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A COMPARISON BETWEEN DIFFERENT OPTIMIZATION TECHNIQUES FOR MILLING PROCESS TO OPTIMISED PARAMETRIC DETERMINATION ON ATLAC 382-05 COMPOSITES

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ABSTRACT

Milling operation in FRP composite materials is one of the challenging tasks in the manufacturing industries. At the same time, to achieve the concern dimensional accuracy in the product with the required surface quality is equally important rather than any such challenges. Delamination is the major concern in processing of FRP materials. 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 six designated algorithms. Cutting speed and tool feed are taken as input parameters and the surface finish, delamination, machining forces as output parameters while drilling ATLAC 382-05 composite. The analysis through the regression relationship as a link to the optimisation algorithms is performed. As a new move in the simulation through soft computing the outcome of the second best resulted algorithm is assigned as the input to the first best responded algorithm and the optimised parameter combinations were identified for each output parameter.

Key words- ATLAC 382-05composite, Milling, Regression, Simulated Annealing Algorithm, Genetic algorithm, Scatter search algorithm, Particle swarm optimisation algorithm, Ant colony optimisation algorithm, Tabu search Algorithm, Minitab, MATLAB.

I. INTRODUCTION

The application of FRP composite materials are attractive and more significant in the fields aerospace, aircraft, transportation, marine bodies etc because to their high strength and rigidity attached with low weight, excellent fatigue strength and in various aspects, thereby they replace the conventional engineering materials. The

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alteration of these composites into final products is connected with machining by conventional as well as non conventional methods of machining. Among these machining operations, milling has the considerable degree of application in assembling parts to make into the final product for application. At time of milling operations manufacturers used face the common quality problems like delamination, obtaining the dimensional accuracy and precision, required surface finish. All of these main issues are closely associated 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. Cutting Speed, feed, delamination factor, Surface roughness and Machining force are the parameters considered.

II. RELATED LITERATURE

For a considerable period of time many researches are performed sequentially by making 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. Moreover in order to understand the effects of machining parameters in the various machining many of the researchers used optimization techniques. Raviraj Shetty et al. [1] conducted an exclusive study with the Taguchi optimization method to optimize the machining parameters in the turning operation on the age hardened AlSiC - MMC with CBN cutting tool. Feng [2] has established with the findings of the research that the feed rate, the tool nose radius, the work material and speeds and the tool point angle have a significant impact on the surface quality by applying the fractional factorial experimentation method. Paulo Davim et al.[3] conducted experiment in milling operations on two FRP materials ATLAC 382-05, Viapal VUP 9731 and analysed the influence of cutting speed and feed on the outcome variables like delamination, surface roughness and cutting force through Anova technique.

David et al. [4] have demonstrated through an approach for predicting Surface roughness in a high speed end-milling process by ANN approach and statistical tools to predict the different surface roughness predictor's combinations. Kirby, D.E, and Joseph, C.C. [5] have recognized the occurrence of the quality issues in the resultant parameters in cutting operations carried out on turning and milling machines which includes the machine tool condition, job clamping, tool and workpiece geometry, and cutting parameters used for machining. They developed a Fuzzy based prediction approach to optimize the surface roughness. Palanikumar K [6] stated that the average surface roughness / surface finish are recognized as significant aspect in the processing of composites and the average surface roughness (Ra) is commonly used in industry.

Xinwang et al. [7] have investigated the thrust force and torque influence while drilling over GFRP, CFRP materials using HSS drills and carbide drills. During the investigation 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. This is the consequence of the increment in the MRR as the feed rate increases. C.C.Tsao [8] has proposed 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

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process of A6061P-T651 aluminum alloy. Emad Ellbeltagi et al. [9] offered a dissertation on assessment among five evolutionary–based optimization algorithms namely GA, MA, PSO, ACO, and SFL. A couple of yardstick continuous optimization test issues were resolved through using all and through the study, they have concluded that, the PSO method was generally found to perform better than other algorithms in terms of success rate and solution quality.

In this paper the analysis and prediction of optimized parametric combination is identified with six designated optimization algorithm methods through MATLAB programming. A novel approach of feeding the regression equation relationship as input instead of random approach based on the fitness of the equation developed in Minitab.

