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Experimental Investigation of MRR and Surface Finish Using Abrasive Jet Machining of Aluminum Alloy 7475

V. Mouni Sashi Tej[1], V. Lahari Kiran[2]*
[1]Mannan College of Engineering, Jawaharlal Nehru Technological University, Hyderabad, Telangana, India
[2]Malla Reddy College of Engineering, Jawaharlal Nehru Technological University, Hyderabad, Telangana, India

ABSTRACT

In this thesis, different experiments are performed on aluminum alloy 7475 by varying various parameters such as pressure, sand feed, transverse speed and standoff distance, i.e. nozzle-to-work-piece distance to determine material removal rates and surface finish. Optimization is done using L9 orthogonal array by Taguchi technique to determine better parameters to obtain maximum removal rates and minimum surface roughness. The parameters considered are transverse speed 50, 100, 150 mm/min; standoff distance 0.5, 1, 1.5 mm; and sand feed 200, 400, 600 g/min; and pressure 100, 200, 300 MPa.

Keywords: aluminum alloy 7475, material removal rates, pressure, sand feed, transverse speed

Corresponding Author
E-mail: vmounisashitej@gmail.com

INTRODUCTION

In abrasive jet machining (AJM), work material is removed by erosion of high-velocity abrasive particles by impinging stream of abrasive particles carried by high-pressure air or gas through a nozzle on the work surface.

In AJM, abrasive elements are made to impinge on work material at greater velocity. A jet of abrasive particles is carried by carrier gas or air. The high-velocity stream of abrasives is produced by transforming pressure energy of carrier gas or air to its kinetic energy and hence high-velocity jet. Nozzles thru abrasive jet in a measured manner When is objected on the work piece material. The high-velocity abrasive particles eliminate the materials by micro-cutting exploit as well as brittle fracture of the work material.

LITERATURE REVIEW

In this thesis, the experimental analysis of AJM is discussed. The experimentations conducted by various researchers by influencing the AJM process parameters on material removal rate (MRR), surface integrity and kerf are discussed. The parameters like SOD, carrier gas, air pressure, type of abrasive, size, mixing ratio, etc. are focused.

In Jankovi´c et al. [1], the research aim was connected with the demands of industry, i.e. the end user. Having in mind that the conventional machining processes are not only lagging behind in terms of quality of cut, or even some requests are not able to meet, but with the advent of composite materials were not able to machine them, because they occurred unacceptable damage (mechanical damage or delamination, fiber pull-out, burning, frayed edges).

Paul and Roy [2] carried out the effect of the carrier fluid (air) pressure on the MRR, and the material removal factor (MRF) has been investigated experimentally on an indigenous AJM setup developed in the laboratory. Experiments are led on porcelain with silicon carbide as abrasive particles at various air pressures. It was observed that MRR has increased with increase in grain size and nozzle diameter. The relation of MRR with standoff distance reveals that MRR increases with increase in SOD at a particular pressure.

Sreenevasa Rao and Shrekanth [3] reviewed that Ingulli C.N. (1967) was the first to explain the effect of abrasive flow rate on MRR in AJM. Along with Sarkar and Pandey (1976), they concluded that the standoff distance increases, the MRR and penetration rate increase, and on reaching an optimum value, it start decreasing. J. Wolak (1977) and K. N. Murthy (1987) investigated that after a threshold pressure, the MRR and penetration rate increase with nozzle pressure. The extreme MRR for brittle and ductile materials is obtained at different impingement angles. For ductile material, impingement angle of 15–20 results in maximum MRR and for brittle material normal to surface results maximum MRR.

Li and Seah [4] stated that during cutting of work piece, reinforcement particles made impact on surface of the work which causes wear of work specimen. These particles get dislodged in material surface. It is described that pressured air method minimizes the tool wear and also avoid particles from being surrounded in work piece. Experimental tests for cutting of SiC–Al have been passed out with tungsten carbide tool with or without the aid of the pressured air jets that are piloted. It shows that pressured air jet method expressively minimizes the wear of work piece.

Wakuda et al. [5] reported that the material response to the abrasive impacts indicates a ductile behavior, which may be due to the elevated temperature during machining. Chipping at the peripheral region of the dimples was found for coarse-grained alumina samples. The use of synthetic diamond abrasive is a possible choice if high machining efficiency is desired. However, the machined surface reveals a relatively rough appearance as a result of large-scale intergranular cracking and subsequent crushing.

Ghobeity et al. [6] have experimented on process repeatability in AJM. They mentioned that many applications have several problems inherent with traditional abrasive jet equipment. Poor repeatability in pressure feed AJM system was drawn to uncontrolled difference in abrasive particle mass flux produced by particle packing and local cavity formation in reservoir. Use of mixing chamber enhanced the process repeatability. For finding out process repeatability, they measured the depth of machined channel.

