DEVELOPMENT OF ELECTROCHEMICAL MICROMACHINING PROCESS INFLUENCE OF PWEDM METHODOLOGY

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ABSTRACT

In recent times, ceramic alloys (Graphene and Silicon Carbide) are widely used in aerospace, chemical and marine industries owing to their supreme ability to retain the mechanical properties at elevated temperature in combination with remarkable resistance to corrosion. Some of the properties of these alloys such as low thermal conductivity, strain hardening tendency, chemical affinity and presence of hard and abrasives phases in the microstructure render these materials very difficult-to-cut using conventional machining processes.The traditional machining consists of a specific contact between the tool and work piece. As a result of this contact the tool may wear out after a few operations. In addition to that, the MRR (Material Removal Rate), Surface Finish, etc. is also lowered. As a result of these drawbacks, traditional or conventional machining processes cannot be used to machine ceramic based alloys and thus we opt for unconventional machining process.Electrical discharge machining (EDM) is a manufacturing process whereby a desired shape is obtained by using electrical discharges (sparks). Material is removed from the work piece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. One of the electrodes is called the tool-electrode or simply the "tool" or "electrode" while the other is called the work piece-electrode or "work piece." The process depends upon the tool and work piece not making actual contact.Therefore, the aim of the current research is set to improve the MRR and reduce the TWR of machined surface of Aluminum-Silicon Carbide Composite using copper tool and graphene mixed electrolyte.

Keywords: - Graphene, Silicon Carbide, EDM, MRR, TWR

1.0.Introduction

Despite the fact that the material removal mechanism of EDM is not absolutely identified and is still contentious, the most widely established principle is the transformation of electrical energy into thermal energy through a sequence of distinct electric discharges. Fig.1.4.3 shows a representative diagram of a typical EDM setup. Build-up of suitable voltage across tool and work-piece (cathode and anode respectively) that are submerged in an insulating dielectric, causes cold emission of electrons from the cathode. These liberated electrons accelerate towards the anode and collide with the dielectric fluid, breaking them into electrons and positive ions. A narrow column of ionized dielectric fluid molecules is established connecting the two electrodes. A spark generates due to the avalanche of electrons. This results in a compression shock wave. Very high temperature (8,000 to 12,000 ºC) is developed which induces melting and evaporation of both the electrodes. The molten metal is evacuated by the mechanical blast (of the bubble), leaving tiny cavities on both tool and work piece.

2. LITERATURE REVIEW BASED ON VARIOUS AUTHORS:

1. Ahmed al khazraji et al worked on the effect of Si-C powder mixing EDM on white layer thickness, heat flux and fatigue life of AISI D2 die steel. The fatigue stress increases with decrease in the pulse current. It is observed that different types of performance parameters are applied by different authors using artificial neural network (ANN) for the optimization of the performance variables and response variables. It is found that different types of optimization techniques are used to optimize the machining parameters in electrical discharge machining (EDM). The research work mostly use single objective approach but for high optimization and for good machining efficiency multi objective approaches are used. Artificial Neural Network (ANN) is one of the multi object approach technique used in it. Mostly research work carries out the Material removal rate (MRR), Tool wear rate (TWR), Surface roughness (Ra), etc. for different types of work material.

2. Amandeep Singh et al worked on effect of silicon powder mixed EDM on surface roughness of Al6063 aluminum alloy. When current increases, the MRR also increases. The higher the current, intensity of spark is increased and results in high metal removal rate. When the current is increased, surface roughness is also increased. When pulse-on-time increases, the MRR is decreased. The higher the pulse-on-time, intensity of spark decreases due

Fig.1.4.3 EDM

to expansion of plasma channel and results in less metal removal. When Pulse-on-time is increased, surface roughness is decreased. With increase in pulse-off time, the MRR increases as with long pulse off time the dielectric fluid produces the cooling effect on wire electrode and work material, decreasing the cutting speed. Surface Roughness improves with increase in pulse-off time. The MRR first increase with increase in servo voltage and then starts to decrease. At low value of pulse duration, the SR increases with increase in servo voltage up to 30 v and then decreases with increase in servo voltage while at high value of pulse duration SR decreases continuously with increase in servo voltage. The MRR first increases with increase in wire feed rate and then decreases with further increase in wire feed rate. The SR decreases with increase in wire feed rate.

