Periodicals of Engineering and Natural Sciences ISSN 2303-4521
Vol. 8, No. 2, June 2020, pp.933-941

Enhancement of the performance surface roughness of wire cutting process by additives Nano [AL2O3]

Azwan Bin Sapit[1], Saad Kariem Shather[2] & Farook Nehad Abed[3]
[1-3]Faculty of mechanical, manufacturing, university tun Hussein onn Malaysia
[2] Production Engineering University of Technology, Iraq

ABSTRACT

Experimental investigation and optimization of machining parameters in Wire EDM in terms adding particles Nano-reinforced titanium alloy composite abstracts among the various mechanical processes, the process of manufacturing in wire electrical discharge machines WIRE EDM is one of the most effective and cost-efficient manufacturing processes in the manufacture of titanium alloys Ti-6242. Ti has been dealt with in this article investigate each of operating parameters such as pulse on time, pulse off time, voltage and current insulating liquid with Nano powder [AL2O3] in WIRE EDM compounds titanium alloy. Experiments on titanium alloy carried out with powder mixture with particles size average of [5 nm]. Operating parameters such as voltage, pulse on time and pulse off time are taking into consideration four factors based on the response surface methodology. The performance of thesis evaluated WIRE EDM for ti-6242 using the surface roughness factor SURFACE ROUGHNESS. Quadratic models were developed between parameters and WIRE EDM responses by regression analysis is. The derived mathematical models are then optimized using Box-Behnken optimization based on desire analysis. The search indicates that the expected values of the model obtained to match the experimental values. Improvement in surface roughness is observed in terms of the values obtained from the Box-Behnken analysis.

Keywords: RSM, Box-Behnken Design, SR, additives Nano

Corresponding Author:

Farook Nehad Abed
Departement, production engineering
University, University of technology
Address.slah al deen Iraq
E-mail: farookalbadry1@gmail.com

1. Introduction

In recent years, titanium and alloys gained considerable attention because of the growing need for materials structural lightweight in field space and motor vehicles. Ti-6242 is one of the lighter metals engineered on steel compared to aluminum the low-density alloy titanium reason for use in infrastructure lightweight in spacecraft industries to get better withstand temperatures efficiency. Seem run on nanopowder Alemania at with suitable operating environment so it was mixed nanopowder in works to improve and reduce the presence and harness of ceramic reinforcement of the materials flow capacity on the surface during slippage, thus enhancing the corrosion resistance in the composite microstructure [1] with an increase in the percentage of booster size,
Certain properties such as the softness and strength of the nano compost effect are maintained lone until the adding of 2.0% volume of the above Nano powder which greatly decreases the value due to the excessive aggregation of the Nano powders [2]. The heterogeneity of compounds is due to uncontrolled aggregation of Nanopowders due to the forces of van der vall. By doing some other practical ways, such as spray mining and deposition, Heat has a practical role in moving and is an economically feasible and flexible process reduced production cast and higher manufacturing rate. Furthermore, The processes used can also be used in near-grid form of vehicles [3] mechanical stirring One of the most widely used methods in manufacturing materials matrix components, enhanced with fine particles of ceramic materials, however, for the manufacture of nanomaterial is it would be very, for the manufacture of nanomaterial is it would be very difficult for a matrix because Nanopowders have significantly higher surface areas. The ultrasonic cavity process was developed along with

sclerosis to achieve the equivalent dispersion and dispersion of Nano powders in magnesium a magnetic compound s[4]. Ultrasound is an effective and applicable process in dispersing nanotubes widely used in the magnesium matrix. [5].

