Abrasive Assisted Electrical Dischargemachining: An innovative hybrid approach

S. Wankhade[1*], B. Dabade[2] and M. Khond[3]

[1] AISSMS College of Engineering, Pune, India
[2]SGGS College of Engineering, Vishnupuri, Nanded, India
[3]College of Engineering, Pune, India
{shwankhade@aissmscoe.com}

Abstract: The Electric Discharge machine (EDM) has evolved from a nontraditional machining process and positioned itself in industries as a most indispensable conventional machine. It is multipurpose and excels with ability of precisely producing difficult-to-machine, geometrically complex component of any hardness. Low material removal rate (MRR) restricts its productivity. Abrasive Jet Machine (AJM), another versatile process acquires edge of quick set up and rapid machining of virtually any material. Key advantage is that it do not cause any heat affected zone; is flexible and able to machine hard and brittle materials. The major limiting factor is that the process produces a tapered cut.Hybridization is an approach to tackle more than one process in order to add their advantages and avoid the limitations. This paper proposes an indigenously developed hybrid system to take advantage of the best part of each of the above processes. The appropriate abrasives are routed along with compressed air through the hollow electrode to construct the hybrid process of AJM and EDM i.e. Abrasive Assisted Electric Discharge Machining (AAEDM). An attempt is made to study the benefits of the hybrid process over the standard EDM and results are verified by confirmation experimentation. The main process parameters were varied to explore their effects on material removal rate and surface integrities. The experimental results show that the hybrid process of AAEDM can enhance the machining efficiency and the developed hybrid process can fit the requirements of modern manufacturing challenges.

Keywords: ***Hybrid Machining, Electrical Discharge Machining, Abrasive Jet Machining, Material Removal Rate, Abrasive Assisted EDM***

1 Introduction

Electrical Discharge Machining (EDM) and Abrasive Jet Machining (AJM) are extensively being employed in industries and hence seeking the interest of researchers. The development of a hybrid machining process makes use of the collective or jointly benefiting results of the two or more individual processes, this furthermore evade or atleast reduce some adverse effects produced by the elementary processes [1-3]. With the evolution of hybrid machining processes, the productivity is reported to be increased in multiples than the individual processes. A small number of them have been studied and made known to be very effectual in machining novel and advanced materials.

As depicted in the Fig. 1, the base of triangle stands for kind of interaction, that is Thermal [Electron Beam (EB), Plasma Beam (PB), Laser Beam (LB) and Electrical Discharges (ED)]; Electrochemical (EC) and chemical (CH); Mechanical [Abrasion (A), Cutting (C), Ultrasonic Wave (US) and Flow Fluid action (F)].

A method termed as Powder-mixed EDM (PMEDM) uses abrasives in certain composition, grit size and concentration in the dielectric liquid and is accomplished to impart better machined surface upto mirror finish without cracks and pores [4-6]. To ascertain the presence of abrasives in the machining region a stirrer is constantly required. In attempt of maintaining the efficiency of stirring the system becomes complex, hence a method is evolved in which the abrasives are routed with compressed air directly to the machining area and is termed as Abrasive Assisted Electrical Discharge Machining (AAEDM). This process is developed wherein the electrode is made hollow and apposite vents are provided so as the abrasives remain present in the spark zone during entire machining [7,8].

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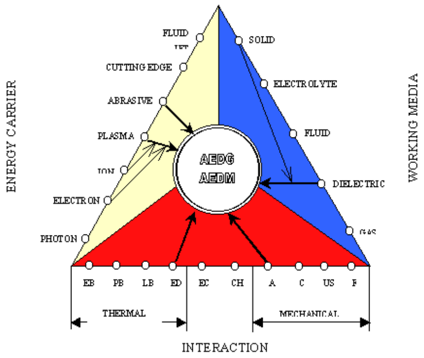

Fig. 1. Diagram of principle of Abrasive Assisted EDM [1]

