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An Experimental Study for Surface Roughness of M42 HSS Resulted from Wire Electrical Discharge Turning.

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Abstract: Axisymmetric cutting processes are developing very fast nowadays, this development involves cutting harder materials which is not achievable by traditional ways, wire electrical discharge turning "WEDT" is a non-traditional cutting technique that is used to cut cylindrical formed workpieces on difficult-to-cut materials. In this research, the Surface roughness "R_a" of the machined parts was studied concerning changing some of the machining variables (wire feed 'W_f', workpiece rotational speed 'ω_{wp}', and pulse-on time 'T_{on}'). The study was performed on AISI M42 HSS steel, using a CNC WEDM machine, with the assistance of a well-designed spindle to enable the manufacturing of the cylindrical geometry. An L_9 (3 x 3) Taguchi standard orthogonal array was chosen for designing the experiments, the analysis for the results was done using ANOVA to get the most significant factor on R_a, and regression analysis was used to define the relationship between involved process variables and R_a.

Keywords: WEDT; WEDM; Surface roughness; Turning.

1. Introduction

Non-traditional manufacturing processes are defined as the machining processes that cut the unneeded material by non-traditional techniques using some forms of energy such as thermal, electrical, mechanical, or chemical energy or a hybrid system of these energies with no direct contact with the workpiece "WP", and no use of sharp cutting tools as it is the traditional manufacturing processes [1].

The usage of non-traditional cutting techniques is developing nowadays, because of the advantages of cutting hard or brittle materials which are difficult to cut in the traditional techniques, many methods of non-traditional machining processes are being developed to fulfill extra requirements. One of the newly developed techniques is wire electrical discharge turning "WEDT", this process is a unique type of electrical discharge machining "EDM.", that is being used to generate cylindrical profiles from difficult-to-cut materials [2].

EDM process is widely used in machining hard, brittle, high strength, temperature-resistant, and complex-shaped materials, as it is a non-contact cutting technique. And, recently, the process has been replacing many traditional machining processes such as milling, drilling, and grinding [3].

Wire EDM "WEDM" is a special case of EDM process that uses a wire as an electrode to erode the unneeded material from the WP, by a spark developed between the electrode "wire", and the conductive WP, then the eroded material is flushed away by the presence of a dielectric fluid to get the needed shape regardless of its complexity [4].

As the process is under development, the main issue of the WEDT process is the choice of the correct work factors to get high accuracy with a fine surface finish, as this process is suitable for high alloyed materials that are used in critical industries such as aerospace industry, cutting tools, dies and molds manufacturing [5].

Workpiece material was chosen considering its importance in a wide range of industries as cutting tools, punches, dies, molds, and reaming tools, most of them are needed in cylindrical form, these industries require high accuracy while performing to obtain good surface finish and high accuracy [6].

1.1 literature review

Many researchers have put up their research to develop the EDT process. [7]studied the influence of ω_{wp} during cutting AISI D2 tool steel using EDM with a copper electrode, the study showed that ω_{wp} has a positive effect on dielectric flow, and gap flushing; so, material removal rate "MRR" increases with ω_{wp} increase up-to two times of traditional EDM, and surface roughness is affected positively too with the increase of ω_{wp}. [8] studied the usage of WEDM to machine cylindrical parts to manufacture small pins.

[8] developed an experimental study on drilling process conducted on rotary EDM, the WP material was Titanium, while the tool material was copper tungsten, the results indicate that rotating the tool improves the MRR, while have a bad effect on surface roughness R_a. [9] studied the surface roughness of WEDT parts through a mathematical model. [10] studied rotary EDM performed on Al-SiC composite material, the study showed that rotating the tool on MRR improves MRR and reduces R_a.

[11] studied WEDT to evaluate the parameters' effect on R_a and roundness. [12] performed an experimental comparison between EDT, electrical discharge grinding

"EDG", and WEDG to analyze the machining effect of increasing $\omega_{electrode}$ on MRR and R_a, the results show MRR, and R_a increases with the increase of circumferential speed and discharge energy. [13] studied the influence of machining parameters on MRR, R_a, and roundness error using pulse train data analysis. [14] deduced a mathematical model for MRR using response surface methodology factored in machining parameters (power P, voltage V, pulse-off time T_{off}, and ω_{wp}). [15] modeled the WEDT process using the artificial neural network "ANN" to study the process parameters MRR and R_a. The results were verified with experiments to find the optimum values for process variables achieving high MRR and accepted surface finish.

