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ELECTROCHEMICAL SPARK MACHINING: A HYBRID MACHINING PROCESS

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Abstract

Precision machining of electrically non-conducting or partially conducting engineering materials is an urgent need of present industries. Machining of these materials by conventional methods is a serious problem yet to be resolved. Some of the advanced machining processes that can be used for machining these materials. But these processes have their own limitations too. Electro Chemical Spark Machining (ECSM) process is an effective spark-based hybrid machining method suitable for machining of low machinability, high strength electrically conducting as well as non-conducting materials. This paper reports regarding the Electro Chemical Discharge Phenomenon, Mechanism of Electro Chemical Spark Generation and Material removal mechanism of ECSM operation.

Keywords: Electro Chemical Spark Machining (ECSM), Material Removal Rate (MRR), Electro Chemical Discharge (ECD), Electro Chemical Spark Generation, Hybrid Machining.

Introduction

Hybrid machining processes, which are combination of two or more machining processes, have attracted special interest in the field of machining advanced engineering materials. These processes are developed to exploit the potential advantages and to restrict the disadvantages associated with an individual constituent process. Usually the performance of hybrid process is better than the sum of their constituent processes performance with the same parameter settings. In some of these processes, besides the performance from individual component processes, an additional contribution may also come from the interaction of the component processes. Table-1 shows the major hybrid machining processes either used in industries or under development stage.

Hybrid machining processes are either electrical energy based (called as Electrical Hybrid Machining Processes) or mechanical energy based (called Abrasive Hybrid Machining Processes). Table-2 shows the classification of hybrid machining processes based on their energy sources, material removal mechanism, tool used and medium in which process is performed. Electrical Hybrid Machining Processes are conceived to overcome the major limitation of ECM and EDM in which tool and work piece are required to be electrically conducting and also to increase the productivity. Electrochemical arc machining (ECAM) and electrochemical spark machining (ECSM) are such hybrid machining processes in which the phenomenon of electro-chemical discharge is employed for material removal from electrically conductive and nonconductive materials respectively. In ECAM, discharge takes place between the tool and the work piece due to breakdown of entrapped hydrogen gas bubbles causing erosion of both the electrodes. The productivity of ECAM is reported to be 5 to 50 times greater than the productivity using individual process of ECM and EDM. On the other hand, in ECSM the discharge takes place (in the form of desirable sparks) between the tool and the surrounding electrolyte in the vicinity of the electrically non-conducting material work piece.

These processes have been successfully applied for the machining of soda lime glass, borosilicate glass, quartz, glass fiber reinforced plastics, and ceramics. These processes can be used for hole drilling, die sinking and wire cutting for machining/cutting of composites and partially conducting ceramics. ECAM/ECSM is specifically effective when dealing with materials with tensile strength higher than 1500 N/mm^2 and heat resistance alloys. Machining capacity of the order of 104 mm^3 /min, accuracy of 0.04 -0.02 mm and surface roughness of Ra= 1.25-2.5 mm are obtained. Ultrasonic assisted electro-chemical machining (UAECM) and ultrasonic assisted electro-discharge machining (UAEDM) are developed by combining ultrasonic machining (USM) with ECM or EDM respectively. UAEDM has been found to increase MRR and grinding ratio while lowering grinding forces for hard materials like WC and TiB_2. Hot machining has also been tried on advanced materials. Softening of materials by localized heating with aid of a plasma jet or a laser beam facilitates substitution of grinding by other machining processes that are less expensive.

The abrasive hybrid machining processes are developed by combining EDM, ECM, or USM with abrasive machining, and they are most commonly used in industries. These can be classified in three main subgroups: Electro-Discharge Abrasive Machining (EDAM), Electrochemical Abrasive Machining (ECAM) and Electro-Chemical Spark Abrasive Machining (ECSAM). Electro-chemical Abrasive Grinding (ECAG), Electro-Discharge Abrasive Grinding (EDAG) and Electro- Chemical Abrasive Honing (ECAH) use abrasive tool with metallic bond. Electro-Chemical Abrasive Finishing (ECAF), Electro-Discharge Abrasive finishing (EDAF) and Ultrasonic Assisted Electro-Chemical Machining (UAECM) use free abrasive grains.

