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Original Article

An Experimental Study for Surface Roughness Effect on SS 316L by Copper Electrode in Biomedical Fabrication Machined using EDM

Mohammed Imran[1], M.A. Saloda[2], B.L. Salvi[3], Chitranjan Agarwal[4], S. Jindal[5]

[1,2,3,4,5]*Department of Mechanical Engineering, MPUAT, CTAE, Udaipur, Rajasthan, India.*

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Abstract - *Hydrophobic surfaces are actively studied across a wide range of applications in different industries. Now in the biomedical arena, these surfaces play a major role as substrates to control protein absorption, bacterial growth, and cellular interaction and provide a better platform for drug delivery devices. Researchers have used various methods to generate hydrophobicity on metallic surfaces which are naturally hydrophilic. Surface texture plays an important role in generating hydrophobic surfaces; these textures are fabricated by non-conventional electric discharge machining (EDM) on a metallic surface. In this work, the authors are analyzing the effects of various EDM operating parameters such as discharge current, pulse on time, pulse off time, and voltage for measuring surface roughness (SR) and contact angle (CA) on stainless steel 316 L (SS 316L). The machinability of SS 316L is investigated using a copper electrode having a 16 mm diameter to achieve the high surface roughness value. The results are observed using the surface roughness tester SJ-216. The copper electrode in biomedical hydrophobic surfaces is treated as an antibacterial coating to reduce infections. The copper electrode at a high current intensity gives a high SR value. Surface roughness values are obtained from 7.47µm to 13.81µm, which shows the better roughness value for hydrophobic nature SS 316L after EDM.*

Keywords - *EDM, Biomedical implants, SS 316L, Electrode, Surface texture, Hydrophobic.*

I. INTRODUCTION

For the last two to three decades**,** surface texture has been the hottest topic in the research field of manufacturing for the different industries of different applications. Nowadays, in the modern manufacturing industries, their manufacturing demands better surface texture for the suitable application need. Some industries need a better finish surface on the material, and some need high surface roughness. In the manufacturing industries sector, mechanical components manufacturing is frequently substituted with a non-conventional machining process over the conventional process. Epically electric discharge machining (EDM) is very popular in all non-conventional processes for the surface texture. There is a great advantage of using EDM that this technology is especially used for the mechanical components having the complex geometry and materials having great hardness. Another major challenge is to increase the strength and life of the textured surface of the material by electric discharging machining.

In this EDM technology, the desired geometry of the machined part is directly given by the electrode shape. A high-temperature thermal process governs the material removal in this process.

Kumar et al. [1] carried out many reviews on various methods of surface texture modification in EDM. Their research first introduced the texturing application of electric discharge machining, and this EDM texturing was initiated in the steel roller mills. Surface texturing by EDM technique is used to find many numbers applications like aerospace, food industries, biomedical industries, solar panel industries, etc. [2] Jatin et al. Increasing **s**urface roughness (SR) on the material while using the electric discharging machining can be obtained by analyzing of various parameters like discharge current, pulse on time, pulse off time and servo voltage. Their results found that the discharge current is a significant parameter for better surface roughness.

Khan and Ali [3] have done their experiment to investigate the surface roughness with discharge current and servo voltage using the wire EDM on stainless steel. Their result found that surface roughness on the machined surface becomes rougher with an increase in current and voltage. Strasky et al., [4] surface treatment has been done for the application in orthopedics, on using peak discharge current to impose the high surface roughness of two parameters Ra and Rmax is observed as high. Hindus et al., [5] surface roughness was the highly significant factor on stainless steel

316L at high current and pulse on time with the EDM parameters. In this, the copper electrode was used for better results. Sharif et al., [6] copper and graphite electrode were used on stainless steel 316L to get the value of surface roughness high with the desired parameters of current and pulse on time by increasing during the experiment.

