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# WIRE ELECTRIC DISCHARGE MACHINING OF TITANIUM GRADE 12 ALLOY USING MO WIRE AND ZINC COATED BRASS WIRE

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## Abstract

Titanium and its alloys are utilised in a wide range of industries due to their excellent properties such as high tensile strength, fatigue resistance, high strength-to-weight ratio, corrosion resistance, toughness at higher temperatures, and the ability to sustain high temperatures. WEDM has emerged as one of the most extensively utilised processes for creating precise geometries in refractory materials such as titanium alloy in recent years. The Titanium Grade 12 alloy is machined utilising the WEDM process in this experiment. In WEDM, both Mo wire and Zinc coated brass wire are used as electrodes. The effect of Titanium Grade 12 alloy WEDM with Mo Wire and Zn coated brass wire on surface roughness (SR) was investigated. The surface of a Titanium Grade 12 alloy that had been worked on with a wire electrical discharge machine (WEDM) was examined with a scanning electron microscope. The images that were produced by scanning electron microscopy show that the substance had uniform solidification and a columnar grain structure along the build direction. This was discovered by observing the structure of the grains. It has been observed that the SR rises along with an increase in $T_{ON}$. Titanium Grade 12 alloy with Mo wire and Zn coated brass wire both have minimum SR values of 2.131µm and 1.763µm at a $T_{ON}$ of 20µs. It has come to our attention that a higher $T_{OFF}$ results in a lower SR value. Titanium Grade 12 alloy with Mo wire and Zn coated brass wire both have a minimum SR of 2.689µm and 1.618µm at a $T_{OFF}$ of 20µs. It has come to our attention that an increase in the peak current causes a rise in the SR value. The minimal SR is reached at a peak current of 2A and is equivalent to 2.071µm and 1.689µm for Titanium Grade 12 alloy with Mo wire and Zn coated brass wire respectively This is the case when the SR is measured at its lowest point.

**Keywords:** WEDM, Titanium Grade 12, Mo wire, Zn coated brass wire, SR,

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## 1. Introduction

Titanium alloys are types of hard metals that are made up of a combination of titanium and a number of other chemical components. The most widely used titanium alloy is Grade 12, which has several applications in fields as diverse as aerospace, marine, power generation, and offshore. Titanium alloys offer remarkable properties, including great tensile strength, resilience to fatigue, low weight (highest strength-to-weight ratio), high temperature resistance, extraordinary corrosion resistance, and high toughness even at elevated temperatures. Titanium alloys can tolerate extreme heat too. However, because to the high cost of both the raw materials and the manufacture of these metals, their use is limited to military applications, aircraft, spacecraft, medical devices, connecting rods in high-end sports vehicles, and a small selection of high-end sporting goods and consumer electronics [1]. Titanium alloys are used in engine components by automakers Porsche and Ferrari due to the durability features that titanium possesses in high-stress settings such as those found in engines. Although "commercially pure" titanium has adequate mechanical qualities and has been used for orthopedic and dental implants, titanium is often alloyed with minor amounts of aluminium and vanadium for the majority of applications. This is because commercially pure titanium is not available. This mixture's solid solubility shifts substantially with temperature, which enables it to go through the process of precipitation strengthening. Alloys undergo this heat treatment procedure after they have been shaped into their final form but before they are used. This simplifies the production of a robust product [2].

The WEDM technique has found widespread application in a variety of industries, including those that manufacture tools and dies, automobiles, medical equipment, and virtually any other type of conductive material. Cutting the workpiece along a predefined path with a continually cycling wire as the electrode is an unconventional machining technique. WEDM, also known as wire-cut EDM, involves moving a single-stranded metal wire through a workpiece submerged in a tank of dielectric fluid. Punches, tools, and dies made from hard metals that are notoriously difficult to process using conventional methods are commonly produced with WEDM [3]. Since WEDM may remove material without the use of substantial cutting forces, it is often used when minimal residual stresses are required. It is possible to foresee little change in the mechanical characteristics of a material if the energy per pulse is very low due to the presence of these low residual stresses; however, a material that has not been stress-relieved before to the machining process can deform as a result of the technique. The workpiece may be subjected to a significant heat cycle, the intensity of which is determined by the technological parameters employed. These heat cycles can leave residual tensile strains on the work piece and even cause a recast layer to form on the part [4].

