euspen's 19th International Conference & Exhibition, Bilbao, ES, June 2019
www.euspen.eu

Revamp of a conventional start hole EDM-Machine to a near dry EDM-Machine for the manufacturing of holes in a dental alloys CoCrMo

Mathias Lorenz[a], Tassilo-Maria Schimmelpfennig[a]

[a] *Hochschule Wismar, University of Applied Science Technology, Business and Design/ Fakultät für Ingenieurwissenschaften Bereich Maschinenbau/ Verfahrens und Umwelttechnik, Philipp-Müller- Str. 14, 23966 Wismar, Germany*

mathias.lorenz@hs-wismar.de

Abstract

Conventional electrical discharge machining (EDM) uses dielectric media such as oil, kerosene or deionized water. For economic, environmental and health reasons it is important to reduce them to a minimum. Actually, the process is done in the dielectric fluid or with a ray cooling which has some disadvantages in contrast to mist cooling. The influence of the edge zones is much greater with conventional cooling than with mist cooling, since the larger surface area of the individual drops makes the evaporation enthalpy much larger and thus the process heat Q is better dissipated. Furthermore, the heat transfer coefficient of mist α= 1600 W / (m^2 · K) is greater than the other cooling methods. This work presents the result and a comparison of a near dry EDM process with a simple wet EDM start hole drilling Machine, Mitsubishi ED 24, for conventional EDM of steel and cemented carbide. The simple revamps of a mist nozzle and a modification of the fluid pressure system allows near dry EDM, in this case for special dental alloys. A mist nozzle is used with a mist precipitation rate of V_S= 0.80 kg/(m^2 · s). Based on the application in dental technology, the NEM alloy CoCrMo is drilled with a brass electrode d_A= 1 mm holes of h_B= 15 mm and then analysed by using methods of design of experiments. The results show that the process parameters as erosion time t_{ero}, relative electrode wear ϑ and bore inlet d_{in} are just as good or partly better than with conventional EDM. In addition, this paper presents the impacts of a mist cooling compared to conventional EDM.

Keywords: EDM, near dry EDM, precise holes, CoCrMo

1. Introduction

Electrical discharge machining which has been developed in 1980s for industrial application [1-3], is still an important established manufacturing process in mould and tool construction, automotive engineering and medical technology due to its many advantages. For example, dental technology uses electrical discharge machining for high-precision stress-free production of tailor-made, biocompatible dental prostheses made of hard NEM alloys (CoCrMo) and titanium, especially in combination prosthetics and implant prosthetics [4-8]. The processing takes place in oil-based dielectrics such as IonoPlus IME-MH, which then have to be removed from the implant structures without residue. The operation of the oil-based dental EDM machines as well as the associated cleaning equipment for the implant structures causes additional costs for staff, operating materials, cleaning and maintenance. Both, the remnants of the EDM process on the surface of the implants and those which come from cleaning the surface can significantly affect the biocompatibility of the porous titanium layer. In time of climate change, it is important to consider the environmental impact of the use of polluting substances produced from limited mineral oil as well as the release of harmful vapours like CO and CH_4 due to the decay of hydrocarbons during ignition [9, 10]. Likewise, green manufacturing is becoming more and more important for the industry. Further to the conventional use of oil-based dielectrics novel approaches with gas-liquid mixtures, known as near dry EDM, have existed since 1989. Tanimura et al. [11] were the first who study on near dry EDM processing in water mist with air, nitrogen, argon and identified it as a stable process. Two decades later Kao et al. [12] and others [13- 15], achieved a higher material removal rate (MRR) with a larger gap distance and low discharge energy input compared to conventional EDM with liquid dielectric medium. Responsible for the high MMR are stronger process forces caused by electrochemical reactions such as oxidation, which contributes significantly to the evacuation of the removed particles [17]. The disadvantage of the deionized water compared to other dielectrics is the oxidation on the workpiece surface and the higher electrode wear [18, 19]. Furthermore, a research conducted by Kwan Chung Do et al. [20] showed that the surface finish of micro-EDM hole using deionized water is greatly improved. The decisive factor for this process, which takes place in comparison to the wet process in the working tank, is now influenced by air, which mainly consist of oxygen O_2 and nitrogen N_2. Kunieda et al. [21, 22] and other [23] achieved a very high MMR by using gas based dielectrics (dry-EDM) and mirror surfaces than with the conventional EDM. They identified oxygen as a process stabilizing medium due to the large oxidation capacity. Schimmelpfennig [24, 25] developed and optimized process technologies for dry EDM of high performance materials and identified a supporting effect on the material removal rate caused by the oxidation effect of oxygen.