Electro-chemical Abrasive Grinding (ECAG) with metal bonded rotating abrasive tool is a combined process of mechanical grinding and ECM. An increase in performance index of this process is due to improvement in surface layer properties and reduction in tool wear and energy consumption. ECAG is particularly effective for machining parts made of difficult to cut materials, such as sintered carbides, creep resisting alloys (e.g. Inconel and Nimonic), metallic composites (e.g. PCD-Co, Al-SiC, Al-Al_2CO_3), etc. In this process, about 90% of the material is removed by electro-chemical means and rest by abrasion. Better surface finish can also be obtained after machining non-homogeneous materials like cemented carbide. The quality of surface machined by this process is independent of mechanical properties of work piece. Since the dimensional accuracy obtained in ECAG is not as good as in conventional grinding, it is normal practice to finish components with no-electro-chemical material removal (or zero current).

Electro-discharge abrasive grinding (EDAG) is a hybrid machining process involving EDM and Grinding. The combination of metal bonded diamond grinding and EDM is the only one so far experimentally successful hence more specifically this hybrid process is called as Electro-discharge diamond grinding (EDDG). In this process, synergetic interactive effect of electro-discharge action and abrasion action are employed to increase machining performance. The electrical discharges of EDDG cause considerable decrease in grinding forces, and grinding wheel wear, and also effectively resharp the grinding wheel. The abrasive action in this process helps to increase metal removal rate (MRR) and surface quality. The EDDG of advanced engineering materials has been found to be feasible and advantageous.

Table 1 Interaction of different machining processes to develop a hybrid-machining process

		THERMAL PROCESSES				**CHEMICAL AND ELECTRO-CHEMICAL PROCESS**		**MECHANICAL PROCESSES**			
		EDM	LBM	EBM	PBM	CHM	ECM	ABRASION (A)	USM	FLOW (F)	CUTTING (C)
THERMAL PROCESSES	EDM	**EDM**					ECSM ECAM	EDAG	UAEDM		
	LBM		**LBM**			LAE	LAECM		UALBM		LAT
	EBM			**EBM**							
	PBM				**PBM**						PAT
CHEMICAL AND ELECTRO-CHEMICAL PROCESSES	CHM		EALBM			**CHM**		EEM		CHP	
	ECM	ECSM ECAM	LAECM				**ECM**	ECAG/ ECAH	UAECM		

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MECHANICAL PROCESSES	ABRASION (A)	EDAG				EEM	ECAG	**AM**	UAG		
	USM	UAEDM	UALBM				UAECM	UAG	**USM**	UAP	UAT
	FLUID FLOW (F)					CHP			UAP	**FFM**	
	CUTTING (C)		LAT		PAT				UAT		**CUTTING**

AM: Abrasive Machining

CHM/CHP: Chemical Machining/ Chemical Polishing
EALBM: Etching Assisted Laser Beam Machining
EBM: Electron Beam Machining
ECAG/ECAH: Electro-Chemical Abrasive Grinding/ Electro-Chemical Abrasive Honing
ECSM/ECAM: Electro-chemical Spark/Arc Machining
ECM: Electro-Chemical Machining
EDAG: Electro-Discharge Abrasive Grinding
EDM: Electrical Discharge Machining
EEM: Elastic Emission Machining
FFM: Fluid Flow Machining
LAE: Laser Assisted Etching
LAECM: Laser Assisted Electro-chemical Machining
LAT: Laser Assisted Turning
LBM: Laser Beam Machining
PAT: Plasma Assisted Turning
PBM: Plasma Beam Machining
UAECM: Ultrasonic Assisted Electro-Chemical Machining
UAEDM: Ultrasonic Assisted Electrical Discharge Machining
UAG: Ultrasonic Assisted Grinding
UALBM: Ultrasonic Assisted Laser Beam Machining
UAP: Ultrasonic Assisted Polishing
UAT: Ultrasonic Assisted Turning

Table 2 Classification of Hybrid Machining Processes

Major Source of Energy	Process	Combination of Energy Sources	Mechanism of Material Removal	Tool	Transfer Media
Thermal	UAEDM	Thermal and Ultrasonic Vibration	Melting & Evaporation	Sonotrode	Dielectric
	UALBM	Thermal and Ultrasonic Vibration	Melting & Evaporation	Laser beam	Air
Electro Chemical and Chemical	ECSM/ ECAM	Electrochemical and Thermal	Melting & Evaporation	Electrode	Electrolyte
	ECAG	Electrochemical and Mechanical	Electrochemical dissolution and abrasion	Metal bonded abrasive wheel	Electrolyte
	LAECM	Electrochemical and Thermal	Electrochemical dissolution and heating	Electrode	Electrolyte
	UAECM	Electrochemical and Ultrasonic Vibration	Electrochemical dissolution	Sonotrode	Electrolyte
	BEDMM	Electrochemical Thermal, and Mechanical	Electrochemical Melting and Mechanical Rupture	Rotating Metal brush	Water glass Solution in water
	LAE	Chemical and Thermal	Chemical dissolution and	Mask	Etchant

