International Journal of Pure and Applied Mathematics
Volume 117 No. 20 2017, 741-758
ISSN: 1311-8080 (printed version); ISSN: 1314-3395 (on-line version)
url: http://www.ijpam.eu
Special Issue
ijpam.eu

Optimization of Process Parameters on Commercial Mild Steel Using Regression and Principal Component Analysis

[1]V. Jaiganesh, [2]C. Satheesh, [3]S. Manova Raja Singh, [4]P. Sevvel and [5]A.J. Balaji

[1]Department of Mechanical Engineering,
S.A. Engineering College,
Thiruverkadu, Chennai, India.
drjai@saec.ac.in

[2]Department of Mechanical Engineering,
Madha Institute of Engineering & Technology,
Tharapakkam, Chennai.
aero.satish@yahoo.com

[3]Department of Mechanical Engineering,
S.A. Engineering College,
Thiruverkadu, Chennai, India.
manovarajasingh@saec.ac.in

[4]Department of Mechanical Engineering,
S.A. Engineering College,
Thiruverkadu, Chennai, India.
drsevvel@saec.ac.in

[5]Department of Mechanical Engineering,
S.A. Engineering College,
Thiruverkadu, Chennai, India.
1512022@saec.ac.in

Abstract

In the modern manufacturing process the parameter optimization plays a vital role, in which Metal Removal Rate (MRR), Chip Thickness Ratio

(CTR) and Surface Roughness (SR) plays significant characteristics on machining. In recent years Computer Numerical Control (CNC) machines is adopted in major manufacturing components. The metal cutting process carried out in this experiment is by simple turning and it is commonly used in initial operation and finishing operation. In this experiment, the regression and PCA model has been generated for output parameters such as Metal Removal Rate (MRR), Chip Thickness Ratio (CTR), and Surface Roughness (SR) against input parameters as (Speed, Time and Depth of Cut). The statistical method such as Regression and Principal Component Analysis is used to find interrelation between two or more parameters and homogenous values. The optimized values are found for Speed, Time and Depth of Cut by using "MINITAB" software. Optimized metal cutting parameter values can be obtained on commercial mild steel based on this experiment conducted.

Key Words: Metal removal rate, depth of cut, chip thickness ratio, surface roughness, regression, principal component analysis.

1. Introduction

At present, the main objective of the industries is to manufacture a component at a minimal cost, with all the insistent qualities in minimum period of time. The most commonly adopted method of operation to perform cutting and finishing processes is turning [1–3]. A group of researchers including Ozel and Karpat [4] have found that the surface finish of machined components are directly influenced by cutting parameters (Feed rate, Cutting Speed, Depth of Cut, tool geometry and material properties of tool).In turning operation, the parameters like materials, DOC, feed, cutting speed and the use of cutting fluids will directly affect the material's metal removal rate and surface roughness of the material. Feng C. X. and Wang X [5] investigated the influence of time, speed, Depth of cut on Surface Roughness. In this study our ultimate aim is to find the optimized values for process parameters by using Regression analysis and Principal Component Analysis, R.Ramanujam, K. Venkatesan, Vimal Saxena, Rachit Pandeya, T.Harsha, Gurusharan Kumar [6] Three important indexes are required to evaluate the overall performance of the turning process. They are surface roughness, power consumption and material removal rate.

Regression analysis is commonly used to find how the response variable changes as particular predictor variable changes. It is also used to find interrelation between variables. Principal components analysis is often used as one step analysis in the series of analyses [7–11]. Principal Component analysis is used to reduce the data and avoid muticollinearity or when one has too many predictors relative to the number of observations. In this investigation ANOVA is generated to notion the most significant values. A principal components analysis often uncovers unsuspected relationships, allowing you to interpret the data in a path breaking way. Stepwise regression is used in this study. Stepwise regression is a method that creates a model by including variables in or excluding variables from the experiment based on the specified Alpha-to-Enter and Alpha-to-Remove values [12–16]. Principal components are found on the basis of Eigen values. Based on the proportions the percentage of variance is influenced.

2. Experimental Details

One of the venerable and popular method of cutting metals by using single point cutting tool is called as turning operation. It has even replaced grinding in several applications with reduced lead time without affecting the surface quality [17–18]. In these investigations, the experiments were carried out on a rigid CNC machine. Nine turning operations were conducted by considering three different spindle speeds and Depth of Cut, different time interval for machining operation. Another cutting parameter is taken as feed of 0.2 mm/revolution as a constant factor. The tool used in CNC for our experiment is carbide tipped general purpose tool. The turning operation is carried out for 20mm length in mild steel cylindrical rod. Fig 1 shows the image of machined work piece.

