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Simulation of Hybrid Tabu Search Algorithm for Surface Roughness Prediction in Dry Milling Operations

D.Ramalingam[1], Dr.M.Saravanan[2], R.Rinu Kaarthikeyen[3], T.Muthumari[4]

[1]Associate Professor, Nehru Institute of Technology, Coimbatore, (India)

[2]*Principal, SSM Institute of Engineering and Technology, Dindigul, (India)*

[3]*Research Associate, Manager – Engineering, TCMPFL, Chennai,(India)*

[4]*Research Associate, Nehru Institute of Engg & Tech, Coimbatore, (India)*

ABSTRACT

Machining operations on the FRP composite materials always recognized as the major taxing tasks by the manufacturers. Dimensional accuracy along with the good surface finish of the product is the main concern towards the final product functional aspects. Fibre damage and the structural damage known as delamination is the major setback at time of machining by any metal cutting process. Machining speed and toll feed, depth of cut are the three key input variables which took vital role on the end quality of the materials being processed. In order to obtain the desired quality outcome in this investigation the optimisation of machining parameters and forecasting the best suited combination are effected through Tabu search algorithm in MATLAB programming. With the analysis through the regression relationship and linked to the optimisation algorithm to perform the optimised parameter combinations were identified for the minimum delamination on the work material ATLAC 382 -05 (FRP) in dry milling process.

Key words-ATLAC 382-05composite, Milling, Regression, Tabu Search Algorithm, Minitab, MATLAB.

I. INTRODUCTION

In the midst of machining operations, milling process has its own substantial degree of application in assembling parts to make into the final product for purpose. With the high strength and rigidity attached with low weight, excellent fatigue strength and in various aspects, the usage of FRP composite materials are more significant in the fields aerospace, aircraft, transportation, marine bodies etc, thereby they replace the conventional engineering materials. The modification to the dimensional accuracy and quality aspects of these composites into final products is connected with machining by conventional as well as non conventional methods of machining. During machining operations the common quality problems like delamination, obtaining the dimensional accuracy and precision, required surface finish is still exist. All such issues are directly linked with the materials properties and process parameters like machining speed; tool feed rate, tool material and properties, tool geometry etc. In this investigation the FRP composite namely ATLAC 382-05 is taken for analysis while undergoing milling operations. Machining speed, feed, delamination factor, are the parameters considered in this investigation to forecast the suitable combination of machining parameters through Tabu search Algorithm application in MATLAB programming..

