RESEARCH ARTICLE OPEN ACCESS

Experimental Investigation and Development of Mathematical Correlations of Cutting Parameters for Machining Titanium with CNC WEDM

[a]Aviyyapu mounika, [b]K.S.V.S Sarath Chandra

[a]M.Tech student sanketika vidya parishad engineering college,[b]Assistantprofessor,
Department of mechanical engineering,
sanketika vidya parishad engineering college,mounikaviyyapu95@gmail.com

ABSTRACT

Wire Cut EDMprocess material Titanium different parameters of machining current, cutting speed, spark gap and Material removal rate will be investigated and best suited values forstable and controlled machining with least wire breakage.In the present work aimed at Experimental Investigation to determining optimal values of machining parameters in the machining of Titanium material of different Thickness using wire cut electric discharge machine. It also aimed at development of mathematical correlations to determine the effect of machining parameters on Current, Cutting speed, Spark gap, and Material Removal Rate investigated and best suited values for stable and controlled machining with least wire breakage. The experiments are conducted on the Titanium material by cutting L and U shapes by varying machining current from a lower value to a higher value in 5 steps. The cutting speed is noted down from machine display and surface finish is measured on using Tallysurf.The spark gap is calculated from cutting width. The optimum values of machining current, cutting speed, spark gap, surface roughness and MRR are used for plotting the curves and best fit curve is selected using the Origin 8.0,software.The mathematical relation is for best fit curve and statistically analysis is performed to find fitness of the curve. The maximum error obtained from calculated values and experimental values are found to be less than 4 %.From these we, conclude that Regression Statistical analysis gives better prediction values with less error%.

Keywords*:* WEDM, Cutting speed, MRR, Spark gap, surface roughness,Mathematical correlations, Regression Analysis

1. Introduction to WEDM

Wire Electrical Discharge Machining (Wire EDM), is a machining process in which a wire carrying electrical charge is used to cut the hard materials. The two major components required for the wire EDM machine the wire electrode and the degree of precision and the amount of material that can be removed. In order to cut complicated or intricate designs with greater precision and 3D profiles, Wire EDM machines requires not only the traditional X and Y axis but also the U and V axis for a standard 4-axis tooling but can also have a 5th axis. In Wire EDM the material being machined is commonly inserted in a fixture and pumped with dielectric fluid, typically a deionized water of rated conductivity. Electrical currents passing through metals increase internal temperatures and metal tooled in higher heat environments becomes less rigid and have a loss of tensile strength. Tooling in water is to remove the chips and debris from the work area, in turn decreasing the amount of scoring of the finished product, to decrease the overall heat affected zone and to extend the life of the wire electrode.

1.1 Machining parameters:

Generally by increasing the spark energy one can achieve an increase in the cutting rate. To achieve optimum results of cutting rate and the job accuracies, the machining parameters should be properly set the parameters which control the pulse energy and ultimately the machining speed are described below. The different parameters controlling the pulse energy and machining conditions are given along their setting formats.

TON: Pulse ON time

During this period the voltage (VP) is applied across the electrodes

TOFF: pulse OFF time
Voltage for the gap is absent during this period.
Range: 00-63(in step of 1)
Higher the TOFF setting larger is the pulse off period
With a lower value of TOFF there are number of discharge in a given time, resulting in increase in the sparking efficiency. As a result the cutting rate also increases.
Using very low values of TOFF period however cause wire as and when the discharge conditions becomes unstable, one can increase the TOFF period. This will allow lower pulse duty factor and will reduce the average gap current.

IP: Peak current (A)
This is for selection of pulse peak current
Ip=XY
X: Select fine pulse Y: select power pulse
X = 0 - Fine pulse OFF
X = 1 - Fine pulse ON
Y = 0 - Power pulse OFF
Y = 1 - One power pulse section ON
Y = 2 - Both power pulse section ON

Higher the IP setting larger is the peak current value. Increase in the IP value will increase in the IP pulse value will increase the pulse discharge energy which in turn can improve the cutting rate further.
For higher value of IP, gap conditions may become unstable with improper combinations of TON, TOFF, SV, &SF settings. As and when the discharge conditions becomes unstable one must reduce he IP value (and/or increase the Toff period).

VP: Pulse peak Voltage setting.
This is for selection of open gap voltage.
Range: 0-2
Increase in the VP value will increase the pulse discharge energy.
Normally it is always `1"
VP should be selected to 2 only when special material like PCD, CBN is to be cut.

