Effect of Carbon Nano Tube Addition with Dielectric Fluid in Die Sink EDM

Moshim Gulab Mulla, Anshuman Kumar

Abstract: Advance machining processes such as Electrical Discharge Machining (EDM) have been extensively discussed these days due to its novel applications in industry. Series of experiments are conducted across various researchers for performance improvement of the EDM process. Mixing micro/nano powder in working fluid for better result of material removal rate is one of the developments in conventional EDM process, known as Powder Mixed EDM. Many Researchers got successes in getting mirror like surface finish in PMEDM at low energy level, but still there will be improvements are possible by using Nano powders. Due to excellent performance in dielectric and better physical properties of the Carbon Nano Tubes (CNT's), there is need of generalization of CNT based Powder Mixed Electric Discharge Machining (CNT-PMEDM) to increase industrial application. But less work has been reported in NPMEDM, this paper aim is to discuss all CNT's based experimental investigation in Die Sink EDM process and its future scope to help the researchers for further development in it. In this paper details about Carbon Nano Tube and its applications as additives in EDM process to get better results are presented which helps for finding research gap and future scope in CNT-PMEDM process.

Keywords: MRR, MWCNT's, Nano Powder Mixed Die Sinker EDM, SWCNT's, SR.

I. INTRODUCTION

EDM is also identified as Electro-erosion or Spark erosion process, based on principle of erosion of metal (melting and vaporization). It is one type of thermo electric material removing process, 3D view of the EDM machine is as shown in figure no.01. Main advantage of this process is non-contact characteristics between tool and work while machining, therefore it is widely used for machining hard materials like nickel based alloys, tungsten carbide, and titanium based alloys, hardened steels and super alloys. EDM is restricted only for conductive materials and also low machining rate, time consuming are the main drawback of this system. For eliminating these limitation many research work has been done and use of powder added fluid as dielectric get started and this development is named as powder mixed EDM process.

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In PMEDM, various types of powders like Si, Al, Cu, Cr, Gr, Sic are used as an additives and string mechanism was provided for uniform mixing. PMEDM process give 30 to 40 % increased rate of MRR than without powder added fluid.

Abbreviations:

EDM	Electric discharge Machining
MRR	Material Removal Rate
TWR	Tool Wear Rate
SF	Surface Finish
SR	Surface Roughness
CNT's	Carbon Nano Tubes
PMEDM	Powder Mixed EDM
NPMEDM	Nano Powder Mixed EDM
I	Current
V	Voltage
Ton	Pulse on time/duration
Toff	Pulse off time/duration
Conc.	Concentration
RSM	Response Surface Methodology
O.A.	Orthogonal Array
DOE	Design of Experiments
CCD	Central Composite Design
AFM	Atomic Force Microscope
SWCNT's	Single Walled Carbon Nano Tubes
MWCNT's	Multi Walled Carbon Nano Tubes

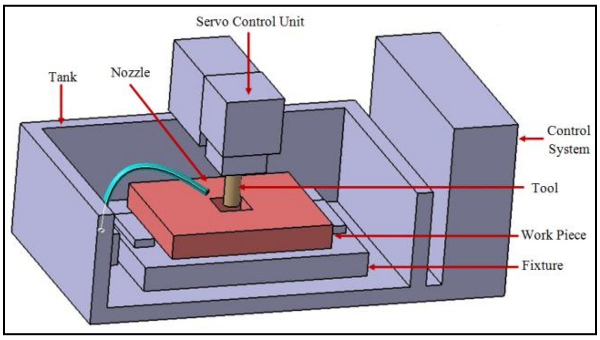


Fig.01: 3D diagram of EDM Machine

Lazarenko and Lazarenko, are two Russian scientists has developed EDM technique in the late 1940's, [1] and till now this technique is on the developing phase. Due to surface roughness and less efficiency of machining practical use of the EDM process are restricted. [1,2]. EDM process extensively used in various areas like automotive sector, airship industries, various metal moulds and dies making, precise manufacturing farms up to micro to nano level surface finish, which are the current need of the marketplace.

