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Research Article

# System Dynamics Approach for Optimization of Process Parameters to Reduce Delamination in Drilling of GFRP Composites

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***Abstract***

*Among various machining processes used for Fiber Reinforced Polymers (FRPs) conventional drilling is the most frequently used machining process in industry. For bolted joints and assemblies, damage free and precise holes must be drilled in FRP components to ensure high joint strength and precision. Since the drilling process is associated with a large number of process parameters, the damage free and precise drilling of FRPs is a difficult task. Simulation of process parameters is essential in order to estimate the value of the output parameters at any intermediate level and also to optimize the process to get the best quality of drilled holes. The optimization has been undertaken for the material thickness, the drill point angle, the drill diameter, the spindle speed and the feed rate. Many researchers have attempted the simulation as a tool for the optimization of the process parameters for quality holes, however, the System Dynamics (SD) based simulation is a novel method which has been attempted in this research. The simulation was performed by developing a simulation model through causal loop diagram followed by developing the mathematical equation. The results through System Dynamics, Artificial Neural Network (ANN) and Response Surface Methodology (RSM) were superimposed on experimental values for validation. The results of the RSM and the System Dynamics results exhibit a closer matching.*

***Keywords:*** *Composite drilling; delamination: system dynamics; artificial neural network, response surface methodology*

## 1. Introduction

Composite materials possess several desirable properties such as: higher specific strength and specific modulus, variable directional strength properties, and the better fatigue strength in comparison to conventional metals (Jain *et al*., 1994). As a result, the use of composites has grown considerably, particularly in the field of aerospace, aircraft, automobile, sporting goods and marine engineering. Since most of the composite components are moulded to a near-net shape, the machining is often necessary to get the dimensional accuracy and for the assembly purpose. Machining of composite materials poses particular problems that are seldom seen with the metals due to the in-homogeneity, anisotropy and abrasive characteristics of the reinforced fibers (Abrate *et al*., 1992). The conventional machining practices such as: turning, milling and drilling are used with composites because of the availability of equipment and experience in the conventional machining. Compared to all other machining processes, drilling is the most frequently employed operation of secondary machining for fiber-reinforced materials owing to the need for structure joining. The twist drills are widely used in industry to produce holes rapidly and economically (Hocheng *et al*.,). The drilling process of the composite is a complicated process since it involves so many independent parameters such as: type of reinforcement material, volume fraction of reinforcement material, the thickness of composite laminate, spindle speed, tool feed rate, tool geometry, tool material etc., and all these independent variables have effects on the dependent variables such as delamination, thrust, torque, surface roughness, cylindricity and tool wear.

The drilling induced delamination occurs both at the entrance and the exit planes of the work-piece. The investigators have studied analytically and experimentally the cases in which delamination in drilling have been correlated to the thrust force. The thrust induced during drilling has a significant effect on the quality of the hole. This force depends on several factors such as tool geometry, speed, feed etc. It is observed that higher the value of thrust, higher will be the hole damage and tool wear. Hence, many researchers have tried to minimize the generation of this force by designing different types of drilling tools. Friedrich *et al*., (1979) cited the ‘split’ or ‘crankshaft’ point as being very popular in the aircraft and automotive industries. Haggerty and Ernst (1958) found

