

Experimental Study of Eco-friendly Wire-Cut Electrical Discharge Machining Processes

Arul Dass james.D¹, Dr.Boopathi.S²

PG Student, Department of Mechanical Engineering, Bannari Amman Institute of Technology, Sathyamangalam, India¹

Assistant Professor, Department of Mechanical Engineering, Bannari Amman Institute of Technology,
Sathyamangalam, India²

ABSTRACT: In the wire-cut electrical discharge machining (WEDM) process, the liquid dielectric fluid is replaced by the minimum quantity of liquid with the gas mixture, called near-dry WEDM. Near-dry WEDM exhibits the advantage of low environmental impact, good surface quality and machining stability at the minimum discharge energy input. This study reveals the development of new experimental setup of near-dry WEDM to achieve the good machining performance. The experiments have been conducted by mixing of minimum quantities of liquid with air (air-mist) and oxygen (oxygen mist) as a dielectric medium using HSS-M2 material. The Taguchi approach has been applied to investigate the effect of pulse width, pulse interval, inlet liquid-gas pressure and discharge-current on the MRR and surface finish. The low pulse width and pulse interval are identified as key factors for improving the surface finish. The pulse-width, liquid-gas pressure and discharge-current are experimentally found that the significant parameters for high MRR and fine surface finish. It is observed from the comparative study; the use of the oxygen- mist dielectric medium has the good machining performance than air-mist dielectric medium.

KEYWORDS: Near-dry WEDM, Air-mist, Oxygen-mist, Taguchi method, Material Removal Rate, Surface Finish

1. INTRODUCTION

In conventional WEDM, the de-mineralized water and kerosene based oil is used as a dielectric medium. The dielectric mediums are reacting with the eroded materials and producing the harmful smell to the operators. If the kerosene and water based dielectric fluids are used in electrical discharge machining (EDM), then it will produce harmful vapor (carbon monoxide, nitrogen oxide, xylene, formaldehyde and toluene) during the decomposing process (Leao, Fabio N. and Ian R. Pashby, 2004). Replacing liquid dielectric by gases and liquid-gas mixture is an emerging trend in the environment-friendly WEDM technology. The minimum numbers of research were conducted in dry and near-dry WEDM because of the problem of high thermal load, breakage of wire tool, low MRR and surface finish, the weld of the wire tool to the work piece and short-circuit problem. The first methodology in dry electrical discharge machining was reported by NASA (1984). This report elaborated the methods of electrical discharge drilling and wire cut EDM processes working under the dielectric mediums such as air, oxygen, nitrogen, argon and helium. M. Kunieda et al. (1991) compared the performance of EDM works under the gas and distilled water as the dielectric medium. The report showed that introducing oxygen gas in the discharge gap improves MRR in dry EDM. The high velocity of pure oxygen gas jet through a thin walled tube electrode improved the MRR in dry EDM. The subsequent study made by M. Kunieda and Y. Miyoshi (2003), revealed that strong oxidation in the sparking zone will improve the MRR by applying oxygen gas in dry EDM. Further, the author listed some advantages in the dry EDM that have no dielectric corrosion, high accuracy of cutting due to the low sparking gap and edge of the cut of the work material. It was found from the literatures that many numbers of investigators were trying to establish to improve the MRR without affecting the accuracy and surface roughness. M. G. Xu et al. (2009) proposed an improvement over dry EDM by applying ultrasonic vibrations to the work piece. A mathematical model for MRR in terms of process parameters (gap voltage, discharge current, pulse duration and pulse interval) was also developed. P. Govindan et al. (2010) investigated another method to improve MRR with zero tool wear rate by applying pulsating with the magnetic field. It is the hybrid dry

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EDM process in which high thermal and chemical energy in the work piece due to higher ionization and plasma confinement.