PMEDM: In the previous few a long time,

superior and developed version of the EDM process is nothing but PMEDM process which outperform than the conventional EDM because of the added powder in to the dielectric which create sparks with larger gap in between tool and work. Therefore PMEDM process is more stable and gives better performances than without powdered fluid. High resistance to corrosion abrasion surface is produced by PMEDM process [3-5]. So many research works was done in PMEDM process with considering various micro level powders in dielectric fluid but nano level powder added considerations are only few[8,11-13,18-21,23,25,26,36,37]. In spite of the improved results, practical application of NPMEDM in industry is very low rate. [6, 7, 26] From the previous research in NPMEDM, it is clear that CNT's addition in dielectric fluid give better results than other powders. So, to make CNT's base PMEDM process more practical, there is need to recall all the work done by various researcher on the CNT-PMEDM which is helpful to researcher to find the gap and new development in this field. Due to superior advantages and scope of improvements of the CNT's based PMEDM method, author motivated and try to recall all previous research work on CNT's based PMEDM. This paper is presented as; first represents introductory part on EDM and PMEDM, second presents Carbon Nano tube, Third presents literature survey exclusively on CNT's based Powder mixed Die Sink EDM, fourth represents scope of the CNT's- PMEDM and ended by conclusions.

In PMEDM, because of the conductive powder mixed dielectric fluid, electric field aberration is carried out in the spark gap, resulting increase in gap between two electrode i.e. tool and work piece. The added particles becomes charged, get accelerated due to the influence of high potential intensity and moving in zigzag fashion. Due to effect of bridging particles are acts as conductors to pass electricity from one electrode to other electrode in between discharge region, create multiple sparks or discharges within single input energy. Then charge accumulation is take place in powder particles and which initiates discharge in the successive particles of the conductive powder, which results "series of discharge" phenomenon as shown in below figure no.2 [26].

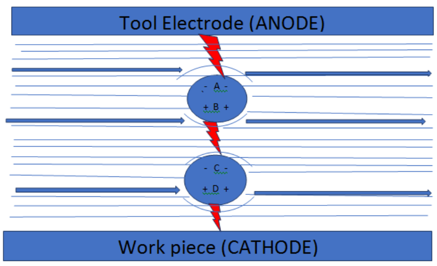


Fig.2: Series of discharges phenomenon [26]

II. CARBON NANO TUBE

Generally two types of Carbon Nano Tubes first is Single-Walled varieties, which contain single cylindrical wall as in figure 3, and second is the Multi-Walled type, which contain two cylindrical walls one inner and other is outer as shown in figure no. 6. Depending on the manufacturing, lengths of both types vary significantly, and details about their physical and electrical properties are as follow,

Most attractive characteristics of CNT's are; [11, 15]

1. As compare to steel 100 times stronger and one sixth time smaller in weight
2. Young's modulus greater than 1 TPa
3. Strength to weight ratio is very high 500 time more than aluminum
4. High strain carrying capacity (near about 10 % more than all materials)
5. Vacuum Stability up to 2,800^{0}C, and in air up to 750^0 C.
6. High current carrying capacity and aspect ratio
7. Good field emitter

A. *Single-Walled Carbon Nanotubes (SWCNT's)*

SWNT's are best nano tubes but principal downside of these is that hard to make in comparison to MWCNT's. These have excellent physical properties. SWCNT's are cap ended graphite tubes, and capes can be removed easily as shown in figure no. 5. Some hexagons and pentagons are mixed each other to form caps therefore nano tubes are sign as buckminsterfullerene cousins is as shown in figure no.4, with the help nearly sixty carbon atoms are used for making spherical molecule which seen like soccer ball and also known as Buckminster Fuller as shown in figure no.5. [15].