On the topic of WEDM of Titanium Alloy, a literature review has been carried out, and the results are given in the following paragraphs.

Saravanan P. Sivam et al.[1] looked into how different process factors impacted WEDM work done using Ti Gr 5 alloy and brass electrode. The findings demonstrate that the $T_{ON}$ is the single most important element that has a significant impact on all of the responses that were given significant ranking. An examination into the influence of WEDM parameter on fatigue strength was carried out by Mahendra U et al.[2] during the machining of Ti Gr 2 alloy. It was discovered that the MRR increased in response to an increase in current. An examination of the surface characterization of the WEDMd surface of titanium alloy was carried out by Siva

Prasad Arikatla et al.[3]. According to the findings, the SR went up whenever the $T_{ON}$ or pulse duration, pulse peak current, or servo feed rate were increased. M. Manjaiah et al.[4] investigated the effect that different process parameters had on the MRR and SR of Ti50Ni40Cu10 shape memory alloy during WEDM. The $T_{ON}$ and SV have the most impact on the MRR and the SR. The $T_{OFF}$ has a very insignificant impact on either of the performance criteria. MRR and SR both decline further as SV increases beyond a specific limit after having climbed along with $T_{ON}$ up to that limit. Bhiksha Gugulothu et al. [5] investigated how WEDM of titanium alloy was affected by the parameters and dielectric fluids used in the experiment. According to the findings, a considerable role in WEDM operations is played by drinking water, discharge current, $T_{ON}$ and $T_{OFF}$. The effect of utilising a variety of tool materials on the performance of Ti Gr 6 alloy was investigated by Munmun Bhaumik et al.[6]. When compared to copper electrode, the MRR that can be machined with brass and zinc electrodes is significantly higher. At a peak current of 20A across all the electrodes, the MRR was at its highest. Siva Prasad arikatla et al.[7] investigated the impact that servo voltage and dielectric fluid pressure have on WEDM processing of titanium alloy. It has been observed that the MRR and SR are high when the servo voltage and dielectric pressure are both at low and high values, whereas they are moderate when the servo voltage and dielectric fluid pressure are both at medium levels. K. Hareesh et al.[8] investigated how the different process parameters of WEDM affected the surface roughness of Ti6Al4V. It was observed from the main effect plot that wire speed and feed rate are the most critical factors affecting the average roughness value. The SR value goes up when the wire speed is slowed down and the feed rate is increased. The effects of wire feed rate and wire tension on wire electrical discharge machining (WEDM) of titanium alloy were studied by Siva Prasad Arikatla et al.[9]. Increasing the wire feed rate and wire tension leads to a corresponding increase in the kerf width and MRR, however these two factors have a relatively small effect on the kerf width itself. The effects of the WEDM process parameters on Ti Super alloy were investigated by J. Laxman et al.[10]. MRR increases constantly with the increase in $T_{ON}$ up to 20μs, and then it begins to decline continuously. It also increases with $T_{OFF}$ up to 50μs, and then it begins to fall continuously.

Based on the preceding review of relevant literature, it is clear that WEDM of Titanium Grade 12 Alloy using Mo wire and Zinc coated brass wire is still in its infancy and has not been attempted before. Therefore, the purpose of this research was to examine the impact of process parameters and machining features on Wire Electric Discharge Machining of Titanium Grade 12 Alloy using Mo wire and Zinc coated brass wire.

