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Effects of Nanoparticles on the MRR and TWR of graphene-based Composite by Electro discharge Machining

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Abstract: In the current scenario, Graphene-based carbon fiber composite is highly used nanomaterial for the work-piece material that is employed in various applications (aerospace, automotive) due to its light weight, great strength, as well as high strength-to-weight ratio. In the experimental work, copper based tool electrode is used to remove the material. The work approach involves the four processing parameters of EDM such as input current (Ip), voltage gap (Vg), pulse on time (Ton) and pulse off time (Toff) which was used to evaluate the material removal rate (MRR) and tool wear rate (TWR). For optimization of MRR and TWR via processing parameters, Taguchi method was used in the experimental work. The L9 orthogonal array was generated using MINITAB 17 software. The work analysis approaches towards the different weight fractions of (0.1 and 0.3wt% of graphene) in carbon fibre composite for comparing the MRR and TWR. The effects of processing parameters on MRR and TWR via EDM oil and copper nanoparticles is examine. The MRR and TWR via Copper nanoparticle mixed EDM oil was observed to have the maximum and minimum value respectively as compared to normal EDM oil. The suitable value of MRR and TWR was observed with 0.3wt% of graphene in carbon fibre composite as compared to 0.1wt% of graphene via copper nanoparticle mixed EDM oil.

Keywords: Electro Discharge Machine, Material Removal Rate, Tool Wear Rate, Taguchi Method, MINITAB 17, Carbon fibre composite.

1. Introduction

In a non-conventional machining process, there is no direct contact between work piece and tool[1)]. Electro Discharge Machine (EDM) is used to create moulds, punches, dies, and automobile parts, among other things[2),3),4)]. EDM is used for hard materials and for complex shapes that are difficult to machine with conventional machining processes. Material is removed from the work piece in this procedure as a result of a high spark discharge between the work piece and the tool[5)]. In general, a very small space of 0.005mm is kept between the tool and the work piece[6),7)]. As shown in Figure 1, a DC pulse generator is used to convert the AC power into a high-pulsed DC power supply that is used for generating a spark between the work piece and the tool. The servo motor is used to control the feed rate of the tool. A spark occurs when the tool and work piece are in a very close position and the desired shape on the work piece is the opposite of the tool[8)]. Mineral oils, de-ionized water, and hydrocarbon oils are used to immerse the tool and work piece in dielectric fluid[9)]. Dielectric fluid isolates the work-piece and the tool from each other, reducing the heat generation between the tool and the work-piece. Normal EDM oil and Copper nanoparticles mixed EDM oil are used in this experimental work[10)]. Copper nanoparticles are mixed with normal EDM oil at a concentration of 12gm/litre and then sonication process is done for proper mixing of copper nanoparticles in EDM oil. The flushing of the dielectric is used to remove the suspended material from the work piece and tool and it avoids the adhesion of the suspended material to the work-piece and tool[11),12)]. The material is removed from the work piece due to erosion[13),14)]. Kumar et al. discussed the effects of powder particles on the machined surface of a work piece, powder particles from the tool electrode migrate to the machined surface and decrease voids and micro-crakes, and these powder particles help to obtain a better machined surface[15)]. Prasanna et al. discussed about the effects of various machining parameters such as input current, Ton, voltage gap, duty factor at different levels for material removal rate (MRR) and tool wear rate (TWR) for Ti-6Al-4V work piece material and tungsten copper composite was used as an electrode tool. The combination of process parameters for obtaining maximum MRR are: Gap Voltage 50, Peak Current 10 Amp., Ton 30 μs, Duty Factor 6% and for minimum

TWR, the combination of process parameters are: Gap Voltage 50 V, Peak Current 5 Amp, Ton 20 µs, Duty Factor 3%[16]. Angelos P. Markopoulos et.al investigated Aluminium alloy named as Al5052 was used as wok piece material and detailed study was carried out on MRR, Surface Roughness and average white layer thickness(AWLT) for various process parameters on on Electro discharge machine (EDM) by using ANOVA[17]. Wang et al. reported the effects of input parameters like to MRR, TWR and Surface Roughness (SR) and also discussed about the effect of different dielectric fluid (EDM oil and Al based oil). Iconel 706 is used as work piece and cu tool used as electrode. Iconel 706 has high corrosion resistance and high mechanical strength[18]. Gupta et.al the effect of input process parameters like input current, Ton and Toff for MRR, TWR and SR on AISI D2 Steel and Aluminium is used as tool electrode. It was found that most effective parameter for MRR is Toff and most influencing process parameter for TWR is input current and most affecting process parameter for SR is Ton[19].

