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Experimental Investigation on Multi Pass Drilling Of GFRP Using Fuzzy Logic

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***Abstract**: Drilling is an hole making process in metal cutting operation performed by extrusion which finds wide application in various industries for manufacturing components using metals and non metals. This process is applied widely in assembly of components or elements, where processing challenges are severe issue such as to maintain surface integrity, ovality, machining time, Metal Removal Rate etc., In the recent trends of engineering GFRP is a fast growing material which found to have the application of drilling operation and also facing the above mentioned processing challenges in the hole making process. So in this work the drilling of GFRP was investigated for characteristic behavior of cutting parameters spindle speed, feed with 10 mm diameter of hole. The experiment was carried out using 6 mm HSS, 6 mm TiN coated HSS,10 mm HSS, 10 mm TiN coated HSS drill bits in three different configuration of drill pass ie., three multipass (1. 6mm HSS then 10mm HSS drill 2. 6mm TiN coated HSS then 10mm TiN coated HSS drill 3. 6mm TiN coated HSS then 10mm HSS drill). The responses considered were Surface finish, Delamination, ovality and machining time were tested for significance for the effects of parameters and the results were found to be good. The inferences were analyzed both in regression modeling and fuzzy logic modeling and it was found that the fuzzy logic gives more detailed inference system comparatively than regression modeling.*

***Keyword**: single objective, GFRP, delmaination, drill combination, speed, feed, Taguchi method, FIS.*

I. Introduction

GFRP is an emerging composite material widely used in almost all the vital components of the present and the mere future to come. GFRP is replacing conventional metallic materials which are being used in manufacturing of engineering application components. They are used in aerospace, ships, automobiles and sports. Composite materials have many positive properties such as light weight, high strength, high stiffness, corrosion and fatigue resistance. Composites are materials comprising of more than one constituent material resulting in superior quality than the conventional material. GFRP is an anisotropic and inhomogenous material which results in delamination, burrs, swelling ,ovality and fibre pullout and poor surface finish.

II. Literature Review

Eda Okutan et al. [1] conducted the study on the derivation of parametric cutting force equations in drilling of GFRP Composites using DIN 338 HSS drills. Machining of the GFRP samples was performed with different diameters of drills and different feed rates. To minimize vibration during machining, the drill dynamometer was fixed to the table of the machine It was determined that when the drill diameter and feed rate are increased while machining GFRP, the thrust force and drill torque increase. B.Ramesh et al. [2] studied Experimental investigation and optimization in Drilling GFRP polymeric composites using Taguchi and ANOVA to determine the surface roughness and delamination factor. The drill tool used was coated cemented carbide drill. The experimental result shown that The optimal process parameter levels for drilling non-laminated GFRP composites to produce lower order damage factor at entrance are 0.15 mm/rev feed and 1250 rpm speed and that to produce lower order damage factor at exit are 0.05 mm/rev feed and 1000 rpm speed. K. Giasin et al. [3] has conducted drilling test on GLARE fiber metal laminates using TiAlN coated carbide twist drills and observed that increase in feed rate increases the cutting force, increase in spindle speed reduces the cutting forces. Fiber orientation in GLARE had no influence on the cutting forces. Shiba narayan sahu et al. [4] conducted drilling experiment on GFRP using 8 facets solid carbide drill bit. The work focused effects of cutting parameters on Thrust force and torque. The inferences shows feed is proportional to thrust force and torque. Speed is inversely proportionally to the thrust force. The cutting parameters has been optimized using CNSGA – II algorithm. Hari Vasudevan et al. [5] conducted experimentally investigated on multi objective optimization of drilling characteristics for NEMA G-11 GFRP/ EPOXY composite. In this work the desirability optimization is used to find optimal cutting parameters. The experiment is designed using Taguchi's design. The experiment is carried out using WC drill bit. It was concluded that Delamination increases with drill diameter. If feed rate is increased hrust force is increased. Vikas Sonkar et al. [6] investigated on drilling of GFRP composites using TiAlN coated solid carbide drill bits. The process parameters considered in this work are Spindle speed, Feed rate, Plate thickness, Drill diameter. Optimal parametric combination obtained from TOPSIS and Deng's similarity method have been found similar to each other.Sunil Hansda et al. [7] experimentally analyzed the effects of Material thickness, drill diameter, spindle speed, feed rate in drilling of GFRP using HSS twist drill for responses Delamination and surface roughness. The prediction shows Spindle speed is insignificant and feed is highly significant and effective than drill diameter and material thickness. Pandu R. Vundavilli et al. [8] carried out drilling investigation on GFRP using Polycrystalline Diamond, with application of Differential evolution and particle swarm optimization, Artificial bee colony algorithms and found optimal values of cutting parameters.