Figure 1: Machined Work Piece

Table 1 shows the details about the experiments conducted and the respective values are given in the table. For the given input parameters the accordance values of output parameters have been found and the values are tabulated

Table 1: Experimental Input and Output Parameters

S.No	Speed	Time	DOC	SR	MRR	CTR
1	2000	8	1	0.86	30.000	1.08
2	2000	8.2	1.3	0.02	38.050	1.12
3	2000	8.3	1.5	1.50	43.370	1.15
4	1500	8	1	1.60	30.000	1.09
5	1500	9	1.3	0.42	34.630	1.10
6	1500	8	1.5	0.47	45.000	1.14
7	900	11	1	0.38	21.818	1.09
8	900	11	1.3	6.18	28.360	1.13
9	900	12	1.5	2.72	30.000	1.15

3. Regression Analysis: SR versus Speed, Time, DOC

Regression analysis is a statistical tool that helps the researcher/investigator to explore the effects, analyze the behaviour and to obtain the optimum process parameter setting for the corresponding process variables [19-20].

Analysis of Variance

Analysis of variance (ANOVA) is used to analyse the experimental results and identifying the factor which has significant effect on machining variable. Table 2 shows the P-value for regression and time. The p-value is used to analyse whether the regression coefficients are significantly different from zero. For the time and regression the P-Value is 0.130 which is smaller than α =0.15 this says that the values are significant. In this study the Stepwise Selection of Terms is used. The values of α to enter = 0.15, α to remove = 0.15 which is very important to compare with P-Values whether the model is significant or not.

Table 2: Analysis Of Variance

SOURCE	DF	Adj MS	F-value	P-value
REGRESSION	1	8.726	2.95	0.130
TIME	1	8.726	2.95	0.130
ERROR	7	20.710		
TOTAL	8	29.436		

Model Summary

S, R , adjusted R , and predicted R are the values which say that how well the model fits within the data. Several models [21 – 24] have been for predicting the optimal values for Surface Roughness in Al- turning. These values help us to select the model with the best fit. S is measured in the units of the response variable and represents the standard distance that data values fall from the regression line. From Table 3 the R-sq value explains that 24.64% variation in SR, since the R-sq (adj) is 19.59% has been adjusted for the number of terms in model.

Table 3: Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.72004	26.64%	19.59%	0.00%

Coefficients

If P-Value is less than 0.15 the value is significant. If the P-Value is greater than 0.15 the values are not significant [25–27]. In this study for Time the values are significant. If VIF values are near to one then the predictors are not correlated. If the values of VIF are greater than five the regression equations are poorly estimated.

Table 4: Coefficients

TIME	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-4.49	3.58	-1.26	0.250	
Time	0.653	0.380	1.72	0.130	1.00

Regression Equation

The regression equation is an algebraic representation of the regression line and describes the relationship between the response and predictor variables [29–30].

SR = -4.49 + 0.653 Time

Fits and Diagnostics for Unusual Observations

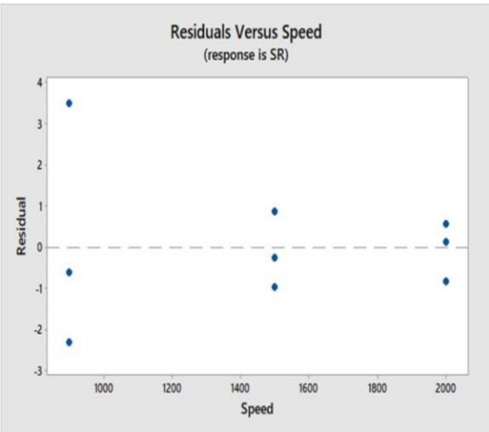
There is only one unusual observation in this study. This is predicted by comparing the observed value with stdResid. If obs is greater than stdResid [30–32] so it is clear that only one value is unusual.

Table 5: Fits and Diagnostics for Unusual Observations

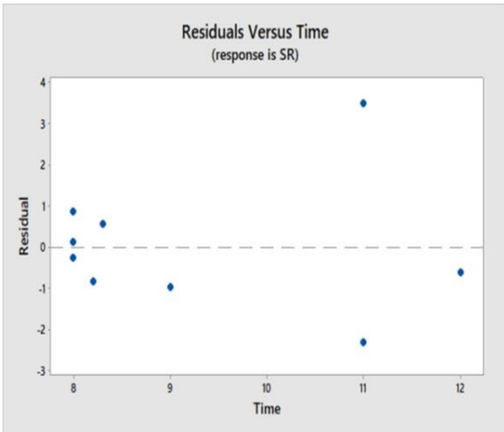
Obs	SR	Fit	Resid	StdResid	
8	6.180	2.698	3.48	2.35	R

