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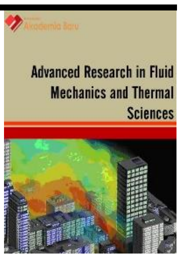

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Performance Enhancement of Energy Saving and Machining Characteristic in Electrical Discharge Machining on Magnesium Alloy: A Review

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ABSTRACT

Magnesium alloys have been widely used in biodegradable applications due to it tends to corrode inside the human body and combined with its initial mechanical property. Current research revealed that the structural stability of the implant is disturbed and lost rapidly due to the increased rate of degradation of magnesium inside the human body. Because of that, non-traditional machining method such as electrical discharge machining (EDM) die sinking process is implemented to create an intricate form with a high tolerance of magnesium alloy. The advantages of EDM are that it allows a versatile adaption of implant behaviour in machining complex 3D structures along with high corrosion resistant properties of electrochemical surface treatment. Various material types with different parameters are investigated to determine the influence of input process parameters on the energy saving, and machining characteristics included surface roughness, material removal rate, and tool wear rate. In addition to improving the machining performance especially in energy-saving, input on the machining parameter needs to be considered due to interaction with added conductive particles which would affect the size of discharge energy. The objective of this paper is to summarize the findings in research of EDM's energy-saving and machining characteristics on magnesium alloy and to explore challenging issues that need to be resolved for future references and recommendations.

Keywords:
Energy saving; biodegradable metals; magnesium alloy; corrosion; electrical discharge machining

1. Introduction

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The biocompatible is one of the most fundamental requirements for choosing a metallic implant that is, involving the acceptance of an artificial implant by the surrounding tissues and biological system [1]. Currently, the metallic materials have approved and commonly used in structural implants include stainless steel, cobalt-chromium (CoCr) alloys and titanium (Ti) alloys (Table 1). However, thanks to the corrosive medium implantation site and cyclic loading, these metallic products are susceptible to corrosion throughout its operation. Current metallic biomaterials have the possibility to release toxic metal ions and or particles via degradation or wear processes that can trigger to an excessive inflammatory reaction and can irritate the underlying structure which can cause some cancer [2]. In terms of mechanical properties (refer to Table 2), most of them have a mismatch between mechanical properties of natural bone tissue except magnesium element. This mismatch can cause stress shielding, lead to retard the stimulation of new bone growth and their stability becomes decrease. The commonly current metallic biomaterials are essentially neutral in vivo and remained as permanent fixtures to secure fractures and after the tissue has healed completely, this permanent implant can be removed by a surgical technique. The disadvantages of this permanent implant are higher health care cost expenses and more morbidity to the patients due to repeated surgeries.

Table 1
Major metals and alloys for biomedical applications [3]-[5]

Material	Major Applications
316L Stainless Steel	Cranial plates, orthopedic fracture plates, dental implants, spinal rods, joint replacement prostheses, stents, catheters
Cobalt-Chromium alloys	Orbit reconstruction, dental implants, orthopedic fracture plates, heat valves, spinal rods, joint replacement prostheses
Titanium, Nitinol, Titanium alloys	Cranial, orbit reconstruction, maxillofacial reconstruction, dental implants, dental wires, orthopedic, fracture plates, joint replacement prostheses, stents, ablation catheters.

Table 2
Summary of the physical and mechanical properties of natural bone and some implant materials [6]-[8]

Material	Density (g/cm^3)	Toughness ($Mpa(m^{\frac{1}{2}})$)	Modulus (GPa)	Yield Strength (MPa)
Natural bone	1.8-2.1	3-6	3-20	130-180
Ti alloy	4.4-4.5	55-115	110-117	758-1117
Co-Cr alloy	8.3-9.2	-	230	450-1000
Stainless Steel	7.9-8.1	50-100	187-205	170-310
Magnesium	1.74-2.0	15-40	41-45	65-100
Hydroxyapatite	3.1	0.7	73-117	600

To remove all possibilities of harmful results from leaching, wear and corrosion, biomaterials are required, along with the research development in biomedical technologies and tissue engineering. The most concerns are to minimize two major effects in metallic implants which are stress shielding effect and surgical intervention. These demands lead to the development of new degradable of metallic biomaterials and their processing. The biodegradable implants provide a temporary mechanical support the healing tissue until full regeneration or scaring healing is complete. The most important of degradable implants is it can prevent second operation where the implant are completely degraded and dissolve in the human body without toxic effect within tissue healing. The biodegradable metal such as magnesium have an advantage over current biodegradable implants, including polymer, ceramic or bioactive glasses in a load-bearing application that require initial tensile strength and Young's modulus closer to that of bone [9].