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that spiral point drills performed much well than the conventional ones. Chen *et al*., (1993) used multifaceted drills to reduce the thrust force. Mathew *et al*., (1999) investigated the trepanning tool to reduce the thrust force and torque during drilling of glass fiber reinforced plastic (GFRP) laminates. Only in the recent years the cutting tool manufacturers have started developing the tool geometries specifically for drilling of the composite materials. Four-facet, eight-facet, inverted cone and carbide tipped drills are some of the widely used tool designs in drilling of composite materials (Kamandurai 1993; Abrate 1997; Prak *et al*., 1995; Bhatnagar *et al*., 1993). Some of the researchers have tried to minimize the thrust force by optimizing the process parameters through various DOE (Design of Experiments) techniques such as: Taguchi method, ANOVA etc. Chandrasekharan *et al*., (1995) proposed a mechanistic approach of cutting force models to predict the thrust and the torque in drilling based on the chip load, the chip thickness and the cutting angles. Many people observed that, thrust force is primarily a function of feed rate and tool geometry. It increases with increase in the feed rate and chisel edge length. Jain and Yang correlated the feed rate with the onset of delamination (1993). Enemuoh *et al*., (2001) proposed an approach combining the Taguchi's technique and the multi-objective optimization criterion to select cutting parameter for damage-free drilling in carbon fiber-reinforced epoxy composite materials. Ghani *et al*., (2004) developed a similar approach using Taguchi's method to optimize the cutting parameters in the end milling AISI H13. In order to improve the quality of drilled holes, many researchers have developed various methods to simulate the process parameters associated with the drilling of composites materials. Till now the simulations have been done through the mathematical equations, Artificial Neural Networks (ANN) and computer simulation softwares. But in this paper, the system dynamics is applied as a simulation tool to simulate the process parameters involved in the drilling of GFRP composite material.

*System dynamics:* System dynamics deals with the mathematical modeling of dynamic systems and the response analyses of such systems with a view of understanding the dynamic nature of each system and improving system performance. Response analyses are frequently made through the computer simulations of dynamic systems. The steps followed to develop the system dynamics model is presented in figure 1 with the help of a flow chart.

## 2. Experimental

### 2.1 Test specimen

The test specimen used is a GFRP composite material which is manufactured by hand layup method. The chopped strand mat made of E-glass fiber which is having the density of 2590 kg/ $m^3$ and modulus of elasticity of 72.5 GPa is used as the reinforcement material. The matrix system of the specimen consists of general purpose polyester [GP] resin. The hardener used is the methyl ethyl ketone peroxide (MEKP). The weight fraction of the material is 44% which was confirmed through the burn test.

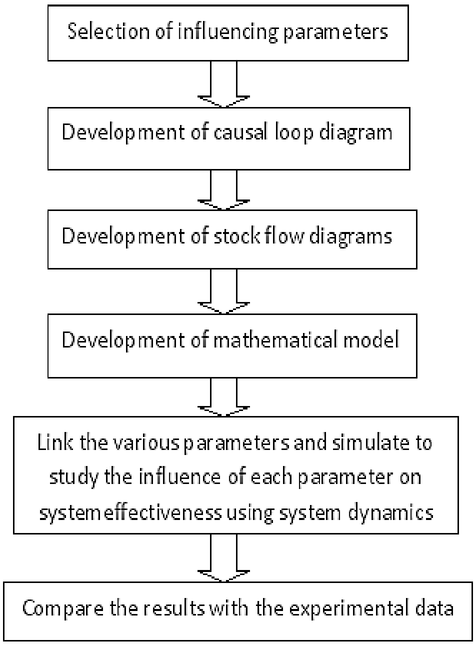


**Figure 1**: System dynamics flow chart.

### 2.2 Drilling process

The experiments were conducted on the TRIAC CNC vertical machining centre which enables high precision machining. The dynamometer was mounted on the machine table. The laminate of the composite specimen was rigidly held over the dynamometer with the help of a fixture. The thrust forces generated during cutting were measured with the help of KISTLER dynamometer and the charge amplifier. The data collected were transferred to a computer for further analysis. Solid carbide drills have been used in the present experiments. The machining set-up is illustrated in figure 2.

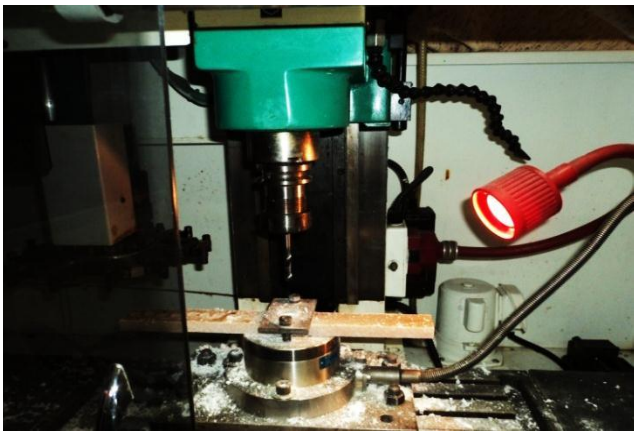

**Figure 2**: Machining set-up

The factors and their levels considered for the present work are shown in table 1. The selection of process parameters has been made based on the basis of literature review, as they are widely used under common machining conditions. According to the full factorial design, for five factors and three levels, the number of experiments $N= L^F= 3^5 =243$, and two replicates were carried out to get the average results.