Ghobeity et al. [7] stated that particle distribution can greatly affect the shape and depth of profile. Analytical model was developed by considering the particle size distribution. Its result is that if particle size circulated regularly, it helps to keep uniform velocity of abrasive jet which causes improvement in MRR.

El-Domiaty et al. [8] did the drilling of glass with different thicknesses, which have been carried out by AJM process in order to determine its machinability under different controlling parameters of the AJM process. The huge diameter of the nozzle leads to the more abrasive flow, which further leads to MRR and the lower size of abrasive unit lead to the low MRR. They have introduced an experimental and theoretical analysis to calculate the MRR [9–11].

EXPERIMENTAL SETUP

Experimentation is conducted by machining copper pieces by varying the process parameters considered: pressure, transverse speed, sand feed and standoff distance (distance between nozzle and work piece), and their performance is measured by determining MRR and surface roughness.

A rectangular piece of copper alloy material plate with dimensions 115 mm length, 855 mm width and 6 mm thickness is taken and machined using water jet machining by varying the process parameters: sand speed, sand feed, and standoff distance, i.e. distance between nozzle and work piece in Table 1 and 2.

Nozzle diameter = 1.1 mm
Abrasive size = 80 mesh [garnet]
Orifice = 0.35 mm
Machine gauge length = 3 m × 1.5 m
Coolant = Ro-purified water

Table 1. *The parameters are varied as per L9 orthogonal array using Taguchi technique.*

Factors	Units	Level 1	Level 2	Level 3
Pressure	MPa	100	200	300
Transverse speed	mm/min	50	100	150
Sand feed	g/min	200	400	600
Standoff distance	mm	0.5	1	1.5

Table 2. *Parameters used for machining.*

Job no.	Pressure (MPa)	Transverse speed (mm/min)	Sand feed (g/min)	Standoff distance (mm)
1	100	50	200	0.5
2	200	50	400	1
3	300	50	600	1.5
4	300	100	400	0.5
5	100	100	600	1
6	200	100	200	01.5
7	200	150	600	0.5
8	300	150	200	1
9	100	150	400	1.5

Nozzle diameter = 1.1 mm
Abrasive size = 80 mesh [garnet]
Orifice = 0.35 mm
Machine gauge length = 3 m × 1.5 m
Coolant = Ro-purified water
Software for design—AutoCAD
Software CNC Coding—Item CAD, Most 2D.
Water consumption—200 l/hr
The experimentation photos are shown in Figure 1–7 and Table 3 and 4.

Fig. 1. *Setting of work piece on the machine.*

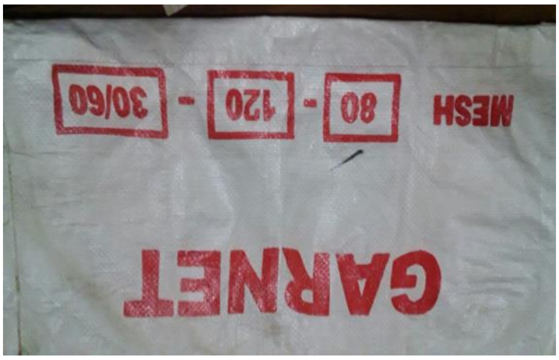


Fig. 2. *Garnet mesh size.*

Fig. 3. *Preparing the cutter for machining.*

Fig. 4. *Display of work piece positions while machining.*

Fig. 5. *Switch display.*

Fig. 6. *Piece to be machined.*

Fig. 7. *Machining process.*

Table 3. *Surface finish results.*

Job no.	**Pressure (MPa)**	**Transverse speed (mm/min)**	**Sand feed (g/min)**	**Standoff distance (mm)**	**Surface finish values, R_a (µm)**
1	100	50	200	0.5	3.96
2	200	50	400	1	2
3	300	50	600	1.5	3.85
4	300	100	400	0.5	2.49
5	100	100	600	1	2.55
6	200	100	200	01.5	3.60
7	200	150	600	0.5	2.63
8	300	150	200	1	3.71
9	100	150	400	1.5	3.37

Table 4. The MRR values calculated from the experimental data.

Job no.	Pressure (MPa)	Transverse speed (mm/min)	Sand feed (g/min)	Standoff distance (mm)	MRR (mm^3/sec)
1	160	70	50	0.5	15.1134
2	160	70	100	1.0	19.2622
3	160	70	150	1.5	35.502
4	160	80	50	1.0	6.081
5	160	80	100	1.5	10.796
6	160	80	150	0.5	35.422
7	160	90	50	1.5	21.127
8	160	90	100	0.5	16.226
9	160	90	150	1.0	6.747

Taguchi Parameter Design—Optimization of Parameters Using Minitab Software

Figure 8 shows Minitab Environment Stat–DOE–Taguchi–Create Taguchi Design Select 3-Level Design and No. of factors–4 shown in Figure 8.