Among their corrosion resistance and properties, the metallic materials have been selected even the concept of biodegradable implant has been acceptance. Among elements that can provide the potential to serve as biodegradable metal implants in orthopedic and cardiovascular surgery applications, the magnesium is the best selection in this area where the magnesium properties can minimize stress- shielding effects and has a higher biological activity compared to current metallic implants. However, high degradation rate of magnesium in the human body that contain aggressive and corrosive chloride solution, which is a combination of the ionic composition and protein concentration in body fluid, limited their clinical applications [10].

The requirements for the production process to fully quality implants are very high. The implants must be built in such a manner that the implant's structural integrity continues long enough before the incubating bone is ready to maintain the structure by itself. To better suited high-profile accuracies and geometries are needed as well as tailor-made surfaces of enhanced biocompatibility. For instance, improved cell adhesion. As these structures are very hard to be machined via traditional methods, alternative manufacturing process such as EDM, need to be developed particularly for complex and high precision 3D structures. EDM is very well adapted for machining large aspect ratios and microstructures in geometries. That is why the strengths of state-of-the-art EDM device systems for medical uses are then analyzed. Furthermore, modern technique is being explored for potential post-treatment of EDM machined surfaces. An electrochemical method is often used to create an oxide layer on top of the EDM surface which can result in improved biological tissue activity and demonstrate promising magnesium corrosion rate limit. As a result, the mixture of EDM and electrochemical surface treatment would then shape a method chain of strong prospects for bio-functional and resorbable magnesium implants to be machined.

The industrial requirement of materials having a good mechanical property is continuously increased. Tough task to ask for machining these materials through the conventional method. That is why non-conventional machining methods are widely used to machine such materials. EDM is one of the proven most common and highly adapted in non-traditional machining [11,12]. To operate, the EDM cycle requires thermal energy to remove and vaporize harmful substance from the work material. Sparks occurring in the inter-electrode gap generates thermal energy [13,14]. To generate the sparks, the electrode and workpiece must be electrically conductive. Dielectric fluid in IEG acts as an electronic insulator. The spark happens as the distance voltage reaches that of the dielectric fluid [15,16]. EDM process does not use mechanical energy, thus material removal rate (MRR) will never be influenced by the toughness and hardness of the workpiece [17].

A few review papers have discussed on surface improvement by using difference method due to increase corrosion resistance [18-21]. In this paper, we try to review the EDM on Magnesium alloys as presented in previous published data with so much closer. Nevertheless, there is no comprehensive literature found on the energy saving and challenges of EDM process. It is believed that controlling the energy consumption on the machining parameter has a direct effect on the machining performance. The purpose of this paper is to understand the interaction of energy with machining parameter, which is a critical factor which affects the performance enhancement for application, and to propose a solution that could lead one to apply most of effective way in EDM of Magnesium alloys by ensuring the characteristic of corrosion resistance is increasing.

2. Biomedical Application

The main application of biomaterials is to repair hard or soft tissues that have been lost or harmed by any pathological process [22]. As a consequence of these conditions, the affected tissue can be withdrawn and substituted with a suitable synthetic substance. Some common uses of biomaterials are listed in the following sub-chapters.

2.1 Orthopedics

One of the most popular use fields for biomaterials is the orthopedic implant systems. It has become possible to replace joints such as arm, knee, neck, leg, and elbow, although, with the advent of anesthesia, antisepsis, and antibiotics, the resultant pains may be significant. Patients are well aware of the effect of the treatment on pain relief and mobility restoration [22].

2.2 Cardiovascular

Problems with heart valves and arteries can be treated with implants. Often, the cardiac valves will not function or shut down entirely, indicating that the valve is compromised by illness, the diseased valve may be replaced with a number of replacements [22].

2.3 Ophthalmic

The eye's tissues suffer from several diseases which lead to reduced vision and eventually blindness. For cataracts, it allows the lens to get fuzzy. This can be substituted by a synthetic (polymer) part. Meanwhile, Biomaterials are used to retain and repair vision, as in intraocular lenses [22].

2.4 Dental

Within the mouth, bacterially regulated infections will quickly kill both the tooth and supporting gum tissues. Teeth in their entirety and teeth fragments can all be removed and repaired via some of materials [22].

3. Biodegradable Material

Biodegradable materials which can help in the healing phase provide benefit over other permanent metallic materials as during the healing treatment, they will not be separated from the human body [23]. Implants in the human body may cause long-term consumption issues like pain and asthma, or other physical problems. However, the overall cost for implant removal can significantly decrease by using biodegradable implants, as there is no need for extra removal surgery [24].