Additionally, the high mol mass and density of oxygen lead to high pressure resulting in a high flow velocity in the working gap, which prevents short-circuits. For Nitrogen, Savas and Ceyhun [26] identify that due to the high specific heat capacity c_P nitrogen has a constricting effect, which leads to the increase the energy density, caused by high speeds of free charge carriers. This effect is supported by low molar mass and the low dynamic viscosity has an increase in dynamic pressure as a result. Furthermore, they observed an increase in short-circuits resulting in a low MMR.

When using an air-water mixture, a distinction is made between different cooling or rinsing methods, as shown in Fig. 1 [27]. Only with a defined mist spray the evaporation cooling is optimal, based on the high enthalpy of vaporization (ΔH_{vap}), so the heat is dissipated from the process (Fig. 1 c). This leads to an optimal cooling of the tool to minimizes the tool wear rate and to decreases the heat affected zone on the workpiece surface. Reiners [28] investigations showed that only an evaporation or mist cooling occurs if the water admission is less than $V_S < 3$ kg/(m² · s), especially with very fine water atomizer. The amount of water should be dosed in such a way that no water film exists, so the complete evaporation is exploited. Regarding to Jeschar et al. [29] is the limit $V_S = 0.6$ kg/(m² · s), with the lowest heat transfer coefficient $\alpha < 500$ W/(m² · K) and he recommends the use of nozzles with high droplet speed and small droplet diameters for ideal heat dissipation ($\alpha = 1600$ W/(m² · K)), [30]. This paper presents further research results from the area of near dry EDM and compares the wet with the near dry process performed with a revamped conventional EDM start hole drilling machine. Through the revamp, dental alloys can now also be worked on near-dry (Fig. 1 c), by feeding an air-deionized water mixture as a dielectric fluid, rather than a wet EDM (Fig. 1 a).

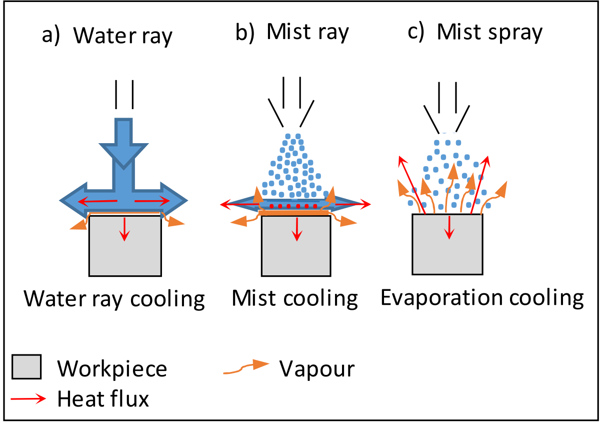

Figure 1. Different cooling technics, changed [27].