Residuals and Contour Plots

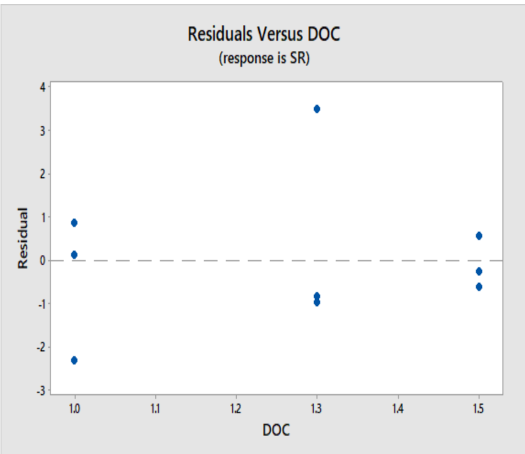
Speed in X- axis and the residuals in the Y- axis in the Fig 2(a). For SR, the residuals appear to be randomly scattered around zero. No evidence of non constant variance, missing terms, and outlier's point exists. Time in X- axis and the residuals in the Y- axis in the Fig 2(b). For the SR, the residuals appear to be randomly scattered around zero. No evidence of non constant variance, missing terms, and outlier's point exists.DOC in X- axis and the residuals in the Y- axis in the Fig 2(c). For the SR, the residuals appear to be randomly scattered around zero. No evidence of non constant variance, missing terms, and outlier's point exists. From Fig 2(d) the graph is plotted between Surface Roughness versus Speed and Time. This clearly explains that speed and time influence the Surface Roughness for this commercial mild steel material. The optimized value is found at the dark blue region <1 speed 1500 rpm and time as 9 seconds. From Fig 2(e) the graph is plotted between Surface Roughness versus Depth of Cut and Speed.



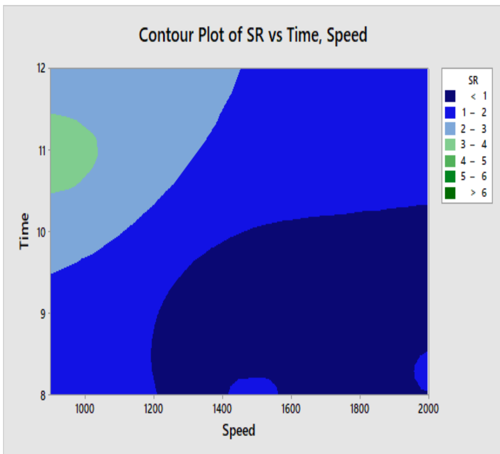
(a)



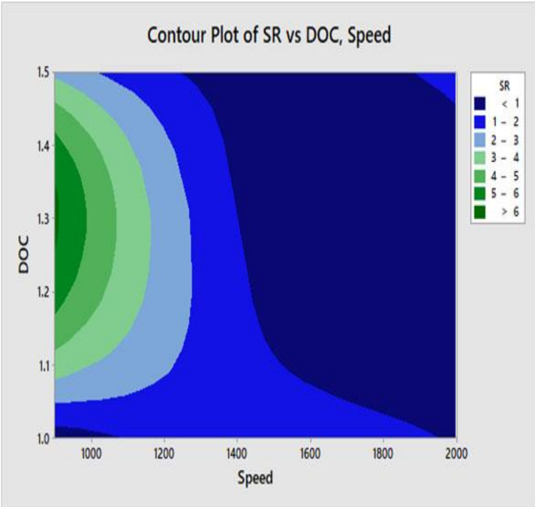
(b)



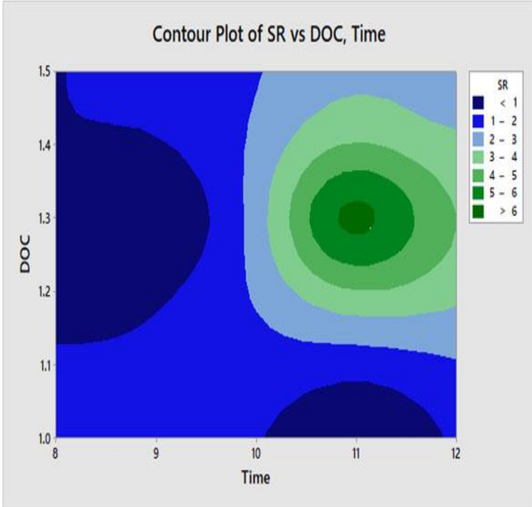
(c)



(d)



(e)



(f)

Figure 2: (a) Residuals Versus Speed. (b) Residuals Versus Time. (c) Residuals Versus Depth of Cut. (d) Contour Plot of Surface Roughness Versus Time and Speed. (e) Contour Plot of Surface Roughness versus Depth of Cut and Speed. (f) Contour plot of Surface Roughness versus Depth of Cut and Time.

The optimized value is found out be to in the dark blue region <1 which means the optimized value of DOC lies in the area of 1.3 and Speed of 2000 rpm. From Fig 2(f) the graph is plotted between Surface Roughness versus Depth of Cut and Time. The optimized value is found out to be in the dark blue region <1 which means the optimized value of DOC lies in 1.3 and Time of 9 seconds.

4. Regression Analysis: MRR versus Speed, Time, DOC

Analysis of Variance

From Table 6, for time and regression the P-Value is 0.000 which is lesser than α =0.15 this says that the values are significant. And in the same case the P-Value for DOC is also 0.000 which is lesser than α =0.15, so the values are significant. In this study the Stepwise Selection of Terms is used. The values of α to enter = 0.15, α to remove = 0.15 which is very important to compare with P-Values whether the model is significant or not.

