



# Experimental Study on Drilling Characteristics of Fiber Metal Laminates

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## Article Information

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**Abstract**— Drilling is often experienced machining process in industry due to the need for element assembly in mechanical pieces and structures. Drilling of composite material appreciably affected by damage tendency of these materials under action of cutting forces (thrust forces and torque). So aim of this experiment is the drilling parameters (feed rate and cutting speed) in fiber metal laminates. The analysis of variance was performed to investigate the drilling characteristics of fiber metal laminates using HSS (High speed steel) two fluted standard twist drill bit in 4mm. The main purpose is to find the chip shape during diverse feed rates in fiber metal laminates materials.

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**Keywords:** *Drilling, Machining, HSS, Fiber, Metal.*

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## I. INTRODUCTION

Fiber Metal Laminates are hybrid materials built up from interlacing layers thin metals and fiber reinforced adhesives. They were developed in late 1970's and have gained wide attention in the aerospace and space industries since late 1980. There are two types of commercially available FML: GLARE and ARALL. The past is made of alternating glass-epoxy and aluminium layers while the latter is formed by alternating aramid epoxy and aluminium layers. Glare is a hybrid composite. In this composites offer several advantages such as better corrosion resistance, better fire resistance, better damage tolerance to fatigue crack growth, foreign object damage and high strength etc.

Fiber Metal Laminates (FML) are new type of composite developed at the Delft University of Technology. Thin sheets of aluminium are alternated with thin sheets of traditional composite. The first FML was ARALL, a combination of aluminium and Aramid/epoxy. Although the material showed promise and adoption by the aerospace industry was slow. In the 1980s, Delft University began developing a glass/epoxy FML called Glare. Glare was intended to be an alternative to aluminium in aircraft structures. Early research showed it had benefit over both aluminium and fiber glass composites, especially in fatigue and impact. Development continued over a number of years, and the commercial breakthrough came when Airbus decided to use the material on the A380. Glass fiber Reinforced Epoxy Aluminium (GLARE) is a Fiber Metal Laminate (FML) composed of several very thin layers of metal (aluminium) interspersed with layers of glass fiber, bonded together with a matrix such as epoxy. The bi-directional glass fiber layers may be aligned in different

directions to suit the predicted stress conditions. Even though GLARE is a composite material, its material properties and fabrications are very related to bulk aluminium metal sheets. It has far less in common with composite structures when it comes to design, manufacture and inspection are maintained. GLARE parts are constructed and repaired using generally conventional metal matrix techniques.

Its major advantages over conventional aluminium are:

- Better damage tolerance
- High stiffness
- Better corrosion resistance
- Lower specific weight

While a simple manufactured sheet of GLARE will be more exclusive than an equivalent sheet of aluminium, considerable production savings can be made using the aforementioned optimization. A structure properly designed for GLARE will be significantly lighter and less complex than an equivalent metal structure, and will require less inspection and maintenance and enjoy a much longer life time-till failure, making it a cheaper, lighter and safer option over all.

GLARE is a relatively successful FML, patented by Akzo Nobel in 1987, which has entered commercial applications in the Airbus A380. GLARE is also the substance used in the ECOS3 blast-resistant Unit Load Device. This is cargo container shown to completely contain the explosion and fire resulting from a bomb such as that used over Lockerble. Other applications include among

others the application in the Learjet 45 and in the earlier period also in cargo floors of the Boeing 737.

GLARE is presently produced by Cytec Engineered Materials in Wrexham, UK who supplies it to the Airbus A380 component manufacturing facilities at Stork Fokker in the Netherlands plus at Airbus in the Nordenham, Germany. Stork Fokker has opened a brand new ability next to its existing facilities in Papendrecht, the Netherlands. There Stork Fokker is able to produce Glare sheets of 4.5m\*11.5m including the milling of doors windows etc.

## II. LITERATURE REVIEW

Tamersinmazcelick, Mustafa ozgur, Onur coban ARALL, GLARE and CARALL laminates are now being used as structural materials. It can be said that GLARE laminates found more than ARALL and CARALL laminates in aircraft application.

Mechanical properties of FMLs are being improved by the interface bond between composites and metal plies. This enhancement could be controlled by various test method. This control reports give quality information are suitable for design specification. In this review, test method of bending, fatigue, tensile, low and high velocity impact and blast loading tests for determining the mechanical properties of FMLs and research studies utilized form these test method were explained in detail.

Mohamed K.Hassan, S.K.Azabi, W.W. Marzouk. GLARE is a hybrid composite material; it has a competitive role in aerospace industry. The proposed procedure for manufacturing the GLARE material is an effective and having durability. Increasing the number of glass fiber laminates gives good strength but increase the thickness the thickness of the whole specimen in form of de-lamination failure.