[16] studied the influence of some of the WEDT variables (pulse-on time T_{on}, V, wire feed W_f, and dielectric flushing pressure $P_{flushing}$) on R_a of the machined WP. [17] investigated the effect of the process variables and WP diameter on the CWEDT process. [18,19] performed an experimental investigation on EDT of Titanium alloy, the results indicate that MRR is affected the most by peak current "I_{peak}", T_{on}, and V. And R_a has a direct proportional relationship with I_{peak}, and T_{on} while R_a has an inverse proportional relationship with the duty factor. [20] improved a real-time energy monitoring system to improve the performance and efficiency of the WEDM process by monitoring the transient state of the process. [21] studied the WEDM process and improved a pulse discriminating and control system depending on the gap-voltage waveform of the process.

1.2 Present Work

In this research, the WEDT process was performed on AISI M42 HSS, to investigate the effect of changing different machining variables on the surface roughness R_a of the WP material, the experiment was designed using the Taguchi model L9(3x3), and the analysis of the most significant variable on R_a was done using ANOVA technique, the relationship between involved process variables and R_a was studied using regression analysis.

2. Material and Methods

In this research, all the experiments were performed on a SUZHOU BAOMA CNC wire cut EDM DK7740 machine "Fig. 1", with table allowable travel size of 500 x 400 mm, and a maximum load capacity of 500 kg, table 1 shows all machine specifications.

The WP was chosen to be AISI M42 HSS in cylindrical form "Fig. 2", a WP diameter of 10mm, and length of 10cm, with hardness of 61HRC, and UTS of 1750MPa, table 2 shows the chemical composition of the material.

This material was chosen as its 8% Cobalt mix molybdenum HSS gives it high red hardness, high wear resistance, and toughness. These properties make it a perfect choice for several cutting tools, dies, and molds, and make it a perfect choice when testing a new cutting technique for difficult-to-cut materials.

The WP was held on a spindle "Fig. 3" during the cutting process to rotate the WP to perform the turning process, this spindle is attached to the table of the machine during operation. The spindle is designed to withstand working in the presence of the dielectric fluid with the use of seals, and the spindle is driven by a servomotor which has six different speeds (15, 22, 27, 30, 33, 42), this servomotor is designed to be above dielectric fluid workplace, to protect it while cutting. Three of these six spindle speeds were chosen for the experiments, with 15, 30, and 42 rpm values.

Runout accuracy of the spindle is an important factor affecting the process outputs such as (MRR, surface roughness, or out-of-roundness error) whether in conventional turning or in the WEDM process assisted by turning. So, measuring runout is a must when performing experiments related to turning [22]. The measuring process was performed using a precise cylindrical mandrel, and a precise dial gauge placed on the machining table "Fig. 4". The value for runout indicated in the experiment was less than 10 μm.

TABLE 1. SUZHOU BAOMA CNC wire cut EDM DK7740 machine specifications.

CNC WIRE CUT EDM DK7740C – CT	Unit	BMDK7740C – CT
Worktable size (L x W)	mm	500 x 800
Table travel (X x Y)	mm	400 x 500
Max. WP thickness	mm	300
Max. taper angle/plate thickness	degree/mm	6
Max. machining speed	mm²/min	300
Max. working current	A	9
Roughness, three cutting	mm	≤1.2
Wire diameter	mm	0.15 ~ 0.2
Wire traveling speed	m/s	5~11
Load of table	kg	500
Working solution		working solution BM - 06GP
Working reservoir capacity	L	100
Power supply		3N - 380V / 50Hz
Power consumption	kVA	3
Wire guide frame		Adjustable
Controller type		BMW – 5000

TABLE 2. Chemical composition of M42 HSS material

AISI No.	C	Co	Si	Cr	V	Mn	Mo
M42	1.10%	8%	0.70%	3.90%	1.20%	0.40%	9.30%

FIGURE 1. SUZHOU BAOMA CNC wire cut EDM DK7740 machine.

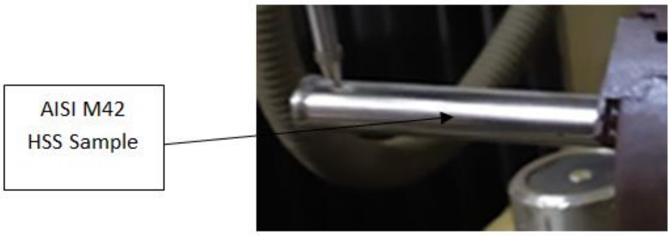

FIGURE 2. AISI M42 HSS Sample used in the experiments.