The biodegradable material is required to degrade in the human body within a certain period. Hence, degraded products should be non-toxic as well as does not cause allergy, sensitization, irritation, or inflammation. The excess amount of the degradation products is required to pass through the body (such as urine) in a secure way [25]. The degradation process should has preserved sufficient mechanical properties and the corrosion products will not fall into pieces that will harm the internal body system. The biodegradable implants should be uniformly dissolved to prevent physical injuries. Hence, it is important to control the degradation rate of the biomaterials [26].

The biodegradable material is required to degrade in the human body within a desirable period. An illustration of Figure 1 shows the process of tissue healing, when the implant materials can gradually lose its mechanical property by its continuing degradation process.

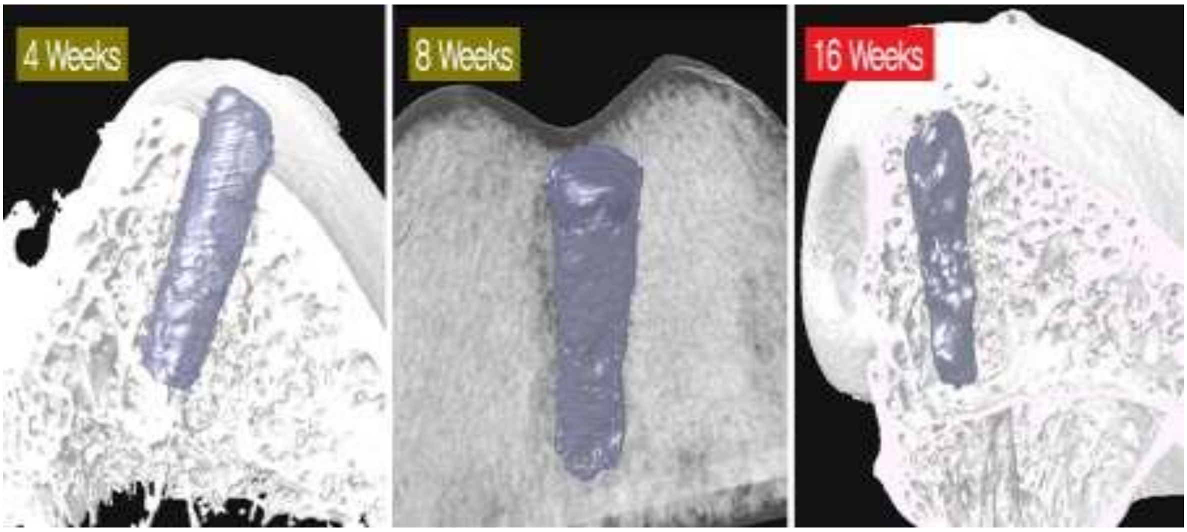

Fig. 1. The schematic of the degradation process of biodegradable implant in vivo test [27]

Inside human body, rational bio-corrosion was occurring on the biomaterial surface such as implants and stents. The rational bio-corrosion involves oxidation reaction in electrolytic physiological media and this reaction should prevent bacteria and fungi colonization in tissues like blood and bones. The rate of corrosion must fully pay attention to prevention of implant is been completely degraded before the cure of injured tissue.

These days, more researchers are now focused on the alloying elements' effect on the development of corrosion-protective interfaces and the underlying biological environment in vitro and in vivo to enhance mechanical properties, corrosion resistance as well as production expense. One of biodegradable implant has been successful investigated in animal-based magnesium alloys is cardiovascular stent [28]. The other implants are still ongoing including bone implants for example screw, plates and other fixture devices, magnesium chip for vertebral fusion in spinal surgery (sheep) and open porous scaffolds as load-bearings for tissue engineering [29].

3.1 Magnesium Alloy

Magnesium and its alloys are ultralight materials and which similar to natural bones in term of density wise. The density of magnesium is 1.6 and 4.5 times lighter than aluminum and steel separately [29]. Most importantly, Mg and its alloys are very appropriate material for degradable implant due to low elastic modulus (44 GPa). Moreover, the compressive yield strength and fracture toughness of magnesium closer to those of natural bones shown in Table 2. The magnesium has higher fracture toughness compared to hydroxyapatite.

Recently, magnesium alloys are developed into potential candidate to serve as implants into orthopedic application due to excellent biocompatibility and biomechanical properties [30]. Various clinical cases as well as in vivo and vitro assessment shown that magnesium alloys can function as biodegradable implants due to good biocompatibility in the human body. In fact, the Mg^{2+} ion is the fourth most abundant cation in the human body. The redundant Mg^{2+}can be harmlessly since normal adult takes Mg about 300-400 mg per day and these Mg^{2+} ions efficiently excreted through excrement and urine. In terms of mechanical properties, magnesium alloys have lower elastic modulus (about 45 GPa) compared to current implant materials and also have closer yield strength with natural bone, that cover them with the potential for preventing the stress shielding effects [29].