III. EXPERIMENTAL PROCEDURE

ATLAC 382-05 is the 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	Value
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 ^{0}C
Thermal conductivity (DIN 52612)	0.22 W/m^{0}C

Operations were carried out in the ‘‘VCE500 MIKRON’’ machining center which has the maximum spindle speed as 7500 rpm and 11 kW spindle power. The cutting tool selected for this a cemented carbide end mill with 5 mm diameter. The depth of cut chosen to 2 mm. The input cutting parameters selection with three levels quoted in the Table 3.2.

Table 3.2 Cutting parameters level

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

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), surface roughness (Ra) and machining force on the workpiece (Fm). 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

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9257B piezoelectric dynamometer was used to observe the components of machining forces. 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	Cutting speed, m/min	Feed, mm/rev	Delamination factor	Surface Roughness µm	Machining Force (N)
1	47	0.04	1.050	1.65	20.64
2	47	0.08	1.062	1.81	28.54
3	47	0.12	1.081	2.04	36.58
4	79	0.04	1.062	1.56	17.53
5	79	0.08	1.074	1.72	23.44
6	79	0.12	1.093	1.86	31.15
7	110	0.04	1.072	1.38	13.32
8	110	0.08	1.086	1.55	18.22
9	110	0.12	1.113	1.69	23.87

IV. MATHEMATICAL MODELLING

Minitab17 software is used to analyze the influence of the input variables with the output variables for statistical regression analysis. Since the second order regression relationship between the variables are with the higher values of the R – sq comparing to the first order regression, it is evident that the second order regression is more significant statistically in projecting the influence between the variables. R-sq(adj) and R-sq(pred) values of second order also in line with the R-sq values. Hence forth second order equation is selected for further analysis. From the Table 4.1 to 4.3 output parameter wise comparison of the first and second order regression model is listed.

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

Table 4.2 Regression model comparison for Surface roughness

Parameter	Regression	S	R-sq	R-sq(adj)	R-sq(pred)	Durbin - Watson
Ra	1st order	0.0292914	98.29%	97.72%	95.83%	1.07698
	2nd order	0.0246532	99.39%	98.38%	92.85%	2.15594

Table 4.3 Regression model comparison for cutting force

Parameter	Regression	S	R-sq	R-sq(adj)	R-sq(pred)	Durbin - Watson
Fm	1st order	1.20053	97.99%	97.23%	93.90%	1.13125
	2nd order	0.312616	99.93%	99.82%	99.39%	2.95007

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Such framed second order regression equations through the Minitab17 for the individual output parameter in terms of input parameter combination are

Delamination factor = (1.0443) + (0.000064*cutting speed) – (0.176*feed) + (0.000001*cutting speed^2) + (2.812*feed^2) + (0.001973*cutting speed*feed); (4.1)

Surface roughness = (1.478) + (0.00121*cutting speed) + (5.09*feed) – (0.000029*cutting speed^2) + (2.1*feed^2) – (0.01598*cutting speed*feed); (4.2)

Machining force = (14.45) + (0.0186*cutting speed) + (206.4*feed) – (0.000597*cutting speed^2) + (280*feed^2) – (1.069*cutting speed*feed); (4.3)