The near-dry EDM is the alternative method to achieve the high speed machining process with the best surface finish. In this concept, mixing of a minimum quantity of liquid (MQL) with the compressed air or gas is a dielectric medium. This process certainly improves the MRR, lower tool wear rate and good surface quality. C.C.Kao et al. (2007) conducted the experiments in the near-dry EDM drilling and WEDM and reported that good improvement in MRR and the elimination of debris deposition. The mathematical models were also developed for dielectric strength, spark gap, dynamic viscosity and water mixture ratio based on liquid and air properties. Tao Jia et al. (2008) conducted many experiments based on pure gases and mixing of gas like air, oxygen, nitrogen and helium with the water, de-ionized water, and kerosene. They also reported that the effect of different gases and liquid mixtures on the MRR and surface roughness. Masahiro Fujiki et al. (2009) developed the Computational Fluid Dynamics (CFD) model of dielectric fluid flow to predict the air-liquid mist flow rate, MRR and Ra in near-dry EDM milling. The experiments were conducted in near-dry wire-cut EDM and reported that the effect of the pulse width and pulse interval on the machining rate and surface roughness by the same authors. It is observed that only a few authors attempted to optimize the input process parameters in the dry and near-dry EDM. Sourabh K. Saha et al. (2009) developed an empirical model for the MRR and Ra and optimized using response surface method. Very recently, Y. Jia et al. (2010) investigated the near-dry milling EDM process to machine the satellite alloys and important output parameters of MRR, Ra and tool wear were optimized using response surface method. Later, the experiments were conducted in near-dry wire-cut EDM and reported that the effect of the pulse width and pulse interval on the machining rate and surface roughness by the same authors (2010). It can be observed from the fore mentioned literatures that still required the research in the dry and near-dry EDM to improve the performance of machining with low environmental impact. Generally, the conventional WEDM has the good machining speed with the stable process. However, the considerable environmental impact with high tool wear is the demerits of conventional WEDM. The dry WEDM is an unstable machining process with minimum MRR, poor surface finish. The main advantage of this process is the very low environmental impact during the process. The drawbacks of wet and dry WEDM process have been eliminated in the near-dry WEDM that yields better surface quality with considerable MRR, low tool wear, no chemical reaction of the dielectric fluid, less residual stress and no environmental impact. In this research, the near-dry WEDM system was developed and experiments have been conducted based on Taguchi design of experiments using air-mist and oxygen-mist dielectric medium. It is observed from the comparative study; the use of the oxygen-mist dielectric medium has the high machining rate than air-mist dielectric medium.

II. EXPERIMENTAL SETUP AND PROCEDURE

2.1. Experimental Setup

The near-dry experiments have been conducted on computer aided automatic fuzzy controlled CNC Wire-cut EDM machine. The hydro-pneumatic circuit (Figure 1) is used to perform the mixing of a minimum quantity of demineralized water with air/oxygen gas. It consists of an oxygen cylinder and a compressor, a fluid tank, bi-axial hose, a nozzle, flow control valves and the pressure gauges. This circuit has the capability to control the parameters of the near-dry medium in terms of liquid flow rate, oxygen/air pressure and outlet temperature by adjusting the oxygen and air pressure into the circuit. The outlet temperature of gas/air mist is maintained at 7°C at the nozzle outlet. The flow rate of mixing liquid with the gas medium has been measured by the amount of liquid collected in the vessel with respect to time using a digital stop watch. The flow rate of the liquid dielectrics constantly maintained at 7 ml/min while changing the air/oxygen gas pressure from 3 to 7 bar. The two separate hoses (bi-axial) of 8 mm and 3 mm diameter are used to pass the gas medium and liquid respectively. Air/oxygen gas and demineralized water are mixed together at the end of the bi-axial hoses. Then, air-mist/oxygen-mist is passed through the 2 mm outlet diameter of the nozzle. Thus, these are employed to provide the eco-friendly machining environment with cooling effect in the cutting zone and to flush-out the eroded materials. The experimental setup of the near-dry WEDM process is represented in the Figure 2. The material chosen for this study was HSS-M2 due to the growing application in the field of manufacturing aircraft components, dies and machine tool cutters. The HSS-M2 tool steel of 6 mm thickness as a workpiece and pure

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molybdenum wire of 0.18mm diameter as a wire tool are used. The near-dry machining conditions are summarized in the Table1.

Table1: Near-dry WEDM machining conditions

Wire tool	Material	99.95% Pure Mo
Work piece	Diameter	0.18mm
	Wire Speed	250 rpm
	Material Composition	High Speed Steel(HSS-M2)
Dielectric Fluid	Thickness	6.15W-5% Mo-4.15% Cr-1.85% V-0.85% C-0.30% Si-0.28% Mn-81.4% Fe
	Composition	6mm
	Flow rate	Air and Oxygen gas mixed with de ionized water
	Working Air pressure	7ml/min
	Temperature	3, 5 and 7bar
		7°C at Nozzle Outlet

2.2. Experimental Procedure

The rectangular path of cutting operation was performed on the workpiece by near-dry WEDM process. During the experiments, the time taken to cut the 20mm length of material removal is noted. Then, the volume of material removal rate is calculated using the dimensions of cutting path and time. Center line average (CLA) surface roughness parameter, Ra was used to quantify the surface roughness. Ra was measured using a contact type stylus-based surface roughness tester, C3A Mahr Perthometer (5µm stylus radius). The cutoff length of the surface roughness tester is 0.8mm and an evaluation length of 4mm was used. Raw as measured along four different paths on the work piece surface, and the average value was considered for further analysis.

