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Analysis of surface characteristics of AISI D2 tool steel material using Electric Discharge Machining process with Single wall carbon nano tubes

S. Prabhu and B.K. Vinayagam

Abstract—**The developments in EDM have opened up new avenues for finishing of hard and brittle materials with nano surface finish, high tolerance and accuracy. A single wall Carbon nano tube (SWCNT) is having high Mechanical and Electrical Properties specifically High Electrical Conductivity. By using these properties of the single-wall carbon nano tube mixed with dielectric fluids in EDM process to analysis the surface characteristics like surface roughness, micro cracks in AISI D2 tool steel a work piece material which is very much used in moulds and dies. Experimental results indicate that the surface texture after EDM is determined by the discharge energy during processing. An excellent machined nano finish can be obtained by setting the machine parameters at low pulse energy. The surface roughness and the depth of the micro-cracks were proportional to the power input. Furthermore, the SEM application yielded information about the depth of the micro-cracks is particularly important in the post treatment of AISI D2 tool steel machined by EDM.**

Index Terms—**Single wall carbon nano tube, Electric Discharge Machining process, surface roughness, Scanning Electron microscope.**

I. Introduction

Electrical discharge machining (EDM) is one of the most successful and widely accepted processes for production of complicated shapes and tiny apertures with high accuracy. This method is commonly used for profile truing of metal bond diamond wheel, micro nozzle fabrication, drilling of composites and manufacturing of moulds and dies in hardened steels. These hard and brittle materials fabricated by conventional machining operation cause excessive tool wear and expense. The mechanical properties of tool steels have been studied extensively for many years. During EDM, the tool and the work piece are separated by a small gap, and submerged in dielectric fluid. The discharge energy produces very high temperatures on the surface of the work piece at the point of the spark. The specimen is subject to a temperature rise of up to 40 000 K causing a minute part of the work piece to be melted and vaporized. The top surface of the work piece subsequently resolidifies and cools at very high rate.

Carbon nanotubes tiny tubes with diameters down to 0.4 nm, while their lengths can grow up to a million times their diameter. Using their remarkable electrical properties, simple electronic logic circuits have been built. These structures are promising for the semiconductor industry which is leading the search for miniaturization. They are not only very good conductors, but they also appear to be the yet found material with the biggest specific stiffness, having half the density of aluminum. The special nature of carbon combines with the molecular perfection of single-wall CNTs to endow them with exceptional material properties, such as very high electrical and thermal conductivity, strength, stiffness, and toughness.

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1.1 Literature Review

Guu Y.H. et al, [1] proposed the electrical discharge machining (EDM) of AISI D2 tool steel was investigated. The surface characteristics and machining damage caused by EDM were studied in terms of machining parameters. Based on the experimental data, an empirical model of the tool steel was also proposed. Surface roughness was determined with a surface profilometer. Guu Y.H. [2] proposed the surface morphology, surface roughness and micro-crack of AISI D2 tool steel machined by the electrical discharge machining (EDM) process were analyzed by means of the atomic force microscopy (AFM) technique. Pecas, P, et al. [3] presents on EDM technology with powder mixed dielectric and to compare its performance to the conventional EDM when dealing with the generation of high-quality surfaces. Kansal, H.K, et al., [4] study has been made to optimize the process parameters of powder mixed electrical discharge machining (PMEDM). S.Prabhu, et al [5] analysed the surface characteristics of tool steel material using multiwall carbon nanotube to improve the surface finish of material to nanolevel. Ko-Ta Chiang, et al [6] methodology for modeling and analysis of the rapidly resolidified layer of spheroidal graphite (SG) cast iron in the EDM process using the response surface methodology. The results of analysis of variance (ANOVA) indicate that the proposed mathematical model obtained can

Assistant professor-Senior grade, school of Mechanical Engineering, SRM University, Chennai. prabhume@yahoo.co.in

adequately describes the performance within the limits of the factors being studied. Seung-Han Yang, et al [7] proposes an optimization methodology for the selection of best process parameters in electro discharge machining. Regular cutting experiments are carried out on die-sinking machine under different conditions of process parameters. Erzurumlu and Oktem [8] have developed an ANN and response surface model to predict surface roughness in milling mould parts. Jegaraj and Babu [9] attempted to make use of Taguchi's approach and analysis of variance (ANOVA) using minimum number of experiments for studying the influence of parameters on cutting performance in AWJ machining considering the orifice and focusing tube bore variations to develop empirical models.