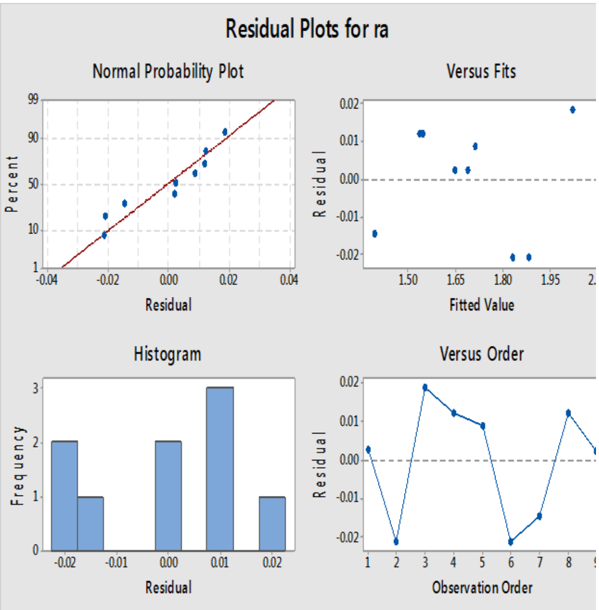

Figure 4.1 Residual plots of surface roughness

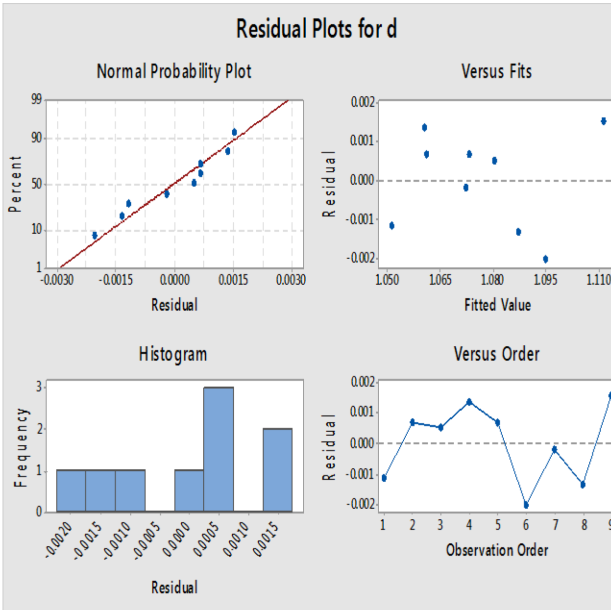

Figure 4.2 Residual plots of delamination factor

The residual plots through Minitab analysis for the two important resultant parameters surface roughness and delamination factors are depicted in Figure 4.1 and 4.2. Through performing the best subset regression analysis the parameter feed is highly influencing on all the three output parameters followed by the speed. The influencing level of feed and speed over individual output parameters are listed through Table 4.4. 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.

Table 4.4 Input parameters influencing level on the output parameters

Output parameters	Influence level of Feed	Influence level of Speed
Surface Roughness	55.4 %	42.8 %
Delamination	61.8 %	35.4 %
Machining Force	62.3 %	35.7 %

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V. OPTIMISATION METHODOLOGY

In the present analysis towards optimizing the parameters Scatter search algorithm, Simulated Annealing Algorithm, Ant colony algorithm, Particle swarm optimisation algorithm, Tabu Search Algorithm and Genetic algorithm are employed. Prediction of the optimized Surface roughness and Delamination factor along with the machining force which is the process parameter generated at time of machining in the experimented ATLAC 382-05 composite material was prepared 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 through these algorithms are compared with the experimental observations individually. Figure 5.1 reveals the progress of the training data in MATLAB. The accuracy level of the each algorithm is assessed with the error rate in computation and listed in the Table 5.1

Table 5.1 Error rate of computation for 25000 iterations

Algorithms	SSA	SAA	Tabu	PSO	ACO	GA
Error rate	0.008738	0.008883	0.009623	0.010436	0.012409	0.018553
Ranking	1	2	3	4	5	6

In the lead of the comparison, it is evident that the Scatter Search algorithm is focusing the most optimized values as the error rate revealed is with the lowest value (0.008738) which is immediately followed by Simulated Annealing Algorithm of error value (0.008883). Tabu Search, PSO, ACO and GA algorithms are attained the third, fourth, fifth and sixth position respectively. As a new approach the second best algorithm (SAA) results are given as the input to the first best algorithm (SSA) and the computation was effected. Along with this the condition for computation is modified with the regression relationship equations instead of taking random selection of combination while computing through the algorithms. Final results were checked for the accuracy in computations and noticed that the error value (0.008664) is further reduced and converges with the lowest deviation. Hence the Regression relationship based Simulated Annealing Algorithm feed Scatter Search Algorithm (**SAA feed SSA**) results are taken as the optimisation method which suitable for this attempt. 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 5.2 to Table 5.