Furthermore, the lifespan of high-speed steel tooling and tungsten- carbide decreases with the addition of Molecules ceramic enforcement due to corrosion [6]. It is difficult to operate the machines through docking methods due to high rigidity and strength of reinforcement. These compounds can be easily formed by unconventional methods such as manufacturing jet water and laser cutting, but these methods may be limited to linear cutting only. Thus, WIRE EDM becomes an appropriate process for cutting complex shapes in these types the composite materials [7]. In WIRE EDM , the material is removed from the work by corrosion resulting from a combination of several sparks between the workpiece and wire are continuously supplied in the automation area, separated by a stream of insulating fluid. The continuous moving electrode wire used in WIRE EDM consists of copper, copper or thin tungsten, and the thick density ranges from 0.05mm to 0.3mm to chieve a very small angle radius [8]. is surface roughness [SR] as important in properties. WIRE EDM [9]. WIRE EDM -based vehicle on SKD!! With peak current, wire speed. pulse time, and tracking coefficient as putting in parameters with surface roughness and MRR carded output. , mathematical models of surface roughness, to study effect important machinery parameters such as pulse on time, peak current, operator in WIRE EDM ceramic materials process [10]. Pulse on time, pulse off time, dielectric flow and voltage are considered as auxiliary WIRE EDM superconductors of the nimonic c-263 while superconductors MRR, plug surface termination, wire erosion rate, and spark existed performance measures [12]. One of the things to pay attention to is the pulses stop and playback as well as voltage connectors and dielectric all of this affects WIRE EDM superconductors MRR, plug surface termination, wire erosion rate, and spark existed performance measures. The effects of parameters detected WIRE EDM different such as the service voltage, pulse on time and flow rate were at the cutting speed, a width of the channel and roughness of the surface when manufacturing polycrystalline silicon [13]. An experimental relationship was developed between Among all the variables to give more efficient to work on the wire speed and pulse frequency.

Produced [14] use an array orthogonal based Taguchi to formulate plan for investigation WIRE EDM taking into account input process which includes level reinforcement and size parameters, and pulse on time, the shutdown time pulse off time, the results indicate that pon and %w of reinforcement have a significant effect on SURFACE ROUGHNESS and compared to other process parameters. RSM is a supportive technique for estimating the relationship between critical input factors then one or more of the observed responses. The optimal experimental design can get by deterred by using the optimal experimental design method to estimate the parameter[15]. The principle D-optimal, one of many optimizations, alphabet [16]. Was created to select design points in a way that minimizes the variance associated with estimates of coefficients model described [17] based on optimal design RSM for modeling and analysis machine responses in drilling composite materials matrix metal hybrid. This review left the researcher able to test the efficacy of process parameters on surface roughness during WIRE EDM on titanium alloy and reconstituted using nano powder prepared by the ultrasonic cavity with stiffness. Therefore, adequate and adequate research has not been undertaken to confirm the impact of parameters WIRE EDM on responses MMNC [18]. This is very important because these effects have a vital role to play in component performance. Manufacturing parameters such as are selected Ton, Toff, and vas control parameters by looking at performance WIRE EDM such as surface roughness. quadratic models of the response surface have been developed and improved using a desire-based approach

In recent years, titanium and alloys gained considerable attention because of the growing need for materials structural lightweight in field space and motor vehicles. Ti-6242 is one of the lighter metals engineered on steel compared to aluminum the low-density alloy titanium reason for use in infrastructure lightweight in spacecraft industries to get better withstand temperatures efficiency. Seem run on nanopowder Alemania at with suitable operating environment so it was mixed nanopowder in works to improve and reduce the presence and harness of ceramic reinforcement of the materials flow capacity on the surface during slippage, thus enhancing the corrosion resistance in the composite microstructure [1] with an increase in the percentage of booster size,

Certain properties such as the softness and strength of the nano compost effect are maintained lone until the adding of 2.0% volume of the above Nano powder which greatly decreases the value due to the excessive aggregation of the Nano powders [2]. The heterogeneity of compounds is due to uncontrolled aggregation of Nanopowders due to the forces of van der vall. By doing some other practical ways, such as spray mining and deposition, Heat has a practical role in moving and is an economically feasible and flexible process reduced production cast and higher manufacturing rate. Furthermore, The processes used can also be used in near-grid form of vehicles [3] mechanical stirring. One of the most widely used methods in manufacturing materials