3. Divya Rana et al worked on study of powder mixed Dielectric EDM and research trends in EDM process using water and powder mixed dielectric. In powder mixed electric discharge machining (PMEDM) to avoid the wastage of kerosene oil, a small dielectric circulating system is designed. A stirring system is incorporated to avoid the particle settling. For constant reuse of powder mixed dielectric fluid, magnetic forces are used to separate the powder particles from the debris produced due to machining. PMEDM has a different machining mechanism from the conventional EDM. In this process, a suitable material in the powder form is mixed into the dielectric fluid of EDM. The mechanism of PMEDM is totally different from the conventional EDM . A suitable material in the powder form is mixed into the dielectric fluid of EDM. When a suitable voltage is applied, the spark gap filled up with additive particles and the gap distance setup between tool and the work piece increased from 25–50 to 50–150 mm. The powder particles get energized and behave in a zigzag fashion.

4. Gangadharudu Talla worked on powder mixed EDM of Inconel 625 and process parameters were calculated using different powders (Aluminum Graphite and Silicon). The addition of suitable powder particles to the dielectric leads to a superior surface finish, and better machining rate compared to those for conventional EDM(without powder mixed electrolyte. A novel EDM two tank system was first developed and marketed by Mitsubishi. One tank is consisted of standard dielectric oil and the second one contained powder-mixed dielectric. And the tank with the powder mixed dielectric showed better response than the standard dielectric oil.

5. Kanwaljit Singh worked on the optimization of process parameters of powder mixed EDM for higher carbon high chromium steel through grey retlation analysis to improve the highest MRR of D2 steel is achieved using copper- chrome as a tool.In this experimental work, input parameters, namely, pulse on-time, discharge current, tool material and grit size, are selected. The design of the experiment has been constructed with the help of MINITAB 7 Software, in which L16 orthogonal array has been preferred for the experimentation. The effect of input parameters, namely, material removal rate, tool wear rate and surface roughness, is investigated. Grey relational analysis and analysis of variance are performed to optimise the input parameters and better output results.

6. Kumar Sandeep et al worked on current trends in EDM, this process becomes more stable and improves machining efficiency and MRR.Vibration, rotary and vibro-rotary mechanism makes the equipment simple and increases the material removal rate, provide better surface finish ejection from work piece. Better circulation of dielectric fluid and debris removal from work piece.

7. Lijo Paul et al make an attempt to machine silicon water of 500 µm thickness using stainless steel wire. Characterization of micro hole has been reported mainly In terms of Material Removal Rate. Diamaterialovercut and heat affected zone. The machining parameters are optimized using multi response analysis – Grey Relation Method. The main contribution includes:An inhouse prototype model of ECDM was developed with micro linear actuators and XY scanning device to machine micro holes in silicon water. Design of experiments to perform the experiments which are optimized using multi-objective optimization of GRA and results characteristics using SEM using.MRR depend on applied voltage, higher the MRR. In order to reduce DOC and HAZ, voltage should be at optimum around 45V and electrolyte concentration should be 30% lower DF of 60%. This will reduce the side spark formation thereby reducing HAZ.

8. S.S. Desai et al worked on the optimization of EDM process parameters using the Taguchi method. The result shows that current, pulse on time and pulse off time have significant effect on MRR, TWR and SR. The results of the present work reveal that proper selection of input parameters will play a significant role in Electric Discharge Machining. The MRR is increasing with increase in current. MRR is decreasing initially with increase in the pulse on time and increasing later with an increase in pulse on time. MRR is increasing with increase in the pulse off time but the increase is less as compared to pulse on time. For optimum MRR, I3V1C3 levels must be selected.

9. Shah Abulais worked on the current research on EDM.Electrical discharge machining (EDM) is one of the earliest non-traditional machining processes. EDM process is based on thermoelectric energy between the work piece and an electrode. A pulse discharge occurs in a small gap between the work piece and the electrode and removes the unwanted material from the parent metal through melting and vaporising. The electrode and the work piece must have electrical conductivity in order to generate the spark. There are various types of products which can be produced using EDM such as dies and moulds. Parts of aerospace, automotive industry and surgical components can be finished by EDM. This paper reviews the research trends in EDM on ultrasonic vibration, dry EDM machining, EDM with powder additives, and EDM in water.

