International Journal of Scientific Research in Mechanical and Materials Engineering
© 2019 IJSRMME | Volume 3 | Issue 3 | ISSN : 2457-0435
doi : https://doi.org/10.32628/IJSRMME19339

Superior advance research in the electro-discharge machining of Ti alloys: Review

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ABSTRACT

Electro Discharge Machining (EDM) known as an advanced machining process that much used for machining material with any hardness and complexity geometry in a high level of the accuracy in the cases of demand of the industrial application. The conception of the EDM process is included in applying electro-thermal energy in the gap, by discharge electrical power on the breaking point of the dielectric without any contact between electrodes. Due to the existing ability for removing debris from the surface, there is a lot of metallurgy defect on it. To improve and optimize EDM performance, the machine's operating parameters, Input, during& output parameters, need to be optimized. Another handy way to reform of the view metallurgical must take picture sub-structure from the initial and subsequent layer. At the end for catching special status, adjust the technical parameters with metallurgical defects. Studies in case of the EDM have indicated that the appropriate selection of the way to control of the process, material, and operating parameters had considerably improved the process performance and also causing to was better the quality machined surface. This paper made a comprehensive review of the research studies in a different section of the EDM of various grades of titanium and its alloys. This review presents the simulation, experimental and theoretical studies on EDM that helped to improve the process performance, including material removal rate, surface quality, and tool wear rate, the stability of process among others. However, here are collected most of the research are done surrounding of EDM of Ti alloys as the developments of EDM and are seen material for future.

Keywords: EDM, Titanium alloys, Micromachining, Modelling and simulation, PMEDM, SEM.

I. INTRODUCTION

Electro Discharge Machining (EDM) is known as the advanced machining method to use for conduction material with any hardness and complexity under topology and metallurgy concept, that it's considered for sensitive industries such as aerospace, biomedical, electronic and mold. This process has been used in modern industries to facilitate highly accurate machining, cut complex shape with every started degree, and with better surface conditions [1–6]. Since the electrical discharge phenomenon between the two instrument electrodes and the workpiece is suspended in a liquid dielectric without any contact, the lack of physical stress on the machined surface can be considered as one of the advantages of using this method [7]. The tension resolidified in the melt resulting from the process of evacuation is due to the high heat generated by this phenomenon and the very high cooling rate. The EDM principally due to has used energy directly is applied in many forms, including wire EDM, micro EDM, sinking EDM or die-sink EDM, powder-mixed EDM, dry EDM, and semi-dry EDM. Due to the vast varieties of EDM processes, it is suitable for both relatively large and micro-scale machining areas. Titanium and its alloys have high strength-to-density value and corrosion resistance properties. Due to these unique characteristics, titanium and its alloys are extensively used in a wide range of applications. However, titanium and its alloys are considered as hard-to-cut material using conventional manufacturing processes [8], [9]. As developed industries go to the content with involved shape inside high accuracy, so, in the traditional method, this matter possible with high-class CNC that all of the cost increase for this status, utilizing the non-conventional process that is used for machining without attention to the amount of hardness or complexity of the shape. This research is a kind of review of electrical discharge processes in different types and dimensions, and expressions of effects, testing methods and simulations, as well as laboratory equipment for machining on all types of titanium alloys, in order to allow researchers to access research data into applied data in the fastest time and in a comparative way. The paper starts with a brief introduction on titanium and its alloys and EDM techniques, and then it introduces the working principle of this machining method. After it, discussed surrounding of the diversity of the type of EDM and all development are achieved until now and its performance. The conclusions and the trend of the reviewed bodies of research are subsequently drawn after the focus of the current publications is discussed. At end discussed the suggestions that it'll under research on the future.

II. GENERAL VIEW OF THE EDM METHOD

2.1 EDM PRINCIPLE

The EDM process is known as one of the non-conventional means that's created in the 40th century by the Lazarenko's brothers. The law of this process described with discharge phenomena by break down of obstacle of dielectric electricity through of the tool and workpiece electrodes suspension into dielectric insulation and semi-insulation without contact between it. Due to it's not any tangency and use of the thermal feature of energy for disconnect debris from surface material during discharge occurrence, so it's not physical free stress and vibration on the EDMed surface. The discharge phenomena occurred on the minimal distance that it's called as gap machining, that due to detached debris from the surface during EDM procedure, it's used the flushing the dielectric from the filtered tank fluid to release material quickly and rarely observes sort circuit occurrence. This process is done in a fraction of time on the high temperature of the heated area [10–15].

2.2 CONTROLLABLE AND MEASURABLE PARAMETERS OF THE EDM

For doing the best controllable and catch the acceptable result set of parameters at the three levels (Table 1).

Table **1**. list of the set parameters in EDM

Inptut	During	Output
• current Discharge • Voltage Open circuit • Voltage Gap • Polarity	• Gap Distance • Voltage Frequnce • Flushing pressure • Pulse On Time • Pulse Off Time	• MRR • TWR • SR

2.2.1 Input parameters

- current Discharge
  the intensity current during in applying spark calculates according to:

$$\rightarrow I = \frac{Vs}{R} e^{\frac{-t}{R\times C}}$$

t, introduce as the total time during the charge to discharge circuit.

- Voltage Open circuit
  The maximum voltage sets on the circuit's machine. It's observable when implying any spark at the machining gap.
- Voltage Gap

The voltage between both of the electrodes rather than the source voltage calculable following this,

$$\rightarrow Vc = Vs(1 - e^{\frac{-t}{R \times C}})$$

- Polarity

Positive and negative pole belongs to every electrode in the EDM system. In related to the process is finishing or roughing, the pole of every electrode is different. When it has a finishing process, usually the electrode workpiece is the negative pole, and about roughing is reverses.