2. Experimental setup

The experiment is set up by an EDM start hole drilling machine, Mitsubishi ED24 for a conventionally wet EDM, as shown in Fig. 2. Equipped with a current source for static impulse discharges and a relaxation generator for capacitance discharge. Mainly Parts of this machine is a positioning table, generator (Open circuit voltage $U_0 = 150$ V), pressure system for deionized water up to $p_d = 120$ bar, drilling module system, three axes digital display and a three axis handle wheels (*X*, *Y* and *Z* axis). For the near dry EDM process investigations it was mounted a nozzle ($V_S = 0.80$ kg/(m²· s)) that allows an airflow guidance with $p_A = 7$ bar outside at the electrode, whereby the flushing with deionized water 0 bar ≤ p_d ≤ 30 bar is done via a pressure system to the hollow shaft and then through the electrode. As shown in Fig. 2 the nozzle consists of a housing for the ceramic guide, which is positioned $x_G = 1$ mm above the workpiece during processing. The housing is equipped with an air connection and seals inside, between which the ceramic guide was pressed in. The guide has holes through which the air is guided and pressed directly outside along the electrode. The wet EDM investigations are carried out by using a flushing nozzle for water ray cooling as well as a flushing through the electrode with 0 bar ≤ p_d ≤ 80 bar. A brass tube electrode $l_E = 300$ mm with the diameters $d_A = 1$ mm and $d_i = 0.6$ mm was chosen. The workpiece is a dental alloy CoCrMo (Okta C) cylinder, where a bore hole with a depth of $h_B = 15$ mm will be drilled. Both, the wet and near dry EDM investigations use deionized water as dielectric fluid and Air, mainly consist of Oxygen and Nitrogen ($4\,N_2 + O_2$), for near dry EDM were applied.

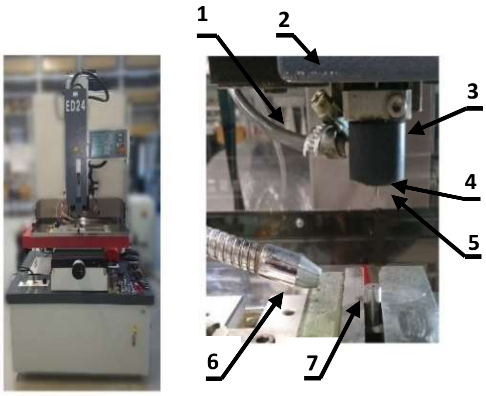

Figure 2. left: Start hole machine ED24, right:

1- air connection; 2 –spindle housing;
3- nozzle housing; 4- ceramic guide;
5 -electrode; 6- flushing nozzle; 7- workpiece.

3. DOE and parameter optimisation

For optimisation of the wet and near dry EDM process, in order to be able to compare them afterwards, the energy influencing process parameters were evaluated by using Design of Experiments (DOE). The DOE is a method for efficient planning and systematically evaluation of experimental series, to get control for this process and thus to optimise the process, according to Siebertz et al. [31]. The 2k-fractional factorial experimental plan is used in which the variance of five of the most important parameters, also called factor and their influence at erosion time t_{ero}, electrode relative wear ϑ and bore inlet b_{in} is experimentally and statistically investigated. The factors which were evaluated in this investigation are: Capacitance C_e, Switch On-Time t_{on}, Switch Off-Time t_{off}, Charging current i_L and Average gap voltage u_{Gap} as shown in Table 1. Each process was repeated three times in order to define the optimised parameters. By analysing the results of the DOE, conducted with the statistics software Minitab, the influential factors for both processes could be determined. It could be observed that the Charging current i_L and Capacitance C_e, indirectly due to the discharge energy W_e, had the most influence on the relative electrode wear ϑ and bore inlet b_{in}. The row with the best results in terms of quality features (t_{ero}, ϑ and b_{in}) was selected and then optimised by varying the setting of the most influential parameters. Subsequently, a further optimisation of the flushing pressure was carried out, whereby the value of the near dry EDM has been reduced by half, from p_d= 60 bar to p_d= 30 bar. Listed in Table 1, the optimised parameters for both methods of drilling CoCrMo with a brass tube electrode (d_A=1 mm, d_i= 0.6 mm).

Table 1. DoE optimised parameters for wet and near dry EDM.

