TITANIUM GRADE 2 MACHINING IN CNC WEDM USING BRASS AND ONLINE CRYOGENIC COOLED BRASS WIRE

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Abstract

The present study highlights the effectiveness of online LN_2 cryogenic treated electrode discharge machining of Titanium and compare the machinability with non-cryogenic electrode. To improve strength and machining process, brass wire electrode is cooled using online LN_2 in this research. Ti grade 2 is machined with two different wires i.e. online LN_2cryogenic treated brass wire, non-cryogenic brass wire, so as to find in which high material removal rate (MRR) and low surface roughness are achieved. Cryogenic Cooling is a method of deepfreezing process in which the material is cooled to -196°C, which change the molecular alignment of the material. This change in alignment increases the hardness of the material and also improves the conductivity. Increase in the conductivity of the wire electrodes helps to improve the machinability of the Titanium alloys in the WEDM process. Response surface methodology (RSM) is an empirical modeling approach used for determining the relationship between input parameters and output responses and Central Composite Design (CCD) method of RSM is used for designing the experiments to reduce the errors by repeating certain experiments.The selection of input parameters is the most important process in WEDM, as the inappropriate selection leads to wire breakage. To avoid this, machine variables which have been investigated in this study are pulse on time, pulse off time and wire tension. Material removal rate and surface roughness focused as output responses.The mathematical models were developed using RSM for Material removal rate and surface roughness for WEDM of Ti grade 2 alloy for various electrodes and its condition.The SEM analysis is carried out to analyze the surface integrity of the best results obtained in both the wire. Online LN_2 cooled brass wire gave much better surface than that of the surface obtained when brass wire is used.

Keywords: *Wire Electric Discharge machining (WEDM),Material Removal Rate (MRR), Surface Roughness (Ra),RSM, Pulse on time, Pulse off time, Wire tension, Online LN_2 Cryogenic treated Brass wire*

1. Introduction

Wire Electrical Discharge Machining (WEDM) is used to machine Die materials and press tools etc., high strength and low ductility materials with high accuracy. WEDM can machine anything that is electrically conductive regardless of the hardness, from relatively common materials such as tool Steel, Aluminum, Copper, and graphite, to exotic space-age alloys including Hastaloy, Waspaloy, Inconel, Titanium. The properties of titanium alloys make it more difficult to achine. Titanium alloys have high heat resistant, which detriment the life of the cutting tool. Due to its low thermal conductivity, the heat produced during metal cutting accumulates at the small area of the tool-work piece contact point, and results in high thermal stresses and frictional forces. The chemical reactivity of the material at elevated temperatures makes it easily react with the surrounding atmosphere. Ordinary cutting tools may fail prematurely under these adverse conditions. So that, unconventional machining processes are introduced for machining titanium alloys.

Sarkar et al. (2005) investigated the parametric analysis and optimization of wire electrical discharge machining of ɤ-titanium aluminide alloy. The process was modeled using additive model in order to predict the response parameters i.e. cutting speed, surface finish and dimensional deviation as function of different control parameters and the main influencing factors were determined for each given machining criteria [1].

Low elastic Modulus, less chemical reactivity, poor thermal conductivity are the problems in Titanium which makes difficult in machinability of Titanium and its alloys [2]. When machined using conventional machining process, low thermal conductivity results in increase in temperature near tool/workpiece, and leads to alteration in metallurgical surfaces and its chemical reactivity of titanium causes cutting tool to weld on its surface during machining [3].

Mohan et al. experimented machining of 6025 Al-alloy when it is reinforced with 20 and 25 vol% of SiC. Discharge current, Volume percentage of SiC particles and Pulse duration on metal removal rate (MRR), electrode wear rate (EWR) and surface roughness (SR) are used as input parameters. At medium range of pulse duration maximum material removal rate is obtained. Electrode wear rate increases with increase in SiC percentage and affects the surface roughness value which is due to debonding of SiC particles which lefts the void on the specimen [4].

Wire Electric Discharge machine (WEDM) is one of the most commonly used Unconventional machine in Industries. Wire Electric discharge machine in which wire acts as cathode and work piece as anode. A full form alternating current pass through the wire-tool, which helps in cutting intricate shapes without considered the hardness of the materials. WEDM works on Spark erosion theory [5]. Wire electrode made of materials like Copper, Brass, Zinc coated brass of diameters varying from 0.05mm to 0.25mm, which is continuously feed to remove the material. The eroded material is flushed by passing dielectric fluids like Deionized water, Kerosene. Dielectric fluid helps in reducing the short circuit between workpiece and wire [6]. For precise machining the gap must be maintained between 10-100µm using dielectric fluids.

