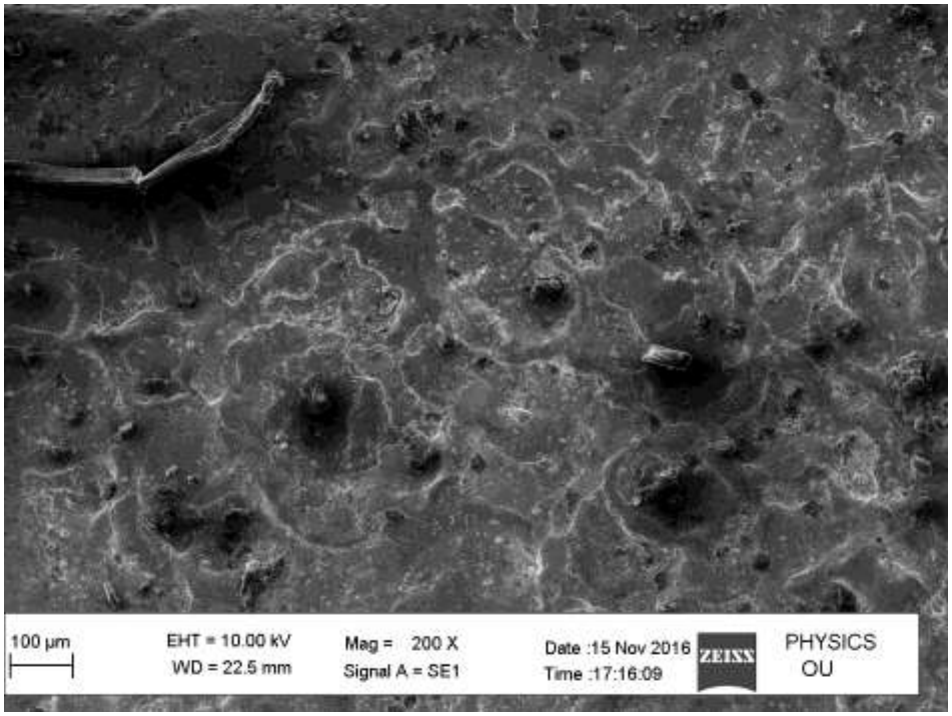
100 µm
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WD = 22.5 mm
Mag = 200 X
Signal A = SE1
Date :15 Nov 2016
Time :17:16:09
ZEISS
PHYSICS
OU

3.7 Design matrix and Observation table

Table 3.4 Observation Table for Copper Tool

Sl.no	Peak Current (A)	Ton (µs)	Gap Voltage(V)	Initial wt.(gm)	Final wt.(gm)	Mrr (milligm/min)	Ra (µm)
1	3	45	40	730.00	729.10	0.09	4.208
2	3	90	45	729.10	727.98	0.112	4.182
3	3	200	50	727.98	726.41	0.128	4.108
4	6	45	40	726.41	725.61	0.8	4.202
5	6	90	45	725.61	724.00	0.161	4.256
6	6	200	50	724.00	722.47	0.153	4.270
7	9	45	40	722.47	720.89	0.158	4.301
8	9	90	45	720.89	718.98	0.191	4.391
9	9	200	50	718.98	716.78	0.22	4.397

Table 3.5 Observation Table for Graphite Tool

Sl.no	Peak Current (A)	Ton (µs)	Gap Voltage(V)	Initial wt.(gm)	Final wt.(gm)	Mrr (milligm/min)	Ra (µm)
1	3	45	40	716.78	716.14	0.064	4.623
2	3	90	45	716.14	715.77	0.037	4.627
3	3	200	50	715.77	715.40	0.037	4.641
4	6	45	40	715.40	714.13	0.127	4.721
5	6	90	45	714.13	713.08	0.205	4.727
6	6	200	50	713.08	710.28	0.280	4.784
7	9	45	40	710.28	706.17	0.411	4.817
8	9	90	45	706.17	701.28	0.489	4.844

9	9	200	50	701.28	696.17	0.511	4.897

3.8 Sample Calculation

For the Material Removal Rate of Copper

(a) Overall Mean:

$\bar{y}$= (Sum of means of response variable)/Total number of means

$= \sum y/n = 2.013/9 = 0.22366$

(b) Sum of squares of Total:

2

$SS_T = \sum y$

$= 0.836202$

(c) Sum of squares due to mean:

$S_m = n\,\bar{y}^2$

$= 0.45021416$

(d) Sum of squares:

SS = Mean of levels

SS_A = Sum of squares due to Peak Current

$= (\text{Mean of A1})^2 \times n1 + (\text{Mean of A2})^2 \times n2 + (\text{Mean of A3})^2 \times n3 - S_m$

$= 3(0.11^2 + 0.37133^2 + 0.189^2) - 0.45021416 = 0.106906$

SS_B = Sum of squares due to Ton

= (Mean of B1)^2×n1 + (Mean of B2)^2×n2+ (Mean of B3)^2×n3 – S_m

= 0.070614

SS_C = Sum of squares due to Gap Voltage

= (Mean of C1)^2×n1 + (Mean of C2)^2×n2+ (Mean of C3)^2×n3 – S_m = 0.070614

(e) Sum of squares of error:

$$SS_E = (SS_T - (SS_A+SS_B+SS_C)) - S_m$$

$$= 0.137$$

(f) Degree of freedom:

DOF = Level-1 =3-1 =2

(g) Mean squares:

MSS= Sum of squares/DOF

MSS_A = Mean squares due to Peak Current $SS_A/2$ =

MSS_B = Mean squares due to Ton = $SS_B/2$ = 0.1300

MSS_C = Mean squares due to Gap Voltage = $SS_C/2$ = 0.0055

(h) Percentage of contribution:

P = (Sum of squares/ S_t)

$S_t = SS_T - S_m = 0.385988$

P_A = Percentage contribution of Peak Current

$= (SS_A / S_t)*100$

$= 27.69\%$

P_B = Percentage contribution of Ton

$= (SS_B / S_t)*100$

$= 18.294\%$

P_C = Percentage contribution of Gap Voltage

$= (SS_C / S_t)*100$

$= 18.294\%$

(i) Material Removal Rate (MRR):

MRR = (Initial Wt – Final Wt) / Total Machining Time

= 48.33 – 48.28 = 0.05/12 = 0.417 milli gm

3.9 Conclusion

Experiments were conducted according to Taguchi method by using the machining set up and by using two different Tools with same dielectric on Inconel 600. The control parameters like Peak current (Ip) ,pulse duration (Ton) and Gap Voltage were varied to conduct 9 different experiments for each Tool and the weights of the work piece before and after the experiment were taken for calculation of MRR and also Surface Roughness is measured by using Handy Surf unit.

CHAPTER 4

RESULTS AND DISCUSSION

Introduction In This chapter are related about influences of control factors and different dielectric medium on MRR and Surface roughness and finding the result which factors Peak current , Ton and Gap Voltage is most important with help of Taguchi method.

4.1 Response table for Copper Tool

The response table for MRR and Surface roughness is shown in Table 4.1 along with the input factors for Kerosene.

Table 4.1 Response table for Copper Tool

Peak current	Ton	Gap voltage	MRR(mg/min)	Ra(µm)
3	45	40	0.09	4.208
3	90	45	0.112	4.182
3	200	50	0.128	4.108
6	45	40	0.8	4.202
6	90	45	0.161	4.256
6	200	50	0.153	4.270
9	45	40	0.158	4.301
9	90	45	0.191	4.391
9	200	50	0.22	4.397

Response table for MRR with copper as a tool

Table 4.1.2 Response table for MRR with copper as a Tool

Level	Peak current(A)	Ton(B)	Gap voltage(C)
1	0.11	0.34	0.34
2	0.37	0.15	0.15
3	0.18	0.16	0.16
Delta	0.26	0.19	0.19
Rank	1	2	3

Optimum process parameters: A1,B2,C2

Peak current = 3 Amps
Ton = 90 Micro seconds
Gap voltage = 45Volts

ANALYSIS OF VARIANCE TABLE FOR MRR

Symbol	Process parameters	Degrees of Freedom	Sum of squares	Mean squares	Contribution (%)
A	Peak current	2	0.106906	0.05345	27.6
B	Ton	2	0.070614	0.03530	18.2
C	Gap voltage	2	0.070614	0.35307	18.2
Error			0.137	-	-
St		8	0.3859	-	-
Mean			0.45021	-	-
ST			0.8362	-	-