**Table 1** Factors and levels

| Factor | Level 1 | Level 2 | Level 3 |
|---|---|---|---|
| A: Spindle speed (rpm). | 900 | 1200 | 1500 |
| B: Feed (mm/min). | 75 | 110 | 150 |
| C: Drill diameter (mm). | 6 | 8 | 10 |
| D: Drill point angle (deg). | 90 | 103 | 118 |
| E:Material thickness (mm). | 8 | 10 | 12 |

*2.3 Measurement of Delamination factor (Df)*

In order to estimate the delamination factors, the surface of the each drilled hole is scanned by a surface scanner which is the resolution of 1200dpi. The scanned images are stored in the computer. Further, the parameters of the delamination (D and $D_{max}$) were measured by opening each image in the CATIA software. The delamination factor is measured using the following equation:

$$Df = D_{max} (mm) / D (mm)$$

Where $D_{max}$ = Maximum damaged diameter, D = Actual diameter of the hole to be drilled.

Figure 3 shows the scanned image of the hole and the parameters measured for the estimation of the delamination.

*2.4 Development of system dynamics simulation model*

Figure 4 shows the System Dynamics model developed to simulate the delamination using VENSIM software. The steps followed are given below;

- The drill point angle, drill diameter, material thickness, spindle speed and the feed rate were considered as the input variables.
- Delamination was considered as the output variable.
- Each input variable was linked to the output variable as shown in the figure 4.
- A mathematical equation which shows the relation between the input and the output variables was developed and loaded to the output variable equation box.
- When the model was run and the input variables are changed, the model shows the corresponding output. By varying the input variables, corresponding output results were predicted for the required number of intermediate intervals and tabulated.
- Simulation graphs were plotted using MATLAB software.

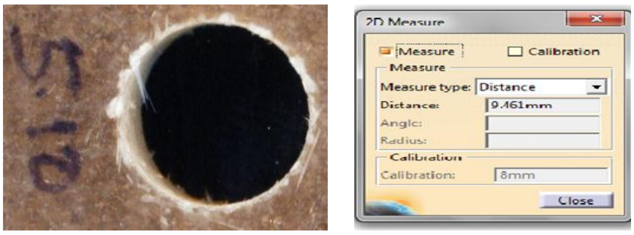


**Figure 3**: Measurement of delamination factor.

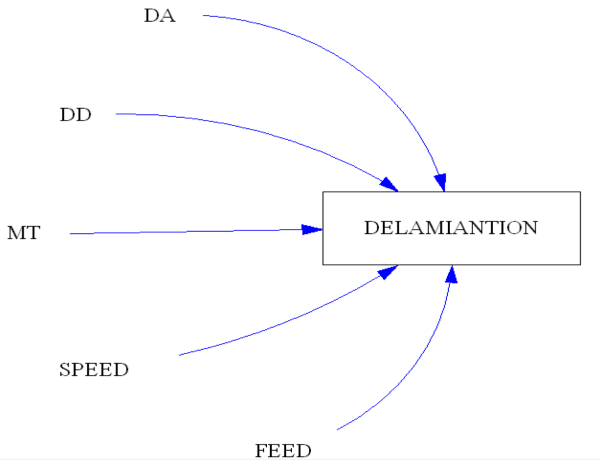


**Figure 4.** System dynamics simulation model for delamination

## 3. Results and Discussion

The sample of data obtained by dynamometer for the thrust force when the spindle speed is 900 rpm, the drill diameter is 6mm, the drill point angle is $90^0$, and the feed rate is 110mm/min, is presented in figure 5.