High voltage initiates the ignition of discharge by overcoming the breakdown. During this the workpiece and wire electrode will not be in direct contact, which leads to reduction in stresses [7]. When wire electrode is coated material removal rate and surface integrity will be more than that is obtained by using uncoated wires [8].

Dilip Jerold and Pradeep Kumar machined Ti–6Al–4V using Cryogenic Coolants during machining it was observed that temperature was reduced up to 36% and 47% when CO_2 and LN_2 cryogenic are used respectively. Surface roughness is improved by 48% compared when machined using LN_2 compared to CO_2. Better controlled chip and less tool wear are observed when cryogenic liquid is used [9]. Treatment of material to very low temperature called cryogenic treatment effects the materials microstructure and improves the properties of material i.e. thermal, mechanical [10]. Cryogenic treated diffused brass wire gives higher Material removal rate than cryogenic treated plain brass wire [11]. Wear of tool was reduced by 8% when brass electrode was treated with cryogen compares with treated copper wire [12]. When EN-31 steel was machined using brass wire which was deep and shallow cryogenic treated brass wire. Material removal rate increases and surface finished decreased with the treatment of cryogenic liquid [13].

2. EXPERIMENTAL WORK

Titanium grade 2 was chosen as work piece materials for the present experiments. Due to their high tensile strength to density ratio, high corrosion resistance, fatigue resistance, high crack resistance and ability to withstand moderately high temperatures without creeping. Titanium grade 2 possesses excellent weldability and fabricability, and is the most corrosion resistance of all titanium alloys. In fact, it is most resistant to corrosion in reducing acids. Titanium grade 2 is used as workpiece of 3mm thick works as cathode and non-cryogenic treated brass wire and online LN_2 cryogenic treated brass wire of 0.25mm is used as anode. The chemical composition of titanium grade 2 is shown in Table 1

Table 1 Chemical Composition of Ti Grade 2 alloy

Element	Composition
Carbon	0.005 %
Iron	0.05%
Oxygen	0.19%
Nitrogen	0.04%
Hydrogen	0.009%
Titanium	Balance

In this study the selected input parameter with its three levels are shown in Table 2

Table 2 Selected process parameters

Symbol	Unit	Parameter	Coding Levels		
			-1	**0**	**1**
A	µs	Pulse on time	7	8	9
B	µs	Pulse off time	2	3	4
C	Gms	Wire tension	1000	1150	1300

Response surface methodology is used to optimize the input parameters. In the RSM central composite design is the most commonly used response design experiment, it is a full factorial design with center points augmented with group of axial points. In the central composite design, central composite face centered design is another type with α=1. Response surface Methodology (RSM) has been applied for developing the mathematical model in the form of multiple regression equations for the quality characteristic of the WEDM machined titanium alloys.

The machining is carried out in Maxicut-e machine WEDM which is shown in Figure 1

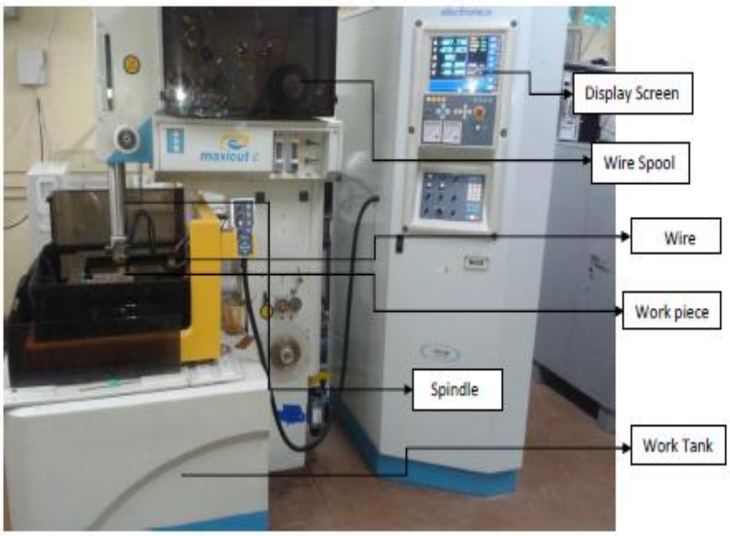

Figure 1 Maxicut e WEDM machine

A setup for the online cryogenic cooling of wire electrode was fabricated. This setup consists of a rectangular box which is made up of stainless steel. A hollow vertical tube which is made up of copper is positioned at the center of the box. Brass electrode for WEDM is passed through the hollow copper tube. A layer of thermocoal is placed inside the rectangular box around the copper tube. The liquid nitrogen is stored in the thermocoal box which surrounds the copper tube. The constant level of liquid nitrogen at the thermocoal box is maintained by manually switching on the compressor to pump the liquid nitrogen which is stored in thermoflask.