EDM process is highly adaptable in a sense one could machine any material irrespective of the hardness of the material, provided it is electrically conductive. Hence, this technique is used to machine many hard and difficult-to-cut materials. SS 316L is a material that is difficult to machine using conventional machining techniques. C. Leyens et.al.[7] Investigated the structure's final surface, which consists of debris and drops of solidified material. This has been reported earlier that EDM affects the surface roughness and the surface quality. This resulting surface roughness depends, for the most part, on the peak current of the EDM process. According to M. Bigerelle et.al.[8] EDM has already been proposed as a suitable surface treatment for biomedical applications with favorable biocompatibility and osteointegration.

This paper aims to analyze an effective method to fabricate a long-term stable hydrophobic surface to achieve the experimental results of getting a high value of surface roughness for the use of generating hydrophobic surface in the application of biomedical implants on material stainless steel 316L using a copper electrode with respect to significant machining parameters and level of machining parameters for multiple performance characteristics. ANNOVA does all these results and Analyses.

Taguchi's methodology is used for experimental design to set suitable machining parameters to effectively control the number of removed materials and produce the complicated, precise component.

II. MATERIALS AND METHODS

A. Experimental set-up and instruments

The experiments have been conducted on the non-conventional EDM model ZNC 250 die electric series of JK machines available at the department laboratory. With the help of three factors (discharge current, pulse on time, and pulse off time) are used with a total number of 25 experiments were carried out on the die-sinking ZNC 250 machine. The experimental set is shown in Figure 1. The EDM specifications are in Table 1.

Fig 1. EDM machine set-up

For performing the machinability of SS 316L, four-machining parameters have been used to carry out all the experiments using cooper electrodes to achieve the maximum surface roughness value. Discharge current (I), pulse on time (Ton), pulse off time (Toff), and servo voltage has been taken as parameters.

Table 1. Specifications of EDM

Brand	**JK Machines**
Model	ZNC-250
No. of axis	3 axes (X, Y and Z)
X, Y & Z axle range	250, 250 & 200 mm
Maximum capacity of the operating platform	200 mm
Maximum processing speed	200 mm^3/min
Maximum power consumption	6 kW
Pulse width (T_{on})	4-999 microseconds
Pulse gap (T_{off})	1-99 unit being 10 microseconds
Adjusting current	0-40 Ampere
Servo tracking voltage (processing voltage)	1-9 volts
Least count	0.005 mm

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To evaluate the machining time of each and every sample was noted down by using a stopwatch. After that, surface roughness was then measured for all the machined samples by Mitutoyo SURFTEST SJ-210 roughness tester shown in Figure 2, and the features are as follow in Table 2:

Fig 2. Mitutoyo SURFTEST SJ-210

Table 2. Features of Surftest SJ-210

Features	Descriptions
Detector measuring force (mN)	0.75
Stylus tip angle (°)	60
Measuring range (mm)	16
Measuring speed (mm/s)	0.75
Range (µm)	360

B. Materials

To perform the investigation, stainless steel 316L is used as this metal is biocompatible with the human body, and copper is used as an electrode treated antibacterial coating. The properties for both the workpiece and the electrode are given in Table 4 and Table 5.

The selection of workpiece material is based on the research work for biomedical applications. Those materials where the surface interacts with tissues, cells, biological fluid, and/or biological molecules and all these surfaces have some texture that can achieve all the required properties. The material selected to produce biomedical components should be sensitive to corrosion in vitro physiological fluid; SS316L is a suitable material. SS 316L has excellent mechanical and chemical stabilities (hardness, stiffness, wear, and corrosion), so it is used, and its chemical composition is as in below table 3.

Table 3. Chemical composition (wt.%) of stainless steel 316L material for this work

Compo sition	C	Si	M n	P	S	C r	Ni	M o	Fe
Wt. %	0.0 17	0. 56	1. 21	0.0 25	0.0 01	17 .6	11 .1	2. 16	bala nce

The metal was cut into a machinable slice of dimension 50 mm × 13mm × 5 mm, and a copper electrode had a diameter of 16mm, as shown in Figure 3 and Figure 4, respectively. The slice was then abraded using a grinder before carrying out for machining. Table 4. shows the properties of SS 316L.