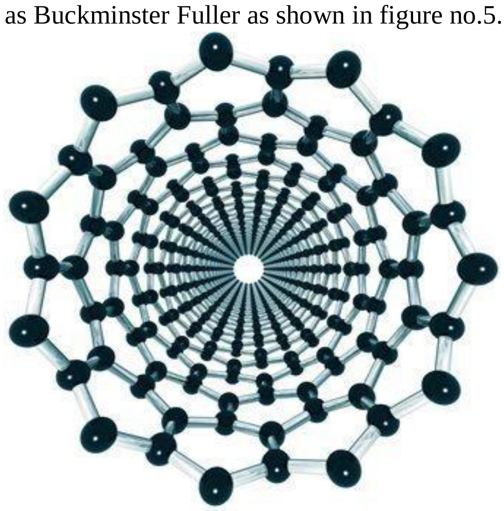


Fig.3: Simulated structure of a CNT [15]

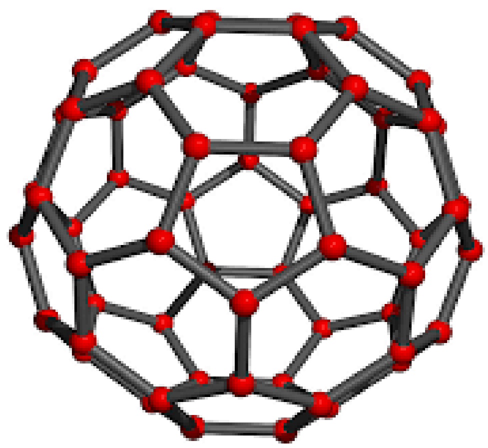


Fig.4: Buckminsterfullerene [15]

Other physical properties of carbon nano tubes with comparison of various materials are as shown in table 1, due to these excellent properties of CNT application as additives in PMEDM is most beneficial and author motivated to review all previous research work to for identifying improvements in CNT based PMEDM process.

Table 1: Additive Powders Properties [11, 17]

Powder	Thermal Cond. (W/m·K)	Density (kg/ m^3)	Electric Resistivity (μΩm)	Spec. Heat (J/ kg· K)	Melting Point (^{0}C)
Si	148	2330	39.68	702.2	1414
Al	238	2700	0.027	898.7	660
Gr.	3000	2260	0.50	706.4	3652
Cr.	670	7160	0.026	450	1873
Cu	416	8960	0.015	385	1083
CNT	2000-6000	2000	0.50	752.4	2800

B. *Multi-Walled Carbon Nano tubes (MWCNT's)*

MWCNT's are graphite tubes of concentric cylinders and made by using SWCNT's. MWCNT's have very complex structure and these can be easy to produce in required amount as compared to SWCNT's. Carbon Nano Tubes have three types of geometries also referred to as flavors. The three flavors are armchair, zigzag, and chiral as shown in figure 6. Classifications are based on how the carbon sheet is wrapped into a tube (see below pictures) [15].

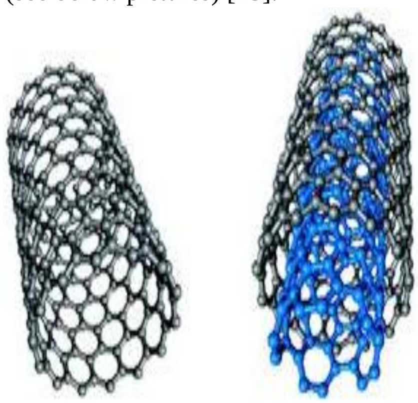
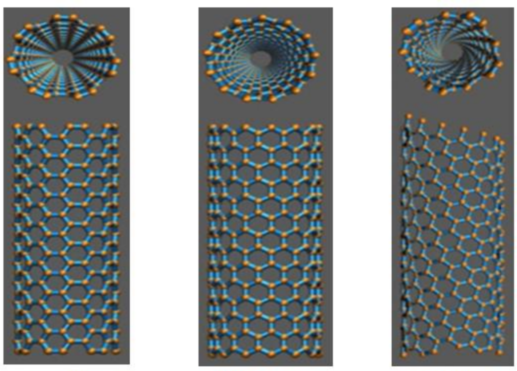