WP: Flushing pressure of water dielectric
This is for selection of flushing input pressure.

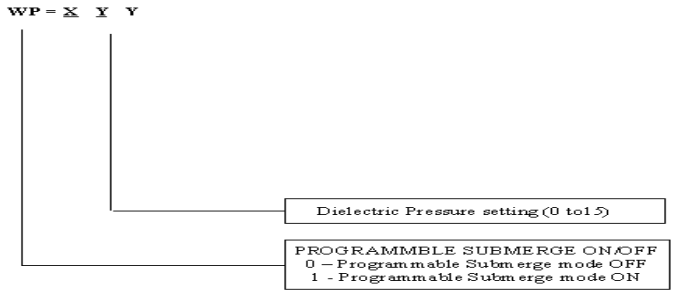


Figure: Machining parameters

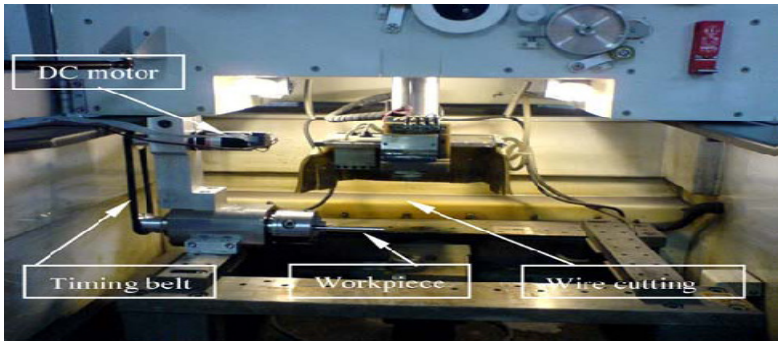


Figure: Wire-cut EDM machine table

5.1 Results and Discussions:

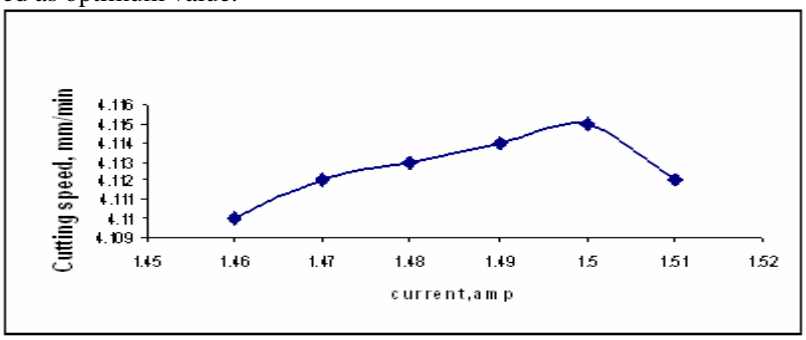
5.2 Parametric analysis based on experimental data:

5.2.1 Effect of machining current on cutting speed for 5 mm thickness:

Table 5.1 Parameters obtained for 5mmthickness

S.No	Current Amp	Cutting speed, mm/min	Spark gapµm	Ra, µm	MRR, mm^3/min
1	1.46	4.110	42.00	0.50	6.864
2	1.47	4.112	42.00	0.50	6.867
3	1.48	4.113	42.05	0.49	6.871
4	1.49	4.114	42.10	0.47	6.878
5	1.50	4.115	42.15	0.46	6.875
6	1.51	4.112	42.00	0.50	6.867

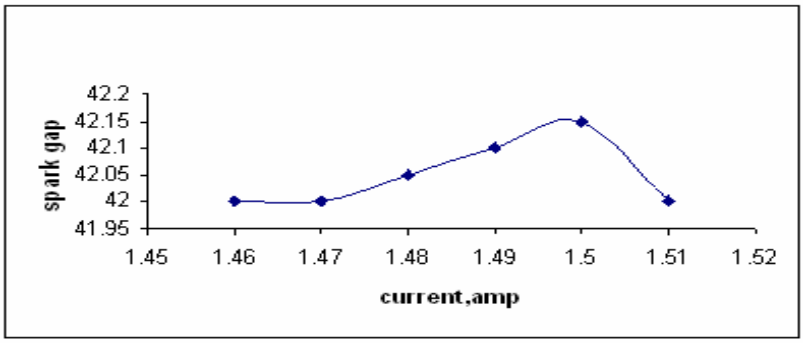
The experiment is performed for **5mm** thickness current varies **1.46 Amp to 1.50Amp** and **cutting speed varies4.110 mm/min to 4.112mm/min** Graph 5.1 gives the effect of machining current on cutting speed for machining 5mm thick Titanium work piece. The plot shows an increasing trend in cutting speed with increase in current. As the current increases, energy input increases, causing raise in cutting speed. But beyond 1.5 amp current, the machining is observed to be erratic and wire getting ruptured causing decrement in cutting speed. The maximum cutting speed of 4.115mm/min is obtained with minimum wire rupture. The current at this cutting speed is considered as optimum value.