2.2.2 During parameters

- Gap Distance
  The distance between the electrodes requirement implies discharge.
- Voltage Frequency
  Amount of voltage used to charge the circuit to arrive break down.
- Flushing pressure
  Setting the amount of demand for cooling and improving the divided debris.
- Pulse on Time
  The period requires the charge circuit and arrive to break down.
- Pulse Off Time
  The period requires deionization and cooling both of the electrodes and dielectric.

2.2.3. Output parameters

- **MRR**

The amount of material removed in every period of discharge. It calculates following this:

$$MRR = \frac{\text{different from the workpiece weight during machining}}{\text{machining time}}$$

- **TWR**

For the reason that the polarity changes during charge and discharge, material removal always exists in the EDM process. It calculates following this:

$$TWR = \frac{\text{different from the tool weight during machining}}{\text{machining time}}$$

- **SR**
  Since the amount of spark energy augments in the gap between the electrodes, so the heat-affected zoon and then the melted pit is higher and more profound. Following

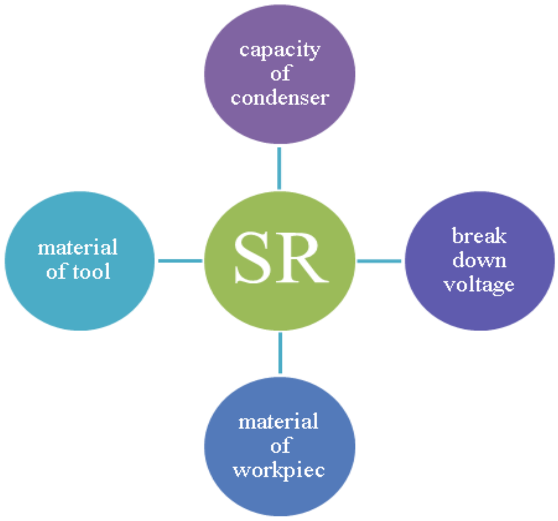

Figure 1. the Surface roughness related to this objective.

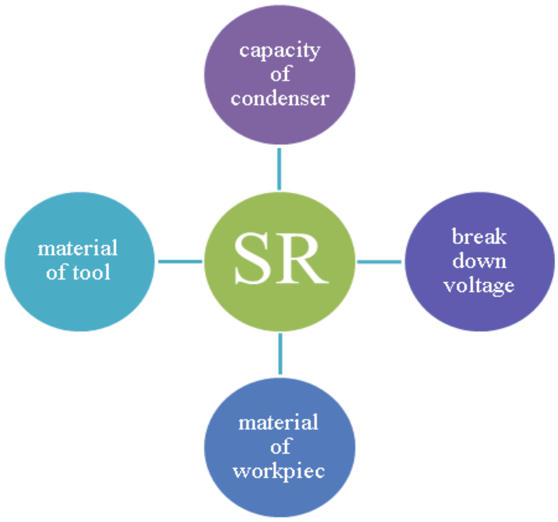

Figure 1. useful parameters on the SR.

2.3. SUBSYSTEM IN EDM

Optimization and innovation uniquely don't relate to the particular part or component, and, as the EDM processes include of the different part with physical, chemical, mechanical, and electrical performance. So, it can be dividing this case of study in EDM that called the subsystem, as shown in Figure 2.

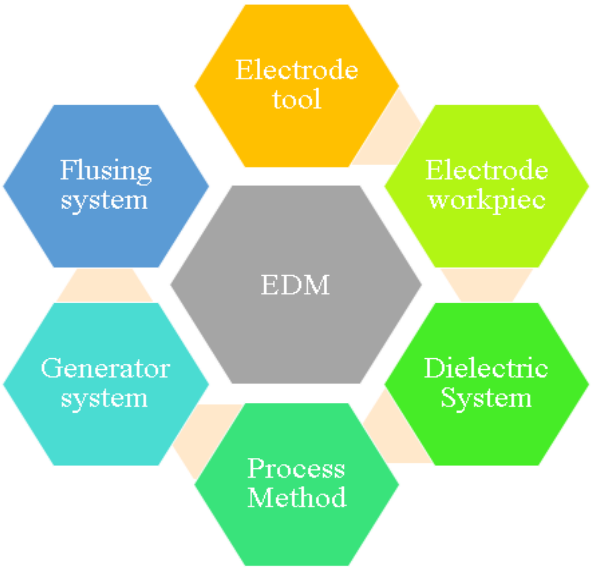

Figure 2. subsystems of the EDM.

2.3.1.ELECTRODE TOOL

2.3.1.1.COMPOSITE TOOL

The electrode is an important part to influence the machining effect of EDM. Electrodeposition technology is an effective method to fabricate electrode material [15], [16]. So, to catch the conductivity and strength feature of the tool electrode, it can use the composite structure on it. The review result showed when it'd combined primary material with high conductivity quality such as the commercial copper, into of the material composition with sufficient strength caused to decrease the TWR and to be better electro-discharge machining stability [17]. Other research with detail comes in below (
Table **1**

Table 1 research electrode tool area

Nom.	Ref.	Cu	Graphite	composite		WC	W	brass	pure Ti	Hydroxyapatite (HA)	Wire electrode
1.	[17]			Cu-SiC	*						
2.	[18]								*		
3.	[19]								*		
4.	[20]			Cu-Cr	*						
5.	[21]									*	
6.	[22]	*	*			*		*			
7.	[23]										BWE * ZCBWE * BDWE *
8.	[24]								*		
9.	[25]								*		
10.	[26]	*									
11.	[27]						*				