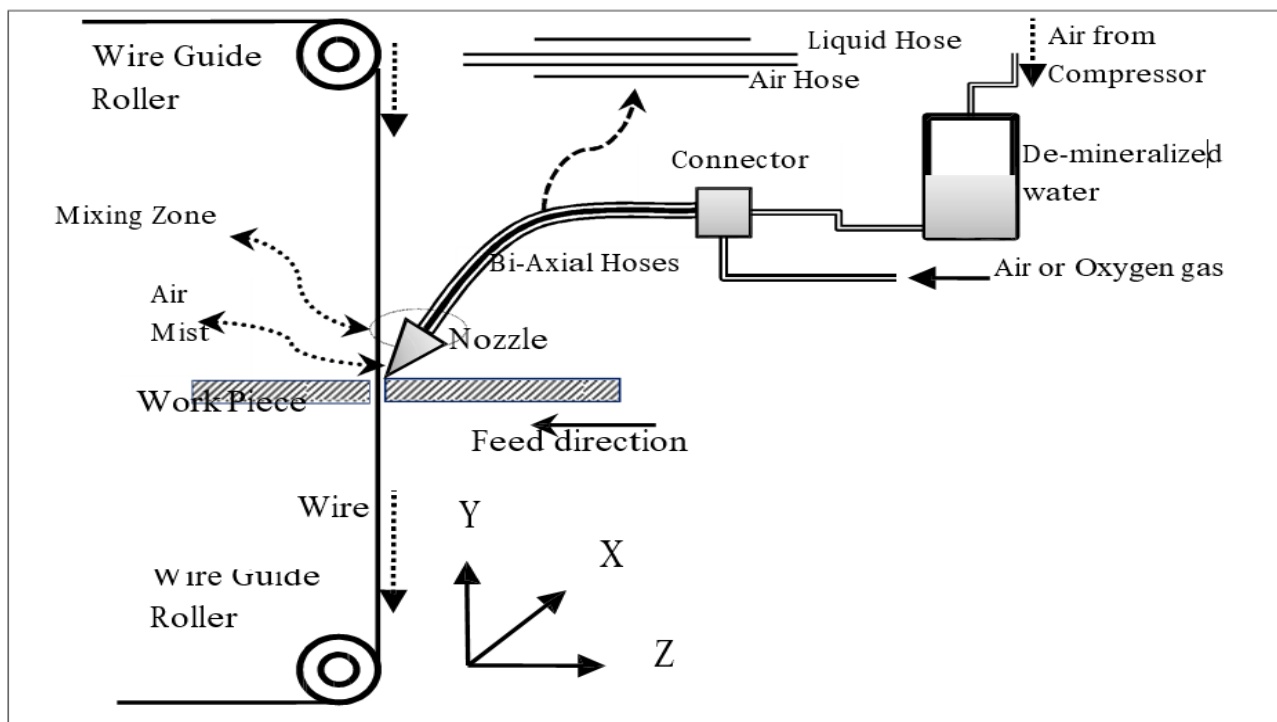


Figure1: Schematic diagram of hydro-pneumatic circuit for near-dry WEDM

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2.3. Plan of Experiments

Experiments were performed in two stages: first a set of exploratory experiments followed by the Taguchi design of experiments using air-mist and oxygen-mist dielectric medium. Exploratory experiments were conducted to select suitable appropriate values of parameters for the later stage experiments. Taguchi designs of experiments were then performed to systematically study the effect of various process parameters on MRR, surface roughness (Ra).

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2.3.1. Exploratory Experiments

Initial parametric studies of MRR and Ra have been made by considering one variable at a time (OVAT). By keeping all other variables at fixed average values, one variable at a time was varied and its effect on MRR and Ra has been studied. For each input parameter, experiments were conducted up to five different levels and a single run was performed at each level. Although the OVAT analysis does not give a clear picture of the phenomena over the entire range of the input parameters, it can highlight some of the important characteristics. This approach is helpful in deciding the range values of the levels of later stage experiments.

2.3.2. Design of Experiments

Taguchi method is a partial fractional method to conduct the experiments by consuming less time and Economic manner. Based on exploratory experiments, the levels of each parameter are selected for the Taguchi design of experiments (Lee,H.T.andJ.P.,Yur,2000).The mixed orthogonal array L18 (two levels for one factor and three levels for remaining four factors) have been chosen to evaluate the effects of machining parameters on performance characteristics (MRR and Ra) of this study.