Fig.5: SWCNT and MWCNT



a) Armchair (n=m) b) Zig-zag (m=0) c)Chiral

Fig.6: Nanotube geometry

III. CARBON NANO TUBE IN DIE SINK EDM

Researchers had made a lot of efforts on the conventional EDM as well as PMEDM process to produce better surface finish and high MRR with low TWR. Requirement of Nano surface finish has increases day by day in current industries such as semiconductor, aerospace sectors, optical, automotive, surgical sectors, die and mould making industries. Materials used in these industries are very high strength, tough, hard and wear resistive which have difficult for machining (usually called as "difficult to machine" materials) by convection methods. Because of the market demand and customer need of theses material, industries facing great challenge to manufacturing parts with help of these materials. EDM is one of the methods, which satisfy these needs to compute the current market. In die sink EDM process correct selection of the parameters are most important for getting better quality results. Various input parameters which effect on MRR and SF are shown in cause and effect diagram figure no.7. Here dielectric fluid is also considered as an input parameter because number of research work has been done for finding better dielectric fluid which outperformed than others. [27-35].

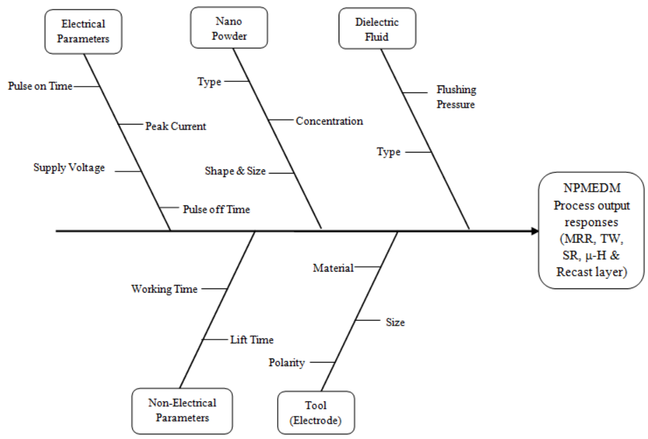


Fig.7: Ishikawa diagram for NPMEDM

Detail summary about previous studies on CNT based Die Sink EDM is explained in tabulation format as shown in table no.2. From the research progress it is very clear that, CNT performance and results are better than other powders. Only little research work was done in this field, therefore there is scope for improvements and to generalize this CNT-NPMEDM process. Therefore author has decided to do our research work into this field to generalize and increasing practical applications of CNT-NPMEDM process.