II. RELATED LITERATURE

Over a period of time many researches are performed serious attempts through several methods and technology to locate the issues related and suggesting various approaches to achieve the most desired results in various machining processes on various materials like metals, alloys, composites. Meanwhile productivity and quality are the two distinct aspects which is necessary for any manufacturing industry. To achieve these, the process parameters as well as the machining environment should be suitably synchronized as they are contradictory in nature. It is an accepted fact that maximizing productivity is directly associated to the machining cost. By fact, productivity can be interpreted in terms of MRR and quality can be interpreted in terms of product characteristics, i.e. dimensional accuracy, surface smoothness and form stability, etc. Moreover in order to understand the effects of machining parameters in the various machining many of the researchers used optimization techniques. Optimisations as well as process modeling are two parallel important criteria in manufacturing in which such manufacturing processes are entangled through a variety of vigorously interacting process variables. Delamination is one among such important factors of machining outcome to predict the concert of any machining operation. The literature includes only soft computing applications and meta-heuristic methods in the analysis of machining parameters for composite materials. Xinwang et al. [1] have investigated the thrust force and torque influence while drilling over GFRP, CFRP materials using HSS drills and carbide drills. They noticed that with the increase in the depth of the hole, the thrust force increased. In addition to that, the observation lead to identify the increase in the thrust force along the feed rate increases. C.C.Tsao [2] has studied the usage of Grey - Taguchi method towards optimizing the machining parameters while conducting milling operations in aluminium alloy. They conclusion was that the grey-Taguchi method is appropriate for solving the surface finish quality and tool flank wear issues in milling process of A6061P-T651 aluminum alloy. Wang et al. [4] have investigated on the surface quality prediction and cutting parameters optimization in high-speed milling of AlMn1Cu using regression and GA. Pathak et al. [5] have presented the preparation of an aluminium silicon carbide composite. They have also given a detailed discussion about the microstructure and its different mechanical properties. Neelima Devi et al. [6] also presented about the characterization of an aluminium silicon carbide composite. In their research, tensile strength experiments were conducted by varying mass fraction of SiC (5, 10, 15, and 20 %) with aluminium. Palanikumar and Karthikeyan [7] experimented and examined regarding the input parameters influence on the product outcome variables while machining of Al/SiC particulate composites, using tungsten carbide tool inserts (K10). Dabade et al. [8] through their experimental study investigated the surface integrity as a function of process parameters and tool geometry by analysing cutting forces, surface finish, and microstructures of the machined surfaces on Al/SiC/10p and Al/SiC/30p composites using cubic boron nitride (CBN) inserts. Hou et al. [9] incorporated Taguchi method, RSM and GA by integration and applied to set the optimal parameters for a nanoparticle milling process. The fitness function of GA was obtained by RSM and was applied to find the optimal parameters for a nanoparticle milling process. Subramanian et al. [10] applied Genetic Algorithm and Response Surface Method in order to establish an optimum end mill process parameters guiding to minimum cutting force during shoulder milling of aluminum 7075–T6 with different cutting condition and found good agreement of results. Julie et al [11] focused their attention in a study of the Taguchi design application to optimise surface quality in a CNC face milling operation. Adeel et al. [12] conducted an experimental study to optimise the cutting parameters when measuring work piece surface temperature and surface roughness by Taguchi techniques. The results showed that the workpiece surface temperature can be sensed and used effectively as an indicator to control the cutting performance and improves the optimisation process. They reported that it is possible to increase machine utilization and decrease production cost in an automated manufacturing environment. Emel Kuram et al [13] have utilized the Taguchi based grey relational analysis for multi-objective optimization in micro-milling process parameters.

In this paper an approach of feeding the regression equation relationship (developed in Minitab) as input instead of random approach based on the fitness of the equation, thereafter the analysis and prediction of optimized parametric combination is identified by Tabu Search Optimisation Algorithm through MATLAB programming.

III. EXPERIMENTAL PROCEDURE

Paulo Davim et al**.** [3] have experimented milling operation on the ATLAC 382-05 composite materials prepared through hand lay-up to the specification of 22 mm of thickness disc used as the specimen material to carry out the machining operations. The specific properties of the material are as follows in Table 3.1.

Table 3.1 Properties of ATLAC 382-05 composite

Property	Quantity	Uints
Flexural strength (DIN EN 63)	380	N/mm^2
Tensile modulus (DIN 53457)	25,275	N/mm^2
Tensile strength (DIN EN 61)	404	N/mm^2
Compressive strength (DIN 53454)	145	N/mm^2
Tensile elongation (DIN EN 61)	1.73	%
Impact resistance (DIN 53453)	190	kJ/m^2
Martens temperature (DIN 53458)	240	^0C
Thermal conductivity (DIN 52612)	0.22	W/m^0C

In the ‘‘VCE500 MIKRON’’ machining center which has the maximum spindle speed as 7500 rpm and 11 kW spindle power the experimental operations were carried out. The cutting tool selected for this a cemented carbide end mill with 5 mm diameter. The input cutting parameters selection with three levels quoted in the Table 3.2. Taguchi’s L9 array was fixed for the experimental follow up. The output parameters considered for evaluation of the performance of the operations on the specimen materials were delamination factor (Df).

Table 3.2 Cutting parameters level

Milling operation parameters	Level 1	Level 2	Level 3
Cutting speed, m/min.	47	79	110
Feed, mm/rev.	0.04	0.08	0.12

The experiment conducted and the data observed by Paulo Davim et al**.** [3] taken for this investigation are presented in the Table 3.3.

