DRILLING OF GLASS FIBER REINFORCED POLYMER (GFRP) COMPOSITES: MULTI RESPONSE OPTIMIZATION USING GREY RELATION ANALYSIS WITH TAGUCHI'S METHOD

Thesis submitted in fulfilment of the requirements for the Degree of

Master of Technology (M. Tech.)

In

Production Engineering

By

SHARWAN KUMAR SAHU

Roll No. 213ME2417

Under the Supervision of

Prof. SAURAV DATTA

NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA 769008, INDIA

NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA 769008, INDIA

Certificate of Approval

This is to certify that the thesis entitled ***Drilling of Glass Fiber Reinforced Polymer (GFRP) Composite: Multi-Response Optimization using Grey Relation analysis with Taguchi's Method*** submitted by ***Sharwan Kumar Sahu*** has been carried out under my sole supervision in fulfilment of the requirements for the award of the ***Degree of Master of Technology (M. Tech.)*** in ***Production Engineering*** at National Institute of Technology, Rourkela, and this work has not been submitted elsewhere before for any other academic degree/diploma.

Dr. Saurav Datta

Assistant Professor
Department of Mechanical Engineering,
National Institute of Technology,
Rourkela-769008

Date:

Acknowledgement

In the pursuit of this academic endeavour, I have been especially fortunate as inspiration, guidance, direction, co-operation, love and care all came in my way in abundance and adequately expressing my gratitude towards that would be very hard.

It gives me an immense pleasure to express my deep sense of gratitude towards my supervisor ***Dr. Saurav Datta***,, Department of Mechanical Engineering, NIT Rourkela, for his valuable guidance, motivation and constant inspiration. Above all, he provided me unflinching encouragement and support in various ways which exceptionally inspire and enrich my growth as a student.

I am obliged to ***Prof. S. S. Mahapatra,*** HOD, Department of Mechanical Engineering, NIT Rourkela who inspired me with his advice and experiences.

I express my thankfulness to the faculty and staff members of the workshop especially, ***Mr. Sudhansu Samal*** (Technician) and ***Mr. Mukesh Kumar*** **(**Technician**)** who helped me in CNC Drilling during my project work.

I feel lucky to have ***Mr. Kumar Abhishek***, Ph.D. Scholar (Production Engineering) who worked with me in every difficulty faced and his constant efforts and encouragement was the tremendous sources of inspiration.

The blessings and encouragement of my beloved parents greatly helped me in carrying out this research work. Special thanks to my brother ***Mr. Basant Kumar*** for his infallible motivation and support.

It's my pleasure to express my indebtedness to my friends**.**

Finally, but most importantly, I thank almighty **God** for giving me the will, power and strength to complete my research work.

SHARWAN KUMAR SAHU

Abstract

Nowadays, GFRP (glass fiber reinforced polymer) composites are widely used in manufacturing industries specially aircraft, aerospace, and automobile industries due to their excellent mechanical and thermal properties such as more specific strength, better specific modulus of elasticity, high damping factor or damping capacity, better resistance to corrosion, effective fatigue resistance, low thermal expansion coefficient. Hence, it is necessary to understand the machinability behavior of these composites. Drilling is widely used to assemble the components in aforementioned industries. But machining of these composites is dissimilar to conventional metals due to their isotropic nature and in-homogeneity. Major drawbacks of these composites in machining are fiber pull out, delaminating and burring of fibers. So, appropriate selection of process parameters is an important concern in machining of GFRP composites. This work mainly focuses on assessing the effects of process parameters i.e. spindle speed, feed and drill diameter on thrust, torque, delamination factor (both at entry and exit) in drilling of GFRP composites using TiAlN coated drill bit. The study also utilizes the Grey methodology coupled with Taguchi L_{16} OA to determine the optimal parametric combination.

.***Keyword***: GFRP, Drilling, Grey Relation analysis, Taguchi.

Contents

List of Table

List of Figure

Chapter 1.Introduction

1.1 Composite Material: Composite is a combination of two or more material having individual chemical, mechanical and physical properties. After combining these material, the property of the particular material change and a better single material is obtained, as a composite. Now this composite have many advantages of being used in fields like shipping, aerospace, and aircraft industries. A composite has enough specific stiffness, high specific strength **[1]**, less thermal expansion coefficient, high moisture absorption ability with time **[2]** and a real ability for corrosion protection. Composite materials are fully different from conventional materials. In conventional material, machining is easy in comparison with polymer composite. The machining of composites is performed under consideration of some behavior as it depends on physical and mechanical properties of fiber of the composite. And also the properties depends on the amount of fiber, quality of fiber, type of fiber and chemical composition of fiber **[3]**. The fibrous material is the most advanced composite, made by resin matrix. It's laminated in a sequence of particular direction hence get enough material stiffness and better strength. Composite stiffness and strength also depends the orientation of fibers. The value of orientation is determined by applying proper load on fiber filament. Carbon composite material has little orientation value as compare to glass composite material.

The composites consists of two primary phases: matrix and reinforcement

- ***Matrix***: Matrix is the first phase in composition present in large amount and is continuous. In structure composite, matrix possess individual property and enhances the overall property of the product.
- ***Reinforcement***: It is more strong, more stiff and harder than the first phase that is the matrix. Reinforcement changes the physical properties like thermal resistance, wear resistance, and thermal conductivity. In this phase machining operation such as extrusion, rolling, forging and drilling, etc. can be performed. Carbon fiber, silicon fiber or glass fiber is

monofilament fiber that is used in continuous reinforcement. When both phase meet its make other physical identification**[4]**

1.2 Classifications of composite materials:

Due to many property of composite materials it has been classified in two phase that are described below

1.2.1 According to arrangement and nature of reinforcement

i. Reinforced composites
ii. Laminated composite
iii. Particulate reinforced composite
iv. Hybrid composite

i. Reinforced Composite: When a length of the reinforcement is higher than cross-sectional dimension, this type of composite is known as the Reinforced composite. In a single layer composite, length of reinforcement may be long or short It depends on the size of the reinforce **[5]**.

