Application of RSM and ANN for the Predication and optimization of the circularity Error of DSS 2205 Under Hybrid Cryo-MQL Process

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Abstract

In this research paper, parametric optimization was carried out by using the response surface method (RSM) with the Box-Behan design of the matrix under a hybrid (the combination of MQL and the LCO2) process. The hybrid process is an environmentally friendly machining process. For optimization, select three input parameters e.g. drill diameter, spindle speed, and feed rate while circularity error is an output parameter. After the analysis of variance (ANOVA) analysis, it was observed that feed rate is the most effective process parameter compared to other process parameters on circularity error. In MATLAB software Artificial Neural Network (ANN) implements for validation of experimental results. Also, it was observed that the experimental results and predictive results are in close agreement with each other.

Keywords: Response surface method (RSM), Artificial Neural Network (ANN), DSS 2205, Circularity, Drilling Process.

Introduction

Duplex stainless steel (DSS) 2205 is a combination of two phases e.g. ferrite and austenite. DSS 2205 has many properties e.g. higher strength, higher toughness, and high machinability, and is used in welding because of improved weldability. DSS 2205 has higher strength so it is challenging to cut. In this situation, at present time environmentally friendly techniques are used for improved machinability [1]. Different types of environmentally friendly machining techniques are used at the present time e.g. dry machining, mist cooling approach, higher pressure cooling approach, and cryogenic cooling (with LN2 and LCO2,), etc [2].

In this paper, a hybrid technique (the combination of (MQL+LCO2) is implemented in the drilling process and evaluation of machinability on DSS 2205. This paper implemented Cryo-MQL for milling on Inconel 718 and observed improved tribology properties [3]. In this paper, the Cryo-MQL setup is used for the analysis of cutting zone temperature, tool wear, and surface properties. It was observed that improve all responses under Cryo-MQL [4]. In this paper, MQL and MQL with Nanoparticles is used for analysis [5]. In milling EMQL approach is used for response analysis [6]. From the literature review, it can be observed that a lack of studies can be observed in the field of duplex stainless steel 2205 drilling with the combination of MQL + LCO2 machining process. Figure 1 shows the actual image of the hybrid (MQL + LCO2) machining setup. In this paper, the ANN model is developed for the prediction of the effect of several machining parameters on circularity error using experimental results obtained based on the Box-Behan design. ANOVA test was performed to evaluate significant factors in the drilling of DSS 2205.

