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EXPERIMENTAL INVESTIGATION TO PREDICT METAL REMOVAL AND SURFACE ROUGHNESS IN WIRE CUT PROCESS

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ABSTRACT: - This paper focuses on intervening variables in wire cut process such as pulse on time, pulse off time, voltage, type of wire which use in experiments, it finds that all values from experiments to use in statistical package of social science model. The **R square** pieces are (0.998). Also they Show that 99.8% of the observed variability in material removal rate can explain by the independent variables. The multiple R is 0.999 for coat wire. This means that the correlation coefficient between the observed value of the dependent variable and the predicted value base on the regression model which are high as this means that the statistical model could predict. The Ra with about 98.7 % and 96.8 % accuracy of the testing data set for coat wire respectively.

1- INTRODUCTION

Wire EDM has introduced in the late 1960s', and has revolutionized the tool and die, mold, and metal working industries. It has probably the most exciting and diversified machine tool to develop for this industry in the last fifty years, and has numerous advantages to offer. It can machine anything that has electrically conductive regardless of the hardness, from relatively common materials such as tool steel, aluminum, copper, and graphite, to exotic space-age alloys including in conel, titanium, carbide, polycrystalline diamond compacts and conductive ceramics [1]. Wire cut process has one of thermal nontraditional machining which has important applications and most widely in different industries, electrical discharge machining which has based on the principle of removing material by repeated electrical discharges between the tool termed as electrode and the workpiece in the presence of a dielectric fluid [2].The wire has not touch the workpiece, so there has no physical pressure imparted on the workpiece compared to grinding wheels and milling cutters[3]. The amount of clamping pressure has required to hold small, thin and fragile parts have minimal, preventing damage or distortion to the workpiece. The accuracy, surface finish and time have required to complete a job which have extremely predictable, making it much easier to quote, EDM leaves a totally random pattern on the surface as compared to tooling marks left by milling cutters and grinding wheels. The EDM process have leave no residual burrs on the workpiece, which have reduced or eliminates the need for subsequent finishing operations [4]. Wire EDM has also given designers more latitude in designing dies, and management more control of manufacturing, since the machining has completed automatically [5]. Parts have complex geometry and tolerances has not required you to rely on different skill levels or multiple equipments. Substantial has increased in productivity which has achieved, since the machining has untended, allowing operators to do work in other areas. Most machines have run overnight in a "lights-out" environment [6]. Long jobs have cutten overnight, or over the weekend, while shorter jobs have scheduled during the day. Most workpieces have comen off the machine as a finished part, without the need for secondary operations. It's a one-step process[5] .today has important applications in manufacturing solar cells which led to high dimensional accuracy and smooth work surfaces by using wire cut machine present work involve intervening effective variables in process such as (pulse on time, pulse off time, servo feed rate, Arc on time, wire tension) to predict metal removal and surface roughness [7].

2- LITERATURE REVIEW:

The literature review will include experimental work on WEDM (using coated and uncoated wire electrode), and numerical models (modeling and optimization techniques for WEDM using coated and uncoated wire electrode).

Anish Kumar,et al.[8]. They present an investigation in the experimental plan based on Box-Behnken design. Six parameters i.e. pulse on time, pulse off time, peak current, spark gap voltage, wire feed and wire tension have been varied to investigate their effect on surface roughness. The surface roughness has been optimized using multi-response optimization through desirability. Dharmender, et al. [9]. They studied the effect of different process parameters viz. peak current, pulse on time, pulse off time, wire tension on response variable- surface roughness using brass wire electrode (0.25mm diameter).ANOVA and main effect plot have been used to find the significant process parameters and their effect on the response variables. Swati. D. Lahance, et al. [10]. They present weighted principal component (WPC) method which is used to optimize the multiple responses of WEDM processes. The results show that the WPC method offers significantly better overall quality than the other approaches. Danial Ghodsiyeh,et al.[11]. They studied behavior of three control parameters based on Design of Experiment (DOE) method during WEDM of titanium alloy (Ti6A14V). A zinc coated brass wire of 0.25mm diameter was used as tool electrode to cut the specimen.

3- EXPERIMENTAL PROCEDURE:

Experimental procedure involves the following:

3.1- Machine:

The experimental work has been performed on 4-axis (ELEKTRA EDM 400 A) EL PULSE 5, as shown in Figure (1).