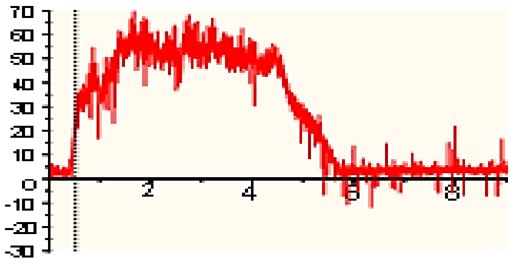


**Figure 5**: Sample of thrust and torque obtained

*3.1 Analysis of delamination factor*

Table 2 shows the ANOVA for the delamination. According to the table, all the parameters under consideration are having the significant effect on the delamination factor. However, the parameter material thickness is the most significant parameter than the other parameters and this is followed by drill point angle. Hence any variation in the level of these parameters will affect the delamination significantly.

**Table 2**: ANOVA for delamination

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| DA | 2 | 3.35484 | 3.35484 | 1.67742 | 587.53 | 0.000 |
| DD | 2 | 0.98168 | 0.98168 | 0.49084 | 171.92 | 0.000 |
| MT | 2 | 4.96222 | 4.96222 | 2.48111 | 869.03 | 0.000 |
| SPEED | 2 | 0.46880 | 0.46880 | 0.23440 | 82.10 | 0.000 |
| FEED | 2 | 1.05827 | 1.05827 | 0.52914 | 185.33 | 0.000 |
| DA*DD | 4 | 0.05186 | 0.05186 | 0.01297 | 4.54 | 0.002 |
| DA*MT | 4 | 0.44813 | 0.44813 | 0.11203 | 39.24 | 0.000 |
| DA*SPEED | 4 | 0.00739 | 0.00739 | 0.00185 | 0.65 | 0.629 |
| DA*FEED | 4 | 0.01792 | 0.01792 | 0.00448 | 1.57 | 0.184 |
| DD*MT | 4 | 0.02553 | 0.02553 | 0.00638 | 2.24 | 0.067 |
| DD*SPEED | 4 | 0.01243 | 0.01243 | 0.00311 | 1.09 | 0.363 |
| DD*FEED | 4 | 0.00556 | 0.00556 | 0.00139 | 0.49 | 0.746 |
| MT*SPEED | 4 | 0.01531 | 0.01531 | 0.00383 | 1.34 | 0.256 |
| MT*FEED | 4 | 0.01788 | 0.01788 | 0.00447 | 1.57 | 0.185 |
| SPEED*FEED | 4 | 0.01399 | 0.01399 | 0.00350 | 1.22 | 0.302 |
| Error | 192 | 0.54817 | 0.54817 | 0.00286 | | |
| Total | 242 | 11.98998 | | | | |

### *3.2 Correlation between thrust force and delamination factor*

The variation of delamination with respect to the change in the thrust force for the present experimentation conditions is presented in figure 6. As shown in the figure, the delamination produced is directly proportional to the thrust force generated. The similar trend was observed by many researchers (Hocheng *et al.*, 2007; Faramarz *et al*, 2011).

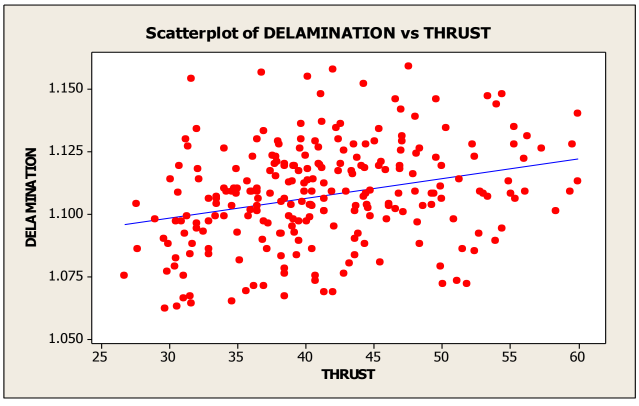


**Figure 6**: Relation between delamination and thrust developed.

### *3.3Simulation of Delamination*

The second order regression equation used in the System Dynamics simulation model is:

Df= 0.645875+0.00365634*DA-0.00111433*DD +0.0253077*MT+3.66488E-05*SPEED-7.71157E-05*FEED-2.83679E-05*DA*DA-1.57407E-04*DD*DD-0.00206944*MT*MT -1.13169E-08*SPEED*SPEED + 4.19165E-07*FEED*FEED+7.55832E-05*DA*DD +0.000272189*DA*MT-1.10199E-07*DA*SPEED +3.21850E-06*DA*FEED+2.31481E-06*DD*MT +2.31481E-06*DD*MT+1.38889E-07*DD*SPEED +5.38571E-06*DD*FEED-1.06481E-06*MT*SPEED +5.25970E-07*MT*FEED-1.02345E-07*SPEED*FEED

The simulation for delimitation of the combinations of different parameters was developed by varying the input variables in the System Dynamics simulation model and noting down the corresponding output. Figures 7-10 illustrate the simulation graph for the various combinations of the process parameters.

### *3.4 Optimization of process parameters to achieve low delamination*

The optimization of the parameters to obtain the low delamination for the present study can be done by selecting the combination of the parameters from each graph (7-10), which are yielding low delamination. The combination of parameters obtained is: drill angle is $90^0$, drill diameter is 6mm, material thickness is 8mm, spindle speed is 1500 rpm and feed rate is 75mm/min.

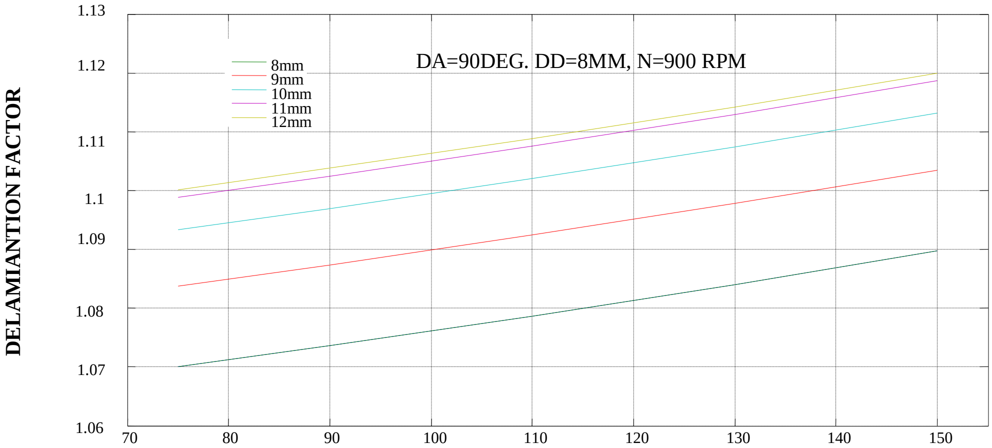


Figure 7: Simulation of delamination as a function of the feed and material thickness.

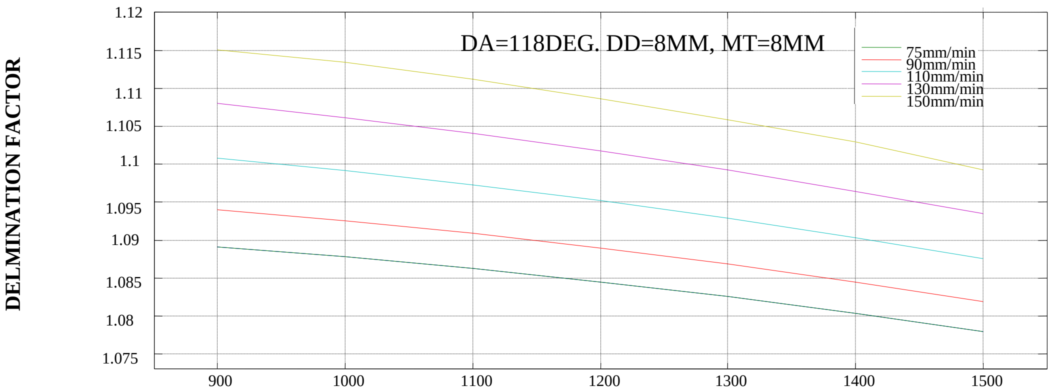


Figure 8: Simulation of delamination as a function of the speed and feed rate.