10. Shivam Goyal et al worked on experimental investigation of machining parameters of powdered mixed EDM and optimization of MRR, Surface roughness, TWR using Taguchi method with increasing the concentration of alumina powder MRR and surface finish increases.A set of experiments are performed on AISI 1045 steel work pieces by using copper electrode in aluminium powder mixed EDM. The experimental studies are conducted by keeping various parameters like Current, Voltage, Pulse on time, Duty factor constant and by varying two parameters i.e. Grain size of aluminium powder & Concentration of aluminium powder. Mixing of Aluminium powder in Di-electric fluid ensures improved MRR and surface finishing. Based on the results obtained, the following conclusions have been drawn: The analysis of the experimental observations highlights that Grain size of aluminium powder and concentration of aluminium powder mixed with EDM oil have a great influence on MRR and Surface finish. Too low and too high concentration of aluminium powder in EDM oil reduces MRR of AISI 1045 Steel. Too low and too high Grain size of aluminium powder in EDM oil reduces MRR of AISI 1045 Steel. As the concentration of aluminium powder in EDM oil increases, surface roughness starts decreasing and keeps on decreasing. So as a result we get lowest surface roughness on concentration 6 gm/ltr. ofaluminium Powder mixed with EDM oil. Lower surface roughness shows the better surface finish. This means that the best surface finish is achieved on concentration of 6 gm/ltr. ofaluminium Powder mixed with EDM oil. As the Grain Size of aluminium powder in EDM oil increases, surface roughness starts decreasing and keeps on decreasing.

11. Sugunakar. A. worked on the effect of various powders added to dielectric fluids on MRR an SR during PMEDM of RENE80 to get the better MRR with the same powders and quantity. It is observed that different types of performance parameters are applied by different authors using artificial neural network (ANN) for the optimization of the performance variables and response variables. It is found that different types of optimization techniques are used to optimize the machining parameters in electrical discharge machining (EDM). The research work mostly use single objective approach but for high optimization and for good machining efficiency multi objective approaches are used. Artificial Neural Network (ANN) is one of the multi object approach technique used in it. Mostly research work carries out the Material removal rate (MRR), Tool wear rate (TWR), Surface roughness (Ra), etc. for different types of work material.

12. Sushil Kumar Choudhary et al worked on current advance research of EDM by using the powder mixed in electrolyte to provide a mirror like surface finish, increases MRR. It revels what has be do in particular area and what further need to be done in the chosen field. It, was therefore, decided to review the existing available literature to avoid duplication and to carry forward the research direction. Extensive literature review has been done using different sources, which include books, national and international journal and internet. In order to investigate the outcome of input process parameters on the quality of machining in Inconel 600 super alloy by EDM Process, it is essential to fully understand all the aspect of EDM process and analysis tools, which have already been attempted by different researcher in this field.

13. Taylor and Francis worked on surface roughness and micro hardness evaluation for EDM with Cu–Mn powder and the percentage of alloying element in tool electrode and duty facor don't effect surface roughness whereas peak current does.In this experimental work, input parameters, namely, pulse on-time, discharge current, tool material and grit size, are selected. The design of the experiment has been constructed with the help of MINITAB 7 Software, in which L16 orthogonal array has been preferred for the experimentation. The effect of input parameters, namely, material removal rate, tool wear rate and surface roughness, is investigated. Grey relational analysis and analysis of variance are performed to optimise the input parameters and better output results.

14. Visal Kumar Jaiswal et al worked on the literature review on EDM performance evaluation on the basis of TWR, MRR and Hardness.In this conclusion, there are following major factors are reviewed: Resulting foremost conclusions can be stated from review of work in this area that EDM performance is generally evaluated on the basis of TWR, MRR, Ra and hardness. In Material removal rate (MRR) from all selected parameters, spark current (I) is the most significant input factor affecting the machining of work piece. The performance is affected by discharge current, pulse on time, pulse off time, duty cycle, voltage for EDM. For tool wear rate (TWR) from the all selected parameters, spark current (I) is the most significant input factor affecting the machining of work piece followed by spark time and voltage. Innovative technology in the EDM is unceasingly progressing to make this procedure further appropriate for the Machining. In the field of manufacturing additional attention is on the optimization of the method by dropping the number of Electrode

3.0SELECTION OF WORKPIECE, TOOL AND POWDERS

3.1.ALUMINIUM 6061(AA6061):

Aluminum alloys have been the primary material of choice for structural components of aircraft since about 1930. Although polymer matrix composites are being used extensively in high-performance military aircraft and are being specified for the major structural weight of the new Boeing 787 and Airbus A350, aluminum alloys will continue to be used for many commercial and military applications. AA

It is commonly available in pre-tempered grades such as 6061-O (annealed), tempered grades such as 6061-T6 (solutionized and artificially aged) and 6061-T651 (solutionized, stress-relieved stretched and artificially aged).The mechanical properties of 6061 depend greatly on the temper, or heat treatment, of the material. Young's Modulus is 69 GPa (10,000 ksi) regardless of temper.