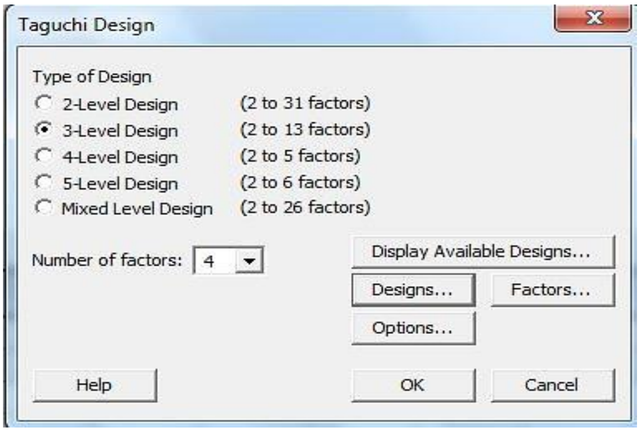


Fig. 8. Level design 4 factors.

Select Factors—Enter factors and their respective values as shown in Figure 9.

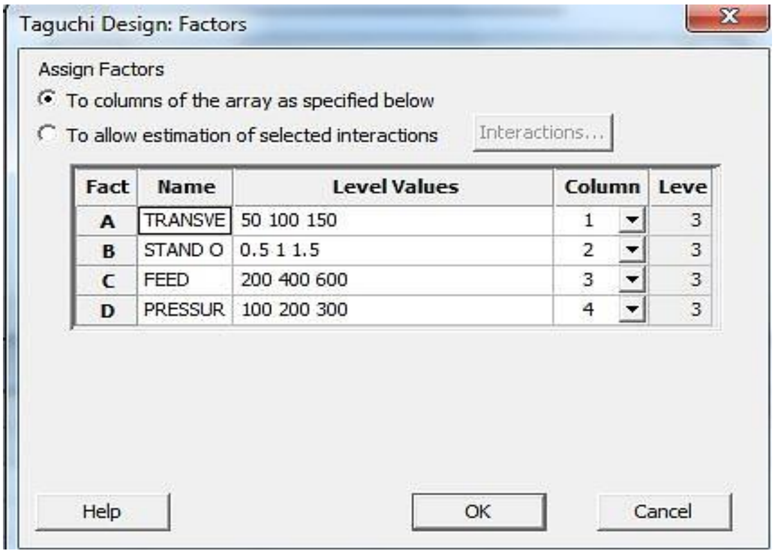


Fig. 9. Considered parameters with their values.

ANOVA

To optimize parameters using ANOVA, first, the arrangement of L9 orthogonal array is done in Taguchi Method. Enter surface roughness values in the table as shown in Figure 10.

Procedure for ANOVA

Stat–ANOVA–General Linear Model–Fit General Linear Model

Optimization for Surface Roughness

Select Response–Surface Roughness and Select Factors–pressure, feed, standoff distance and transverse speed as shown in Figure 11.

Worksheet 1 ***

↓	C1	C2	C3	C4	C5
	TRANSVERSE SPEED	STAND OFF DISTANCE	FEED	PRESSURE	SURFACE ROUGHNESS
1	50	0.5	200	100	3.96
2	50	1.0	400	200	2.00
3	50	1.5	600	300	3.85
4	100	0.5	400	300	2.49
5	100	1.0	600	100	2.55
6	100	1.5	200	200	3.60
7	150	0.5	600	200	2.63
8	150	1.0	200	300	3.71
9	150	1.5	400	100	3.37