Graph: 5.1 Effect of machining current on cutting speed for 5 mm thickness

5.2.2 Effect of current on spark gap for 5 mm thickness:

The experiment is performed for **5mm** thickness current varies **1.46 Amp to 1.50Amp** and spark gap varies **42.00µm to 42µm**. Graph 5.2 shows the spark gap value for machining at different current values The plot is depicting that, the spark gap is increasing with increase in current up to 1.5amp and then decreases. As the current increases, the energy input will be higher and the spark jumps longer causing wider cut, creating more spark gap. Beyond 1.5 amp current the spark gap decreased. It is an indication that at higher energy levels, wire rupture will be more than that of work piece. The cutting speed is also observed to be decreased beyond the same current. The observations reveal that 1.5amp is optimum machining parameter.



Graph : 5.2 Effect of current on spark gap for 5 mm thickness

5.2.5 Effect of machining current on cutting speed for 30mm thickness:

The experiment is conducted for **30mm** thickness **current** varies **1.70 Amp to 1.77Amp** and **cutting speed** varies **3.73 mm/min to 3.75mm/min**.

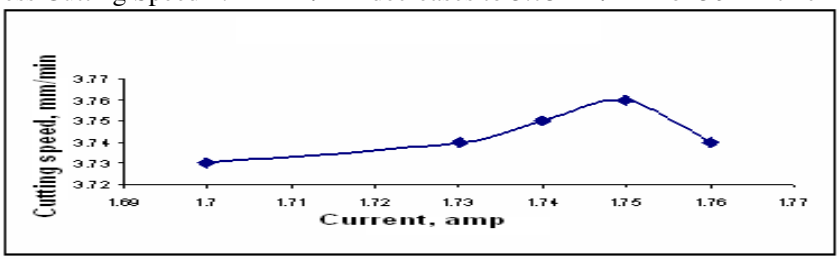
Table 5.2 Parameters obtained for 30 mm thickness

Sino	CurrentAmp	Cuttingspeed,mm/mn	Sparkgapam	Ra, am	MRR, mm^3/min
1	1.70	3.73	48.63	0.63	39.171
2	1.73	3.74	48.64	0.63	38.861
3	1.74	3.75	48.66	0.62	39.072
4	1.75	3.76	48.64	0.62	39.273
5	1.76	3.74	48.64	0.61	38.967
6	1.77	3.75	48.65	0.62	38.968

Graph 5.5 to 5.8 depicts the variation of different machining criteria with change in current for cutting 30 mm thick titanium by WEDM.

Graph 5.5 gives the variation of machining current on cutting speed. The machining current has been varied from 1.7amp to 1.76amp in 0.01amp steps. The plot shows an increasing trend in cutting speed with increase in machining current till 1.75amp then suddenly fall. At 1.76amp current the machining is getting interrupted with large toll wear and wire brake edge. This may be due to avalanche of high energy sparks striking back the wire, breaking it. So 1.75amp is considered to be the optimum current value with highest cutting speed for machining

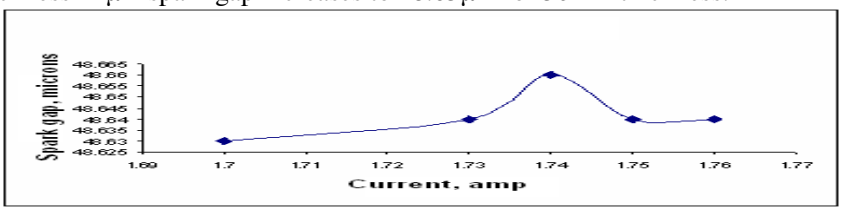
30mm thick titanium work piece. The cutting speed for 30mm thick job is lower than that of 5mm thick.Compare with 5mm thickness Cutting Speed 4.112mm/min decreases to 3.75mm/min for 30mm thickness.