Table2: Near-dry WEDM parameters and levels

Machining Parameter	Unit	Symbol	Level1	Level2	Level3
Gap voltage	Volt	V	75	100	-
Pulse-on time	µs	PW PI	4	8	12
Pulse-off time	µs Bar Amp	P	24	36	48
Air-Mist pressure		C	3	5	7
Discharge current			1.6	2.4	3.2

The values of the control parameters are assigned to the different level of L18 mixed orthogonal array as shown in Table2. The near-dry WEDM experiments are conducted using air-mist and oxygen-mist. The experimental results of near-dry WEDM are shown in the Table3.

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Table3: Experimental design and results using L₁₈orthogonal array

Exp. No.	Control Factor					Air-mist		Oxygen-mist	
	V	PW	PI	P	C	MRR	Ra	MRR	Ra
1.	75	4	24	3	1.6	0.891	1.14	0.891	1.30
2.	75	4	36	5	2.4	1.545	1.29	1.545	1.48
3.	75	4	48	7	3.2	1.363	2.23	1.363	2.59
4.	75	8	24	3	2.4	4.721	1.99	4.721	2.35
5.	75	8	36	5	3.2	6.673	2.23	6.673	2.63
6.	75	8	48	7	1.6	0.849	1.26	0.849	1.44
7.	75	12	24	5	1.6	2.147	1.58	2.147	1.83
8.	75	12	36	7	2.4	4.385	1.79	4.385	2.11
9.	75	12	48	3	3.2	5.836	2.32	5.836	2.75
10.	100	4	24	7	3.2	4.835	1.99	4.835	2.30
11.	100	4	36	3	1.6	1.292	1.41	1.292	1.60
12.	100	4	48	5	2.4	2.186	1.53	2.186	1.75
13.	100	8	24	5	3.2	9.008	2.42	9.008	2.81
14.	100	8	36	7	1.6	1.508	1.86	1.508	2.17
15.	100	8	48	3	2.4	4.863	2.68	4.863	3.17
16.	100	12	24	7	2.4	4.983	2.41	4.983	2.80
17.	100	12	36	3	3.2	7.565	3.05	7.565	3.56
18.	100	12	48	5	1.6	4.555	1.74	4.555	2.06

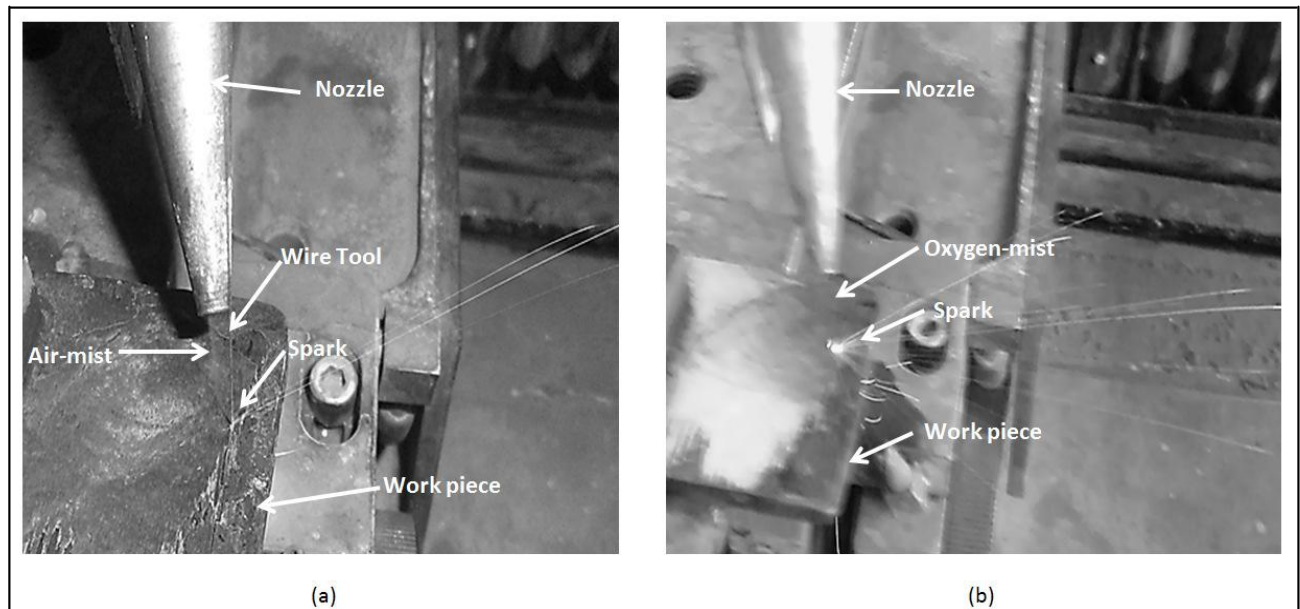


Figure2: a.Near-dryWEDMusingAir-mistdielectricmediumb.Near-dryWEDMusingOxygen-mist dielectric medium

III. RESULTS AND DISCUSSIONS

3.1. Effect of Working Medium Pressure

The inlet pressure of near-dry dielectric medium is an important parameter in near-dry WEDM process. The air-mist/oxygen-mist is used to provide the dielectric strength, cooling effect and drag-out the eroded material from the cutting zone. While increasing the pressure up to 5bar, the MRR and surface finish is improved. Further increasing the

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pressure, the MRR and surface finish values are reduced due to increasing the velocity of the medium in the cutting zone.

