

CASE STUDY IN SUSTAINABILITY ANALYSIS FOR EDM

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ABSTRACT: The paper analyses a generic EDM process in terms of its environmental impact, carbon balance and occupational health and safety risks. Various cases are tested and discussed based on simulations and mathematical modelling to determine their viability and possible interpretations. The efficiency and the sustainability of the process are linked with assessing the occupational, health and safety (OHS) risks that employees face. The results of the paper show that a mature and capable EDM process can reduce the risks that the employees face within the manufacturing environment. This investigation addresses the broader question of how sustainability can be leveraged as a strategy to enhance both operational outcomes and employee safety and security.
KEYWORDS: EDM sustainability, EDM occupational health and safety, risk management

1. INTRODUCTION

Nowadays, all the companies are increasingly focused on implementing sustainable processes. This paper analyses the EDM (Electrical Discharge Machining) process evaluating its key manufacturing parameters to identify best practices for achieving sustainability. The OHS (Occupational Health and Safety) risks are then correlated and reviewed to underline if sustainability practices reduce the risks faced by employees directly involved in the EDM process. The paper aims to highlight the connection between the importance of EDM parameters and the risks faces by the employees. These factors are assessed through the lens of sustainability practices to determine if they enhance efficiency and benefits towards all stakeholders within the organization.

EDM processes are a metal manufacturing technique that uses electrical discharge to perform cutting, engraving or shaping using conductive materials, and is useful for particularly hard metals or complex alloys that are challenging to manufacture using traditional methods [1]. For studying these processes, an online EDM simulator will be used [2] which is going to provide information about material removal rate (MRR) – essential for sustainability and electrode wear rate (EWR) – essential for efficiency, depending on critical factors, namely peak current, voltage, and electric pulse timings, in relation to the material and consumables used [2].

The employees must face many significant risks regarding this process due to several specific factors, such as air quality around the machines, high temperatures, exposure to electrical currents, noise and vibrations, mechanical risks and others. The purpose of the paper is to determine if increasing sustainability of this process is linked with decreasing the OHS risks that employees must encounter. Specifically, it seeks to assess whether implementing more sustainable practices [3]—such as optimizing energy use, minimizing harmful emissions, and reducing waste—can lead to a safer work environment. By analyzing how sustainable improvements can mitigate hazards like toxic fumes, electrical risks, and mechanical dangers, the paper aims to provide insights into the relationship between company objectives like productivity and worker concerns like safety. This investigation addresses the broader question of how sustainability can be leveraged as a strategy to enhance both operational outcomes and employee safety and security.

2. METHODOLOGY

The following demarche is going to determine what are the critical process parameters which interfere with efficiency and sustainability. Also, the risks involved in these processes regarding human health are going to be analysed to identify ways to diminish their impact related to the process characteristics.

The first part of the paper employs the EDM simulator [2] where the impact of each characteristic is defined. In this simulator, analyses of various parameter configurations have been performed with the end goal to enhance sustainability.

The interface of the simulator in shown figure 1, where the process input parameters are set, resulting after the simulation in determining the remaining weights of electrode and work piece, and the machining time required.

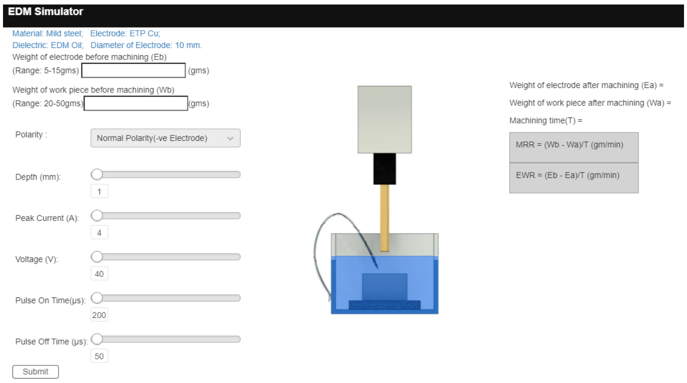

Figure 1. Simulator interface – screen capture [2]

The paper proposes four scenarios where the time machining (T), and the MRR and EWR are computed and compared to enable the interpretation of possibilities.

After simulation, the risks that have a high likelihood to occur are examined under the influence of the settings of each process parameter. The exploration of the connections between efficiency, sustainability and risks can yield important benefits for companies that employ such technologies. Figure 2 shows the methodology applied in this paper.