Vinod kumar vankanti et al. [9] considered chisel edge width and point angle also as process parameters in addition to speed, feed and the objectives selected were Torque, thrust force, surface roughness, circularity. It was concluded that For thrust force speed of 500rpm, feed 0.04mm/rev, point angle at 90 deg. And chisel edge with of 0.8mm was optimum. Feed rate and speed are most significant influencing surface finish. Panda et al. [10] conducted drilling experiment on Bone using HSS drill bit for responses temperature, surface roughness and force with application of methodologies ANOVA and Fuzzy logic. It has been predicted that Optimum level was feed 40mm/min, speed 500 rpm . Feed rate has strongest influence on the multiple response characteristics. MAJ.Bosco et al. [11] has experimentally investigated on drilling of GFRP armour steel sandwich plates using solid carbide drill and it has been concluded that Increase of drill diameter increases delamination. Increase of spindle speed reduces delamination.Tom Sunny et al. [12] carried out investigation on drilling of Unidirectional E glass fiber using HSS twist drill and it has been observed that all the tools have high delamination factor at very low feed rate. Drilling induced delamination increases with spindle speed (1000 rpm -2500 rpm) and decrease with feed rate (100mm/min to 400mm/min).

III. Issues And Challenges Involved In The Present Work

The various issues faced while drilling GFRP were unable to maintain a minimal Surface roughness of the drilled surface, ovality in the drilled hole , delamination of the GFRP material at the drilled surface.

IV. Scope And Objectives Of The Present Work

To reduce surface roughness, ovality and to eliminate delamination by selecting optimal cutting parameters like speed, feed and to find best combination of drill bits and to analyze the inferences using regression modeling and fuzzy system and to find the best one.

V. Methodology Of Present Work

The experimentation has been carried out from Taguchi Design of experiments L9 orthoghonal array (3 Levels and maximum 4 factors), since 2 factors and 3 levels were considered in the work. The experimental runs of (i) two pass using 6mm, 10mm HSS drill bit shown in table (ii) Two pass using 6mm, 10mm TiN coated HSS drill bits. (iii) Two pass using 6mm TiN coated HSS drill , 10mm HSS drill bits.

Taguchi's design of experiments helps in reduction of runs with effective design points of quantitative change in response accordance with process parameters. The Analysis of Variance is used to predict the extent of considerable effects of process parameters on responses. In drilling of GFRP surface roughness must be reduced not only for smoother mating but also it is necessary because it affects the delamination.

VI. Present Work

The drilling is carried out using HSS, TiN coated HSS drill bits shown in figure 2 as follows:

1 Two pass using 6mm, 10mm HSS drill bits.

2 Two pass using 6mm, 10mm TiN coated HSS drill bits.

3 Two pass using 6mm TiN coated HSS drill bit, 10mm HSS drill bit.

VII. Experimental Work Details

This analysis deals with the finding the optimal cutting conditions in drilling of GFRP composite material of size 150mm x 150mm and 10 mm thick using 6mm,10mm HSS and 6mm,10mm TiN coated HSS drill bits in Vertical machining centre MCV 400S (Make : AMS Machine) shown in figure1, with a hole making of diameter 10 mm on Glass fibre Reinforced plastic (E-glass with isophthalic resin) using variant of drill bit combination in multipass drilling and three different category of experiment. The objective functions are Surface roughness, Ovality, Delamination and Machining time. The surface roughness is measured using surface tester Make : Mitutoyo Model : SJ 201. The delamination is measured using Large tool maker's microscope, Ovality is measured using Bridge CMM Make: Spectra Model : 264. for three different values of spindle speed, feed.The details of Levels and Factors are shown in Table 1.

Table 1. Levels and factors

Level/factors	Speed	Feed
1	790	0.1
2	1200	0.2
3	1600	0.3

Figure 1 Vertical machining centre MCV 400S

VIII. Data Analysis

The analysis of data collection is much important to be carried out, which reveal the significance of parameters considered in experimentation. This prediction of significance of parameters is necessary in forwarding the work towards the synthesis for inference collection. The data collection of table 2,3,4, are analyzed with test of hypothesis (ANOVA) and are shown in table 5,6,7.

Table 2 L9 Orthogonal Array for two pass 6mm, 10mm HSS Drill bits & experimental results

Sl No	Speed rpm	feed mm/rev	Machining time seconds.	Ovality (microns)	Delamination	Surface roughness microns
1	790	0.1	41	10.4	1.089	1.96
2	790	0.2	29	10.2	1.101	2.9
3	1600	0.1	25	10.5	1.011	4.3
4	1600	0.3	19	28.4	1.019	5.78
5	1200	0.1	33	10.7	1.038	3.87
6	1200	0.2	23	19.8	1.004	3.42
7	1600	0.2	21	13.6	1.009	3.71
8	790	0.3	21	18.2	1.086	5.28
9	1200	0.3	19	23.8	1.023	5.68

Table 3 L9 Orthogonal Array for two pass 6mm, 10mm TiN Coated HSS drill bits & experimental results

Sl No	Speed rpm	Feed Mm/rev	Machining time seconds.	Ovality microns	Delamination	Surface roughness microns
1	790	0.1	39	10.1	1.084	1.92
2	790	0.2	29	9.5	1.097	2.87
3	1600	0.1	25	10.3	1.008	4.28
4	1600	0.3	19	28.2	1.015	5.74
5	1200	0.1	33	10.2	1.035	3.85
6	1200	0.2	23	19.2	0.999	3.37
7	1600	0.2	21	13.1	1.006	3.68
8	790	0.3	21	17.8	1.084	5.27
9	1200	0.3	19	22.8	1.02	5.65