The present work aim to calculate MRR and TWR of graphene based composite carbon fibre and copper tool based on the Input parameters (input current (Ip), voltage gap (Vg), pulse on time (Ton) and pulse off time (Toff)) by varying the dielectric fluid (EDM oil and Copper mixed EDM oil). the L9 standard orthogonal array is used to signify the input parameters and taguchi method is used for analysis of MRR and TWR. The variation in MRR and TWR by varying dielectric fluid is discussed in detail in this experimental work.

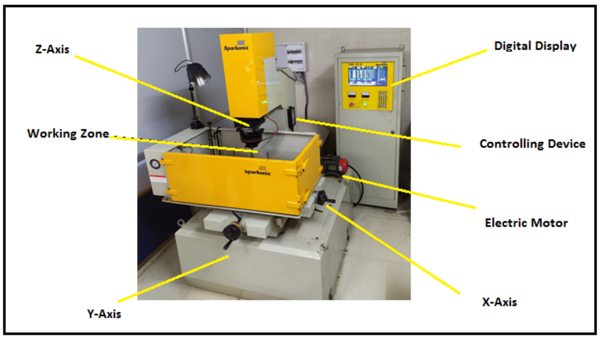

Figure 1: Shows the schematic representation of EDM working machine

2. Method and Materials

2.1 Experimental Setup

The Sparkonix ZNC electro discharge machine is used in this investigation. This is an electric discharge die-sinking machine. The Z axis of this machine is completely numerically controlled, with a movement of 250 mm, while the x and y directions have motions of 350 mm and 250 mm, respectively[20]. This machine is equipped with a flashing system with two nozzles.

In the experiment, EDM oil and copper nano-particle mixed EDM oil were used as dielectrics. Copper nanoparticles are mixed with normal EDM oil at a concentration of 12gm/litre and then sonication process is done for proper mixing of copper nanoparticles in EDM oil. First, we have performed experimental work with normal EDM oil and then using copper nano-particle mixed EDM oil. The L9 standard orthogonal array was employed in this work, which is a suitable array for three levels of parameter. The specified parameter and its level are displayed in the table. As shown in table 2, L9 offers sufficient and necessary information on the experimental nature and determines the effect of changing variables as well as the optimum technique for quality improvement during the experimental design process[21]. Table 1 and Table 2 represents the process parameters of EDM and standard L9 array used for experimentation respectively.

Table 1: For Process parameters and levels

Machining Parameters	**Level 1**	**Level 2**	**Level 3**
I/p current (Amp.)	3	5	7
Gap voltage (Vg)	50	60	70
Ton (µs)	90	120	150
Toff (µs)	4	5	6

Table 2: For std. L9 array for experiment

Exp. NO.	**Input current**	**Voltage gap**	**Ton**	**Toff**
1	3	50	90	4
2	3	60	120	5
3	3	70	150	6
4	5	50	120	6
5	5	60	150	4
6	5	70	90	5
7	7	50	150	5
8	7	60	90	6
9	7	70	120	4

2.2 Workpiece and Tool

As shown in figure 2, Graphene reinforced 14 layered nano composite carbon fibre is used as the work piece. Graphene increases the electric conductivity of the work piece material due the electric conductive nature of graphene nanoparticles. This developed material have light weight and high mechanical strength[22],[23] so this material widely used on light weight robots and in aerospace industry. Table 3 and Table 4 showcase the detailed description of work-piece and tool used in the experimental work. As shown in figure 3, As a tool electrode, copper is used. Copper tool electrode is connected to the positive terminal and acts as an anode.

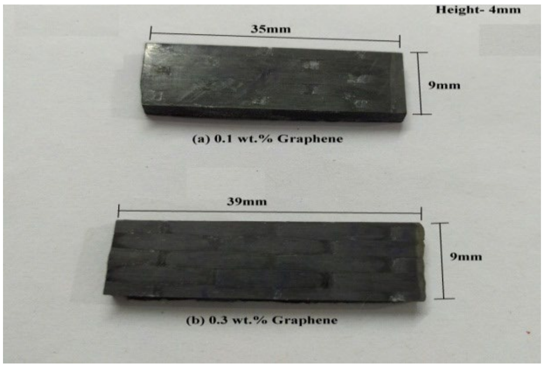

Figure 2: Shows the prepared work-piece of Graphene reinforced 14 layered nano composite carbon fibre

Table 3: Description of work piece material

S. NO.	Description
Carbon Fibre	T700
Hardener	HY5200
Resin	LY556
Density of Resin	1.20-1.29 g/cc
Graphene	AFMT (0.1 wt.% and 0.3 wt.%)
Size of work piece (a) and (b)	35×9×4 mm3 and 39×9×4 mm3
Number of carbon fibre layers	14