However, magnesium and its alloys are extremely exposed to degradation [31]. When magnesium reacts with air and it slightly soluble in water the magnesium hydroxide passivated layer was formed, which accumulates on the surrounding of magnesium matrix and act as corrosion protective layer of water. The magnesium oxide layer is fragile, hence; it cannot adequately protect the matrix against corrosive media. Refer to Pilling-Bedworth ratio, the oxide layer cannot act as a barrier and protect the substrate when the volume of forming oxide is smaller than metal consumes. Due to electrochemical active state, magnesium alloys have low corrosion tolerance in atmospheric air or aqueous conditions. The Pilling-Bedworth magnesium oxide ratio is 0.81 and is less than one because the matrix cannot be covered by the deposition of oxide film on magnesium and its alloys.

3.2 Element of Magnesium Alloy

In magnesium implant products the chemical elements Al, Mn, Zn, Ca, Li, Zr, Y and Rare Earth (RE) are used alongside pure magnesium. In industrial applications, these components typically affect the mechanical and physical properties of magnesium alloys. So long as the alloying components stay in solid solution, they may be used to reinforce rigid solutions. Besides, several of the alloying elements will react with or through magnesium to form intermetallic phases. Such phases add to improving the alloy's intensity by precipitation. All solid water improving and precipitation improving strength yet weakening metal ductility. Almost any alloying feature, however, contributes to some degree to grain refining which serves as a mechanism for reinforcement. Strengthening the grain border increases both intensity and ductility [32]. Table 3 demonstrates the effect of the alloying elements at room temperature on the properties of Mg alloys.

Table 3
Influence of alloying elements on properties and processing of Mg alloys at ambient temperature [32]

Alloying Element	UTS	Ductility	UCS	Creep resistance	HTS	CR	GR	Cast ability
Aluminium (Al)	+	+		++		-	+	+
Manganese (Mn)	+	+					+	
Zinc (Zn)	+	-						
Calcium (Ca)	+			++	+		+	+
Lithium (Li)	-	+	-			-		
Zirconium (Zr)	+	+			+		++	
Yttrium (Y)	+			++	+		+	+
Rare Earth (RE)				++	+		+	

Note: UTS = ultimate tensile stress, UCS = ultimate compressive stress, HTS = high temperature strength, CR = corrosion rate, GR = grain refiner, effect coding: “ ++ ” = excellent, “ + ” = good, “ – ” = bad.

As an alloying factor, Al may provide both reinforcement of the solid solution and reinforcing precipitation. The Mg17Al12 step of the Mg–Al device sadly has a small melting point and cannot be used to increase high temperature strength. The rise in Al content decreases the temperature of the liquidus and solidus lines and raises the casting ability of high Al alloys.

Ductility is enhanced mainly through Manganese. The development of Al–Mn intermetallic phases in Al comprising magnesium alloys is significant because such phases can accumulate iron (Fe) and can thus be used to regulate magnesium alloy corrosion due to Fe's adverse impact on corrosion behavior. Zn leads to intensity in smaller quantities owing to stabilization of a solid solution. It can also increase cast capability but in greater quantities (> 2 wt. percent) of Zn in combination with Al contributes to embrittlement [32].

Calcium leads to improving the stable water and to increasing precipitation. It also serves as a grain processing agent to some degree, and also contributes to reinforcing the grain boundary. The Laves phase Mg2Ca is produced in binary Mg–Ca alloys while the Laves phase Al2Ca arises first in Al comprising alloys. Both phases enhance creep resistance due to reinforcement of strong solution, enhancing precipitation and pinning of the grain boundary [32].

Lithium (Li) is the only recognized element that can alter the lattice structure of magnesium alloys from hexagonally near packed (h.c.p.) to body-centered cubic (b.c.c.) crystal structure [32]. It may also be used to improve magnesium alloy ductility and formability, but sadly it has a negative effect on strength. Zirconium is an important grinding agent for grain in magnesium alloys clear of Al. With regard to the interaction between Hall and Petch, Zr is helping to improve due to the development of fine grains.

Master alloys such as mischmetal (typically 50 per cent cerium (Ce), 45 per cent lanthanum (La), limited quantities of neodymium (Nd) and praseodymium (Pr)), Y-, Ce-or Nd-rich hardeners usually inject rare earth elements (RE) into magnesium alloys. Any volume of RE is stored in solid solution and hence RE will reinforce the substance by reinforcing the solid solution. On top of that, Al or Mg can work together with all RE to form complex intermetallic phase. Both intermetallic processes serve as barriers to the passage of dislocation at high temperatures and induce amplification of precipitation. Early during solidification, RE with reduced solubility shapes intermetallic phases. RE will, therefore, arrest the grain boundaries at elevated temperatures and primarily add to intensity by increasing the precipitation. This process raises the service temperature of Mg alloys in the transport industry and enhances both the resistance to creep and corrosion [32].