2.3.2.Electrode workpiece

2.3.2.1.Ti alloys

Titanium alloys are known as the most used of material in unique and sensitive industries; it has been used in aerospace and medical sectors primarily, due to having unique mechanic properties such as high strength in front of corrosion and tension, hard machining by traditional methods and also a cryogenic feature. So for these reasons, it always considered from sensitive industries[28]. It's provided a list of popular alloys of the Ti used in the same sensitive industries, biomedical, aerospace, and production automobile, on the three-phase unique without intermetallic with other phases on Table 2. It's observable that among of these alloys, α+β-Ti alloys are used in these industrial commonly, and also β-Ti alloys are used on biomedical applicants. However, ''it has rather a poor machinability owing to the inherent properties of poor thermal conductivity, chemically reactivity and low elastic modulus''[29]. Another side, as the traditional machining process due to make a hardness material (Ti alloys) and sophisticated shape, must use to the special tools and CNC with high axial level, so that is no inconsiderable from economic view[30]. Also, these alloys have poor wear-resistant [31]. Therefore, Ti-6Al-4V is unsuitable to undertake heavy loads without surface treatment, especially in sliding contact condition. On another hand, EDM is known as the non-conventional method that used the electrical erode phenomena on the surface [32], [33]. Another research surround of the electrode workpiece is used, came in Table 3.

Table 2. list of the common Ti alloys

Phase alloy	Chemical composition(tw%)	General title
α-Alloys		
	CP – Ti (0.2 Fe, 0.81 O)	**I**
	CP – Ti (0.3 Fe, 0.25 O)	**II**
	CP – Ti (0.3 Fe, 0.35 O)	**III**
	CP – Ti (0.5 Fe, 0.4 O)	**IV**
	Ti – 0.2 Pd	**V**
	CP – Ti (0.2 Fe, 0.81 O)	**VI**
	Ti – 5 Al – 2.5 Sn	**Ti – 5 – 2.5**
	Ti – 3 Al – 2.5 V	**Ti – 3 – 2.5**
α+β-Alloys		
	Ti – 8 Al – 1 V – 1 Mo	**Ti – 811**
	Ti – 6 Al – 2 Sn - 4 Zr – 2 Mo – 0.1 Si	**Ti – 6242**
	Ti – 6 Al – 4 V (0.2 O)	**Ti – 6 – 4**
	Ti – 6 Al – 4 V (0.13 O)	**Ti – 6 – 4 ELL**
	Ti – 6 Al – 6 V – 2 Sn	**Ti – 662**
β-Alloys		
	Ti – 6 Al – 2 Sn – 4 Zr – 6 Mo	**Ti – 6246**

Ti – 5 Al – 2 Sn – 4 Zr – 6 Mo	**Ti – 17**
Ti – 4.5 Al – 3 V – 4 Zr – 6 Mo	**SP – 700**
Ti – 5 Al – 2 Sn – 4 Zr – 4 Mo – 2Cr – 1 Fe	**Beta – CEZ**
Ti – 3 Al – 10 – V – 2 Fe	**Ti – 10 – 2 – 3**
Ti – 3 Al – 15 Mo – 2.7 Nb – 0.2 Si	**Beta 21 S**
Ti – 1.5 Al – 6.8 Mo – 4.5 Fe	**Ti – LCB**
Ti – 3 Al – 15 V – 3 Cr – 4 Mo – 4 Zr	**Ti – 15 – 3**
Ti – 3 Al – 8 V – 6 Cr – 4 Mo – 4 Zr	**Beta C**
Ti – 3 Al – 13 V – 11 Cr	**B 120 VCA**
Ti-35Nb-7Ta-5Zr	**-**

Table 3. Research electrode workpiece area

Nom.	Ref.	phase	Ti Alloys	Application
1.	[20]	Alpha	Ti–5Al–2.5Sn	Non-heat treatable, very weldable, excellent mechanical properties at cryogenic temperature
2.	[18][19] [25]	Beta	Ti-35Nb-7Ta-5Zr	Dental, orthopaedics, shape memory, and stents
3.	[17][21][23] [34][35][36] [27][37][38]	Alpha+Beta	Ti-6Al-4V	Aerospace, industrial and chemical industries
4.	[23] [39]	Intermetallic nickel-titanium	NiTi-60	Bearing, high-end knives, implantable medical devices (Shape memory alloy)
5.	[26]	Intermetallic Aluminium-titanium	γ-AlTi	Use to replace the heavier nickel-base superalloys at moderately high temperatures

2.3.3 DIELECTRIC SYSTEM

2.3.3.1 POWDER MIXED

On the electro-discharge machining (EDM), when using the fine conductive powder into the dielectric fluid, this procedure is known as powder combined electro-discharge machining (PMEDM), it has been more stable machining during discharge action. Due to be less conductivity of obstacle dielectric and to make more thin plasma channel through it instead without powder condition (Figure 3).

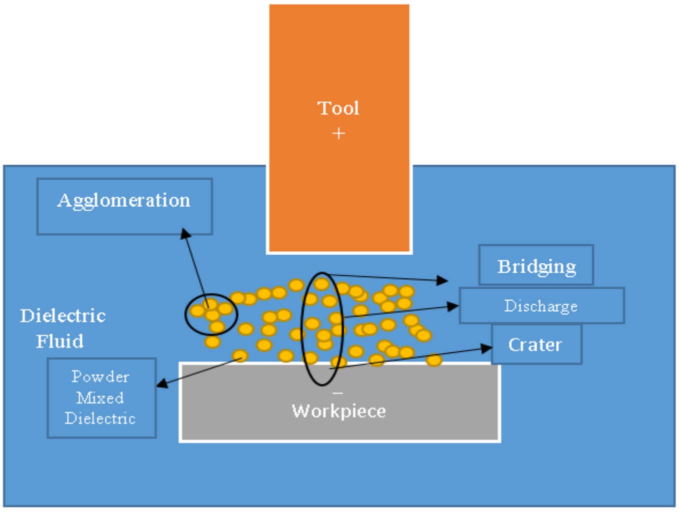

Figure 3. Powder Mixed Electro Discharge Machining process.