1.2. Electric Discharge Machining

Electric discharge machining (EDM) shown in Fig.1. is an important non-traditional manufacturing method to produce plastics mouldings, die castings and forging dies etc. 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.

Fig.1. Die-sinking EDM SD35-5030

1.3 AISI-D2 Tool Steel

AISI D2 tool steel is one of the carbon steels alloyed with Mo, Cr, and V, is widely used for various dies and cutters for its high strength and wear resistance due to formation of chrome carbider in heat treatment. Table 1. Lists the chemical composition (wt. %) of the material, while Table 2 lists the mechanical properties of the AISI D2 tool steel.

Table 1 Chemical Composition of the AISI D2 tool steel [wt. %]

Elements	C	Si	Mn	Mo	Cr	Ni	V	Co	Fe
Wt.%	1.5	0.3	0.3	1.0	12.0	0.3	0.8	1.0	Balance

Table 1 Chemical Composition of the AISI D2 tool steel [wt. %]

0.2% offset yield strength	1532 MPa
Tensile strength	1736 MPa
Hardness [HRC]	57

1.4 Single wall Carbon Nano Tube (SWCNT)

Most single-walled nanotubes (SWCNT) have a diameter of close to 1 nanometer, with a tube length that can be many thousands of times longer. The 3D structure of a SWCNT can be conceptualized by wrapping a one-atom-thick layer of graphite called graphene into a seamless cylinder. Single-walled nanotubes are the most likely candidate for miniaturizing electronics beyond the micro electromechanical scale that is currently the basis of modern electronics. The single wall carbon nano tube shown in Fig 2.

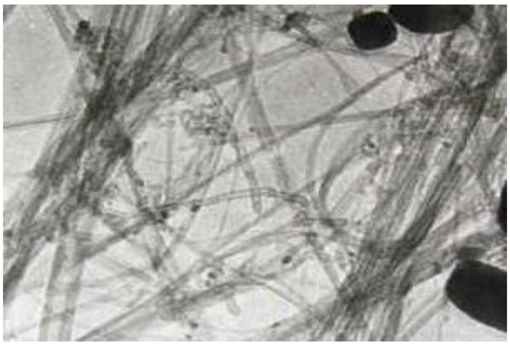


Fig.2 a TEM image of our Single Walled Nanotubes - SWNTs 60wt% 1-2nm OD

Table 3 Specifications of SWCNTs

OD	1-2nm
Length	5 um to 30 um
Purity	> 60 wt%
Ash	< 3.0 wt%
Specific Surface Area	> 407 m^2/g
Electrical Conductivity	> 100 S/cm
Bulk Density	0.14 g/cm^3

1.5. Scanning Electron Microscope (SEM)

The SEM is a microscope that uses electrons instead of light to form an image. The SEM has a large depth of field, which allows more of a specimen to be in focus at one time. The SEM also has much higher resolution, so closely spaced specimens can be magnified at much higher levels. Because the SEM uses electromagnets rather than lenses, the researcher has much more control in the degree of magnification. The Scanning Electron Microscope as shown in Fig.3

Table 4 Electrical discharge machining conditions

Work material	AISI D2 tool steel
Dielectric	Kerosene
Electrode material	Copper
Pulsed current	1, 2, 3,4,5A
Pulse-on duration	2 to 8 µs
Pulse-off duration	1 to 7 µs

Fig. 3 Scanning Electron Microscope

1.6 Surface roughness meter

Model Hommel Tester T500 surface roughness tester is a multi-application measuring instrument for component surface quality evaluation. It is capable of checking the work piece surface roughness on plane, cylinder, groove and bearing raceway. The surface roughness meter is shown in Fig.4.

Fig 4. Surface roughness testing machine-Hommel

II. Research Methodology

The specimen was made of the AISI D2 tool steel, which is widely used in the mold industry. The electrode material used is copper. The raw materials were machined as using conventional methods such as turning, parting and grinding. The specimens were made to a size of diameter 20mm and length 20.5mm and the electrode were made to a size of 24mm diameter and length 50mm. The machined material was heated to 1030 ^{0}C at a heating rate of 20^{0}C /min in muffle furnace. It was kept at 1030 ^{0}C for one hour and then quenched. After quenching, the specimens were tempered at 520^{0}C for two hours and then air cool. The hardness obtained for the specimen is 58HRC Table 2 lists the chemical composition (wt. %) of the material. The EDM specimens were sparked on a die-sinking EDM machine model type SD35 – 5030. The experiment was carried out in kerosene dielectric covering the work piece by 40 mm. A cylindrical copper rod machined was used as the electrode for sparking the work piece. The copper electrode was the negative polarity and the specimen was the positive polarity during the EDM process. During EDM, the primary parameters are pulsed current, pulse-on duration, and pulse-off duration. Table 4 shows the electrical discharge machining conditions.