3.2.1 Mg-Ca based alloys

Calcium is a major component of human bone and is important for cell-based chemical signaling. Magnesium is required for calcium absorption into the bone, along with the co-release of Mg and Ca ions may be assumed to be helpful for bone healing. Grain refinement of magnesium alloys also can be benefited from Ca. Ca in Mg's solubility maximum is 1.34 wt percent. The Mg-Ca alloys are made predominantly of phase α-Mg and phase Mg2Ca. With Ca content can, more and coarser Mg2Ca phase precipitates along grain borders, degrading both the mechanical properties and corrosion resistance of as-casted Mg-Ca alloy. The power of binary Mg-Ca alloys is increased when extruded with the Ca content but the ductility will decrease. Mg-1Ca alloy pins deteriorated slowly in vivo within 90 days, and fresh bone formed [33].

3.2.2 Mg-Zn based alloys

Zn resides in all tissues of the human body and it is one of the most available nutritionally important components in the human body. Zn is a common alloying factor with a solubility limit of 6.2 wt percent in magnesium alloys which can effectively boost the mechanical properties of magnesium. Diverse forms of alloys dependent on Mg-Zn have been tested. Zhang *et al.,* [34] investigated an extruded Mg-6Zn alloy as a biodegradable material. This alloy comprises of a standardized single step after the preparation of a strong solution and the hot job, thereby preventing galvanic corrosion. The Mg-6Zn alloy's mechanical properties are considered appropriate for implant applications. The Mg-6Zn alloy rods were inserted into the rabbit's femoral shaft and slowly absorbed in vivo at a pace of deterioration of around 2.32 mm / y with freshly developed bone covering the implant. The study of viscera histology and the biochemical analyses showed that the deterioration of Mg-Zn alloy did not damage the important organs [33].

3.2.3 Mg-RE based alloys

Li and Zheng [34] reported that the primary usage of rare earth elements in magnesium alloy is for strengthening and enhancing corrosion resistance. Rare earth elements include 17 atoms, i.e.: scandium (Sc), yttrium (Y), lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu) and promethium (Pm). Master alloys or so-called hardeners which contain mainly 1 or 2 rare earth elements and nearly all other rare earth elements in smaller amounts incorporate them into magnesium alloys. Rare Earth Elements are commonly described by RE in the ASTM nomenclature of magnesium alloys, except that Yttrium is uniquely described by Y.

Mg-RE related alloys currently being developed for biomedical application include Mg-Y, Mg-Gd, WE43 and so on. Zhang *et al.,* [35] prepared a new kind of Mg-Nd-Zn-Zr alloy (called JDBM) that outperforms WE43 on mechanical properties and resistance to corrosion. While magnesium-containing alloys are only in preclinical trials in orthopedic applications, cardiovascular stents containing on magnesium have also reached clinical trials in patients with peripheral arterial obstructions and coronary artery disease. Magnesium alloys examined for cardiovascular application are primarily alloys dependent on Mg-RE, as stated in the section on introduction. However, the biosafety of rare earth elements is still under concern [34].

4. EDM on Magnesium Alloy

4.1 Machining Parameter

In EDM, some of the machining parameters include peak current, pulse on time, pulse off time, servo voltage, wire feed, servo feed, wire tension and dielectric fluid pressure. All these parameters are affecting the machining characteristic such as material removal rate (MRR) and surface finish which in turn decides the productivity and capability to machine materials. Improper setting of process parameters causes surface defects on the machined surface [36]. Acknowledgement of machining parameters before conducting any planning and designing of machining process was likely to be more preferable and economical as suggested by numbers of previous researchers.

4.1.1 Peak current

One of the key input parameters of an EDM cycle is peak current. Peak current controls the amount of amperage (current) that is applied to the wire, and also sets whether to the “AC” or “DC” circuit. Peak current is one of the factors that add power to the wire. Higher amount of peak current contributes to shorter machining time yet poor accuracy and finish result are likely to be expected. In normal practice, excessive amount of current should be avoided as it often causes heat damage to the work surface, deeper penetration of the recast layer, hardened workpiece and others. Nevertheless, higher peak current could shorten the electrode wear rate. It is also important that an acceptable current value is chosen to reduce electrode fatigue and to maintain the current density within tolerable limits until the actual machining phase takes place. Swiercz *et al.,* [37] published experimental work into the effects of discharge current, pulse length, and pulse frequency on surface roughness (Ra), white layer thickness, and MRR found that the discharge current had a significant impact on Sa, WL, and MRR. With rise in the discharge current and pulse duration, the amount of energy added to the work piece allowed a larger quantity of material to melt and evaporate, which created craters of a greater size and width. However, there was no elimination from the work piece surface of the content that melted in the single crater and it was re-solidified on the floor. The time period between pulses did not greatly influence the shift in the integrity of the surface and the MRR, but it played an important role in process stability.