Table 6: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-value	P-Value
Regression	2	451.226	225.613	304.65	0.000
Time	1	229.173	229.173	309.46	0.000
DOC	1	277.324	277.324	374.48	0.000
Error	6	4.443	0.741		
total	8	455.669			

Model Summary

From Table 7 the R-sq value explains that 90.02% variation in MRR, since the R-sq (adj) is 98.70% has been adjusted for the number of terms in model. The R-sq (pred) is 96.92%.this model is a better fit because the values are keep on increasing when compared to the regression model of SR. If P-Value is less than 0.15 the value is significant. If the P-Value is greater than 0.15 the values are not significant. In this study for Time the values are significant. If the VIF values are near to one then the predictors are not correlated. If the values of VIF are greater than five the regression equations are poorly estimated. From Table 8 clearly we can say that all the P- Values are significant.

Table 7: Model Summary

S	R-sq	R-sq (adj)	R-sq (pred)
0.860557	99.02%	98.70%	96.92%

Coefficients

If P-Value is less than 0.15 the value is significant. If the P-Value is greater than 0.15 the values are not significant. In this study for Time the values are significant. If VIF values are near to one then the predictors are not correlated. . If the values of VIF are greater than five the regression equations are poorly estimated. From Table 8 it is that all the P-Values are significant.

Table 8: Coefficients

Term	Co-eff	SE coef	T-value	P-value	VIF
Constant	30.35	2.38	12.78	0.000	–
Time	-3.375	0.192	-17.59	0.000	1.02
DOC	27.22	1.41	19.35	0.000	1.02

Regression Equation

The regression equation is an algebraic representation of the regression line and it describes the relationship between the response variables and predictor variables

MRR = 30.35 - 3.375 Time + 27.22 DOC

Fits and Diagnostics for Unusual Observations

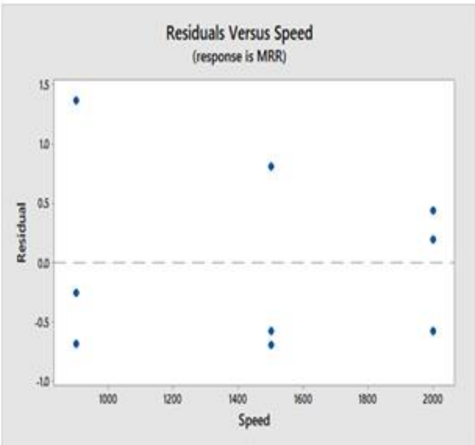
There is only one unusual observation in this study. This is predicted by comparing the observation value with stdResid. If obs is greater than stdResid so it is clearly found that only one value is observed unusual.

Table 9: Fits and Diagnostics for Unusual Observations

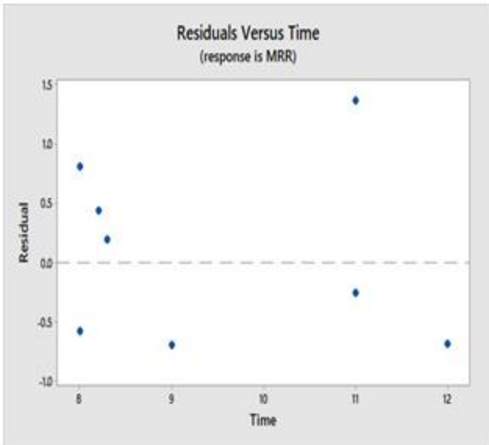
Obs	MRR	Fit	resid	Stdresid
7	21.818	20.453	1.365	2.22

Residuals and Contour Plots

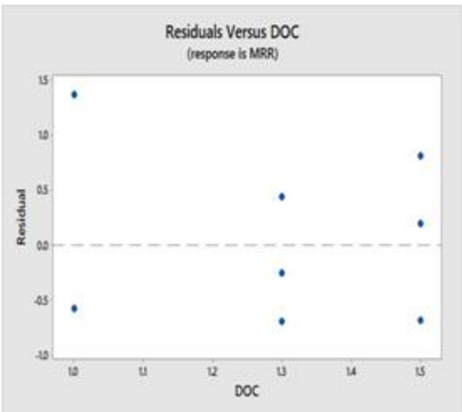
Speed in X- axis and the residuals in the Y- axis in the Fig 3(a). For MRR, the residuals appear to be randomly scattered around zero. No evidence of non constant variance, missing terms and outliers point exists. Time in X- axis and the residuals in the Y- axis in the Fig 3(b). For the MRR, the residuals appear to be randomly scattered around zero. No evidence of non constant variance, missing terms and outliers point exists. DOC in X- axis and the residuals in the Y- axis in the Fig 3(c). For the MRR, the residuals appear to be randomly scattered around zero. No evidence of non constant variance, missing terms and outliers point exists. From the Fig 3(d) the graph is plotted between the Metal Removal Rate versus Time and Speed. This clearly explains that speed and time does not influence the Metal Removal Rate for this commercial mild steel material. So there is no significant optimised value for this graph plot. From Fig 3(e) the graph is plotted between the Metal Removal Rate versus Depth of Cut and Speed. The optimized value are found to be in dark green region >45. The optimized value for Depth of Cut is found to be of 1.5 and Speed between 1500 rpm and 1800 rpm. From Fig 3(f) the graph is plotted between the Metal Removal Rate versus Depth of Cut and Time. Clearly explains that Depth of Cut and Time do not influence the Metal Removal Rate for this commercial mild steel material.