Two types of wire electrodes were used in this present study, namely brass wire, online LN_2cryogenic treated brass wire. A negatively polarized brass wire with a diameter of 0.25mm was used as the tool. The yield strength of brass wire was observed as 464MPa. Liquid nitrogen was used to treat the wire which is referred to as cryogenic treated. The selected brass wires were subjected to LN_2 cooling at a distance of 100mm from the work piece. Using brass wire and online LN_2 cooled treated brass wire is used to machine Titanium grade 2. Hexgonal profile of each side 10mm is used for machining in both cases.

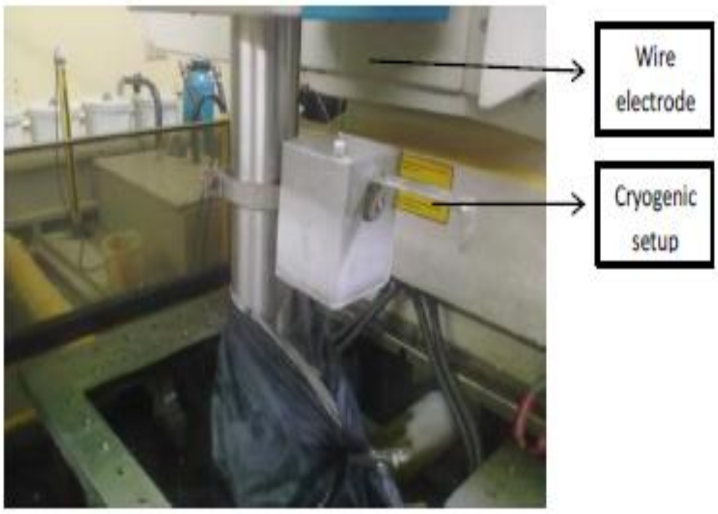

Figure 2 Cryogenic setup mounted on WEDM machine

3. Results and Discussion

Ti grade 2 alloy was machined with brass wire, online LN_2 cooled brass wire. 20 experiments were carried out for each wire as per the CCF design; MRR and Surface roughness was measured for each condition. The measured values of MRR and Ra for Ti grade 2 using Brass, online LN_2 cooled brass are tabulated in Table 4

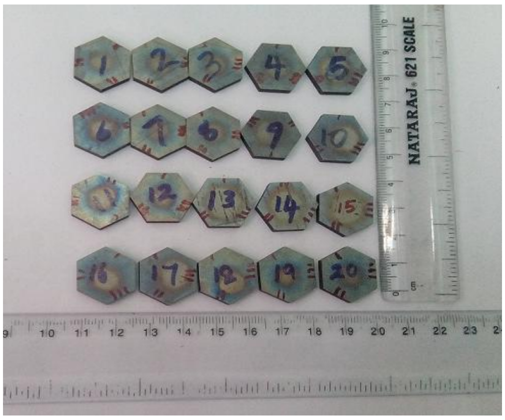

Figure 3 Machined Samples of Ti Grade 2(Brass wire)

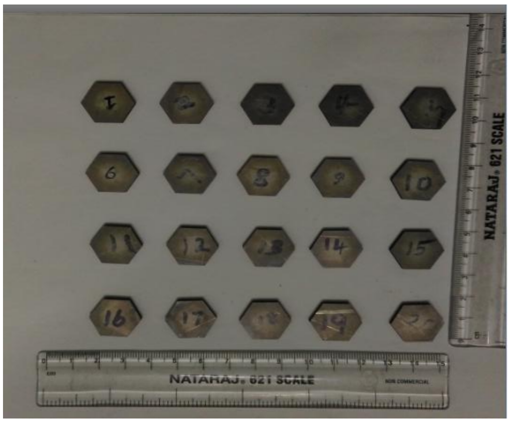

Figure 4 Machined Samples of Ti Grade 2 (cryogenic treated wire)