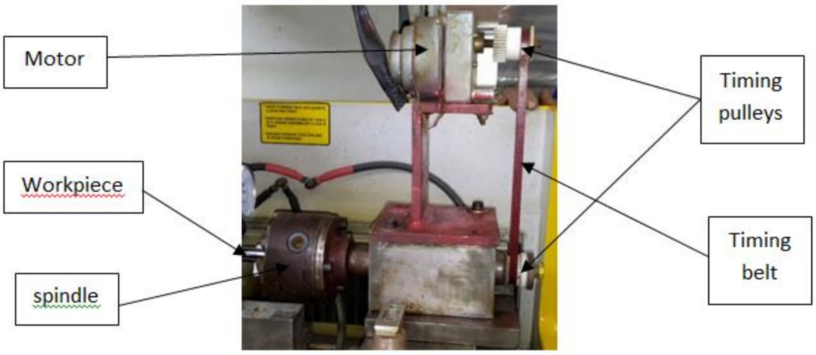

FIGURE 3. Rotating mechanism unit.

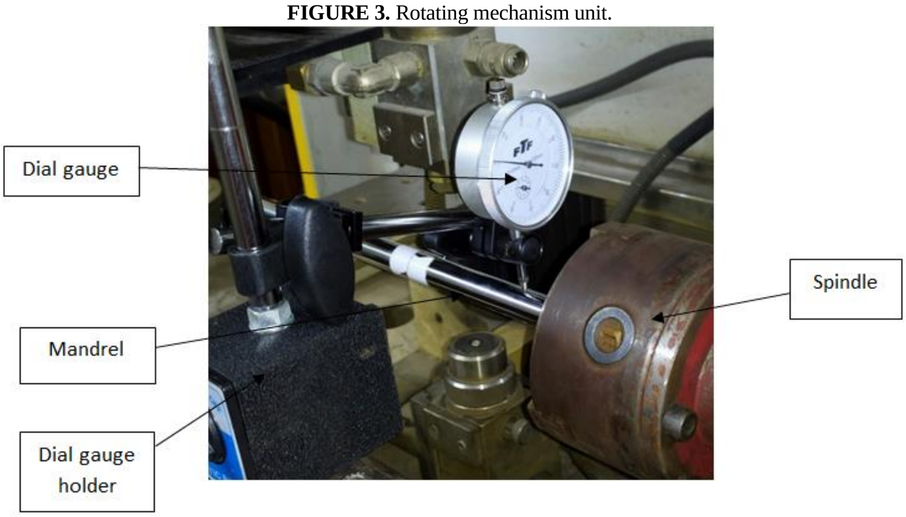

FIGURE 4. Measuring of runout of the spindle.

3. Experimental design

In this research, the influence of parameters (wire feed 'W_f', workpiece rotational speed 'ω_{wp}', and pulse-on time 'T_{on}') on surface roughness R_a was decided to be studied. Table 3 shows the selected values for each parameter to be tested.

The study was concerned with the influence of the main parameters, so, the intersections between parameters were excluded during the analysis. The experiment was designed using a single-level orthogonal array L9(3x3), experiment trials were designed by MINITAB software, and trials are shown in Table 4.

TABLE 3. Experiment layout.

Parameters 'symbol' "unit"	Level 1	Level 2	Level 3
wire feed 'W_f' "m/s"	12	18	27
Wp rotational speed 'ω_{wp}' "RPM"	15	30	42
pulse-on time 'T_{on}' "µs"	150	200	250

TABLE 4. Experiment runs.

Run	W_f	ω_{wp}	T_{on}
1	12	15	150
2	12	30	200
3	12	42	250
4	18	15	200
5	18	30	250
6	18	42	150
7	27	15	250
8	27	30	150
9	27	42	200

4. Experimental work

Experiments were performed on the CNC machine and surface roughness was measured afterward using Taylor and Hobson, Surtronic 3 "Fig. 5", this device measures R_a, where R_a is the most used international parameter to measure roughness, and it is the arithmetic mean of the departures of the profile form the mean line. the device consists of a stylus with a small tip, a gauge or transducer, a traverse datum and a processor. Roughness is measured by moving the stylus across the machined surface, this movement is converted to a signal to be converted to a value for R_a. Roughness for each cut was measured three times along the perimeter and the average for the three values is considered in the analysis, table 5 shows the roughness for each cut.

The below instructions were considered during measurement, to get verified measurements:

a) The surface of measurement was free of vibrations, and the instrument was steady during measurements, WP was held on a V-block.
b) The stylus was perpendicular to the surface to be measured.
c) The transfer was directed towards the predominant direction "Fig. 5".
d) As the measures were done to a cylindrical surface, the optional roll was fitted.