2.3.3.2 SURFACTANT

In chemical industries, the surfactants are used for to get lesser tension between the two surfaces (solid-solid, solid-liquid, and liquid-liquid). When adding the powder in the dielectric, agglomerating and don's spread evenly. Surfactant causing to individual and dispersing evenly. This condition caused to have a stable process and remove material on the surface regularly. The surfactant, according to the head receptor that it must be contacted with others, is divided of the four groups as following as below:

- Anionic surfactants
  These cases are included of the negative reception part (sulfonates, sulfates, or carboxylates) on the one of its head and was to interact by the sodium or potassium as positive part included in the head and usually makes a neutral condition on reaction point.
- Nonionic surfactants
  These cases are included of no ionic part on the head reception, and also its kinds have two molecular (one side of it, consist of the oxygen-rich and another have a lot of natural molecules) head for made connection.
- Cationic surfactants
  These cases usually make a reaction with the positive reception head, due to it has a specific part on the head that it keenly to form an insoluble compound in the neutralized action.
- Amphoteric surfactants
  These cases were different from others because, under the amount PH of the soluble, it can affect the reception head status to which one of another kind.

In some research using the non-ionic surfactant, because of the discharge procedure was controllability and foreseen, and it's not numbered as an ionic composition. In following is provided a list and a scheme of non-ionic structure (Table 4, Figure 4).

Table 4. Non-ionic surfactant

Trademark	Chemical Name
Span 85	Sorbitan trioleate
Span 80	Sorbitan Oleate
Span 60	Sorbitan Monostearate
Span 20	Sorbitan Monolaurate
Tween 60	Polysorbate 60 (Polyoxymethylene Sorbitan 20 Monostearate)
Tween 80	Polysorbate 80 (Polyoxymethylene 20 Sorbitan Monooleate)
Tween 20	Polysorbate 20)Polyoxymethylene 20 Monolaurate)

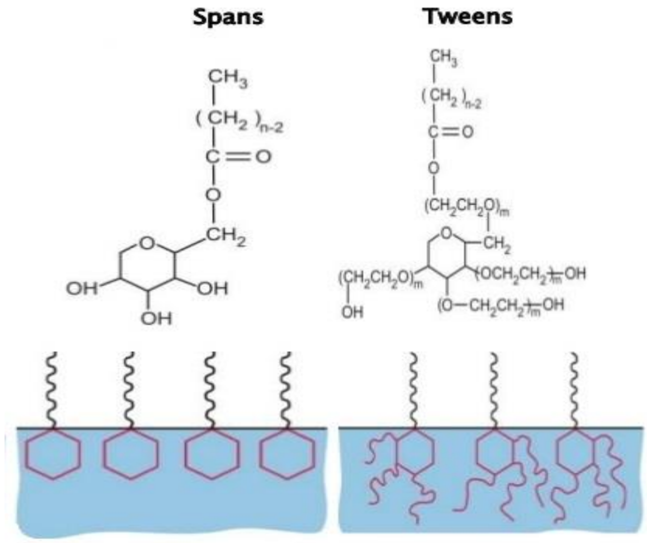

Figure 4. structure of the conventional non-ionic surfactant.

Research area (Table 5)

- ✓ enhances the machining performance by improving MRR and reducing TWR
- ✓ the best optimal condition to achieve required low SR and high micro-hardness was determined
- ✓ HAZ area in EDMed surface is deeper Enhances the machining.
- ✓ Performance by the stability of the process (increase Gap, decrease Arc).
- ✓ reduces the agglomeration of powder particles and sediment particles
- ✓ With the active oxidation of the dielectric, the sizes of the debris became large
- ✓ Effect on the corrosion resistance.

Table 5. Research the material as a dielectric area

Nom.	Ref.	Powder	Kerosene Oil	Distilled water	Hydrogen peroxide	Non-ionic water-	Tap water	Trance oil	Water-in-oil	Surfactant	Research area
1.	[38]	Silicon	*								I
2.	[39]	Silicon	*								II
3.	[44]	-		*							I, II
4.	[45]	Alumina	*	*							I
5.	[47]	Silicon	*								II, III
6.	[48]	Silicon									I, IV
7.	[49]	Graphite						*		* Span 20	I, II, VI,
	[50]	Graphite						*		* Span 20	I, II
8.	[51]	-		*	*	*	*				I, IV, VI
9.	[52]	-					*				I, IV
10.	[53]	Al, Cr, SiC, Graphite, Fe	*								I, VII, II
11.	[54]	boron carbide	*	*							I, II, VI
12.	[57]	-							*		I
13.	[58]	-									IV

2.3.4 PROCESS METHOD

2.3.4.1 MICROMACHINING

The use of light, thin, and in the small-scale mechanical elements have recently become a global trend. Nowadays, In the advanced industries serving in small scale for manufacturing the microstructures with couple Micro Electro Mechanical System (MEMS) in machining procedure. An increasing number of products such as micro-pumps, micro-engines, micro-robots, and micromechanical elements have been developed recently to fulfil technical requirements. Amongst all of the micro-machining processes, the production of micro-holes and micro-slits has received the most attention in the area of micro-machining[33], [40]. The correlated EDM technique has also played a prominent role in fulfilling the new criteria of micro-machining. The advanced production limited material into the Micro/Nanoscale with high surface quality. It's desired this procedure the micro-EDM machining and the wire-cut extensively.

2.3.4.2 SEMI-Dry EDM

The principle of the semi-dry EDM is the used of the gas or air that it's injected through the pipe replace the tool electrode and play the same of the dielectric fluid role into the gap distance. Due to being denser related to gas, removed material, and done the cooling action during semi-dry machining procedure evenly.