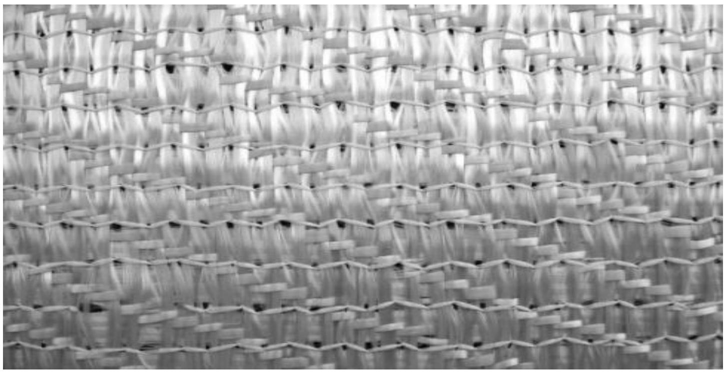

Fig 1. Reinforced Composite

Orientation of long reinforced fiber composite is in one way or one direction, this type of fiber is known as the continuous fiber reinforced composite and the length of fiber is neither too short nor too long, this type of composite is known as discontinuous fiber reinforcement composite.

ii. **Laminated Composite:** The layer of fibrous is arranged in a particular way or particular direction, by bonding some unusual condition that increase the engineering property of tensile strength by 33% and tensile modulus by 75% **[6]** of the composite. For better bonding of fibrous, three layers are arranged in alternative way between reinforcement and polymer matrix. Combining individual layer results in increment of the property of high modulus **[1]**, high strength and corrosion resistance. An example of laminated composite is paper and plywood. Shown fig.2

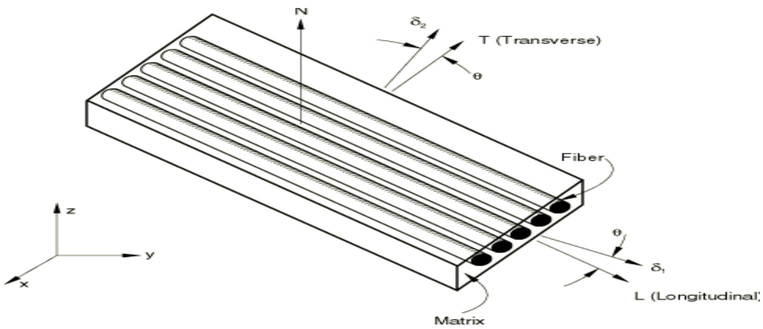

Fig 2. Laminated Composite

iii. **Particulate Reinforced Composite:** Reinforcement used equally in all the available directions results in making Particulate reinforced composite. This phenomenon results in improved stiffness but at the same time it also effects the strength of particulate composite. Advantages of particulate composites are high wear resistance, high thermal performance of composite, low coefficient of friction and very small shrinkage in the composite in compared to others.

iv. .**Hybrid Composite:** In single matrix fillers are that increase their mechanical property. When two or more types of fillers are used, the composite is said to be hybrid composite. This type of composite is efficient in improving the properties due to hybridization. Hybrid composite is more economical when compared to others. Most standard hybrid composites are carbon fiber, glass fiber and polymeric resin in the matrix. The property of single phase composite is lower than the hybrid fiber composite.

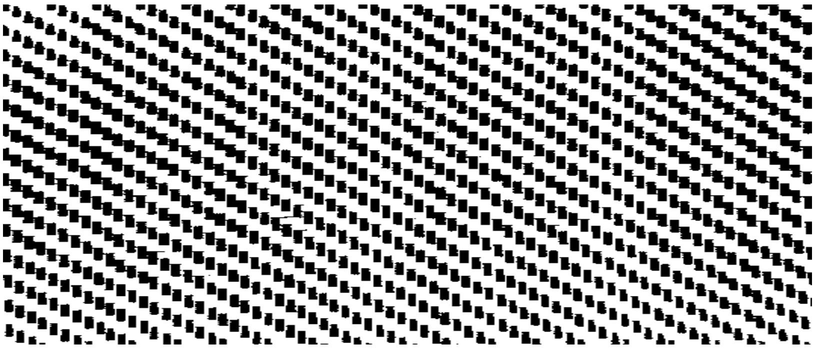

Fig 3. Hybrid Composite

1.2.1 According to Types of Matrix Material

I. Polymer Matrix Composite (PMC)

II. Metal Matrix Composite (MMC)

III. Ceramic Matrix Composite (CMC)

I. **Polymer Matrix Composite (PMC):** Polymer matrix composite are most useful in the field of structural components due to their unique properties. The use of reinforced polymer in matrix improves the strength and stiffness. Polymer matrix composite doesn’t need high temperature and high pressure in the processing phase. Manufacturing of polymer matrix composite is simple with compare to Metal Matrix Composite (MMC) and Ceramic Matrix Composite (CMC) which makes it viable in structure field. Particles reinforced polymer (PRP) and Fiber reinforced polymer are the type of polymer matrix composite.

II. **Metal Matrix Composite (MMC):** In this composite metal is used in the form of matrix hence this composite is called metal matrix composite. It has greater properties **[7]** elevated in the range of temperature, thermal expansion coefficient low, high specific modulus and high strength of composite as compared to monolithic. Metal matrix composite is used in many industry like in thermal plant turbines, boilers, combustion chambers, nozzles of rocket, heat exchanger and in structure fields etc. Shown fig 4.

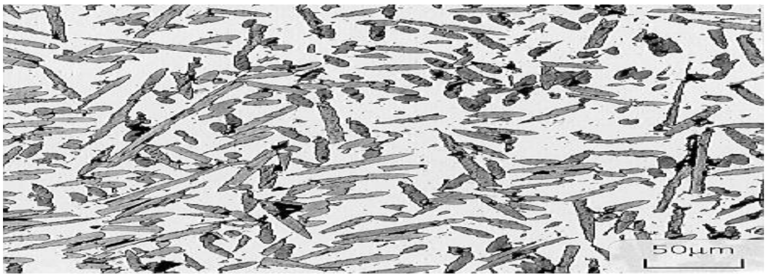

Fig 4. Metal Matrix Composite

III. Ceramic Matrix Composite (CMC): In matrix phase, ceramic materials are used to make the composites. The primary aim in manufacturing ceramic composite is, it has improved strength and stiffness along with the toughness of the material. It is able to performs in very high-temperature condition, even in stressed placed. It’s also used in construction field.