The high dielectric pressure restricts the transferring of spark between the wire tool and work piece due to the low spark thickness (0.2mm) and low contact area between the workpiece and the wire electrode. At the high pressure, the minimum of sparks are contributing to cut the work materials. The dragging-out of the sparks from the cutting zone is shown in Figures2a and 2b. The experimental analysis of Taguchi plot shows that the surface roughness is decreasing due to increasing pressure up to 5bar. After that, the Ra is increasing to higher value. Thus, the high surface finish is achieved at the moderate pressure and low surface finish at higher pressure. The significant moderate pressure is slightly varied by changing the di-electric medium and work material.

3.2. Effect of Gap Voltage

It is observed that the gap-voltage is a momentous factor for the MRR and Ra in the near-dry WEDM process as shown in Tables4 and 5. Since spark energy is proportional to the gap voltage, an increase in voltage would lead to a higher MRR. The MRR and Ra values are increased by increasing the gap voltage. The requirement of maximum MRR for the rough cutting operation can be accomplished with high gap-voltage. At the low gap voltage condition, the fine machining operation is possible with better surface finish.

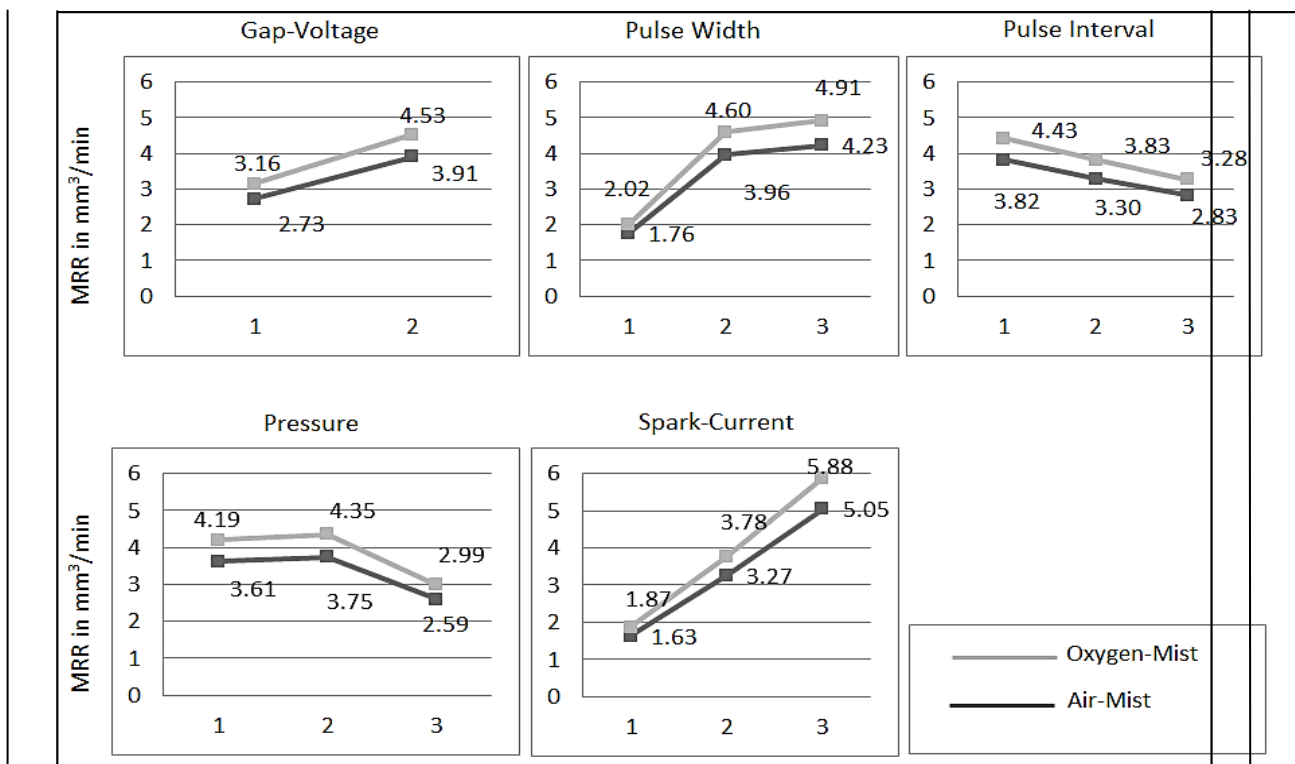


Figure3: Analysis of effect of machining parameters on MRR

3.3. Effect of Spark Current

The spark-current is also an important factor which affects the machining parameters of the near-dry WEDM process. The sparking strength is an impact factor on the MRR, and it is increased by the input current. It has the proportional effect on MRR and inverse effects on the surface finish. While increasing the spark current, the MRR is increasing and surface finish is getting down. For the finishing cut requirement, the low spark current can be used .In MRR aspect, at the same spark current, the oxygen-mist has better performance than air-mist working medium.