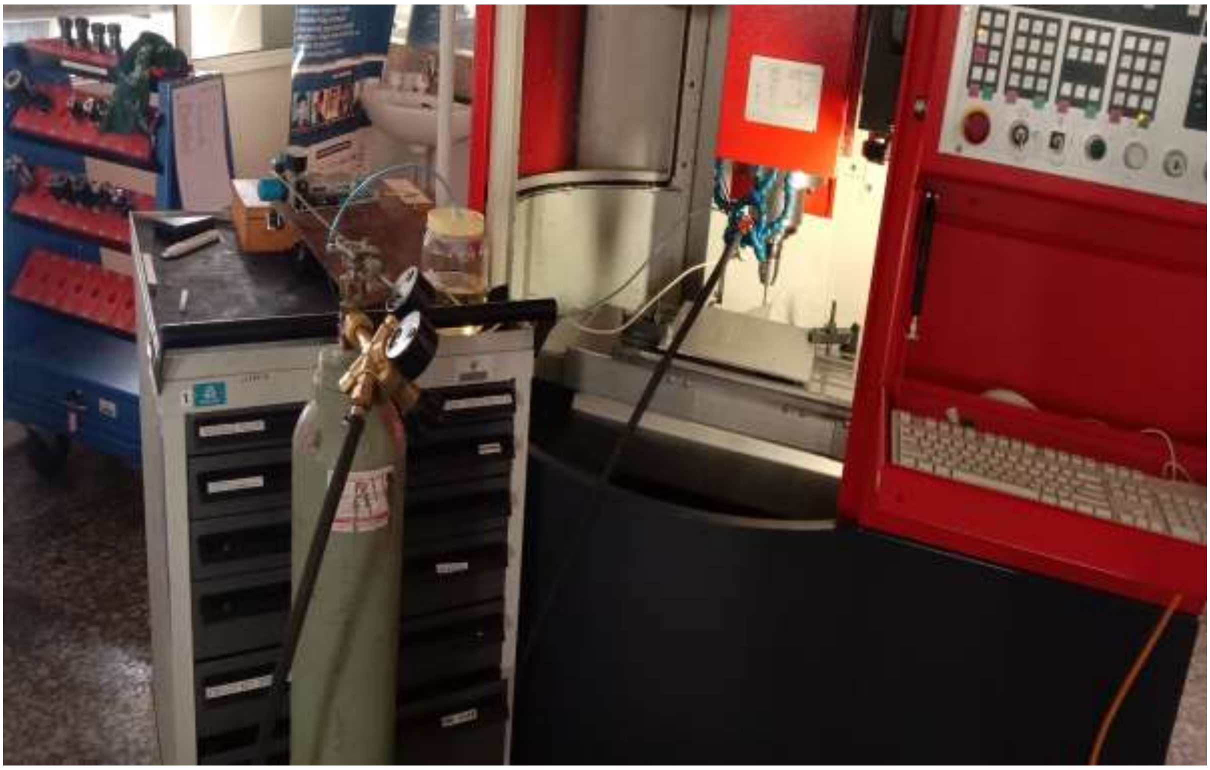

Fig. 1 Shows Actual Image of Hybrid Set-Up

Experimentation

The MQL and LCO2 setup was developed on a CNC milling machine for drilling operations to perform experiments. Figure 1 shows the actual image of the setup on the CNC milling machine. Table 1 shows the description of the MQL + LCO2 set-up.

Table 1 Description of MQL + LCO2 Setup

Description	Specification
Machine	CNC milling
Process	Drilling
Workpiece material	DSS 2205
Tool Material	TiAlN coated solid carbide
Oil type	Vegetable oil
The pressure of MQL Flow	3 Bar
The pressure of the LCO2 cylinder	35 Bar
The flow rate of LCO2	18 M/L
Response measured	CMM

All the experiments are conducted on duplex stainless steel 2205 (300*300 mm with 5mm thickness) with TiAlN coated solid carbide drill. Table 2 shows the chemical composition of DSS 2205.

Table 2 Chemical composition of DSS 2205

Element	Carbon	Chromium	Nickel	Molybdenum	Nitrogen	Others
%	0.030%	21-23%	5.5- 6.5 %	3.1-35%	0.18-0.20%	S-0.001-0.020% P-0.030%, Si-1%

In this research paper, select three input parameters while circularity error as a response variable. The level of process parameters shows in Table 3.

Table 3 Level of Process Parameters

Input Factor			**Coded Level**		
Description	Units	Symbol	-1	0	1
Drill Diameter	mm		2	4	6
Spindle Speed	RPM		1100	1300	1500
Feed Rate	Mm/rev.		0.01750	0.01875	0.020

For parametric optimization, the Box-Behan design is used and found in 15 sets of experiments, and this value is shown in table 4 with the response, respectively. The response variable e.g. circularity error measured by a coordinate measuring machine (CMM).

Table 4 experimental table

Run order	**Drill Dia.**	**Spindle S.**	**Feed Rate**	**Experimental Value**
				Circularity Error
1	2	1300	0.02000	0.00610
2	4	1100	0.02000	0.00630
3	6	1500	0.01875	0.00540
4	4	1300	0.01875	0.00560
5	2	1300	0.01750	0.00550
6	6	1300	0.01750	0.00544
7	2	1100	0.01875	0.00567
8	4	1300	0.01875	0.00550
9	6	1100	0.01875	0.00575
10	4	1500	0.01750	0.005300
11	4	1500	0.02000	0.00580
12	6	1300	0.02000	0.00561