Figure **5** shows the principle of dry EDM. In this subject, the matter is followed as the development way are decrease the pollution resulted from the liquid dielectric, which leads to the made of vapor during EDMed and the economic sides.

So, two points that are considering it,

- The pressure air must be in amount don't disturbance fluid in the gap machining.
- The pressure air must be in mount exist dielectric in the gap machining.

In the case of matter are called, if the pressure air is the optimum area. If it's so small, it doesn't have any effect on the cooling and removal debris matter, and if it's more than the optimum area, the stability of the machining will decrease and possibly make an arc, or open circuit phenomena will increase. In the research area, Elshtain published a literature review done on gas-based coolant-lubricants (CLs) which used in the state either gas or cooled-pressured gases inside of the dielectric fluid. From Previous research resulted obtain a lot of the experiment and observed information from it, caused to catch improvement and optimization statues have been used on EDM parts until to be controllable cutting temperature, tool wear, and surface roughness and material removal rate. As a result, that it got, gas-based coolant-lubricants (CLs) has been determined as one of the most suitable cooling processes inside dielectric for machining cutting operation in terms of improvement in tool life and surface roughness[39].

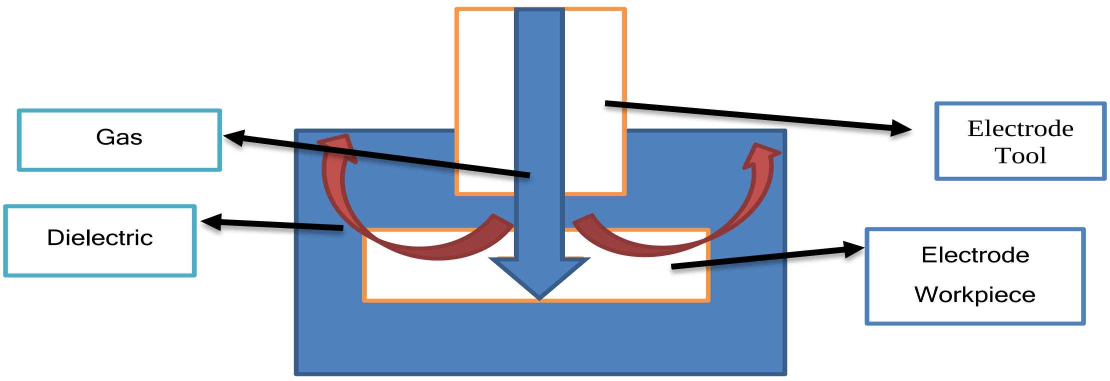

Figure 5. The shape of the Semi-Dry EDM process.

2.3.4.3 Dry EDM

As following shown in Figure 6, the EDM process doing in an environment of any Dielectric liquid, this is even though the presence of liquid dielectrics in the removal of particulate matter has a significant effect. Investigations of Yu on the impact of using oil-liquid dielectric in EDM milling and die-sinking EDM on the cemented carbide machining showed the importance of this case of dielectric on MRR, TWR and machining stability. In addition to this research, the effect of gas instead of dielectric in the process of electric drainage, known as "Dry-EDM," is on the machining of the same piece of cemented carbide with the same machining forms. Because when using a gas dielectric compared to a liquid dielectric, the dielectric coefficient of the capacitor created between the two electrodes is less, so machining in a larger chaperon and expecting more stable conditions. The results indicate that during the use of gas in comparison to oil, both EDM milling and die-sinking EDM processes have significantly reduced machining time. As a reason for this is matter would describe that, due to the time required for charging, discharging, and discharging the dielectric fluid, which is much less time consuming than the gas dielectric. The issues also show that the rate of filtration during the use of gas compared to the oily dielectric, in both machining and machining mode, has increased about six times, and the wear rate of the tool has decreased to one-third of the liquid use rate [41]. Fabio surveyed on the use of dielectric fluids that provide an alternative to hydrocarbon oil. As a result, this paper has been reported that may replace water-based as the dielectrics to oil-based fluid in the EDM process. Gaseous dielectrics like oxygen may also be the alternative[42]. Also, Elshwain did, in another part of the dry EDM process, used of the gas-based coolant-lubricants (CLs) which used both of the gas or cooled-pressured gases without any the dielectric fluid[39].

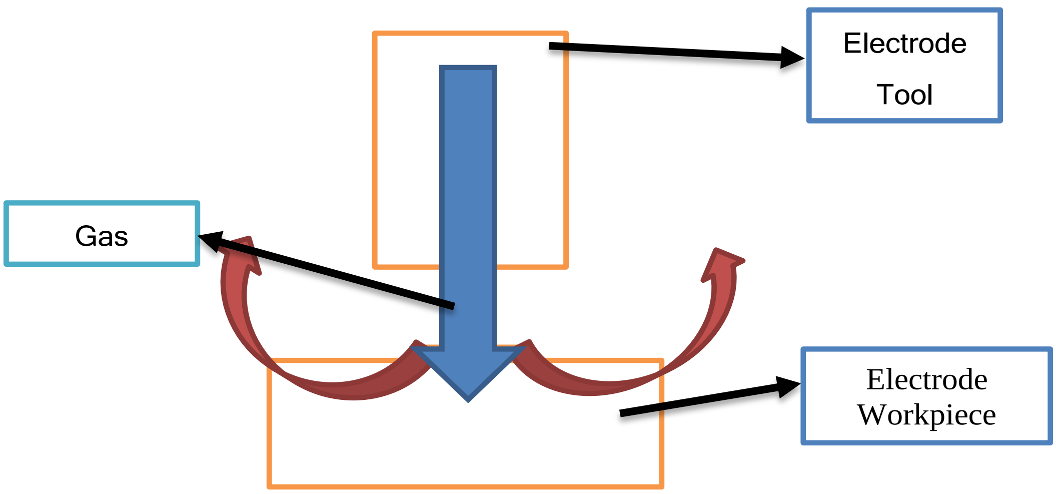

Figure 6. The shape of the Dry EDM process.

