Investigation of EDM machining parameters of different volume fraction of WC/Ni composites

S Ashokkumar1, C Thiagarajan1, Hitheshu Jose2, P Aswin Murali2 and Akhil Reji Jacob2

1 Assistant Professor, Department of Mechanical Engineering, Aarupadai Veedu Institute of Technology, Vinayaka Mission Research Foundation, Deemed to be University, Tamil Nadu, India.
2 UG Scholar, Department of Mechanical Engineering, Aarupadai Veedu Institute of Technology, Vinayaka Mission Research Foundation, Deemed to be University, Tamil Nadu, India.
Email: ashokkumar@avit.ac.in

Abstract. The main objective of this paper is to analyze the machining and mechanical characteristics of Tungsten carbide/Nickel (WC/Ni) composite materials which are produced through the powder metallurgy route. It also concentrates on various parameters such as Percentage of Nickel composition (%Ni), Electrode rotation (S), Pulse on time (T), Current (C) and Flushing pressure (P), Sliding Speed, Contact Load (N), Time (T) of EDM to investigate the process performance characteristics in terms of material removal rate (MRR) and surface roughness (Ra) and also wear rate. From the experimental results it can be observed that increase % of Ni in Composites (WC/Ni), compositions ([85WC-15Ni], [90WC-10Ni], [95WC-5Ni]) the surface roughness and material removal rate which increases gradually. The above condition is achieved when Pulse on time (T), Current (C) and Flushing pressure (P) maintained at constant values. In addition to that surface roughness was analyzed by using response surface methodology. Comparison of the results of un machined surface of WC/Ni composites with EDMed surface was also performed and the worn-out morphologies of WC/Ni composites were analyzed with the help of Scanning Electron Microscope (SEM).

Keywords: Tungsten carbide, Nickel, cutting tools, Scanning Electron Microscope.

1. Introduction

EDM is a technique used in the high precision machining industry for all forms of conductive materials, such as metals, metallic alloys, graphite, ceramics, etc. The material of any kind of hardness can be machined as long as the material can conduct electricity. Since researchers have experienced significant difficulties due to the complexity of physics in the EDM process, physical models are found to be far removed from reality [1]. Electric discharge machining (EDM) is an effective machining process and a potential route of development for the manufacture of dies and conductive moulds. EDM is in theory a thermo-electric device utilizing repeated electrical discharges (sparks) to erode electrode and electrically conductive work pieces [2]. EDM technology has become attractive in precision die making, as there is no physical contact between the electrode and the work piece. In addition, the EDM cycle makes heavy, broken, and complicated machine materials simpler for machines with substantial electrical transport properties [3]. EDM provides the major advantage that, in contrast with conventional machining methods, this machining method enables us to manufacture components of the desired form and greater dimensional tolerance in a shorter period. The key benefit of EDM is that in less time, we can produce parts with the desired shape and greater dimensional tolerance than traditional machining methods.
Electrical machining as one of the most commonly used methods for non-traditional material removal. Its unique feature of machining electrically conductive elements with thermal energy, irrespective of its hardness has been its distinctive advantage in mold, die, car, aerospace, and surgical components production [4].

And also it has carried out a study on the effect of process parameters on the machining characteristics defined. In his research, the emphasis was on the machining of conductive ceramics [5]. It’s mainly focused on the statistical molding of EDM with aluminum-silicon carbide particulates. A three-level, the full factorial design was chosen. Finally, critical designs were tested by ANOVA [6]. The worked on a proven outcome of electrode wear rate and a demonstration of the removal rate on the powder mixed electrical discharge machine (PMEDM) of cobalt-bonded tungsten carbide (WC-Co) was used [7]. The develop model for an MRR and Ra over the most important process parameters in EDM of WC/30% Co composites [8]. The RSM approach is used to define the most important parameters for optimizing MRR and minimizing Ra. Surface roughness is one of the important parameters in conventional machining. Optimizing these parameters is the most challenging task in the turning process [9].

The objective of this paper, the EDM machining process of (WC/Ni) compositions ((85WC-15Ni),( 90WC-10Ni),(95WC-5Ni)), Electrode rotation (S), Pulse on time (T), Current (C) and Flushing pressure (P) on the EDM sinking die increased the material removal rate and improved the surface finish of the WC/5Ni composites [10].

The effect of current (C), pulse on time (T), electrode rotation speed (S), and flushing pressure (P) on the EDM sinking die increased the material removal rate and improved the surface finish of the WC/5Ni composites [10].