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Table4: Mean Input Parameters Response for MRR

Parameter	Air-mist dielectric					Oxygen-mist dielectric				
	Level1	Level2	Level3	Delta	Rank	Level1	Level2	Level3	Delta	Rank
Gap-Voltage	2.054	2.470	-	0.416	3	3.157	4.533	-	1.376	3
Pulse-on time	1.838	2.429	2.519	0.682	2	2.019	4.604	4.912	2.893	2
Pulse-off time	2.233	2.259	2.294	0.062	5	4.431	3.828	3.275	1.156	5
Pressure	2.456	2.094	2.236	0.362	4	4.195	4.352	2.987	1.365	4
Spark Current	1.734	2.278	2.774	1.040	1	1.874	3.781	5.880	4.006	1

Table5: Mean Input Parameters Response for Ra

Parameter	Air-mist dielectric					Oxygen-mist dielectric				
	Level1	Level2	Level3	Delta	Rank	Level1	Level2	Level3	Delta	Rank
Gap-Voltage	1.760	2.122	-	0.362	3	2.054	2.470	-	0.416	3
Pulse-on time	1.599	2.074	2.149	0.550	2	1.838	2.429	2.519	0.682	2
Pulse-off time	1.923	1.939	1.961	0.038	5	2.233	2.259	2.294	0.062	5
Pressure	2.099	1.799	1.924	0.300	4	2.456	2.094	2.236	0.362	4
Spark Current	1.499	1.949	2.374	0.875	1	1.734	2.278	2.774	1.040	1

3.4. Effect of Pulse Width

Taguchi analysis shows that the pulse width is one of the most important input parameter. The MRR of the near-dry WEDM is significantly increased by increasing pulse width. However, the surface finish is decreasing due to increasing the pulse width. Better surface finish cutting is achieved with minimum MRR at the low pulse width rate.

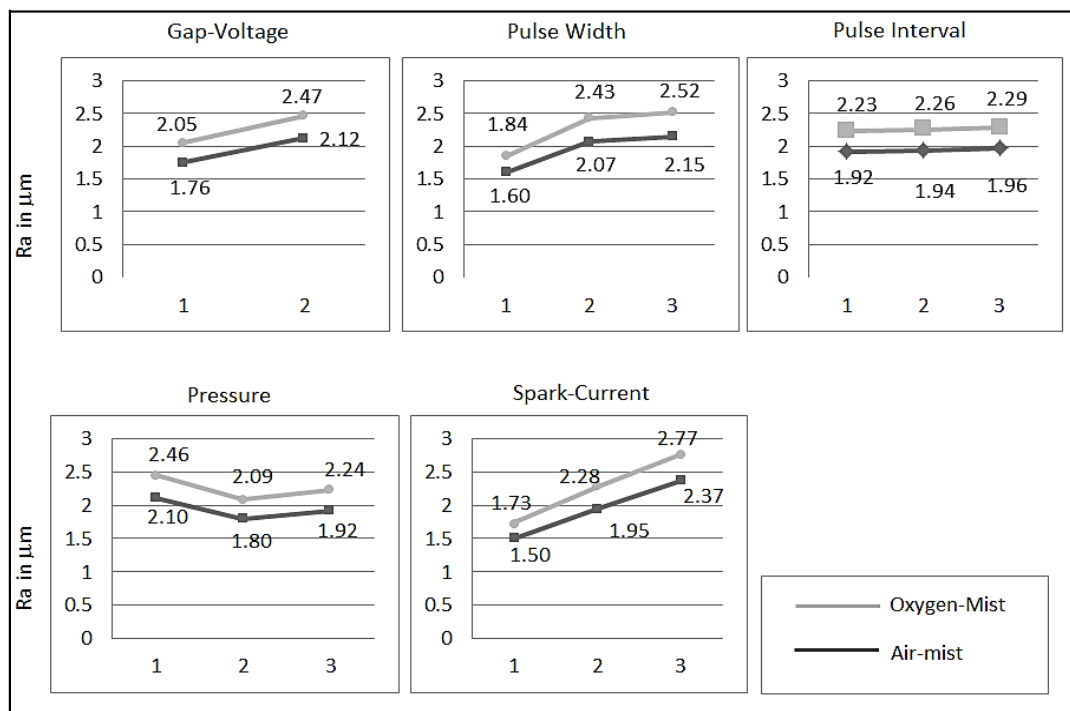


Figure 4: Analysis of effect of machining parameters on Ra

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3.5. Effect of Pulse Interval