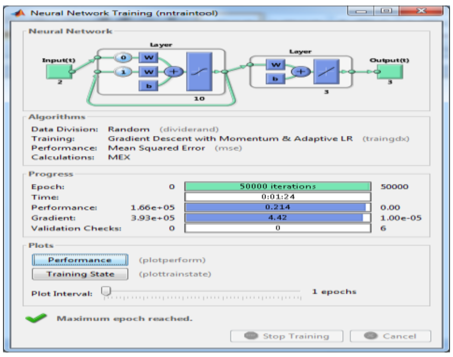

Figure 5.1 Data training progress of 50000 iterations

Table 5.2 Df, Ra, Fm for the speed 47, 53.3 m /min Vs all combination of feed

Speed 47 m / min				Speed 53.3 m / min		
Feed	Delamination	Surface Roughness	Machining Force	Delamination	Surface Roughness	Machining Force
0.040	1.091	1.655	20.696	1.112	1.643	20.169
0.048	1.078	1.699	22.145	1.079	1.689	21.560
0.056	1.080	1.740	23.627	1.072	1.731	22.987
0.064	1.083	1.784	25.143	1.073	1.772	24.451
0.072	1.074	1.826	26.697	1.077	1.813	25.954
0.080	1.086	1.867	28.289	1.076	1.854	27.488
0.088	1.071	1.909	29.912	1.076	1.897	29.060
0.096	1.088	1.953	31.574	1.080	1.942	30.669
0.104	1.074	1.996	33.274	1.081	1.987	32.313
0.112	1.092	2.041	35.007	1.084	2.031	33.992
0.120	1.080	2.082	36.771	1.086	2.073	35.706

Table 5.3 Df, Ra, Fm for the speed 59.6, 65.9 m /min Vs all combination of feed

Speed 59.6 m / min				Speed 65.9 m / min		
Feed	Delamination	Surface Roughness	Machining Force	Delamination	Surface Roughness	Machining Force
0.040	1.109	1.632	19.591	1.107	1.617	18.967
0.048	1.075	1.674	20.930	1.074	1.658	20.249
0.056	1.069	1.717	22.304	1.070	1.702	21.572
0.064	1.076	1.760	23.713	1.071	1.742	22.929
0.072	1.074	1.801	25.159	1.074	1.784	24.321
0.080	1.077	1.841	26.643	1.072	1.830	25.749
0.088	1.071	1.885	28.162	1.075	1.870	27.211
0.096	1.084	1.928	29.716	1.076	1.911	28.715
0.104	1.077	1.971	31.302	1.081	1.957	30.250
0.112	1.089	2.015	32.929	1.081	1.999	31.821
0.120	1.082	2.060	34.590	1.088	2.042	33.427

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Table 5.4 Df, Ra, Fm for the speed 72.2, 78.5 m /min Vs all combination of feed

Speed 72.2 m / min				Speed 78.5 m / min		
Feed	Delamination	Surface Roughness	Machining Force	Delamination	Surface Roughness	Machining Force
0.040	1.103	1.599	18.296	1.097	1.580	17.575
0.048	1.072	1.642	19.527	1.071	1.623	18.756
0.056	**1.068**	1.683	20.792	1.071	1.663	19.966
0.064	1.076	1.727	22.097	1.073	1.704	21.214
0.072	1.074	1.768	23.432	1.075	1.746	22.499
0.080	1.078	1.808	24.807	1.074	1.789	23.819
0.088	1.071	1.854	26.217	1.079	1.832	25.177
0.096	1.084	1.894	27.663	1.077	1.873	26.568
0.104	1.076	1.940	29.147	1.085	1.920	27.994
0.112	1.088	1.985	30.664	1.081	1.965	29.459
0.120	1.079	2.027	32.217	1.093	2.005	30.958

Table 5.5 Df, Ra, Fm for the speed 84.8, 91.1 m /min Vs all combination of feed

Speed 84.8 m / min				Speed 91.1 m / min		
Feed	Delamination	Surface Roughness	Machining Force	Delamination	Surface Roughness	Machining Force
0.040	1.095	1.558	16.809	1.086	1.532	15.995
0.048	1.072	1.601	17.934	1.072	1.577	17.066
0.056	1.070	1.641	19.092	1.072	1.618	18.171
0.064	1.078	1.681	20.284	1.076	1.659	19.311
0.072	1.078	1.726	21.516	1.080	1.702	20.489
0.080	1.079	1.770	22.784	1.081	1.742	21.699
0.088	1.079	1.811	24.084	1.085	1.785	22.948
0.096	1.087	1.852	25.425	1.085	1.826	24.234
0.104	1.082	1.898	26.800	1.092	1.872	25.553
0.112	1.093	1.938	28.207	1.089	1.913	26.908
0.120	1.084	1.985	29.656	1.099	1.958	28.302