## 2. Materials and Experimental

### 2.1 Materials

Titanium Grade 12 (Ti Gr 12) is an alloy of titanium that is mostly composed of molybdenum (Mo) and nickel (Ni) and contains 0.2-0.4% Mo and 0.6-0.9% Ni. It has an excellent corrosion resistance in both oxidising and reducing environments and is known for having a high strength-to-weight ratio, good ductility, and weldability. Additionally, it can be easily cut and welded. In addition to this, it has a fantastic ability to be welded. When the elements nickel and molybdenum are added to the mixture, the mechanical properties of Ti Gr 12 are enhanced, and the material's resistance to localised corrosion is increased [11]. For the preliminary machining, we considered using a forged bar that was 20mm broad, 20mm thick, and 100mm long. The chemical composition of the alloy Ti Gr 12 is presented in Table 1, which may be found below. The induction of Ni and Mo raises the high-temperature characteristics, which is particularly helpful in situations where crevice corrosion is a problem.

**Table 1. Chemical composition of Ti Gr 12 alloy**

| C | N | O | Fe | Ni | H | Mo | Ti |
|---|---|---|---|---|---|---|---|
| 0.08 | 0.03 | 0.25 | 0.3 | 0.6-0.9 | 0.015 | 0.2-0.4 | Balance |

In this particular investigation, Zn coated brass wire and Mo wire were utilised as the electrodes. Due to the presence of zinc and copper in brass wire, it is currently the most common type of WEDM wire. The majority of brass wires used in WEDM are constructed of a Cu/Zn alloy, with compositions ranging from 63/37 to 65/35. Because it has a lower point at which it vaporises and melts, zinc is a superior material for electrodes versus copper because of its lower melting point. For the purpose of this experiment, we used a wire with a diameter of 0.25mm. Mo wire is exceptionally durable, with a tensile strength that is greater than 275,000 pounds per square inch (psi). Mo wire, on the other hand, is a relatively poor material for electrode due to its exceptionally high melting and vaporisation temperatures [12].

### 2.2 Experimental Procedure

The WEDM machine CONCORD DK7732 was utilised during all of the trials. Figure 1 depicts the WEDM machine as well as the samples that were analysed. Figure 2 shows the WEDM samples. Experiments were carried out with two distinct wires-a thin single-strand re-usable Mo wire with a diameter of 0.18mm and a single use Zn coated brass wire with a diameter of 0.25mm-in order to gain an understanding of the best machining parameters by adjusting one variable at a time. In addition, the trials were carried out with the process parameters adjusted to a variety of different levels. There are some basic machine settings that are kept for WEDM, like the wire tension, wire speed, and servo control voltage [13]. There have been some investigations carried out on the SR of WEDM utilising Mo wire and Zn coated brass wire. WEDM allows for the utilisation of deionized water as a dielectric fluid because of its low viscosity in addition to its rapid cooling rate. The studies were carried out by altering the $T_{ON}$, $T_{OFF}$, and peak current values one at a time for each individual trail. Through machining of Ti Gr 12 alloy, the impact of these three crucial factors on MRR and SR was investigated and evaluated. The WEDM process produced a form with dimensions of 5mm by 20mm by 20 mm.

In the current study, the process parameters utilised in WEDM of Ti Gr 12 with Mo wire and Zn coated brass wire and Ti Gr 12 alloy with Zn coated brass wire alloy include peak current, $T_{ON}$ and $T_{OFF}$. Additionally, Ti Gr 12 alloy with Zn coated brass wire alloy is fabricated using Zn coated brass wire. In this particular study, we have chosen to focus on three process factors and five levels. The $T_{ON}$ varies in increments of tens, such as the 20μs, 30μs, 40μs, 50μs, and 60μs respectively. The $T_{OFF}$ is increased or decreased in increments of 2μs, such as 12μs, 14μs, 16μs, 18μs, and 20μs. The peak current is increased or decreased in increments of 1A, such as 2A, 3A, 4A, 5A, and 6A.


**Fig. 1 Machining process**

**Fig. 2 WEDM samples**

## 3. Results and Discussion

The considerable influence that machining boundaries of $T_{ON}$, $T_{OFF}$, and peak current have on the SR of WEDMd Ti Gr 12 alloy with Mo and Zn coated brass wire is depicted in Figures 3 to 5.