Figure 3: Shows the prepared Cupper Tool

Table 4: Tool Description

S. No.	Description
Diameter of working end	5mm
Diameter of holding end	10mm
Length	94mm

2.3 Fabrication and Methodology of MMC

In the fabrication process, Graphene reinforced 14-layered nanocomposite carbon fibre is used as the work-piece. The hand lay-up method is used to stack the carbon-epoxy and graphene layer, stacking at an orientation of 90. 14 layers has been stacked by this approach. Thereafter, hot press moulding is used to compress and compact each layer to form the graphene-interleaved CFRPs (carbon fibre-reinforced particles). The suitability of the hand layup method is evidence of the formation of graphene-interleaved CFRPs. The fabrication approach is listed in figure 4.

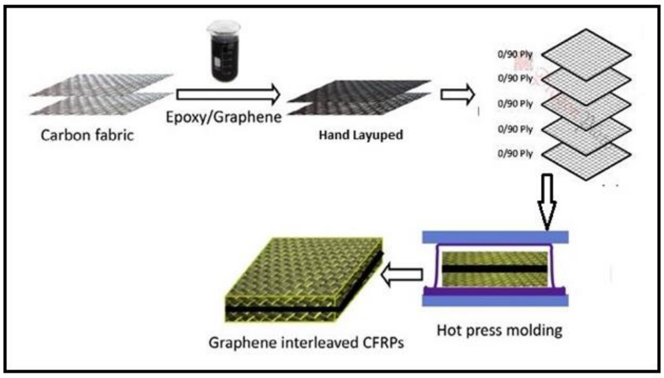

Figure 4 Fabrication process of Metal Matrix Composites

All the experimental work is conducted on graphene-based composite carbon fibre using copper as tool electrode[24),25)]. MRR and TWR were calculated from the experiments and the most influencing process parameters are observed[26)]. The effect of copper nanoparticles mixed in EDM oil had been observed with respect to Normal EDM oil. The Taguchi technique is a component of the design of experiment (DOE), and it is used to determine the smallest number of tests possible within factor and level constraints. Table 5 and Table 6 show tabular representation of MRR and TWR respectively for 0.1wt% of Graphene reinforced carbon fibre composite. The Taguchi technique, which shows the desirable (mean) and unwanted (standard deviation) values for output variables, is applied using the signal to noise ratio (S/N Ratio). Table 7 and Table 8 show tabular representation of MRR and TWR respectively for 0.3wt% of Graphene reinforced carbon fibre composite. Table 9 show tabular representation of signal to noise ratio for 0.1wt% and 0.3wt% of grapheme reinforced carbon fibre composite. L9 method is used over L27 which advantageous in obtaining the better results revealing the smaller number of experiments. Since the size of work-piece is small, therefore, the design of experiment is restricted to L9array, obtaining the comparable outcomes to L29 array.

Table 5: For Material Removal Rate (MRR) on 0.1 wt.% Graphene reinforced carbon fibre composite.

S NO.	Machining Time (minute)	Weigh (t using EDM oil) g		Weight (using cu mixed EDM oil) g		MRR	
		Before machining	After machining	Before machining	After machining	EDM OIL	Cu mixed EDM oil
1	10	3.4343	3.4127	3.1812	3.1564	0.00216	0.00248
2	10	3.4127	3.3892	3.1564	3.1290	0.00235	0.00274
3	10	3.3892	3.3638	3.1290	3.1005	0.00254	0.00285
4	10	3.3638	3.3372	3.1005	3.0719	0.00266	0.00286
5	10	3.3372	3.3065	3.0719	3.0397	0.00307	0.00322
6	10	3.3065	3.2813	3.0397	3.0121	0.00252	0.00276
7	10	3.2813	3.2459	3.0121	2.9778	0.00324	0.00341
8	10	3.2459	3.2164	2.9778	2.9477	0.00295	0.00303
9	10	3.2164	3.1873	2.9477	2.9162	0.00291	0.00315

Table 6: For Tool Wear Rate (TWR) on 0.1 wt.% of Graphene reinforced carbon fibre composite.