Table 3.3 Experimental observed data

S. No	**Ms, Machining speed, m/min**	**f, Feed, mm/rev**	**Df, Delamination factor**
1	47	0.04	1.050
2	47	0.08	1.062
3	47	0.12	1.081
4	79	0.04	1.062
5	79	0.08	1.074
6	79	0.12	1.093
7	110	0.04	1.072
8	110	0.08	1.086
9	110	0.12	1.113

The damage affected on the work material during machining was measured with the microscope Mitutoyo TM 500, with 30 x magnification and 1 µm resolution. Hommeltester T1000 version profilometer was used to measure the surface roughness and the Kistler type 9257B piezoelectric dynamometer was used to observe the components of machining forces.

IV. MATHEMATICAL MODELLING

While carrying out the statistical regression analysis in Minitab17 software to analyze the authority of the machining speed, feed over the delamination, second order regression relationship is of the higher values of the R – sq comparing to the first order regression. R-sq (adj) and R-sq (pred) values of second order also in line with the R-sq values. Hence more significant statistical second order equation is selected for further analysis. First and second order regression model is listed in Table 4.1.

Table 4.1 Regression model comparison for Delamination factor

Parameter	**Regression**	**S**	**R-sq**	**R-sq(adj)**	**R-sq(pred)**	**Durbin - Watson**
Df	1st order	0.0036684	97.18%	96.24%	92.71%	2.12627
	2nd order	0.0020493	99.56%	98.83%	94.82%	1.96034

Such framed second order regression equations through the Minitab17 for the output parameter in terms of input parameter combination are, $Df = (1.0443) + (0.000064 \times Ms) – (0.176 \times f) + (0.000001 \times Ms^2) + (2.812 \times f^2) + (0.001973 \times Ms \times f)$; where Ms stands for machining speed, f stands for feed and Df stands for Delamination.