From Taguchi approach, it is found that the pulse interval is the least significant factor in the near dry WEDM process. The MRR and surface finish are improved due to reducing the pulse interval .Better surface finish is attained from the minimum value of the pulse interval.

3.6. Comparative Study: Air-Mist verses Oxygen-Mist Medium

The parametric effect of the each individual factor on the MRR and Ra are similar to both (air-mist and oxygen-mist) near-dry dielectric medium as shown in Figures3and4. The oxygen-mist dielectric medium is accelerating the thermal erosion process due to oxidation in the cutting zone. The surface finish of the air-mist di-electric medium is better than oxygen-mist dielectric medium. However, the MRR is higher in oxygen-mist than air-mist dielectric medium. The improvement of MRR of oxygen- mist is 19.8% than air-mist dielectric medium. Conversely, the surface finish of work material in the air-mist dielectric medium is 17.38% higher than the oxygen-mist near-dry WEDM processes. For the requirement of eco-friendly machining with high MRR in WEDM process, the oxygen mist medium is preferred. For the need of fine surface finish in near dry WEDM process, the air-mist dielectric medium is suggested through this experimental study. These comments are established from the Taguchi parametric comparative study plots as shown in Figures5aand5b.

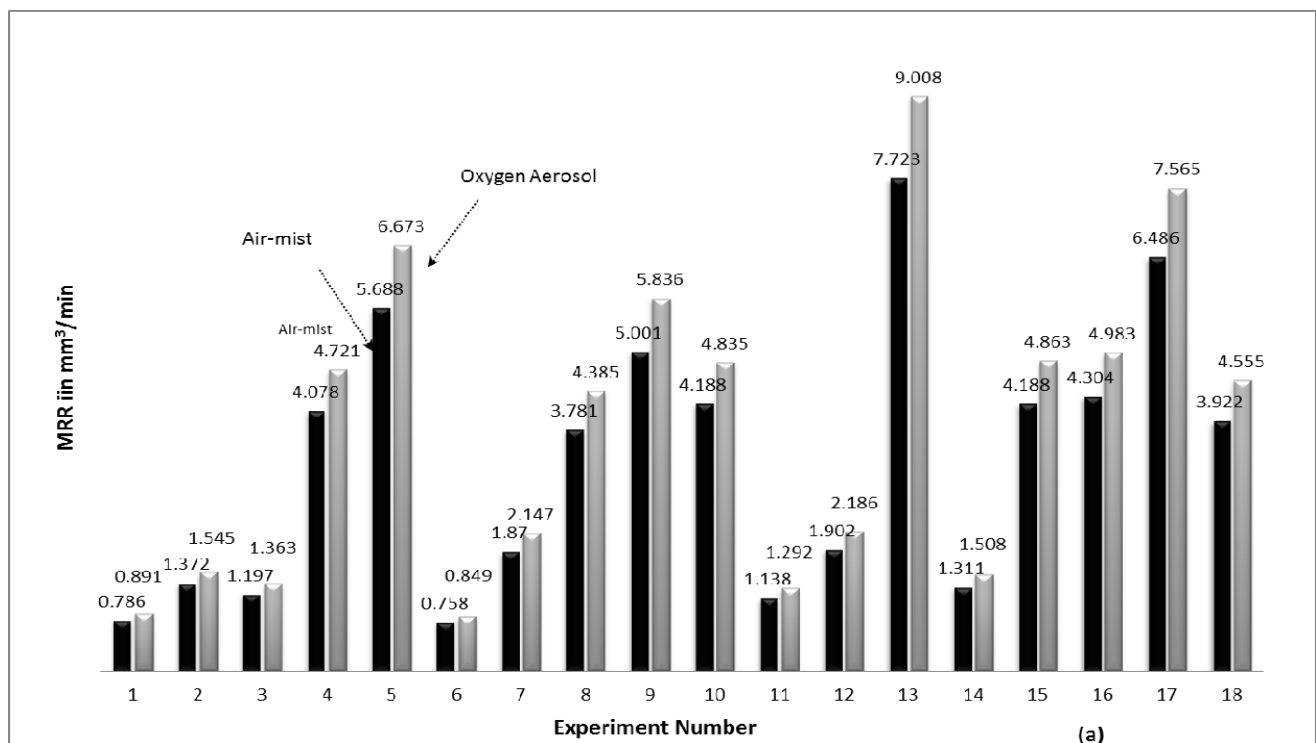


Figure 5a: Comparative Analysis between Air-mist and Oxygen-mist Dielectric medium on MRR