3.2.SILICON CARBIDE:

Silicon carbide (SiC), also known as carborundum , is a semiconductor containing silicon and carbon. It occurs in nature as the extremely rare mineral moissanite. Synthetic SiC powder has been mass-produced since 1893 for use as an abrasive. Grains of silicon carbide can be bonded together by sintering to form very hard ceramics that are widely used in applications requiring high endurance, such as car brakes, car clutches and ceramic plates in bulletproof vests. Electronic applications of silicon carbide such as light-emitting diodes (LEDs) and detectors in early radios were first demonstrated around 1907. SiC is used in semiconductor electronics devices that operate at high temperatures or high voltages, or both. Large single crystals of silicon carbide can be grown by the Lely method and they can be cut into gems known as synthetic moissanite.

3.3.PRODUCTION:

Because natural moissanite is extremely scarce, most silicon carbide is synthetic. Silicon carbide is used as an abrasive, as well as a semiconductor and diamond stimulant of gem quality. The simplest process to manufacture silicon carbide is to combine silica sand and carbon in an Acheson graphite electric resistance furnace at a high temperature, between 1,600 °C (2,910 °F) and 2,500 °C (4,530 °F). Fine SiO_2 particles in plant material (e.g. rice husks) can be converted to SiC by heating in the excess carbon from the organic material. The silica fume, which is a byproduct of producing silicon metal and ferrosilicon alloys, can also be converted to SiC by heating with graphite at 1,500 °C (2,730 °F).

3.4.PROPERTIES OF SILICON CARBIDE:

Silicon carbide exists in about 250 crystalline forms. The polymorphism of SiC is characterized by a large family of similar crystalline structures called polytypes. They are variations of the same chemical compound that are identical in two dimensions and differ in the third. Thus, they can be viewed as layers stacked in a certain sequence. Alpha silicon carbide (α-SiC) is the most commonly encountered polymorph. It's formed at temperatures greater than 1700 °C and has a hexagonal crystal structure (similar to Wurtzite). The beta modification (β-SiC), with a zinc blende crystal structure (similar to diamond), is formed at temperatures below 1700 °C. Until recently, the beta form has had relatively few commercial uses, although there is now increasing interest in its use as a support for heterogeneous catalysts, owing to its higher surface area compared to the alpha form.

3.5.ALUMINIUM SILICON CARBIDE:

Aluminium-Silicon Carbide is a metal-ceramic composite material consisting of silicon carbide particles dispersed in a matrix of aluminium alloy. It combines the benefits of high thermal conductivity of metal and low CTE (coefficient of thermal expansion) of ceramic. Surface finishing and surface grinding is done on both sides of the obtained sheet to make the two surfaces parallel to each other. The work piece has a density of 2.64 g/cc.

4. **STIR CASTING:**

Aluminum ingot with 99.8 wt% commercial purity was used as a matrix. The chemical composition of the used ingot obtained using a M5000 optical emission spectrometer. Micron-sized SiC particles with an average particle size of 80 lm and 99.9 % purity were supplied (Shanghai Dinghan Chemical Co., Ltd. China) as the reinforcement of metal matrix composite. The morphology of the silicon carbide particles used in this study. In order to fabricate the composites, 1 g reinforcement SiC powder was encapsulated carefully in an aluminum foil packet for insertion into the molten aluminum in order to fabricate a composite with 3 wt% SiC as reinforcement. These powders were preheated at 350 C for 4 h before the casting process to remove the moisture and impurities. The pure aluminum was heated to various temperatures of 680 and 850 C within a bottom-pouring furnace. A preheated graphite stirrer was placed below the surface of melt and rotated at a speed of 500 r min-1, and simultaneously argon gas of high purity was used as a protective shroud on the melt surface.. The composite slurry was poured into a low-carbon steel mold. 1 wt% Mg was added to the melt to increase the wettability between the matrix and the reinforcements. Mg acts like a surfactant power, which reduces the aluminum oxide coating by binding to the oxygen. Al/SiC are noted.

3.1.5 WORKPIECE IMAGES:

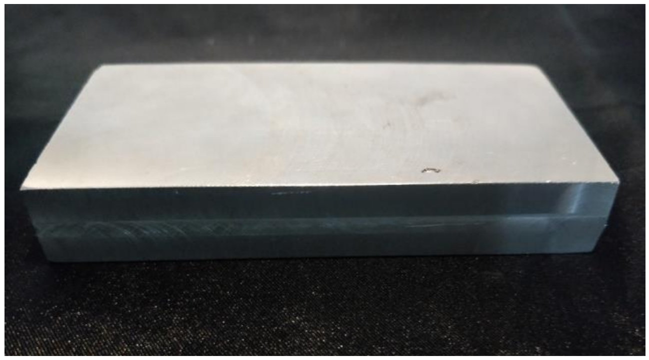

Figure1. Work piece

4.1.TOOL SELECTION:

✓ EDM electrodes consist of highly conductive and/or arc erosion-resistant materials such as graphite or copper.