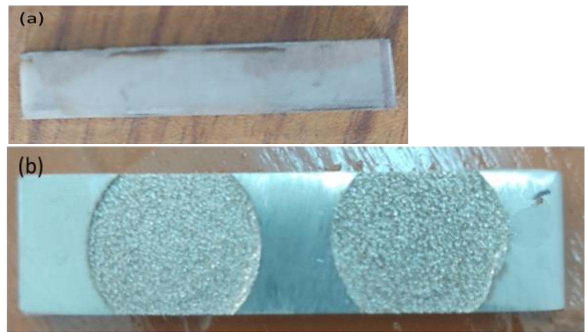


Fig 3. (A) Workpiece SS 316L plate and (B) EDM machined workpiece

Table 4. Mechanical properties of SS 316L

Tensile Stress (MPa) min	Yield Stress 0.2% (MPa) min	Proof Elongation (% in 50 mm)	Hardness	
			Rockwell B (HRB) max	Brinell (HB) max
485	170	40	95	217

Copper is selected as the electrode for applying biomedical superhydrophobic surfaces because it is treated as an antibacterial coating to reduce infections. The copper ions are impregnated with the nanoparticles to protect the bacterial growth in the surrounding culture.

Using copper in the EDM machining of the randomly distributed craters and holes potentially help to generate rough surface is useful for hydrophobicity and protection from bacterial growth.

Fig 4. copper electrode

Table 5. properties of copper electrode

Essential properties	Description
Specific gravity (g/cm3)	8.94
Melting range (°C)	1,065–1,083
Specific heat (J/kg·K)	385
Thermal conductivity (W/m·K)	388
Electrical resistivity (Ω·cm)	1.7×10−6
Thermal expansion coefficient (1/°C)	16.7×10−6

C. Design of the Experimentation

In this research work, Taguchi's parameter design approach is used to study the effect of process parameters on the various responses of the EDM process. Taguchi is a powerful technique for designing a high-quality system. Taguchi design involves using orthogonal arrays to organize the parameters that affect the process and the levels at which they should be varied. We have taken three parameters and five levels, so from Table L25 orthogonal array is used. Minitab 18 software has been used for the same. This method allows collecting user data to decide which factors most affect product quality with minimal experimentation, thus saving time and resources.

The basic steps for the methodology are

Step 1- Selection of process parameters to be evaluated
Step 2- Selection of orthogonal array and assign these process parameters
Step 3- Running the experiments based on arrangements of orthogonal array
Step 4- Analysis of the experimental results using ANNOVA
To determine the effect of an electrode on surface roughness, machining of 2mm depth is done with the different parameters and their levels, as shown in Table 4.

Table 6. Machining parameters and their levels

Machining parameters	Symbols	levels				
		Level 1	Level 2	Level 3	Level 4	Level 5
Discharge current (A)	Ip	10	12	14	16	18
Pulse on time (μs)	T_{on}	150	250	350	450	550
Pulse off time (μs)	T_{off}	20	30	40	50	60

III. RESULTS AND DISCUSSION

In experiments conducted by the EDM from different electrical parameters, the influence of the electrode and workpiece material machining characteristics is significant to the response. In this paper, the results obtained for Ra are analyzed by the DOE technique. This section discusses the mechanism of surface roughness. The electrical and thermal properties of the material and the machining parameters in use affect the machining output parameter surface roughness.