During the EDM process, the varying pulse-off duration setting from 1 µs to 10 µs could effectively control the flushing of the debris from the gap, giving machining stability. Hence, the effect of the pulse-off duration on the machined characteristics was not considered in the present work. After each experiment, the machined surface of the EDM specimen was studied by means of a scanning electron microscope. The dielectric fluid was mixed in a proportion of 1gm of SWCNT for 1lit of kerosene. The sparking was carried out in this setting Fig 5. After experiment, the machined surface of the EDM specimen was studied by means of a scanning electron microscope. Different samples were examined.

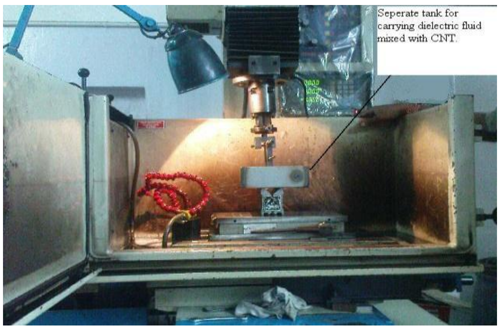


Fig 5. EDM set up using SWCNT

A separate tank was made to hold the dielectric fluid containing SWCNT in which the specimen was placed. After experiment, the machined surface of the EDM specimen was studied by means of scanning electron microscope.

III. Results and Discussions

3.1 Surface morphology

During the EDM process, the primary parameters were pulsed current and pulse-on duration, both of which are settings of the power supply. In order to assess the surface measurement results, an SEM study of the surface nanomorphology of the EDM machined surface with SWCNTs was conducted. Fig. 6 shows the three-dimensional SEM images of the machined surface obtained from the EDM specimens, where Ip is the pulsed current, and ton denotes the pulse-on duration. The darker contrast corresponds to the lower areas of the surface, and the brighter corresponds to the higher.

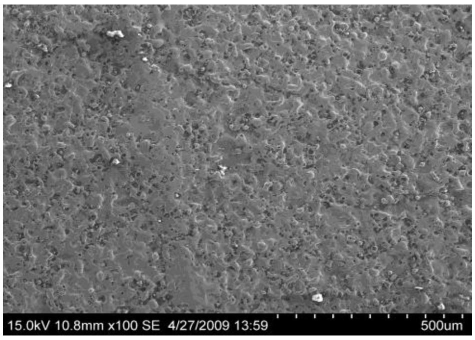


Fig 6. SEM Image of AISI D2 tool steel for 500 µm magnification

It is clear that the surface micro geometry characteristics include machining damages such as ridge-rich surfaces, micro-voids, and micro-cracks. The ridge-rich surface was formed by material melted during EDM, and blasted out of the surface by the discharge pressure. However, the surface immediately reached the solidification temperature being cooled by the surrounding working fluid. The micro-voids can be attributed to the gas bubbles expelled from the molten material during solidification. The micro-cracks were the result of the thermal stresses. The primary causes of the residual stress in the machined surface were the drastic heating and cooling rate and the non-uniform temperature distribution. In addition, the morphology of the EDM surface was dependent on the applied discharge energy. When applying the varying pulsed current and the pulse-on duration (Fig. 7), the surface characteristic without SWCNTs shows varying hillocks and valleys. The pulsed current and pulse-on duration variation shows different types of deeper cracks or voids and more pronounced defects.

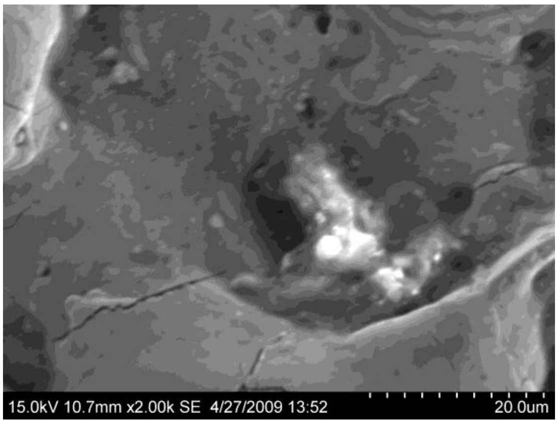


Fig 7. SEM Image of AISI D2 tool steel for 20 µm magnification

3.2. Surface Roughness

To determine the effect of the EDM process on the surface roughness of the tool steel, the surface profiles of the EDM specimens were measured by SEM and Surface roughness tester (Hommel Tester T500). The average surface roughness, Ra, of the machined specimen was calculated from surface roughness tester T500 and topographical images and cracks have been found out using SEM.