Graph: 5.5 Effect of machining current on cutting speed for 30mm thickness

5.2.6 Effect of machining current on Spark gap for 30 mm thickness:

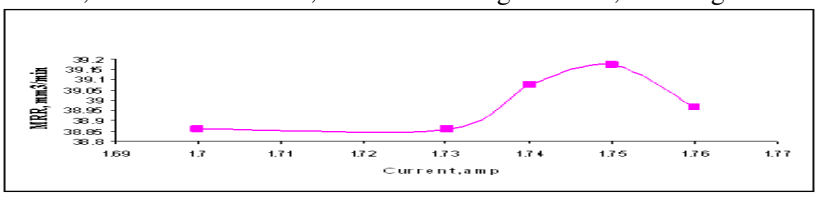
The experiment is conducted for **30mm** thickness **current** varies **1.70 Amp to 1.77Amp** and **spark gap** varies **48.63µm to 48.65µm.**Graph 5.6 shows the variation of spark gap with current. The spark gap is observed to be increasing with a small variation. The profile of the plot is similar to that of the plot obtained for 5mm thick job. The spark gap value is to be adopted which is obtained at the optimum current value 1.75amps.Compare with 5mm thickness 42µm spark gap increases to 48.65µm for 30mm thickness.



Graph: 5.6 Effect of machining current on Spark gap for 30 mm thickness

5.2.8 Effect of machining current on MRR 30 mm thickness:

The experiment is conducted for **30mm** thickness **current** varies **1.70 Amp to 1.77Amp** and **MRR varies 39.171 mm^3/min to 38.968mm^3/min.** Graph 5.8 shows variation of MRR with current. At the optimum current 1.75 amp. The MRR is observed to be highest. This is another indication that the Current is optimum. Beyond 1.75 amp. Current, the MRR decreases, as the machining is erratic, with huge wire rupture.



Graph : 5.8 Effect of machining current on MRR 30 mm thickness

The plots for 30mm thick and 5mm thick jobs machining shows similar profiles. This indicates the machining characteristics. Compare with 5mm thickness MRR 6.867mm^3/min increases to 38.968mm^3/min for 30mm thickness.

5.2.9 Effect of machining current on Cutting speed for 60 mm thickness:

The experiment is conducted for 60mm thickness **current varies 1.93 Amp to 1.97Amp** and **cutting speed** varies **3.23mm/min to 3.23mm/min**. Compare with 5mm thickness Cutting Speed 4.112mm/min decreases to 3.23mm/min for 60mm thickness.

Table 5.3 Parameters obtained for 60 mm thickness

S.No	CurrentAmp	Cuttingspeed,mm/mn	SparkgapMm	Ra, µm	MRR,mm^3/min
1	1.93	3.23	54.45	0.65	69.985
2	1.94	3.24	54.48	0.66	69.782
3	1.95	3.25	54.51	0.67	69.574
4	1.96	3.23	54.51	0.67	69.574
5	1.97	3.23	54.48	0.66	69.574
6	1.97	3.23	54.48	0.66	69.574

5.2.13 Effect of Current on Cutting speed for 90 mm thickness:

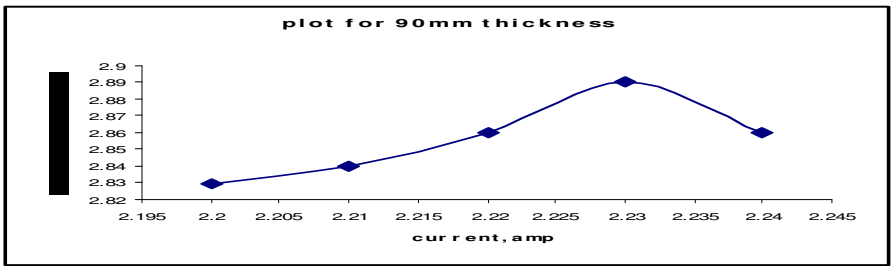
The experiment is conducted for 90mm thickness **current** varies **2.20 Amp to 2.24Amp** and **cutting speed** varies **2.83mm/min to 2.86mm/min.**