A

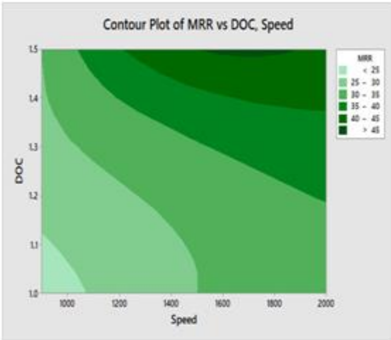


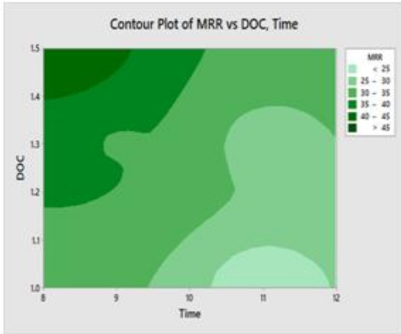
B



C

D





E F

Figure 3 (a) Residuals Versus Speed. (b) Residuals Versus time. (c) Residuals versus Depth of Cut. (d) Contour plot of Metal Removal Rate Versus Speed and Time. (e) Contour plot of Metal Removal Rate versus Depth of Cut and Speed. (f) Contour plot of Metal Removal Rate versus Depth of Cut and Time

5. Regression Analysis: CTR versus Speed, Time, DOC

Stepwise Selection of Terms, α to enter = 0.15, α to remove = 0.15

Analysis of Variance

From Table 10, for time and regression the P-Value is 0.000 which is lesser than α =0.15 this says that the values are significant. And in the same case the P-Value for DOC is also 0.000 which is lesser than α =0.15, so the values are significant. In this study the Stepwise Selection of Terms is used. The values of α to enter = 0.15, α to remove = 0.15 which is very important to compare with P-Values whether the model is significant or not.

Table 10: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	0.005329	0.005329	55.59	0.000
DOC	1	0.005329	0.005329	55.59	0.000
Error	7	0.000671	0.000096		
Total	8	0.006000			

Model Summary

From Table 11 R-sq value explains that 88.82% variation in MRR, Since the R-sq (adj) is 87.22% has been adjusted for the number of terms in model. The R-sq (pred) is 84.09%. This model is slightly lower fit when compared to the MRR regression analysis.

Table 11: Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0097911	88.82%	87.22%	84.09%

Coefficients

If P-Value is less than 0.15 the value is significant. If the P-Value is greater than 0.15 the values are not significant. In this study for Time the values are significant. If VIF values are near to one then the predictors are not correlated. . If the values of VIF are greater than five the regression equations are poorly estimated. From Table 12 it is that all the P-Values are significant.

Table 12: Coefficients

Term	coef	SE coef	T-Value	P-Value	VIF
Constant	0.9667	0.0204	47.43	0.000	
DOC	0.1184	0.0159	7.46	0.000	1.00

Regression Equation

The regression equation is an algebraic representation of the regression line and it describes the relationship between the response and predictor variables, CTR = 0.9667 + 0.1184 DOC

Fits and Diagnostics for Unusual Observations

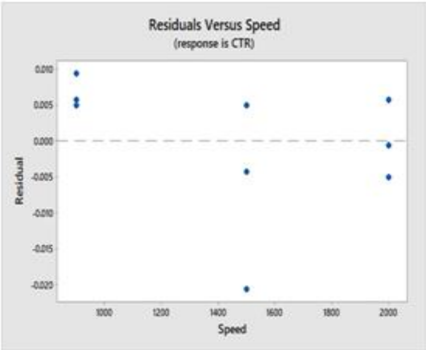
There is only one unusual observation in this study. This is predicted by comparing the observed value with stdResid. If obs is greater than stdResid it is clearly found that only one value observed unusual.