Fig. 10. *Observed surface roughness values.*

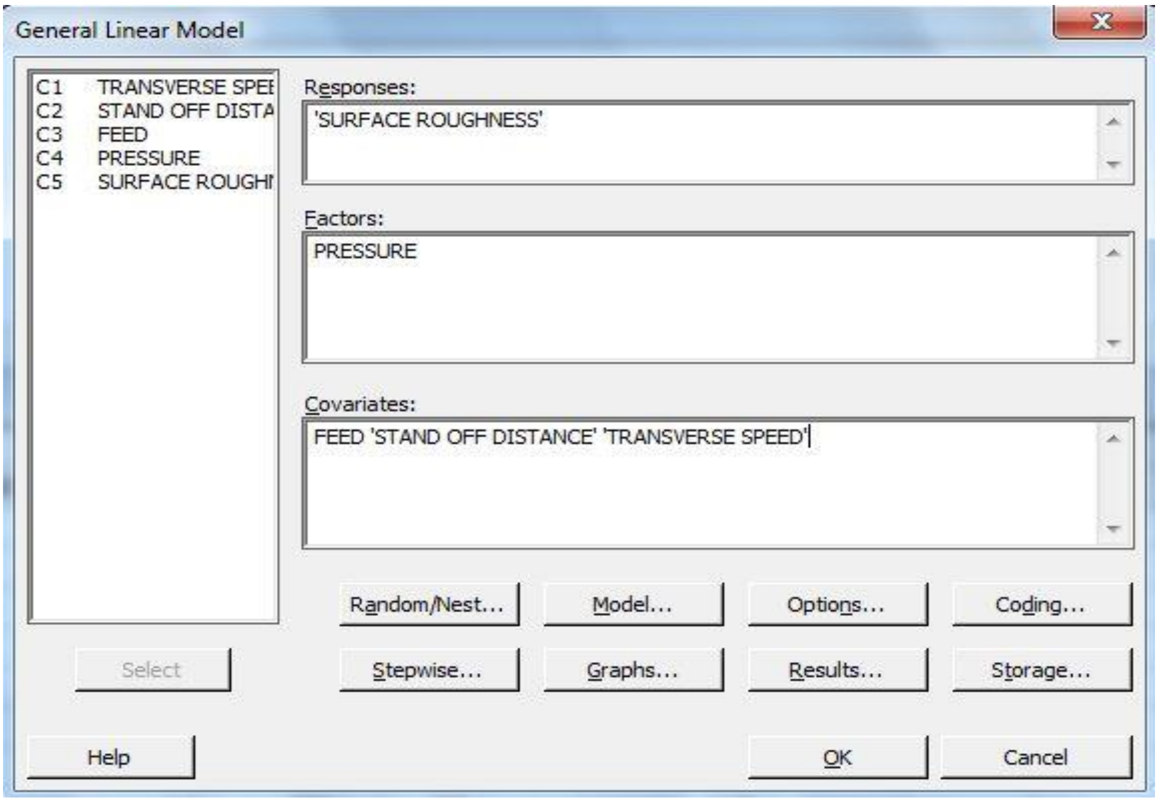


Fig. 11. *Selecting responses, factors and covariates.*

Select model as shown in Figure 12.