✓ EDM electrode materials need to have properties that easily allow charge and yet resist the erosion that the EDM process encourages and stimulates in the metals it machines.

✓ Different materials that are used as EDM electrodes are: ➢Brass ➢Copper ➢Molybdenum

➢Copper tungsten

➢Silver tungsten

➢Graphite

➢Tellurium copper

✓ In this project, Copper is used as electrode because of its ability to machine hard materials with less wear.

✓ Copper and copper alloys have better EDM wear resistance than other materials, but are more difficult to machine than either brass or graphite.

✓ It is also more expensive than graphite. Copper is, however, a common base material because it is highly conductive and strong.

✓ It is useful in the EDM machining of tungsten carbide, or in applications requiring a fine finish.

5.0.EXPERIMENTATION

5.1.EXPERIMENTAL SETUP:

S.NO.	CONTENT	SETUP-1	SETUP-2	SETUP-3
1	Dielectric Fluid	EDM oil	EDM oil	EDM oil
2	Powder	Nil	Silicon Carbide	Graphene
3	Work piece	Al-SiC	Al-SiC	Al-SiC
4	Work piece Dimensions(mm)	117x55x20	117x55x20	117x55x20
5	Tool	Copper	Copper	Copper
6	Tool Diameter	6mm	6mm	6mm

Table 1. Experimental Setup

5.2. DEVELOPMENT OF EXPERIMENTAL SETUP:

All experiments were conducted on a die sinking EDM machining setup (make: ELEMECH ENGINEERS, India; model: EMS 5030) as shown in Fig. 3.1. Since it was planned to use a fresh dielectric fluid with varying concentrations of powder for every experiment, a separate dielectric circulation system was designed, fabricated and attached to the existing machine. Since the experiments require the work piece to be completely submerged in the dielectric fluid, a customized tank of mild steel having dimensions 180x180x100 mm was made. The image of the EDM machine is shown as below:

Schematic diagram of PMEDM setup is depicted in Fig. 3.2. The recirculation system consists of a cylindrical working tank of 20 liters, a work holding fixture, a dielectric reservoir (bucket), 0.5 HP pump and delivery pipes. A pressure gauge was also attached to the system to measure the dielectric pressure during experimentation. The pump receives the dielectric fluid from the outlet of the cylindrical tank and re-circulates it to the tool-work inter electrode gap to flush out the debris. The continuous circulation of the dielectric fluid avoids the settlement of powder particles in the flushing system. In the current investigation, side jet flushing was selected to flush out the debris.

5.3. PROCESS PARAMETERS:

Four process parameters:

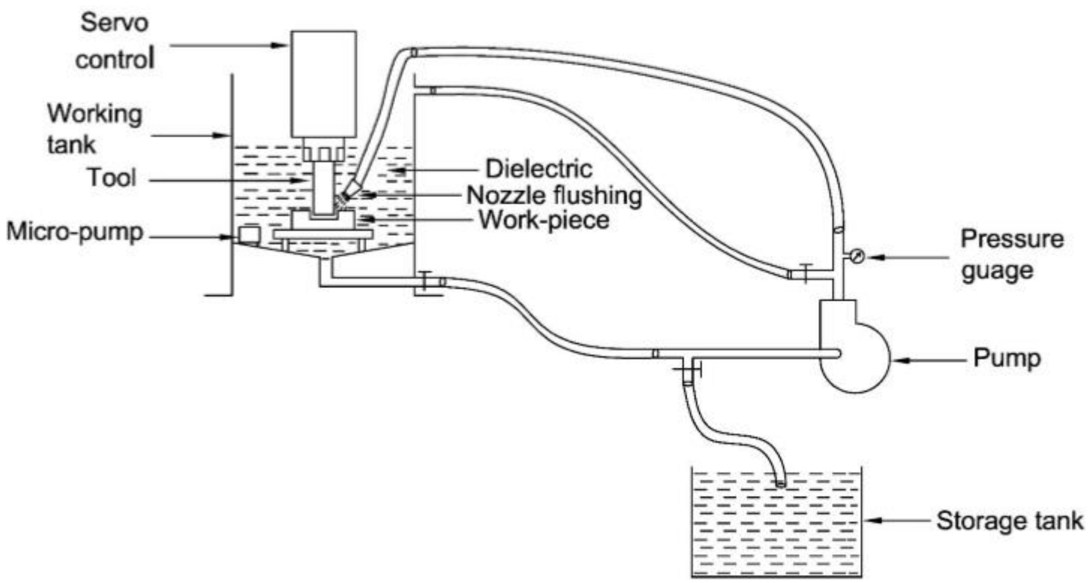

Figure 2. EDM Machine Setup

5.4. **DESIGN OF EXPERIMENTS USING TAGUCHI METHODS:**

The experiments were designed according to Taguchi Methods. Taguchi methods are statistical methods, or sometimes called robust design methods, developed by Genichi Taguchi to improve the quality of manufactured goods, and more recently also applied to engineering, biotechnology, marketing and advertising. Professional statisticians have welcomed the goals and improvements brought about by Taguchi methods, particularly by Taguchi's development of designs for studying variation, but have criticized the inefficiency of some of Taguchi's proposals.