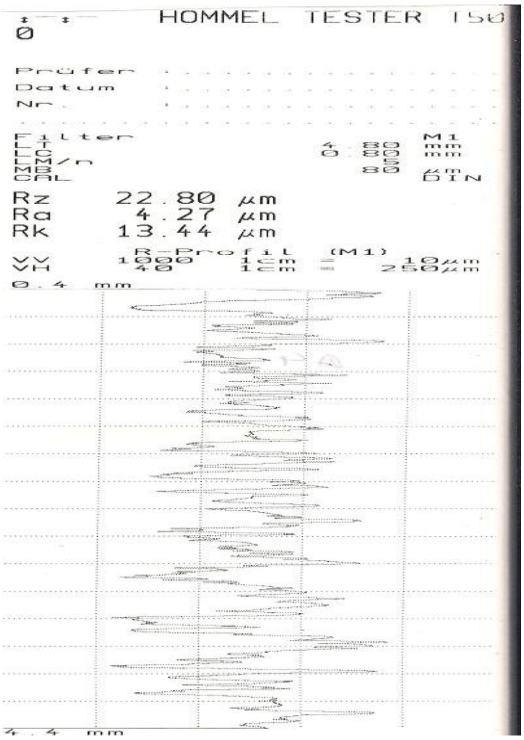


Fig 8.Surface roughness (Ra) value for 4 amps with SWCNT

The Fig 8. Shows the Ra value and its graph results for the specimen which was sparked with using SWCNT. The parameters used are current 4amps, pulse on duration 3 µs and pulse off duration 2 µs. The roughness value obtained for the specimen using this parameter is 4.27 µm.

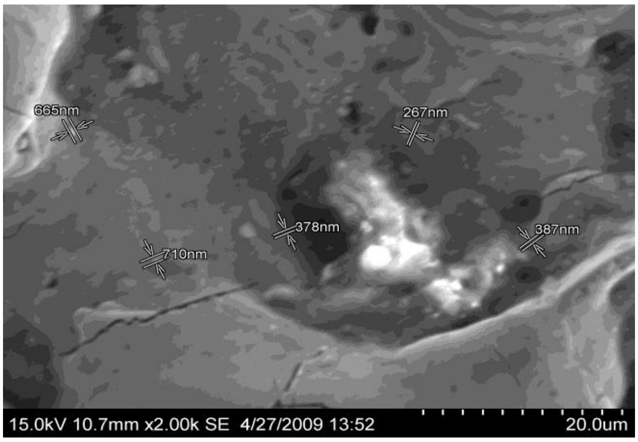


Fig 9. SEM topographical images for 4 amps without CNT

The Fig 9. Shows the SEM topographical images and its results for the specimen which was sparked without CNT. The parameters used are current 4amps, pulse on duration 3 µs and pulse off duration 2 µs.