Parameter	Unit	Quantity	
		Wet EDM	Near dry EDM
Average gap voltage u_{Gap}	V	25	30
Charging current i_L	A	21.3	17.5
Capacitance C_e	µF	0.057	0.2
Switch On-Time t_{on}	µs	20	30
Switch Off-Time t_{off}	µs	5	10
Pressure p_d	bar	60	30

4.Comparison

The comparison of the results (t_{ero}, ϑ and b_{in}) for each process is presented in Fig. 3, whereby all of them were improved for near dry EDM. The erosion time, shown on the left was reduced for a bore hole of d_i = 1 mm and Depth h_B = 15 mm by 23 % from 173 s to 133 s. The relative electrode wear ϑ for the near dry EDM (ϑ = 26 %) is 11 % lower than the conventional wet EDM (ϑ = 38 %). Furthermore, the bore inlet, shown on the right in the diagram, was reduced from b_{in} = 1.22 mm to b_{in} = 1.16 mm with an electrode diameter of d_A = 1 mm.

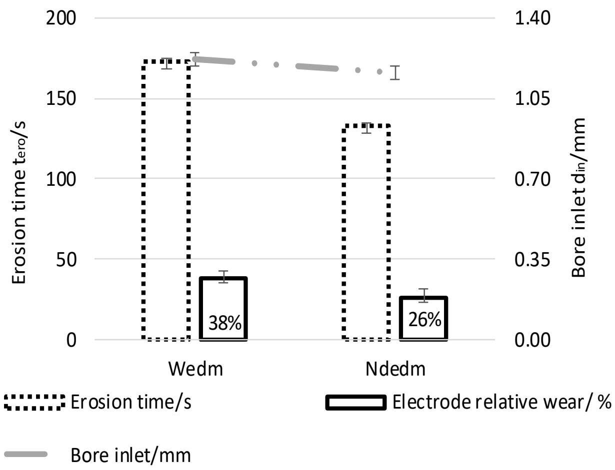

Figure 3. Comparison of erosion time, electrode relative wear and bore inlet for wet and near dry EDM.

The drill holes were examined by using the digital microscope model VHX-2000 by Keyence. In Fig. 4 a), the borehole of the wet EDM is shown. It could be observed that the bore hole edge is partly broken, deposits of removed particles and areas which have been melted. There are also dark brown spots, an evidence for poor cooling. For the near dry EDM, Fig. 4 b) the bore hole edge is sharp, free of removed particles and no discoloration on the workpiece surface could be observed. For the analysis of the bore hole walls and ground, the cylinders were separated in the middle initially, clamped in a fixture and then processed, so that after the process two identical cylinder halves with the symmetric drill holes are prepared for microscopy. In Fig. 5 a) is shown the bore hole of the near dry EDM process with no removed particles over the length of the bore hole and very straight sharp bore hole edges. The measurement of the near dry EDM processed bore hole revealed bore hole diameter, which is consistently stable over the depth of bore hole. Up to a bore hole depth of h_B= 12 mm, the surface of the bore hole wall is very uniform and all removed particles were well flushed out.

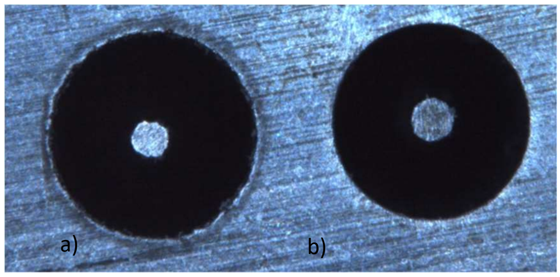

Figure 4. Bore hole a) wet EDM; b) near dry EDM.

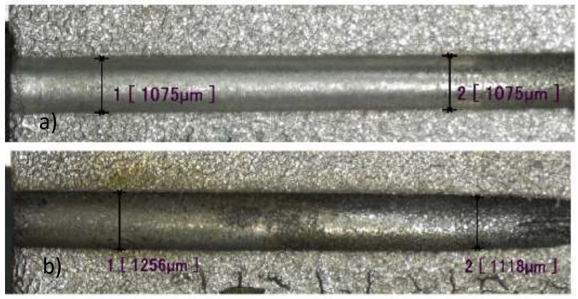

Figure 5. Cross section of the bore holes: a) near dry EDM b) wet EDM.