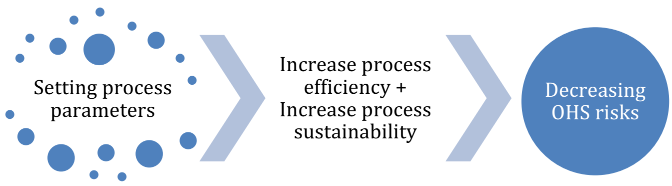

Figure 2. Methodology for exploring decreasing OHS risks in the EDM process through enhanced efficiency and sustainability

3. RESULTS AND DISCUSSION

The parameters of EDM process in the simulation tool are [2]:

- Material;
- Electrode;
- Dielectric environment;
- Diameter of electrode;
- Weight of electrode before machining;
- Weight of work piece before machining;
- Polarity;
- Depth;
- Peak current;
- Voltage;
- Pulse on/off time.

Setting these parameters in the simulation helps in defining usage scenarios that more closely mimic the actual employment situations. The outputs that are obtained through the simulation refer to: remaining weight of electrode (Ea) from initial weight (Eb), remaining weight of the work piece (Wa) from the initial (Wb), and the needed process machining time (T). With those outputs, the MRR and the EWR are computed for analysis and interpretation in the context of process sustainability, with the following formulas [4]:

$$MRR = \frac{Wb-Wa}{T} g/min \quad (1)$$

$$EWR = \frac{Eb-Ea}{T} g/min \quad (2)$$

To ensure a valid comparison, it is necessary to maintain consistent settings for certain parameters that serve as the baseline.

For the studied cases, the baseline is presented in Table 1 below, taking into account common values of the parameters and materials used.

Table 1. Constant baseline parameters

Baseline parameters	Settings
Material	Mild steel
Electrode	ETP Cu
Dielectric	EDM Oil
Diameter of electrode	10 mm
Weight of the electrode before machining (Eb)	5 g
Weight of work piece before machining (Wb)	50 g
Polarity	Normal Polarity (-ve Electrode)

The mild steel material is configured in the simulator. This metal is easier to manufacture due to its properties, which allows for a slower removal rate that contributes to a more precise cutting, enhances the surface quality and reduces tool wear, ensuring a longer tool life cycle. Of course, longer processing time can also be counted as a disadvantage in the case of this material.

The use of a coper electrode is particularly advantageous due to is excellent electrical and thermal conductivity, as well as its purity.

This type of electrode performs a better cutting in the material, resulting in less tool wear, albeit at a higher cost. An increasing tool wear reduce the accuracy and the quality of the machined work piece.

The dielectric environment used in electrical discharge machining is dielectric oil. The properties of this dielectric [5] isolate effectively the surface manufactured and permit a proper management of the electrical discharges, resulting in improving the stability of the electrode and the quality of the surface. Compared with dielectric water, oil is more efficient in reducing the material remove rate [5].

The diameter of the electrode [6] also helps the process to perform a better cutting detail. The 10mm diameter means a precise cutting in the workpiece and a reduced removal rate due to the increased surface area [6].

The weights of the electrode and the workpiece prior to machining are significant, as they provide a baseline for comparison with their post-manufacturing weights. A substantial weight loss in the electrode indicates high wear, which can negatively affect cutting quality and precision. In the scenarios performed in the study, the baseline for weight of electrode is 5 grams and for the weight of workpiece is 50 grams.

As for the polarity parameter, the electrode is typically negatively charged while the workpiece is positively charged. This negative polarity enhances the material removal rate and improves cutting precision. As it can be seen until now, the baseline of the parameters is set to enhance the sustainability of the process.

To assess the most sustainable manufacturing method, the remaining parameters that need to be configured in the simulation will be adjusted in four scenarios, where the depth is a constant and the peak current, the voltage, and the timing of the pulses are being varied. These parameters play an important role in identifying the most efficient and sustainable way to manufacture through the EDM process.

The depth in this case means how extensive the machining should be. A greater depth increases the material removal needs but implies also an increase in manufacturing time and a higher peak current, leading to an increased electrode wear rate.

Peak current is the maximum amount of electric current that flows through the EDM process during a single discharge. A higher peak current performs a faster material removal rate, but also increase the tool wear rate and the roughness of the surface. A too high peak current can lead to instability of the electrode and its eventual breaking up, further increasing the costs of the process, as well as the need for more recycling after use.