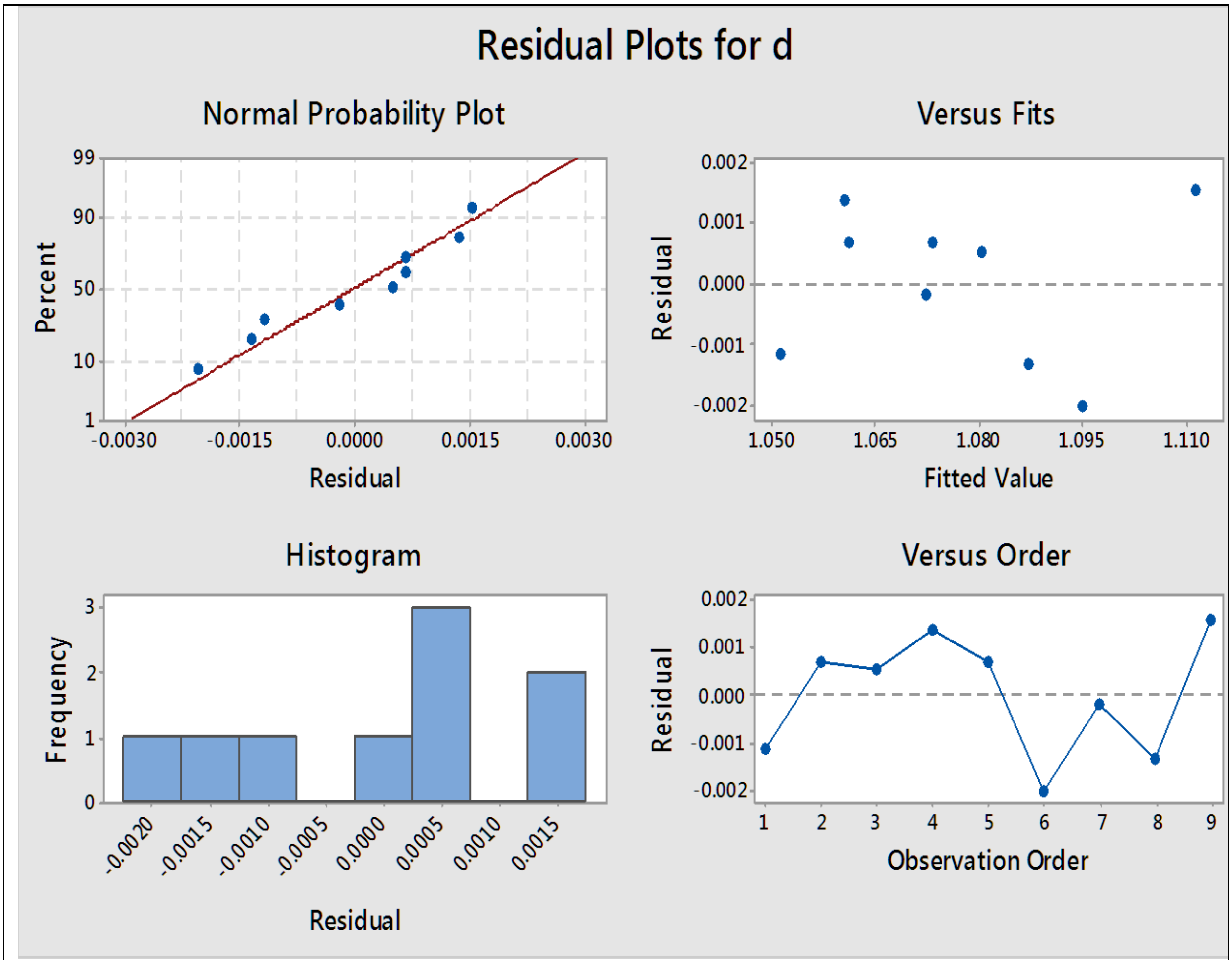


Figure 4.1 Residual plots of delamination factor

Figure 4.1 depicts the residual plots through Minitab analysis for the delamination factor. Through performing the best subset regression analysis the parameter feed is highly influencing on delamination followed by the speed.

Table 4.2 Input parameters influencing level on the output parameters

Output parameters	Influence level of Feed	Influence level of Speed
Delamination	61.8 %	35.4 %

The influencing level of feed and speed on the output parameter is listed through in Table 4.2. This shows that the perfect balancing of both the parameters in the optimum level is to be maintained at time of machining so as to obtain the objectives of the manufacturing.

V. OPTIMISATION METHOD

Tabu Search is a Global Optimization algorithm and a Metaheuristic or Meta-strategy for controlling an embedded heuristic technique. The objective for the Tabu Search algorithm is to constrain an embedded heuristic from returning to recently visited areas of the search space, referred to as cycling. The strategy of the approach is to maintain a short term memory of the specific changes of recent moves within the search space and preventing future moves from undoing those changes. Additional intermediate-term memory structures may be introduced to bias moves toward promising areas of the search space, as well as longer-term memory structures that promote a general diversity in the search across the search space. Algorithm provides a pseudocode listing of the Tabu Search algorithm for minimizing a cost function. Tabu Search Algorithm is applied in this analysis to predict the optimized Delamination factor at time of machining in the experimented ATLAC 382-05 composite material was programmed with the objective of analyzing the influence of the cutting speed and the feed of the tool in the MATLAB R2017 platform with the Elman Back Propagation approach. With 50000 turns of iterations the values of the output parameters with reference to the input parameters combinations are computed with the experimental observations individually. Figure 5.1 reveals the progress of the training data in MATLAB.