Process parameters and their levels:

PARAMETERS	LEVEL 1	LEVEL 2	LEVEL 3
Current	10	20	30
Pulse-on	40	60	80
Pulse-off	2	5	8
Lift time	1	2	3

Table 2. Parameters and Levels

The process parameters and their levels are provided in the Table above. The ranges of the parameters were so chosen that the process falls under semi-finishing operation. The values of the different parameters are then set into the EDM machine and then the corresponding output parameters are calculated.

Plan of Experiments:

S.NO.	I	T_{on}	T_{off}	LIFT TIME
1.	10	40	2	1
2.	10	60	5	2
3.	10	80	8	3
4.	20	40	5	3
5.	20	60	8	1
6.	20	80	2	2
7.	30	40	8	2
8.	30	60	2	3
9.	30	80	5	1
10.	10	40	2	1

11.	10	60	5	2
12.	10	80	8	3
13.	20	40	5	3
14.	20	60	8	1
15.	20	80	2	2
16.	30	40	8	2
17.	30	60	2	3
18.	30	80	5	1
19.	10	40	2	1
20.	10	60	5	2
21.	10	80	8	3
22.	20	40	5	3
23.	20	60	8	1
24.	20	80	2	2
25.	30	40	8	2
26.	30	60	2	3
27.	30	80	5	1

Table 3.Plan of Experiments

The values of the different parameters are then set into the EDM machine and then the corresponding output parameters are calculated.

5.5. MATERIAL REMOVAL RATE (MRR)

Weight of the workpiece before and after the experiment was measured using an electronic balance (Make: Skywalk, India;) shown in Fig. 4.5.1. Time duration of each experimental run was recorded using a digital stop watch.

The equation that is used to calculate the MRR value is as below:

where w_b and w_a are weights of the specimen before and after the machining,

and 'T_{mach} ' is machining time.

5.6. TOOL WEAR RATE:

Weight of the tool before and after the experiment was measured using an electronic balance (Make: Skywalk, India;) shown in Fig. 4.5.1. Time duration of each experimental run was recorded using a digital stop watch. The equation that is u calculate the TWR value is the same as the MRR value with the only difference that the weight of the tool asured instead of the work piece.

5.7. FINAL VALUE OF MRR AND TWR:

After the experiments are conducted the values of the MRR and TWR are tabulated and are listed as below:

S.NO.	I (A)	T_{on} (μs)	T_{off} (μs)	LIFT TIME(s)	MRR (mg/min)	TWR (mg/min)
1.	10	40	2	1	9.169980383	0.489847
2.	10	60	5	2	9.886003745	0.545041
3.	10	80	8	3	9.399215879	0.492828
4.	20	40	5	3	37.51543125	2.595326
5.	20	60	8	1	20.07170813	1.414433
6.	20	80	2	2	16.85791613	1.337926
7.	30	40	8	2	41.21213772	3.0115

Img.4.5.1 Weighing Machine

$$MRR = \frac{w_b - w_a}{T_{mach}}$$

8.	30	60	2	3	39.30366469	3.006638
9.	30	80	5	1	24.05147935	1.984416
10.	10	40	2	1	16.65750824	0.654296
11.	10	60	5	2	14.32434998	0.550341
12.	10	80	8	3	10.45526773	0.386521
13.	20	40	5	3	42.05575254	2.046287
14.	20	60	8	1	28.56336932	0.969895
15.	20	80	2	2	23.88985063	1.12843
16.	30	40	8	2	48.59425768	2.134642
17.	30	60	2	3	45.63920236	2.330458
18.	30	80	5	1	33.82185937	1.373403
19.	10	40	2	1	34.6726217	0.756179
20.	10	60	5	2	26.12489386	0.577216
21.	10	80	8	3	15.81311456	0.359387
22.	20	40	5	3	53.92234476	1.491836
23.	20	60	8	1	39.18903608	0.655453
24.	20	80	2	2	30.65540402	0.529778
25.	30	40	8	2	62.29890228	1.460006
26.	30	60	2	3	54.16945119	1.335615
27.	30	80	5	1	38.522389	0.532911