Table 4 L9 Orthogonal Array for two pass 6mm TiN coated HSS & 10mm HSS drill bits & experimental results

Sl No	Speed rpm	feed mm/rev	Machining time seconds.	Ovality microns	Delamination	Surface roughness microns
1	790	0.1	39	10.6	1.964	1.93
2	790	0.2	29	10.7	2.904	2.87
3	1600	0.1	25	10.6	4.305	4.27
4	1600	0.3	19	30.5	5.776	5.74
5	1200	0.1	33	10.5	3.875	3.85
6	1200	0.2	23	20.8	3.423	3.38
7	1600	0.2	21	14.1	3.715	3.68
8	790	0.3	21	20.1	5.286	5.26
9	1200	0.3	19	24.8	5.685	5.65

TABLE 5 ANOVA results for two pass 6mm, 10mm HSS Drill Bits

	MACHINING TIME	OVALITY	DELAMINATION	SURFACE ROUGHNESS
MODEL	2 F I	LINEAR	LINEAR	2 F I
S S	428.4816094	282.5127	0.0094379	10.363225
D O F	3	2	2	3
M S	142.8272031	141.2563	0.004719	3.4544085
F VALUE	61.99963539	10.57006	10.941989	5.6169707
PROB>F	0.0002	0.0108	0.0100	0.0466
RESULT	Significant	significant	Significant	significant
R-SQUARED	0.97382184	0.778925	0.7848227	0.7711766
S/N RATIO	21.778	8.303	6.888	6.554

From Table 5 it is obvious that the Machining time, Ovality, Delamination and Surface roughness is significant with cutting parameters Speed and Feed rate for two pass HSS drill at 95% confidence level with F –value. R – squared value for all the above responses are greater than 0.8 this shows that the fitness function holds good.

TABLE 6 ANOVA results for two pass TiN coated HSS 6mm and 10 mm drill bits.

	MACHINING TIME	OVALITY	DELAMINATION	SURFACE ROUGHNESS
MODEL	2 F I	LINEAR	2 F I	QUADRATIC
S S	372.693	277.11225	0.009366	13.0087888
D O F	3	2	3	5
M S	124.231	138.55613	0.003122	2.60175776
F VALUE	65.18418	10.116461	5.735454	17.0575291
PROB>F	0.0002	0.0120	0.0449	0.0206
RESULT	Significant	significant	significant	significant
R-SQUARED	0.975069	0.7712798	0.774839	0.96602016
S/N RATIO	22.488	8.184	5.287	11.331

From Table 6 it reveals that the Machining time, Ovality, Delamination and Surface roughness is significant with cutting parameters Speed and Feed rate for two pass TiN drill at 95% confidence level with F –value. R – squared value for all the above responses are greater than 0.8 this shows that the fitness function holds good.

TABLE 7 ANOVA results for two pass 6mm TiN coated HSS & 10 mm HSS drill bits

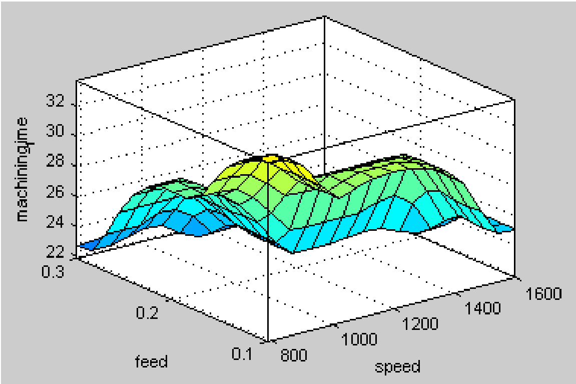
	MACHINING TIME	OVALITY	DELAMINATION	SURFACE ROUGHNESS
MODEL	2 F I	LINEAR	QUADRATIC	QUADRATIC
S S	372.693	350.316	13.1342417	13.1492545
D O F	3	2	5	5
M S	124.231	175.158	2.62684834	2.6298509
F VALUE	65.18418	11.79728	27.9546208	27.3614575
PROB>F	0.0002	0.0083	0.0101	0.0105
RESULT	significant	significant	significant	significant
R-SQUARED	0.975069	0.79726	0.97898764	0.97854189
S/N RATIO	22.488	8.625	14.405	14.239

From Table 7 it is obvious that the Machining time, Ovality, Delamination and Surface roughness is significant with cutting parameters Speed and Feed rate for two pass 6mm TiN drill & 10 mm HSS drill at 95%

confidence level with F –value. R – squared value for all the above responses are greater than 0.8 this shows that the fitness function holds good.