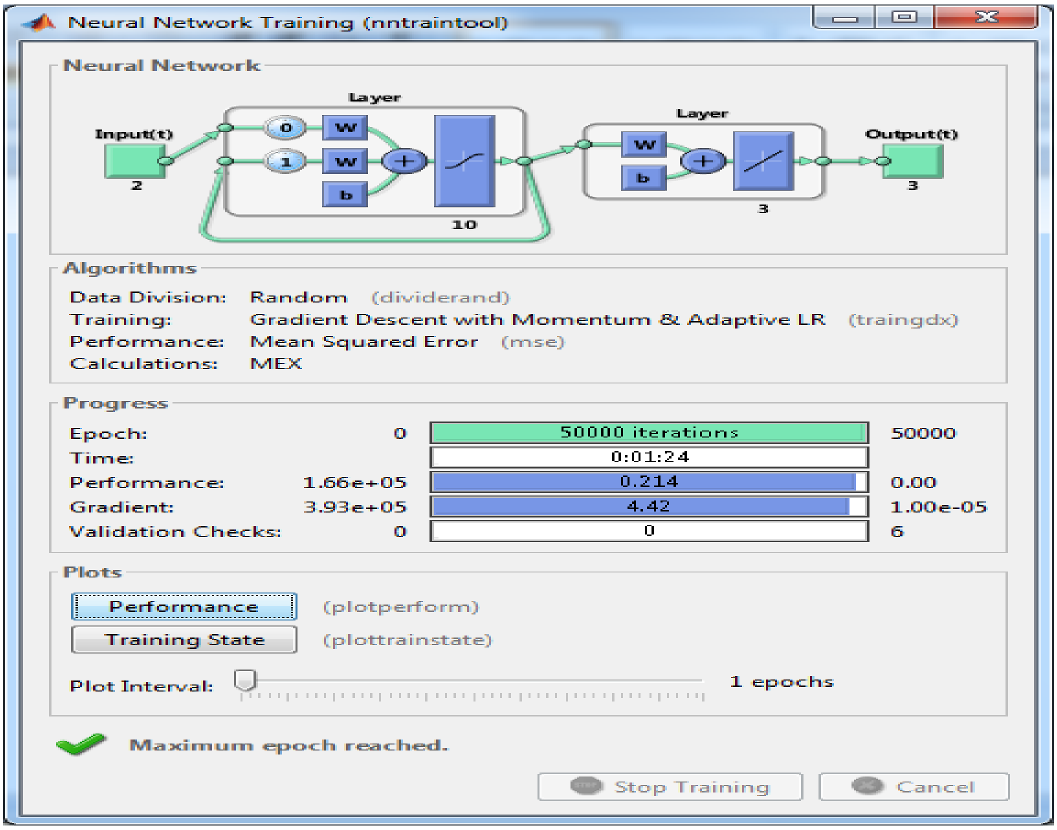


Figure 5.1 Data training progress of 50000 iterations

The accuracy level of the each algorithm is assessed with the Mean Squared Error (MSE) 0.026837 in computation. Tabu Search optimisation is programmed with the fitness condition for computation is modified with the regression relationship equations instead of taking random selection of combination while computing through the algorithm. Final results were checked for the accuracy in computations and noticed that the MSE as 0.00883which is further reduced and converges with the lowest deviation. Hence the Regression relationship based Tabu Search Algorithm results are taken as the optimisation method which suitable for this attempt shown in Figure 5.2.