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2. Materials and methods

2.1 Specimen preparation

In the present experimentation work, three different compositions of tungsten carbide and Nickel metal powders are used for preparing test specimens. The reduction process metal powders are manufactured through powder metallurgy (P/M) route. Tungsten carbide composites are very hard (85-93 HRA) with a density between 14.5 g / cc and 15.3 g / cc and a nickel density of 8.9 g / cc and a melting temperature of 1455°C. The sizes of the powders are 3μm and 2μm respectively. Keeping the concept of metal powder compacting die for producing carbide inserts or other small thickness components, work material in present case is taken as WC/Ni composite in the form of a circular specimen. Diameters of the specimen are 12 mm and height of the specimen was 10 mm. Table 1 describes the various compositions of work materials.

| SL.No. | Types of composition |
|--------|----------------------|
| 1      | 85WC-15Ni            |
| 2      | 90WC-10Ni            |
| 3      | 95WC-5Ni             |
2.2 Metal Powder Compacting Die

Metal compaction is the method of compacting the metal powder in a die by applying high pressures. Usually, tools are kept in a vertical orientation with a punching tool surrounding the bottom of the cavity. The powder is then compacted into a shape and expelled from the cavity of the die is shown in figure 2. Metal powder compacting die method shown in figure 3.

![Figure 2 Metal powder compacting die method](image)

2.3 Sintering of Green Compact

Sintering is a process by which a solid material mass is created by heat and/or pressurization in a controlled air furnace at the temperature without melting to the limit, but high enough for the liquefaction to be bonded. As the green compact test specimen is heated, the sintering process begins and binds naturally to mineral deposits or as a process of manufacturing the bonding of the particles. Pure argon gas, in particular in small furnaces, is often used in the sintering process, where very powerful oxide free reduction is needed. Argon gas is used for sintering reactive metals at high temperatures. The argon atmosphere is used as a sintering medium in this test. The three distinct compositions of the sintered components of WC / Ni are shown in Figure 4.

![Figure 3 Cylindrical die and hydraulic press 150-Ton](image)
2.4 EDM machinery

In Figure 5 for the composition of three different composites, the effect of electro discharge machinery on these features is analyzed, whereas constant input parameters were used in this research work:
1. Rotating Speed(S), rpm (400rpm)
2. Current(C), A (20Amps)
3. Pulse on time (600) μs
4. Flushing pressure of 1.5 kg/cm².

The three major control factors selected for the experiments are Sliding speed (V), Contact load (N), and Time (T). The studies on the wear behavior of WC/Ni composites indicate that the coefficient of friction (μ), and wear rate (WR) are affected by sliding speed and Contact load.

3. Result and discussions

3.1 MRR and Surface roughness

EDM of WC-Ni to analyze the effect of a steady current intensity, pulse times, electrode rotational speed and flushing pressure on technological variables such as surface roughness, and metal removal rate. The machining precision is mainly influenced by applied voltage, feed rate and electrolyte concentration in an electrical discharge machining with high frequency pulse current. The rate of material removal of the (WC – Ni) composite surface has been analyzed. Table 2 shows the machining characteristics of the electro-discharge (WC-Ni) composites values.

Table 2 Electro discharge machining characteristics of WC-Ni composite

| SL. No | % of Ni Composition | Electrode rotation in rpm | Current (C), A | Pulse on time, μs | Flushing pressure, Kg/cm² | MRR in (mg/min), MRR = Vol.of metal /Time removal | surface roughness (Ra), μm |
|--------|---------------------|---------------------------|----------------|-------------------|------------------------|-----------------------------------------------|--------------------------|
| 1      | 5%Ni                | 400                       | 20             | 600               | 1.5                    | 38.19                                         | 2.65                     |
| 2      | 10%Ni               | 400                       | 20             | 600               | 1.5                    | 46.05                                         | 3.64                     |
| 3      | 15%Ni               | 400                       | 20             | 600               | 1.5                    | 51.37                                         | 4.60                     |
The bar graph Figure 6 shows metal removal rate against three different compositions of Nickel composites with tungsten carbide. From the graph 5%Ni composite have low metal removal rate when compare to other Ni composites. The graph clearly shows the value of metal removal rate in gm/min. The 5%Ni composite specimen have the lowest metal removal of 38.19 gm/min. The highest metal removal rate was obtained 51.37mg/min for the 15% Ni composite. Moderate metal removal rates of 46.05 mg/min were obtained for 10%Ni composite.

The bar graph Figure 7 shows of three different nickel composition of surface roughness. From the graph 5%Ni composite have very low surface roughness of 2.65μm, which is lowest value when compare to other Ni composites. In this contest the lowest Ni percentage (5%) was added with high hard material of tungsten carbide.

### 3.2 Wear Rate

| Sl. No | % of Ni Composition | Sliding Speed (Rpm) | Contact Load (N) | Time (Min) | Wear Rate (mg/min) |
|--------|---------------------|---------------------|------------------|------------|-------------------|
| 1      | 5%Ni                | 300                 | 20               | 30         | 20.64             |
| 2      | 10%Ni               | 300                 | 20               | 30         | 43.41             |
| 3      | 15%Ni               | 300                 | 20               | 30         | 53.66             |
The various wear process parameter and their level are tabulated in Table 3 and the bar graph Figure 8 shows the specimens are influenced by sliding speed, contact load and running time with the wear rate. The variation of wear rate with the constant sliding speed of 200rpm, it is observed that minimum wear rate 20.64mg/min is observed at 5% Ni composite, the maximum wear rate 53.66 mg/min is obtained at 15% Ni composite and the moderate wear rate is obtained 43.47mg/min. It seems the wear rate increases gradually with the percentage of Nickel percent increases.