Table 4 Comparison of MRR and Ra for Ti Grade 2

Exp. No.	Brass wire		Online LN_2 cooled brass wire	
	MRR (mm^3/min)	Ra (µm)	MRR (mm^3/min)	Ra (µm)
1	2.325	4.15	2.861	3.65
2	2.425	4.65	2.989	3.98
3	2.395	3.85	2.798	3.56
4	2.375	4.00	2.895	3.80
5	2.500	3.78	3.120	3.62
6	2.625	4.02	**3.200**	3.52
7	2.425	3.75	2.880	3.43
8	2.520	3.81	2.970	**3.25**
9	2.385	3.82	2.825	3.56
10	2.495	4.05	2.950	3.62
11	2.415	3.98	2.868	3.56
12	2.337	3.75	2.658	3.40
13	2.285	3.89	2.840	3.67
14	**2.640**	**3.65**	3.030	3.41
15	2.369	3.81	2.803	3.50
16	2.374	3.85	2.809	3.57
17	2.385	3.80	2.810	3.54
18	2.380	3.83	2.817	3.56
19	2.379	3.79	2.815	3.53
20	2.387	3.87	2.813	3.51

Table 5 Comparison of results of Ti grade 2 machined in WEDM with Brass and onlineLN$_2$ cooled brass wire

Response	Non-cryogenic treated wire	Cryogenic treated wire	% increase in response
Maximum MRR (mm^3/min)	2.640	3.200	21.21
Minimum Ra(µm)	3.65	3.25	10.95

From the table 5, it is clearly understood that the experiments done using cryogenic treated wire yields better results on output response. The maximum MRR is increased by 21.21% and the surface roughness is minimized by 10.95%.

3.1Effects of Pulse on Time and Pulse off Time on MRR

Figure 5 and 6shows the surface plots of MRR against pulse on time and Pulse off time when brass and online LN$_2$ cooled brass wire are used respectively. The MRR increases with the increase in pulse on time and decreases with increase in pulse off time. As pulse on time increases, more discharge energy is generated, which causes melting and evaporation of the material leads to deep penetration on surface of material (Ram Prasad et al. 2014). With increase in pulse off time, there is a decrease in MRR. This may be due to incomplete removal of the machined material from the gap between wire and work piece. (Kapilgupta&Neeleshkumarjain, 2014). The thermal conductivity of cryogenic treated wire increases which causes heat in inter-electrode gap to dissipate discharge energy at faster rate. Hence MRR increases when the wire is cooled using Cryogenic (Harpeet Singh &Amandeep Singh 2012). When Pulse off time increases the number of spark discharged decreases, which leads to less material removal from the surface of the work piece. Thus there is decrease in MRR (RupeshChalisgaonkar&JatinderKapoor 2014).

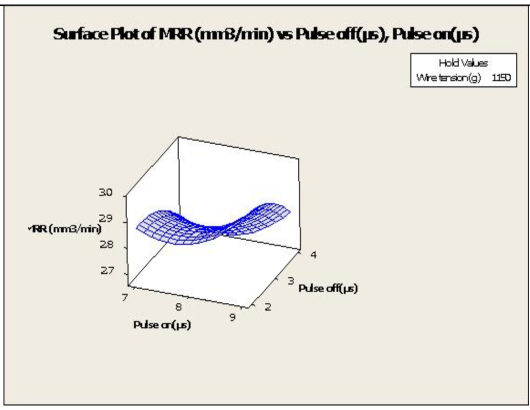

Figure 5 Surface plot of MRR vs T$_{on}$, T$_{off}$ using brass wire

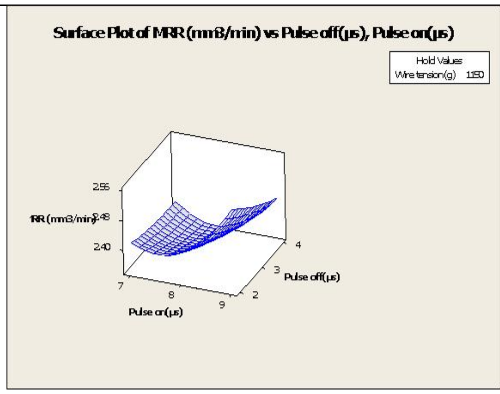

Figure 6 Surface plot of MRR vs T$_{on}$, T$_{off}$ using LN$_2$ cooled brass wire

3.2 Effects of Pulse off Time and Wire Tension on MRR

Figure 7 and 8 shows the surface plots of MRR against pulse off time and wire tension time when brass and online LN_2 cooled brass wire are used respectively. It is apparent from figure that MRR increases with increase in Wire tension. Increase in wire tension decreases the vibration which leads to increase in easy and rapid escape of eroded material (AmiteshGoswami&Jatinder Kumar, 2014).When pulse off time is increased, MRR decreases due to lower energy transfer per unit time (Suresh Kataria et al. 2013).