IX. Comparison Of FIS And Regression Modelling

Two pass HSS (6mm, 10mm)machining time



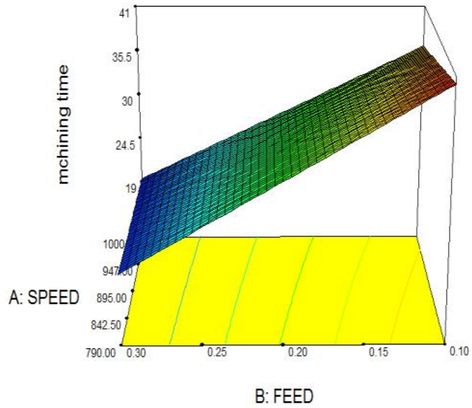
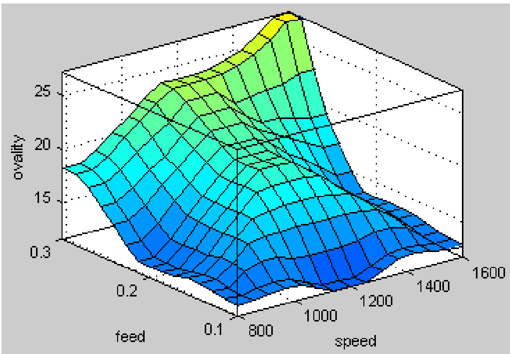


Figure 2. Machining time from Fuzzy inference system (FIS) model

Figure 3. Machining time from regression model

From Figure 2,3 it is clear that the machining time decreases with increase in feed and slightly decreases with increase in spindle speed.

Two pass HSS (6mm,10mm) Ovality



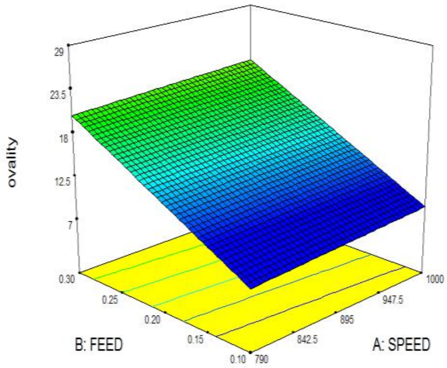
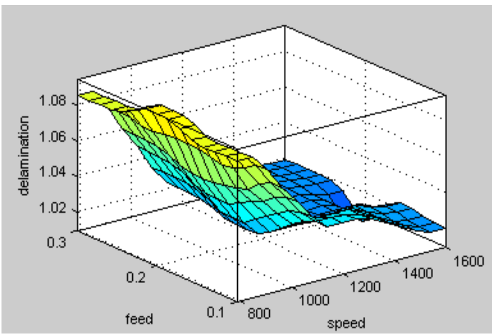


Figure 4. Ovality from Fuzzy inference system (FIS) model

Figure 5. Ovality from regression modeling

From Figure 4,5 it is observed that the ovality decreases with decrease in feed and it has negligible effect of speed on it.

Two pass HSS (6mm, 10mm) Delamination



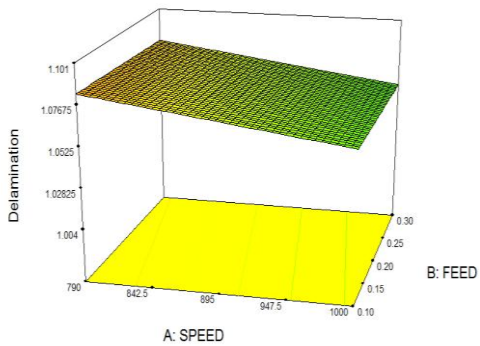


Figure 6. Delamination from FIS Figure 7. Delamination from regression modeling

From Figure 6,7 it reveals that the delamination decreases with increase in spindle speed and has negligible effect of feed on it.

Two pass HSS (6mm, 10mm)surface roughness

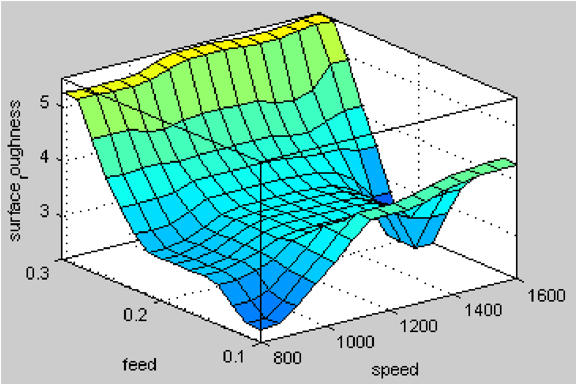


Figure 8. Surface roughness from FIS

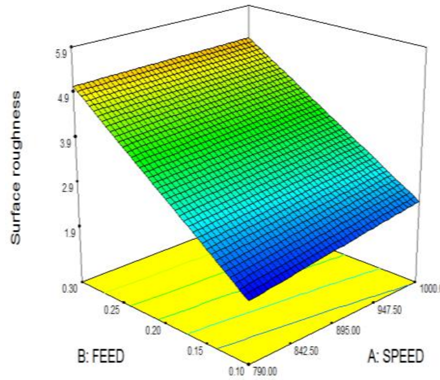


Figure 9 Surface roughness from regression modeling

From Figure 8,9 it shows that the surface roughness decreases with decrease in feed and it has negligible effect of speed