S NO.	Machining Time (minute)	Weigh (using EDM oil) g		Weight (using cu mixed EDM oil) g		TWR	
		Before machining	After machining	Before machining	After machining	EDM oil	Cu mixed EDM oil
1	10	29.34287	29.34257	29.33701	29.33672	0.030	0.029
2	10	29.34257	29.34224	29.33672	29.3364	0.033	0.032
3	10	29.34224	29.34194	29.3364	29.33611	0.030	0.029
4	10	29.34194	29.34165	29.33611	29.33583	0.029	0.028
5	10	29.34165	29.34136	29.33583	29.33554	0.029	0.029
6	10	29.34136	29.34107	29.33554	29.33525	0.029	0.028
7	10	29.34107	29.34079	29.33525	29.33497	0.028	0.027
8	10	29.34079	29.34048	29.33497	29.33468	0.031	0.029
9	10	29.34048	29.34022	29.33468	29.33443	0.026	0.025

Table 7: For Material Removal Rate (MRR) on 0.3 wt.% of Graphene reinforced carbon fibre composite.

S NO.	Machining Time (minute)	Weigh(using EDM oil) g		Weight (using cu mixed EDM oil) g		MRR	
		Before machining	After machining	Before machining	After machining	EDM OIL	Cu mixed EDM oil
1	10	3.5253	3.4976	3.2378	3.2045	0.00277	0.00333
2	10	3.4976	3.4678	3.2045	3.1698	0.00298	0.00347
3	10	3.4678	3.4422	3.1698	3.1407	0.00256	0.00291
4	10	3.4422	3.4113	3.1407	3.1028	0.00309	0.00329
5	10	3.4113	3.3757	3.1028	3.0691	0.00356	0.00387

6	10	3.3757	3.3465	3.0691	3.0372	0.00292	0.00319
7	10	3.3465	3.3090	3.0372	2.9983	0.00375	0.00389
8	10	3.3090	3.2735	2.9983	2.9619	0.00355	0.00364
9	10	3.2735	3.2387	2.9619	2.9272	0.00348	0.00347

Table 8: For Tool Wear Rate (TWR) on 0.3 wt.% of Graphene reinforced carbon fibre composite

S NO.	**Machining Time (minute)**	**Weigh (using EDM oil) g**		**Weight (using cu mixed EDM oil) g**		**TWR**	
		Before machining	**After machining**	**Before machining**	**After machining**	**EDM oil**	**Cu mixed EDM oil**
1	10	29.34022	29.33991	29.33443	29.33414	0.031	0.029
2	10	29.33991	29.33957	29.33414	29.3382	0.034	0.032
3	10	29.33957	29.33927	29.3382	29.33354	0.030	0.028
4	10	29.33927	29.33898	29.33354	29.33327	0.029	0.027
5	10	29.33898	29.33869	29.33327	29.333	0.029	0.027
6	10	29.33869	29.33839	29.333	29.33272	0.030	0.028
7	10	29.33839	29.33812	29.33272	29.33247	0.027	0.025
8	10	29.33812	29.3378	29.33247	29.33216	0.032	0.031
9	10	29.3378	29.33755	29.33216	29.33191	0.025	0.025

Table 9: Show signal to noise ratio of 0.1 wt% and 0.3wt% of Graphene reinforced carbon fibre composite.

S. No.	**0.1 wt.%**				**0.3 wt.%**			
	MRR using	**TWR using**	**MRR using Cu**	**TWR using Cu**	**MRR using**	**TWR using**	**MRR using Cu**	**TWR using Cu**
1	-53.3109	-30.4576	-52.111	-30.752	-51.1504	-30.1728	-49.5511	-30.752
2	-52.5786	-29.6297	-51.245	-29.897	-50.5157	-29.3704	-49.1934	-29.897
3	-51.9033	-30.4576	-50.9031	-30.752	-51.8352	-30.4576	-50.7221	-31.0568
4	-51.5024	-30.752	-50.8727	-31.0568	-50.2008	-30.752	-49.6561	-31.3727
5	-50.2572	-30.752	-49.8429	-30.752	-48.971	-30.752	-48.2458	-31.3727
6	-51.972	-30.752	-51.1818	-31.0568	-50.6923	-30.4576	-49.9242	-31.0568
7	-49.7891	-31.0568	-49.3449	-31.3727	-48.5194	-31.3727	-48.201	-32.0412
8	-50.6036	-30.1728	-50.3711	-30.752	-48.9954	-29.897	-48.778	-30.1728
9	-50.7221	-31.7005	-50.0338	-32.0412	-49.1684	-32.0412	-49.1934	-32.0412

3. Result and Discussion

The variation in material removal rate (MRR) using normal EDM oil and Cu nanoparticles mixed with EDM oil is shows in figure 5 and figure 7. It has been discovered that material removal rate has found to be significant increase via normal EDM oil and Cu mixed EDM oil. But the MRR rate for Cu mixed EDM is obtained to be higher as compared to normal EDM oil. The enhancement in the concentration of Cu nanoparticles in the dielectric developed the formation of cracks over the surface of work piece during the machining surface of the work piece. As a result of that, the continuous increase in the MRR is obtained to be higher for Cu nanoparticles.