Fig 5. Ceramic Matrix Composite

1.3 Fiber Reinforced Polymer (FRP): When thermoset or thermoplastic resin matrix is used in a composite it is called fiber reinforces polymer composite. A Polymer may be epoxy, vinylester, polyester, phenolic and the reinforcing material may be aramid, silicon, boron, carbon and glass, etc. Use of fiber in composite enhances the various properties of the composite. While undergoing machining operation problem of fiber pull may occur in the FRPs which leads to certain damage factors like; delamination, bumming and burr formation, etc. This problem occurs due to non-homogeneous property of composite materials. Carbon fiber and glass fiber are the most common example of fiber reinforcement polymer composite.

Table 1.Properties of fiber

Fiber Properties	Waste Cotton	Cotton Fiber
Fiber tenacity (cN/tax)	23.2	27.1
Fiber elongation (%)	6.6	6.7
Mean length by weight(mm)	12.77	23.9
CV length by weight(mm)	1.94	1.91
Short fiber content by weight (%)	21.1	7
Maturity index	0.81	0.82
Micron air	4.29	4.38

1.3.1 Glass fiber reinforced polymer: Glass fiber reinforced polymer gives favorable circumstances over conventional methods of reinforcement. Due to its significant property these materials are used in various industrial field like sport goods, aircraft, aerospace, automobile etc. While machining these material, the process parameters affects the hole quality **[6]**, surface roughness and dimensional accuracy of glass fiber composite material. Glass fiber reinforced polymer has excellent modulus of elasticity, better specific strength. In comparison to other fiber composite polymer, GFRP possess high corrosion resistance, less weight and ease of handling.

1.3.1.1 Advantages of GFRP Composites

- i The weight of Glass fiber reinforced composite is lesser than the conventional materials.
- ii Corrosion resistance of GFRP is high.
- iii Stiffness, Strength, and modulus can be improved by the design of manufacturing.
- iv GFRP composite can be made in any shape and size according to the requirement.
- v It possess excellent damping characteristic that provides better fatigue resistance.
- vi GFRP composites can be easily fabricated.

1.3.1.2 Disadvantages of GFRP

1. Economically use of GFRP is costlier.
2. Waste while drilling GFRP is very harmful for health.
3. Difficult to manufacture a delicate shape.
4. Application of GFRP is limited.

1.4 Need of Machining on GFRP: As above discussed GFRP is used in various industries due their extensive properties. Many mechanical operations are done in GFRP such as drilling, turning, milling, etc. Presently the conventional materials are not been used in the shipping industry, aircraft and aerospace field due to the cost of the material, weight of material and difficulty of fabrication. While GFRP gives more advancements, compared to conventional materials. Its costs less, weight of this composite is very less with compare to conventional material, and can easily perform any mechanical operation. So due to these qualities of Glass Fiber reinforced polymer is used in building, equipment bodies and industrial field.

1.5 Drilling- Drilling is a cutting process which produces hole in a solid metal by means of a revolving tool called drill bit. The drill tool is rotary instrument which have multi-cutting face. Drill tool are made of carbon steel, carbide, or high speed steel. Shown fig 6.

Fig 6.Drill Tool Parts

1.5.1 Advantage of Twist Drill

1. The chips and cutting of metal are automatically driven out of the hole.
2. The cutting edge is retained in good condition for a long time.
3. They need less power in compare to other type of drill.
4. Compared to other drills heavier feed and speed can be used.

1.6 CNC Machines

Automation and mass production are associated with advancement in technology. In mass production units since the quantity if item required is very high with little of variety, special purpose machines, automatic or transfer lies, have been used. In the conventional general purpose skilled operator is responsible for many inputs to the machining. Computer numerical control machine tools, a dedicated computer are used to perform all the basic NC function. The complete part Programme to produce a component is input and stored in the computer memory and information for each operation is fed to the machine tool i.e. motors, etc. The part programmers can be stored in the memory of the computer and used in future. Conventional NC machine tools are not much in use these days. CNC tools are widely used to many new control features available on these machines.

I. The part Programme can be input to the controller unit through key-board or the paper tape can be read by the tape reader in the control unit.

II. The part Programme once entered into the computer memory can be again and again.

III. The part programme can be edited and optimized at the machine tool itself. If there is any change in the design of the component, the programme can be changed according to the requirements

IV. The CNC machine have the faculty for proving the part programme without actually running it on the machine tool. The control system processes the part programme and movement of the cutting tool in each operation shown on the monitor screen. The shape of the component which will be produced after machining is also shown on the screen without actual machining taking place.

V. CNC system, possible to obtain information on machine utilization which is useful to the management. The control system can provide the information such as number of component produced, time per component, time for setting up a job, time for which a particular tool has been in use, time for which machine has not been working and fault.

Structure of CNC Part Programming

- ❖ Sequence Number.
- ❖ Preparatory Function.
- ❖ Coordinates(X, Y, and Z)
- ❖ Feed Function.
- ❖ Spindle Speed Function.
- ❖ Tool section Function.
- ❖ Miscellaneous Function.

1.6.1 Advantages of CNC machines

1. Reduced Lead Time-The time between the receipt of a design drawing by the production engineer and manufacturer getting to start production on the shop floor,
2. The part program tape and reader are used only ones to enter the program into computer memory. This result in improved reliability.
3. CNC can accommodate conversion of tapes prepared in unit of inches into the international system of units.
4. Greater Flexibility to alter conventional NC system, it needs rewiring, modification in CNC system means reprogramming.

5. A reduction in hardware circuits and simplification of the remaining hardware, as wll as the availability of automatic diagnostic program, bring a subsequent need for fewer maintenance personnel.