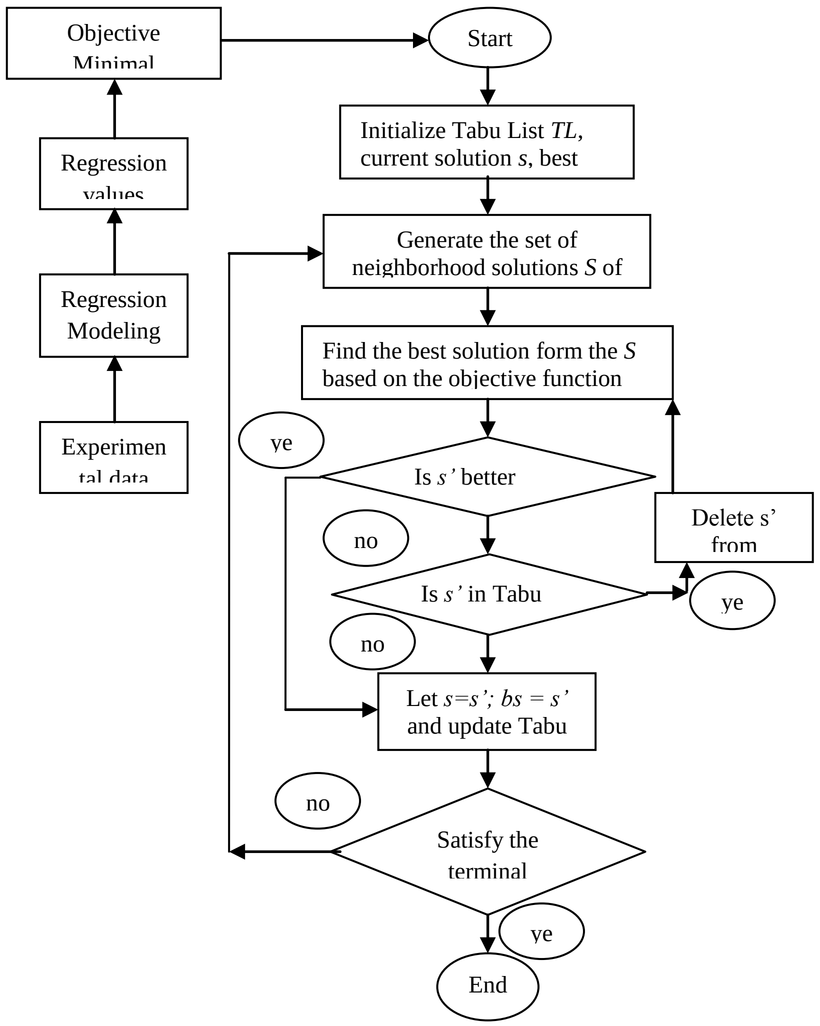


Figure 5.2 Regression feed Tabu search Flow

In view of obtaining the results for the in between values of the level chosen for the experiment, the condition with uniform step interval is fed into the algorithm computation. The step value taken for speed is 6.3 and feed is 0.008 (ten equal intervals for both the cases). The computed results through this approach are listed in the Table 5.1 to Table 5.2.

Table 5.1 Delamination Vs feed for speed 47, 53.3, 59.6, 65.9, 72.2 and 78.5 m /min

Ms	47	53.3	59.6	65.9	72.2	78.5
f	Df	Df	Df	Df	Df	Df
0.040	1.0459	1.0509	1.0504	1.0547	1.0531	1.0563
0.048	1.0479	1.0502	1.0515	1.0556	1.0583	1.0607
0.056	1.0518	1.0544	1.0545	1.0556	1.0579	1.0594
0.064	1.0522	1.0533	1.0555	1.0601	1.0613	1.0632
0.072	1.0541	1.0576	1.0616	1.0637	1.0629	1.0669

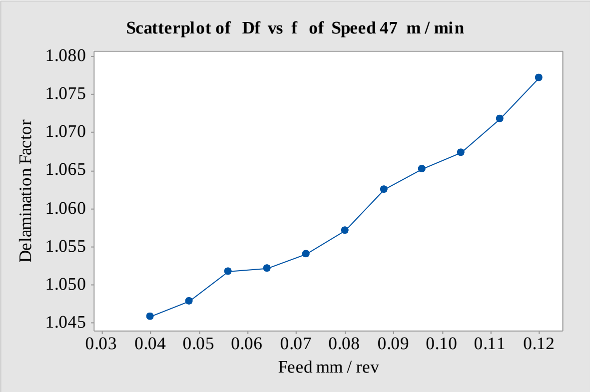
Table 5.1 Delamination Vs feed for speed 47, 53.3, 59.6, 65.9, 72.2 and 78.5 m /min (contd)

Ms	47	53.3	59.6	65.9	72.2	78.5
f	Df	Df	Df	Df	Df	Df
0.080	1.0571	1.0625	1.0639	1.0652	1.0658	1.0709
0.088	1.0625	1.0639	1.0671	1.0702	1.0687	1.0722
0.096	1.0653	1.0692	1.0671	1.0734	1.0728	1.0764
0.104	1.0675	1.0730	1.0738	1.0783	1.0790	1.0787
0.112	1.0718	1.0735	1.0790	1.0821	1.0850	1.0849
0.120	1.0772	1.0776	1.0825	1.0835	1.0899	1.0897