The variation in Tool Wear Rate (TWR) using normal

EDM oil and Cu nanoparticles mixed with EDM oil is displays in figure 6 and figure 8. It is observed that It is observed that tool wear rate has found to be significant decrease via normal EDM oil and Cu mixed EDM oil. But the TWR for Cu mixed EDM is obtained to be lower as compared to normal EDM. The decrease in tool wear rate is often observed due to the formation of dielectric cracks that occurs on the work piece surface by increasing the concentration of Cu nanoparticles in the EDM oil. As a result, these nanoparticles help in removing the material from the machining surface of work-piece. Therefore, the tool wear rate is normally decreased with increase in the metal removal rate.

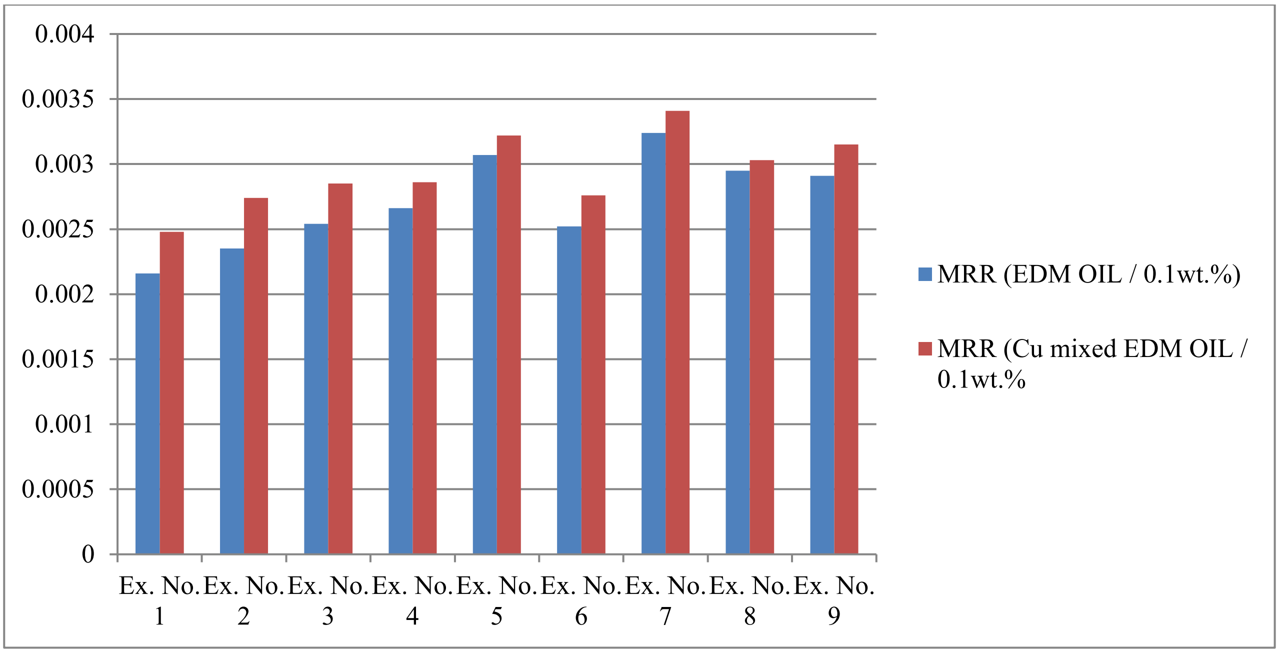

Figure 4: Shows the Comparison of Material Removal Rate using EDM oil and Copper nano particle mixed EDM oil (for 0.1 wt.%)