The reason for this could be the oxidation and the suspected stronger process forces which leads to the fast evacuation of the removed particles, according to Mane et al. [16] and other [21, 24]. But up to a depth of h_B= 12 mm and at the end of the bore hole were contaminated with a large number of removed particles. In contrast, see Fig. 5 b) the conventional processed bore hole is significantly discoloured and thus undesired heat influences have occurred, resulting from poor cooling conditions, according to Reiners [28]. In addition, the structure of the bore hole wall is very irregular. Furthermore, removal particles can be detected along the beginning of the hole. The comparison of the wet and near dry EDM process shows advantages and significantly better results for near dry EDM processing.

5. Summary

This paper presented the optimisation and comparison between wet and near dry EDM process with a conventional start hole EDM machine. Precise holes were drilled with a brass electrode, using two dielectric liquids (deionized water, water-air mixture) into dental material CoCrMo. The results like erosion time t_{ero}, electrode relative ϑ wear as well as bore inlet b_{in} were chosen for the optimisation and comparison. The comparison between the two processes shows that the near dry EDM process achieved better results in total. For example, a bore hole depth of h_B= 15 mm was processed with the optimised parameters with a time of t_{ero}= 133 s and an electrode relative wear of ϑ = 26 %. This has decreased the processing time by 23 % and the electrode relative wear by 11 %. However, the investigations with the microscope have also shown the limitations of the flushing method and further investigations will work on a mist cooling directly through the electrode.

References

[1] Bhaskar C, Reddy G, Reddy J and Reddy C E 2012 Growth of Electrical Discharge Machining and Its Applications – A Review *J. of Engineering Research and Development* **4** 13-22

[2] Houman L 1983 *Electrical Discharge Machining: Tooling, Methods and Applications* Society of Manufacturing Engineers (Dearbern Michigan) **1** pp 5–19

[3] Marashi H, Sarhan A A D, Maher I and Sayuti M 2017 Techniques to Improve EDM Capabilities: A Review *Comprehensive Materials Finishing* Hashmi, M.S.J. (Oxford: Elsevier) **1** 171–202

[4] Haase K 2000 Individuelle Prothetik auf Branemark-Implantaten mittels Funkenerosion *Quintessenz Zahntechnik* 2. Teil: Versorgung einzelner Implantate mit Hilfe der Funkenerosion (Berlin QZ) **26** 8

[5] Rübeling G 1995 *Patentschrift DE 4402511 C1* Verfahren und Vorrichtung zur Ausbildung von an Implantaten zu befestigenden zahnprothetischen Gerüsten

[6] Ntasia A, Dieter W, Mueller B, Eliadesa G and Zinelis S 2010 The effect of Electro Discharge Machining (EDM) on the corrosion resistance of dental alloys *Dental materials* (Berlin) **26**

[7] Eisenmann E, Mokabberi A, Walter M and Freesmeyer W B 2004 Improving the fit of Implant-Supported Superstructures Using the Spark Erosion Technique *The Int. J. of Oral & Maxillofacial Implants* **9** 810-18

[8] Eisenmann E and Rübeling G 1999 The Monometallic strainfree Restoration on Implants *Quintessence of Dental Technology* (Berlin) **30** 128-37

[9] Leão F N, Pashby I R 2004 A Review on the Use of Environmentally-Friendly Dielectric Fluids in Electrical Discharge Machining *J. Mater. Process. Technol.* **149** 341–46

[10] Zinelis S 2006 Surface and elemental alterations of dental alloys induced by electro discharge machining (EDM) *Department of Biomaterials* School of Dentistry University of Athens **23**

[11] Tanimura T, Isuzugawa K, Fujita I, Iwamoto A and Kamitani T 1989 Development of EDM in the Mist *Proceedings of Ninth Int. Symposium of Electro Machining* (ISEM IX), (Nagoya) 313–16.