1.6.2 Disadvantages of CNC machine

1. The capital cost for buying the machine is high.

2. Control systems are costly.

3. Maintenance cost increase owing to the sophistication of the control systems.

4. CNC machine are much move more complex than the conventional machines.

Chapter 2: Literature Review

2.1 Coverage

The aim of literature review is to provide background information on the issues to be considered in this dissertation and highlight the significance of the present study. This dissertation highlights the various machinability aspects and the advantages of multi-objective optimization methods during machining of GFRP composite.

2.2 Background and Rationale

Davim et al. [8] established an empirical relation between feed rate and cutting velocity with reference to thrust force, cutting pressure, a factor of damage and surface roughness in machining of GFRP composites by using cemented carbide tool. ANOVA has been also performed to investigate the effects of process parameters. **El-SonbatyI.et al. [9]** examined the effects of process parameters on the thrust force, torque and surface roughness in drilling of fiber-reinforced composite materials. It has been demonstrated from the result that epoxy resin, cutting speed has insignificant effect on thrust force whereas cutting speed and feed has significant influence on surface roughness. **Langella et al. [10]** investigated the effect of machining parameters such as chisel edge and type of drill on thrust and torque in drilling of composites. **Singh et al. [11]** approached a fuzzy inference system to predict torque and thrust in drilling of GFRP composites using solid carbide drill bit with eight facet. Experiments conducted by L_{27} Orthogonal array and ANOVA has been done to investigate the influence of process parameters. **Kilickap et al. [12]** investigated the effect of cutting parameter that was feed rate, chisel angle of drill tool and cutting speed in drilling of glass fiber reinforced polymer. The primary aim was in this paper minimized the delamination that was produced after drill on GFRP and Taguchi method had used in this research. **Latha et al. [13]** assessed the effects of drill parameters on thrust in machining of GFRP composites.

Here, researchers utilized the different type of drill bits such as multifaceted drill tool, spur and brad drill in order to carry out the experimentation. **Palanikumar et al. [14]** has utilized grey relation analysis with Taguchi Technique to obtain the optimal machining condition. Experiments were carried out throughL_{16} 4-level orthogonal array in order to investigate the effects of spindle speed, feed on thrust force, delamination factor at an inlet and outlet on composite and surface roughness. **Verma et al. [15]** proposed fuzzy inference system integrated with Taguchi to assess the favorable machining condition in turning of GFRP composites using HSS tool. The machining evaluation characteristics are taken as Material removal rate and surface roughness. **Tsao et al. [16]** aimed to reduce delamination in drilling of GFRP composites by active backup force. It has been noticed that applied backup force contributes to reduction of the growth of the delamination at drilling exit by 60–80%.**Krishnaraj et al. [17]** analyzed the influence of drilling parameters on thrust force, torque, an eccentricity of hole and delamination of both side of the hole in machining of CFRP composites using ANOVA. The study also used of grey relation analysis method to evaluate the optimal machining condition. **Kumar et al. [18]** studied the influence of factors such as feed rate, cutting velocity, environment condition of the experiment, rake angle of tool and depth of cut in turning of GFRP composites. The optimal machining condition is obtained by Distance Based Pareto Genetic Algorithm.

From the aforementioned research it has been revealed that works are mainly focused on evaluation of favorable machining environment during the machining of GFRP composites. Hence, this dissertation utilized grey integrated with Taguchi in order to evaluate the optimal parametric combination in drilling of GFRP composites. Here, the drilling parameters are taken as spindle speed, feed and drill diameter whereas machining evaluation characteristics are thrust, torque, delamination (both at entry and exit) and surface roughness.

Chapter 3. Study and Experimentation

3.1 Introduction: This chapter includes the experimental details for the present work. This chapter includes the details of machining parameters and their performance characteristics.

3.2. Experimentation

In this study, experimentation has been conducted on CNC machine shown in Fig7.[MAXMILL 3axis CNC machine with FANUC OI MATE controller, Model NO CNC 2000EG].

Fig 7. MAXMILL 3axis CNC machine

Work-piece: Glass fiber reinforced polymer composite with 5mm thickness of the plate has been taken as work-piece material. After drill of work-piece is shown fig 8.

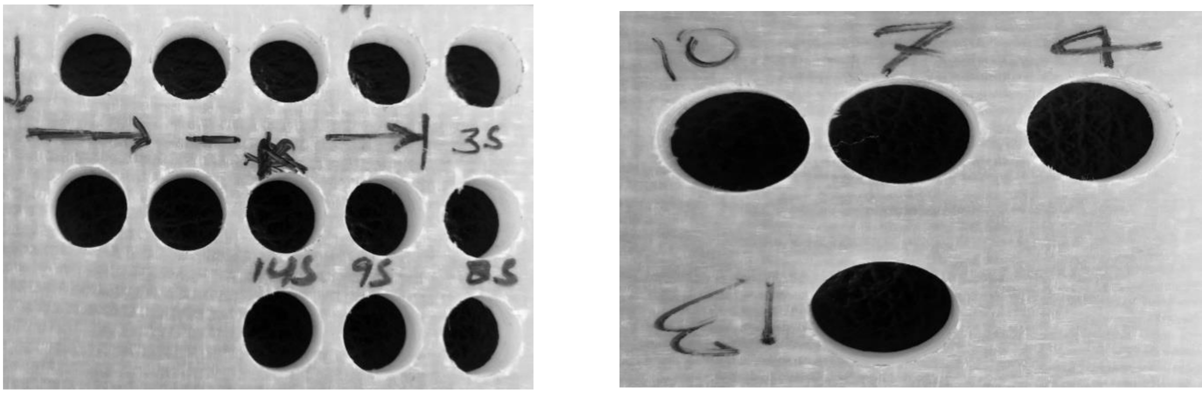

Fig 8. Work piece of GFRP

Tool material: TiAlN coated solid carbide drill bit of different diameter such as are 5 mm, 6mm, 8mm and 10 mm. has been taken as tool material for drilling operation.Shown fig 9.