matrix components, enhanced with fine particles of ceramic materials, however, for the manufacture of nanomaterial is it would be very, for the manufacture of nanomaterial is it would be very difficult for a matrix because Nanopowders have significantly higher surface areas. The ultrasonic cavity process was developed along with sclerosis to achieve the equivalent dispersion and dispersion of Nanopowders in magnesium a magnetic compounds [4]. Ultrasound is an effective and applicable process in dispersing nanotubes widely used in the magnesium matrix [5].
Furthermore, the lifespan of high-speed steel tooling and tungsten- carbide decreases with the addition of Molecules ceramic enforcement due to corrosion [6].it is difficult to operate the machines through docking methods due to high rigidity and strength of reinforcement. These compounds can be easily formed by unconventional methods such as manufacturing jet water and laser cutting, but these methods may be limited to linear cutting only. Thus, WIRE EDM becomes an appropriate process for cutting complex shapes in these types the composite materials [7]. In WIRE EDM , the material is removed from the work by corrosion resulting from a combination of several sparks between the workpiece and wire are continuously supplied in the automation area, separated by a stream of insulating fluid. The continuous moving electrode wire used in WIRE EDM consists of copper, copper or thin tungsten, and the thick density ranges from 0.05mm to 0.3mm to chieve a very small angle radius [8]. is surface roughness [SR] as important in properties. WIRE EDM [9]. WIRE EDM -based vehicle on SKD!! With peak current, wire speed. Pulse time, and tracking coefficient as putting in parameters with surface roughness and MRR carded output. , mathematical models of surface roughness, to study effect important machinery parameters such as pulse on time, peak current, operator in WIRE EDM ceramic materials process [10] pulse on time, pulse off time, dielectric flow and voltage are considered as auxiliary WIRE EDM superconductors of the mnemonic c-263 while superconductors MRR, plug surface termination, wire erosion rate, and spark existed performance measures [12]. One of the things to pay attention to is the pulses stop and playback as well as voltage connectors and dielectric all of this affects WIRE EDM superconductors MRR, plug surface termination, wire erosion rate, and spark existed performance measures. The effects of parameters detected WIRE EDM different such as the service voltage, pulse on time and flow rate were at the cutting speed, a width of the channel and roughness of the surface when manufacturing polycrystalline silicon [13]. An experimental relationship was developed between Among all the variables to give more efficient to work on the wire speed and pulse frequency.
Produced [14] use an array orthogonal based Taguchi to formulate plan for investigation WIRE EDM taking into account input process which includes level reinforcement and size parameters, and pulse on time, the shutdown time pulse off time, the results indicate that pon and %w of reinforcement have a significant effect on SURFACE ROUGHNESS and compared to other process parameters. RSM is a supportive technique for estimating the relationship between critical input factors then one or more of the observed responses. The optimal experimental design can get by deterred by using the optimal experimental design method to estimate the parameter [15]. The principle D-optimal, one of many optimizations, alphabet [16]. Was created to select design points in a way that minimizes the variance associated with estimates of coefficients model described [17-19] based on optimal design RSM for modeling and analysis machine responses in drilling composite materials matrix metal hybrid. This review left the researcher able to test the efficacy of process parameters on surface roughness during WIRE EDM on titanium alloy and reconstituted using nano powder prepared by the ultrasonic cavity with stiffness. Therefore, adequate and adequate research has not been undertaken to confirm the impact of parameters WIRE EDM on responses MMNC [20-23]. This is very important because these effects have a vital role to play in component performance. Manufacturing parameters such as are selected Ton, Toff, and vas control parameters by looking at performance WIRE EDM such as surface roughness. Quadratic models of the response surface have been developed and improved using a desire-based approach

2. Material used

The effects of titanium alloy have been studied Ti-6242 on metal cutting by using a cast iron with an insulating liquid mixed with particles nano AL2O3 with an average particle size of 5nm. The ultrasonic cavity arrangement used in the synthesis and the preheating chamber is made up of powder. Nanopowders are heated with the insulating liquid at about 80^{o} C for one hour in the pre-powder chamber to improve the ability to mix

Table 1. Chemical composition and mechanical properties Ti-6242

Element	AL	Sn	Zr	Mo	Si	Fe	O2	C	N2	H2	Ti
Max. weight[%]	6	2	4	2	0.13	0.25	0.15	0.08	0.05	0.0125	85.3

2.1. Experimented design

In this work, I conducted experiments designed by Design Expert 10 to optimize modeling and studying responses such as the surface roughness in the WIRE EDM of titanium Ti-6242. In this study, models are optimized for models in which qualitative factors interrelate with the quadratic effects of quantifiable factors. The design map appears in Table2 where three factors are changed on three levels when one class factor changes at two levels.