6.0.RESULT AND DISCUSSION

6.1. GRAPH BETWEEN CURRENT VS MRR:

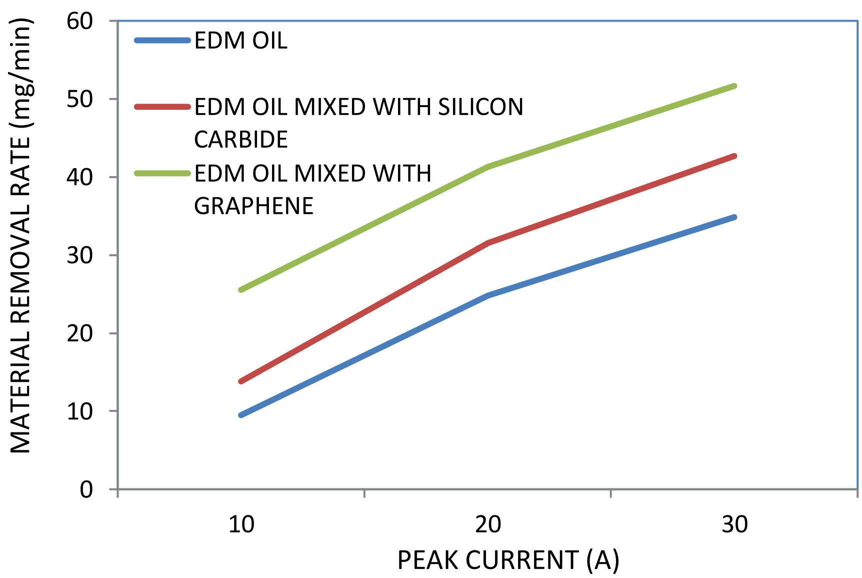

Figure 3. current vs mrr grpah

The above pictorial representation gives the comparison between the three setups. In this graph the current is plotted in the X-axis and the corresponding MRR value is plotted in the Y-Axis. The maximum MRR value that was recorded as 51.6636 mg/min when the current was 30A and Graphene was mixed to the EDM oil. The next highest value of MRR was found to be 42.6851 mg/min when the current was at 30A and Silicon Carbide was mixed in the EDM oil. At 30A the MRR was found to be least (34.8558 mg/min) when no powder was added. It is clearly visible from the graph, the MRR increases as the current increases. So from the graph it can be incurred that the MRR is directly proportional to the current. It can also be inferred that the addition of Graphene considerably increases the MRR when compared to the other two setups. This is because Graphene has high thermal conductivity when compared to Silicon Carbide and thus acting as a better medium to transmit the spark from the tool to the work piece.

6.2.GRAPH BETWEEN PULSE-ON TIME VS MRR:

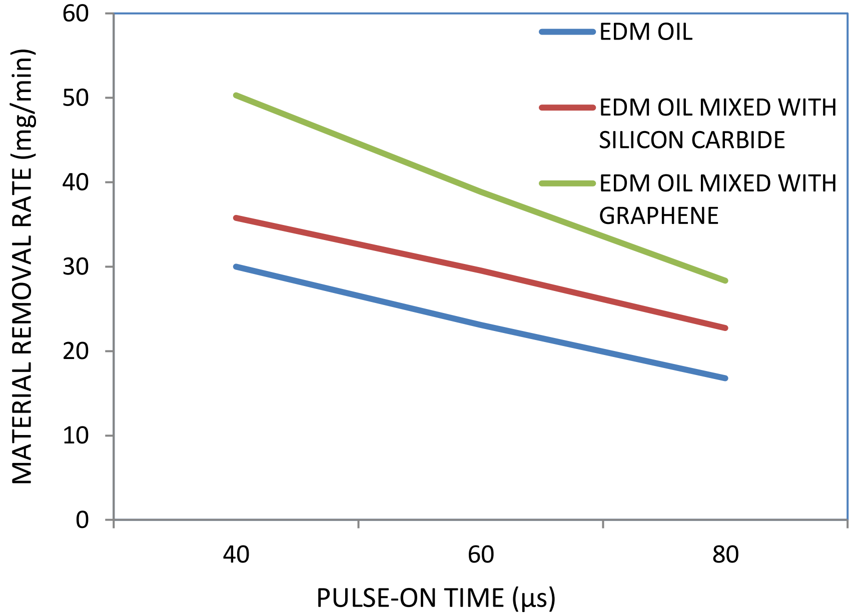

Figure 4. Grpah between Time vs MRR

The above graphical representation gives the comparison between the three setups. In this graph the Pulse-on time is plotted in the X-axis and the corresponding MRR value is plotted in the Y-Axis. The maximum MRR value that was recorded as 50.298 mg/min when the Pulse-on time was 40 µs and Graphene was mixed to the EDM oil. The next highest value of MRR was found to be 35.7692 mg/min when the Pulse-on time was at 40 µs and Silicon Carbide was mixed in the EDM oil. At 40 µs the MRR was found to be least (29.9918 mg/min) when no powder was added. It is clearly visible from the graph, the MRR decreases as the Pulse-on time increases. So from the graph it can be incurred that the MRR is indirectly proportional to the Pulse-on time. It can also be inferred that the addition of graphene considerably increases the MRR when compared to the other two setups. The gradual decrease in MRR with respect to T_{on} can be credited to deburr being formed in between the tool and the workpiece. As a result further removal of workpiece is slowed down, and thus MRR decreases.