Fig 9. TiAlN Coated Carbide tool with [10] diameter.

3.3 Design of Experiment (DOE) Design of Experiment comprises of set of experiments which are to be carried out in a sequential manner for evaluating the response measurements. Taguchi's orthogonal array design of experiment is an economic as well as effective method to examine the effects of the machining parameters through limited number of experiments. The present paper concentrated on effect of drilling parameter like spindle speed, feed and drill diameter. In this experiment aforementioned cutting parameters are varied into four different levels (as shown in Table 1) to evaluate torque, thrust force, surface roughness and delamination factor (at both entry and exit). Here, the experiment has been used with mixed level L_{16} Orthogonal array which is presented in Table 2.

. Table 1. Domain of the experiment

Cutting Parameter			
Levels	Spindle Speed N [RPM]	Feed Rate f [mm/min]	Drill Bit Diameter d[mm]
1	800	150	5
2	1000	200	6
3	1200	250	8
4	1400	300	10

Table 2: Design of experiment

Sl. No	N	F	D
1	800	150	5
2	800	200	6
3	800	250	8
4	800	300	10
5	1000	150	6
6	1000	200	5
7	1000	250	10
8	1000	300	8

9	1200	150	8
10	1200	200	10
11	1200	250	5
12	1200	300	6
13	1400	150	10
14	1400	200	8
15	1400	250	6
16	1400	300	5

Performance Evaluation Characteristics: After carried drilling operation in glass fiber reinforcement polymer, responses such as thrust force, torque, delamination factor (at entry and exit) as well as surface roughness are consider as performance evaluation characteristics. Thrust force and Torque are assessed by Digital Drilling Tool Dynamometer shown as fig 10. [Model No: MLB-DTM-DI-3 mfd by Medilab Enterprises Chandigarh] whereas surface roughness are measured by Mitutoyo Surf Test (SJ -210).

Fig 10. Digital Drilling Tool Dynamometer

Delamination Factor which can be defined as ratio of maximum hole diameter such as damage place of the hole to the nominal diameter of the tool

Delamination factor can express in mathematically eq^n 1.

$$F_d = \frac{D_{max}}{d} \tag{1}$$

Where,

F_d= Delamination Factor,

D_{max} = Maximum Diameter of composite hole after drill at Damage place

d = actual diameter of hole that are equal to drill bit

Optimum parameters decision for general change in machining

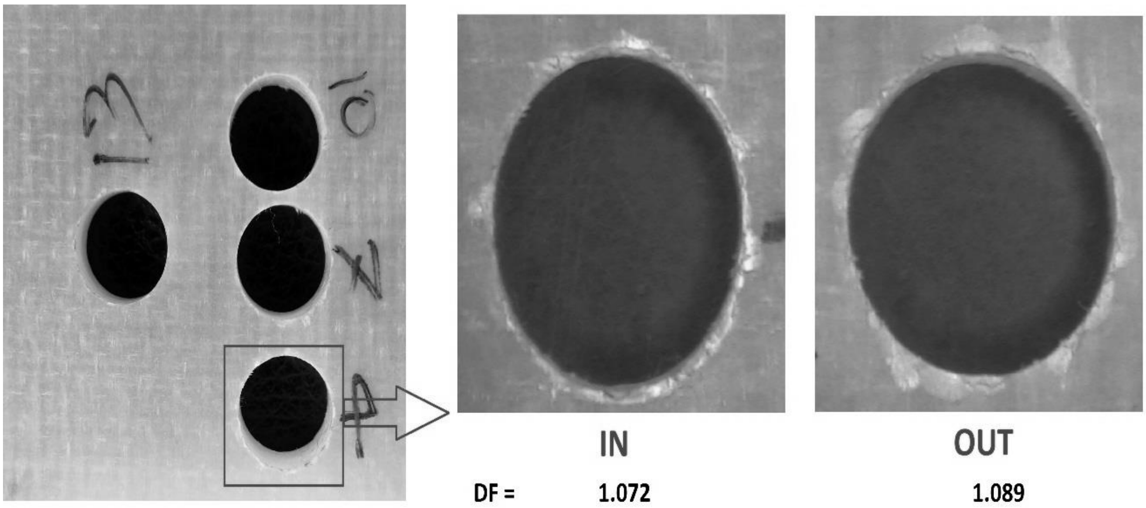

Fig 11. Delamination observed by Optical Microscope

Chapter 4: Optimization of multi-response by grey relation analysis with Taguchi method and Conclusion

4.1 Grey Relational Analysis: One of the intense, powerful, and useful tool to search best characteristic of outcome responses that are carried after experiments. In real Practice, the condition to seek best parameter without GRA method is very difficult. When having some information about outcome response and some information is not known about it so in this condition recounted as being grey. For most of part, GRA is easy to tackling various issues that have correlating among the assigned performances qualities. In grey has two level one is black, and another is white, means no perfect information. This examination can be utilized to an evolution of two different sequences so that a relation between these factors can be measured attentive. For the situation, when experiments are debatable grey relation analysis make correlation between series with exclusively data and can predicted some factor which affecting the statistical process. Grey Relation Grade who are help to make a relation between the sequence of factor and decrease the distance between these sequences. Grey Relation Analysis is connected by a several researcher to analysis cutting parameter having multi-response through grey relation grade. Following steps in Taguchi method include grey relation analysis to optimize the drilling operation having multiple performance qualities.

1. Determined the process performance quality and cutting parameter to be collected.
2. Find No of levels for cutting parameter in experiment
3. Investigate the proper type orthogonal array and implement the cutting parameter to be this orthogonal array
4. According to orthogonal array experiment conducted by a suitable situation that are obey the particular sequence.
5. Normalize the multi response which are carried out after the experiments
6. Apply Grey Relation method and determined coefficient of grey relational.