Predicted MRR for copper tool:

μ (predicted Mean) = $\bar{y}$+ (A_m-$\bar{y}$) + (B_m-$\bar{y}$) + (C_m-$\bar{y}$)

= 0.2236 + (-0.2236 +0.11) + (-0.2236 +0.154) + (-0.2236 +0.154)

=-0.0292

Response table for Surface Roughness with copper as Tool

Table 4.1.4 Response table for Surface Roughness with copper as Tool

Level	Peak current(A)	Ton(B)	Gap voltage(C)
1	4.166	4.237	4.237
2	4.242	4.276	4.276
3	4.363	4.258	4.258
Delta	0.197	0.039	0.039
Rank	1	2	3

Optimum process parameters: A1,B1,C1

Peak current = 3 Amps
Ton = 45Micro seconds
Gap voltage = 40Volts

ANALYSIS OF VARIANCE TABLE FOR SURFACE ROUGHNESS

Symbol	Process parameters	Degrees of Freedom	Sum of squares	Mean squares	Contribution (%)
A	Peak current	2	0.057	0.0285	7.8
B	Ton	2	0.006	0.003	82
C	Gap voltage	2	0.006	0.003	82
Error			0.028	-	-
St		8	0.73	-	-
Mean			163.115	-	-
ST			163.188	-	-

Predicted Surface Roughness for Copper:

μ (predicted Mean) = $\bar{y} + (A_m - \bar{y}) + (B_m - \bar{y}) + (C_m - \bar{y})$

= 4.257+ (-4.257+4.166) + (-4.257+4.237) + (-4.257+4.237)

=4.166

4.2 Response table for Graphite Tool

The response table for MRR and Surface roughness is shown in Table 4.1 along with the input factors for Copper tool

Table 4.1.6 Response table

Peak current	Ton	Gap voltage	MRR(mg/min)	Ra(µm)
3	45	40	0.064	4.623
3	90	45	0.037	4.627
3	200	50	0.037	4.641
6	45	40	0.127	4.721
6	90	45	0.205	4.727
6	200	50	0.280	4.784
9	45	40	0.411	4.817
9	90	45	0.489	4.844
9	200	50	0.511	4.897

Response table for MRR with Graphite as Tool:

Table 4.1.7 Response table for MRR with Graphite as Tool

Level	Peak current(A)	Ton(B)	Gap voltage(C)
1	0.046	0.392	0.392
2	0.204	0.243	0.243
3	0.470	0.276	0.276
Delta	0.424	0.149	0.149
Rank	1	2	3

Optimum process parameters: A1,B2,C2

Peak current = 3Amps
Ton = 90Micro seconds
Gap voltage = 45Volts

ANALYSIS OF VARIANCE TABLE FOR MRR:

Symbol	Process parameters	Degrees of Freedom	Sum of squares	Mean squares	Contribution (%)
A	Peak current	2	0.2759	0.1379	93
B	Ton	2	0.3503	0.17515	119
C	Gap voltage	2	0.3503	0.17515	119
Error			-0.68291	-	-
St		8	0.29368	-	-
Mean			0.5188	-	-
ST			0.8125	-	-

Predicted MRR for graphite tool:

μ (predicted Mean) = $\bar{y}$+ (A_m-$\bar{y}$) + (B_m-$\bar{y}$) + (C_m-$\bar{y}$)

= 0.2401 + (-0.2401 +0.046) + (-0.2401 +0.243) + (-0.2401 +0.243)

=0.0518

Response table for Surface Roughness with Graphite as a tool

Table 4.1.9 Response table for Surface Roughness with Distilled water as dielectric

Level	Peak current(A)	Ton(B)	Gap voltage(C)
1	4.63	4.72	4.72
2	4.74	4.73	4.73
3	4.82	4.77	4.77
Delta	0.19	0.05	0.05
Rank	1	2	3