Figure 8 depicts the effect of pulse off time and wire tension on MRR. It is clearly observed from the graph that there is decrease in MRR with increase in pulse off time and increase in MRR with increase in Wire tension. When pulse off time increases, the cutting rate decreases because the number of discharge in given period of time become less (Kamal kumarjangra et al. 2014). As wire tension increase the vibrations in the wire decreases, that improves the surface quality of the material (Aniza Alias et al. 2012).

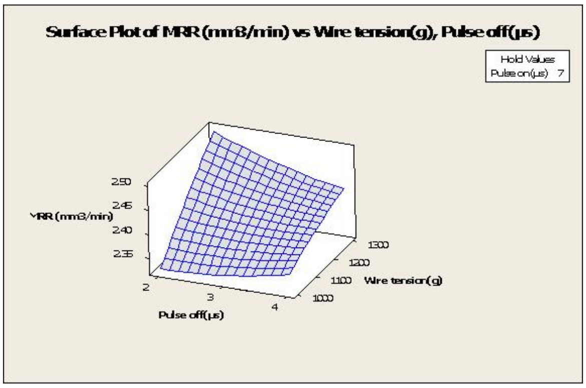

Figure 7 Surface plot of MRR vsT_{off}, WT using Brass wire

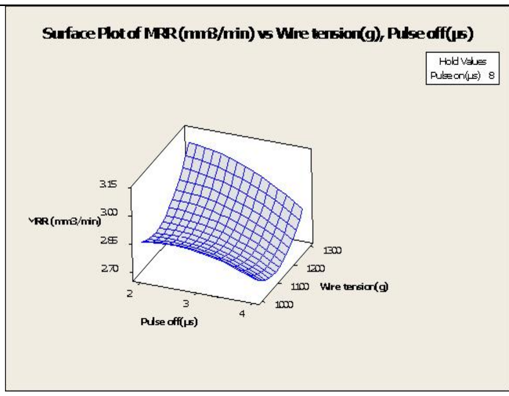

Figure 8 Surface plot of MRR vs T_{off}, WT using LN_2 Cooled brass wire

3.3 Effects of Pulse on Time and Wire Tension on MRR

Figure 9 and 10 shows the surface plots of MRR against pulse on time and wire tension time when brass and online LN_2 cooled brass wire are used respectively. It is observed from the figure MRR increases with increase in pulse on time and wire tension. With increase in pulse on time, more number of sparks per time are generated, which causes more amount of discharge. These sparks removes material from the work piece and increases the material removal rate (AveekMohanty et al. 2014). Increasing wire tension reduces the wire lagging and vibrations in the wire, thus wire become stiff. Stiff wire creates craters of more depth thus material removed from surface increases (Vamshi Krishna Pasam et al. 2010). Figure 10 illustrates the material removal rate with wire tension and pulse on time. With increase in pulse on time there is more discharge energy transferred to the work piece, which increase the heat developed between wire and work piece. This heat developed melts and evaporates more material from work piece (BijoMathew et al. 2014). Increase in wire tension reduces the deflections in wire which generates uniform sparks and increases the overcut of material (Neeraj Sharma et al. 2014).