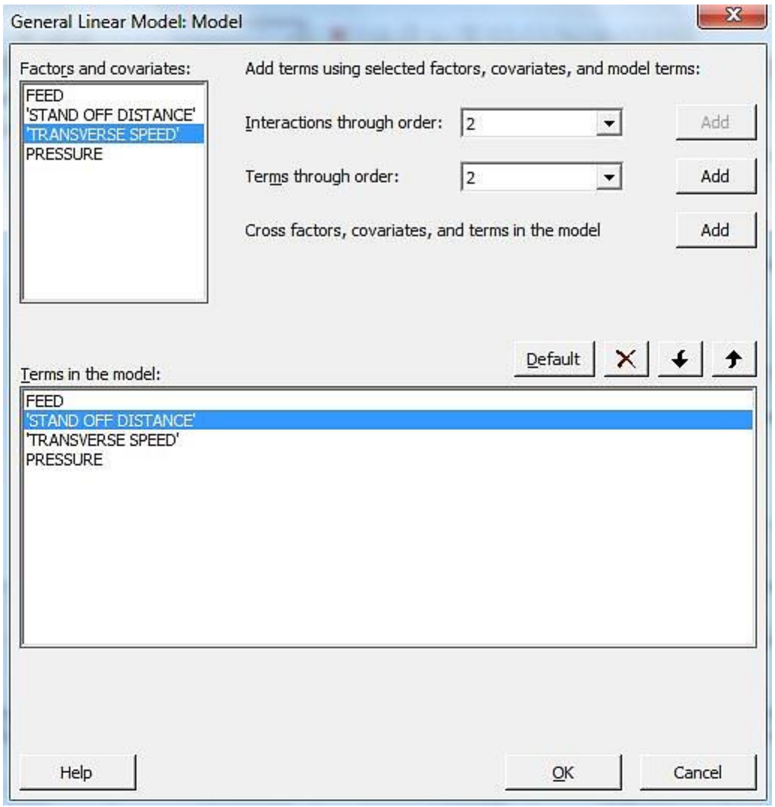


Fig. 12. *Terms in the model.*

Select graphs as shown in Figure 13**.**

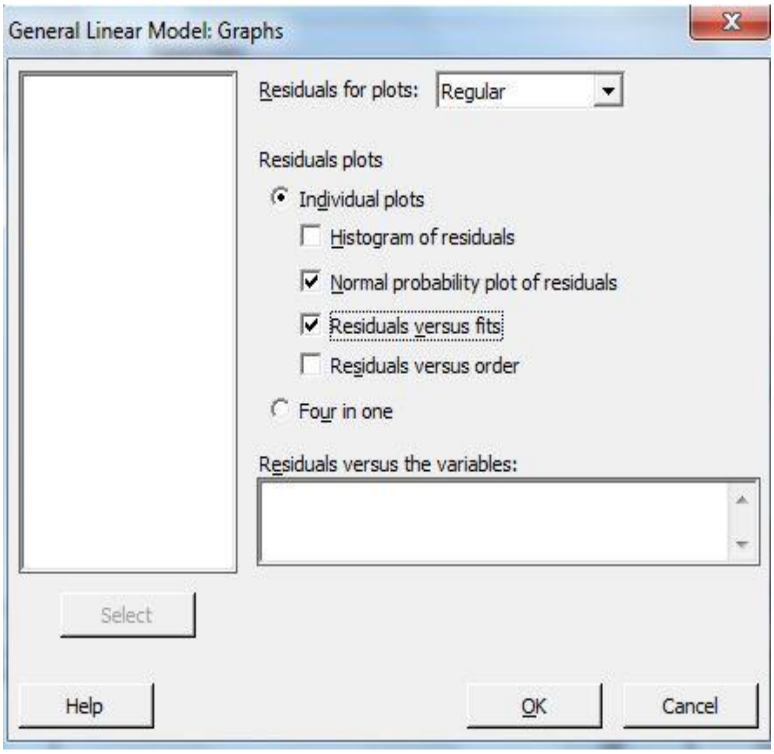
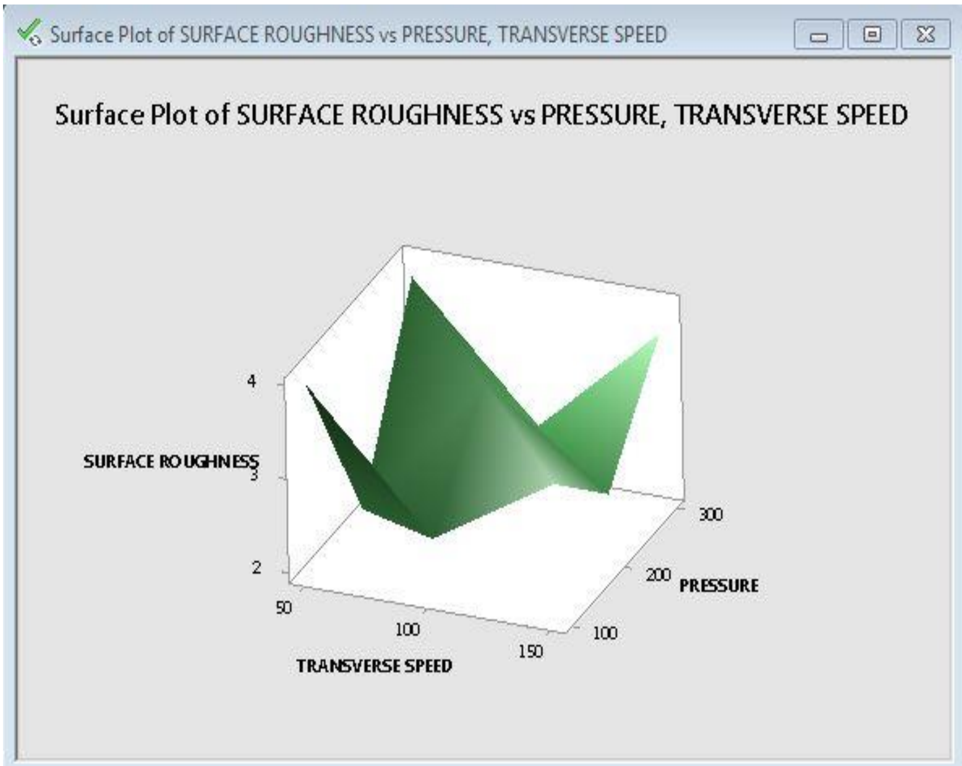