The voltage refers to the level of electrical potential difference that occurs during a discharge in the EDM process. A peak voltage is critical for the stability of the dielectric environment between the electrode and the workpiece. This affects the spark discharge and the stability of the electrode, leading to a rough surface of the material and a greater electrode wear, with similar repercussion as before.

The pulse on time means the time in microseconds, applied in each discharge cycle. If the pulse on time is too long, it can cause an excessive tool wear, a roughness surface and the potential for unsafe sparks and tool instability, with impact on the work risk management process.

A pulse off time means the time in microseconds, when the current is turned off between two pulses. A large pulse off time allows for more effective cooling and waste removal, which enhances arc stability. However, if the pulse off time is too long, it can reduce the material removal rate, increasing overall machining time, leading to prolonged operator exposure to hazards.

To analyse the MRR and EWR parameters of the EDM process, the four relevant scenarios analysed range the parameters in a specific order. The goal is to ascertain which settings are the most sustainable in terms of efficiency and environmental impact.

(1) The first scenario aims to serve as a control for the comparisons performed in the paper. All the parameters are set to the average range.

(2) In the second scenario the impact of using maximum values for the parameters on MRR, EWR and time machining is analysed.

(3) The third scenario aims to evaluate a lower voltage, which could reduce EWR and improve process stability. Also, the peak current value and timing of the pulse on period are increased. This scenario seeks to increase the sustainability of the process.

(4) The fourth scenario evaluates the impact of a lower peak current in a context where pulse on time is high. This scenario seeks to study the relationship between the peak current value and pulse on duration in increasing the efficiency of the process.

In the next part (Table 2), the results of the calculations of post-processing weights and machining time, as well as the determined MRR and the EWR, are presented.

Table 2. MRR & EWR values in the four scenarios based on the simulations with [2]

Parameters/scenarios	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Material	Mild steel	Mild steel	Mild steel	Mild steel
Electrode	ETP Cu	ETP Cu	ETP Cu	ETP Cu
Dielectric	EDM Oil	EDM Oil	EDM Oil	EDM Oil
Diameter of electrode	10 mm	10 mm	10 mm	10 mm
Weight of the electrode before machining (Eb)	5 g	5 g	5 g	5 g
Weight of work piece before machining (Wb)	50 g	50 g	50 g	50 g
Polarity	(-ve Electrode)	(-ve Electrode)	(-ve Electrode)	(-ve Electrode)
Depth (1-10 mm)	10	10	10	10
Peak current (4-20 A)	12	20	20	4
Voltage (40-60 V)	50	60	50	50
Pulse on time (200-400 µs)	300	400	400	400
Pulse off time (50-150 µs)	100	150	100	100
Weight of electrode after machining (Ea)	**4.88**	**4.45**	**4.93**	**4.16**
Weight of work piece after machining (Wa)	**49.27**	**49.32**	**49.45**	**49.61**
Machining time (T)	**1.09**	**0.3**	**0.28**	**3.74**
MRR	***0.67***	***2.27***	***1.96***	***0.10***
EWR	***0.11***	***1.83***	***0.25***	***0.22***

In the table above, the weight of electrode, the weight of workpiece and machining time machining are computed by the simulating software [2]. The MRR and the EWR are computed by the authors following the formulas presented in this chapter.

According to Table 2, in the first scenario, all the parameters are set to the average interval value as a reference baseline. The MRR obtained is 0.67 g/min which means that this amount of mild stee is removed from the workpiece in the presented conditions. The EWR is 0.11 g/min which means that this quantity of electrode is lost in the machining process. In general, this ratio, where MRR is higher than EWR suggest an efficient machining, because the material removed is higher than the electrode lost.

In the second scenario, all the parameters are set to maximum. The MRR and EWR are 2.27 g/min and 1.83 g/min, respectively. Even if the time machining is short and the ratio between MRR and EWR is considered efficient, the fact is that this process is not sustainable because of the high amount of tooling wear rate. So, in this case the sustainability of the process is not validated from the perspective of environmental impact.

In the third scenario, the voltage and the pulse off time are set to the average value and the peak current and pulse on time are set to maximum. In this case, the machining time is short, at 0.28 seconds, the MRR is 1.96 g/min, and the tooling deterioration rate is 0.25 g/min. This process can be considered efficient and sustainable. The amount of material removal is high, and the electrode wear is low, and their ratio is better than the baseline. Also, the machining time in this process is reduced, which increases more the efficiency of the process.