6.3.GRAPH BETWEEN PULSE-OFF VS MRR

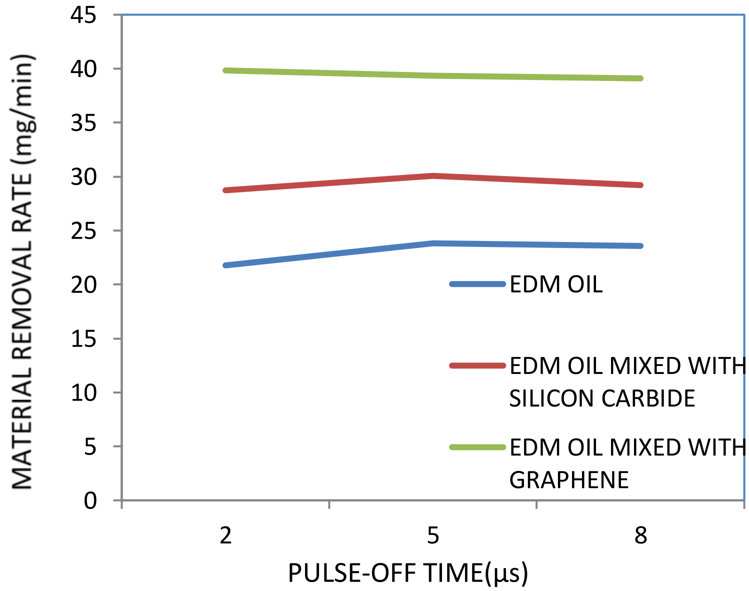

Figure 5. Grpah between Pulse vs MRR

The above graphical representation gives the comparison between the three setups. In this graph the Pulse-off time is plotted in the X-axis and the corresponding MRR value is plotted in the Y-Axis. The maximum MRR value that was recorded as 39.8325 mg/min when the Pulse-off time was 2 µs and Graphene was mixed to the EDM oil. The next highest value of MRR was found to be 28.7289 mg/min when the Pulse-on time was at 2 µs and Silicon Carbide was mixed in the EDM oil. At 2 µs the MRR was found to be least (21.7719 mg/min) when no powder was added. It is clearly visible from the graph that when graphene is added to EDM oil the MRR decreases constantly as the Pulse-off time increases. It can also be observed that the addition of Silicon Carbide increases the MRR to a particular value and then decreases gradually. The same trend can be observed when no powder is added to the EDM oil. The gradual increase in MRR with respect to T_{Off} can be credited to enough time being provided for the deburr to be carried away with the EDM oil that is being circulated.

CONCLUSION

From the experiments that were conducted on EDM, the following points can be concluded:

- ✓ The Aluminium Silicon Carbide work piece was made using the stir casting process and milling process was used in order to give the finishing.
- ✓ There were various parameters that were listed and out of those parameters, the parameters that were selected were: Peak Current (I), Pulse-on time (T_{on}), Pulse-off time (T_{off}) and Lift Time (LT).
- ✓ There were four parameters and three levels of the parameter were selected. Later by using Taguchi methods, the L9 set of experiments were selected and the experiment plan was framed.
- ✓ The MRR was found to be highest when graphene was added and the parameters were found to be Peak Current: 30A, Ton: 40µs, Toff: 8µs and Lift Time: 2s
- ✓ The TWR was found to be lowest when graphene was added and the parameters were found to be Peak Current: 10A, Ton: 80µs, Toff: 8µs and Lift Time: 3s
- ✓ The MRR was found to be second highest when Silicon Carbide was added and the parameters were found to be Peak Current: 30A, Ton: 40µs, Toff: 8µs and Lift Time: 2s
- ✓ The TWR was found to be Second lowest when Silicon Carbide was added and the parameters were found to be Peak Current: 10A, Ton: 80µs, Toff: 8µs and Lift Time: 3s
- ✓ Overall, the addition of graphene has influenced the Material Removal Rate and the Tool Wear Rate in the EDM machining process.

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