### 3.1 Influence of $T_{ON}$ on SR

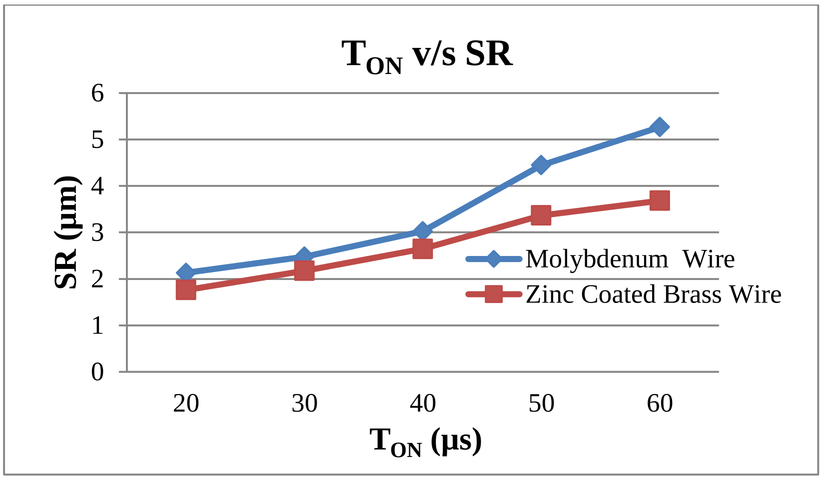



**Fig. 3 $T_{ON}$ v/s SR**

Figure 3 illustrates the relationship between $T_{ON}$ and SR for Ti Gr 12 alloy with Mo wire and Zn coated brass wire. This relationship is shown above in the Figure. This reveals a rising trend of SR in conjunction with an increasing $T_{ON}$. The flushing out of molten material causes wider and deeper craters to be produced on the surface by WEDM when additional discharge energy is applied to the process. The rate of change in surface irregularity typically reaches a plateau when $T_{ON}$ reaches a certain threshold [14].

Variations in the SR that are significant can be seen between the 20 and 60 units. The minimal SR for Ti Gr 12 alloy with Mo wire is 2.131µm, while the minimal SR for Zn coated brass wire is 1.763µm when measured at a $T_{ON}$ of 20µs. When compared to Ti Gr 12 alloy with Mo wire, the SR of Ti Gr 12 alloy with Zn coated brass wire is significantly lower. This is because Zn-coated brass wire has a lower melting point and higher thermal conductivity than uncoated brass wire [15].