A. Surface Roughness

Experiments are performed in EDM varying the parameters such as discharge current, pulse on-time, pulse off time, and gap voltage to find the surface roughness variation concerning these parameters. Surface roughness values were measured on different textured samples, and the results were in the range of 7.47μm to 13.81μm. The effects of different parameters on surface roughness are discussed in the following sections.

a) Discharge current

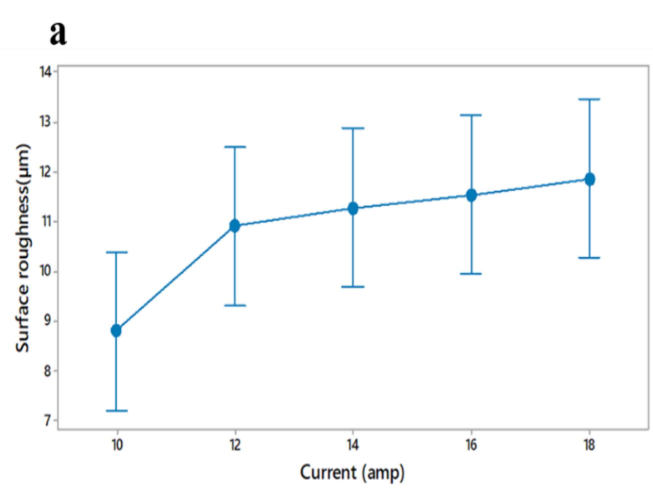
The variation of surface roughness with discharge current is shown in Figure 5 (a). From the obtained results, it could be understood that the increase in the value of surface roughness shows by the increase in discharge current. Value of discharge current ranges from 10 amp to 18 amp.

b) Pulse on time

The variation of surface roughness with a pulse on time is shown in Figure 5 (b). It could be observed that the surface roughness shows an increase with the increase in pulse on-time duration. The highest surface roughness value is observed at a pulse on-time value of 350 μs. Using the copper electrode, there is an increase in surface roughness with an increase in pulse on-time duration in the EDM process.

c) Pulse off time

The variation of surface roughness with pulse off time is shown in Figure 5 (c). The parameter pulse off time has less impact on surface roughness on the workpiece. From the results, it could be observed that the value of pulse off time ranges from 20 μs to 60 μs; it also shows that as the value of pulse off time is increased, the surface of the workpiece becomes smoother, which means that the surface roughness value will be less.