2.3.4.4 Wire EDM

The wire-cut machining process is known as one of the EDM process modes for machining parts with super-complicated shapes and excellent surface quality, along with its advantages, the major drawback for this method, in addition to its higher cost than EDM, is also due to the rate High dielectric cooling of water In this process, the surfaces contain a large number of superficial micro-cracks [43]. In this process, copper wire with a diameter of about 0.1-0.3 mm is used, and given that the surface area of the discharge is vast in relation to the dimensions of the electrode, the result is that the wear rate of the tool is high and, as a result, the workpiece and the abrasion of the wire depend on the amount of wire addition. On the other hand, since the simultaneous control of the speed and wear on the copper wire is extremely difficult and superficial, hence controlling the X-Y direction on the workpiece [44]. The wire EDM process is widely in the fields of medicine, electronics, and the automotive industry[45].

2.3.4.5 COMBINED & HYBRID-EDM PROCESS

Combining EDM with another method as the Hybrid-EDM process is known the way to stabilized machining procedure, and then achieved near demanded on the quality surface. As the use of the vibration energy inside of heat resulted from discharge cause to imply power at a high level to the molecules of the material. And also discharge involved in lesser than of energy and removal materials from surface done evenly with less deep[46]. It came more than a research process method area in Table 6.

Table 6. Research surrounds the standard advance machining process method

Nom.	Ref.	Die Sinking EDM	Tehran spark	μ-EDM	Wire-Cut	Combined & Hybrid-EDM	Semi-Dry EDM	Dry EDM	Model
1.	[18] [19] [24]	*							SZNC-35-5030
2.	[20]	*							OSCAR MAX S 645. FERROLAC 3 M
3.	[21]	*							AJANEDM CNC983
4.	[22]		*						204H
5.	[23]				*				ELPULS 40A DLX
6.	[34]	*							Spark Erosion 450
7.	[35]	*							EDM-50 with Electronica PSR-20 controller
8.	[26]	*							Charmilles Roboform 200
9.	[27]	*		*					ELECTRONICA
10.	[37]					* Neuro Solutions package			-
11.	[42]	*							-

2.3.5 GENERATOR SYSTEM

A different generation of power system mostly by used in EDM that some of those are listed below:

• Resistance-capacitance type (RC type) Relaxation generator
• Rotary impulse type generator
• Electronic pulse generator
• Hybrid EDM generator

2.3.6 FLUSHING SYSTEM

Flushing is an action for though out materials were removed and cleaning gap machining from any pollution and then helping to heat treatment and cooling process in the EDM process. It's following this purpose:

- Cooling procedure for the electrodes simultaneously
- Abandoned away the removed debris through the gap
- Injection fresh dielectric fluid include lesser deposited waste

Due to select of the pulse off time-related to the kind of dielectric chemical properties, so it must be the rang off of pulse for turn back to deionization status. As we don't except in during EDM, pulse off time desired to zero and didn't must increase moreover, so must take an optimization of status for to obtain minimum pulse off time and maximum vibration on time until to increase the efficiency of the EDM process. It came to some research around flushing subject in Table 7.

Table 7. Research flushing system area

Nom.	Ref.	Side	suspension
1.	[20]	*	
2.	[34]	*	*
3.	[35]	*	
4.	[26]	*	*

2.5 DESIGN OF EXPERIMENTAL AND OPTIMIZATION

Although, several linear equations were developed relating the dependent variables (SR, MRR, TWR and white-layer thickness) to the independent variables (T_{off}, T_{on}, I, V_g, V_C, SV, WT) under different program regimes, however, the experimental procedure was not suitably planned according to any appropriately available design of experiments (DOE) techniques (
Table 8). Therefore, the possible interactions between process parameters and their eventual effects on process responses have not been identified from the statistical point of view. Nevertheless, the role of pulse-on time was omitted, and no attempt was made to determine optimum machining conditions quantitatively (Table 9)[47].

Table 8. List of DOE program

Nom.	Ref.	RSM	Taguchi	NSGA-II	Grey relational analysis	Genetic Algorithm
1.	[35]		*			
2.	[17]					
3.	[19]	*	*	*		
4.	[22]		*			
5.	[23]		*			
6.	[24]	*		*		
7.	[36]		*		*	
8.	[26]		*			
9.	[37]					*

Table 9. Relation of the variable parameters with output tribology results

Nom.	Ref.	Microhardness	Surface roughness	MRR	TWR	electrochemical corrosion resistance	Variable parameters
1.	[17]	*					T_{off}, T_{on}, I
2.	[19]			*	*		I, T_{on}, τ, P_c
3.	[20]	*	*	*	*		I, T_{on}
4.	[21]						I, T_{on}
5.	[22]		*	*	*		T_{off}, T_{on}, I, V_c
6.	[23]						T_{off}, T_{on}, I, SV, WT
7.	[24]		*				I, T_{on}, τ, P_c
8.	[25]	*					-
9.	[34]		*	*			I, T_{on}, $P_{c,}$ P_{cs}
10.	[35]		*	*	*		I, $P_{c,}$ P_{cs}
11.	[48]			*	*		-
12.	[36]		*	*	*		T_{off}, T_{on}, I, V_c, LW
13.	[26]		*	*		*	I, T_{on}, P_c
14.	[27]			*	*		T_{on}, I, V_c
15.	[37]		*				-
16.	[42]			*	*		

2.6 Modelling and simulation

2.6.1 Mathematical modeling

In the research area, study and use the fundamental theoretical science for modelling and simulation of the machining or parameter effectiveness on the machining performance is used to have a predictable and controllable process. Although, Because of numerous difficulties in measuring temperature, no adequate knowledge on temperature distribution of workpiece, tool, and plasma channel is available. On the one hand, a lot of paper that published, it has been reported so far to the modelling of the temperature distribution on gap region, either analytically or numerically. On the other hand, an enormous amount of experimental attempt has been put into measuring the temperature by directly-measuring methods[49]. Fazli Shahri presented a comprehensive review of analytical, numerical and experimental investigations on temperature prediction has been provided to organize different ways to integrate them as useful information for elucidating the differences between approaches and identifying their proximities to the real temperature distribution[49]. Lin Gu showed that the crater size increases with the rising of the peak current but insensitive to the pulse duration when the discharge current is small. The reason that caused to analysing these matters pay the attention of the current density distribution under observation radius of plasma [50].