13	4	1100	0.01750	0.00602
14	2	1500	0.01875	0.00587
15	4	1300	0.01875	0.00552

Results & Discussion

ANOVA

For the ANOVA test, MINITAB software is used and the ANOVA test was performed, and results are shown in table 5 for circularity error. The value of R^2 = 86.34% for circularity error, which indicates only the last 14.64% of the variation in circularity error. As per Normal distribution of residual is a straight line and all the value is near to straight line shown in the figure 2. From the ANOVA analysis, it was observed that feed rate is a more effective process parameter compared to other process parameters e.g. spindle speed, and drill diameter.

Table 5 ANOVA results

Source	DF	Seq SS	Adj SS	Adj MS	F Value	P-Value	Contribution
Model	3	0.000001	0.000001	0.00000	5.07	0.019	58.05%
Drill Diameter	1	0.00000	0.00000	0.00000	2.60	0.135	9.93%
Spindle Speed	1	0.00000	0.00000	0.00000	5.53	0.038	21.10%
Feed Rate	1	0.00000	0.00000	0.00000	7.08	0.022	27.01%
Error	11	0.00000	0.00000	0.00000			41.95%
Lack-of-fit error	9	0.00000	0.00000	0.00000	18.29	0.053	41.45%
Pure error	2	0.00000	0.00000	0.00000			0.50%
Total	14	0.00001					100%