4.1.2 Pulse on-time

This parameter controls the length of time that electricity is applied to the electrode (per spark). At the current flow time, all the machining work is performed while the electro discharge happens between the spark gap and the workpiece. The quantity of substance elimination depends upon the length of the burst or vibration. Longer spark length may also result in larger and deeper craters contributing to bad surface finish. Apparently, shorter duration of sparks could produce better surface finish but longer machining time is required. Hourmand *et al.,* [38] found that pulse ON time, current and voltage had remarkable effects on the microstructure, crater size and machined surface profile and had no impact on other regions. In comparison, rising spark energy results in fewer microstructural shift and a stronger surface finish. Khan *et al.,* [39] published findings indicate that the roughness of the aluminum oxide dispersion in the dielectric fluid surface improved whereas the rate of material removal (MRR) increased to some degree. These mean an increase in the efficiency of EDM utilizing dielectric fluid aluminum oxide. It was also observed that both MRR and surface roughness increase dramatically with rise in pulse on time.

4.1.3 Pulse Off time

This parameter sets the off period of the applied electricity to the wire between each spark. Pulse interval is critical as it offers the opportunity for effective cut removal by clearing the disintegrated particles from the distance between the electrode and the workpiece. The interval time serves as a significant role in pace up of operation where some inadequate off time will result in irregular cycling and retraction of the advancing servo and slowing down the operation cycle. Thus, the interval time should be sufficiently long to enable the arcing distance to deionize between two discharges to stabilize the machining process. Increasing the pulse interval or off time will generally mean slower cutting but increased in stability and less wire breakage. On the other hand, too small pulse interval may raise relative wear and roughen the surface. Usually, pulse duration and pulse interval are considered together for their effects. Pulse interval cannot be lower than pulse duration. Razak *et al.,* [40] concluded that the pulse off-time was the most important operation variables affecting the corrosion rate of magnesium alloy with the higher pulse off-time ensuing in lower corrosion rate.

4.1.4 Powder concentration

Another most important parameter needs to be consider during performing the EDM is powder concentration. The influence of this parameter significantly effecting to corrosion rate which the biodegradable preferred to material selection criteria. The zinc particles contained in the dielectric fluid were also shown to have an important effect on improvements in the magnesium alloy corrosion rate [40]. Kavimani *et al.,* [41] revealed that powder concentration and pulse ON Time are the most influencing parameters for MRR and Ra. Due to the actions of the machining parameters, traces of intermetallic forming are found over the machined surface.

4.2 Performance Measurement

There are three machining characteristics that important in EDM practice which is material removal rate (MRR), electrode wear rate (EWR) and surface roughness (Ra). High MRR is significant measure of the performance and cost-effectiveness of the EDM process, but it does not necessarily ideal for all applications because this may scarify the workpiece's surface integrity. The outcome of fast removal rate is a rough surface finish [42]. Electrode wear rate is the ratio of electrode wear volume to workpiece removal time. Requirements for any two of the characteristics can be fulfilled if the remaining one is discarded using the existing waveforms of discharge shown in Figure 2.

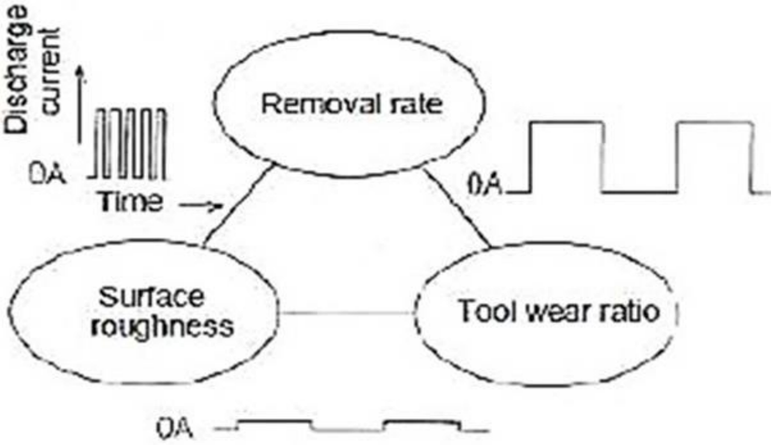

Fig. 2. Relation between discharge current waveforms and machining characteristics [42]

Conversely, no current waveform could satisfy all the requirements. In EDM, the electrode wear is less significant in an environment of extremely short discharge duration and high peak current where the problem of electrode wear is insignificant. It was also found that the significant EDM performance measures are MRR and surface finish.