3.2- Work material:

The Work material has use steel (33) according to (DIN:17100) as shown Figure (2) and machined under different cutting conditions which has the following chemical composition as shown in table (1) with dimensions (3 × 120 × 200 mm) :

3.3- Coated wire: Coated brass wire has used with 0.25 mm diameter.

3.4- Wire Specification: Non –paraffin wire /Japan /Hitachi Cable, ltd. Coated brass wire: (Cu 60 – Zn 40 %). +coated layer of (Zn)

3.5- Surface roughness measurement.

General data

Name: tally surf 4.

Company: Taylor – Hobson shown in Figure (3).

Over all accuracy CLA measurement: within the effective range of the meter better than 3 % full scale deflection for selecting magnification.

3.6- Material Removal Rate Calculation.

The material removal rate (MRR) is expressed as the ratio of the difference of weight of workpiece before and after machining to the machining time and density of the material. Material removal rate has calculated as follows [5]:

$MRR = Vc * b * h \quad (mm^3/min)$ ………………………….. (1)

$b = d\ wire + 2S \quad (mm)$ …………………………….. (2)

Where: V_C=cutting speed in (mm/min)

b =width of cut in mm

h =thickness of work piece in (mm), (3 mm)

d wire = wire diameter has (0.25 mm).

S = spark gab has (0.2 mm).

3.7- Cutting Conditions: There are four parameters which has used in experiments as shown in table (2)

3.8-Dielectric Used: Pure (distilled) water has used, flush WEDM (10 L), control of water conductivity: (2.5 – 5.0) * 10^4 L. cm .

4-RESULTS AND DISCUSSION:

The effect of machining parameters on material removal rate and surface roughness in machining steel 33 according to (DIN 17100) have studied. From the results, it has found that for increasing pulse on time lead to increase surface roughness as shown in tables (3,4) from 3.25 to 3.90 (µm) at 100 µsec and metal removal rate 0.585g while pulse of time 115 µsec was 5.4016 (µm) and metal removal rate 1.58.

4.1- Prediction of Surface Roughness and Material Removal Rate Using (SPSS) Software.

A statistical model has created by using regression function in SPSS from the test data set.

4.1.1- Prediction of Ra:

a- R Square:

From table (5) the **R square** pieces have 0.968 coated wire. It has shown that 96.8% of the observed variability in Ra can be explained by the independent variables. The multiple R has 0.984 for coating wire. This means that the correlation coefficient between the observed value of the dependent variable and the predicted value based on the regression.

b- Analysis of variance (ANOVA).

A mathematical technique has known as the sum of squares has used to quantitatively evaluate the deviation of the control factor effect response averages from the overall experimental mean response. The value F- ratio has used to test the significance of factor affect. F results have (60.9367) for coating wire, as shown in the ANOVA Table (6).

c- Coefficients and the Multiple Regression Equation.

In following Table (7) the coefficients for the independent variables have listed in column β for coated wire and coated wire respectively.

Using these coefficients the multiple regression equation can be expressed as:

Where **r**: surface roughness, **a:** pulse on time, **b**: pulse off time, **c:** arc on time, **d:** servo feed rate. It has refered to the increasing in **r** with increasing in **a, c, d**. Also it has refered to the decreasing in **r** with increasing in **b**.

For zinc coated wire of 0.25 mm diameter, the surface roughness prediction equation could be expressed as:

$$R= 17.431 + 0.148A – 0.993233B - 0.908233C + 0.041D \quad \text{……………….. …….} \ (3)$$

Where **R**: surface roughness, **A:** pulse on time, **B**: pulse off time, **C:** wire tension, **D:** servo feed rate. It has refered to the increasing in **R** for increasing in **A, D**. It Also has refered to the decreasing in **R** with increasing in **B**, **C**. This means the statistical model can predict the Ra with about 98.7 % and 96.8 % accuracy of the testing data set for brass and coated wire respectively.

4.1.2 Prediction for MRR:

a- R square:

The **R square** pieces has (0.998). They have shown that 99.8% of the observed variability in MRR can be explained by the independent variables.

The multiple R has 0.999 for coated wire. This means that the correlation coefficient between the observed value of the dependent variable and the predicted value based on the regression model has high as shown in Table (8).

b- Analysis of Variance (ANOVA).

The value F- ratio has used to test the significance of factor effect .F has 274.204 for coated wire respectively, as shown in the ANOVA Table (9).

c- Coefficients and the multiple regression equation.