Model Summary- S= 0.0001743, R-Seq= 86.34%%

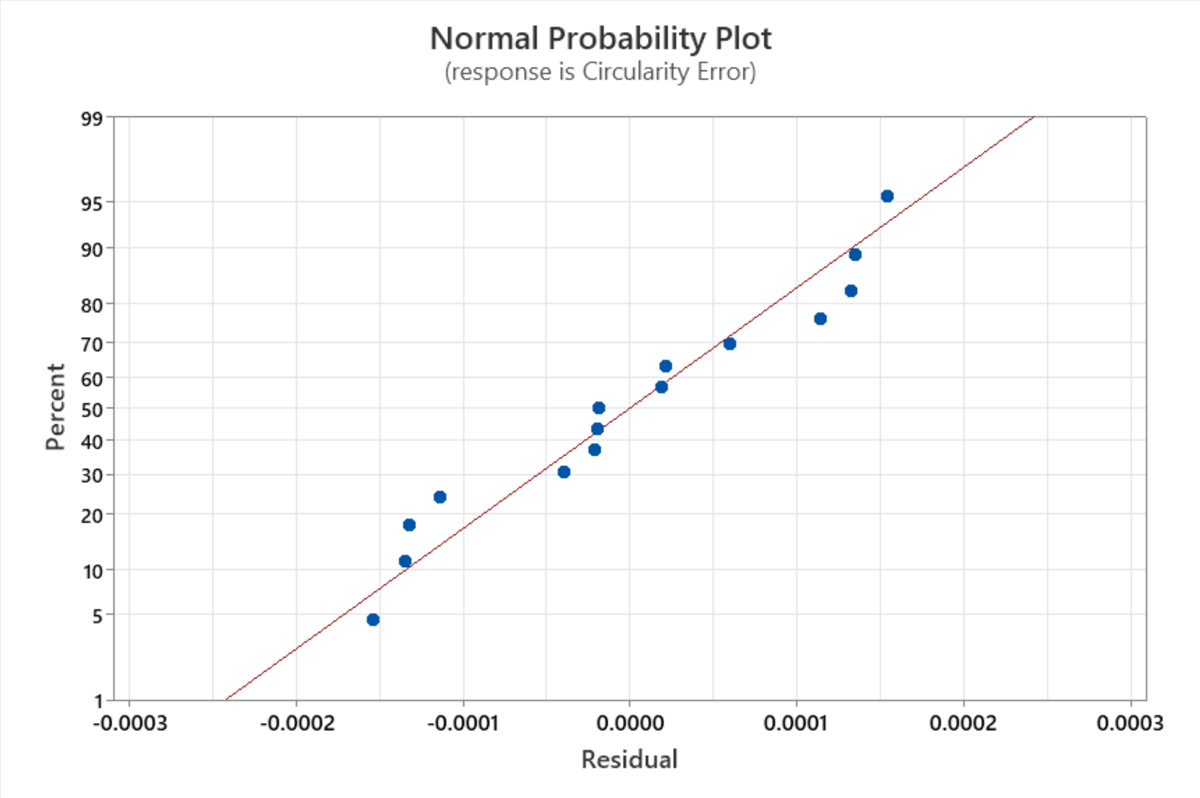

Fig. 2 Shows residual plot of circularity error

Prediction of Circularity Error In the Drilling process By Artificial Neural Network (ANN)

ANN is one of the widely used dominant computational tools used to explain complex functions in numerous applications. ANN has been efficaciously adopted for solving various problems in areas like fault diagnosis, process identification, property estimation, data smoothing, and error filtering, product design and development, optimization, and estimation of activity coefficients. The neural network is an immensely parallel distributed processing method consisting of greatly interconnected neural computing elements having the capability to learn, obtain information, and make it available for use. Therefore, by appreciating the computational capability of a multi-layered neural network, it has been adopted in the modeling of the drilling process and used to predict the circularity error in the machining of Inconel duplex stainless steel 2205. In this study, the effects of drill diameter, spindle speed, and feed rate on circularity error was statistically investigated in the drilling of duplex stainless steel. The best ANN architecture was designed by MATLAB software. The training of the network was done using Levenberg–Marquardt (LM) backpropagation neural network (BPNN) algorithm for fast supervised learning, and 70% of data have been used for training, whereas

15% of data were used for testing and 15% for validation each. The details of the ANN model developed are shown in Table 7.

After ANN is implemented, the regression plot for the value of R-square and the value of response in each point shows in figure 3. Figure 4 shows the mean square error and at the point the best validation performance. It was observed that almost the value is near to straight line, so it means implemented of ANN is successful each value is close in agreement to the experimental value shown in table 6.