### 3.2 Influence of $T_{OFF}$ on SR

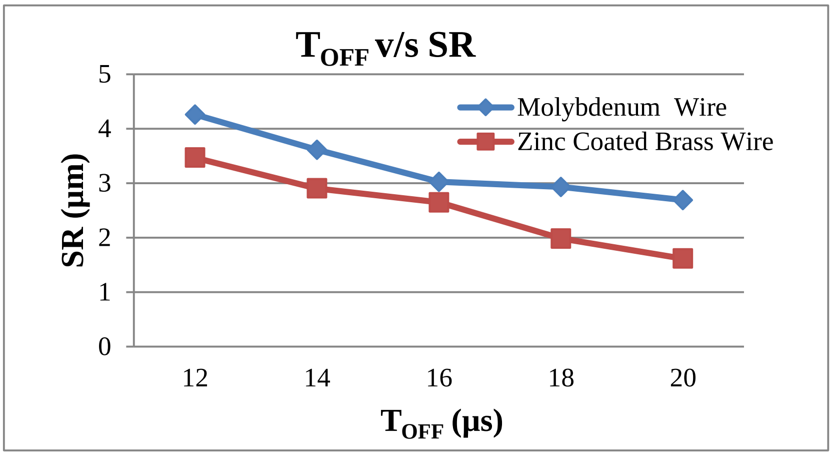



**Fig. 4 $T_{OFF}$ v/s SR**

Figure 4 illustrates the relationship between $T_{OFF}$ and SR for Ti Gr 12 alloy with Mo wire and Zn coated brass wire. This relationship is shown above in the Figure. It has been discovered that increasing $T_{OFF}$ results in a lower SR value. The graph illustrates an interesting correlation between the amount of time interval and the surface smoothness: the longer the period, the smoother the surface. The temporal gap between the two events widens proportionally with the length of the delay in the discharge. When compared to a shorter time interval, a longer time interval produces a smoother surface [16]. This is because the erosive force is reduced. This is because there is an interval of time between each discharged pulse, which also helps flush the machined fragments and freeze the material. As a result, this phenomenon has arisen. For a $T_{OFF}$ of 20µs, the minimum SR for Ti Gr 12 alloy with Mo wire is 2.689µm, while the minimum SR for Zn coated brass wire is 1.618µm. When compared to Ti Gr 12 alloy with Mo wire, the SR of Ti Gr 12 alloy with Zn-coated brass wire is significantly lower.

### 3.3 Influence of Peak Current (A) on SR

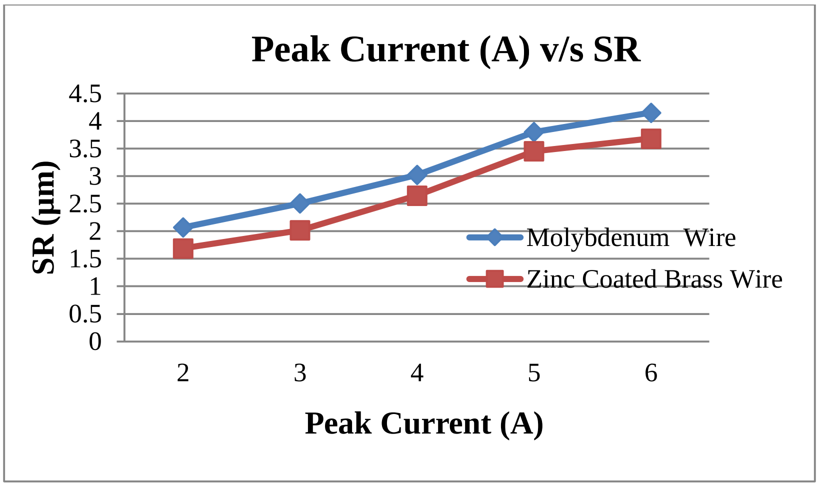
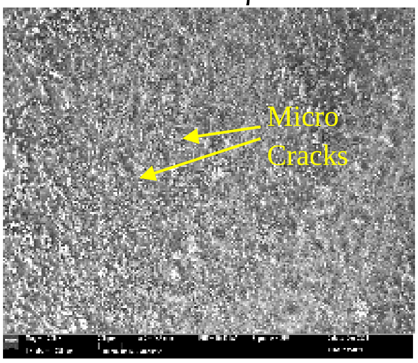



**Fig. 5 Peak Current v/s SR**

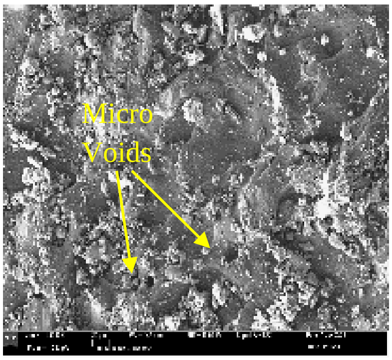
The relationship between peak current and SR for Ti Gr 12 alloy with Mo wire and Zn coated brass wire is depicted in the above Figure 5. An increase in the peak current has been seen to result in a rise in the SR value. An increase in the current discharge leads to a greater output of energy as well as a more rapid evaporation of material, which results in a surface that is more textured [17]. A larger crater is created when the peak current and discharge energy are both high, which leads to a higher SR. If the current is increased, the spark intensity will also be increased, which will result in a discharge gap that is reduced. According to the observations, the effect on SR is noticeable during the phase of the peak current where it is just beginning to increase. The SR goes up gradually as the peak current goes up, but not at the same pace as what was seen at the beginning of the process. At a peak current of 2A, the minimal SR is achieved, which is 2.071µm for Ti Gr 12 alloy with Mo wire and 1.689µm for Zn coated brass wire. Ti Gr 12 alloy with Zn coated brass wire has a higher SR than Ti Gr 12 alloy with molybdenum due to its lower specific resistance.