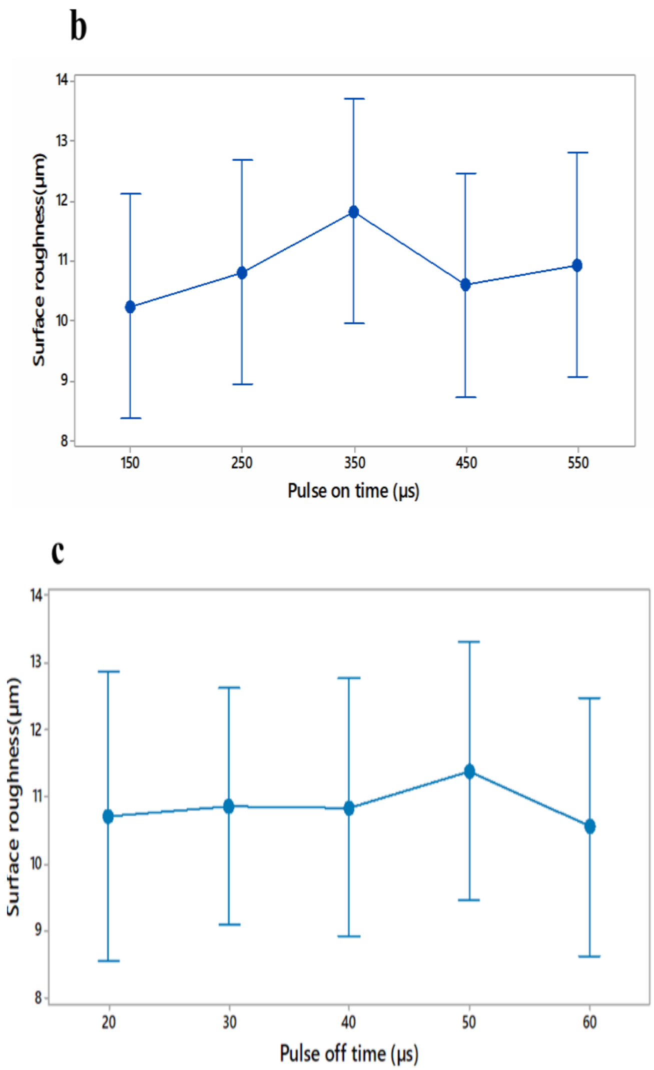


Fig. 5 Variation of surface roughness with a pulse on-time, b discharge current, and c pulse off time

As can be seen from the pareto chart in Figure 6, the effects are arranged in order of importance and the interaction effect between current intensity and pulse on time and pulse off time. As observed from the figure, the current intensity is the most influential factor on Ra, to such an extent that the higher its value is, the higher the value of surface roughness is. This maximum value was obtained with the highest values of current intensity 18 amp and pulse on time is 250 µs and at the low valve of pulse off time which is 30 µs.

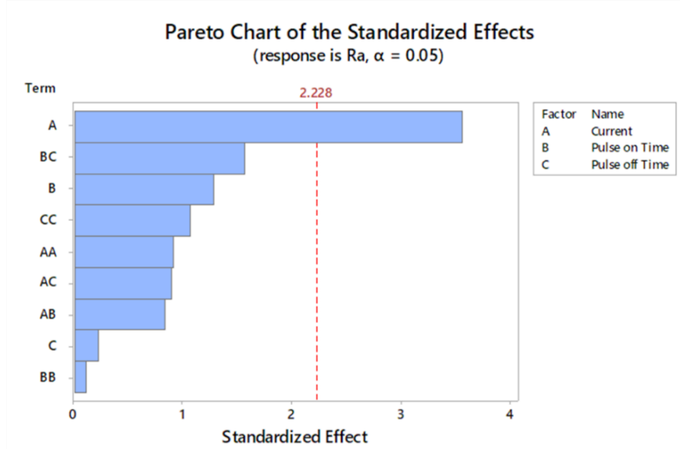


Fig. 6 Pareto chart for surface roughness

The pareto chart shows absolute values of the standardized effects from the largest effect that the intensity of the current is the most significant value for variation of surface roughness.

d) Analysis of Variance

The Analysis of variance is shown in Table 7. The Analysis of variance studied for the effect of factors on surface roughness is indicated below. Results show that the discharge current is the most significant factor while machining SS316 L with a copper electrode tool. After that, pulse on time is an important parameter, and pulse off time is less significant during machining. For this case, "lesser is better" is chosen.

Table 7. Analysis of variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	48.4625	5.3847	2.23	0.113
Linear	3	34.5962	11.5321	4.78	0.026
Current	1	30.5137	30.5137	12.66	0.005
Pulse on Time	1	3.9601	3.9601	1.64	0.229
Pulse off Time	1	0.1224	0.1224	0.05	0.826

It is shown clearly in Figure 7 (a) and (b) shows three-dimensional surface plots of the relationship with the different parameters of the intensity of current and pulse on time which helps to Analysis of the response of surface roughness for maximum value. From this response surface methodology, it is also clear that the surface valve is higher at the higher intensity of current and pulse on time. So, we can say that the rate of increase in Ra was observed to be high enough with copper electrodes.