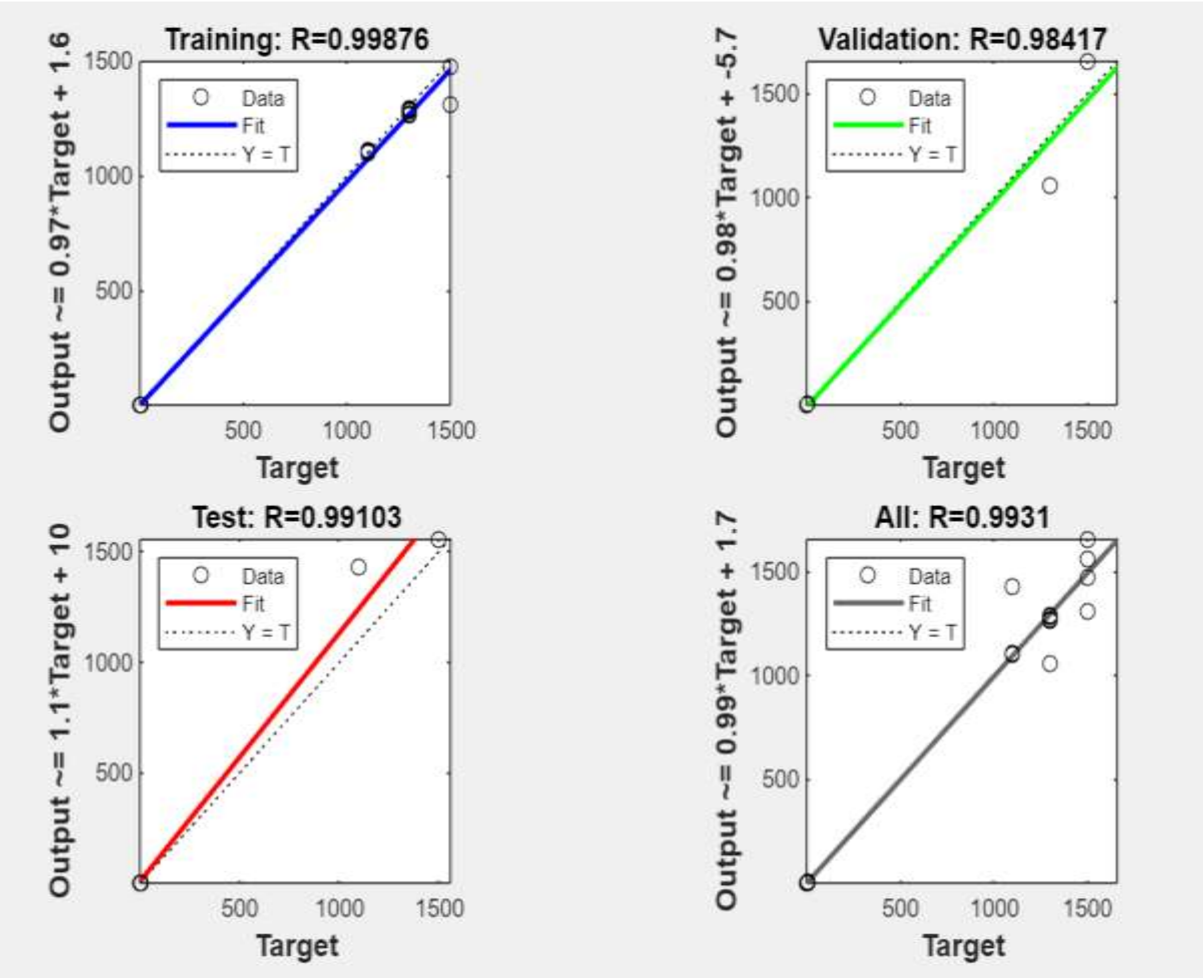

Fig. 3 Shows Regression analysis of ANN

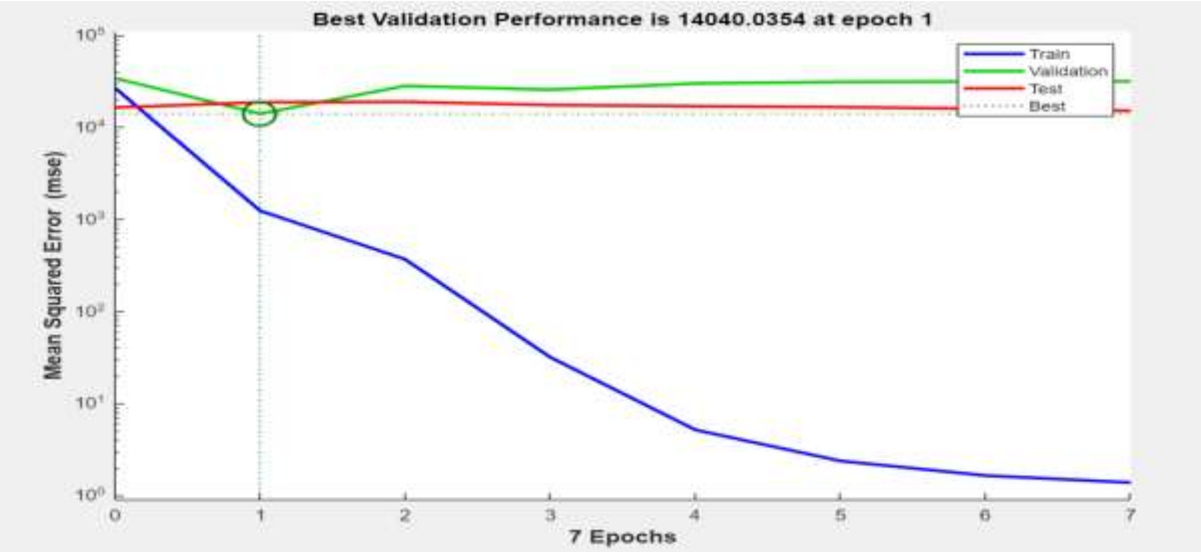

Fig. 4 Shows Performance Level of ANN

Surface Plot

The surface plot for circularity error in 3-D (dimensional) by varying factor sectors at one factor is constantly shown in Figure 5. As per the surface plot, it was observed that with the feed rate increase the circularity error is reduced.