5. Results and Discussion

To use ANOVA in this experiment, verification of the analysis assumptions was necessary as follows:

a) Normal probability plot of residual point is a straight line "Fig. 6".
b) Standardized residual vs fitted values plot is randomly distributed around the zero-line "Fig. 7".
c) P-value is calculated based on confidence level (95%).
d) No pattern is seen in the residual plot, which implies that the variance is constant "Fig. 7".

TABLE 5. experiment results for surface roughness Ra

Run	1	2	3	4	5	6	7	8	9
R_a (µm)	6.09	5.9	5.1	5.61	5.12	4.32	5.55	5.12	4.61

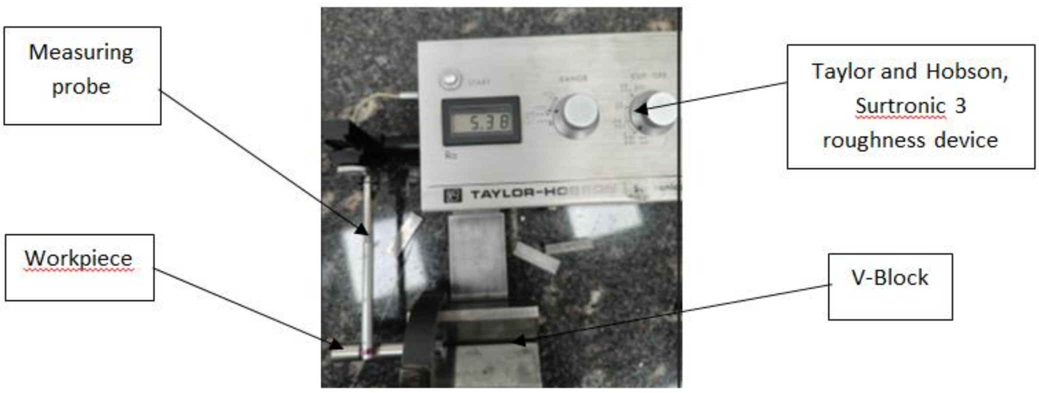

FIGURE 5. Roughness measuring process using Taylor and Hobson, Surtronic 3 roughness device.

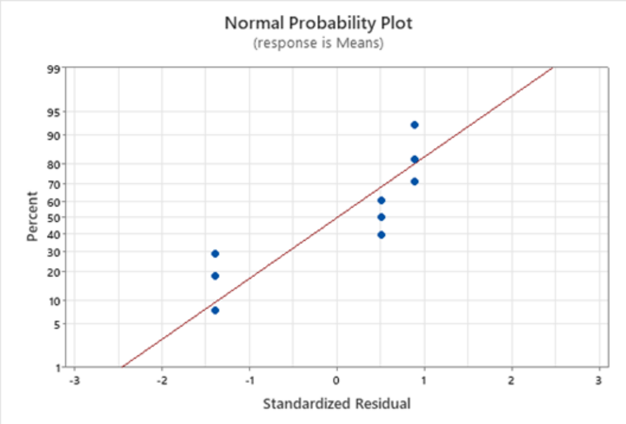

FIGURE 6. Normal probability of residuals.

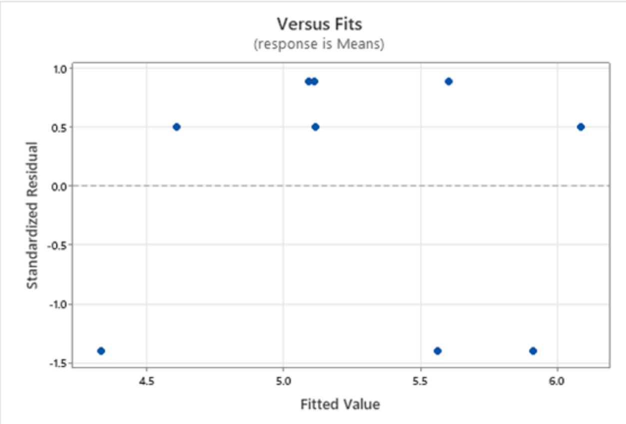

FIGURE 7. Standardized residual vs fitted values plot.

After verifying the assumption, ANOVA is proved to be valid, and analysis can be performed with valid conclusions, table 6 shows the results of ANOVA for means of R_a, with a confidence level of 95% chosen for this experiment, so, the P-value below 5% indicates null hypothesis to be rejected, that R_a is dependent on process variable with a significant effect.