7. Find Grey relation grade that are average of coefficient of grey relational
8. Investigate the performance results with help of grey relational grade and MINITAB
9. Select the best cutting parameter by Graph which generated by MINITAB

4.2 Taguchi method: Taguchi method is introduced by Dr. Genichi Taguchi, a Japanese quality administration. The method investigated the idea of quadratic quality loss function and utilized a statistical measure of characteristic called Signal to Noise ratio. The S/N ratio is the proportion of signal (mean) to the standard noise (devotion) quality of the process to be optimized. This method has a simple design of experiment, better effective and systematic sequence to optimize process performance, time and cost [19]. The standard S/N ratio expresses in following:

1) Higher-is-better
2) Smaller-is-better
3) Nominal-the-best

4.3 Methodology Details: Grey Analysis relation with Taguchi method

Step 1: Selection of cutting Parameter (Spindle Speed, Feed, and diameter of drill bit) which used in experiments. In experiment, three process parameters and four different levels have been chosen.

Steps2: In this study, L_{16} orthogonal array has been applied to conduct the experiments to evaluate the performance characteristics (thrust force, torque, surface roughness and delamination at entry and exit of composite) as shown in Table 3 to analysis this process quality.

Table 3.Experimental Results

Sl. No	Thrust [KN]	Torque [KN-mm]	Ra [μm]	D.F at entry	D.F. at exit
1.	0.098	0.36	4.14	1.3888	1.4087
2.	0.091	0.41	4.58	1.3687	1.4368
3.	0.189	0.91	4.015	1.2827	1.3575
4.	0.202	1.26	5.595	1.0716	1.0885
5.	0.061	0.33	5.615	1.4175	1.4242

6.	0.099	0.24	5.124	1.414	1.444
7.	0.123	0.43	6.56	1.0651	1.0809
8.	0.177	1.13	7.685	1.3905	1.4021
9.	0.109	0.52	5.18	1.2881	1.3653
10.	0.092	0.48	5.94	1.1031	1.1654
11.	0.087	0.54	5.34	1.4177	1.4483
12.	0.084	0.8	7.293	1.3963	1.4652
13.	0.081	0.7	6.739	1.0493	1.072
14.	0.113	0.61	9.4	1.2754	1.3215
15.	0.07	0.49	7.463	1.4345	1.5247
16.	0.085	0.53	8.95	1.3944	1.4002

Steps 3: Data Pre-Processing– It involves the conversion of data in common scale at the range from 0 to 1 which eliminates the dimensional effect and reduce the variability. Here, 0 is considered as worst value whereas 1 is considered as best value. Following are steps involved for data pre-processing.

Higher-is better

Zij = Normalized value for i_{th} trial for j_{th} dependant response

$$Z_{ij} = \frac{Y_{ij} \quad \min(Y_{ij}, i = 1,2,3,4,5.....................................n)}{\max(Y_{if}, i = 1,2,3,4,..............n) \quad \min(Y_{ij} = i,2,3,4...........n)} \tag{2}$$

Lower-is better

$$Z_{ij} = \frac{\max(Y_{ij}, i = 1,2,3,4,5......................................n) \quad Yij}{\max(Y_{if}, i = 1,2,3,4,..............n) \quad \min(Y_{ij} = i,2,3,4...........n)} \tag{3}$$

Nominal-the-best

$$Z_{ij} = \frac{(|Y_{ij} - T|) - \min(|Y_{ij} - T|Y_{ij}, i = 1,2,3,4,.......................................n) - Yij}{\max(|Y_{ih} - T|, i = 1,2,3,4,...............n) - \min(|Y_{ih} - T_{ij}|, i = i,2,3,4.............n)} \tag{4}$$

Normalized values are represented in Table 4.

Table 4. Normalized of value

Sl. No.	N-Thrust	N-Torque	N-RA	N-D.F. entry	N-D.F. Exit
1	0.737589	0.882353	0.976787	0.118794	0.25624
2	0.787234	0.833333	0.895079	0.171042	0.194168
3	0.092199	0.343137	1	0.394593	0.36934
4	0	0	0.706592	0.943332	0.963552
5	1	0.911765	0.702878	0.04419	0.222001
6	0.730496	1	0.794243	0.053288	0.17738
7	0.560284	0.813725	0.527391	0.960229	0.98034
8	0.177305	0.127451	0.318477	0.114375	0.292909
9	0.659574	0.72549	0.783658	0.380556	0.35211
10	0.780142	0.764706	0.642526	0.86145	0.793682
11	0.815603	0.705882	0.753946	0.04367	0.168765
12	0.836879	0.45098	0.391272	0.099298	0.131434
13	0.858156	0.54902	0.49415	1	1
14	0.631206	0.637255	0	0.413569	0.448862
15	0.93617	0.754902	0.359703	0	0
16	0.829787	0.715686	0.083565	0.104237	0.275017

Step 4: Determined the grey relation coefficient (GC) for the normalized value. Its investigated to express the correlation between the best (ideal) and real normalized experiments data. Grey Relation coefficient can be shows in mathematically Eq^n (5)

$$GC_{ij} = \frac{\Delta min + \lambda \Delta max}{\Delta ij + \lambda \Delta max} \quad (5)$$

{ i = 1, 2, 3, 4, ……………n experiments}
{j = 1, 2, 3, 4,………… … m experiments}

Where,

GC_{ij} = Grey Relation Coefficient for the i_{th} experiment and j_{th} depended response or variables

Δ = Quality loss is the difference between best or idle value to the Y_{oj} value for Y_{th} response which is deviation from aim (target) value and can be tread as loss of quality.