Table: 13 Fits and Diagnostics for Unusual Observations

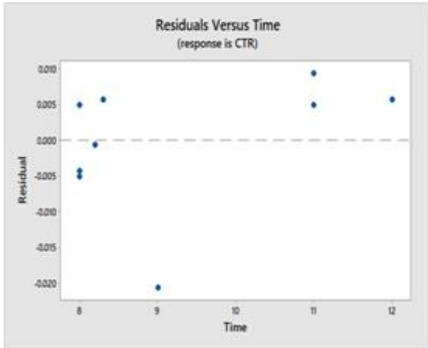
OBS	ctr	Fit	Resid	StdResid
5	1.10000	1.12061	-0.02061	-2024

Residuals and Contour Plots

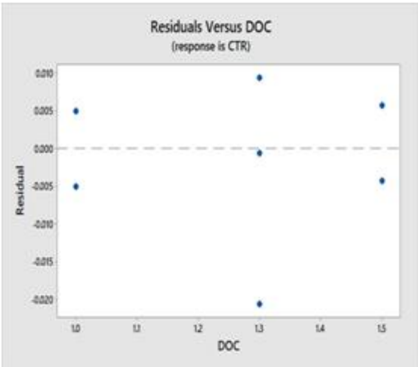
Speed in X- axis and the Residuals in the Y- axis in the Fig 4(a). For Chip Thickness Ratio, the residuals appear to be randomly scattered around zero. No evidence of non constant variance, missing terms and outliers point exists. Time in X- axis and the residuals in the Y- axis in the Fig 4(b). For the Chip Thickness Ratio, the residuals appear to be randomly scattered around zero. No evidence of non constant variance, missing terms and outliers point exists. DOC in X- axis and the residuals in the Y- axis in the Fig 4(c). For the Chip Thickness Ratio, the residuals appear to be randomly scattered around zero. No evidence of non constant variance, missing terms and outliers point exists. From the Fig 4(d) the graph is plotted between the Chip Thickness Ratio versus Time and Speed. The optimized values are found in the dark green region >1.14. The optimized value of Time is 11.5-12 seconds and Speed is 900-1000 rpm. From the Fig 4(e) the graph is plotted between the Chip Thickness Ratio versus Depth of Cut and Speed. The optimized values are found in the dark green region >1.140. The optimized value of Depth of Cut is 1.4-1.5 and Speed 900-1200 rpm and 1600-2000 rpm. From the Fig 4(f) the graph is plotted between the Chip Thickness Ratio versus Depth of Cut and Time. The optimized values are found in the dark green region >1.140. The optimized value of Depth of Cut is 1.4-1.5 and time is 8-9 and 11-12 seconds.



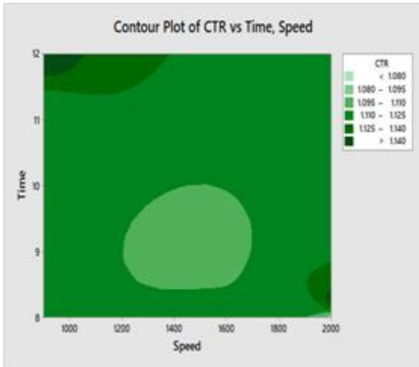
(a)



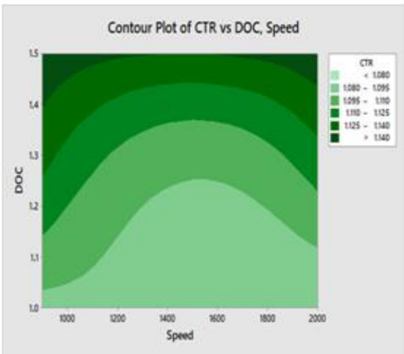
(b)



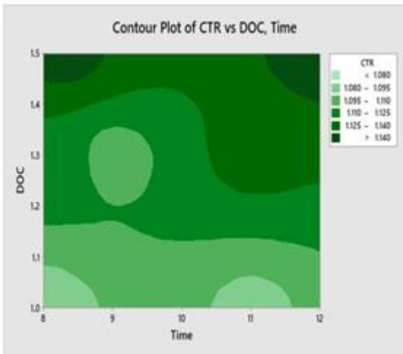
(c)



(d)



(e)



(f)

Figure 4: (a) Residual Versus Speed. (b) Residuals Versus Time. (c) Residuals versus Depth of Cut. (d) Contour Plots of Chip Thickness Ratio versus Speed and Time. (e) Contour plots of Chip Thickness Ratio versus Depth of Cut and Speed. (f) Contour plots of Chip Thickness Ratio Versus Depth of Cut and Time.

6. Principal Component Analysis: SPEED, TIME, DOC

Principal components analysis is commonly used as one step in a series of analyses. Principal component analysis is used for determination of weight criteria in multi objective optimization [32]. For example, you can use Principal Components to reduce your data and avoid multi collinearity or when you have too many predictors relative to the number of observations. A principal components analysis often uncovers unsuspected relationships, allowing you to interpret the data in a new way.

Eigen Analysis of the Correlation Matrix

The numbers of principal components are determined by the size of Eigen values. In the Eigen analysis of the correlation matrix, the Eigen values of the correlation matrix equal the variances of the principal components [33]. The first principal component has variance 1.8886 (equal to the largest Eigen value) and accounts for 0.630 (63%) of the total variation in the data. The second principal component (variance 1.0000) accounts for 0.333 (33.3%) of the total data variation. The third principal component (variance 0.1114) accounts for 0.037 (3.7%) of the total data variation.