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Extensive literature and field survey was performed for selection of workpiece material. The selected work piece material for research is Aluminium and is selected due to its growing range of applications in manufacturing, and its limitations to be machined by EDM has undesirable drawbacks; shops try to avoid the process especially if they also cut steel or graphite. One major problem in machining Aluminium with EDM is the large volume of debris particles created during the process which can quickly clog an EDM filtration system. The particles created are very small and very hard. They shorten the life of certain types of filter media and cause the filter cartridges to be changed more often. Disposal of filters bearing these particles is costly. It is difficult to recycle these particles (if remained in dielectric fluid) and can interfere with the cutting of other materials or contaminate the workpiece surfaces. The use of abrasives in dry air poses several health hazards [9]. In this view AAEDM is expected to increase MRR and provide solutions to overcome the limitations of EDM, AJM and Aluminium machining..

2 Experimental Work

Experiments are conducted on AGIEPULS Die Sinking EDM machine (manufactured by Electronica Machine Tools Ltd., India in collaboration with AEGIS, Switzerland). An attachment is designed and developed as shown in Fig. 2 for routing the abrasives through the hollow cylindrical tool electrode with the help of compressed air at a pressure 0.3 kgf/cm2. A fixture was designed for easy, quick and accurate mounting of workpiece. A separate tank and pump was installed for feeding the dielectric fluid.

The electrode material used for these experiments is Electrolytic Copper, which is of hollow cylindrical shape of 18mm diameter with positive polarity. Two holes were drilled at the base at an angle of 450 from vertical axis, in such a way that they are fused in the cylindrical hole as shown in Fig. 3. The Aluminium alloy (6082) workpieces used were of cylindrical shape having 20 mm diameter and 15mm length. Commercial grade EDM oil (specific gravity = 0.763, freezing point= 94˚C, IPOL Lubricants make) was used as dielectric fluid. The Al2O3 abrasives of 80 and 280 mesh sizes were routed through the hollow electrode with help of a compressed air at a pressure 0.3 kgf/cm2. The machining was performed upto the depth of 1.6mm. A Spark test was performed on ‘Solaris CCD plus’ and the composition of Aluminium (6082) and Electrolyte Copper was ascertained.

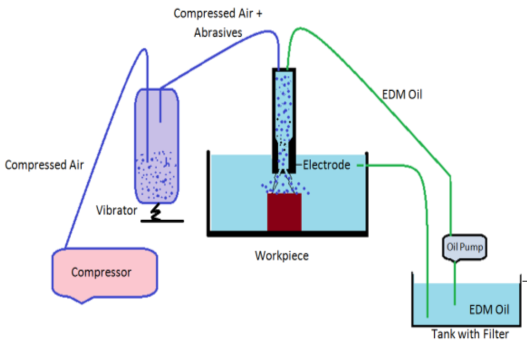

Fig. 2. Schematic of AAEDM process

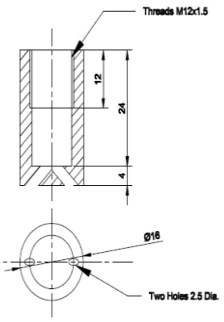

Fig. 3. Schematic of electrode

2.1 Experimental investigations

On the successful fabrication and assembly of the experimentation set up, initial tryout operations were performed, through which it was ascertained that the factors worth consideration were Peak Current (I_p), Pulse on Time (T_{on}) and Duty Factor (τ). Other factors under consideration to be varied were Gap voltage and Compressed air pressure used to carry the abrasives to the sparking zone, but it was realized that these factors need to be set at a constant value in order to attain stable sparking in the AAEDM process. The abrasive grains used are selected on the basis of field survey which is commercially used in industries and manufactured by Grindwell Norton Ltd. It was observed from pilot experiments that the major effect on MRR is of the factor Peak current (I_p). Manifesting the same, appropriate values for screening operations were identified and finalized as given in Table 1.