Table 2. Design of machining parameters and their levels

s.no	Name of parameter	Symbol	Range
1	Pulse on time	P on	100 -120 mu
2	Pulse off time	O off	30 -50 mu
3	Peak current	Ip	10 -12 A
4	Spark gap set voltage	SV	20 -30 V

2.2. Experimental procedure

Al experiments on cutting machine WIRE EDM CNC four cutting [four-axis EL pulse 15 Electra] uses deionized water mixed with powder nano AL2O3 as a dielectric and loose copper wire with a diameter of 0.25 mm as a polle. Three types of men [10*10*10] mm were on formed CNC WIRE EDM, during mechanical testing, roughness, they have been preserved as practical. Test device uses surface roughness [MITUTOYO] to measure surface roughness Ra with 0.8 mm. four readings are measured astatine different points in the vertical direction on the cutting way, and the average value of these one's measurements is taken take one of these values as a response value.

Table 3. Experimental results using box-behanken design

Run	A:pon	B:poff	C:pi	D:spv	SR
1	100	40	12	25	3.23
2	100	40	11	20	2.77
3	120	50	11	25	2.97
4	100	40	11	30	2.78
5	110	40	11	25	2.85
6	120	40	10	25	2.11
7	100	30	11	25	2.76
8	110	40	11	25	2.89
9	110	40	11	25	2.88
10	120	30	11	25	3.05
11	110	40	12	20	3.25
12	120	40	11	30	2.98
13	100	40	10	25	2.09
14	110	40	11	25	2.92
15	120	40	11	20	3.02
16	110	30	11	20	2.75
17	110	50	11	20	2.88
18	120	40	12	25	3.28
19	110	50	10	25	2.09
20	110	40	11	25	2.81
21	110	30	11	30	2.92
22	110	50	12	25	3.22
23	110	40	12	30	3.25

Run	A:pon	B:poff	C:pi	D:spv	SR
24	100	50	11	25	2.76
25	110	50	11	30	2.93
26	110	30	10	25	2.12
27	110	40	10	20	2.13
28	110	30	12	25	3.27
29	110	40	10	30	2.1

2.3. Optimal design-based [RSM] model development

Surface response methodology, a large section of experimental and experimental design is a sharp technique in developing new techniques and improving their performance. RSM design is an important and useful tool for estimating the relationship model is designed to be used with factor factors as a general optimization alternative to design selection. The overall design optimizer can produce designs with more experiments than the experiments that are prepared for their implementation. The best design procedures Box-behnken include the level, choice of design points and selection of the installation model. All design points are selected from the set of filter points based on the selected model [19]. In the manufacturing area, the first step in the RSM sequence is to find an approximation of the real functional relationship between y and the set of independent variables used.

$$Y = \beta 0 + \sum_{i=1}^{k} \beta i\, xi + \sum_{i=1}^{k} \beta ii\, xi^2 + \sum_{i} \beta i\, j\, xi\, xj \quad (1)$$

In D-optimal design, points are selected by the form and at least 14 typical points are used, five of which are used to assess non-relevance and repetition as well. Design-Expert software 10 is used to develop quadrature mathematical models for different responses. In this survey, the final square forms disposed of in specific terms are presented for responses such as surface roughness in WIRE EDM of Ti-6242 with coolant mixed with Nano powder in Tables 4 and 5. Respectively.