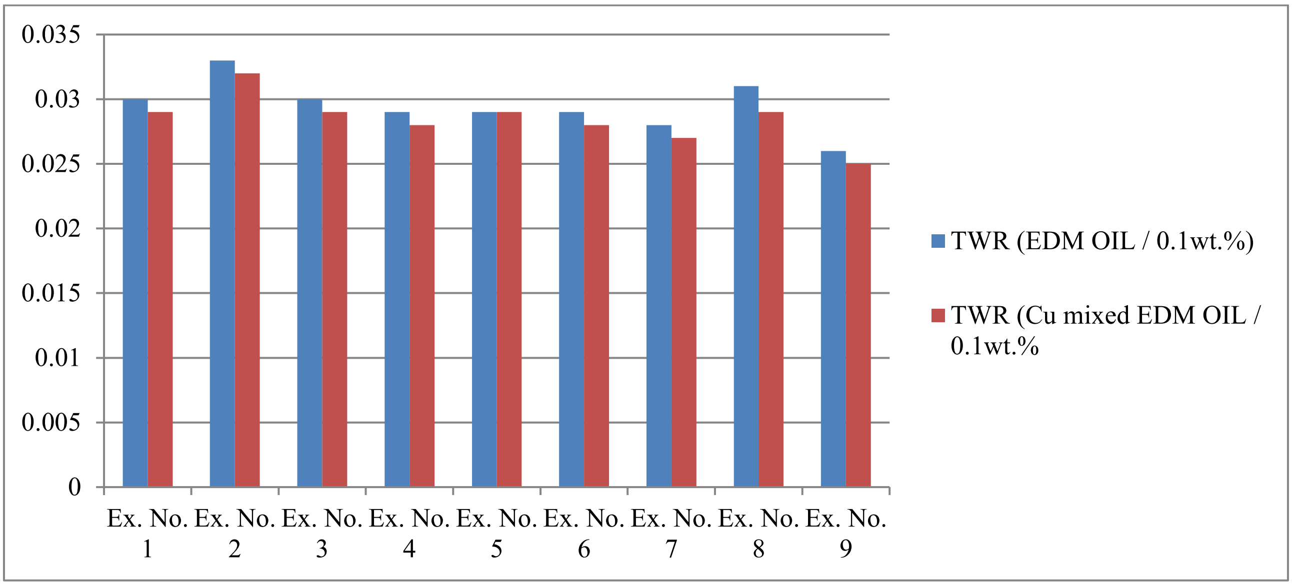

Figure 5: Depicted the Comparison of Tool Wear Rate using EDM oil and Copper nano particle mixed EDM oil (for 0.1 wt.%)

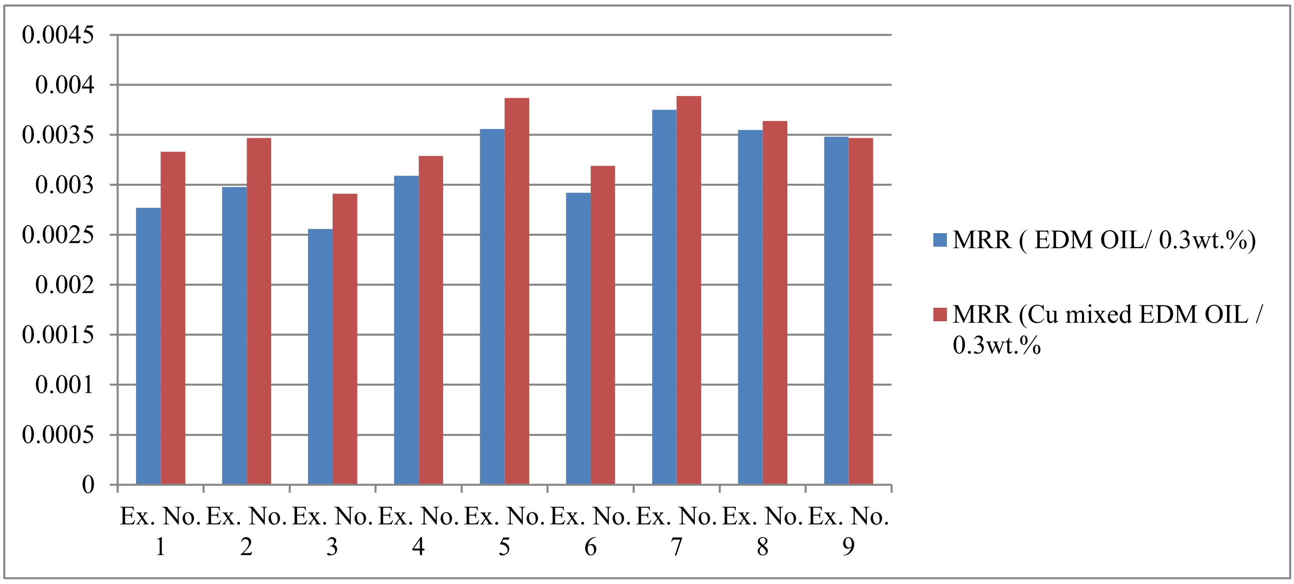

Figure 6: Showed the Comparison of Material Removal Rate using EDM oil and Copper nano particle mixed EDM oil (for 0.3 wt.%)