[12] Kao C C, Tao J and Shih A J 2007 Near Dry Electrical Discharge Machining *Int. J. Mach. Tools Manuf.* **47** 2273–81

[13] Fujiki M, Ni J and Shih A J 2009 Investigation of the Effects of Electrode Orientation and Fluid Flow Rate in Near-Dry EDM Milling Int. J. Mach. Tools Manuf. 2009 **49** 749–58

[14] Tao J, Shih A J and Ni J 2008 Experimental study of the dry and near-dry electrical discharge milling processes *J. of Manufacturing Science and Engineering* **130**

[15] Karden A 2001 Funkenerosive Senkbearbeitung mit leistungs-steigernden Elektrodenwerkstoffen und Arbeitsmedien *Shaker Verlag* (Aachen) **2** 11

[16] Mane S G and Hargude N V 2015 PARAMETRIC OPTIMIZATION OF NEAR DRY ELECTRICAL DISCHARGE MACHINING PROCESS FOR AISI SAE D-2 TOOL STEEL *In. J. of Advanced Research in Engineering and Technology* Department of Mechanical Engineering (Maharashtra:India) **6** 99-114

[17] Albert S and Jun Ni 2008 Experimental Study of the Dry and Near-Dry Electrical Discharge Milling Processes *J. of Manufacturing Science and Engineering* **130**

[18] Khan M A R, Rahman M M, Noor M M, Kadirgama K and Maleque M A 2011 Current Research Trends On Dry, Near-Dry and Powder Mixed Electrical Discharge Machining *Advanced Materials Research* **264** 956-61

[19] Gholipoor A, Baseri H and Shabgard M R 2015 Investigation of near dry EDM compared with wet and dry EDM processes, *J. of Mechanical Science and Technology* **29** 2213-18

[20] Chung D K, Shin H S, Kim B H, Park M S and Chu C N 2009 Surface finishing of micro-EDM holes using deionized water *J. of Micromechanics and micro engineering* **4**

[21] Kunieda M, Furuoya S and Taniguchi N 1991 Improvement of EDM Efficiency by Supplying Oxygen Gas into Gap *CIRP Ann. – Manuf. Technol.* **40** 215–18.

[22] Kunieda M and Yoshida M 1997 Electrical discharge machining in gas *Annuals of the CIRP* **46** 143-46

[23] Govindan P and Joshi S S 2010 Experimental Characterization of Material Removal in Dry Electrical Discharge Drilling Int. *J. Mach. Tools Manuf.* **50** 431–43

[24] Schimmelpfennig T-M 2016 Trockenfunkenerosives Feinbohren von Hochleistungswerkstoffen *Berichte aus dem Produktionstechnischen Zentrum Berlin* (Hrsg. Uhlmann E: Stuttgart) Fraunhofer IRB

[25] Uhlmann E, Perfilov I and Schimmelpfennig T-M 2016 Open Source CNC-Maschinensteuerung für die Trocken-funkenbahnerosion *Zeitschrift für wirtschaftlichen Fabrikbetrieb* **7-8** 430 – 33.

[26] Savas A and Ceyhun V 2011 Finite element analysis of GTAW arc under different shielding gases *Computational Material Science* **51** 35-71

[27] VIŠČOROVÁ R 2007 Untersuchung des Wärmeübergangs bei der Spritzwasserkühlung unter Berücksichtigung des Einflusses der Verzunderung *Institut für Metallurgie TU Clausthal*

[28] Reiners U 1987 Wärmeübertrag durch Spritzwasserkühlung heißer Oberflächen im Bereich der stabilen Filmverdampfung *Technische Universität Clausthal*

[29] Jeschar R, Specht E, Puschmann F and Maibücher L 2000 Experimentelle Untersuchung der Verdampfungskühlung von heißen Metallen mit Sprühnebel *Abschlußbericht BMWi* AiFNr. B11166 (Magdeburg:Clausthal)

[30] Puschmann F and Specht E 2004 Atomized Spray Quenching as an Alternative Quenching Method for Defined Adjustment of Heat Transfer *steel research international* **75** 283-88

[31] Siebertz K, Bebber D V and Hochkirchen T 2010 *Statistische Versuchsplanung Design of Experiments (DoE)* Springer-Verlag (Berlin,Heidelberg) **2** 2-10