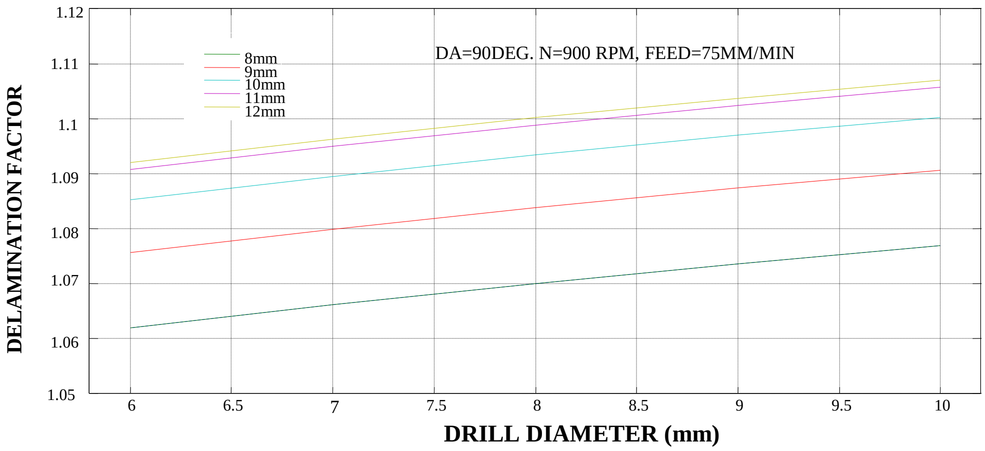


Figure 9: Simulation of delamination as a function of the drill diameter and the material thickness.