Table 5.4 Parameters obtained for 90mm thickness

S.No	Current Amp	Cuttingspeed,mm/mn	Spark gapMm	Ra,µm	MRR,mm^3/min
1	2.20	2.83	60.00	0.75	94.239
2	2.21	2.84	60.10	0.74	94.623
3	2.22	2.86	60.12	0.74	94.966
4	2.23	2.89	60.15	0.73	95.315
5	2.24	2.86	60.16	0.73	95.315
6	2.24	2.86	60.16	0.73	95.315

Graph 5.13 to 5.16 shows the variation of machining criteria with change in current, for cutting 90mm thick Titanium work piece. The variation is similar to that of 5mm, 30mm and 60mm thick jobs machining. The optimum values can be selected in the similar way as that of for 5, 30, 60 mm thick jobs. The optimum values are tabulated

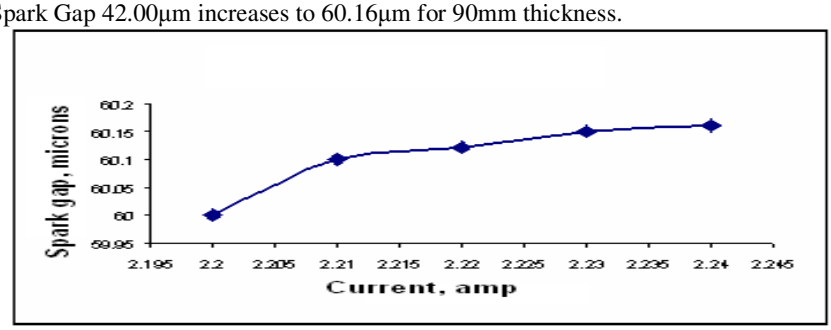
Compare with 5mm thickness Cutting Speed 4.112mm/mindecreases to 2.86mm/min for 90mm thickness.



Graph: 5.13 Effect of Current on Cutting speed for 90 mm thickness

5.2.14 Effect of Current on Spark gap for 90 mm thickness:

The experiment is conducted for 90mm thickness **current** varies **2.20 Amp to 2.24Amp** and **spark gap** varies **60.00µm to 60.16µm.**Graph 5.14 sows the variation of machining criteria change in current increases spark gap. Compare with 5mm thickness Spark Gap 42.00µm increases to 60.16µm for 90mm thickness.

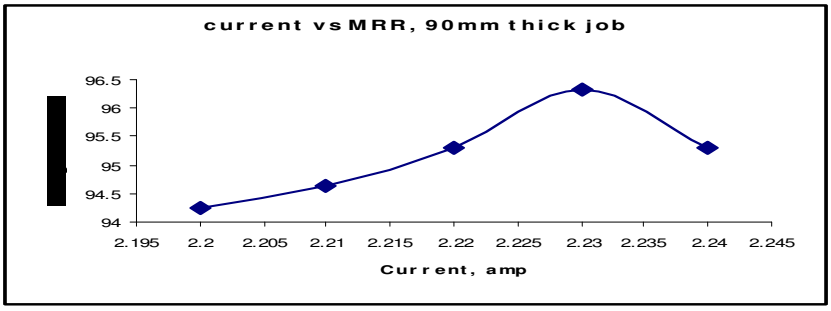


Graph : 5.14 Effect of Current on Spark gap for 90 mm thickness

5.2.16 Effect of Current on MRR for 90 mm thickness:

The experiment is conducted for 90mm thickness **current** varies 2.20 Amp to 2.24Amp and **MRR** varies **94.239 mm^3/min to 95.315mm^3/min.** Graph 5.16 shows variation current

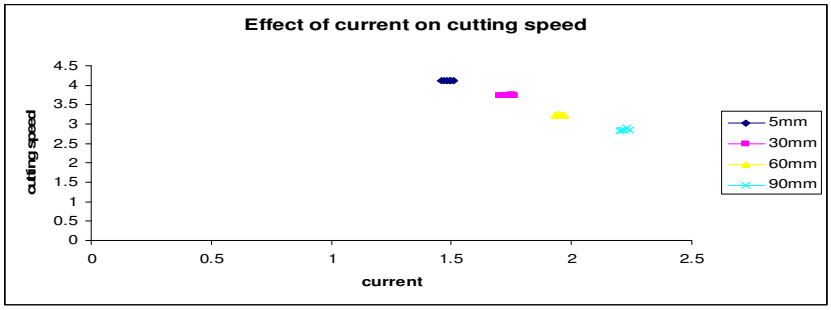
Increases MRR also increases. Compare with 5mm thickness MRR 6.867mm^3/minincreases to 95.315mm^3/minfor 90mm thickness.