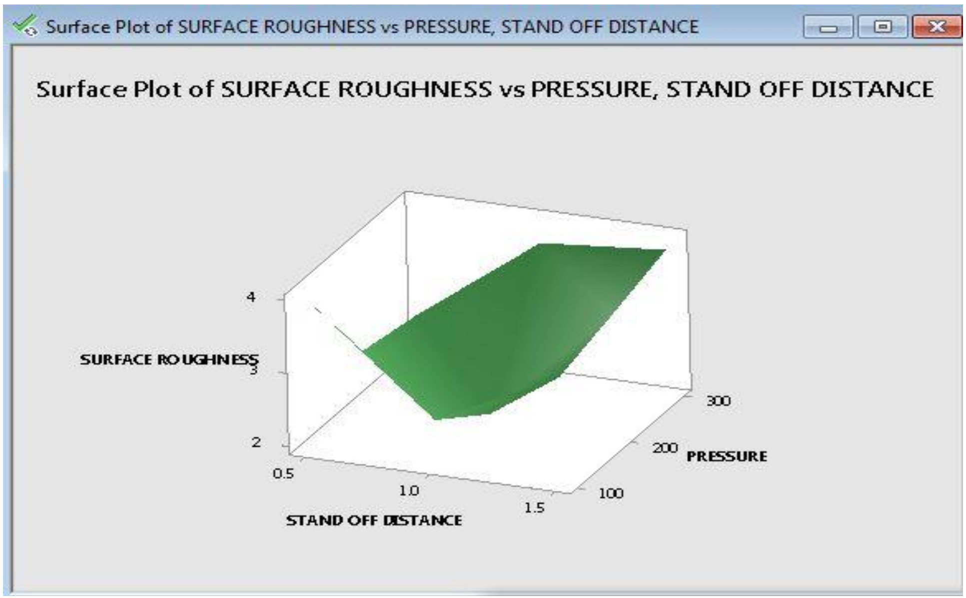
Fig. 13. *Selection of required graphs.*

Surface Roughness

The 3D response surface plot is a graphical representation of the regression equation. It is plotted to understand the interaction of the variables and locate the optimal level of each variable for maximal response. By observing Graph 1, to minimize surface roughness, the transverse speed should be set at 50 mm/min and pressure 300 MPa.



Graph 1. *Surface plot of surface roughness vs. pressure, transverse speed.*



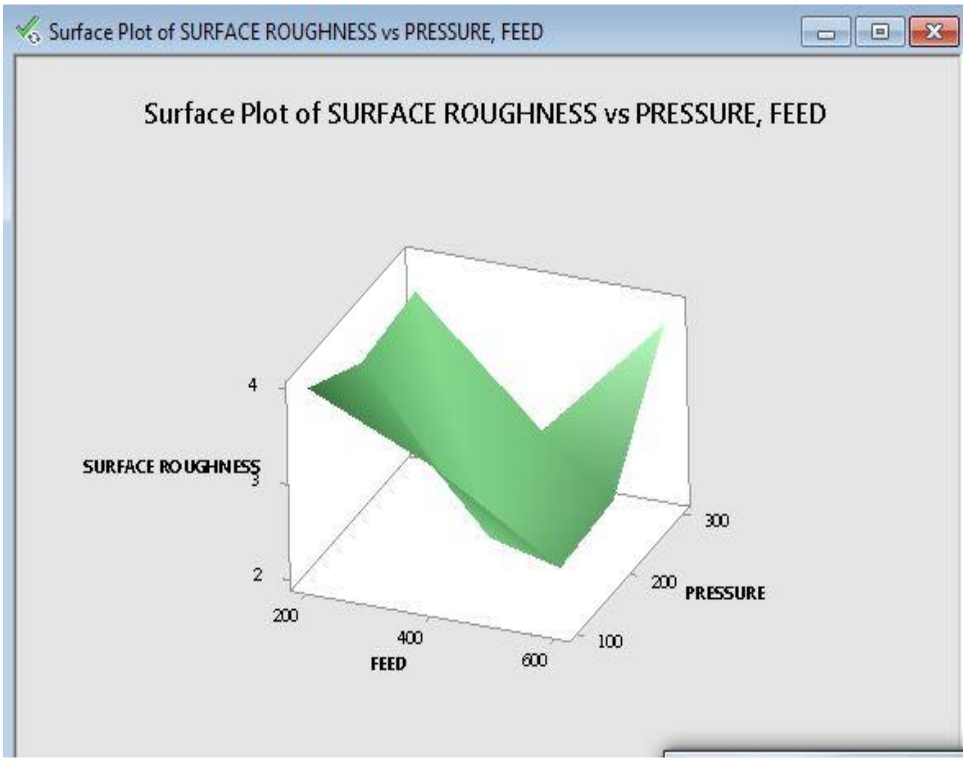
Graph 2. *Surface plot of surface roughness vs. pressure, standoff distance.*

By observing Graph 2, to minimize surface roughness, the standoff distance should be set at 1.5 mm and pressure 300 MPa.

By observing Graph 3, to minimize surface roughness, the feed should be set at 200 g/min and pressure 300 MPa.

MRR

To optimize parameters using ANOVA, first, the arrangement of L9 orthogonal array is done in Taguchi Method.