Table 14: Eigen Analysis of the Correlation Matrix

Eigen value	1.8886	1.0000	0.1114
Proportion	0.630	0.333	0.037
cumulative	0.630	0.963	1.000

Outlier Plot of Speed, Time, DOC

The Mahalanobis distance is the multi-dimensional generalization of measuring how many standard deviations points are away from the mean distribution[9]. In Fig 5 the Mahalanobis distance is plotted in X-axis and the observations are plotted in the Y-axis. There are no outliners because none of the points are above the reference line.

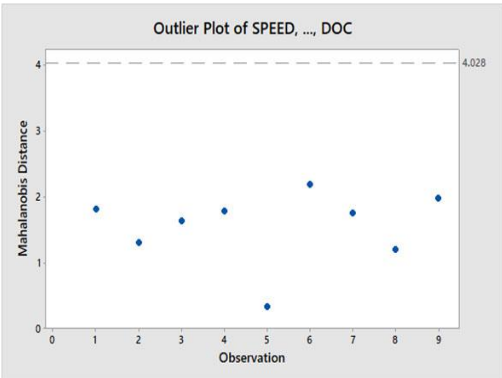


Figure 5: Outliner Plots of Speed, Time and Depth of Cut

7. Conclusion

In this experimental study, the optimization of metal cutting parameters for multiple responses such as MRR, Chip Thickness Ratio and surface roughness were found by using regression analysis and principal component analysis. Investigations have revelaed that speed has no significant effect on Surface Roughness, Depth of Cut also does not influence Surface Roughness, feed rate has significant influence on Surface Roughness. The input parameters influence the output parameters at significant rate, by controlling the input parameters the desired output parameters can be obtained. The results are plotted in the form of graphs and response tables. The optimum values to achieve the better Surface roughness for the various parameters such as speed of 900 rpm, Time as 11 seconds and Depth of Cut of 1.3mm. The optimum values to achieve better Metal Removal Rate are Speed as 1800 rpm and Depth of Cut 1.5mm. The optimum values to achieve better Chip Thickness Ratio are Speed 900 rpm, Time 11 seconds and Depth of Cut of 1.4mm.The Speed accounts for 63.3% of total variance in the data so Speed is the most influencing factor in this study. This experimental study will be useful to the manufacturing industries that are using Commercial Mild Steel as their manufacturing material.

References

[1] Liu D., Xin R., Sun L., Zhou Z., Liu Q., Influence of sampling design on tensile properties and fracture behavior of friction stir welded magnesium alloys, Materials Science & Engineering A 576 (2013), 207-216.

[2] Sutton M.A., Reynolds A.P., Yang B., Taylor R., Mode I fracture and microstructure for 2024-T3 friction stir welds, Materials Science and Engineering, A354 (2003), 6-16.

[3] Sevvel P., Jaiganesh V., Investigation on evolution of microstructures and characterization during FSW of AZ80A Mg alloy, Archives of Metallurgy and Materials 62 (3) (2017), 1779-1785.

[4] Ozel T., karpat Y., Predictive modelling of surface roughness and tool wear in hard turning using regression and neural networks, International Journal of Machine Tools and Manufacture 45 (2005), 467 479.

[5] Feng C.X., Wang X., Development of empirical model for surface roughness prediction in finish turning, International Journal of Advanced Manufacturing Technology 20 (2002), 348 356.

[6] Ramanujam R., Venkatesan K., Vimal S., Rachit P., Harsha T., Gurusharan K., Optimization of Machining Parameters Using Fuzzy Based Principal Component Analysis during dry turning

operation of Inconel 625 A hybrid approach, Procedia Engineering 97 (2014), 668 – 676.

[7] Zeng R., Dietzel W., Zettler R., Chen J., Kainer K.U., Microstructure evolution and tensile properties of friction-stir welded AM50 magnesium alloy, Transactions of Nonferrous Metals Society of China 18 (2008), S76 – S80.

[8] Sevvel P., Jaiganesh V., A detailed investigation on the role of different tool geometry in friction stir welding of various metals & their alloys, Proceedings of the International Colloquium on 'Materials, manufacturing & metrology, Indian Institute of Technology , Madras, India (2014), 103–107.

[9] Liu D., Xin R., Sun L., Zhou Z., Liu Q., Influence of sampling design on tensile properties and fracture behavior of friction stir welded magnesium alloys, Materials Science & Engineering 576 (2013), 207 – 216.

[10] Sevvel P., Jaiganesh V., Improving the mechanical properties of friction stir welded AZ31B magnesium alloy flat plates through axial force investigation, Applied Mechanics and Materials 591 (2014), 11-14.

[11] Jiang J.F., Lin X., Wang Y., Qu J.J., Luo S.J., Micro structural evolution of AZ61 magnesium alloy pre deformed by ECAE during semisolid isothermal treatment, Transactions of Nonferrous Metals Society of China 22 (3) (2012), 555–563.