Optimum process parameters: A1,B1,C1

Peak current = 3 Amps
Ton = 45Micro seconds
Gap voltage = 40Volts

ANALYSIS OF VARIANCE TABLE FOR SURFACE ROUGHNESS

Symbol	Process parameters	Degrees of Freedom	Sum of squares	Mean squares	Contribution (%)
A	Peak current	2	1.69	0.847	99.6
B	Ton	2	1.62	0.8121	95.4
C	Gap voltage	2	1.62	0.8121	95.4
Error	-	-	-3.242	-	-
St	-	8	1.7015	-	-
Mean	-	-	200.78	-	-
ST	-	-	202.48	-	-

Predicted Surface Roughness for Graphite Tool:

μ (predicted Mean) = $\bar{y} + (A_m - \bar{y}) + (B_m - \bar{y}) + (C_m - \bar{y})$

$= 4.742 + (-4.742 + 4.630) + (-4.742 + 4.720) + (-4.742 + 4.720)$

$= 4.586$

4.3 Confirmation Experiment:

Table 4.2.1 Surface Roughness, MRR for optimal Machining parameters obtained while machining with Copper as tool

Output Parameter	Cutting Parameters			Predicted Value	Experimental Value
	Peak Current	Ton	Gap Voltage		
MRR	3	90	45	-0.0292mg/min	0.03012mg/min
Surface Roughness	3	45	40	4.166µm	4.231µm

Table 4.2.2 Surface Roughness, MRR for optimal Machining parameters obtained while machining with Graphite as tool.

Output Parameter	Cutting Parameters			Predicted Value	Experimental Value
	Peak Current	Ton	Gap Voltage		
MRR	3	90	45	0.0518mg/min	0.0621mg/min
Surface Roughness	3	45	40	4.586µm	4.5932µm