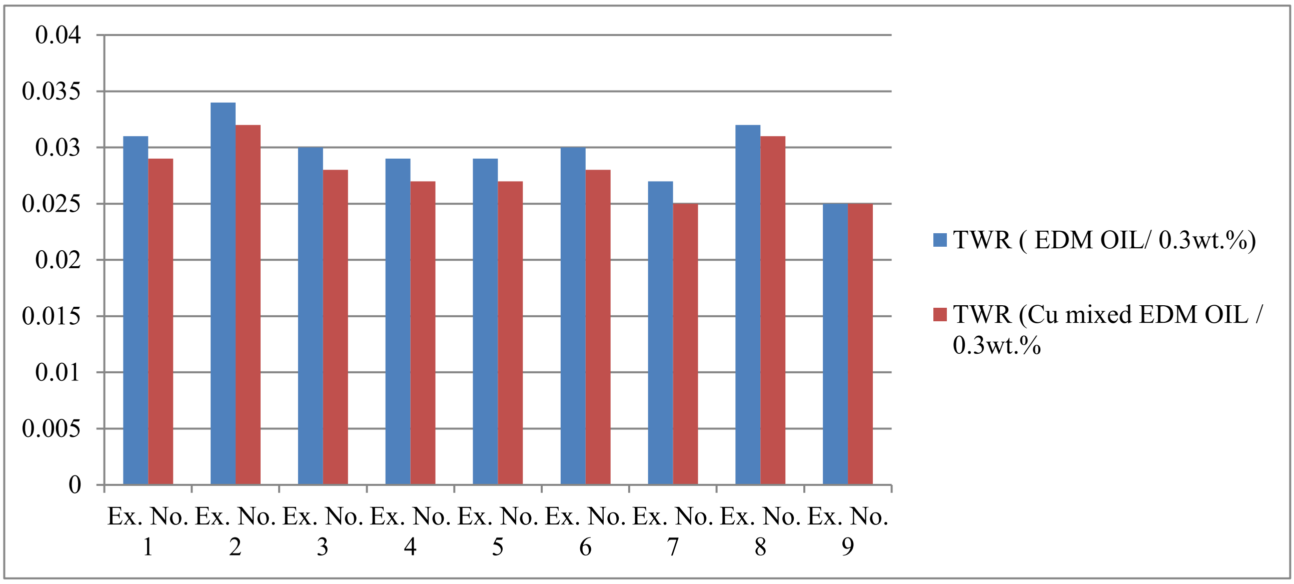

Figure 7: Displays Comparison of Tool Wear Rate using EDM oil and Copper nano particle mixed EDM oil (for 0.3 wt.%)

The variation in weight fractions of graphene in the carbon fibre composite is shows in figure 9 and figure 10. Graphene increases the electric conductivity of the work piece material due to the high electric conductive nature of graphene nanoparticles. Due to the increment in the weight percentage of graphene nanoparticles in the work piece, the electric conductivity of the work piece has been increased. Therefore, the higher electric conductivity of a work piece leads to an improvement in the material removal rate along with the gradual reduction in the tool wear rate. The increase in weight fraction of graphene is beneficial for reduction in tool wear rate and increase in metal removal rate.