Two pass TiN (6mm, 10mm)Machining time

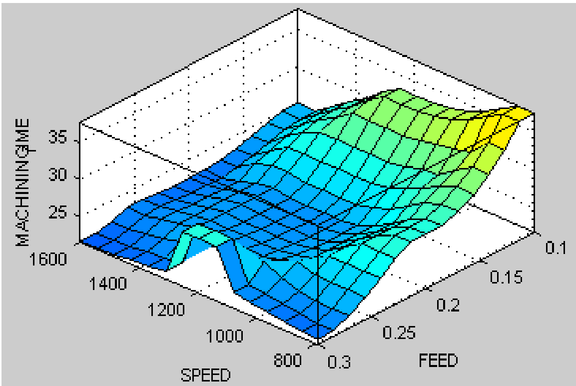


Fig 10 machining time from FIS

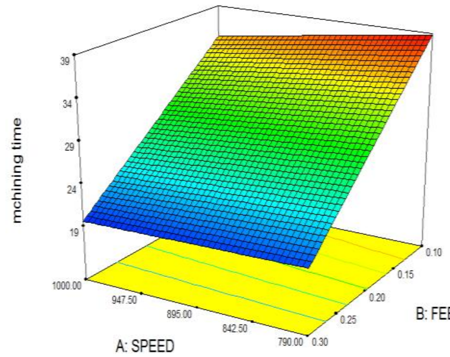


Figure 11. Machining time from regression modeling

From Figure 10,11 it is clear that the machining time decreases with increase in feed and slightly decreases with speed.

Two pass TiN (6mm, 10mm) Ovality

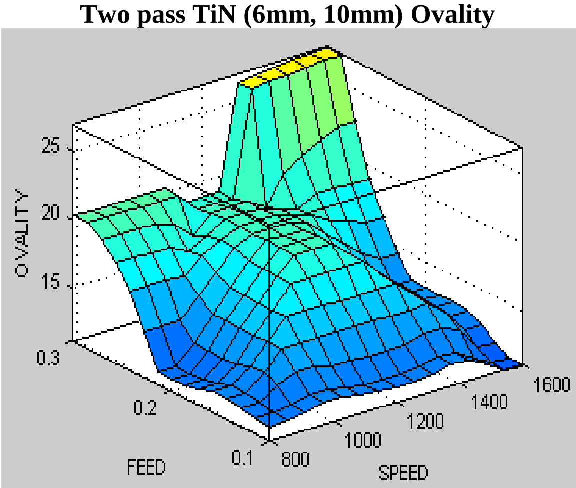


Figure 12 Ovality from FIS

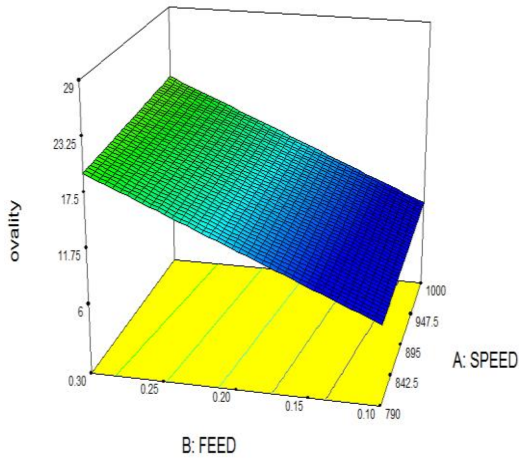


Figure 13. Ovality from regression modeling

From Figure 12,13 it is shows that the ovality decreases with decrease in feed and decrease in speed.

Two pass TiN (6mm, 10mm) Delamination

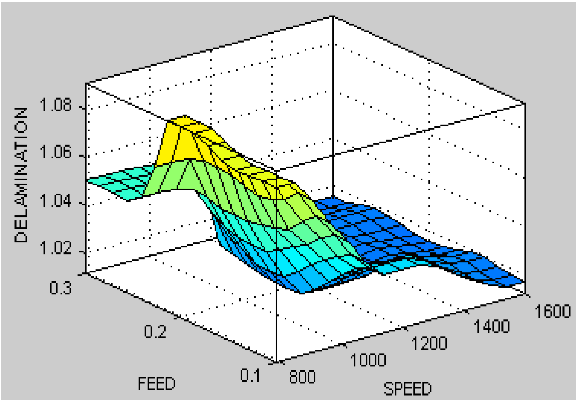


Figure 14. Delamination from FIS

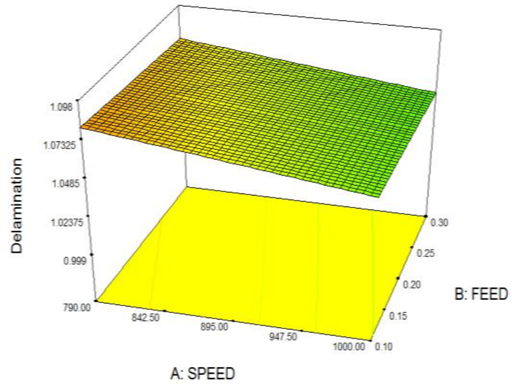


Figure 15 Delamination from regression modeling

From Figure 14,15 it is obvious that the delamination decreases with increase in spindle speed and has negligible effect of feed on it.