Speed 47 m /min	Speed 53.3 m /min

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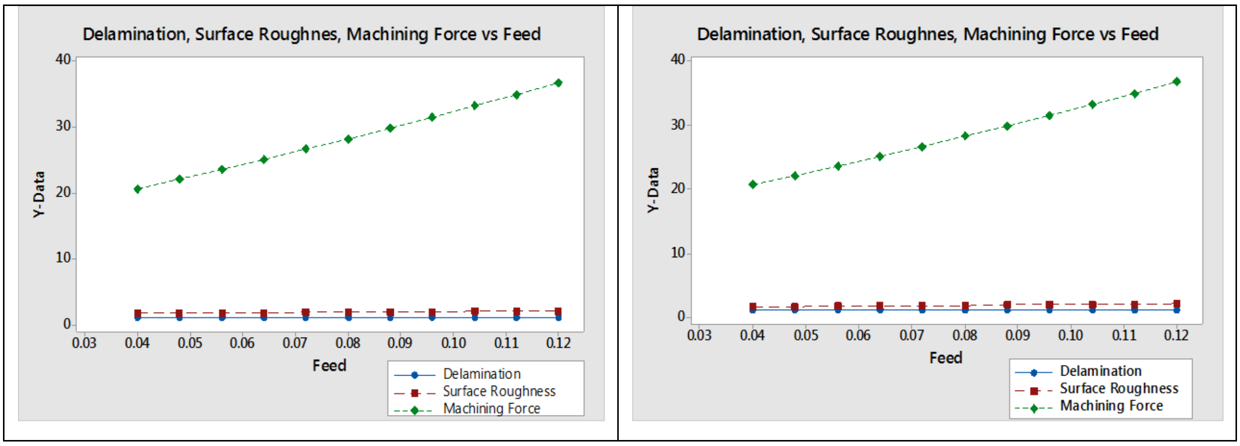

Figure 5.2 Df, Ra, Fm for the speed 47, 53.3 m /min Vs all combination of feed

The plots graphically generated through Minitab software referring to the computed values are follow through the Figure 5.2 to Figure 5.5