			heating		
Mechanical	EDAG	Mechanical and Thermal	Melting, Evaporation and abrasion	Metal bonded abrasive wheel	Dielectric
	LAT/PAT	Mechanical and Thermal	Shearing and Heating	Turning tool	Air
	UAG	Mechanical and Ultrasonic Vibration	Abrasion	Sonotrode of abrasive wheel	Coolant
	UAT	Mechanical and Ultrasonic Vibration	Shearing	Turning tool	Air

Electrochemical Spark Machining (ECSM)

The two most extensively used unconventional machining processes are

i. Electrochemical machining (ECM)

ii. Electric discharge machining (EDM)

Considering the different aspects of their capabilities these two processes are considered to posses maximum potential. However, inspite of their so many virtues both these processes suffer from a very important limitation. To employ either ECM or EDM the work material must be electrically conducting. The development of ECDM has taken place primarily to eliminate this difficulty.

Electrochemical discharge phenomenon

One phenomenon to produce intense localized heat generation without using any sophisticated technology like electron beam or laser beam is the electrochemical discharge. A general electrochemical cell as shown in Fig.2.1 consists of two electrodes dipped in electrolyte. Application of external potential between the electrodes causes the flow of electric current through the cell, resulting in electrochemical reactions such as anodic dissolution, plating of cathode, electrolysis etc., depending upon the electrodes-electrolyte combination.

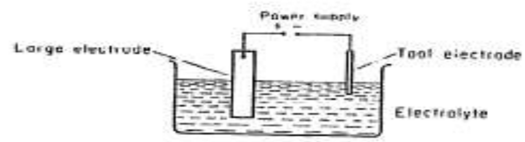

Fig.2.1 Electrochemical discharge cell

It has been observed that if the two electrodes are of grossly different sizes then beyond a certain value of applied voltage, electric sparks appear at the electrode-electrolyte interface of the smaller electrode and the cell current drops. This is known as electro chemical discharge phenomenon.

ECD between the tool and work piece was observed during the attempts at enhancing MRR in ECM by the application of higher potential between the electrodes. This discharge during ECM was considered as a detrimental factor because it damages surfaces of both the electrodes i.e. tool and work piece. However, afterwards the researchers have made productive use of this phenomenon.

Mechanisms of Electrochemical spark generation

The basic mechanism of the ECD is not yet completely understood and is still a matter of research investigations. Various researchers have put forth explanations of ECD phenomenon based on their experimental studies, which are discussed below.

- **Crichton and Mc Gough**

These researchers performed steak photography to get insight into the various stages of discharge by applying an 85 V pulse for duration of 200µs. They concluded that electrical discharge between cathode tool and electrolyte interface occurs due to ----

i. Generation of electrolytic gas at the surface of electrodes.

ii. The growth of layers of low ionic concentration near the electrodes and formation of oxide

films on the anode surface, and

iii. The local variations in the electrolyte flow pattern caused by flow stagnation and eddy.

- **A.Ghosh**

To understand ECD phenomenon an extensive study has been carried out by this researcher. One of the important findings by him is the nature of the potential drop across the electrolytic cell. It is clear that an overwhelmingly large fraction of the total drop takes place across a very thin layer surrounding the tool electrode (the smaller one) during electrochemical discharge. This suggests that a resistance layer develops around the tool electrode. In most experiments this is the cathode and therefore, H_2 evolves in the form of very fine bubbles. Moreover, the temperature of the electrolyte at this region increases because of much higher current density. This leads to boiling if the current density is high enough. Both these result in the development of a non conducting gas and vapor blanket around the smaller electrode (this does not happen at the larger electrode because the current density is much less).