### 3.4 SEM Study of WEDMd Surface of Ti Gr 12 alloy with Mo Wire

SEM pictures of the WEDMd Ti Gr 12 surface with Mo wire are displayed at a magnification of 500X in Figures 6(a) and 6(b), respectively. A scanning electron micrograph of a WEDMd surface is displayed in Figure 6(a) below. This surface had a $T_{ON}$ of 20µs, a constant $T_{OFF}$ value of 16µs, and a peak current of 4A. A SEM image of a WEDMd surface is shown in Figure 6(b), and it has a $T_{ON}$ of 60µs, a constant $T_{OFF}$ value of 16µs, and a peak current of 4A.




**(a)**




**(b)**

**Fig. 6 SEM images of WEDMd surface at**

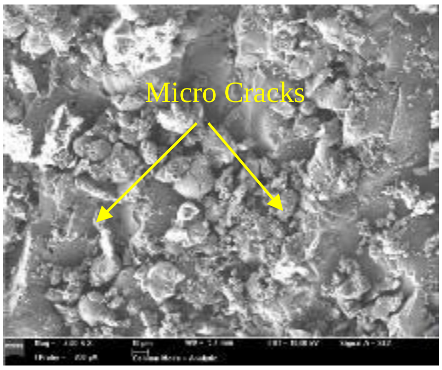
**(a) $T_{ON}$ = 20µs; $T_{OFF}$ = 16 µs; peak current = 4A**
**(b) $T_{ON}$ = 60µs; $T_{OFF}$ = 16 µs; peak current = 4A**

When we increase the $T_{ON}$, we are able to see a greater number of flaws. When the $T_{ON}$ is set to 20µs, there is less surface distortion visible (micro fractures), which results in a lower MRR. A noticeable increase in the amount of deformation (particles, pits, voids, and micro cracks) can be observed if the $T_{ON}$ is raised to the 60µs. During the machining process, there will be less time for debris to be flushed out as the $T_{ON}$ grows. As a direct consequence of this, we are able to observe a greater quantity of particles and trash when $T_{ON}$ is set to 60µs. An increase in $T_{ON}$ led to deeper craters as well as an increase in the rate of material surface erosion [18]. Because the eroded material is trapped in the deeper craters, the SR and $T_{ON}$ are also increased. It was found that the SR was affected by the workpiece's absorption fraction relative to that of the dielectric medium.

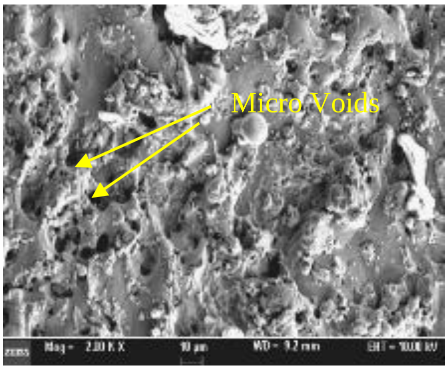
An increase in $T_{ON}$ causes deep craters to form and accelerates the erosion of the material's surface, as seen in Figure 6. It is also clear that as the $T_{ON}$ increases, the SR rises because the eroded material is trapped in the deeper craters. The increased SR causes this result. Recent studies suggest that SR is affected by how much energy is transmitted from the pulse to the workpiece versus how much is sent to the dielectric medium. When the pulse energy, work-material structure, thermal and mechanical qualities, electrode material, and spark discharge mode are all increased, SR increases as well [19]. The proportional size of the craters was also discovered to be affected by the melt temperature and heat conductivity of the titanium alloy.