Table 1 Factors and levels for screening experimentation

SN	Factor	Unit	Levels
1	Pulse Current (I_p)	A	5, 10, 15
2	Pulse on time (T_{on})	µs	100, 120, 140, 160, 180, 200
3	Duty factor (τ)	%	60, 75, 85

For each level of factor Ip, 18 experiments were conducted as per Table 1. Three sets of repetition were done to crease out the variations. The MRR and Tool Wear Rate (TWR) are calculated as

$$MRR(gm/min) = \frac{(Ww_i - Ww_f)\ gm}{(machining\ time)\ min}$$

$$TWR\ (\%) = \frac{(Tw_i - Tw_f)\ gm}{(Ww_i - Ww_f)\ gm}\ x\ 100$$

Ww_i = *Initial Weight of Workpiece* Tw_i = *Initial Weight of Tool*

Ww_f = *Final Weight of Workpiece* Tw_f = *Final Weight of Tool*

3 Results and Discussion

The experiments were performed and the study was undertaken to understand the benefits of Abrasive Assisted EDM over Standard EDM.

3.1 Material Removal Rate

The experiments reveal the performance of the Abrasive Assisted EDM with respect to the Standard EDM. Results are plotted depicting the Values of MRR for StdEDM v/s AAEDM_WAlOx90 (Abrasive Assisted EDM using White Aluminium Oxide abrasives of 90 mesh size) in Fig. 4 and Values of MRR for StdEDM v/s AAEDM_WAlOx220 (Abrasive Assisted EDM using White Aluminium Oxide abrasives of 220 mesh size) in Fig. 5. As shown in the plotted graphs in Fig. 4 and Fig. 5, inferences are derived and framed in order of increase in Pulse Current.