3. Results and discussion.

3.1 The Analysis of the Quadratic Mathematical Model.

Table 4. Enova model validation surface roughness
Table quadratic model for surface roughness

ANOVA for Response Surface Quadratic model
Analysis of variance table [Partial sum of squares - Type III]

Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	0.41	14	0.029	87.71	< 0.0001	Significant
A-pon	*7.516E-003*	*1*	*7.516E-003*	*22.39*	*0.0003*	
B-poff	*2.619E-006*	*1*	*2.619E-006*	*7.802E-003*	*0.9309*	
C-pi	*0.37*	*1*	*0.37*	*1103.24*	*< 0.0001*	
D-spv	*1.786E-004*	*1*	*1.786E-004*	*0.53*	*0.4777*	
AB	*1.329E-004*	*1*	*1.329E-004*	*0.40*	*0.5393*	

ANOVA for Response Surface Quadratic model
Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
AC	*1.210E-005*	*1*	*1.210E-005*	*0.036*	*0.8522*	
AD	*5.292E-005*	*1*	*5.292E-005*	*0.16*	*0.6973*	
BC	*3.132E-006*	*1*	*3.132E-006*	*9.331E-003*	*0.9244*	
BD	*3.208E-004*	*1*	*3.208E-004*	*0.96*	*0.3449*	
CD	*2.660E-005*	*1*	*2.660E-005*	*0.079*	*0.7825*	
A^2	*4.930E-005*	*1*	*4.930E-005*	*0.15*	*0.7073*	
B^2	*8.552E-010*	*1*	*8.552E-010*	*2.548E-006*	*0.9987*	
C^2	*0.030*	*1*	*0.030*	*90.52*	*< 0.0001*	
D^2	*1.734E-005*	*1*	*1.734E-005*	*0.052*	*0.8235*	
Residual	4.699E-003	14	3.357E-004			
Lack of Fit	*4.088E-003*	*10*	*4.088E-004*	*2.68*	*0.1777*	*not significant*
Pure Error	*6.112E-004*	*4*	*1.528E-004*			
Cor Total	0.42	28				
Std. Dev.		0.018		R-Squared		0.9887
Mean		1.67		Adj R-Squared		0.9775
C.V. %		1.10		Pred R-Squared		0.9412
PRESS		0.025		AdeqPrecision		30.463

3.2. Effect of WIRE EDM parameters on performance surface roughness

Pulse effect on current rate and SPV is shown by the insulating fluid mixed with the nanometer with 1gram precipitation and its effect on surface roughness as the 3D response surface in fig,1. Because the copper wire is thin and depends on IP, the current leads to an increase in the roughness of the surface as well as increase the spark resulting in a further depth of the hole and cause increased roughness of the surface. During the pulse period, the time gap between two consecutive pulses allows for stiffness, and the magma is washed from the cutting area. Thus, the increase in pulse time increases surface roughness by simple ratio, where the highest surface roughness is recorded in pon=120, poff =50, ip= 12 and sv=20. The inclusion of nanoparticles in its insulating liquid raises durability, practical strength and heat resistance [20]. Experiments have shown that nanopowders affect improving surface roughness, which reduces surface roughness. This can be attributed to the improvement of the cutting speed in the WIRE EDM during the use of titanium alloy increases in voltage frees the surface of the workpiece further. The diameter and depth of the drilling surface of the WIRE EDM increase with an increase in voltage, resulting in higher surface roughness