In Table (10) the coefficients of the independent variables have listed in column β for coated wire. For using these coefficients the multiple regression equation can be expressed as: For zinc coated brass wire of 0.25 mm diameter, the material removal rate prediction equation could be expressed as:

$$M=21.981+0.3529269A-0.2395419B+064360C+0.016D+0.002A^2+0.004B^2+0.040C^2-0.00006663D^2 \qquad .(4)$$

Where **M**: material removal rate, **A:** pulse on time, **B**: pulse off time, **C:** wire tension, **D:** servo feed rate. It has refered to the increasing in **M** with increasing in **A, C, D**. It also it refered to the decreasing in **R** with increasing in **B** .This means the statistical model can predict the MRR with 99.8% accuracy of the testing data set for coated wire, the relationship between measured and predicted values of Ra and MRR for coated wire have shown in Figures (4,5). The relationship between measured and predicted values of Ra and MRR for coated wire have also shown in Figures (4, 5).

5- C ONCLUSION:

1. The statistical model can predict the Ra with about 98.7 % and 96.8 % accuracy of the testing data.
2. The statistical model can predict the MRR with 99.8% accuracy of the testing data set for coated wire .tee
3. There have agreement between predicted values and experimental values for surface roughness and material removal rate.
4. The low pulse on time and high pulse off time are favorable for better surface finish.
5. Coated wire is used for higher material removal rate and lower surface finish and saving in wire roll design.
6. Wire breakage due to bad cutting conditions may be prevented by increasing water pressure and decreasing cutting speed and pulse on time.

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Table (1) Chemical composition of steel 33.

Sample	**C%**	**Si%**	**Mn%**	**P%**	**S%**	**Cr%**	**Ni%**	**Co%**	**Cu%**	**Fe %**
Work piece material	**0.128**	**0.055**	**0.417**	**0.013**	**0.02**	**0.002**	**0.027**	**0.001**	**0.007**	Bal.

Table (2) Cutting conditions of machine EL PULSE 5 Electra WEDM.

NO.	**Parameters**	**symbol**	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Units**
1	Pulse on time	T_{ON}	100	105	110	115	μsec
2	Pulse off time	T_{OFF}	25	26	27	28	μsec
3	Servo feed rate	**SF**	30	40	50	60	mm/min
4	Wire tension	W_T	6	7	8	9	Kg_f

Table (3) Experimental designs for measured and predicted surface roughness for coating wire.

No.	**Pulse on time (μsec)**	**Pulse off time (μsec)**	**Wire tension (kgf)**	**Servo feed rate (mm/min)**	**Ra (μm) measured**	**Ra (μm) Predicted SPSS**	**Residual**
1	100	25	6	30	3.25	3.1816	-0.068398
2	105	25	6	30	3.90	3.9216	0.02160
3	110	25	6	30	4.46	4.6616	0.20
4	115	25	6	30	5.03	5.4016	0.3716
5	115	26	6	30	4.62	4.4075	-0.21246
6	115	27	6	30	3.8	3.4143	-0.385689
7	115	28	6	30	2.08	2.4210	0.341
8	115	25	7	30	4.87	4.4933	-0.376631
9	115	25	8	30	3.7	3.5851	-0.114864
10	115	25	9	30	2.46	2.6769	0.2169
11	115	25	6	40	5.68	5.8116	0.1316
12	115	25	6	50	6.24	6.2216	-0.0184
13	115	25	6	60	6.65	6.6316	-0.0184

Table (4) Experimental designs for measured and predicted material removal rate model for coating wire.

No.	**Pulse on time (μsec)**	**Pulse off time (μsec)**	**Wire tension (kg_f)**	**Servo feed rate (mm/min)**	**MRR (mm^3/min) Measured**	**MRR (mm^3/min) Predicted SPSS**	**Residual**
1	100	25	6	30	0.585	1.19	0.6
2	105	25	6	30	0.819	1.4835	0.6645
3	110	25	6	30	1.131	1.8689	0.7379
4	115	25	6	30	1.56	2.3542	0.79429
5	115	26	6	30	1.521	2.3187	0.7977501
6	115	27	6	30	1.482	2.2912	0.8209
7	115	28	6	30	1.4625	2.2719	0.809463
8	115	25	7	30	1.4079	2.2306	0.82279
9	115	25	8	30	1.4235	2.1870	0.76359
10	115	25	9	30	1.4254	2.2234	0.79809
11	115	25	6	40	1.6965	2.4726	0.77615
12	115	25	6	50	1.755	2.5676	0.79809

Table (5) Model summary for Ra (coated wire).