Table 2: Summary of Experimental Investigation in NPMEDM

Author/ Year	Nano Particles	Dielectric Fluid	Work piece (size in mm)	Tool (Ø in mm)	Input Parameters	Output parameters	Tech./Method used	Findings and remark
Prasad Bari et.al. (2017) [36]	MWCNT	DEF92 EDM oil	NAK80 steel	Cu (Ø16.5)	1.T_{on} 2.I 3.V 4. Powder Conc.	1.MRR 2.SR	1. Taguchi L9 O. 2.Tagichi Grey Relation Analysis	MRR increased by 25% and SR by 6.87% compared to without CNT
Amit Kumar et.al. (2017) [26]	AL2O3 Nano Powder (0.25%)	Deionized Water	Inconel 825 (100x50x5)	Cu (5X15)	1.I 2.T_{on} 3.V	1.SR 2.MRR	1Box–Behnken Tech for DOE 2.RSM	1. Advantages of powder additives are-high arcing tendency, more gap between tool and work, better SF, less short circuit, long machining time and resulting higher stability. 2. I, T_{on} and V are important process parameters.
Shalini Mohanty et.al.(2017) [37]	AL2O3 Nano Powder	EDM oil (Paraffin oil)	AISIC$_p$12%MMC	Cu (Ø 12)	1.Low voltage current 2.High voltage current 3.T_{on} 4.T_{off} 5.Flushing pressure	1.SR 2.MRR	1.RSM 2.Particle Swarm Optimization 3.Box–Behnken Tech for DOE	Larger spark gap and improved breakdown characteristics are advantages get by adding powder in to dielectric
Mohammadreza Shabgard et.al. (2017) [39]	MWCNT (2g/lit.)	Oil Flux ELFZ	Ti–6Al–4V (Ø 14, H-10)	Cu (Ø 10)	1.I 2.T_{on}	1.Surface Qualities 2.MRR 3.TWR	1. Full Factorial Design	Due to use of MWCNTs into dielectric, 1. Machining stability improved 2. Decrement of inappropriate sparks and surface micro cracks.
K. Karunakaran et.al.(2016) [38]	1. Al (2 g/lit.) 2. Si (2 g/lit.) 3. MWCNT (0.5 g/lit.)	Kerosene	Inconel 800	Silver coated Electrolytic Cu	1.I 2.T_{on} 3.T_{off}	1.SR 2.MRR 3.TWR	1.3x3x3x4=108 runs Full Factorial Design	1. MWCNT's better perform than Al, Si Nano-Powders in dielectric. 2. Max.MRR is found by MWCNT then Si and last AL.
Sachin Mohal et.al. (2016) [25]	MWCNT	EDM oil	Al-10%SiCp MMC	Cu (Ø5)	1.I 2.T_{on} 3.Duty Cycle 4. CNT Conc.	1.SR 2.MRR	1RSM 2.CCRD 3.Ishkawa Cause and Effect Diagram	Due to use of MWCNTs into dielectric, 1. Excellent SF (0.411µm.), 2.Thin craters, 3. Spherical shaped globules. 4.Uniform recast layer
Houriyesh Marashi et.al. (2015) [8]	Ti (Titanium) nano powder (2 g/lit.)	Hydrocarbon oil	AISI D2 Steel	Cu (Ø10)	1.I 2.T_{on} – T_{off} 3.Dielectric Fluids	1.MRR 2.SR	3-factor 3-level	By use of Ti nano additives-measurable improvements are seen in Surface Morphology, MRR (69%) and decrements SR (35%) at all machining parameters.

Harmesh Kumar (2014) [18]	CNT	Kerosene	AISI D2 Die Steel	Cu (Ø5)	1.I 2.T_{on} 3. CNT Conc.	1.SR 2.MRR	1.Factorial Design 2.Ishkawa Cause and Effect Diagram	CNT's Conc. and current are the most significant parameters 2. MRR increased by 80% and SR reduced by 67% due to use of 4g/lit CNT's in dielectric fluid
S.Prabhu et.al. (2013) [23]	MWCNT (2g/0.5lit .)	Kerosene	AISI D2 Tool Steel (Ø20 L-20.5)	Graphite(Ø24 L-50)	Discharge – 1. I 2. T 3. V	1.SR 2.MICRO CRACKS	1.Fuzzy Logic 2.Box–Behnken CCD 3.RSM 4.ANOVA f-test	Optimization of parameters is done by using fuzzy logic and experimentally and results are compared.
S.Prabhu et.al. (2013) [21]	MWCNT (10g/0.5lit.)	Kerosene	AISI D2 Tool Steel (Ø20 L-20.5)	Cu(Ø24 L-50)	Pluse- 1. I 2. T 3. V	1.SR	1.Regression 2. neuro Fuzzy logic (ANFIS)	ANFIS model gives vary closed results as compared with experimental results
S.Prabhu et.al. (2013) [22]	MWCNT (2g/0.5lit .)	Kerosene	AISI D2 Tool Steel (Ø20 L-20.5)	Cu(Ø24 L-50)	Pluse- 1. I 2. T 3. V	1.SR 2.MRR	1. Grey Relational Analysis 2. L9 O.A.	Better SF, reduced Micro crack and better surface morphology is getting by CNT's based process than without CNT's.
M. M. Sari et.al. (2013) [13]	MWCNT (1 g/lit.))	Kerosene	AISI H13 Steel (10x10x10)	Cu (Ø4.9)	1.I 2.T_{on} 3.Interval Time	1.MRR 2.SR 3.TWR 4.Recast Layer	1.3-factor 8-Expts 2.SEM	A smoother surface is achieved at low pulse of energy. Deep research work is required for generalization of the CNT's based PMEDM.
S. Izman et.al.(2012) [35]	MWCNT (1g/lit.)	Kerosene	Ti6Al4V	Cu (Ø 5)	1.I 2.T_{on} 3.Interval Time	MRR	2-level Full Factorial Design	Due to use of MWCNTs in dielectric gives measurable increments in MRR (7%) and SF (9%) and decrements in white layer thickness.
S.Prabhu et.al. (2012) [19]	MWCNT (2g/0.5lit .)	Kerosene	AISI D2 Tool Steel (Ø20 L-20.5)	Cu(Ø24 L-50)	Pluse- 1. I 2. T 3. V	1.SR	1.Regression 2.Box–Behnken CCD 3.ANOVA & f-test	34%.average improvement in SR by using CNT in Dielectric fluid.
C. Mai et.al. (2011) [11]	1.Al 2.Si 3. Gr. 4. CNT (0.4g/lit.)	Kerosene	NAK80 Steel (100x80x10)	Cu (Ø20 -55)	1.I 2.T_{on} 3.V	1.SR 2.TW 3.Machining Time	Comparative study	1. Improvement of SR (70%) and machining efficiency (66%) due to addition of CNT's in kerosene as compared to simple EDM. 2. With large electrode measurable improvements is shown in SR. 3. CNTs performance is better than Al,Si,Gr powders as additives.
S. Prabhu et.al.(2011) [16]	SWCNT (2 g/lit.)	Kerosene	INCONEL825	Cu (Ø20 L-15)	1.I 2.T_{on} 3.V	1.SR 2.MICRO CRACKS	ANOVA AFM(Atomic Force Microscopy)	Better surface finish, surface morphology and reduction in micro cracks can be achieved by use of CNT's in dielectric.
S.Prabhu et.al. (2010) [12]	SWCNT (1g/lit.)	Kerosene	AISI D2 Tool Steel (Ø20 L-20.5)	Graphite(Ø24 L-50)	1.I 2.T_{on} 3.T_{off}	1.SR 2.MICRO CRACKS	Regression Analysis	1. Superior SF is obtained at low pulse energy. 2. Better SF, surface morphology and reduction in micro cracks can be gain by use of SWCNT's in dielectric.