Speed 59.6 m /min	Speed 65.9 m /min

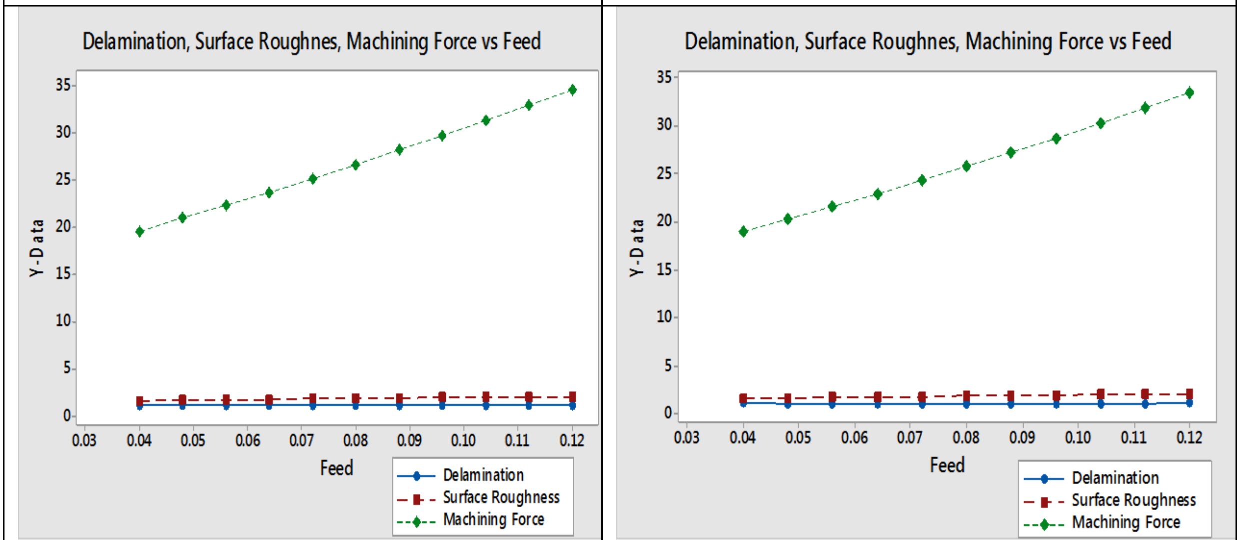

Figure 5.3 Df, Ra, Fm for the speed 59.6, 65.9 m /min Vs all combination of feed

Speed 72.2 m /min	Speed 110 m /min

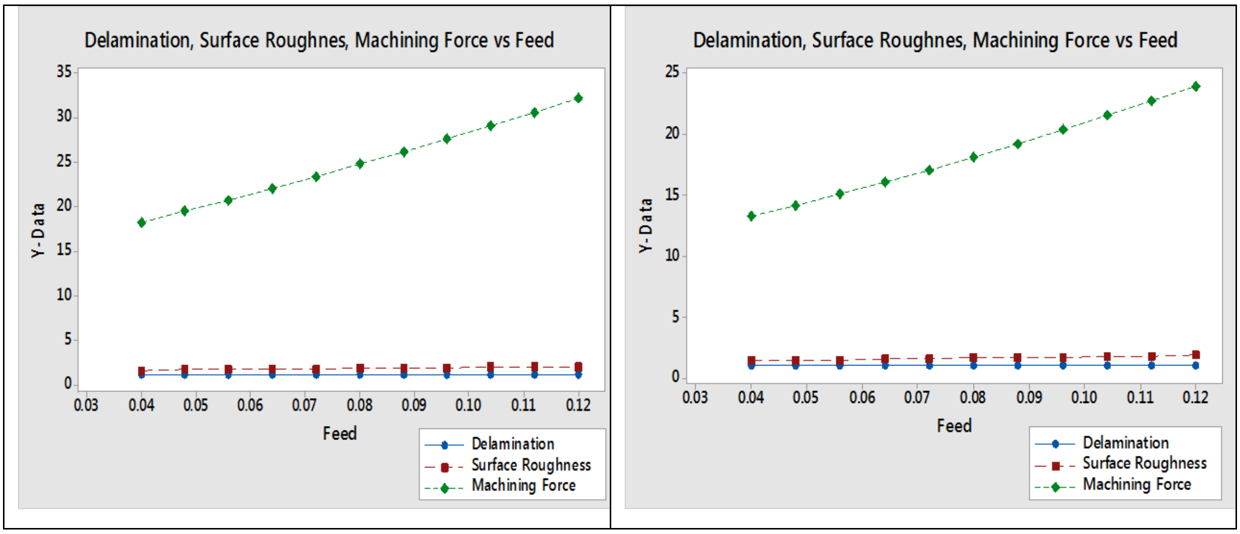

Figure 5.4 Df, Ra, Fm for the speed 72.2, 110 m /min Vs all combination of feed

VI. RESULTS AND CONCLUSION

Milling experiment conducted on the ATLAC 382-05 composite material. Cutting Speed (m / min), Feed (mm / rev) are taken as input variables and Machining force (N), Delamination factor (mm/mm), Surface roughness (µm) are taken as output variable. Second order regression mathematical modelling is taken for processing in simulating the algorithms. For optimizing the parameters Scatter search algorithm, Simulated Annealing Algorithm, Ant colony algorithm, Particle swarm optimisation algorithm, Tabu Search Algorithm and Genetic algorithm were employed in MATLAB platform. Scatter Search Algorithm is converged with the minimum error value as best result followed by Simulated Annealing algorithm. On replacing with the random process with regression relationship, feeding the second best algorithm outcome (SAA) as input to the first best algorithm (SSA) improvement in results was obtained. With the allotment of in-between equal interval values the computation is performed and plotted graphically.

The optimum value of Surface roughness R_a is 1.446 µm for the feed 0.040 mm / rev and speed 110 m / min. Optimum Delamination value is obtained in the feed 0.056 mm /rev, speed 72.2 m / min combination as 1.068. The optimum value of machining force obtained is 13.268 N for the combination of feed as .040 mm / rev and speed 110 m / min. Tool feed is the most influencing input cutting parameter than the speed on all the output parameters. From the plotted graphs, based on the quality requirement on the end product the manufacturers can locate the combination of speed and feed rate.

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