Table 5.2 Delamination Vs feed for speed 84.8, 91.1, 97.4, 103.7 and 110 m /min

Ms	84.8	91.1	97.4	103.7	110
f	Df	Df	Df	Df	Df
0.040	1.0566	1.0606	1.0611	1.0661	1.0653
0.048	1.0615	1.0620	1.0650	1.0660	1.0691
0.056	1.0618	1.0639	1.0655	1.0713	1.0703
0.064	1.0640	1.0701	1.0721	1.0738	1.0734
0.072	1.0687	1.0709	1.0736	1.0781	1.0791
0.080	1.0712	1.0766	1.0752	1.0773	1.0813
0.088	1.0745	1.0792	1.0831	1.0855	1.0844
0.096	1.0776	1.0815	1.0875	1.0857	1.0890
0.104	1.0846	1.0866	1.0904	1.0911	1.0945
0.112	1.0898	1.0935	1.0961	1.0965	1.0988
0.120	1.0945	1.0952	1.0983	1.1039	1.1043

Optimum value of delamination is 1.0459 which obtained for the speed 47 m / min and feed 0.040 mm /rev



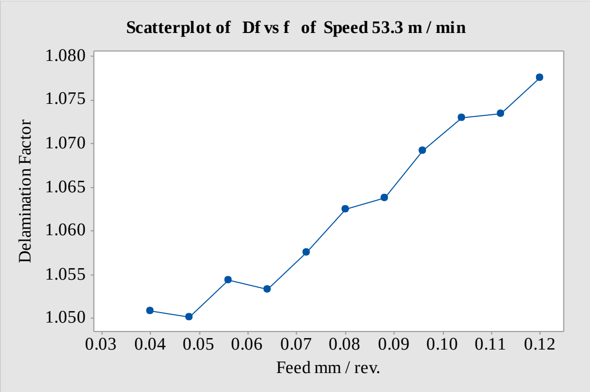


Figure 5.3 Delamination effect Vs feed for the speed 47, 53.6 m / min

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combination. Scatter plots for the framed intervals of feed Vs Delamination for the speed intervals are graphically presented in Figure 5.3 to Figure 5.6.