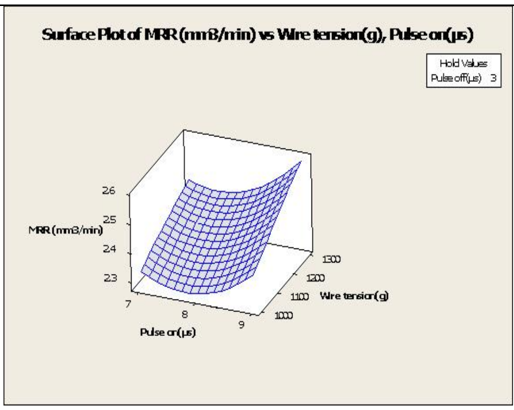

Figure 9 Surface plot of MRR vs T_{on}, WT using brass wire

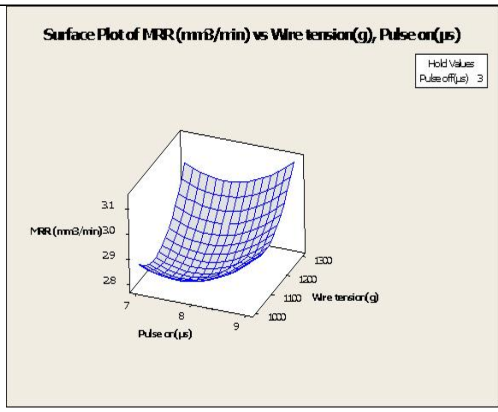

Figure 10 Surface plot of MRR vs T_{on}, WT using LN2 cooled brass wire

3.4 Effects of Pulse on Time and Pulse off Time on Ra

Figure 11 and 12 illustrates surface plot Surface Roughness of the machined component is influenced by the pulse on time and pulse off time with brass and online LN_2 cooled brass wire in Wire-electric discharge machining. When pulse on time is longer, there will be formation of larger and deeper craters exhibiting greater surface roughness (Manjaiah et al. 2014a).As pulse off time is high, there is enough time for cooling and flushing of eroded material which in turn causes good surface finish (Manjaih et al. 2014b).

The effect of pulse on time and pulse off time is shown in Figure 12. Surface roughness increases with in pulse on time and decreases with decrease in pulse off time as shown in Figure12. When pulse on time is increases the discharge energy increases which results in evaporation of more material and deep craters are formed. Thus surface roughness increases (Bahre et al. 2013).With increase in pulse off time there will be enough time for the dielectric fluid to flush off the debris thickness of recast layer formation decreases. Thus surface roughness decreases (Hsieh et al. 2009).

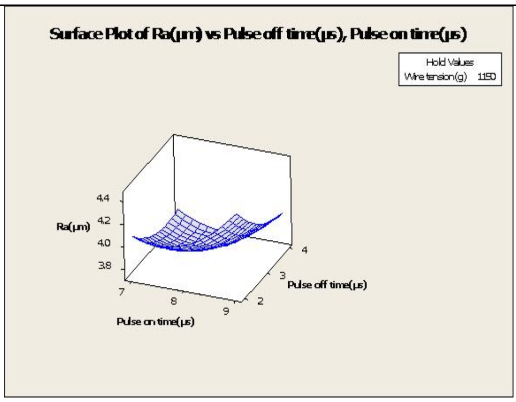

Figure 11Surface plot of Ra vs T_{on}, T_{off} using brass wire

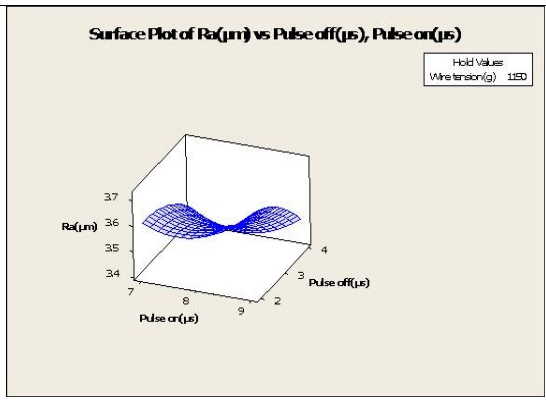

Figure 12 Surface plot of Ra vs T_{on}, T_{off} using LN2 cooled brass wire

3.5 Effects of Pulse on Time and Wire Tension on Ra

Figure 13 and 14 illustrates surface plot Surface Roughness of the machined component is influenced by the pulse on time and wire tension time with brass and online LN_2 cooled brass wire in Wire-electric discharge machining. When pulse on time increases material is eroded material continuously and cannot be flushed completely. This leads to more accumulation of debris that hinders the energy transfer, which results in non-uniform surface finish increases (Hewidy et al. 2005). Surface roughness decreases with increase in Wire Tension because vibrations of the wire reduced (FarnazNourbakhsh et al. 2013).

The effect of pulse on time and wire tension is shown in Figure 14. The surface roughness increases with increase in pulse on time and decreases with increase in wire tension. When pulse on time is less, there will be low spark generation because dielectric needs time to renew it. Hence surface roughness is less when pulse on time is less (Amoljitsingh gill et al. 2012). With increase in wire tension the wire bending decreases which leads to increase in stability of wire and reduces the depth of craters, hence improves surface finish (Hewidy et al. 2005).