IV. FUTURE SCOPE IN CNT'S BASED PMEDM

Previous review on PMEDM shows that, lots of work was done with considering various micro level powders like Al, Cu, Gr, Sic, etc. for improving output parameters such as MRR and SF, and also researcher's get success to achieve mirror like surface finishing qualities form this process. But only few papers [8,11-13,18-21,23,25,26,36,37-39,] are reported on CNT-PMEDM process which have great potential with excellent performance as an additives in dielectric as compared to the other powders such as AL,Cu,Gr,Sic,Cr, etc. For practical application of the CNT-NPMEDM deeper investigation is required. Less work has done on work materials like hard steel, Titanium alloys, Aluminum alloys, Hastelloy, Kovar, and carbide with CNT in dielectric; these are used in various aerospace and automotive sector industries. So many other dielectric fluids are available in market but still now only few are consider (kerosene, EDM oil, Hydrocarbon oil, Deionized Water) with combination of CNT's additives. Less work was done in multi objective optimization of CNT based PMEDM. Littlie work was reported in hybrid methods of the EDM process with considering CNT's as an additives. Also lot of scope in CNT's base sustainable EDM process which have superior than conventional EDM and author is decide to do its further research work in it.

CONCLUSION

This paper covers all details related to the previous research work on nano powder mixed Die Sinker EDM process, and it is clearly seen that CNT's performance in dielectric as an additive was excellent as compared to the other additives. Due to the excellent physical and electrical properties of the CNT's, these are best suit for the application as additives in dielectric fluid. Application of the CNT's in dielectric fluid measurable enhancements compared to conventional EDM are shown in machining output parameters such as MRR improves up to 80%, SF improves up to 70%, and also reduction in micro cracks and white layer. In spite of these advantages, actual use of CNT's additives is limited, because till this process is not generalized and lot of research efforts is required in it. Therefore authors are tried to recall all past progress into it which help for finding gaps in NPMEDM.

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