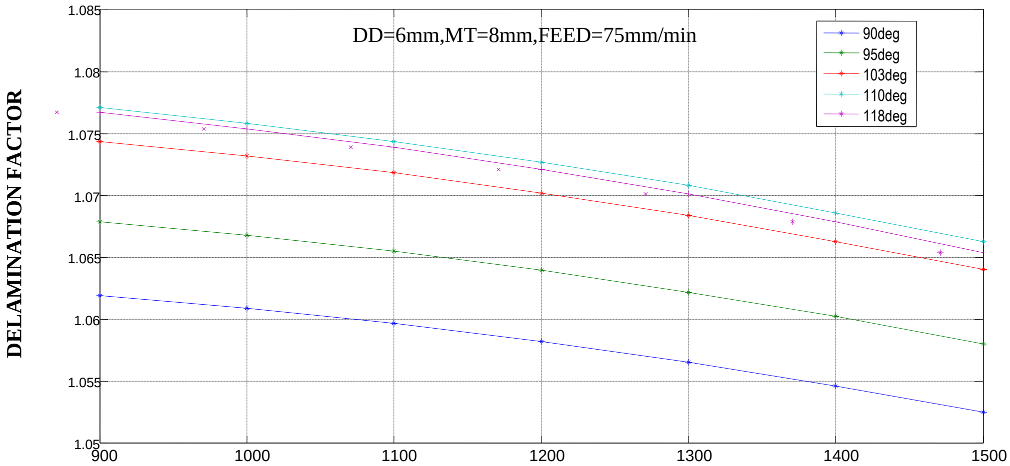


**Figure 10**: Simulation of delamination as a function of the speed and the drill point angle

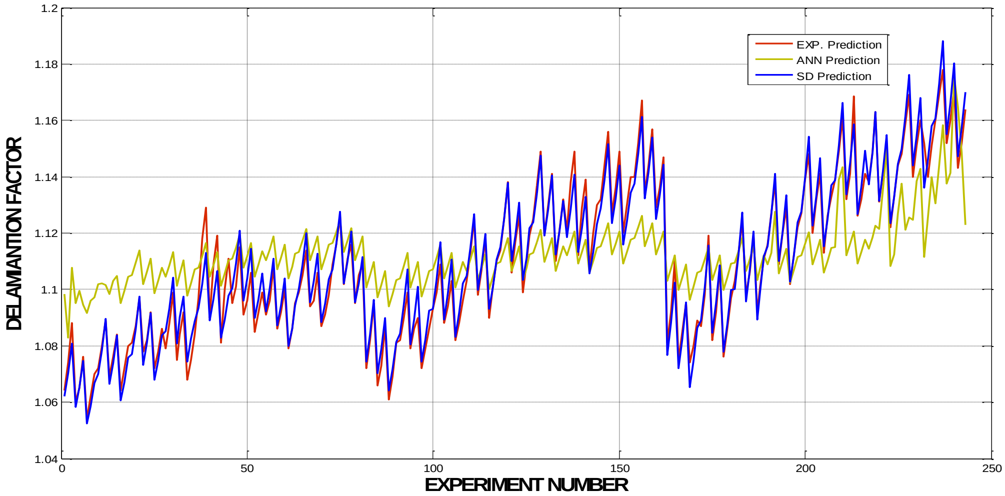


**Figure 11:** Comparison of experimental, ANN and system dynamics results.

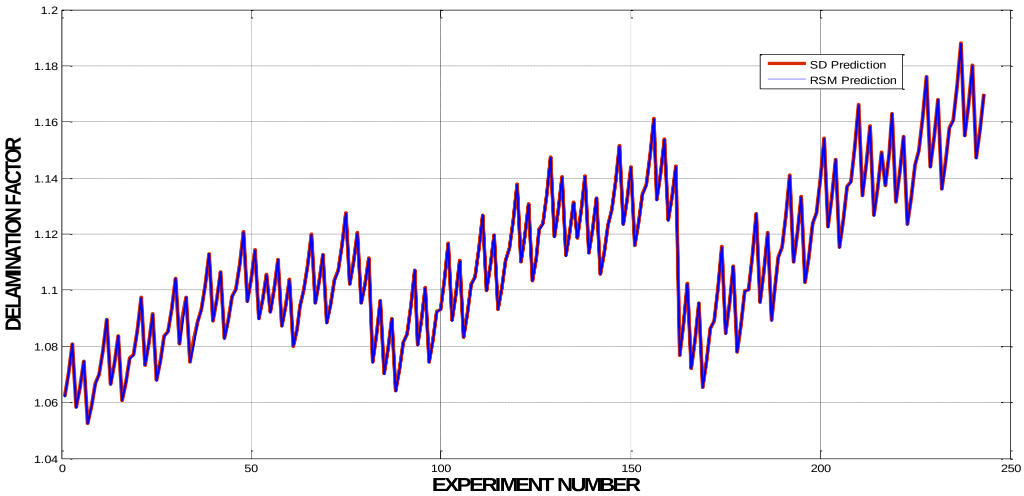


**Figure12**: Comparison of System dynamics and RSM results.

*3.5 Validation of the system dynamics approach*

The ANN simulation results were developed using multi layer perceptron (MLP) technique. The training parameters of the MLP neural network, viz., number of neurons in the hidden layer, the learning rate and the momentum rate have been optimized using the Genetic Algorithm (GA). The training data acquired from the full factorial (243) experimentation was substituted into the ANN model and the epoch number is 2000. The number of iterations used is 100. After trial and error, the hidden neuron number is set to 58, the learning rate is 0.0158 and the momentum rate is 0.0033. Figure 11 shows the comparison between the experimental values, the values predicted by system dynamics and ANN technique. A good agreement between the experimental results and the system dynamics results was observed.

The comparison of delamination results obtained by the System Dynamics simulation and by Response Surface Methodology approach is presented in figure 12. The plot exhibits a very close matching between the results obtained by both the methods. RSM is recognized as one of the reputed simulation methods. The results obtained through the System Dynamics simulation are shows a very close matching with RSM results.