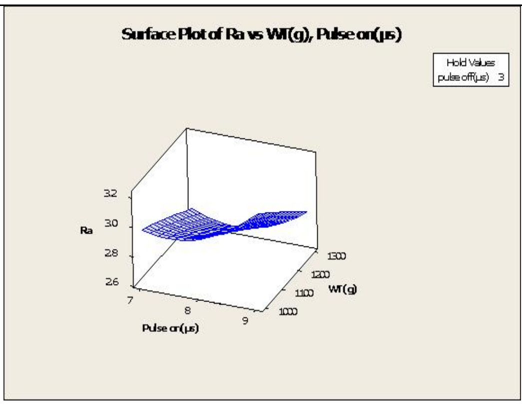

Figure 13Surface plot of Ra vs T_{on}, WT Using brass wire

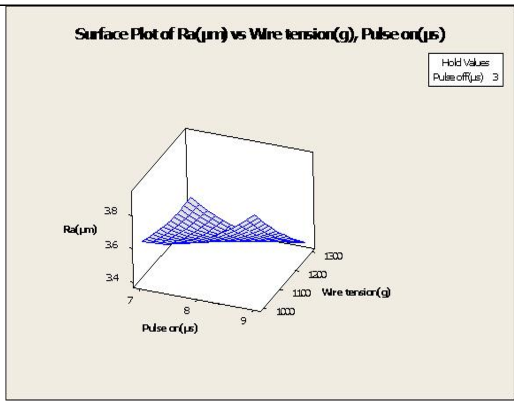

Figure 14 Surface plot of Ra vs T_{on} , WT using LN2 cooled brass wire

3.6 Effects of Pulse off Time and Wire Tension on Ra

Surface plot of Ra vs pulse off time and Wire tension is shown in Figure 15 and 16. The figure illustrates that Surface roughness decreases with increase in pulse off time and wire tension. As wire tension increases, there will be reduction in wire bending which makes the wire more stable. The depth of crater is reduced; hence surface finish is improved (Raju et al. 2014). When pulse off time is increased, the number of sparks decreases, hence good surface finish is obtained (RavindarthnadhBobbili et al. 2013). The variation in surface roughness with pulse off time and Wire tension is shown in Figure 16. When wire tension is increased, the wire gets stiff and vibrations are reduced and produces smooth surface (Navjotsingh et al. 2014). With increase pulse off time surface roughness decreases this is due to low current which results in low thermal loading on both the electrodes, this lead to formation of small craters on the surface (Pramanik 2014)

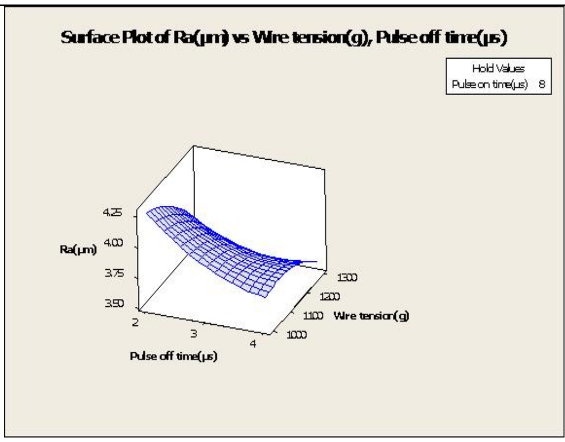

Figure 15 Surface plot of Ra vsT_{off}, WT using brass wire

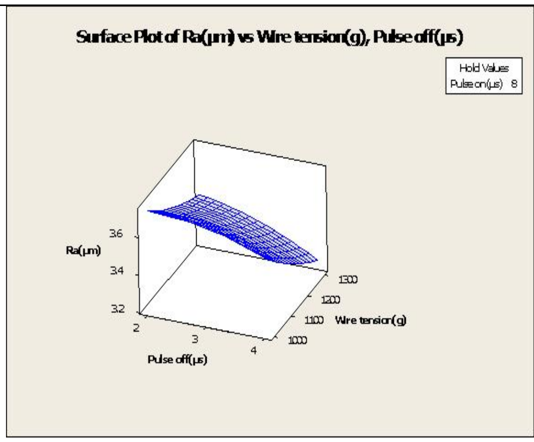

Figure 16 Surface plot of Ra vs WT, T_{off} using LN2 cooled brass wire

4. Surface integrity

Using SEM analysis the changes occurred in the workpiece because of high temperature developed in machining of the work piece is studied. The surface changes due to high temperature developed during machining of the specimen and the changes occurred on the work piece were studied using SEM analysis.

4.1 Surface Topography of Ti grade 2

The SEM images of Ti grade 2 machined using different wires are shown in Figures 17 and 18.