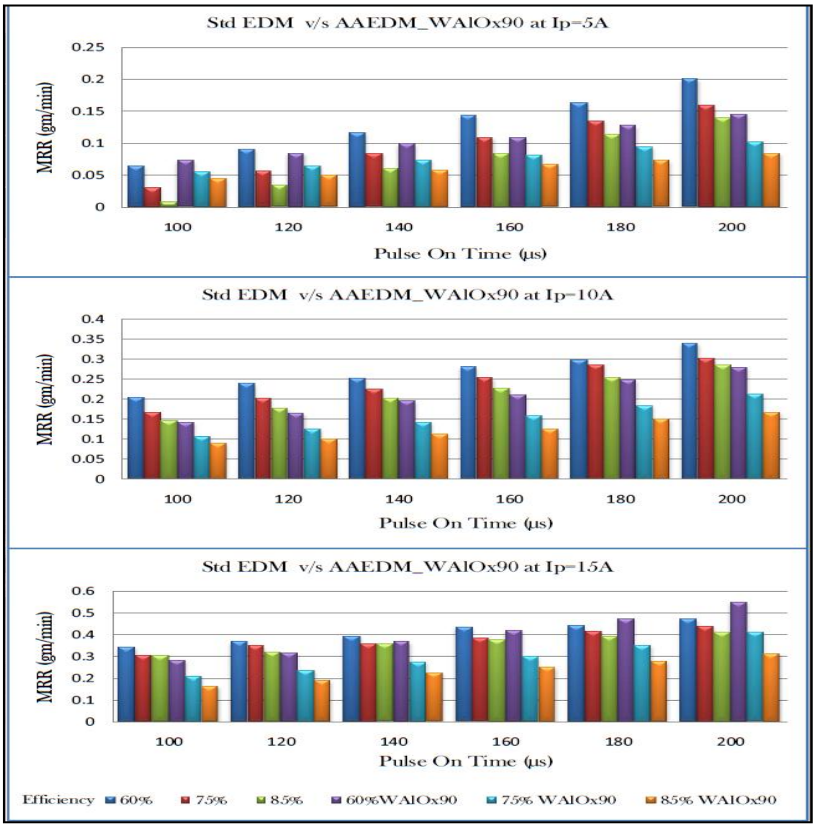

Fig. 4. Values of MRR for StdEDM v/s AAEDM_WAlOx90

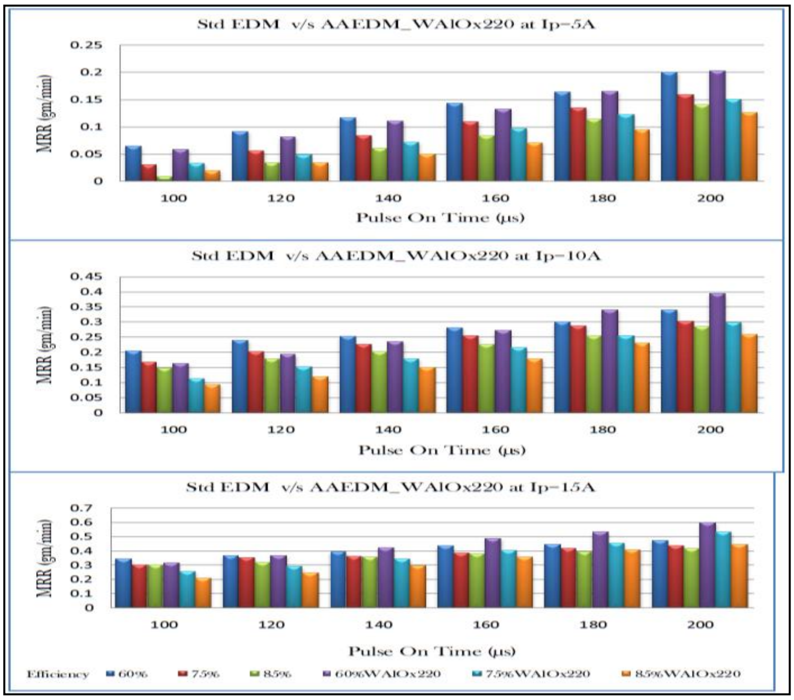

Fig. 5. Values of MRR for StdEDM v/s AAEDM_WAlOx220

A. At low Ip (5 A):

The Abrasives WAlOx90 seems to have negative effect on the MRR; it is difficult for discharge strength to overcome the high resistivity of White Aluminium Oxide (WAlOx) abrasives. However the MRR at T_{on} = 100 µs is more than StdEDM; as at lower T_{on}, the spark gap is less, and powder being coarser, did not flow in more quantity to the sparking zone. Though in fewer amounts, these abrasives could perform abrasion action on the workpiece. As the Duty factor increases, the temperature in the sparking zone also increase, which cause more metal melting, which gets swayed away by the abrasives.

While in the AAEDM_WAlOx220 the pattern of effect of increase in Duty factor results in the reduction of MRR is very consistent with StdEDM. The MRR till T_{on} = 160 µs is lower for AAEDM, as the fine powder in the smaller spark gap entered in large amount causing high resistivity, absorbing the spark discharge and hence leaving less energy for actual material removal. As the T_{on} increases beyond 180 µs, the spark gap increases and the small sized abrasives caused the secondary spark, this along with larger time for swaying and abrasion improved the MRR of AAEDM.

B. At Ip = 10 A:

AAEDM_WAlOx90: The trend of Duty factor being inversely proportional to the MRR still follows. Rather, magnitude of reduction in MRR with increase in Duty factor is more because abrasives being coarse have less flowability hence get accumulated in sparking zone causing unstable discharge condition. The MRR of StdEDM is observed to be better than the AAEDM throughout the experimented range. The reason still lies with the coarseness of the abrasives. At I_p = 10 A, the spark gap increases, which causes more abrasives to flow in the spark zone. These abrasives having coarse grain size cause hindrance in sparking by the virtue of its high resistivity and low flowability. The discharge strength is not enough to overcome the resistance offered by the abrasives. Further the low flowability makes abrasives and debris get accumulated in the spark gap.

AAEDM_WAlOx220: The MRR of AAEDM at I_p = 10 A is lower as compared to the StdEDM till T_{on} = 140 µs, as the discharge strength is lost in overcoming the resistivity offered by the abrasives, the smaller sized abrasives get accumulated in larger amount in the narrow spark zone. As the T_{on} move up beyond 160 µs, the spark gap increases and with the flow the abrasion and swaying action of molten metal gets facilitated along with the better spark discharge. This results in the observed linear rise in MRR.