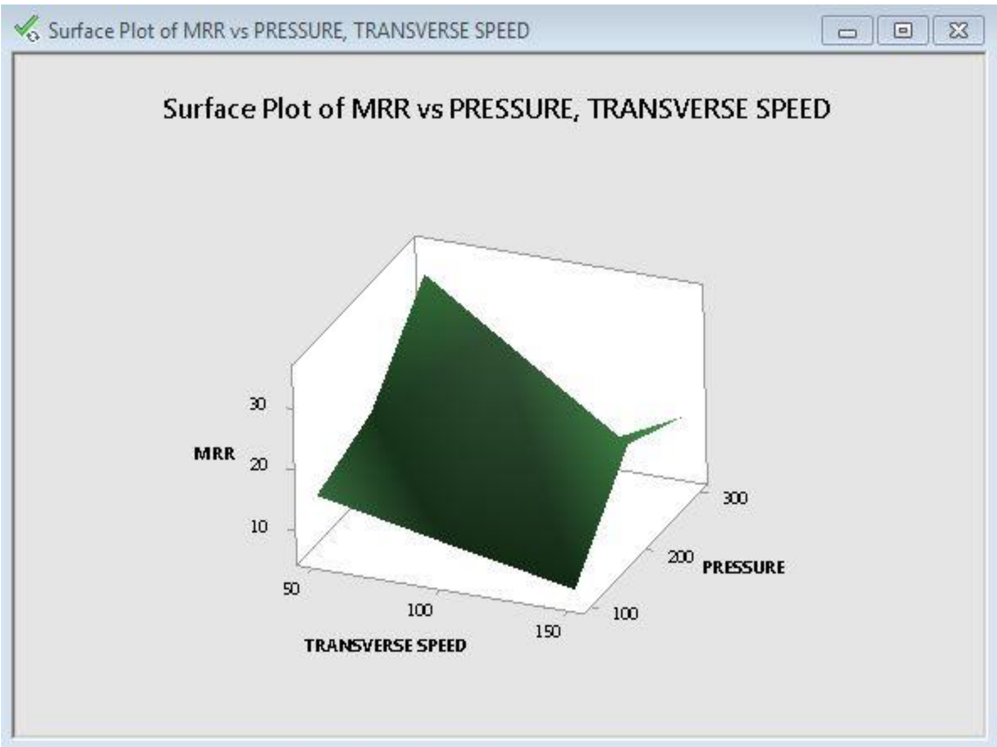
Graph 3. *Surface plot of surface roughness vs. pressure, feed.*

Enter MRR values in Figure 14.