3.3 Scanning Electron Microscope (SEM)

Scanning Electron Microscopy examinations is used to study the morphology of worn-out surfaces from the wear tests. The objective is to obtain information on the influence of fillers on the corresponding wear mechanisms. The wear mechanisms found by microstructural analyses include ironing, scraping, ploughing, plastic deformation and wear by JEOL is shown in Figure 9.

In the ultra-severe wear regime, the intergranular fracture is identified in the sliding speed range at 300 rpm and the contact load range is 20N. The worn out surface shows the pre-existing cracks are developed along the WC grain boundaries. The microstructure of the intergranular fracture surface of the specimen SEM observation, the thermally induced fracture region is not identified in the map due to the sliding temperature is not much impact on the EDMed surface. The surface characteristics indicate that the EDM process causes a lot of damage such as pinholes, micro voids and craters on the machined surface. As discharge energy increases, the machined surface showed a rougher surface morphology, consisting mostly of debris, craters and micro cracks, these results are caused by the high volume of molten and floating metal suspended during EDM in the electrical discharge gap More thermal stress contributes to surface cracks that cause cracks and thus affect the strength of fractures.
Figure 10 SEM Images (a) EDM 5% Ni Composite, (b) EDM 10% Ni Composite (c) EDM 15% Ni Composite and (d) EDM 20% Ni Composite

The SEM image shows the proper bonding of WC-Ni, for this reason the surface roughness and metal removal rate were very low. From 10% Ni composite a moderate surface roughness of 3.64 μm was obtained. And the maximum surface roughness of 4.6 μm was obtained for the 15% Ni composites. It is clearly evident that the percentage of Ni increases the metal removal rate as well as surface roughness also increases.

The SEM picture of 15% Ni composites, methods for material removal is directly related to the morphological and structural qualities of the machined surfaces. The higher surface roughness of the EDMed surface can be due to the presence of surface cracks, craters and droplets. This result in a decrease in thermal shock intensity will significantly decrease the fracture strength of the material and the existence of thermal stress is the primary explanation for the decrease in strength. The overall surface tends to have molten-looking holes of varying diameters and morphology. Significant damage to the surface with micro cracking and small droplets can also be seen. It can be concluded that the EDMed 85%WC-15%Ni ceramic composite have micro cracks and the craters on the machined surfaces may reduce the fracture strength of the material.

4. Conclusions

For this analysis, EDM process parameters for three separate compositions of WC-Ni composites are used. The effect of current (C), pulse on time (T), electrode rotation (S) and flushing pressure (P) in the EDM sinking die on material removal and surface finish of WC-Ni composites (95WC-5Ni, 90WC-10Ni and 85WC-15Ni) was briefly addressed. Electrode rotation and dielectric flushing pressure are affected by both MRR and Ra in EDM. The MRR increases as the electrode rotation and the flushing pressure grows. As the cylinder electrode rotates, the centrifugal action pushes a new dielectric fluid layer into the machining void. This result in an effective discharge driving environment, which results in an increase in
The proportion of Ni is directly proportional to MRR. The best MRR has been increased from 38.17 mg/min to 51.39 mg/min with a ratio of 5% to 15%. The current value increases with the rising work energy so that the craters get deeper and wider.

- Optimum Ra values increased from 2.65μm to 4.6μm when the percentage of Ni content increased from 5% to 15%. In all the composition the optimum Ra values are obtained at constant 20A of current, which is independent of the Ni percentage.
- Optimum wear rate values increased from 20.64 mg/min to 53.66 mg/min as the percentage of Ni content increased from 5% to 15%. In all the composition the optimum wear rate values are obtained at constant sliding speed 300rpm and contact load 20N, which is independent of the Ni percentage. The rate of wear increases with an increasing content of the binder. This is anticipated because the greater volume fraction of nickel results in a greater fraction of the readily removed binder form, which would make it harder to weaken the particles and result in a higher rate of removal of the particles.
- The surface characteristics show that the EDM process produces much damage, such as pinholes, micro-voids, debris, and craters on the machined surface, as observed in SEM observations. Such findings cause surface cracks, which reduce the fracture strength of the EDMed composites.
- For the high nickel content of the specimens, relatively large proportions of the grooves are observed which are not parallel to the direction of relative movement. The SEM observation of a higher percentage of composition microstructures showing distinct differences in appearance between the low nickel and high nickel, indicating the ploughing of the abrasive particles in later spars.
- Electric sparks generate on the machined surface craters, bubbles, and cracks that damage the surface finish and mechanical properties of the EDMed WC-Ni surface and are to be removed for sensitive surface applications.

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