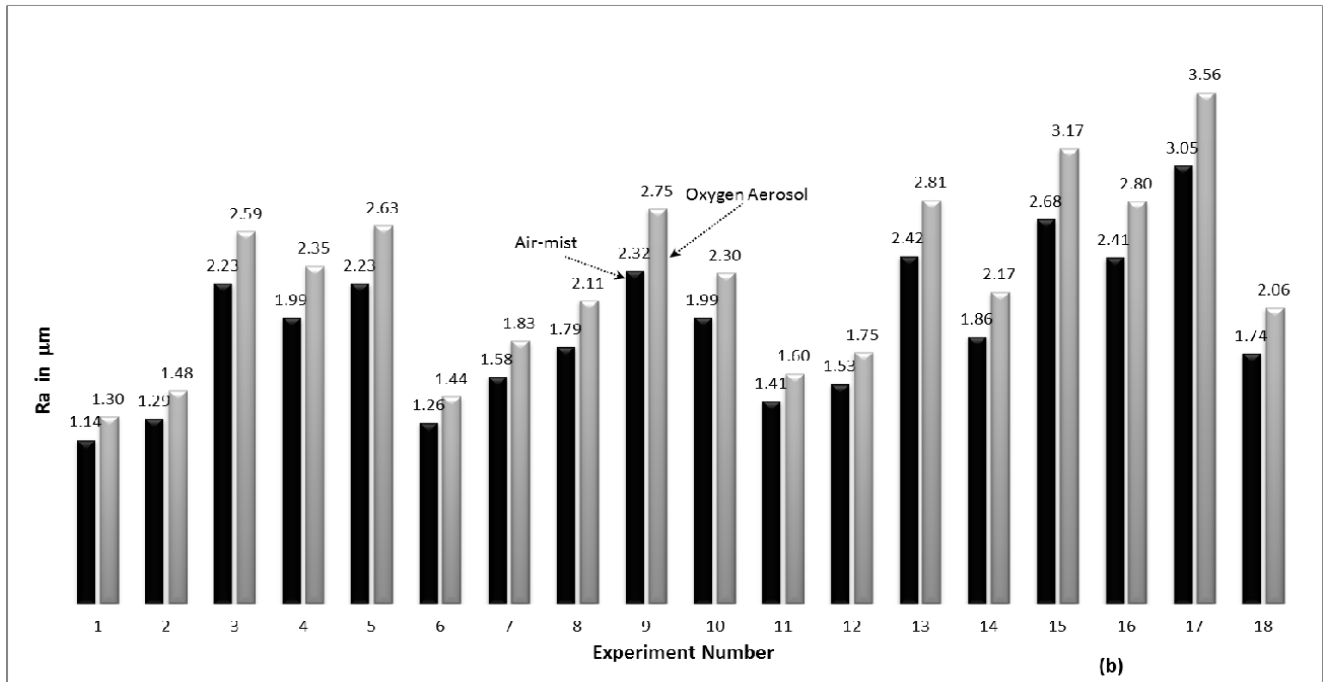


Figure 5b: Comparative Analysis between Air-mist and Oxygen-mist Dielectric medium on Ra

IV. SUMMARY AND CONCLUDING REMARKS

- In this research, the emerging near-dry WEDM experimental performance has been first presented based on Taguchi design of experiments using air-mist and oxygen-mist. It is a stable eco-friendly machining process to produce the higher degree of surface finish with considerable material removal rate.
- The gap-voltage, pulse-width, air-mist/oxygen-mist pressure and discharge current are the significant parameters of near-dry WEDM identified by Taguchi analysis.
- The important result was observed from the investigation that the good machining speed and surface finish could be achieved in the moderate air-mist/oxygen-mist pressure. The high velocity of this medium restricts the transferring the sparks between the wire tool and work piece at the maximum pressure.
- The material chosen for this study was HSS-M2 due to the growing application in the field of manufacturing aircraft components, dies and machine tool cutters.
- From the comparative study, the MRR of the oxygen-mist near-dry WEDM process is 19.8% higher than air-mist dielectric medium. However, the surface finish of the oxygen-mist medium has 17.38% lower than air-mist dielectric medium in the near-dry WEDM process.

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