Graph : 5.16 Effect of Current on MRR for 90 mm thickness

5.2.17 Effect of current on cutting speed for 5, 30, 60, 90mm thickness:

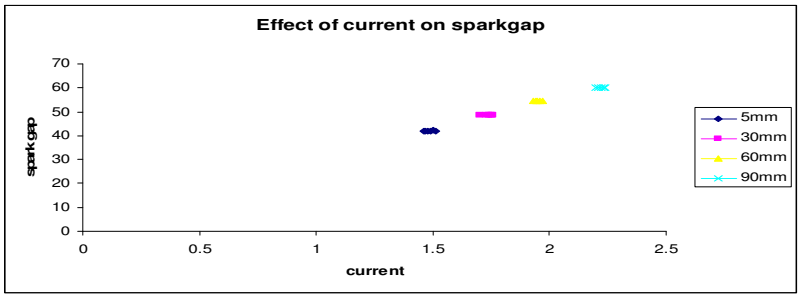
Graph 5.17 shows the variation of cutting speed with respect to machining current for the machining work piece of 5, 30, 60, 90 mm work piece thickness. The plot shows that the variation of all thickness very much similar and **cutting speed** increases for **5mm** thickness **4.12mm/min**, for **30mm** thickness **3.75 mm/min, 60mm** thickness **3.23 mm/min** and **90mm** thickness **2.83 mm/min** with **1.5amp,1.74amp,1.95amp,2.20amp** current. it can be know to from the plot that lower thickness of job higher will be cutting speed achievable .this is through because the energy supplied by the machined the limited and quality of material is melted is higher increases the thickness.



Graph: 5.17 Effect of current on cutting speed for 5,30,60,90mm thickness

5.2.18 Effect of current on spark gap for 5,30,60,90mm thickness:

Graph 5.18 shows the change in spark gap or over cut with respect to machining current for 5,30,60,90 mm the plot affix that **spark gap** increases **42µm** for **5mm** thickness and **30mm** thickness **48.66µm** and **60mm** thickness **54.51µm** and **90mm** thickness **60µm** with increase **1.5amp,1.74amp,1.95amp,2.20amp**current. The plot also shows that the spark gap values are increasing with increases that spark gap. The plot also shows that the spark gap values ate increasing with increase job thickness also. this may be due to higher demand of energy for higher thickness jobs which can supplied by increasing current the plot can be useful identified spark gap deferent values for particular thickness job.



Graph : 5.18 Effect of current on spark gap for 5,30,60,90mm thickness.

PREDICTION USING REGRESSION ANALYSIS

. **6. R, R Square, Adjusted R Square:**

R is a measure of the correlation between the observed value and the predicted value of the response (criterion) variable. R square is called **coefficient of determination**indicates explanatory power of any regression model. Its value lies between +1 and 0. It can be shown that R-square is the correlation between actual and predicted value. It will reach maximum value when dependent variable is perfectly predicted by regression. R Square is the square of this measure of correlation and indicates the proportion of the variance in the response (criterion) variable, which is accounted for by our model. In essence, this is a measure of how good a prediction of the criterion variable we can make by knowing the predictor variables. However, R square tends to somewhat over-estimate the success of the model when applied to the real world, so an Adjusted R Square value is calculated which takes into account the number of variables in the model and the number of observations (participants) our model is based on. This Adjusted R Square value gives the most useful measure of the success of our model. If, for example we have an Adjusted R Square value of 0.75 we can say that our model has accounted for 75% of the variance in the response (criterion) variable.

6.4 Correlation coefficients:

The correlation coefficient matrix represents the normalized measure of the strength of linear relationship between variables. The correlation coefficients range from -1 to 1, where

- Values close to 1 suggest that there is a positive linear relationship between the data columns.
- Values close to -1 suggest that one column of data has a negative linear relationship to another column of data (anticorrelation).
- Values close to or equal to 0 suggest there is no linear relationship between the data columns.

6.5 Mathematical Modeling:

Mathematical model was developed in the regression analysis using MINITAB Statistical. The statistic toolbox provides us four models in regression analysis.