4.4 EFFECT ON MRR

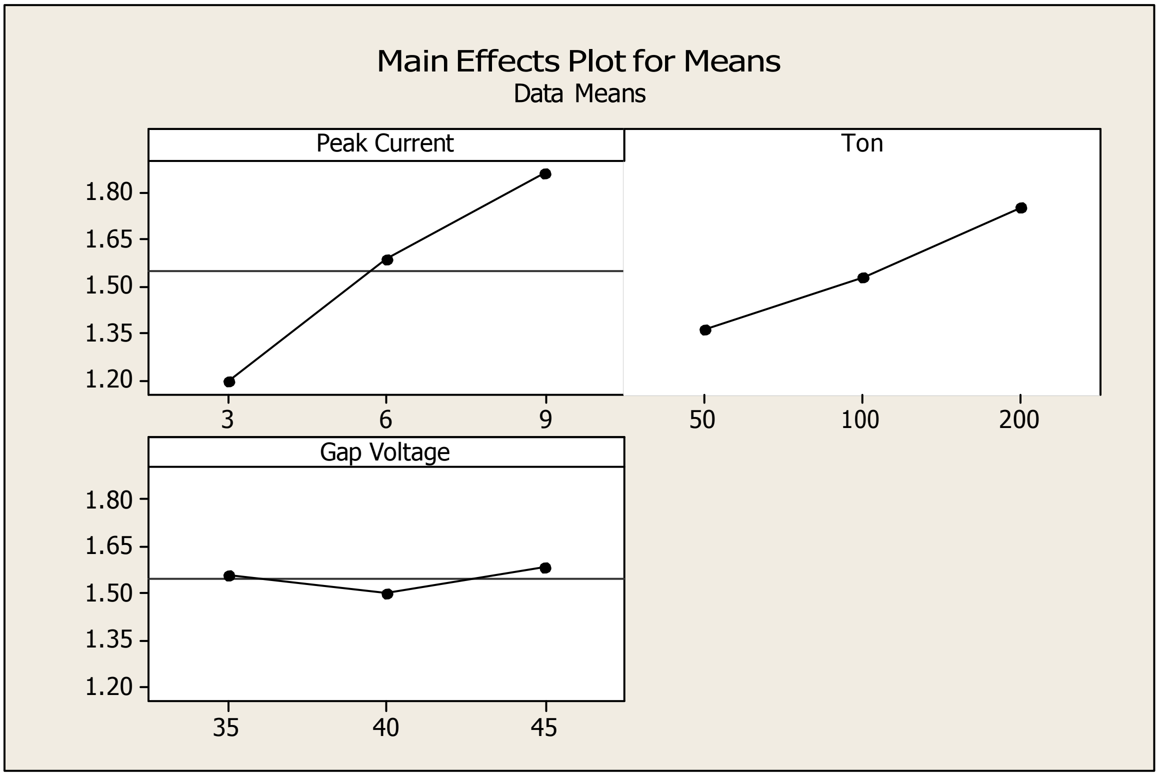

Fig. 4.1 Effect of copper on MRR

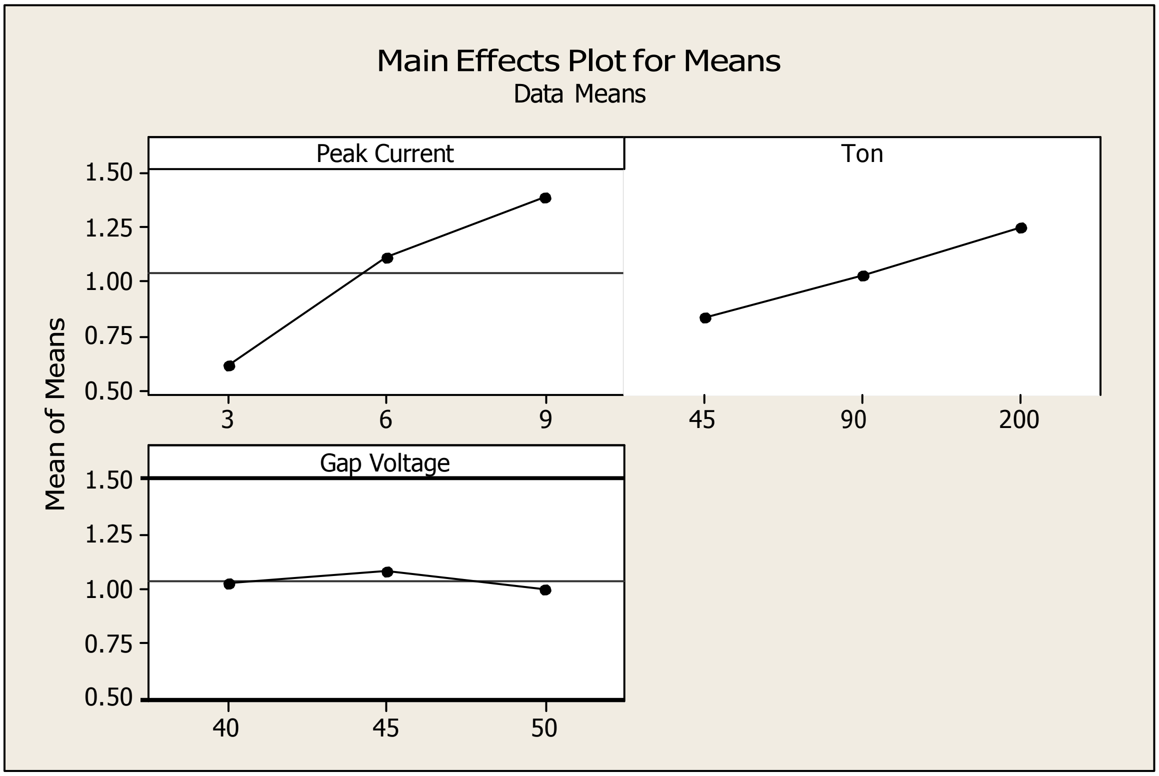

Fig. 4.2 Effect of graphite on MRR

ANOVA is done by using Taguchi optimization technique. The results are

1. It is observed that for copper as tool the control parameters i.e. Peak Current (P=73.24%), Pulse on time (P=24.91%) have statistical and physical significance on the MRR obtained, and Gap Voltage (P=1.18%) has less effect on MRR.
2. It is observed that for graphite as tool the control parameters i.e. Peak Current (P=77.05%), Pulse on time (P=21.53%) have statistical and physical significance on the MRR obtained, and Gap Voltage (P=0.90%) has less effect on MRR.