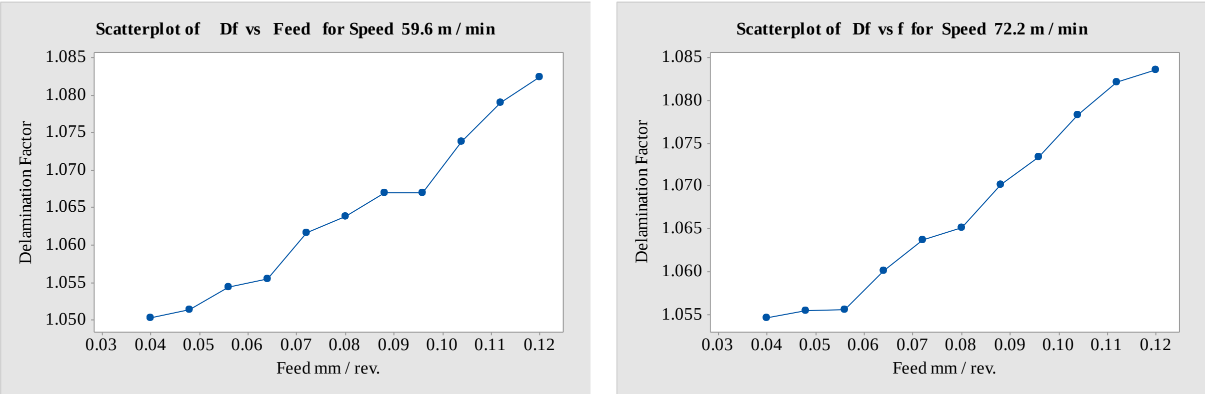

Figure 5.4 Delamination effect Vs feed for the speed 59.6, 72.2 m / min

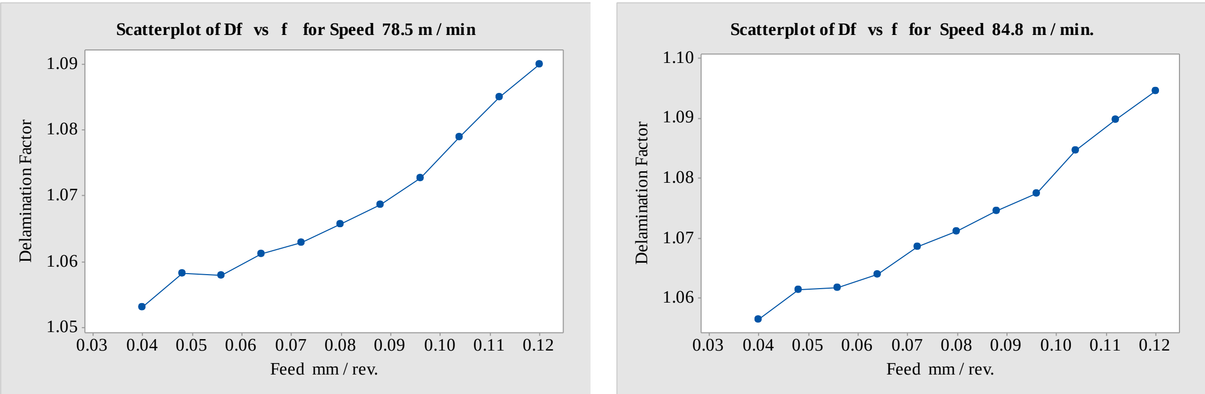

Figure 5.5 Delamination effect Vs feed for the speed 78.5, 84.8 m / min

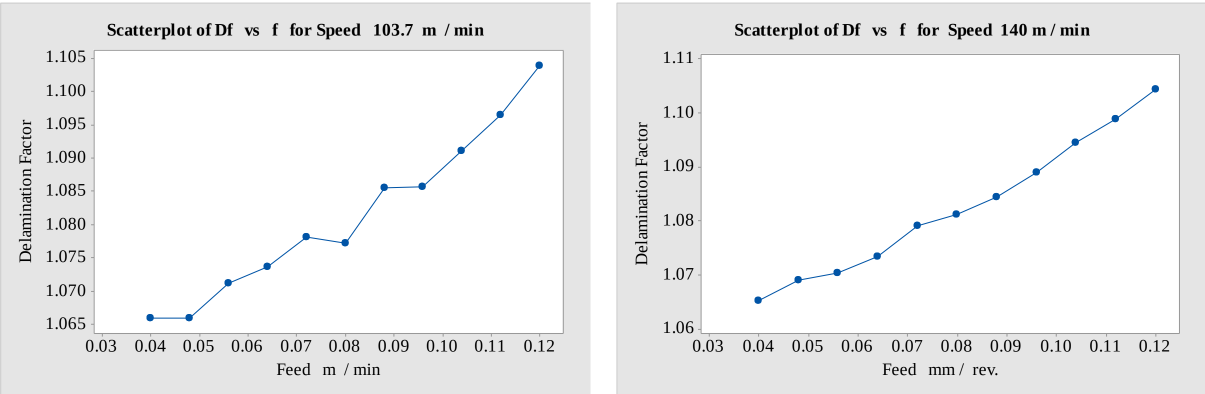

Figure 5.6 Delamination effect Vs feed for the speed 103.7, 110 m / min

VI. RESULTS AND CONCLUSION

- Second order regression mathematical modelling is taken for processing in simulating the algorithms.

- For optimizing the parameters Tabu Search Algorithm and Genetic algorithm were employed in MATLAB platform.
- Optimum value of delamination is 1.0459 which obtained for the speed 47 m / min and feed 0.040 mm /rev combination.
- Through performing the best subset regression analysis the parameter feed is highly influencing on delamination followed by the speed. Tool feed is the most influencing input cutting parameter than the speed.
- Tabu search algorithm with regression relationship equation as fitness function converges with the minimum MSE value of 0.00883. The proposed algorithm may be employed for optimising the machining parameters.
- The plotted graphs give guidelines to the processing Engineers to locate the combination of speed and feed rate based on the quality requirement on the end product.

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