Surface integrity is undeniably one of most critical aspect of EDM. Works by Rival [42] clarified that surface integrity is related to the metallurgical, topological, chemical, physical and mechanical conditions of the surface region. Examples of these attributes are metallurgical transformation, craters, pits, heat affected zone, microhardness, microcracks, residual stresses, surface roughness and tool material diffusion. In manufacturing operations, surface integrity is an important factor because it determines the service life, corrosion resistance and fatigue strength of a particular product. In the case of EDM, the transference of controlled electrical discharge between electrode and workpiece leads to the formation of thermally altered layers which in the end determines the surface integrity of the machined workpiece. The depth of the altered layer depends on the pulse duration and pulse energy. Basically, workpiece’s surface and subsurface are affected by EDM process whereby it produces three layers on top of the unaffected workpiece as depicted in Figure 3.

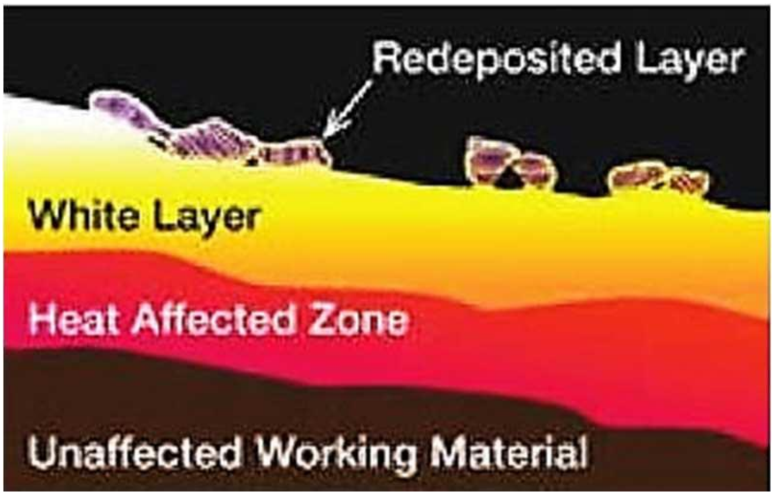

Fig. 3. Thermal effect on sub layers and re-deposited layer [43]

4.2.1 Surface roughness

The number of discharges per second or frequency sparks determines the surface finish. Consequently, the amount of material removed depends on the amount of energy applied. However, higher amount of current applied will result in higher number of craters being eroded from the work thus creating rougher surface finish. In order to achieve balance between metal removal rates and surface finish, it is necessary to increase the discharge frequency. Jinkai *et al.,* [44] stated that the effect of electrical parameters on the coefficient of friction can be transformed into the impact of roughness on the coefficient of friction that is compatible with the energy discharge basis. The recast and the carbon layers were formed on the alloy surface of the AZ91D Mg, and the recast layer strength was increased. The form of the surface furrow and scar depth of wear were greatly decreased, and the toughness of the AZ91D Mg alloy was increased.

4.2.2 Material removal rate

In EDM process, material removal rate (MRR) is defined as the amount of material removed within a period of time. In comparing EDM with conventional machining methods, WEDM provides slower material removal rate. Subsequently, MRR in EDM depends on the following factors which is amount of current of each discharge, frequency of the discharge, wire material, workpiece material and dielectric flushing conditions. Vijayabhaskar and Rajmohan [45] concluded that timing and voltage pulses have major effects on MRR performance. Through the rise in pressure, more liquid metal is released owing to the change in the radiation from the discharge. As the voltage rises, the MRR value is increased, and the SR decreases simultaneously. Mostafapor and Vahedi [46] stated that the pulse on time has the greatest impact on the material removal intensity, kerf distance, and surface roughness among the selected three variable input parameters. Rising pulse on time allows all values of these performance parameters to increase. Rahim *et al.,* [47] reported that the carbon plating phenomenon increased the material erosion rate and lowered the surface roughness value of the machine surface and was found through a scientific methodology and microscopic observation.

The study describes the impact of the EDM parameters on transitions in microstructure and removal rate of materials (MRR). The study revealed that MRR would have the most determined effect from the peak current and pulse ON time interactions. Moreover, pulse ON time and duty factor would have the most significant effect after the peak current, respectively. Demonstrated that current, pulse ON time and pulse OFF Time have a tremendous effect on the microstructure, crater size and machined surface texture. In addition, rising spark energy results in less microstructural shifts and improved surface finishes.