4.5 EFFECT ON SURFACE ROUGHNESS

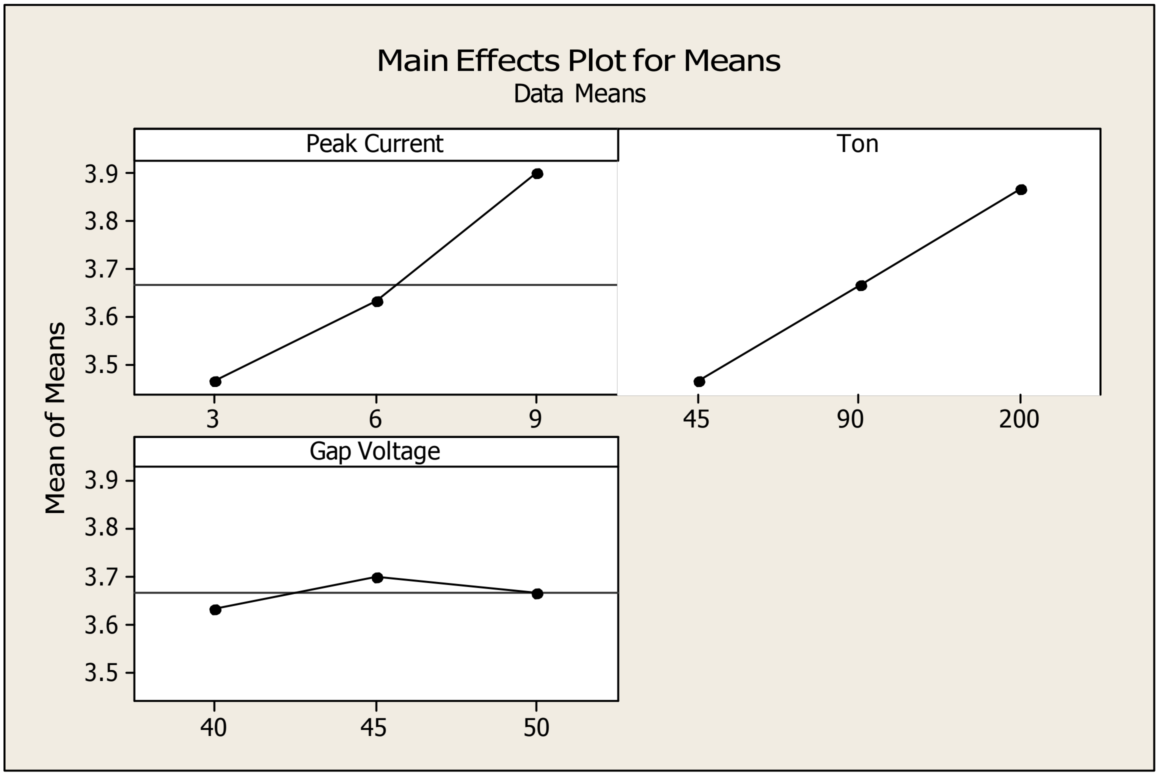

Fig. 4.3 Effect of copper on Surface Roughness

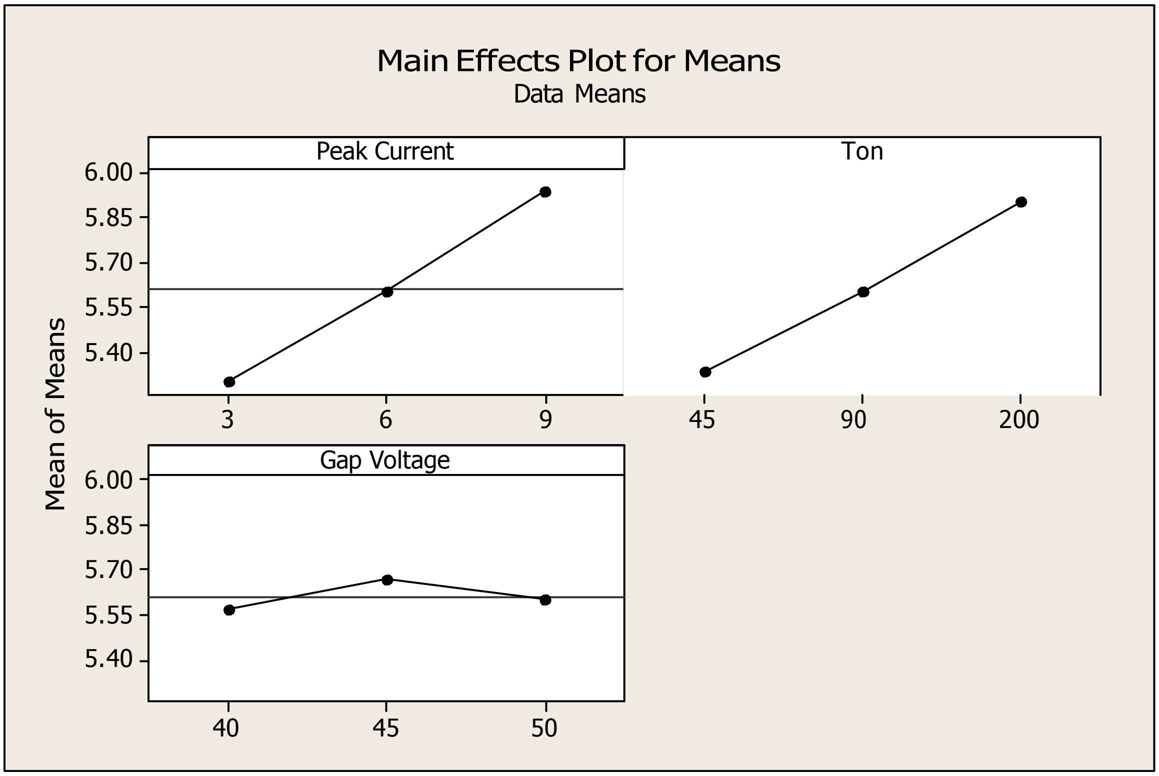

Fig. 4.4 Effect of graphite on Surface Roughness

ANOVA is done by using Taguchi optimization technique. The results are

1. It is observed that for copper as tool the control parameters i.e. Peak Current (P=54.31%), Pulse on time (P=43.49%) have statistical and physical significance on the Surface finish obtained, and Gap Voltage (P=1.40%) has less effect on Surface finish.
2. It is observed that for gaphite as tool the control parameters i.e. Peak Current (P=53.09%), Pulse on time (P=44.44%) have statistical and physical significance on the MRR obtained, and Gap Voltage (P=1.23%) has less effect on MRR.

CONCLUSION

In this study, the EDM characteristics of Nickel-copper alloy (INCONEL 600) were examined using copper and graphite tool as the dielectric. The important results are summarized as follows:

(1) The material removal rate and Surface roughness of INCONEL 600 is greater when using copper as tool.

(2) The tool directly influences the surface properties of INCONEL 600. Carbide is formed on the work piece surface when using graphite

(3) The material removal mechanism of nickel-chromium alloy in copper is more, which is due to melting and vaporization is differ from that in graphite where the material removal is less compared to copper. This is due to the melting point of nickel-chromium which is formed while using copper as tool is -17.2 °C and the melting point of Nickel Oxide is 1984°C which is formed while using graphite as tool.

(4) When using copper as tool the oxygen adhere to the surface of the electrode and oxide is formed on the work piece surface but since oxide has higher melting point, the impulsive force of discharge is unstable thus reducing the metal removal rate. By substituting graphite as tool, no oxide adheres to the surface of the electrode and carbide is formed on the work piece surface. The carbide has lower melting point so that the impulsive force of discharge is much more stable and the metal removal rate is improved.

(5) Surface roughness increased with increasing pulsed current and pulse time. Low current and pulse time with constant pulse pause time produced minimum surface roughness that means good surface finish quality. The selection of these machining parameters is not useful because machining process generally becomes very slow. Material removal rate will be low and thus machining cost increases. This combination should be used in finish machining step of EDM process.

(6) High pulsed current and pulse time provide low surface finish quality. However, this combination would increase material removal rate and reduce machining cost. As a result, this combination (high pulsed current and pulse time) should be used for rough machining step of EDM process.

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