Sunil Bhat and S.Narayanan. GLARE comprising three thin aerospace 2014-T6 aluminium alloy sheets and epoxy resin impregnated unidirectional E-glass fiber based composite prepregs, is successfully fabricated and tested are mechanical properties viz. tensile, shear and flexural strength and interlaminar fracture toughness. Consistency in result supports the accuracy of the value. Viability of laminates fabrication procedure is proved. Quality of interface between un-identical material layers of the laminate is tested theoretically and is found to be good.

Vogelesang L.B. and Volt.A GLARE offers the aircraft structural designer a dent tolerant, lightweight, cost-effective solution for many alloys, tension dominated application. Originally developed for their outstanding fatigue resistance other characteristics of fiber metal laminates include high specific static properties, ease of manufacturing, excellent impact resistance, burn through capabilities rivalling titanium alloys, and good corrosion resistance, already in production on the C-17 aft cargo door and some transport aircraft flooring applications, fiber metal laminates seem poised for a much larger hope in the primary structure of pressurized transport fuselages, like Airbus 340 and the challenging A3XX.

A.Venugopal and N.Manoharan. In this paper, metal matrix composite is fabricated by stir casting process with diverse volume fractions of silicon carbide with aluminium 6061 alloy. It is concluded that the flexural strength of the composite increases with the increasing weight percentage of the Silicon Carbide. The flexural strength of specimen is higher than that of the other four samples. The Brinell hardness of specimen is greater than other samples because of the presence of silicon carbide.

T.Mohan and N.Monoharan. In this paper, hybrid composite is fabricated by stir casting process with diverse proportions of Alumina. It is concluded that the tensile strength of Al matrix composites reinforced with Sic particles is exceeding that of other samples.

G.Reyes, H.Kang. The tensile and fatigue behavior of fiber metal laminate are studied. Initial tensile testing results showed the curved based hybrid materials exhibited a ductile type of behavior, where the ultimate tensile strength and strain at fracture was mainly dominated by the aluminium alloy. Fatigue testing of these thermoplastic based hybrid system revealed that the Twined-based material offer better fatigue properties at all levels of stress over the curve-based materials.

Yi Huang, Jianzhong Liu, Xiao Huang, Guangquan Yue. In this paper delamination addition and fatigue crack growth behaviours' under various single overloads are investigated for GLARE 2/3 with fiber direction are 0/0°. Effect of applied over load variables on fatigue crack growth rates and delamination extension behaviours is analyzed. The relationship between fatigue crack growth rates and delamination extension after application of overhead has been investigated.

Vijya Ramnath.B, C.Elanchuhian, MJavignesh, S.Rajesh. In this Work, three diverse samples are fabricated and the tensile strength of sampling is high and the flexural strength of obtained and the impact test result is higher than the tensile test specimen. The Brinell hardness of Specimen is carried by 52.80Mpa load. The mechanical properties are investigated.

Mahesh M.Senthil Kumar A. In this article, presents the experimental Investigations of tensile and flexural behavior of glass Fiber reinforced aluminium laminates (Glare) with diverse orientation was compared. The following conclusions are drawn:

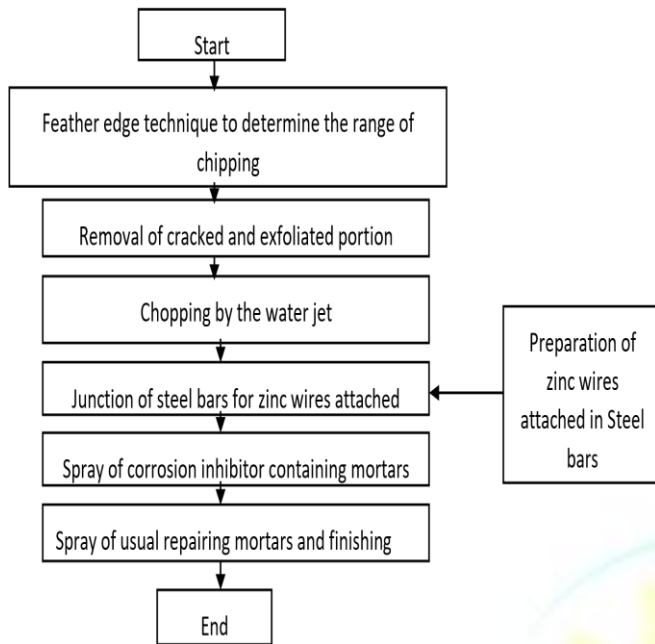
## III. SYSTEM ANALYSIS

It is based on the law of water erosion. When a high speed jet of water strikes the surface, the elimination of substance takes place. Pure water jet is used to machine softer substance. But to cut harder materials, some abrasive particles mixed with the water for machining and it is called as AWJM.