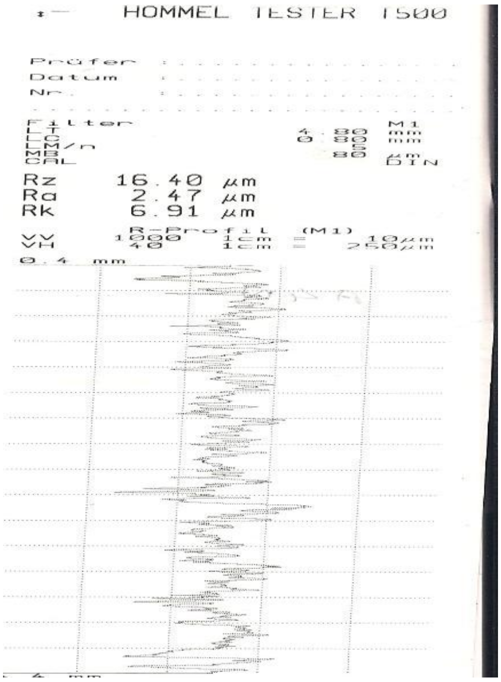


Fig 10.Surface roughness (Ra) value for 4 amps with SWCNT

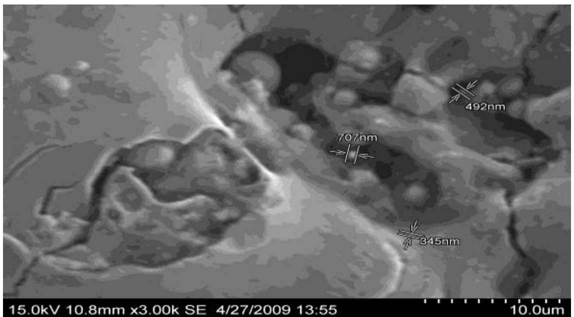


Fig 11 SEM topographical images for 4 amps with SWCNT

The Fig. 11 Shows the SEM image and its results for the specimen which was sparked using SWCNT. The parameters used are current 4amps, pulse on duration 3 µs and pulse off duration 2 µs. The roughness value obtained for the specimen using this using parameter is 2.47 µm.

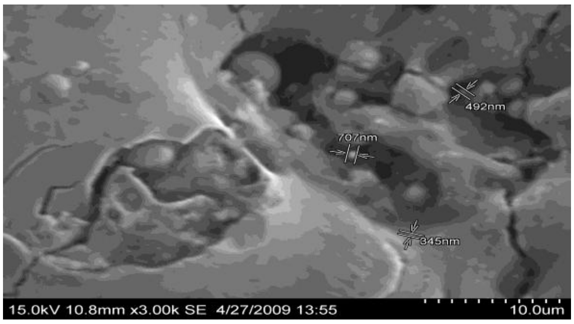


Fig 12.SEM image for 5amps without CNT

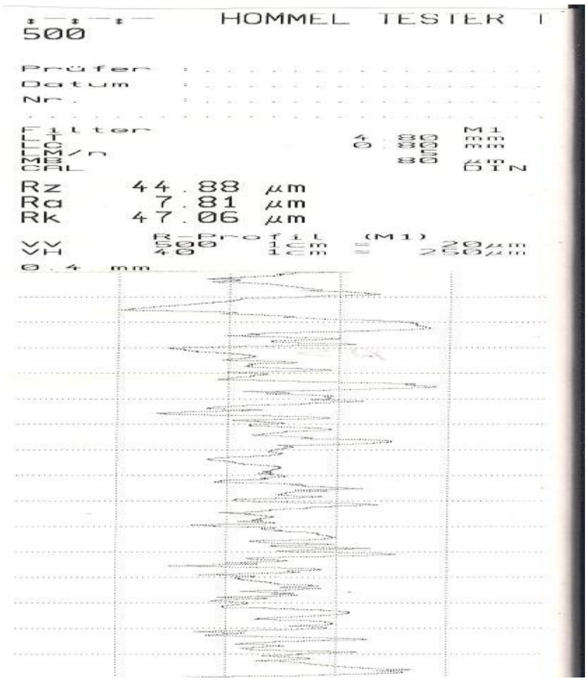
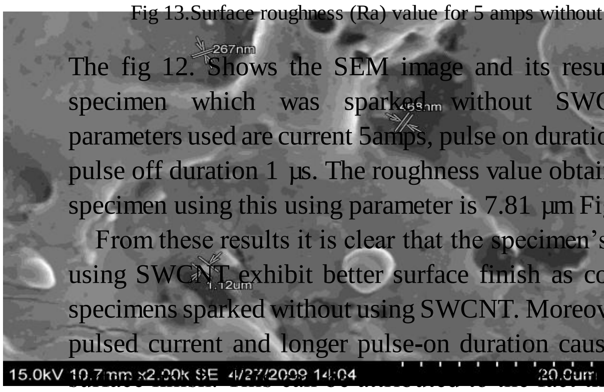


Fig 13.Surface roughness (Ra) value for 5 amps without SWCNT



The fig 12. Shows the SEM image and its results for the specimen which was sparked without SWCNT. The parameters used are current 5amps, pulse on duration 2 µs and pulse off duration 1 µs. The roughness value obtained for the specimen using this using parameter is 7.81 µm Fig 13.