4.3 Energy Saving on EDM

Electrical discharge machining is one of the non-traditional machining methods, focused on electrical energy. The electric power is used explicitly to detach or break the metals. EDM is a mechanism in which the removal of material by producing high temperatures is basically related. The source of energy originates from electrical discharges produced between two electrodes in a plasma tube, the device and the workpiece that it must submerge in a dielectric fluid. Santos *et al.,* [48] reported that the plasma channel ions (H, Cu and N) enter the surface with high kinetic energy leading to melting and evaporation of the surface. The dielectric fluid movement extracts a part of the molten substance, and the remaining component is re-deposited, creating the recast layer. Meanwhile, Dhakar *et al.,* [49] stated that spark energy rises with current, resulting in higher inter-electrode distance (IEG) thermal efficiency. Because of this thermal energy, wide sized craters form, resulting in more MRR.

Al-Khazraji *et al.,* [50] concluded that higher rates of fatigue control were achieved by utilizing low-current and high-pulse copper electrodes over time as lower energy heat discharges at the distance between the electrode and the workpiece. While Bobbili *et al.,* [51] claimed that the machined surface showed craters where located on the top of the unit. During EDM the likelihood of crater forming rises with a higher current and greater pulse-on period. Brass wire wear levels rise with rises in input energy contributing to wire breakage. Also, Guo *et al.,* [52] indicated a lower electrical resistance means that less energy from discharge would be absorbed in the conductive layer, which may be helpful in achieving a higher MRR during the EDM of insulating zirconia. Too high energy from discharge, though, may contribute to overly broad microcracks, craters, and spalling. Additionally, an improvement in the discharge energy can also raise the EWR.

In the case of higher discharge energy, Kumar *et al.,* [53] indicated a lower discharge energy may result in the creation of the smaller size of the hole, whereas deeper hole may be created. Moreover, low and uniform NPEDM discharge energy and a wider distance between electrodes in this phase often provide ample room for bubbles to escape, rather than being stuck in the created surface. During the EDM method, Prakash *et al.,* [54] stated that the large amount of thermal energy generated by repeated electric sparks between electrodes, melts and vaporizes the material from the surface of the workpiece. Shah *et al.,* [55] performed the study and the findings indicate that the samples coated with a bias voltage of -125V have the smallest amount of microdroplets and result in the highest resistance to corrosion and it is also discovered that the appearance of microdroplets on the coated substratum has an adverse impact on the coating efficiency by raising their corrosion rates.

By considering of electrode material, Md Ali *et al.,* [56] stated that Brass electrode shows low ability to withstand of spark energy that produces highest EWR and it is also reveal that thermal conductivity and melting point of electrode materials influence the output quality of material characteristics of workpiece. Meanwhile, Mahmud and Yahya [57] concluded that machining micro-dimples using flyback power supply gave higher MRR as well as provide improvement in its consistency of material removed per minutes. Means that the quantity of material being removed per minutes for each micro- dimple are more precise when flyback power supply is applied.

5. Conclusion

This review article focuses on surface alteration and methodology to enhance Magnesium Alloy's anti-corrosion efficiency as a biodegradable material. It is necessary for all implant materials to undergo surface preparation, as this material will corrode without sufficient surface repair, as several studies and investigations have shown. This is because the chemical reaction with blood promotes corrosion in metal implants. Over the last century, several surface treatments have been carried out but it is not flawless and has a long-term impact. Material combined electric discharge machining (PMEDM) is one of the new developments for improving EDM process capabilities. In PMEDM, the electrically conductive powder is mixed into the EDM dielectric which decreases the dielectric fluid's insulating strength and increases the spark distance between the device and workpiece. As a consequence, the cycle is more efficient, the material removal rate (MRR), surface finish (Ra) increases and the electrode wear rate (EWR) decrease. In addition, the coating exhibits strong corrosion resistance. Nevertheless, this review largely accepted that the machining output would be influenced by regulating the input parameter that is associated with conductive particles to determine the discharge energy level.

6. Future Recommendation

Most researchers give a more attention to parameter optimization rather than process improvement or innovation. Here is future recommendation require further investigation focus on EDM process development by using hybrid and assisted EDM. The type of hybrid and assisted EDM suggested is magnetic force which the expecting result when applying a magnetic field will improve the geometric and surface quality. And for additional, workpiece material will be use is Magnesium Calcium (Mg-0.6Ca) where the review mention that kind material is the best interaction with human body. The discharge energy during that process will be investigate also.

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