Two pass TiN (6mm,10mm)Surface Rougness

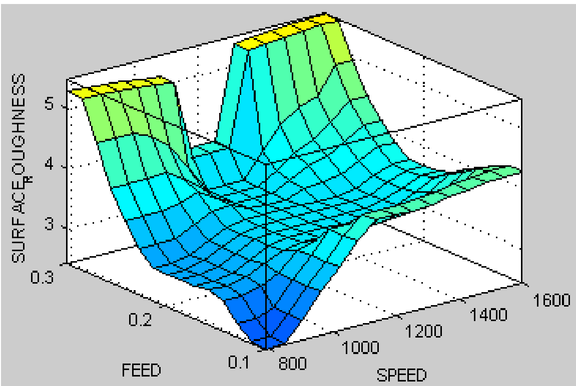


Figure 16. Surface roughness from FIS

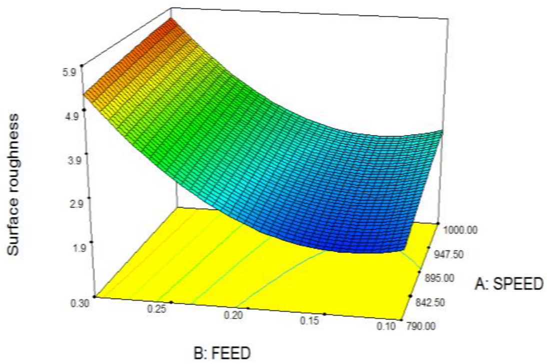


Figure 17. surface roughness from regression modeling

From Figure 16,17 it is obvious that the surface roughness decreases with increase in spindle speed and has negligible effect of feed on it.

Two pass Tin and HSS (6mm,10mm) machining time

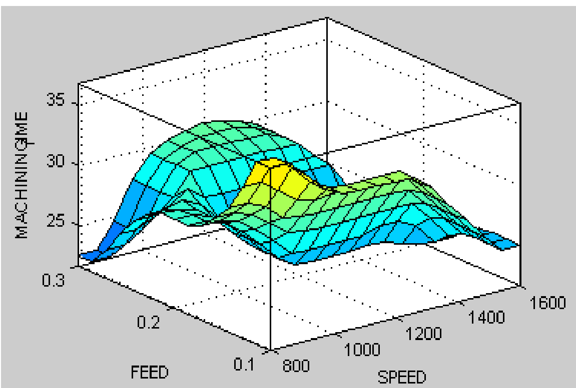


Figure 18 Machining time from FIS

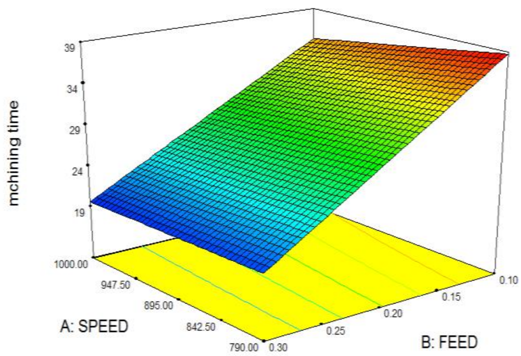


Figure 19. Machining time from regression modelling

From Figure 18,19 it is clear that the machining time decreases with increase in feed and slightly decreases with speed.

Two pass Tin and HSS (6mm, 10mm) ovality

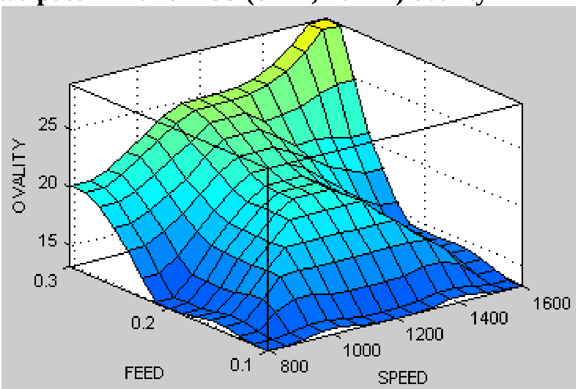


Figure 20. Ovality from FIS

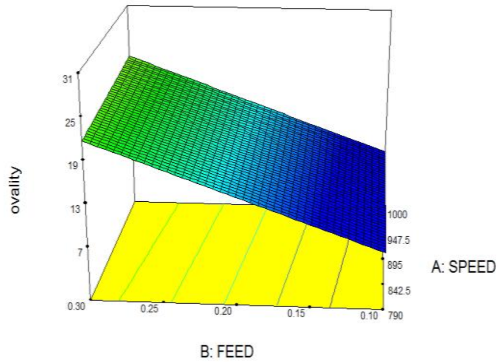


Figure 21. ovality from regression modeling.

From Figure 20,21 it is obvious that the ovality decreases with decrease in feed and slightly decreases with decrease in speed. Ovality is maximum at the highest feed rate.