### 3.5 SEM Study of WEDMd surface of Ti Gr 12 alloy with Zn coated Brass Wire

The SEM pictures of the WEDMd Ti Gr 12 surface with Zn coated Brass wire at 500X magnification are displayed in Figures 7(a) and 7(b), respectively. The scanning electron microscope was used to capture these images. SEM image of the machined surface shown in Figure 7(a), which was generated by WEDM with a $T_{ON}$ of 20μs, a constant $T_{OFF}$ of 16μs, and a peak current of 4A. Figure 7(b) shows an image of the machined surface that was created by WEDM with a $T_{ON}$ of 60μs, a constant $T_{OFF}$ value of 16μs, and a peak current of 4A. The image was captured by a SEM.




**(a)**




**(b)**

**Fig. 7 SEM images of WEDMd surface at**

**(a) $T_{ON}$ = 20μs ; $T_{OFF}$ =16μs ; peak current= 4A**
**(b) $T_{ON}$ = 60μs ; $T_{OFF}$ =16μs ; peak current= 4A**

When we run the $T_{ON}$ process for longer periods of time, we are able to spot a greater number of flaws in the product. It is possible to notice less surface distortion (micro cracks) by employing a $T_{ON}$ of 20μs, which is connected with a lower MRR. This is because of the relationship between the two. The amount of time that the $T_{ON}$ at 60μs is raised may allow us to identify a significantly higher amount of deformation (particles, pits, voids, and micro cracks) [20]. The length of time that the $T_{ON}$ is active during machining cuts into the amount of time that is available for waste to be flushed out of the system. As a direct consequence of this, we are in a position to identify a greater quantity of particles and trash when we set the $T_{ON}$ to 60μs. The longer the $T_{ON}$, the deeper the craters that are produced, which in turn leads to a larger degree of erosion on the material's surface. When the $T_{ON}$ is increased, it is also possible to see that the eroded material is trapped inside the deeper craters, which results in the surface having a higher roughness. This is caused by the increased crater depth. It has been discovered that the fraction of pulse energy that is absorbed by the workpiece in contrast to the dielectric medium has an effect on the SR.

As can be seen in Figure 7, an increase in $T_{ON}$ results in the production of deeper craters as well as an acceleration of the eroding process that occurs on the surface of the material. The amount of eroded material that is trapped within the deeper craters causes the SR value to increase, which also causes the $T_{ON}$ value to increase. Another thing that one might be able to observe is this. The ratio of the amount of pulse energy that is absorbed by the workpiece in contrast to the amount that is absorbed by the dielectric medium is another factor that has an effect on SR, as indicated by the review of past studies. A rise in SR [21] can be attributed to a number of factors, including the pulse energy, the structure of the work material, the temperature and mechanical aspects, the characteristics of the electrode material, and the manner in which the spark discharge occurs. It was discovered that the relative crater size was affected not only by the temperature at which the titanium alloy melted but also by the thermal conductivity of the alloy.

## 4. Conclusion

The following are some of the conclusions that can be derived from the study that was done on the impact of process variables on the SR in WEDM machining of Ti Gr 12 alloy with Mo wire and Zn coated brass wire.

- The Wire Electric Discharge Machining of Titanium Grade 12 Alloy Using Mo wire and Zinc coated brass wire was carried out successfully.
- Images obtained using a scanning electron microscope reveal that the build direction displays both uniform solidification and a columnar grain structure.
- In addition, the micrographs show a porosity that has an uneven shape and is located in a variety of places.
- It has been discovered that an increase in $T_{ON}$ results in a rise in SR. The minimal SR is attained at a $T_{ON}$ of 20µs and is equal to 2.131µm for Ti Gr 12 alloy with Mo wire and 1.763µm for Zn coated brass wire, respectively. This is the case when the SR is measured.
- According to the findings, a higher $T_{OFF}$ was found to be associated with a lower SR value. At a $T_{OFF}$ duration of 20µs, the minimum SR is attained, and it is equivalent to 2.689µm for the Ti Gr 12 alloy with Mo wire and 1.618µm for the Zn coated brass wire, respectively.
- It has been discovered that an increase in the peak current causes a rise in the SR value. The minimal SR is achieved at a peak current of 2A and is equal to 2.071µm for Ti Gr 12 alloy with Mo wire and 1.689µm for Zn coated brass wire, respectively. This is the case when the SR is measured at a peak current.

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