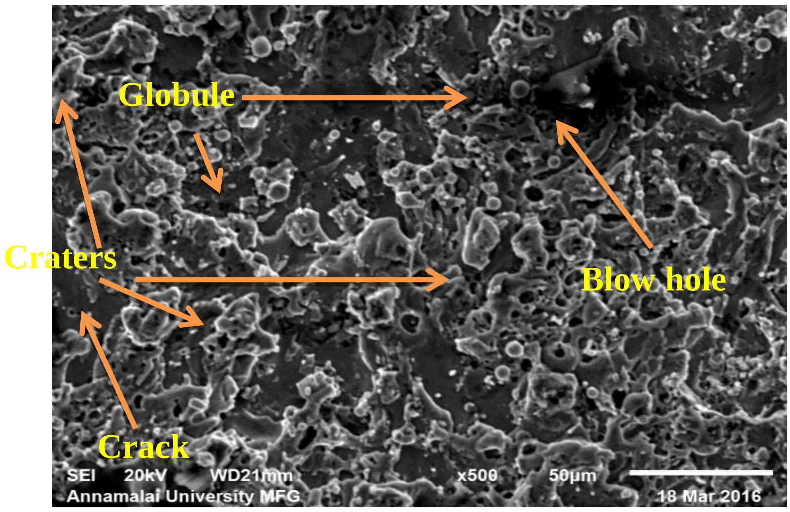

Figure 17 SEM image of Ti grade 2 machined using brass wire

The above Figure 17 shows the SEM image of the work piece machined with brass wire, by keeping parameters at WT 1300g, T_{on} 8μs, T_{off} 3μs. Large numbers of craters, cracks were formed on the surface due to uneven thermal loading produced by brass on the specimen. The uneven thermal loading is due to the improper spark formation and low time for flushing of the debris.

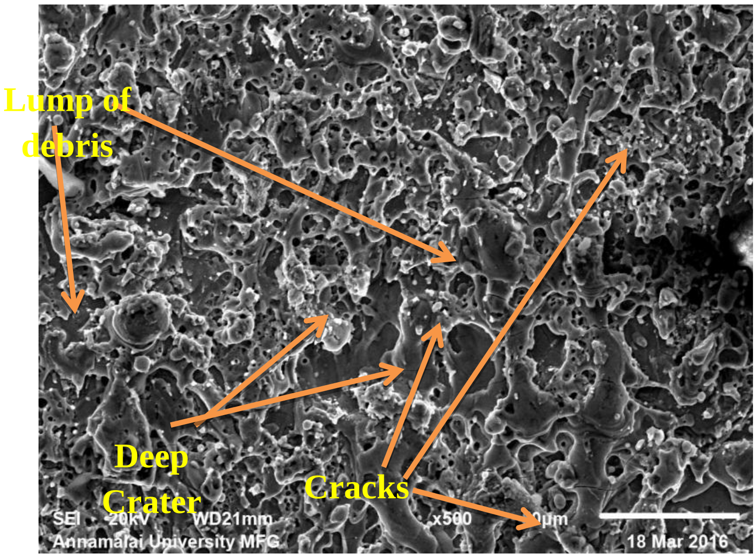

Figure 18SEM image of Ti grade 2 machined using online LN_2 cooled brass wire

The minimum surface roughness value while machining Ti grade 2 machined using online LN_2 cooled brass wire was 3.25µm, which was obtained at T_{on} 9µs, T_{off} 4µs, WT 1300g and its SEM image is shown in Figure 10 (b). In comparison the surface roughness value was minimum with cryogenically cooled brass wire than brass wire while machining Ti grade 2 alloy. As thermal conductivity increases, heat at inter-electrode dissipates at faster rate. High temperature difference between the electrodes i.e. between LN_2 cooled wire and work piece, causes the evaporating material to form as lump of debris on the surface. Even this temperature difference develops thermal stresses and produces cracks on the surface (Kamal Kumar Jangra et al. 2014).

5. Conclusion

i. Ti grade 2 and grade 5 were machined using four different wires i.e. Brass Wire, online LN2 cooled Brass wire, Zinc coated brass wire, and online LN2 cooled zinc coated brass wire and the following conclusions were drawn from the study.

ii. It is observed that MRR increases by 21.21% when brass wire was online LN_2 cooled, because the thermal conductivity of wire increases. Thermal conductivity causes more heat to dissipate and inter electrode gap increases and more materials gets escape from the surface of the work piece. Surface roughness decreases by 10.95%, due to uniform dissipation of heat from online LN_2 cooled brass, which reduces the depth of crater.

iii. MRR and surface roughness obtained by using zinc coated brass wire are 12% more and 16.92% less than that of online LN_2 cooled brass wire respectively. The zinc having lower melting points than brass gets melts away, which helps to increase the plasma channel. This improves the material removal rate and it even provides more space for the dielectric fluid to flush away the material. Thus surface roughness also decreases.

iv. Further online LN_2 cooled Zinc coated brass wire increases the MRR by 10.92% and decreases the surface roughness by 16.67%.

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