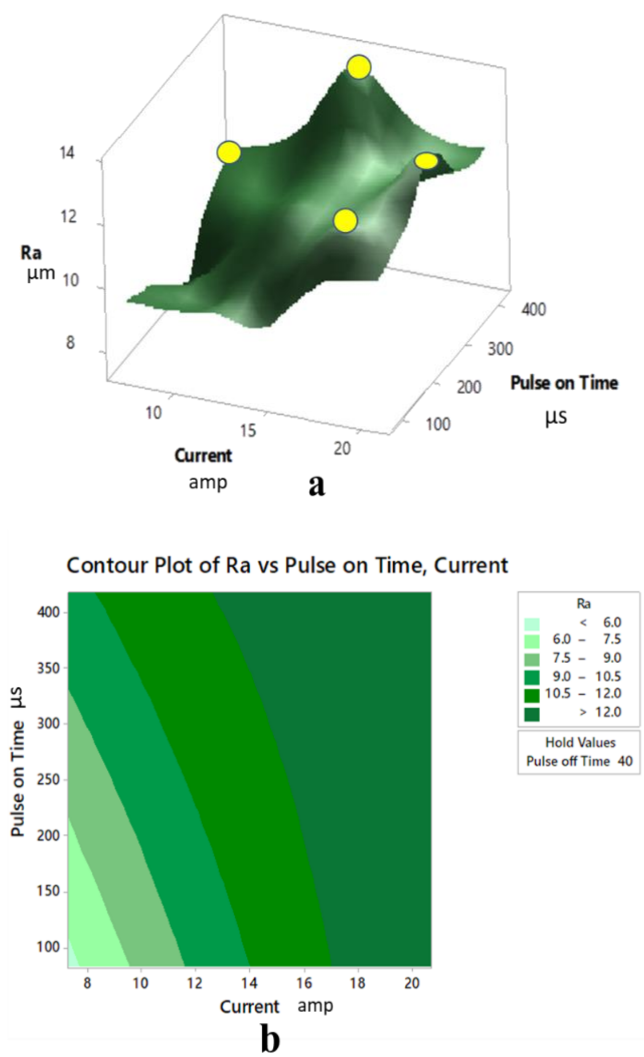


Fig. 7 a & b. Three-dimensional surface plots of the main effects of Ip, T_{on}, & T_{off}

IV. CONCLUSION

This work studied the effect of electrode materials on stainless steel 316 L for increasing surface roughness using hydrophobic surface generation and obtained with EDM. The following are the major conclusions:

- This work introduces EDM as a feasible machining process to induce a high surface roughness value by a copper electrode on SS316 L for generating a hydrophobic surface.
- Surface roughness shows a continuous increase with the parameters such as current intensity and pulse on time. The maximum SR value of 13.81 µm is obtained at 18 amp of current and 350 µs T_{on}.
- The parameters such as intensity of current and pulse on-time influence the surface roughness on the work surface. Value Arithmetic mean height (Ra), an area surface roughness parameter, increased with increasing current and pulse on time.

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REFERENCES

[1] A. Kumar, U. Laxminarayana, and N. Aravindan, Study of Surface Morphology on Micromachined Surfaces of AISI 316 by Die Sinker EDM, Materials Today: Proceedings. 4(2) (1017) 1285–1292.

[2] S. Jithin, S.S. Shetye, J. J. Rodrigues, K. S. Mhetre, S. A. Mastud, and S. S. Joshi, Analysis of Electrical Discharge Texturing Using Different Electrode Materials, Advances in Materials and Processing Technologies. 4(3) (2018) 466–479.

[3] A. A. Khan, M. B. Ali and N. B. Shaffiar, Relationship of Surface Roughness with Current and Voltage during Wire EDM, Journal of Applied Sciences. 6 (2006) 2317-2320.

[4] J. Strasky, M. Janecek, and P. Harcuba, Electric Discharge Machining of Ti-6Al-4V Alloy for Biomedical Use. (2011) 127–131.

[5] J. Hindus, P. Rajendra, P. Kuppan, Experimental Investigations on Electrical Discharge Machining of SS 316L. 12 (2013) 2321–5747.

[6] S. Sharif, W. Safiei, A. F. Mansor, M. H. M. Isa, and R. M. Saad, Experimental Study of Electrical Discharge Machine (Die Sinking) on Stainless Steel 316L Using Design of Experiment, Procedia Manufacturing. 2 (2015) 147–152.