[12] Sevvel P., Jaiganesh V., An detailed examination on the future prospects of friction stir welding a green technology, Proceedings of the International conference on advances in industrial engineering applications, Chennai, India (2014), 62–63.

[13] Yu S., Chen X., Huang Z., Liu Y., Microstructure and mechanical properties of friction stir welding of AZ31B magnesium alloy added with cerium, Journal of Rare Earths 28 (2010), 316–20.

[14] Sevvel P., Jaiganesh V., Effect of Tool Shoulder Diameter to Plate Thickness Ratio on Mechanical Properties and Nugget Zone Characteristics During FSW of Dissimilar Mg Alloys, Transactions of the Indian Institute of Metals 68 (S1) (2015), 41–46.

[15] Xie G.M., Ma Z.Y., Geng L., Effect of micro structural evolution on mechanical properties of friction stir welded ZK60 alloy, Materials Science and Engineering 486 (2008), 49–55.

[16] Jaiganesh V., Sevvel P., Effect of Process Parameters in the Micro structural Characteristics and Mechanical Properties of

AZ80A Mg Alloy during Friction Stir Welding, Transactions of the Indian Institute of Metals 68 (S1) (2015), 99–104.

[17] Narutaki N., Yamane Y., Okushima K., Tool wear and cutting temperature of CBN tool in machining of hardened steels, Ann. CIRP 28 (1) (1979), 23-28.

[18] Sevvel P., Jaiganesh V., Characterization of mechanical properties and micro structural analysis of friction stir welded AZ31B Mg alloy through optimized process parameters, Procedia Engineering 97 (2014), 741–751.

[19] Rajakumar S., Balasubramanian V., Razalrose A., Friction stir and pulsed current gas metal arc welding of AZ61A magnesium alloy: A comparative study, Materials and Design 49 (2013), 267–278.

[20] Sevvel P., Jaiganesh V., Impact of process parameters during friction stir welding of AZ80A Mg alloy, Science and Technology of Welding and Joining 21 (2) (2016), 83 – 90.

[21] Ahmed S.G., Development of a prediction model for Surface Roughness in finish turning of aluminium, Journal of Sudan Engineering Society 52 (45) (2005), 1-5.

[22] Sevvel P., Jaiganesh V., Impact of Tool Profile on Mechanical Properties of AZ31B Mg Alloy during FSW Using Optimized Parameters, FME Transactions 44 (1) (2016), 43–49.

[23] Mehmet E., Investigation of structure and mechanical properties of copper-brass plates joined by friction stir welding, International Journal of Advanced Manufacturing Technology 76 (9) (2015), 1583 – 1592.

[24] Sevvel P., Stephan Thangaiah I.S., Mars Mukesh S., Mohammed Anif G., Laboratory Scale Testing of Thermoelectric Regenerative Braking System, International Journal of Vehicle Structures & Systems 7(4) (2015), 157-160.

[25] Singarvel B., Selvaraj T., Jeyapau R., Multi Objective Optimization in Turning of EN25 Steel Using Taguchi Based Utility Concept Coupled With Principal Component Analysis, Procedia Engineering 97 (2014), 158 – 165.

[26] Sevvel P., Jaiganesh V., Investigation on evolution of microstructures and characterization during FSW of AZ80A Mg alloy, Archives of Metallurgy and Materials 62 (3) (2017), 1779-1785.

[27] Kesharwani R.K., Panda S.K., Pal S.K., Multi-Objective Optimization of Friction Stir Welding Parameters for Joining of

Two Dissimilar Thin Aluminum Sheets, Procedia Materials Science 6 (2014), 178–187.

[28] Hattingh D.G., Blignault C., Van Niekerk T.I., James M.N., Characterization of the influences of FSW tool geometry on welding forces and weld tensile strength using an instrumented tool, Journal of Materials Processing Technology 203 (1–3) (2008), 46–57.

[29] Sevvel P., Jaiganesh V., Influence of the arrangement of materials and micro structural analysis during FSW of AZ80A & AZ91C Mg alloys, Archives of Metallurgy and Materials 62 (3) (2017), 1795-1801.

[30] Jain V., Mishra R.S., Gupta A.K., Study of β-precipitates and their effect on the directional yield asymmetry of friction stir processed and aged AZ91C alloy, Material Science and Engineering, 560 (2013), 500–509.

[31] Sevvel P., Sunil Solomon R., Mahadevan S., Shahul Hamid K., Optimization of Process Parameters and Evaluation of Response Characteristics in EDM Using Taguchi and ANOVA Method A Review, Journal of Advanced Research in Dynamical & Control Systems 9 (5) (2017), 91-100.

[32] Razal Rose A., Manisekar K., Balasubramanian V., Effect of axial force on microstructure and tensile properties of friction stir welded AZ61A magnesium alloy, Transactions of Nonferrous Metals Society of China 21 (5) (2011), 974–984.