In the fourth scenario, the peak current relation to the efficiency of the process is tested. So, the peak current was set to minimum, all the other parameters remaining the same as in the third scenario. It proved that the efficiency is highly linked to the peak current, because in this scenario the electrode wear rate was higher than the removal material rate. Also, the time required for machining was of 3.74, which is the highest time obtained those scenarios.

Consequently, minimum values for all parameters lead to inefficiency, maximum values are efficient but not environmentally friendly, peak current is critical to productivity but can generate OHS risks, which can be reduced with lower voltages and shorter pulse off.

In this regard, the study next analyses the OHS risks involved when setting the process parameters, that have the highest likelihood of occurrence:

- Risk of electrocution – a higher voltage (scenario 2) increases this risk.
- Burning risks – a higher peak current and pulse on time (scenario 2 & 3), without a proper setting of voltage and pulse off time, increases the risk.
- Riks of burns and injuries from sparks and hot waste – a higher peak current and pulse on time generate intense heat which can cause burns and injuries if the operator is not using properly the protective equipment.
- Risk of exposure to toxic vapours and smoke – high pulse on duration and low pulse off duration increases this risk. Pulse off time needs to be longer to reduce the dissipation rate of these vapours into the air.
- Risk of falling and mechanical injury or hearing damage - a high peak current and voltage produce loud noises, which can damage hearing in the long term. In addition, hot sparks can fall onto the work surface, increasing the risk of falling in unsecured areas.

In table 3, the link between the increase of efficiency and the resulting sustainability and OHS performance is presented, based on simulation data and the manufacturing experience of the authors.

Table 3. Evaluating the OHS risks for the risk management process

Process parameters for each scenario	Assessment of OHS risks	Assessment of efficiency	Assessment of sustainability
(1) Average settings of parameters	Moderate	Low	High
(2) Extreme settings of parameters	High	High	Low
(3) High levels of peak current and pulse on time correlated with medium voltage and medium pulse off time	Moderate	High	High
(4) Low peak current correlated with high pulse on time	Low	Low	Low

4. CONCLUSION

In conclusion, there are definitely situations where EDM manufacturing can be both efficient and sustainable at the same time, but their relationship is a complex one. Being sustainable can help to reduce the OHS risks that employees face, with a reduced impact on productivity. The settings of peak current and pulse on duration should be set first for efficiency, followed by voltage and pulse off duration for sustainability and risk reduction. A correct combination of these parameters can produce positive impacts for the company using the EDM process.

5. REFERENCES

[1] HLC Metal Parts, “Electrical Discharge Machining (EDM): Overview, Types, and Applications,” HLC Metal Parts Co., Ltd, 6 10 2023. [Online]. Available: https://www.hlc-metalparts.com/news/what-is-electrical-discharge-machining-edm-71472673.html. [Accessed 09 2024].

[2] S. L. Tatikonda, “EDM Simulator,” [Online]. Available: http://vlabs.iitkgp.ac.in/psac/newlabs2020/vlabiitkgpMM/exp1/webpage/index.html. [Accessed 09 2024].

[3] Y. Chen, S. Hu, A. Li, Y. Cao, Y. Zhao and W. Ming, “Parameters Optimization of Electrical Discharge Machining Process Using Swarm Intelligence: A Review,” *Metals,* vol. 13, no. 5, p. 839, 2023.

[4] K. S. Avdhesh, “EDM Process Parameters Impact on MRR and TWR for Titanium Alloy [Ti6al4v] and their Optimization Using Taguchi and Topsis Method-An experiential Analysis,” *IOP Conference Series: Materials Science and Engineering,* vol. 1116, p. 012030, 2021.

[5] W. Ming, Z. Xie, C. Cao, M. Liu, F. Zhang, Y. Yang, S. Zhang, P. Sun and X. Guo, “Research on EDM Performance of Renewable Dielectrics under Different Electrodes for Machining SKD11,” *Crystals,* vol. 12, no. 2, p. 291, 2022.

[6] A. Kamenskikh, K. Muratov, E. Shlykov, S. Sidhu, A. Mahajan, Y. Kuznetsova and T. Ablyaz, "Recent Trends and Developments in the Electrical Discharge Machining Industry: A Review," *Journal of Manufacturing and Materials Processing,* vol. 7, no. 6, p. 204, 2023.