[7] M. Bigerelle, K. Anselme, B. Noel, I. Ruderman, P. Hardouin, A. Iost, Biomaterials. (2002) 1563–1577.

[8] A. Mahajan, and S. S. Sidhu, Surface Modification of Metallic Biomaterials for Enhanced Functionality a Review, Materials Technology. 33(2) (2018) 93-105.

[9] S. Jithin, U. Bhandarkar and S. S. Joshi, Analytical Simulation of Random Textures Generated in Electrical Discharge Texturing, Journal of Manufacturing Science Engineering. 139(11) (2017) 1–12.

[10] A. Torres, C. J. Luis, and I. Puertas, EDM Machinability and Surface Roughness Analysis of Tib2using Copper Electrodes, Journal of Alloys and Compounds. 690 (2017) 337–347.

[11] M. Wang, K. P. Rajurkar, and W. M. Wang, Improvement of EDM Performance with Advanced Monitoring and Control Systems, Journal of Manufacturing Science Engineering. 119(4B) (1997) 770-78.

[12] K. Saptaji, M. A. Gebremariam, and M. A. Azhari, Machining of Biocompatible Materials a Review, The International Journal of Advanced Manufacturing Technology. 97(5) (2018) 2255-92.

[13] S. Jithin, S. Sagar, Shetye, J. Jewel, Rodrigues, S. Ketan, Mhetre and A. Sachin, Analysis of Electrical Discharge Texturing Using Different Electrode Materials, Advances in Materials and Processing Technologies. 4(3) (2018) 466–79.

[14] Zheng, Quanshui, and Lu. Cunjing, Size Effects of Surface Roughness to Superhydrophobicity, Procedia IUTAM International Congress of Theoretical and Applied Mechanics. 10 (2013) 462–75.

[15] A. Arslan, H. H. Masjuki, M. A. Kalam and M. Varman. Surface Texture Manufacturing Techniques and Tribological Effect of Surface Texturing on Cutting Tool Performance a Review, Critical Reviews in Solid State and Materials Science. 41(6) (2016) 447–81.

[16] M. Peters, J. Kumpfert, C. H. Ward, C. Leyens, Titanium Alloys for Aerospace Applications, Advanced Engineering Materials. 5(6) (2003) 419-27.

[17] Y. Tian, X. Liu, and H. Qi, Generation of Stainless Steel Super Hydrophobic Surfaces Using WEDM Technique, Proceedings of SPIE the International Society for Optical Engineering. 9446 (2015) 1–5.

[18] A. M. Ubaid, F. T. Dweiri, S. H. Aghdeab, and L. A. Al-Juboori, Optimization of Electro Discharge Machining Process Parameters with Fuzzy Logic for Stainless Steel 304 (ASTM A340), Journal of Manufacturing Science and Engineering. 140 (2018) 1-13.

[19] K. Peta, T. Bartkowiak, P. Galek and M. Mendak, Contact Angle Analysis of Surface Topographies Created by Electric Discharge Machining, Tribology International. 1 (2021) 107-139.

[20] S. Singh, S. Maheshwari, and P. C. Pandey, Some Investigations Into the Electric Discharge Machining of Hardened Tool Steel Using Different Electrode Materials, Journal of Materials Processing Technology. 149 (2004) 272–277.

[21] R. D. Amrish and T. Senthilvelan, Empirical Modeling and Optimization of Process Parameters of Machining Titanium Alloy by Wire- EDM using RSM, Materials Today Proceedings. 2 (2015) 4-5.

[22] MINITAB Student Version. (2017).

[23] [Online]. Available: https://www.kruss-scientific.com/products/drop-shape/dsa100/drop-shape-analyzer dsa100/?gclid=Cj0KCQiAnNXiBRCoARIsAJe_1cpXreV97J1ZsHKDeUY_LcfKgf6s1NlsPApS-uO37iIiqJSsn4thiOkaAroMEALw_wcB.