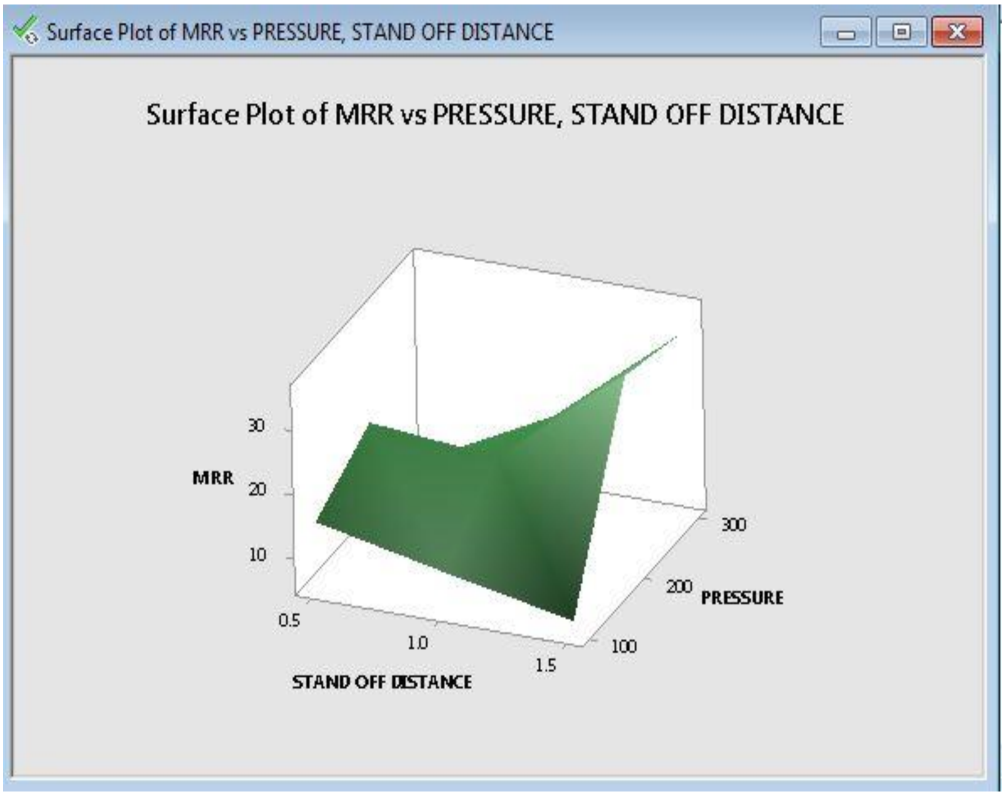
Worksheet 1 ***

↓	C1	C2	C3	C4	C5
	TRANSVERSE SPEED	STAND OFF DISTANCE	FEED	PRESSURE	MRR
1	50	0.5	200	100	15.1134
2	50	1.0	400	200	19.2622
3	50	1.5	600	300	32.5020
4	100	0.5	400	300	6.0810
5	100	1.0	600	100	10.7960
6	100	1.5	200	200	35.4220
7	150	0.5	600	200	21.1270
8	150	1.0	200	300	16.2260
9	150	1.5	400	100	6.7470

Fig. 14. *Observed MRR values.*



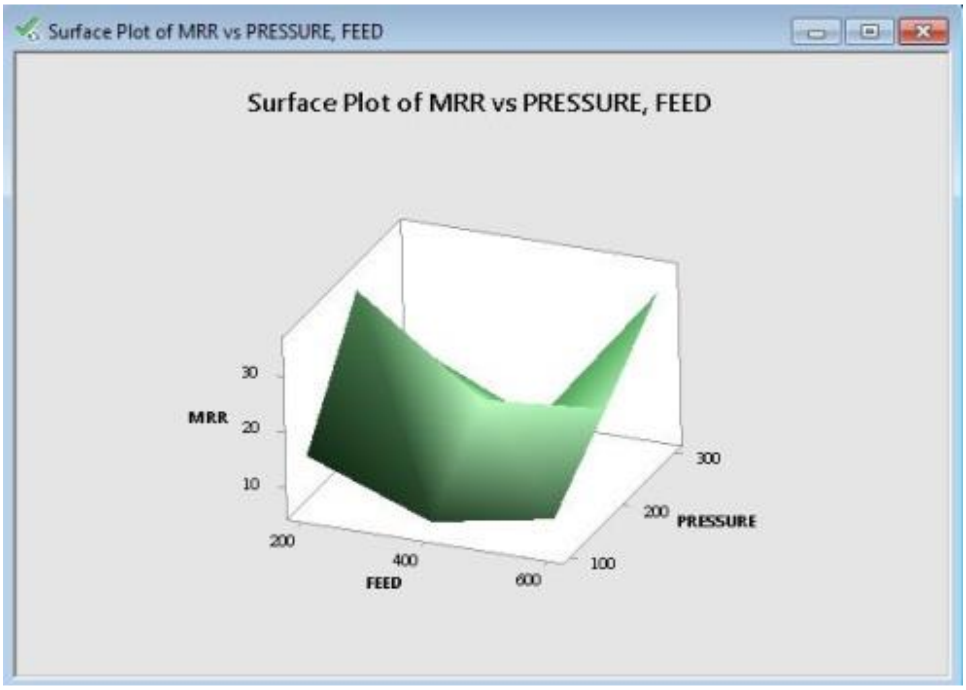
Graph 4. *Surface plot of MRR vs. pressure, transverse speed.*



Graph 5. *Surface plot of MRR vs. pressure, standoff distance.*

By observing Graph 4, to minimize MRR, the transverse speed should be set at 50 mm/min and pressure 300 MPa.

By observing Graph 5, to minimize MRR, the standoff distance should be set at 0.5 mm and pressure 300 MPa.



Graph 6. *Surface plot of MRR vs. pressure, standoff distance.*

By observing Graph 6, to minimize MRR, the feed should be set at 200 g/min and pressure 300 MPa.

CONCLUSION

In this thesis, different experiments are performed on copper work piece by varying various parameters to determine MRRs and surface roughness. The parameters considered are transverse speed 50, 100, 150 mm/min; standoff distance 0.5, 1, 1.5 mm; sand feed 200, 400, 600 g/min; and pressure 100, 200, 300 MPa.

Optimization is done using L9 orthogonal array by ANOVA method to determine better parameters to obtain maximum MRRs and lesser surface roughness values.

From the experimental results and the Taguchi method, the following results can be obtained:

- The effect of pressure on MRR and standoff distance on surface roughness are more.
- For minimum surface roughness, the optimum pressure is 300 MPa, the transverse speed is 50 mm/min, the optimum sand feed is 200 g/min and the optimum standoff distance is 1.5 mm.
- For Maximum MRR, the optimum pressure is 300 MPa, the transverse speed is 50 mm/min, the optimum sand feed is 200 g/min and the optimum standoff distance is 0.5 mm.

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