C. At Ip = 15 A:

AAEDM_WAlOx90: It is observed that for I_p = 15 A, the AAEDM has low MRR as compared to the StdEDM till T_{on} =160 µs. High current caused increase in Spark gap and this enhanced the larger amount of abrasive to enter the spark zone, causing more resistivity to overcome. As the T_{on} increases beyond 160 µs, the MRR at low Duty factor increases. Now the discharge pulse will be of longer duration and this increased pulse time offers more time for material removal to occur. This extended time tenders more opportunity to abrasives for abrasion and swaying of molten metal without letting it adhere back to the workpiece surface.

AAEDM_WAlOx220: Higher peak current (I_p = 15A) brings down the threshold of overcoming the resistivity of abrasives to 120 µs. Later, on account of higher spark gap due to larger T_{on} for the causing longer discharge pulse duration in result offering more time for material removal to occur. This extended time sources more opportunity to abrasives for abrasion and swaying of molten metal without letting it adhere back to the workpiece surface.

To understand the statistical significance of predictors ANOVA was performed. P–value in ANOVA revealed the significance of factor. It is observed that the majorities of P-values are lower than chosen alpha value (0.05%) and hence are significantly contributing in determining the MRR. The Residuals vs. Fit analysis revealed that the AAEDM processes generate unbiased coefficient estimates through minimum variance.

3.2 Tool Wear Rate

It is observed in AAEDM_WAlOx90 that for lower T_{on} the TWR is more and vice versa. The coarse abrasives having high resistivity cause weak discharge. At lower T_{on} the spark gap is less and abrasive flow is not smooth hence the process becomes unstable causing more abrasive action on the tool. At higher T_{on}, the spark gap increases facilitating smooth flow of abrasives resulting in lesser abrasive action on tool. This elucidates the reduced TWR at higher T_{on}. With the increase in I_p, the TWR reduces for the same set of T_{on} and τ. The abrasive being coarse, the resistivity is overcome only after 160 µs. After this point the TWR starts diminishing as the spark gap increases and tool abrasion is reduced.

It is observed in AAEDM_WAlOx220 that the trend of increase in TWR with increase of τ at low value of T_{on} is same in StdEDM as well as AAEDM_WAlOx220. It is found that the value of TWR is low at low τ and high at high τ. Higher τ causes more discharge energy therefore the spark gap is increased marginally, this increases the flow of fine abrasives in sparking zone. At the same time the higher τ results in low interval time between consecutive pulses, leaving less time for the dielectric strength recovery after the deionization of the plasma generated by the previous discharge [10]. This causes unstable sparking, resulting in turbulent gap condition and therefore more abrasion of tool.

3.3 Taguchi Analysis

The signal-to-noise (S/N) ratio is calculated for each factor level combination. For optimizing the response Material Removal Rate, the larger-is-better S/N ratio is used. The analysis is carried out using Minitab® 17.1.0. For the purpose of observing the degree of influence of the process parameters on Standard EDM and that of Abrasive Assisted EDM for abrasive grains; three factors, each at three levels, are taken into account as shown in Table 2.

Table 2 Process factors and levels for Taguchi analysis

SN	Variable/ Factor	Unit	Levels		
			1	2	3
1	I_p	A	5	10	15
2	T_{on}	µs	100	150	200
3	τ	%	60	75	85

The ranking, relationship of factors towards attaining maximum MRR, the effect of individual factors and interactions as well as the setting parameters for accomplishing higher MRR are studied and summarized in the Table 3. The AAEDM processes were studied and the parameters were characterized by Response Surface Methodology (RSM); wherein all the parameter settings along with the various abrasive grain media were varied and the results were observed.