Two pass TiN and HSS (6mm, 10mm) Delamination

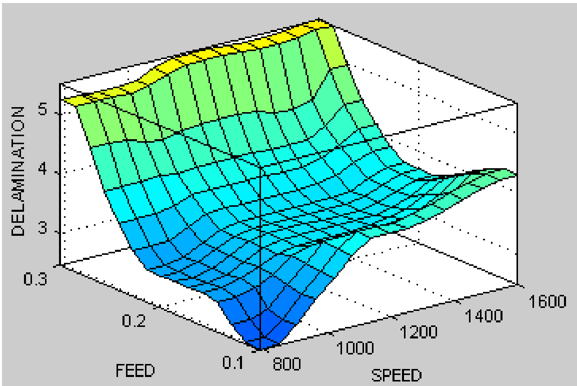


Figure 22. Delamination from FIS

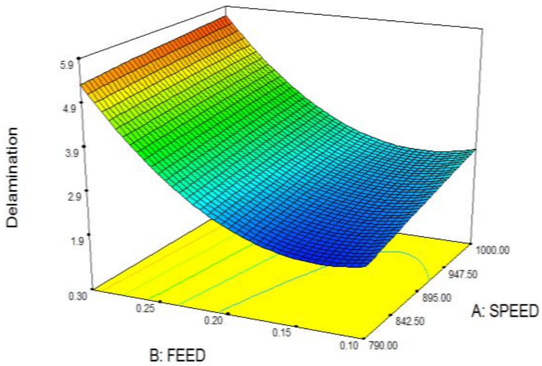


Figure 23. Delamination from regression modeling

From Figure 22,23 it is clear that the delamination gradually decreases with increase in spindle speed and has negligible effect of feed on it.

Two Pass TiN and HSS (6mm, 10mm) Surface roughness

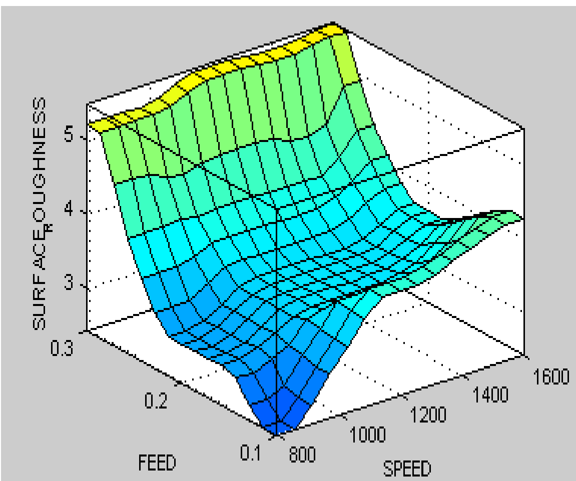


Figure 24. Surface roughness from FIS

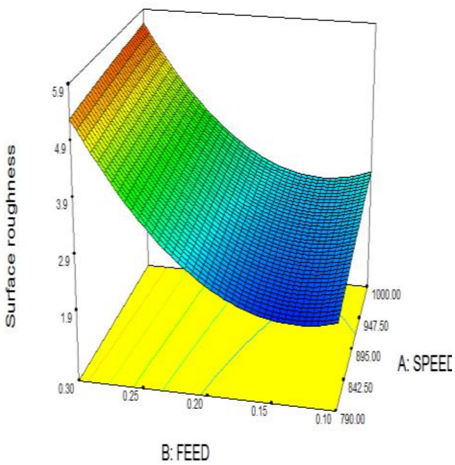


Figure 25. Surface roughness from regression modeling

From Figure 24,25 it shows that the surface roughness gradually decreases with decrease in feed and it has negligible effect of speed.

X. Fuzzy Inference System Rules

Two pass HSS (6mm,10mm) FIS rules

Speed	feed	Machining time	Ovality	Delamination	Surface roughness
790	0.1	MF 7	MF 2	MF 8	MF 1
790	0.2	MF 5	MF 1	MF 9	MF 2
1600	0.1	MF 4	MF 3	MF 3	MF 6
1600	0.3	MF 1	MF 9	MF 4	MF 9
1200	0.1	MF 6	MF 4	MF 6	MF 5
1200	0.2	MF 3	MF 7	MF 1	MF 3
1600	0.3	MF 2	MF 5	MF 2	MF 4
790	0.3	MF 2	MF 6	MF 7	MF 7
1200	0.3	MF 1	MF 8	MF 5	MF 8

Table 8.