2.7 MORPHOLOGY

Surface morphology as a part of the analytical image on the machined surface, it is a developed statue of imaging by high resolution that used for observation of atom, molecules and its structures in the microscope display that these events unobservable by unrepaired eye. Such images originate from the exhibited of the sample or product.

2.7.1 SURFACE IMAGING INFORMATION

- Surface structures & defects
- Atomic or Nanoscale structures & defects exposed by the cross-section of FIB

2.7.2 ANALYTICAL IMAGING TECHNIQUES

- FESEM
- FIBSEM
- Optical microscope
- STEM
- TEM
- UHRSEM

2.7.3 METALLURGICAL ANALYSIS AND DEFECTS

In the metallurgy subject, in qua it exist increasing and decreasing temperature, so it has been changed structural and physical characteristics during the process. For the investigation metallurgy, EDMed area divided to the surface and cross-section part. In the surface will investigate crack, porosity, structural change, change phase, and like it. But in the cross-sectional part, it was the thickness of the recast layer, crack on it, and fundamental and phase change (Figure 7). It is coming research around the metallurgy area in Table 10.

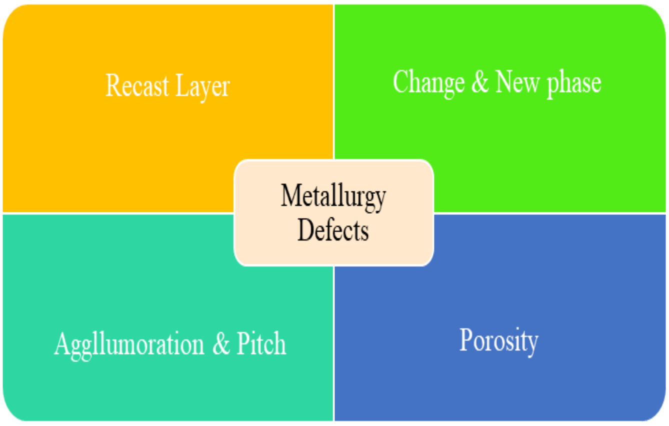

Figure 7. Metallurgical research area.

Objective range (

Table 10)

I. Micro-crack
II. Ridges of redeposited material
III. Discharge crater
IV. Surface Nano porosities
V. The thickness of the recast layer
VI. Created a new phase
VII. HAZ area
VIII. Nano-porous layer
IX. Is used from CT science
X. Effects of Wire Electrodes on Kerf Width
XI. surface topography images of the machined surfaces of workpiece specimens using a scanning electron microscope
XII. PMEDMed surface enabled better adhesion
XIII. growth of biomedical component.

Table 10. Research metallurgy area

Nom.	Ref.	SEM	FESEM	EMA	EDS	XRD	Objective range
1.	[38]	*		*	*		I, II, III, IV, V
2.	[17]	*			*	*	VI ($TiSi_2$, Tic)
3.	[39]	*					V, VII, VIII
4.	[44]	*			*		I, III
5.	[46]	*			*		X, XI
6.	[47]	*			*	*	VII, XI

7.	[48]	*	*		*	*	VI (TiO_2, Nb_2O_5, ZrO_2, SiO_2, Tic, NbC, SiC), XIII
8.	[49]	*			*		V, I, XII
9.	[50]	*			*		I, V
10.	[51]	*				*	I, III, V, XI
11.	[52]	*					I
12.	[53]				*	*	XI
13.	[54]	*					VI (Tic, TiO_2), XI

2.8 SAFETY OF ENVIRONMENT

The increasing progress of the most popular industries caused to need any material with considering it's economical and accuracy profoundly. Also, these demands, as known as the primary source of the environment pollution, and machining processes usually have an essential role in this matter [51], [52]. The necessary part of environmental impact has been a crucial subject for production all around the world, especially after determined the ISO 14000 in case of the environmental management system standards. The achievement that has been used to have clean manufacturing that is by the requirements of the ISO 14000 is to identify and eliminate the source of pollution. If the source is inherent to the process itself, then alternative methods have to be considered (
Table 11) [53].

Table 11. Research the effect of EDM in the safety of the environment.