Table 3 Ranking of the AAEDM processes based on MRR

Ranking	AAEDM Process	I_p (A)	T_{on} (µs)	T (%)	MRR	TWR
1	WAlOx220	15	200	60	0.589	0.581
2	W AlOx90	15	200	75	0.446	0.193
3	Std EDM	15	200	75	0.427	3.447

3.4 Confirmation Experiments

Confirmation experiments are designed and conducted in order to validate the findings and conclusions drawn through the statistical analysis. These experiments serve the purpose of testing the best combination of factors and their level to demonstrate the validity of the levels derived from the designed Taguchi experiments. The testing condition for the confirmation was so selected that the desired response (MRR) should be at its highest and the detrimental(TWR) at the lowest maintaining the level of the factors at the levels defined earlier by S/N ratio in Taguchi Experiments. Three confirmation experiments were conducted at the optimum setting of the process parameters. The values of the performance characteristics MRRand TWR were recorded and are found to be shown in Table 4. The most influential parameters for maximizing the MRR and minimizing the TWR have been identified using the Taguchi and experimentally verified by conducting confirmation experiments.

Table 4 Confirmation experiments on optimum setting of process parameters

AAEDM Process	I_p (A)	T_{on} (µs)	τ (%)	Material Removal Rate (gm/min)				Tool Wear Rate (%)			
				R1	R2	R3	Mean	R1	R2	R3	Mean
WAlOx220	15	200	60	0.546	0.589	0.531	0.555	0.603	0.661	0.621	0.628
WAlOx90	15	200	75	0.501	0.483	0.453	0.479	0.092	0.096	0.102	0.097
Std EDM	15	200	75	0.433	0.402	0.436	0.424	3.921	4.011	4.203	4.045

4 Conclusions

1. AAEDM is a robust method and results in better MRR than Standard EDM
2. The TWR in Hybrid AAEDM is monitored and found lesser than the StdEDM process
3. From all the studied processes, it is principally ascertained that the MRR increases with the increase in Peak Current and Pulse on Time, while the Duty Factor exhibited inverse effect
4. As compared to Standard EDM, Hybrid AAEDM with WAlOx220 and WAlOx90 abrasives gives 31% and 13% better MRR respectively

5. Hybrid AAEDM with WAlOx220 gives better MRR than that with WAlOx90 due to its finer particle size which happens to overcome the resistivity better
6. Less Pollution as increase in MRR reduces use of EDM oil
7. Simple and low cost of implementation
8. More profit to EDM job-shops
9. The health hazards due to inhalation of dry abrasive powders are avoided.

References

[1]. K. P. Rajurkar Cross Process Innovation http://www.columbia.edu/cu/mechanical/mrl/ntm/CrossProcess.htm (2008)

[2]. K. P. Rajurkar, D. Zhu, J. Mcgeough, J. Kozak, "New Developments in Electro-Chemical Machining", *CIRP Annals-Manufacturing Technology,* 48(2), (1999) 567-579.

[3]. J. Kozak, K. P. Rajurkar, "Hybrid machining process evaluation and development", *2nd International conference on machining and measurements of sculptured surfaces,* (2000) 501-536. Krakow.

[4]. P. Pecas, E. Henriques, "Influence of silicon powder-mixed dielectric on conventional electrical discharge machining". *International Journal of Machine Tools and Manufacture,* 43(2003) 1465–1471.

[5]. H. T. Lee and T. Y. Tai, "Relationship between EDM parameters and surface crack formation", *Journal of Materials Processing Technology*, 142(2003) 676-683.

[6]. F. Zhao, Z. Lu, H. Wang, and Z. Qian, "Research on effecting mechanism of particles in powder-mixed EDM", *Journal of Dalian University of Technology,* 45(2005) 668–671.

[7]. S. H. Wankhade and S. B. Sharma, "Study of Hybrid machining of Electrical Discharge and Abrasive Jet Machining", International Colloquium on Materials, Manufacturing and Metrology, ICMMM (2014) 307-308. Chennai, India: IIT Madras.

[8]. S. H. Wankhade and S. B. Sharma, "Study of Productivity and surface Quality of Hybrid EDM", Journal of Institution of Engineers (India): Series C, 97(2016) 71-76.

[9]. C. Winslow, L. Greenburg & D. Greenberg. *The dust hazard in the abrasive industry.* Public Health Report (1919).

[10]. M. Kunieda, B. Lauwers, K. Rajurkar, B. Schumacher, "Advancing EDM through fundamental insight into the process", *CIRP Annals-Manufacturing Technology*, 54(2005) 64-87.