Model	R	R square	Adjusted R Square	Std. Error of the Estimate
1	.984	.968	.952	.298562

Table (6) ANOVA for Ra (coated wire).

Model		Sum of Squares	df	Mean Square	F
2	Regression	21.5950	4	5.3990	60.9367
	Residual	.7130	8	.0886	
	Total	22.3090	12		

Table (7) Variables coefficients in the multiple regression equation for Ra (coated wire).

Model		Un standardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
2	(Constant)	17.431	2.951		5.908	.000
	A	.148	.022	.525	6.643	.000
	B	-.993-	.111	-.705-	-8.920-	.000
	C	-.908-	.111	-.644-	-8.156-	.000
	D	.041	.011	.291	3.685	.006

Table (8) Model summary for MRR (coated wire).

Model	R	R square	Adjusted R Square	Std. Error of the Estimate
4	.999	.998	.995	.266812

Table (9) ANOVA for MRR (coated wire).

Model		Sum of Squares	df	Mean Square	F
4	Regression	1.5630	8	.1950	216.6666
	Residual	.0030	4	.0009	
	Total	1.5660	12		

Table (10) Variables coefficients in the multiple regression equation for MRR (coated wire).

Model		Un standardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
4	(Constant)	21.981	12.459		1.764	.152
	A	-.353-	.113	-4.726-	-3.127-	.035
	B	-.240-	.694	-.642-	-.345-	.747
	C	-.644-	.196	-1.724-	-3.277-	.031
	D	.016	.012	.438	1.385	.238
	A^2	.002	.001	5.641	3.704	.021
	B^2	.004	.013	.552	.299	.780
	C^2	.040	.013	1.576	3.065	.037
	D^2	-6.663E-5	.000	-.154-	-.508-	.638

Figure (1) EL PULSE 5 Electra WEDM.