When the voltage (either full wave D.C. or smooth D.C.) applied across the ECD cell is gradually increased, the corresponding change in the average current is shown in Fig.2.2 (a) An extensive study shows that this characteristic remain unchanged for all situations. It is seen that electrochemical discharge starts only when the applied voltage reaches a critical value which depends on the type of electrolyte, and electrolyte concentration. But the depth to which the electrode is submerged and the electrode diameter do not appear to have much effect so long as the discharging electrode is much smaller than the other one. It is also very interesting to note that the power consumption (for a given electrolyte and set of electrodes) at the critical condition ($VcrI_{cr}$) remains a constant and independent of electrolyte concentration. This strongly suggests that blanketing can be a major factor in the occurrence of electrochemical discharge as both H_2 evolution and vapor production through boiling depends on the power only.

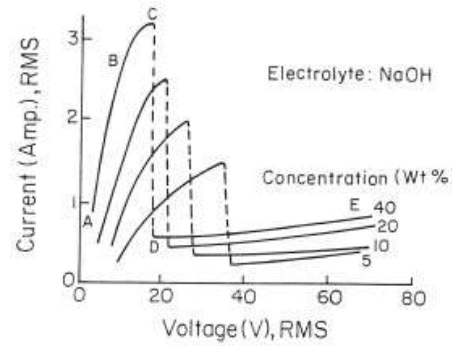

Fig.2.2 (a) V-I characteristics for different concentrations of NaOH Electrolyte

- **Basak & Ghosh**

It was observed by these researchers that as the voltage applied across the electrodes of the electrolytic cell increased, the rate of bubble generation at the electrode also increased. When the critical value (depending on other parameters) of the voltage was reached, sparking started at the smaller electrode, further increase in the voltage increased the intensity of sparking. The pattern of change in the value of the current with the value of the voltage applied is shown in Fig.2.2 (b). The sparking starts at V_c and the corresponding current is I_c. The nature of bubble distribution on the tool electrode surface for different values of applied voltage is shown in fig. It is clear that at the critical condition (i.e. at the onset of sparking) the electrode surface is fully covered with bubbles in a closed packed form.

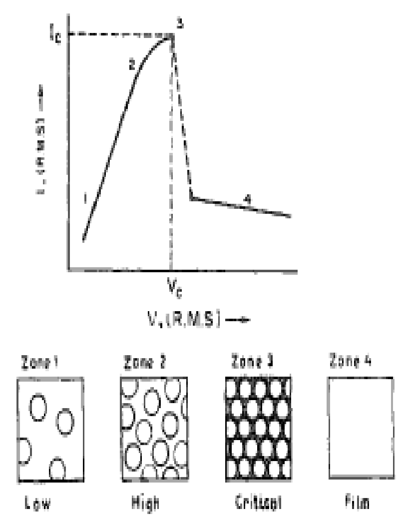

Fig.2.2 (b) Voltage-current relationship for a typical ECD cell and distribution of bubblesOn the tool electrode for different applied voltages

The bubble density at the tool increases with an increase in supply voltage, and when it becomes sufficiently high substantial constriction of the current path takes place at the interface of the tool and electrolyte. The constriction causes an increase in the resistance of the region and ohmic heating of electrolyte solution becomes significant. This leads to the onset of vapor bubble nucleation on the electrode surface in addition to the presence of hydrogen bubbles, and it increases very rapidly with the applied voltage. It is hypothesized that as the density of nucleation reaches a critical value, vapor blanketing of the electrode occurs. The point of contact between the electrolyte and tool, known as the bubble bridge, blow off instantly due to intense heating. Consequently, the current through the circuit, within a very short time span, drops to zero. This has been claimed to be analogous to the switching off phenomenon in an electrical

circuit. Such discharges take place along the locations of the bubble bridges as shown in Fig.2.2 (c).The bubbles get dislodged from the electrode surface due to blowing of the bridges, and the

contact between the electrode and the electrolyte is re-established. The cycle repeats continuously.

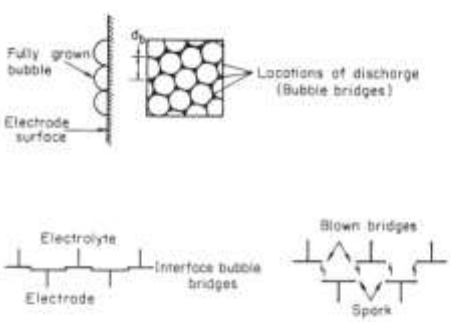

Fig.2.2 (c) Idealization of bubble bridges

- **Jain, Dixit & Pandey**

These researchers have considered each gas bubbles as a valve, which after its breakdown due to high electric field produces discharge in the form of arc.