Y_{oj} = Optimum performance value or best normalized value of j_{th} response

Y_{ih} = for i_{th} normalized data of the j_{th} depended variable or response

Δ_{max} = Largest value of Δ

Δ_{min} = smallest value of Δ

Table 5.Grey Relation Coefficient

Sl. No.	Grey 1	Grey 2	Grey 3	Grey 4	Grey 5
1	0.404011	0.361702	0.338573	0.808024	0.661165
2	0.38843	0.375	0.358403	0.745109	0.720286
3	0.844311	0.593023	0.333333	0.558913	0.575149
4	1	1	0.41439	0.346421	0.341635
5	0.333333	0.354167	0.41567	0.918796	0.69252
6	0.40634	0.333333	0.386326	0.903688	0.738138
7	0.471572	0.380597	0.48667	0.342412	0.33776
8	0.73822	0.796875	0.610891	0.813835	0.630589
9	0.431193	0.408	0.389512	0.567823	0.586779
10	0.390582	0.395349	0.437627	0.367255	0.386494
11	0.380054	0.414634	0.398741	0.919675	0.747647
12	0.374005	0.525773	0.560996	0.834309	0.791849
13	0.368146	0.476636	0.502942	0.333333	0.333333
14	0.442006	0.439655	1	0.547304	0.526947
15	0.348148	0.398438	0.581596	1	1
16	0.376	0.41129	0.856802	0.82749	0.645147

Steps 5: Compute the overall grade (G_i) by mean of grey relational coefficient corresponding to every performance data or value. The gray relational grade can be formulated mathematically as Eq^n (6)

$$G_i = \frac{1}{m}\sum GC_{ij} \qquad (6)$$

Where, m is the number of performance

Steps 6: Application of Taguchi to evaluate the optimal parametric combination. Higher-is- better criterion has been selected

Higher is better

S/N ratio $= -10\log_{10}\left(\frac{1}{n}\sum\frac{1}{Gi_{ij}{}^{2}}\right)$ (7)

Where,

n = Total No of experiment

m = No of response

G_i = Corresponding overall grade

i = 1, 2, 3, 4 ....n

j = 1, 2, 3, 4 ....m

It has been observed from Fig. 12 that the optimal parameter setting obtained as speed (N) at level 1400, feed (f) at level 300, and drill diameter at 8 mm. It has been observed from Table 6 that predicted S/N ratio for this optimal combination is higher among all the computed S/N ratios. It can be concluded from Table 7 that the spindle speed is the most influencing parameter whereas feed has less influence.

Table 6.Overall grade and corresponding S/N ratio

Sl. No	N	F	D	Overall Grade	S/N ratio	P-S/N ratio
1	800	150	5	0.5147	-5.769	-2.8554
2	800	200	6	0.51745	-5.7227	
3	800	250	8	0.58095	-4.7173	
4	800	300	10	0.62049	-4.1453	
5	1000	150	6	0.5429	-5.3057	
6	1000	200	5	0.55357	-5.1366	
7	1000	250	10	0.4038	-7.8766	
8	1000	300	8	0.71808	-2.8765	
9	1200	150	8	0.47666	-6.4358	
10	1200	200	10	0.39546	-8.0579	
11	1200	250	5	0.57215	-4.8498	
12	1200	300	6	0.61739	-4.1889	
13	1400	150	10	0.40288	-7.8965	

14	1400	200	8	0.59118	-4.5656	
15	1400	250	6	0.66564	-3.5353	
16	1400	300	5	0.62335	-4.1054	