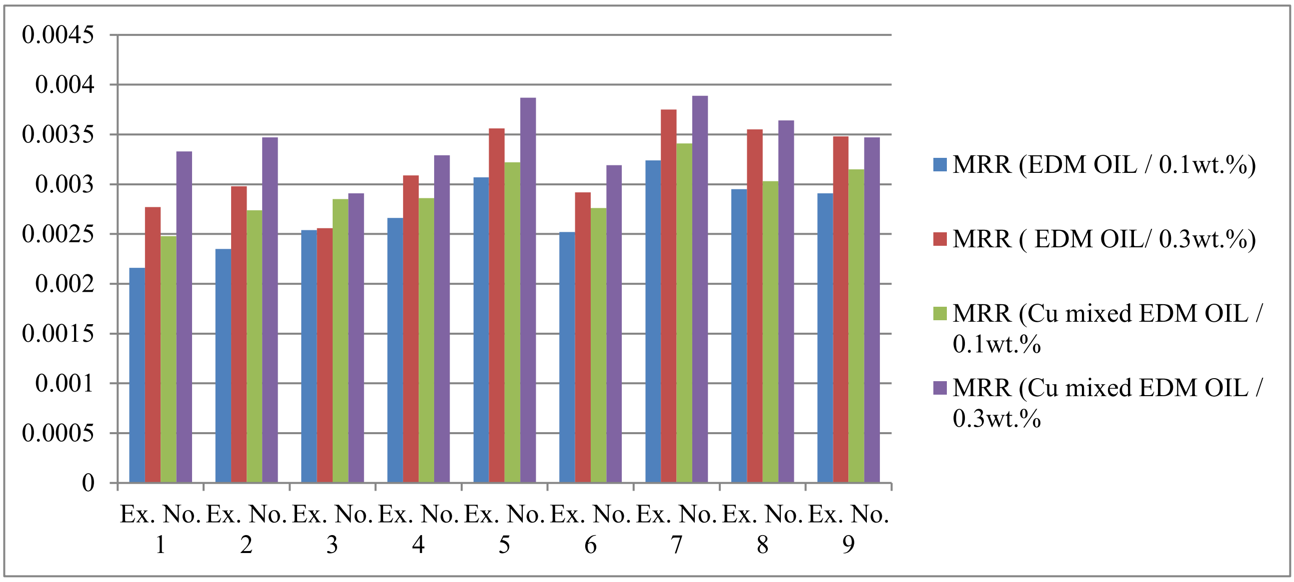

Figure 8: Showed the Comparison of Material Removal Rate for 0.1 wt.% and 0.3 wt.% of Graphene reinforced 14 layered nano composite carbon fibre via EDM oil and Copper nano particle mixed EDM oil.

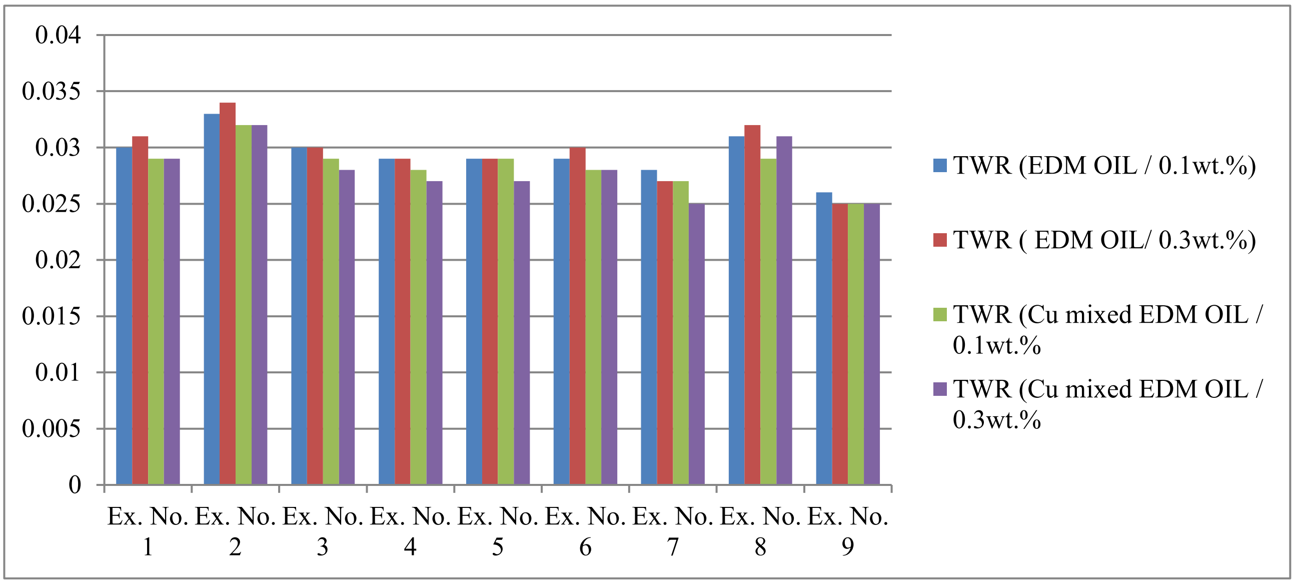

Figure 9: Showed the Comparison of Tool Wear Rate for 0.1 wt.% and 0.3 wt.% of Graphene reinforced 14 layered nano composite carbon fibre via EDM oil and Copper nano particle mixed EDM oil.

4. Conclusion

Graphene reinforced 14 layered composite material is used as the work piece in this study, and copper is used as the tool electrode. With successful accomplishment of the experimental work, the following conclusion had been drawn that are listed below:

- MRR has significant improvement with copper nanoparticles mixed in EDM oil as compared to normal EDM oil.
- The lower TWR is obtained with copper mixed nanoparticles in EDM oil as compared to normal EDM oil.
- MRR was increased by 5.24% after using copper nanoparticles mixed in EDM oil as compared to normal EDM oil.
- TWR was decreased by 3.84% after using copper nanoparticles mixed in EDM oil as compared to normal EDM oil.

5. Future outlook

Based on the literature survey, it has been examined that the variation of different weight fractions of graphene-based carbon composites along with the different dielectric fluid in order to evaluate the MRR and TWR is not illustrated elaborately. Therefore, the present work illustrates the variation of different weight fractions of graphene based carbon composites along with the different dielectric fluids. The effect on MRR and TWR is studied with different weight fractions along with different dielectric fluids.

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