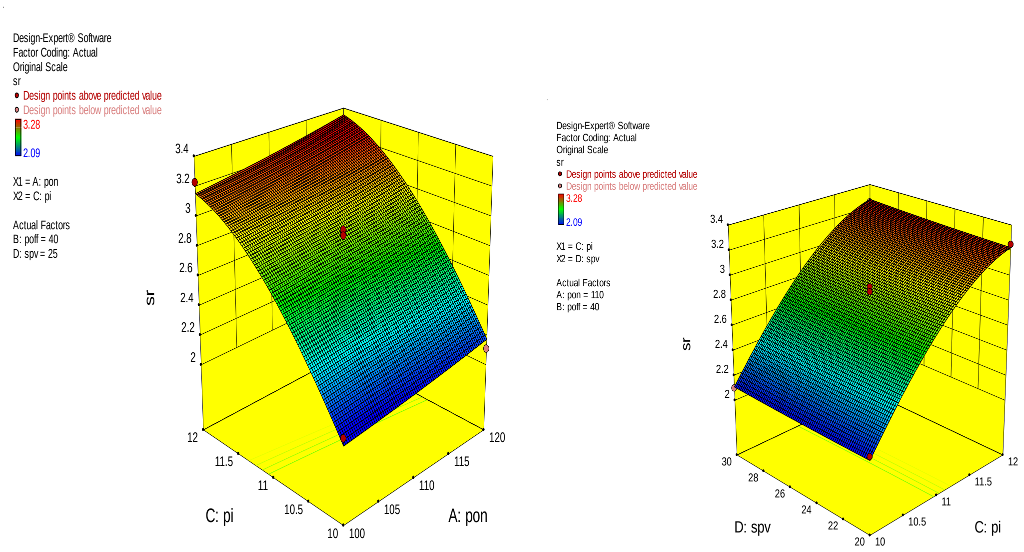

Figure 1. 3D response plots for SR

4. **Conclusion**

WIRE EDM is one of a non-traditional manufacturing process for the production of complex profiles on materials that are difficult to form or accessible from a conventional machine. It is necessary to specify the optimal process parameter's to optimize surface roughness. an effort is prepared in this probe to improve surface roughness simultaneously and using RSM coupled with the desired technique. The following finishes were drawn as of research investigation.

1. The results showed that the pulse on-time and voltage had significant effects on the MRR value.
2. The molten metal is removed with increased voltage due to the increase in discharge power. when the voltage increases and the surface roughness increases, SPV also has a role in reducing surface hardness to the surface.
3. This efficiency has been proven effective through the confirmation experiment.
4. A rigorous examination of the component surface revealed to the surface roughest was due primarily to the high value of pulse time and current.
5. The cooling fluid mixed with the Nanopowders has an effective role in improving the roughness of the surface and increasing the cutting speed.

References

[1] Vijaya Bhaskar, S., Rajmohan, T., Giri Sesha Sai, G.R., Sandeep Kumar Reddy, G., 2015. Multiple Performance Optimization in WEDM Parameters Using Desirability Analysis. Appl. Mech. Mater. 813–814, 352–356

[2] Poovazhagan, L., Kalaichelvan, K., Sornakumar, T., 2016. Processing and Performance Characteristics of Aluminum-Nano Boron Carbide Metal Matrix Nanocomposites. Mater. Manuf. Process. 31, 1275–1285. https://doi.org/10.1080/10426914.2015.1026354

[3] Poddar, P., Srivastava, V.C., De, P.K., Sahoo, K.L., 2007. Processing and mechanical properties of SiC reinforced cast magnesium matrix composites by stir casting process. Mater. Sci. Eng. A 460–461, 357–364. https://doi.org/10.1016/j.msea.2007.01.052

[4] Nourbakhsh, F., Rajurkar, K.P., Malshe, A.P., Cao, J., 2013. Wire Electro-Discharge Machining of Titanium Alloy. Procedia CIRP 5, 13–18. https://doi.org/10.1016/j.procir.2013.01.003

[5] Wang, Y., Wang, Q., Ding, Z., He, D., Xiong, W., Chen, S., Li, Z., 2018. Study on the mechanism and key technique of ultrasonic vibration and magnetic field complex assisted WEDM-LS thick shape memory alloy workpiece. J. Mater. Process. Technol. 261, 251–265. https://doi.org/10.1016/j.jmatprotec.2018.06.006

[6] Babu Rao, T., Gopala Krishna, A., 2013. Simultaneous optimization of multiple performance characteristics in WEDM for machining ZC63/SiCp MMC. Adv. Manuf. 1, 265–275. https://doi.org/10.1007/s40436-013-0029-y

[6] Bobbili, R., Madhu, V., Gogia, A.K., 2015. Modelling and analysis of material removal rate and surface roughness in wire-cut EDM of armour materials. Eng. Sci. Technol. Int. J. 18, 664–668. https://doi.org/10.1016/j.jestch.2015.03.014

[7] Abbasi, J.A., Jahanzaib, M., Azam, M., Hussain, S., Wasim, A., Abbas, M., 2017. Effects of wire-Cut EDM process parameters on surface roughness of HSLA steel. Int. J. Adv. Manuf. Technol. 91, 1867–1878. https://doi.org/10.1007/s00170-016-9881-9

[8] Bobbili, R., Madhu, V., Gogia, A.K., 2015. Modelling and analysis of material removal rate and surface roughness in wire-cut EDM of armour materials. Eng. Sci. Technol. Int. J. 18, 664–668. https://doi.org/10.1016/j.jestch.2015.03.014