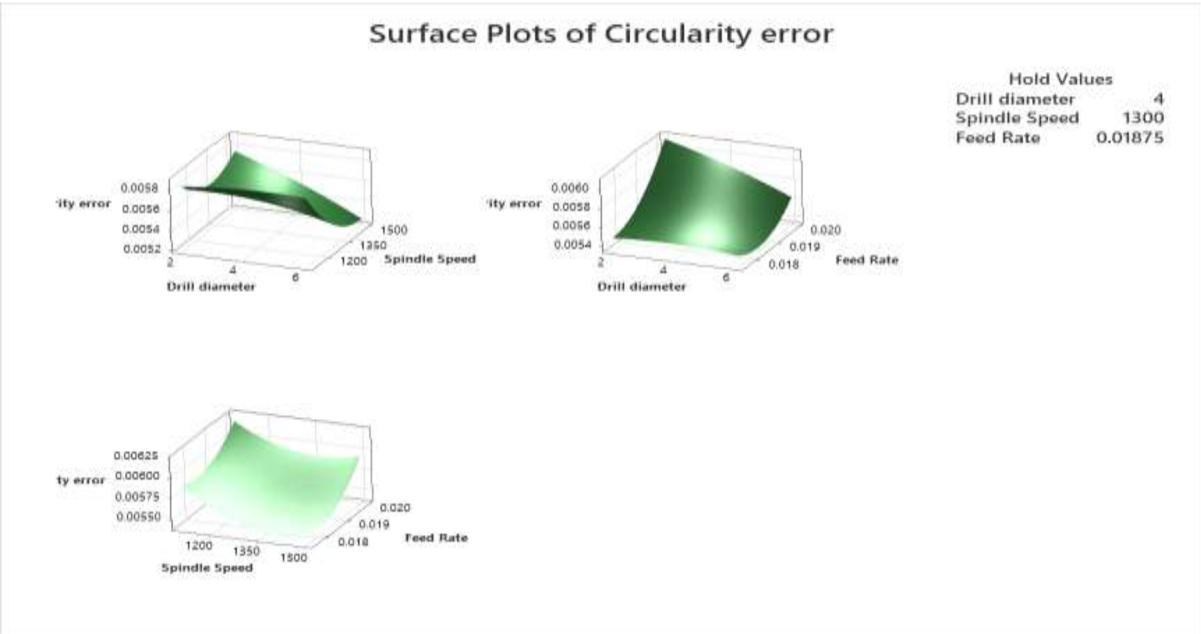

Fig. 5 Shows a Surface diagram with input parameters for response

Comparison of Experimental Value to Predictive Value of ANN

The % of error between the experimental value to the predictive value of circularity error by ANN is listed in table 6. Figure 6 shows a comparison of the experimental value to the predictive value of ANN and also shows that all the value is nearest to each other.

Table 6 Experimental Value and ANN Value

Circularity Error			
S.No.	Experimental Value	ANN Value	% error
1	0.00610	0.0059099113	3.116208
2	0.00630	0.0062514110	0.7712
3	0.00540	0.005652266	4.6715
4	0.00560	0.005652298	0.9252
5	0.00550	0.00546972	0.5505
6	0.00544	0.00531218	2.34349
7	0.00567	0.0056809210	0.19224
8	0.00550	0.0054344	1.9227
9	0.00575	0.00620350	7.3103
10	0.005300	0.00535522	1.0311
11	0.00580	0.0057456211	0.93756
12	0.00561	0.0057456211	2.3604
13	0.00602	0.0059099113	1.8287
14	0.00587	0.0055344	5.7172
15	0.00552	0.00565229	2.3404