The value of membership function for table 8 is as follows
Membership function for machining time in seconds MF 1 =19 , MF 2 =21 , MF 3 =23, MF 4=25,MF 5 =29, MF 6 =33, MF 7=41.
Membership function for ovality in microns
MF 1 =10.2 , MF 2 =10.4 , MF 3 =10.5, MF 4 = 10.7,MF 5 = 13.6, MF 6 = 18.2, MF 7 = 19.8, MF 8 = 23.8 , MF 9=28.4 .
Membership function for delamination MF 1 = 1.004 , MF 2 = 1.009 , MF 3 = 1.011, MF 4 = 1.019,MF 5 = 1.023, MF 6 = 1.038, MF 7 = 1.086, MF 8 = 1.089 , MF 9=1.101 .
Membership function for surface roughness value in microns MF 1 =1.96 , MF 2 =2.9 , MF 3 =3.42, MF 4 = 3.71,MF 5 = 3.87, MF 6 = 4.3, MF 7 = 5.28, MF 8 = 5.68 , MF 9=5.78

Two pass TiN (6mm,10mm) FIS Rules

Speed	feed	Machining time	Ovality	Delamination	Surface roughness
790	0.1	MF 7	MF 2	MF 7	MF 1
790	0.2	MF 5	MF 1	MF 9	MF 2
1600	0.1	MF 4	MF 4	MF 3	MF 6
1600	0.3	MF 1	MF 9	MF 4	MF 9
1200	0.1	MF 6	MF 3	MF 6	MF 5
1200	0.2	MF 3	MF 7	MF 1	MF 3
1600	0.2	MF 2	MF 5	MF 2	MF 4
790	0.3	MF 2	MF 6	MF 8	MF 7
1200	0.3	MF 1	MF 8	MF 5	MF 8

Table 9
The value of membership function for table 9 is as follows
Membership function for machining time in seconds MF 1 =19 , MF 2 =21 , MF 3 =23, MF 4=25,MF 5 =29, MF 6 =33, MF 7=39.
Membership function for ovality in microns
MF 1 =9.5 , MF 2 =10.1 , MF 3 =10.2, MF 4 = 10.3,MF 5 = 13.1, MF 6 = 17.8, MF 7 = 19.2, MF 8 = 22.8 , MF 9=28.2.
Membership function for delamination MF 1 = 0.009 , MF 2 = 1.007 , MF 3 = 1.009, MF 4 = 1.016,MF 5 = 1.019, MF 6 = 1.036, MF 7 = 1.084, MF 8 = 1.085 , MF 9=1.097 .
Membership function for surface roughness value in microns MF 1 =1.924 , MF 2 =2.873 , MF 3 =3.378, MF 4 = 3.684,MF 5 = 4.102, MF 6 = 4.284, MF 7 = 5.276, MF 8 = 5.652 , MF 9=5.745.

Two pass TiN and HSS (6mm,10mm) FIS Rules

Speed	feed	Machining time	Ovality	Delamination	Surface roughness
790	0.1	MF 7	MF 2	MF 1	MF 1
790	0.2	MF 5	MF 3	MF 2	MF 2
1600	0.1	MF 4	MF 2	MF 6	MF 6
1600	0.3	MF 1	MF 8	MF 9	MF 9
1200	0.1	MF 6	MF 1	MF 5	MF 5
1200	0.2	MF 3	MF 6	MF 3	MF 3
1600	0.2	MF 2	MF 4	MF 4	MF 4
790	0.3	MF 2	MF 5	MF 7	MF 7
1200	0.3	MF 1	MF 7	MF 8	MF 8

Table 10

The value of membership function for table 10 is as follows
Membership function for machining time in seconds MF 1 =19 , MF 2 =21 , MF 3 =23, MF 4=25,MF 5 =29, MF 6 =33, MF 7=39.
Membership function for ovality in microns
MF 1 =10.5 , MF 2 =10.6 , MF 3 =10.7, MF 4 = 14.1,MF 5 = 20.1, MF 6 = 20.8, MF 7 = 24.8, MF 8 = 30.5.
Membership function for delamination MF 1 = 1.965 , MF 2 = 2.905 , MF 3 = 3.342, MF 4 = 3.715,MF 5 = 3.875, MF 6 = 4.305, MF 7 = 5.286, MF 8 = 5.685 , MF 9=5.776 .
Membership function for surface roughness value in microns MF 1 =1.93 , MF 2 =2.87 , MF 3 =3.38, MF 4 = 3.68,MF 5 = 3.85, MF 6 = 4.27, MF 7 = 5.26, MF 8 = 5.65 , MF 9=5.74.

XI. Results And Discussion

In this work from all cases, multi pass drilling carried using HSS, TiN drill bits

1. The Machining time decreases with increase in speed and increase in feed. Minimum machining time can be obtained by increasing speed and feed.
2. The ovality decreases with decrease in feed and decrease in speed. Minimum ovality can be obtained by reducing the feed and speed.
3. The Delamination decreases with increase in speed and decrease in feed. In case of multi pass 6 mm TiN, 10 mm HSS the delamination decreases gradually with increase in speed and decrease in feed. However minimum delamination can be achieved by increased spindle speed and decreased feed.
4. Most probably the surface roughness decreases with decrease in feed and the effect of speed is negligible on it.

XII. Conclusion

From all figures however the inferences obtained from FIS and Regression model are seems to be similar, the detail of perception from FIS provides higher vicinity of variation in the response with respect to change in process parameters. ie., the the graphical inference from the regression model simply represents the inferences in sharp and crisp form of straight line, whereas from the FIS it is more detailed for each and every point of variation of process parameter and the response (the graphical representation is in curve form) such a way the perception of prediction is so fine.

So the Fuzzy modeling and Fuzzy Inference system works better for analyzing inference from graphical surface plots than Regression modeling inference system

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