From ANOVA for means of R_a output, ω_{wp} is proved to have the most significant effect on R_a with (P-value = 0 < α = 5%), and in second place W_f which has a significant effect on R_a with (P-value = 0.001 < α = 5%), and in third place T_{on} also has a significant effect on R_a with (P-value = 0.012 < α = 5%).

The R-Sq value points out that 99.97% of the variance in R_a is indicated through the predictors, and the R-Sq (adj) indicates that the number of the predictors in the model is 99.90%, numbers of R-Sq and R-Sq(adj) both shows that the model fits the data used well.

Figure 9 shows the influence of changing each process parameter (W_f, ω_{wp}, and T_{on}) separately on R_a, it's observed that ω_{wp} has the most significant influence on R_a, and the relationship between ω_{wp} and R_a is inverse proportions during the whole period from (15-42 RPMs), which means that WP surface is enhanced with the increase in ω_{wp}, while W_f is the second in place to have a significant influence on R_a, this effect of W_f on R_a varies along the period of the experiment, through period (12 – 18m/sec) the relationship is inverse proportion, while through period (18-27 m/sec) the relationship becomes direct proportion, in the third place T_{on} has the least significant influence on R_a from the tested parameters, and the relationship is direct proportion from T_{on} =150µs to T_{on} =200µs, and then flips to inverse proportion from T_{on} =200µs to T_{on} =250µs.

The abovementioned results correlate with the results of Hocheng [7] who concluded that ω_{wp} has an inverse proportion on R_a, Ayush et al. [23] found that surface quality decreases with T_{on}, but increases with ω_{wp} and W_f, Masooth, and Arunnath [24] deduced that T_{on} and T_{off} have the most significant impact than W_f, and W_t, Gohil, and Puri [2] concluded that T_{on} and I_{peak} are the most affecting parameters on R_a with a directly proportional relationship, while $P_{flushing}$ has a more significant effect on R_a than V_{gap} and ω_{wp}. Haddad and Tehrani [25] concluded that P, V, T_{off}, and ω_{wp} are the most significant factors that affect R_a. El-Taweel and Gouda [26] deduced that V and W_f have a directly proportional effect on R_a, while wire diameter is inversely proportional to R_a.

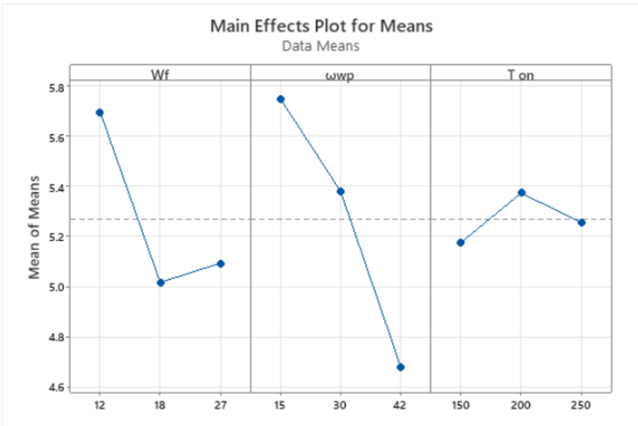

FIGURE 9. Plot for Means for Ra

TABLE 6. ANOVA for means of Ra.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	contribution
W_f	2	0.8323	0.8323	0.41614	1208.2	0.001	31.1%
ω_{wp}	2	1.7836	1.7836	0.89181	2589.1	0.000	66.7%
T_{on}	2	0.0587	0.0587	0.02934	85.19	0.012	2.2%
Residual Error	2	0.0007	0.0007	0.00034			0.0%
Total	8	2.6753					
S		R-Sq		R-Sq(adj)			
0.0186		99.97%		99.90%			

6. Conclusion

An experimental investigation on surface roughness R_a for machined parts by WEDT and the influencing machining parameters was performed. R_a is found to have significant dependency on ω_{wp}, W_f, and T_{on} respectively. The results showed that the best R_a obtained was 4.32 µm, by setting factors at W_f at 18 m/s, ω_{wp} at 42 rpm, and T_{on} at 150 µs. The level of significance of each variable was determined using ANOVA, and it was found that the main parameter that affects R_a is the ω_{wp} with (P-value = $0 < \alpha = 5$) the second and third variables that affect R_a are W_f with (P-value = $0.001 < \alpha = 5\%$), and T_{on} with (P-value = $0.012 < \alpha = 5\%$). The relationship between the affecting parameters and R_a is concluded by the mean of means analysis.

7. Conflict of interest

The authors declare no conflicts of interest.

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