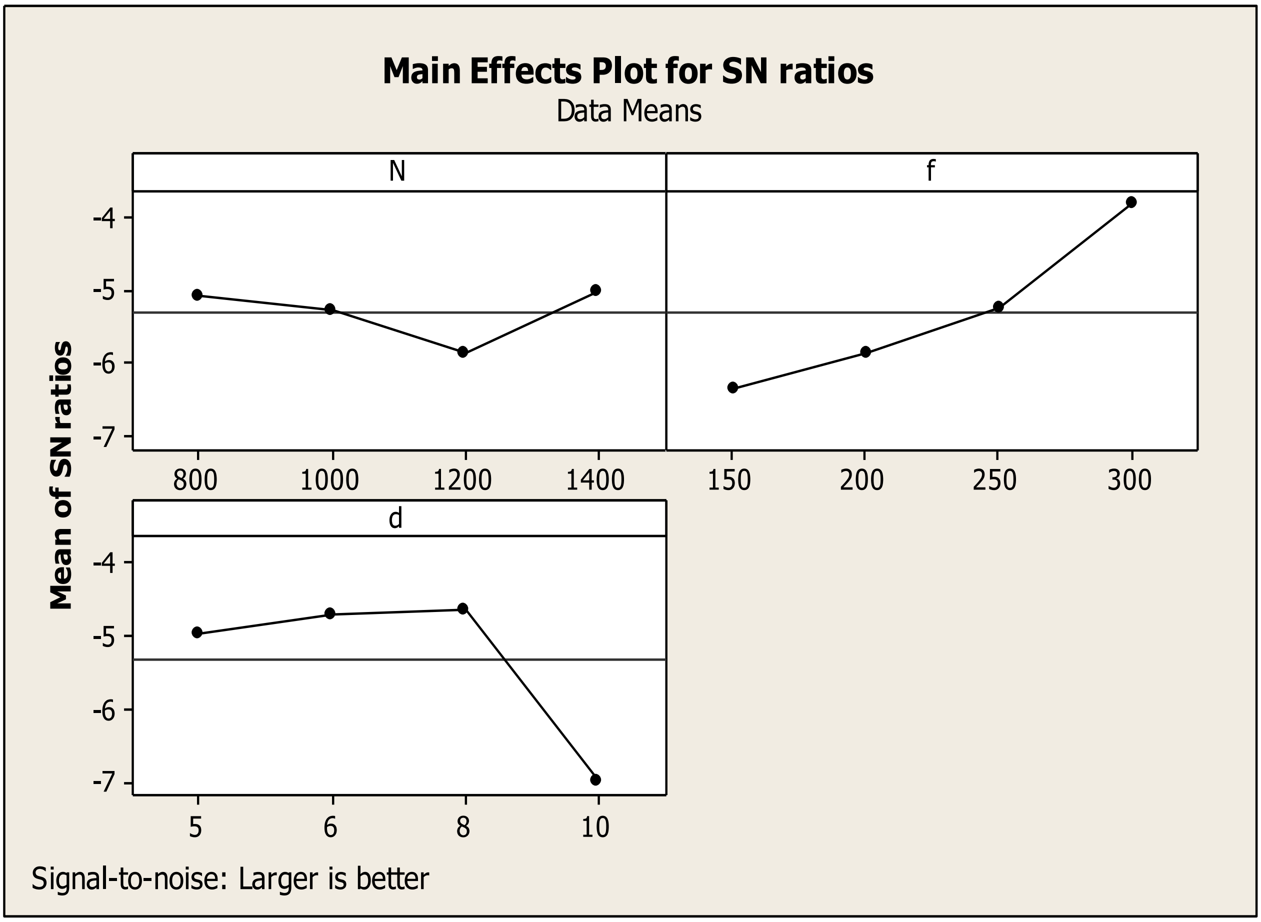

Fig12. Main effect plot for S/N ratio

Table 7: Mean response table

Level	Speed	Feed	Tool diameter
1	-5.08857	-5.30565	-5.13663
2	-5.2988	-8.05792	-3.53526
3	-5.8830	-4.8498	-4.56557
4	-5.02569	-2.87652	-7.87663
Delta=max-min	-0.85731	-5.1814	-4.34137
Rank	1	3	2

4.4 Conclusions

In this study, grey theory combined with Taguchi's rule based model has been adopted to optimize spindle speed, feed rate and drill diameter in drilling of glass fiber reinforced polymer (GFRP) composite. The drilling parameters such as spindle speed, feed and drill diameter has been taken to assess their influence on torque, thrust force, delamination (at both entry and exit) and surface roughness. Grey relation analysis is used to aggregate the output responses into single response. This integrated approach can be considered as an efficient tool for continuous process improvement and off-line quality control.

4.5 Future Scope:

The present study can be extended in the following direction:

1. Mathematical model may be developed using response surface methodology (RSM) and other statistical tools.
2. Apart from the drilling, other convention machining operations such as turning, milling etc. will be carried out to understand the machining behavior of GFRP composites.
3. The present work can be extended for further quality improvement like other machining parameters such as drill geometry and material parameters can also be taken into account for experimental analysis.

References

1. Guner F. S., Yagci Y. And Erciyes A. T. (2006), Polymers from triglyceride oils. Progress in Polymer Science, 31(7): 633-670.
2. Mohanty A. K., Misra M., and Drzal L. T. (2001), Surface modifications of natural fibers and performance of the resulting biocomposites: An overview. Composite Interfaces, 8(5): 313-343.
3. Kaw A. K. (2010) Mechanics of composite materials. CRC press.
4. Ahamed A. R., Asokan P., Aravindan S.and Prakash M. K. (2010), Drilling of hybrid Al-5% SiCp-5% B4Cp metal matrix composites. The international journal of advanced manufacturing technology, 49(9-12): 871-877.
5. Albuquerque De, Joseph A. C., Carvalhode L. H. and Almeida d, J. R. M. (2000), Effect of wettability and ageing conditions on the physical and mechanical properties of uniaxially oriented jute-roving-reinforced polyester composites. Composites Science and Technology, 60(6): 833-844.
6. Rashed H. M. M. A., Islam M. A. and Rizvi F. B. (2006), Effects of process parameters on tensile strength of jute fiber reinforced thermoplastic composites. Journal of Naval Architecture and Marine Engineering, 3(1): 1-6.
7. Mehrabian R. G. R. R., Riek R. G. and Flemings, M. (1974), Preparation and casting of metal-particulate non-metal composites. Metallurgical Transactions,5(8): 1899-1905.
8. Davim J.P., Reis P. and Antonio C.C. (2004), Experimental study of drilling glass fiber reinforced plastics (GFRP) manufactured by hand lay-up. Composites Science and Technology, 64(2): 289-297
9. Sonbaty E.I., Khashaba U. A. and Machaly T. (2004), Factors affecting the machinability of GFR/epoxy composites. Composite structures, 63(3): 329-338

10. Langella A, Nele L and Maio A. (2005), A torque and thrust prediction model for drilling of composite materials. *Composites, Part A* 36(1): 83-93.
11. Singh R.V.S., Latha B. and Senthilkumar V.S. (2009), Modeling and Analysis of thrust force and torque in drilling GFRP composites by multi-facet drill using fuzzy logic. International Journal of Recent Trends in Engineering, 1(5): 66-70.
12. Kilickap E.(2010), Optimization of cutting Parameters on delamination based on Taguchi method during drilling of GFRP composite. Expert Syst. Appl. 37(8): 6116–6122
13. Latha B., Senthilkumar V.S. and Palanikumar K., (2014), An modeling and optimization of process parameters for delamination in drilling glass fiber reinforced plastic (GFRP) composites. S. S. Engineering, Machining Science and Technology, 9(1): 37–41.
14. Palanikumar K. (2011), Experimental investigation and optimisation in drilling of GFRP composites. Measurement, 44(10): 2138-2148.
15. Verma R. K., Abhishek K., Datta S. and Mahapatra S. S. (2011), Fuzzy rule based optimization in machining of FRP composites. Turkish Journal of Fuzzy System, 2(2): 99-121.
16. Tsao C. C., Hocheng H. and Chen Y. C. (2012), Delamination reduction in drilling composite materials by active backup force. CIRP Annals-Manufacturing Technology, 61(1): 91-94.
17. Krishnaraj V., Prabukarthi A., Ramanathan A., Elanghovan N., Kumar M. S., Zitoune R. and Davim J. P. (2012), Optimization of machining parameters at high speed drilling of carbon fiber reinforced plastic (CFRP) laminates.Composites, Part B: Engineering, 43(4):1791-1799

18. Abhishek K, Datta S, Mahapatra S.S., Mandal G. and Majumdar G.(2013), Taguchi approach followed by fuzzy linguistic reasoning for quality-productivity optimization in machining operation: A case study, Journal of Manufacturing Technology Management, 24(6): 929-951
19. Abhishek K., Datta S., Mahapatra S. S., Mandal G. and Majumdar G., (2013), Taguchi approach followed by fuzzy linguistic reasoning for quality-productivity optimization in machining operation: A case study, Journal of Manufacturing Technology and Management, 24(6): 929-951,