1) Linear: $Y = \beta 0 + \beta 1x1 + \beta 2x2$ (5)
2) Interactions: $Y = \beta 0 + \beta 1x1 + \beta 2x2 + \beta 3x1x2$ (6)
3) Pure quadratic: $Y = \beta 0 + \beta 1x1 + \beta 2x2 + \beta 3x1^2 + \beta 4x2^2$ (7)
4) Full quadratic: $Y = \beta 0 + \beta 1x1 + \beta 2x2 + \beta 3x1x2 + \beta 4x1^2 + \beta 5x2^2$ (8)

➢ Here a response variable Y is modeled as a combination of constant, linear, interaction and quadratic terms formed from two predictor variables x1& x2.

➢ Given data on x1, x2 and Y, regression estimates the model parameters.

6.7 Equations Formed from Regression Analysis:

Statistical Analysis, Study on effect of WEDM parameters on machining criteria and development of Regression Equations.

6.2 Optimized parameters for 5 to 90 mm thickness

S.No	Thickness, mm	Current amp	Cutting speed, mm/min	Surface roughness, Ra µm	Spark gap mm/1000	MRR, mm^3/min
1	5	1.50	4.12	0.50	42.00	6.860
2	7.5	1.53	4.05	0.52	42.70	10.180
3	10	1.57	4.01	0.54	43.48	13.923
4	15	1.60	3.97	0.55	44.20	20.150
5	20	1.65	3.91	0.58	45.57	23.43
6	30	1.74	3.75	0.61	48.66	39.10
7	40	1.83	3.54	0.64	51.20	49.80

Figure 6.8.4: Comparison between experimental and predicted values of spark gap on thickness

The percent errors obtained for spark gap and regression model are maximum error is 0.20 % for regression model.

6.8.4 Validation of MRR on thickness with the Regression models

The figure 6.8.5 represents MRR results and regression model are compared with the experimental results with different thickness .

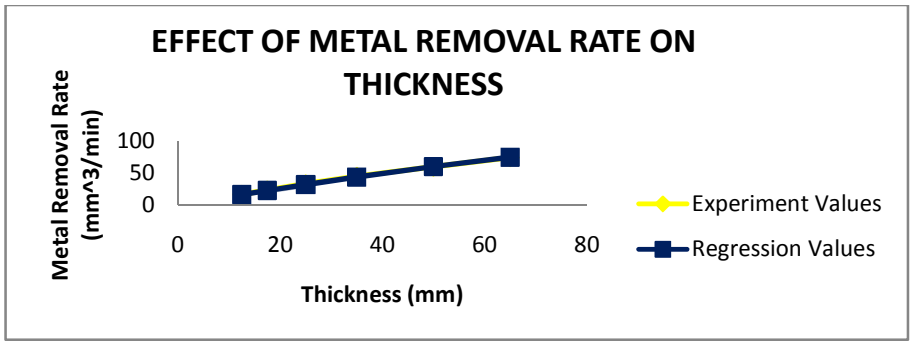


Figure 6.8.5: Comparison between experimental and predicted values of MRR on thickness

The percent errors obtained for MRR and regression model are maximum error is 1.82 % for regression model.

7.1Conclusions:

The influence of parameters, like discharge current, job thickness, on the machining criteria such as cutting speed, spark gap, surface finish, material removal rate are determined. Titanium material of different thicknesses is machined for determining the optimum values of machining parameters have been studied the effect of parameters on current, cutting speed, spark gap and Material removal rate investigated and best suited values for stable and controlled machining with least wire breakage. Variations and effect of cutting speed, Spark gap, surface roughness, MRR with respect to machining current. Regression Analysis are used for predicting current, cutting speed, spark gap, Surface roughness, MRR.

The Mathematical correlations are developed for Regression Analysis.

The developed prediction system is found to be capable of accurate process parameters prediction.

- A regression model is also developed by using the experimental data. The experimental results are compared to the regression models. As it has been anticipated, the regression models provided better prediction capabilities because they generally offer the ability to model more complex non-linearities

- Comparison of predicted current, cutting speed, spark gap, surface roughness and MRR with experimental results in all testing cases indicate that the error is less than 4% for regression model. The average error percentage for all the predicted values in the regression model is 0.67%.Regression model has predictethe machining values with less error percentage. Regression model is found to be capable of predicting the machining process parameters.

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