Nom.	Ref.	Selection objective following in the safety environment
1.	[54]	Survey on the of the dielectric fluids that provide an alternative to hydrocarbon oil. Water-based and gaseous dielectric (Oxygen) dielectric may replace oil-based.
2.	[42]	Select the dielectric-water-in-oil(W/O) as the dielectric
3.	[38]	Use laser confocal microscopy that observed the microstructure morphology of reaction film after the 1000-h sunlight and water immersion aimed at the colouring mechanism the surface of the workpiece.
4.	[39]	The review was done on gas-based coolant-lubricants (CLs) which use in either gas or cooled-pressured gas based

III. CONCLUSION AND FUTURE RESEARCH DIRECTION

At first, it would be said to achieve advanced production in any small scale, and by any complexity or quality, it needs to get on the Quadruple cycle. This procedure has been illustrated in Figure 8, and it defines for every research to productivity procedure [55]

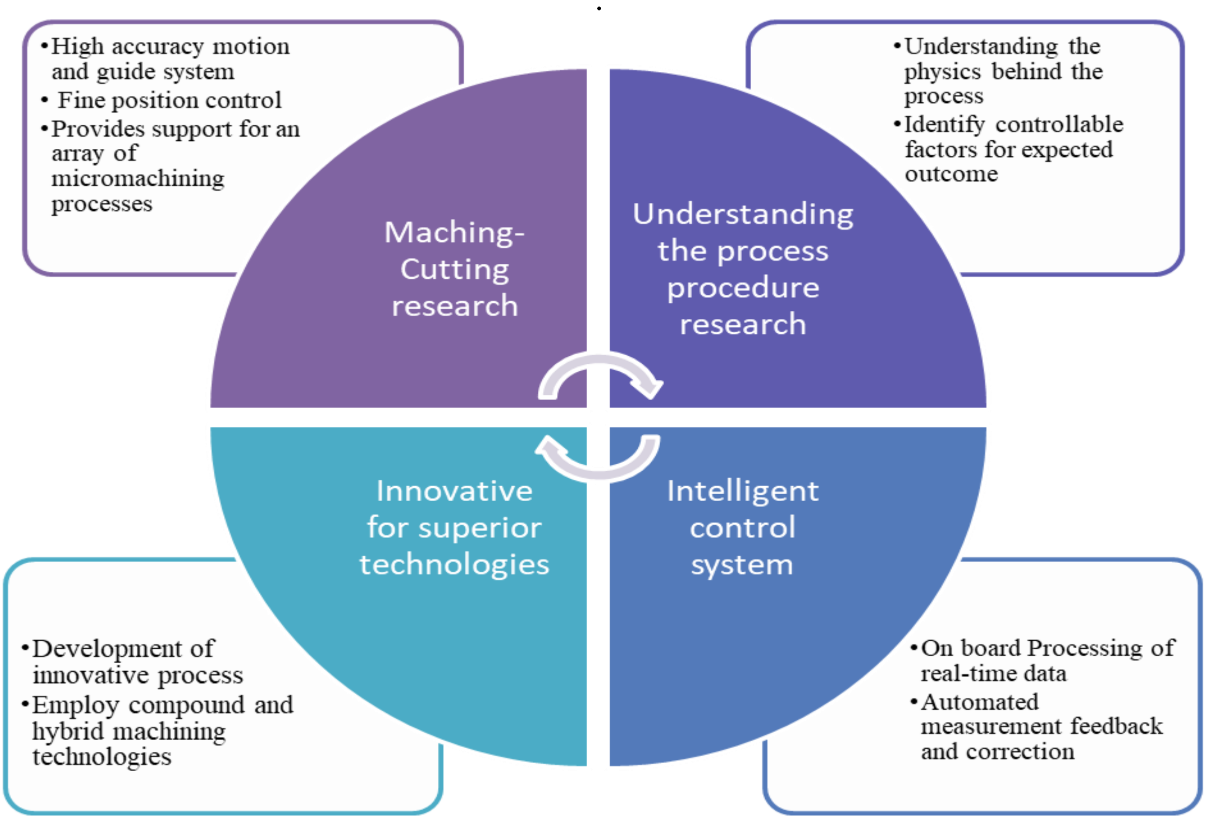

Figure 8. Synergistic research and development areas on the Quadruple cycle.

Second, research work needs to be undertaken towards the understanding of process physics to provide a relevant background for modelling, measurement, identification of control parameters, and application of feedback control to control compound manufacturing processes. Then, the intelligent system needs to be developed and implemented onboard for real-time processing data, which will enable the system to be capable of measurement, feedback, and correction of parameters without operator intervention. Finally, in the future research area needs to the observing working on it as a required part industry (Figure 9).

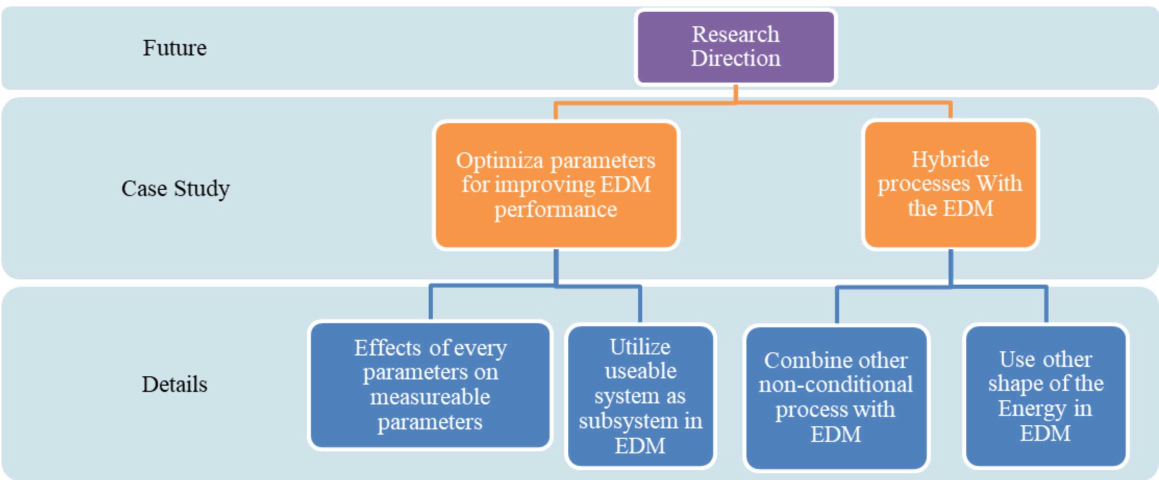

Figure 9. Total graph of future research.

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