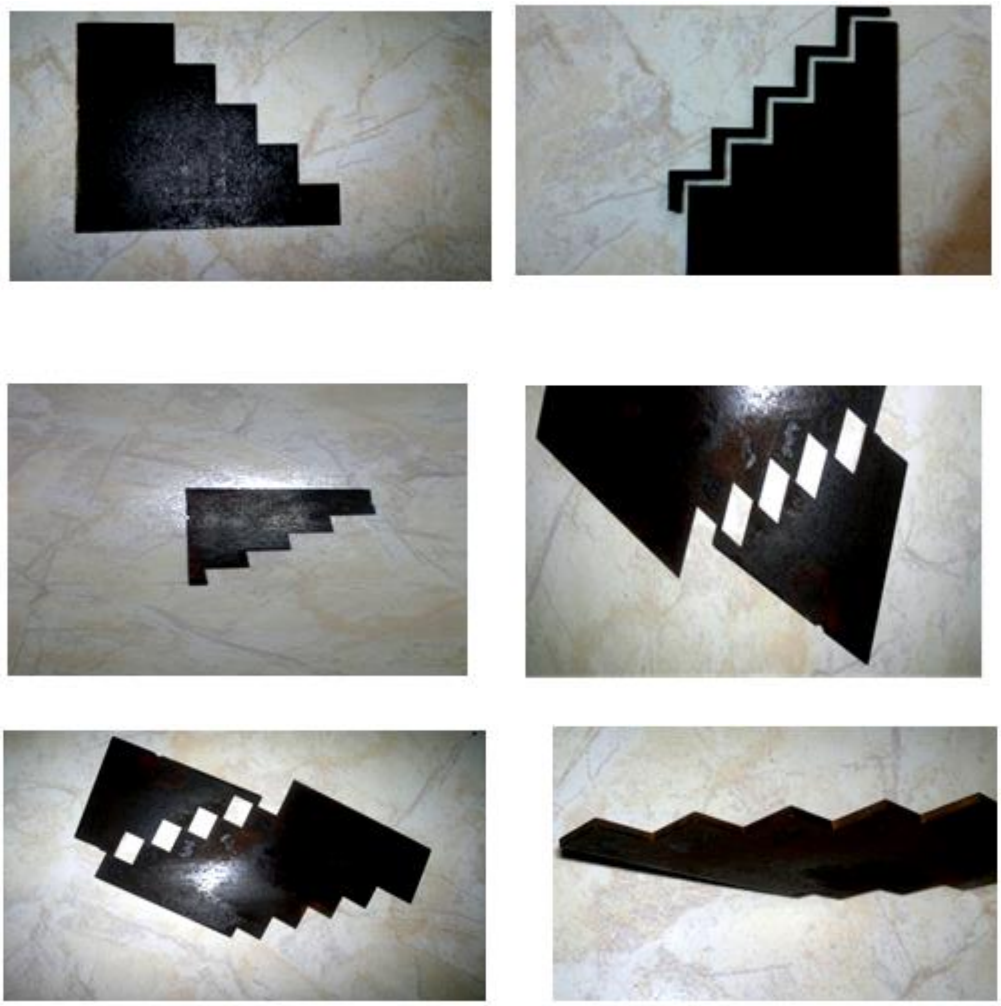

Figure (2) workpiece after machining.

Figure (3) Roughness measuring apparatus.

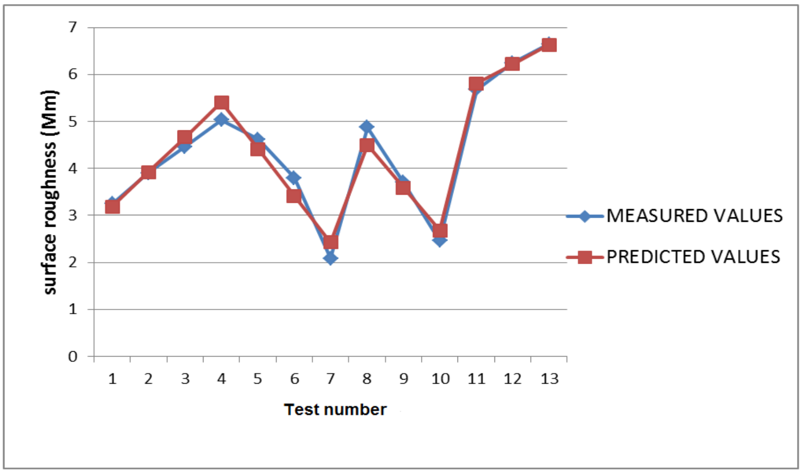

Figure (4) Relationship between measured and predicted Ra (coated wire).

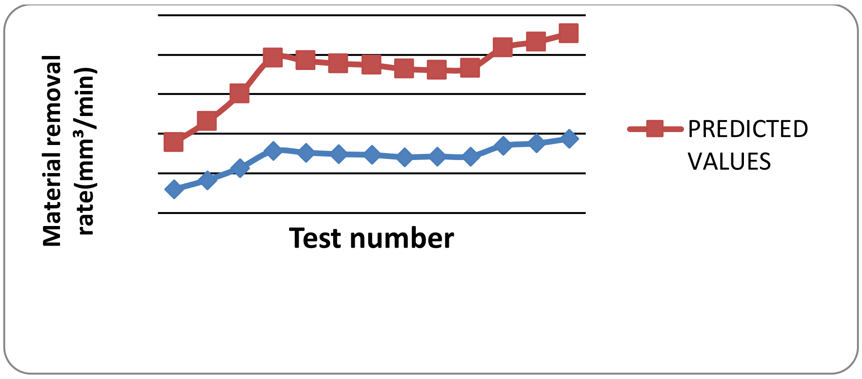

Figure (5) Relationship between measured and predicted MRR (coated wire).

التحقق العملي للتنبؤ بأزالة المعدن والخشونة السطحية في عملية القطع بالسلك

الخلاصة: يركز هذا البحث على ادخال المتغيرات في عملية القطع بالسلك كزمن النبضة الكهربائية , زمن مكوث النبضة, الفولتية , نوع السلك المستخدم في الاختبار, وان كل القيم الناتجة في الاختبارات تم استخدامها في برنامج الحقيبة الاحصائية . ان قيمة R^2 هي (0.998). كذلك فان ذلك يبين ان 99.8% من المتغيرات المقاسة في معدل ازالة المعدن يمكن تفسيرها بواسطة المتغيرات المستقلة. قيمة R المتعدد هي 0.999 للسلك المطلي. هذا يعني ان معامل التصحيح بين القيم المقاسة من المتغيرات المعتمدة والقيم المتنبأة بالاعتماد على نموذج الانحدار المتعدد كانت عالية وهذا يعني قابلية التنبؤ للنموذج الاحصائي. الخشونة السطحية حوالي 98.7% و 96.8% دقة بيانات الاختبار للسلك المطلي على التوالي.