[9] Zhang, C., 2014. Effect of wire electrical discharge machining (WEDM) parameters on surface integrity of nanocomposite ceramics. Ceram. Int. 40, 9657–9662. https://doi.org/10.1016/j.ceramint.2014.02.046

[10] Mandal, A., Dixit, A.R., Chattopadhyaya, S., Paramanik, A., Hloch, S., Królczyk, G., 2017. Improvement of surface integrity of Nimonic C 263 super alloy produced by WEDM through various post-processing techniques. Int. J. Adv. Manuf. Technol. 93, 433–443. https://doi.org/10.1007/s00170-017-9993-x

[12] Wang, Y., Wang, Q., Ding, Z., He, D., Xiong, W., Chen, S., Li, Z., 2018. Study on the mechanism and key technique of ultrasonic vibration and magnetic field complex assisted WEDM-LS thick shape memory alloy workpiece. J. Mater. Process. Technol. 261, 251–265. https://doi.org/10.1016/j.jmatprotec.2018.06.006

[13] Aidoo, A. W. (2019). The impact of access to credit on process innovation. Heritage and Sustainable Development, ISSN 2712-0554, 1(2), 48-63

[14] Silman, H. K., & Ali, A. E. (2020). Breast cancer identification based on artificial intelligent System. Sustainable Engineering and Innovation, ISSN 2712-0562, 2(2), 41-49

[15] Thivagar, M. L., Ahmed, M. A., Ramesh, V., & Hamad, A. A. (2020). Impact of non-linear Electronic circuits and switch of chaotic dynamics. Periodicals of Engineering and Natural Sciences, 7(4), 2070-2091

[16] Poovazhagan, L., Kalaichelvan, K., Sornakumar, T., 2016. Processing and Performance Characteristics of Aluminum-Nano Boron Carbide Metal Matrix Nanocomposites. Mater. Manuf. Process. 31, 1275–1285. https://doi.org/10.1080/10426914.2015.1026354

[17] Gopal, P.M., Prakash, K.S., Jayaraj, S., 2018. WEDM of Mg/CRT/BN composites: Effect of materials and machining parameters. Mater. Manuf. Process. 33, 77–84. https://doi.org/10.1080/10426914.2017.1279316

[18] Chen, X., Wang, Y., Wang, Z., Liu, H., Chi, G., 2018. Study on Micro Reciprocated Wire-EDM for Complex Indexing Structure. Procedia CIRP 68, 120–125. https://doi.org/10.1016/j.procir.2017.12.033

[19] Myers, R.H., Montgomery, D.C., Anderson-Cook, C.M., 2016. Response Surface Methodology: Process and Product Optimization Using Designed Experiments. John Wiley & Sons.

[20] Thivagar, M. L., & Abdullah Hamad, A. (2020). a theoretical implementation for a Proposed Hyper- Complex Chaotic System. Journal of Intelligent & Fuzzy Systems 38. 2585–2590

[20] Nourbakhsh, F., Rajurkar, K.P., Malshe, A.P., Cao, J., 2013. Wire Electro-Discharge Machining of Titanium Alloy. Procedia CIRP 5, 13–18. https://doi.org/10.1016/j.procir.2013.01.003

[21] Rajmohan, K., Kumar, A.S., 2017. Experimental investigation and prediction of optimum process parameters of micro-wire-cut EDM of 2205 DSS. Int. J. Adv. Manuf. Technol. 93, 187–201. https://doi.org/10.1007/s00170-016-8615-3

[22] Vijaya Bhaskar, S., Rajmohan, T., Giri Sesha Sai, G.R., Sandeep Kumar Reddy, G., 2015. Multiple Performance Optimization in WEDM Parameters Using Desirability Analysis. Appl.Mech.Mater.813–814,352–356. https://doi.org/10.4028/www.scientific.net/AMM.813-814.352

[23] Thivagar, L. M., Hamad, A. A., & Ahmed, S. G. (2020). Conforming dynamics in the metric Spaces. Journal of Information Science and Engineering, 36(3) 279-292.