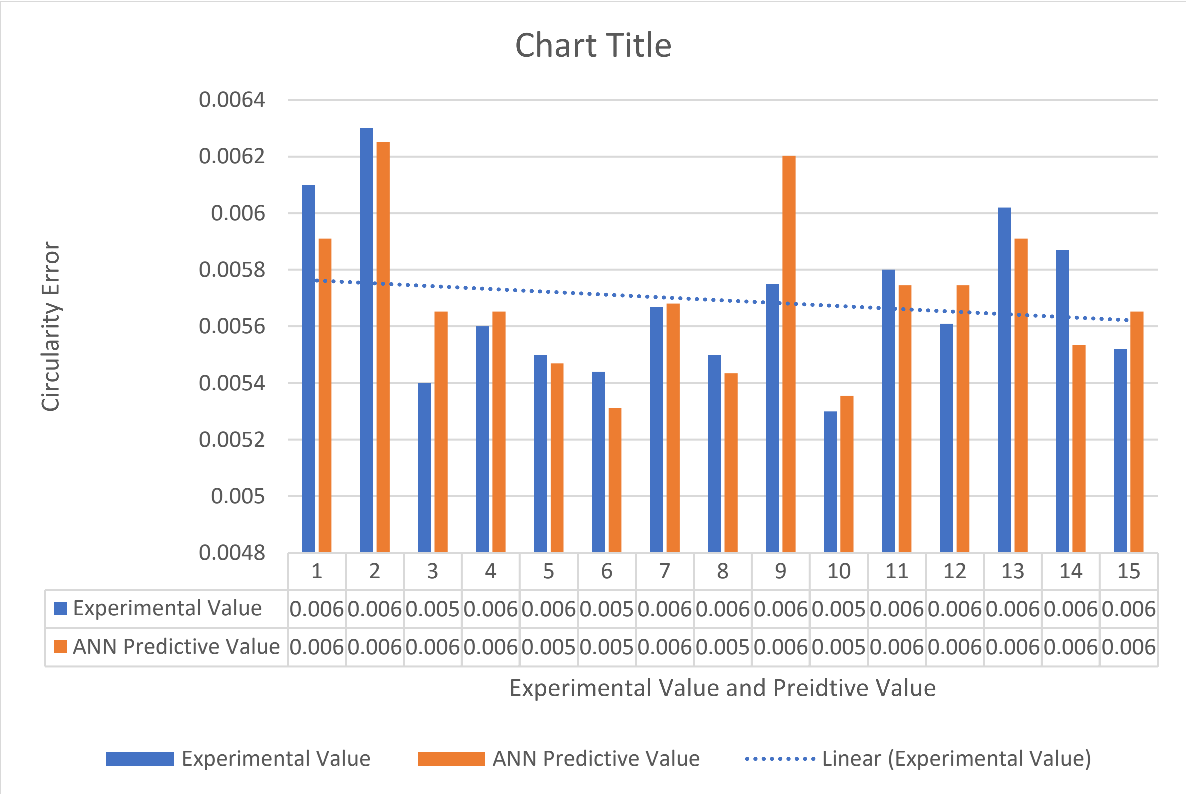

Fig. 6 Shows Comparison of Experimental Value to Predictive Value

Conclusion

In this paper, hybrid (the combination of MQL and Cryogenic cooling) is used for parametric optimization and validation of experimental results of ANN for circularity error. The following conclusions are gathered. These are below;

1. All the experiments are carried out on DSS 2205 with TiAlN coated solid carbide drill and parametric optimization by using the Box-Behan design of RSM.
2. It was observed that feed rate is the most effective process parameter on circularity error compared to other process parameters.
3. From ANOVA analysis, it was obtained the contribution of feed rate is 27.01 % which is more compared to other process variables.
4. Developed ANOVA model, and validation of experimental results to predictive results for circularity error. It was observed that all the values were close to each other.

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