## Conclusions

This study reveals that the most contributing parameter for delamiantion is the material thickness and the least contributing parameter is the spindle speed. Further, the delamination is directly proportional to the thrust force. The System dynamics as a tool of modelling and simulation has been effectively used in this research to predict the delamination for the change in the process parameters. The Response Surface Methodlogy based results have matched very well with the output of the System Dynamics thus justifying its accuracy. This research has pioneered the use of the System Dynamics as a tool for the simulation of process parameters in the drilling process of the composite materials, which can be further explored by the future researchers.

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## References

Jain S, Yang D. C. H, (1994) Delamination-free drilling of composite laminates *Trans. ASME, J. Engng for Industry,* 116, 475-481.

Abrate S, Walton D. A, (1992) Machining of composite materials. *Composites Manufacturing* 3(2)75-94.

H Hocheng, C C Tsao, (1993) Comprehensive analysis of delamination in drilling of composite materials with various drill bits, *Journal of Material Processing and Technology,* 140, 335-339.

M O Friedrich, R O Burant, M J McGinty, (1979) Cutting tools/drills: Part 5—point styles and applications, *Manuf. Eng.* 83, 29–31.

W A Haggerty, H. Ernst, (1958) The spiral point drill—self-centering drill point geometry. *ASTE Paper No.* 101, 58.

S M Wu, J.M. Shen, L.H. Chen, (1982) Drilling of composites using multifacet drills, *Proceedings of the 14th National SAMPE Technology Conference,* pp. 456–463.

J. Mathew, N Ramakrishnan, N K Naik, (1999) Investigations into the effect of geometry of a trepanning tool on thrust and torque during drilling of GFRP composites, *Journal Mater. Process. Technol.* 91, 1–11.

Komanduri R, (1993) Machining fibre reinforced composites. *Mechanical Engineering.* 58–64.

Abrate S, (1997) Machining of composite materials. In: Mallick PK, editor, *Composites engineering handbook, New York: Marcel Dekker,* 777–784.

Park KY, Choi J, Lee DG, (1995) Delamination-free and high efficiency drilling of carbon fibre reinforced plastics. *Journal of Composite Materials,* 29(15), 1995; 1988–2002.

Bhatnagar N, Naik N K, Ramakrishnan N, (1993) Experimental investigations of drilling on CFRP composites, *Materials and Manufacturing Processes* 8(6), 683–701.

Bhatnagar N, Naik N K, Ramakrishnan N, (1995) Some studies on an inverted cone drill for FRP drilling. In: Srivatsan T S, editor, *Engineering systemsdesign and analysis, ASME PD,* 64(2) 1–7.

V. Chandrasekharan, S.G. Kappor; R E DeVor, A mechanistic approach to predicting the cutting forces in drilling: with application to fiber- reinforced composite materials. ASME J. Eng. Ind. 117, 1995; 559–570.

S. Jain, D.C.H. Yang, (1993) Effects of feed rate and chisel edge on delamination in composite drilling, *ASME J. Eng. Ind.* 115, 398–405.

E. U. Enemuoh, A S El-Gizawy, A C Okafor, (2001) An approach for development of damage-free drilling of carbon fiber reinforced thermosets, *Int. J.Mach. Tools Manuf.* 41 (12), 1795–1814.

J A Ghani, I A Choudhury, H H Hassan, (2004) Application of Taguchi method in the optimization of end milling parameters, J. Mater. Process.Technol.145, 84–92.

H. Hocheng, C.C.Tsao, (2007) Computerized Tomography and C-scan for Measuring Drilling-Induced Delamination in Composite Material Using Twist Drill and Core Drill *Key engineering materials,* 339, 16-20.

Faramarz Ashenai Ghasemi, Abbas Hyvadi, Gholamhassan Payganeh, Nasrollah Bani Mostafa Arab, (2011) Effects of Drilling Parameters on Delamination of Glass-Epoxy Composites, *Australian Journal of Basic and Applied Sciences,* 5(12): 1433-1440.