- **Kulkarni, Sharan & Lal**

According to these researchers the electrochemical discharge process can be compared to the arc discharge in gases. When a D.C. voltage greater than the threshold value that is needed to produce the discharge is applied to the ECD cell, electrolysis reactions take place. Reduction of electrolyte at cathode results in hydrogen gas bubbles. These bubbles get accumulated at the cathode tip immersed in electrolyte. Bubble generation goes on increasing, leading to combining of bubbles into a single large bubble which isolates the tip completely from the electrolyte. This causes the local electric field gradient between the tool and the electrolyte interface to go beyond the breakdown limit of 25V/μm leading to an arc discharge.

From the above discussion, it is evident that the mechanism of electrochemical discharge (ECD) has not been studied in depth. However, it has been established that the discharge takes place due to electrical breakdown across the hydrogen gas bubbles generated due to the electrochemical reaction.

Material removal mechanism of ECSM operation

In the ECSM process, the material removal takes place due to the combined effects of electrochemical reaction and electrical spark discharge action. Fig.2.3 exhibits the material removal mechanism of ECSM operation. Although the tool is touching the surface of the work piece, there are micro gaps between the tool and the work piece due to the surface irregularity present on both the surfaces of tool and that of the work piece. The electrolyte present in the micro gaps is responsible for the formation of gas bubbles and steam generation. A low ionic layer is formed in the micro gaps and the surrounding tool surface. When the voltage gradient that is set up is sufficient to breakdown the gas bubble layer between the tool and the work piece, a conducting path is developed for spark discharge owing to the ionization of the gas bubble, which thereby causes the flow of a large amount of current.

Each electrical discharge causes a stream of electrons to move with a very high velocity and acceleration from the cathode (or tool) towards the work piece and ultimately creates compressive shock waves on the work piece surfaces. The phenomenon is completed within a few microseconds and the temperature of the spot hit by electrons may rise to a very high value. As this high temperature is above the melting point of the work piece material, it melts and finally evaporates the material. The high pressure of the compressive shock waves creates a blast, causing metallic vapors to form wear products in the shape of metallic globules, leaving craters in the work piece surface.

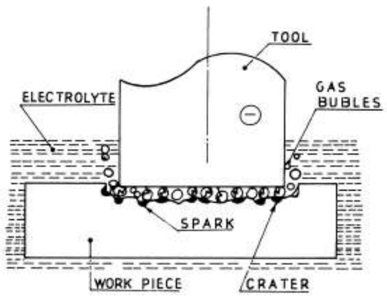

Fig.2.3 Material removal mechanism of ECDM operation

Conclusion

i. The mechanism of Electro-chemical discharge (ECD) has not been studied in depth.

ii. Electro chemical discharges can be used for machining several electrically non conducting materials

iii. The machining mechanism is a combination of thermal and chemical machining, where the thermal effects clearly dominates.

iv. Even known since almost 50 years, this machining process remains an academic application and until now never applied in industrial production

V.The research done until today mainly on experimenting the machining of various materials and investing the effect of different parameters on the material removal rate.

References

[1] Yadava V., Finite Element Analysis of Electro-Discharge Diamond Grinding (EDDG), Ph.D. Thesis, Indian Institute of Technology, Kanpur (2001).

[2] A. Ghosh, Electrochemical Discharge Machining: Principle and Possibilities, International conference on Advances in Mechanical Engineering, 1995, Bangalore.

[3] I. Basak, A. Ghose, Mechanism of spark generation during electrochemical discharge machining: a theoretical model and experimental verification, Journal of Material Processing Technology 62 (1996) 46-53.

[4] B. Bhattacharyya, B.N.Doloi, S.K. Sorkhel, Experimental investigation into electrochemical discharge machining (ECDM) of nonconductive ceramic materials, Journal of Material Processing Technology 95 (1999) 145-154.

[5] V. K. Jain, P. M. Dixit, P. M. Pandey, On the analysis of the electrochemical spark machining process, International Journal of Machine Tools and Manufacturer 39 (1999) 165-186.

[6] A. Kulkarni, R. Sharan, G. K. Lal, An experimental study of discharge mechanism in electrochemical discharge machining, International Journal of Machine Tools and Manufacturer 42 (2002) 1121-1127.

[7] R. Wiithrich, V. Fascio, machining of nonconductive materials using electrochemical

[8] discharge phenomenon- an overview, International Journal of Machine Tools and Manufacturer 45 (2005) 1095-1108.