From these results it is clear that the specimen's machined using SWCNT exhibit better surface finish as compared to specimens sparked without using SWCNT. Moreover a higher pulsed current and longer pulse-on duration cause a poorer [illegible] at a higher pulsed current and longer pulse-on duration may cause more frequent cracking of the dielectric fluid, there is also more frequent melt expulsion leading to the formation of deeper and larger craters on the surface of the work-piece. Comparing with the results of Fig 8 and Fig 10, we find that an excellent machined finish can be obtained by adding SWCNTs to dielectric fluid and setting the machine parameters at a low pulsed current and a small pulse-on duration

3.3 MICRO CRACKS

In order to measure the maximum depth of the micro-cracks of the EDM specimen, the SEM was used to analyse the cracks generation in different sections in nano level shown in Fig. 14 and Fig. 15

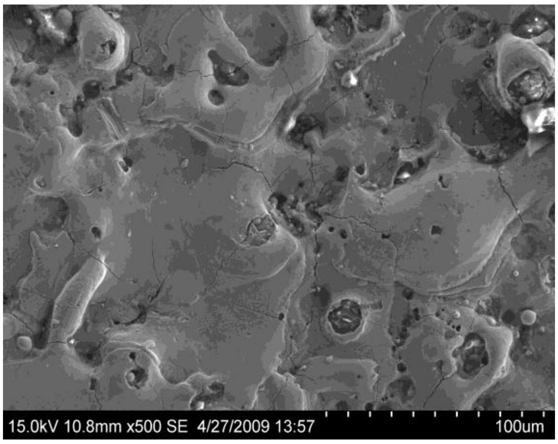


Fig. 14 Profile of an SEM Image for 5 amps with SWCNT

The above line profile SEM image Fig 14 shows the micro cracks for the specimen sparked without CNT. The parameters used are current 5amps, pulse on duration 2 µs and pulse off duration 1 µs.

The figure shows that the depth of the micro-cracks on the EDM specimen increases significantly with increase in the pulsed current and pulse-on duration. The crack generation is seen higher in the absence on CNT sparking. This effect can be explained by the fact that high energy causes a steep thermal gradient beneath the melting zone.

The machined damages layer generated by the EDM process produces a harmful influence decreasing the service strength and life of the virgin material. This damage layer should be removed before being put to use. It is therefore recommended that the EDM specimen should be polished down to at least the maximum depth of the micro-cracks in order to improve its service life.

3.4. PARAMETERS USING COPPER ELECTRODES

The Surface roughness was measured using Surface roughness tester TR500 for given working condition of EDM for with and without carbon nano tube. (Table 5)

TABLE 5 PARAMETERS USING COPPER ELECTRODE

Current (Amps)	Ton (µs)	Toff (µs)	Surface Roughness without SWCNT (Ra) µm	Surface Roughness with SWCNT (Ra) µm
1	6	5	4.57	4.33
2	5	4	4.00	3.69
3	4	3	3.71	2.47
4	3	2	4.47	4.27
5	2	1	7.81	6.41

IV. SCOPE OF THE WORK

Optimization is concerned with maximizing material removal rate, minimizing the tool wear ratio and obtaining a good surface finish. This can be achieved with the help of Regression analysis can done in the later stages of this research. In the present work multi walled carbon tubes is used. In the future research single walled carbon nano tubes may be used leading to better results.

V. CONCLUSION

The experimental results indicate that the surface texture after EDM is determined. Variation in the results is also achieved using Single wall CNTs. An excellent machined finish is obtained by setting the machine parameters at a low pulse energy. The surface roughness and the depth of the micro-cracks are compared with and without CNT's. The specimens sparked using CNTs have better surface finish, reduced micro cracks and better surface morphology as compared with specimens sparked without SWCNTs. Furthermore, the SEM application yielded information about the depth of the micro-cracks is particularly important in the post treatment of AISI D2 tool steel machined by EDM.

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Prabhu Sethuramalingam received his BE in Mechanical Engineering from Bharathiar University, Coimbatore, India, his ME in Production Engineering from Madurai Kamaraj University, Madurai, India and currently doing his PhD in the area of Nanomachining at SRM University, Chennai, India. He has industrial experience of 4 years as Production Engineer and 8 years of teaching and research experience. Currently, he is a Senior Lecturer at SRM University, Chennai, India. He has won the best teacher award and the best project award. He is the author of 24 International journal papers. His research interest includes nanotechnology, nanomachining, machining of nanomaterials and robotics.

B.K. Vinayagam did a 5 years integrated graduate programme in Machine Tool Design and Production in Voroshilovgrad Machine Building Institute, Russia and a PhD programme in Flexible Manufacturing Systems in Voronez Polytechnic Institute, Russia. His professional career started under Ministry of Defence and then 14 years in the Tata Iron and Steel Company in various positions. Currently, he is working as a Professor and Head in Mechatronics Department, SRM University, India. He is intensively involved in different consultancy and developmental projects. He has published 15 research papers in international and 5 in national journals.

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