### A. Abrasive Materials

The most universally used abrasive particles in AWJM are garnet and aluminium oxide. Sand (SiO<sub>2</sub>) and glass bead

is furthermore used as abrasive. The function of abrasive particle is to improve the cutting ability of water jet.



The above shown fig.11 shows the water jet machine for cutting specimens with good surface finish

The various parts of water jet machining are

#### B. Hydraulic pump

It is used to circulate the water from the storage container during the machining process. The pump delivers water to the intensifier at low pressure of about 5 bar. A booster is also used which boost the initial pressure of water to 11 bar before delivering it to the intensifier.

#### C. Hydraulic intensifier

It is used to raise the pressure of water to a very high pressure. It receives the water from the Pump at 4 bar and increases its pressure up to 3000 to 4000 bar.

#### D. Accumulator

It stores the high pressurized water temporary. It supplies that fluid when a large amount of pressure energy is necessary. It eliminates pressure fluctuation circumstances in the machining process.

#### E. Mixing chamber

It is a vacuum chamber where the mixture of abrasive particles into water takes position.

#### F. Control Valve

It controls the pressure as well as path of the water jet.

#### G. Flow Regulator or Valve

The flow of the water is regulated with the assist of flow regulator.

#### H. Nozzle

It is device which is used to change pressure energy of water into kinetic energy in water jet machining. Here nozzle converts the pressure of water jet into high speed beam of water jet. The tip of the nozzle is through of ruby or diamond to prevent it from erosion.

#### I. Drain and Catcher System

Following the machining, the debris and machined particles from the water is separated out with the help of drain and catcher system. It removes the metal particle and other surplus particles from the water and sends it back to the reservoir for further use.

- The water from the reservoir is pumped to the intensifier with the help of a pump.
- The intensifier increases the pressure of the water from 5 bars to 3000 to 4000 bar. This high pressure water from the intensifier is moved to the nozzle as well as in accumulator.
- The accumulator stores the high pressure water and supplies it at any instant when it is required. It is used to eliminate the fluctuation of high pressure requirement of machining hard material.
- The high pressure water is then passed to the nozzle where the high pressure energy of the water is converted into kinetic energy. A very high velocity jet of water (1000 m/s) comes out through the nozzle in the form of narrow beam.
- Abrasive such as garnet or aluminium oxide is mixed with water within the nozzle. A mixing chamber is there in the nozzle where the abrasives get mixed with the high pressure water.
- This high velocity jet of water when strikes the surface of the W/P removes the material from it.
- The water jet after machining is gets collected by the drain and catcher system. Here the debris, metal particles from the water is removed and it is supplied to the reservoir tank.
- The working will same for the water jet machining but abrasive particles is not mixed with the high velocity jet. Only pure water jet comes out from the outlet of the nozzle.

#### IV. EXPERIMENTAL PROCEDURE

Manufacturing process typically used to make products found in construction infrastructure market are covered. Unique to the composites industry is the ability to create a product from many different manufacturing processes. There are a wide variety of products available to the composites manufacturer to produce cost efficient products. Each of the fabrication processes has characteristics that define the type of products to be produced. In order to select the most efficient manufacturing process, the manufacturing team considers several factors such as performance requirement, surface complexity, total production volume and labour



**A. Method for manufacturing fiber metal laminates**

- Resin Transfer Molding (RTM)
- Vacuum Assisted Resin Transfer Molding (VARTM)
- Compression molding Hand lay-up molding process Auto clave molding process.

**B. Hand Lay-Up Method**

Hand lay-up moulding is used for the production of part of any dimensions such as technical parts with a surface area of a few square feet, as well as swimming pools as large as 1600 square feet. But this method is generally limited to the manufacture of parts with relatively simple shapes that require only one face to have a smooth appearance (the other face being rough from the moulding operation). It is recommended for small and medium volumes requiring minimal investment.

The contact moulding method consists of applying these elements successively onto a mould surface:

- A release agent
- A gel coat
- A layer of liquid thermosetting resin, of viscosity between 0.3 and 0.4 and of medium reactivity
- A layer of reinforcement in order to obtain the desired thickness of the structure.

This operation is repeated for each layer of reinforcement in order to obtain the desired thickness of the structure.

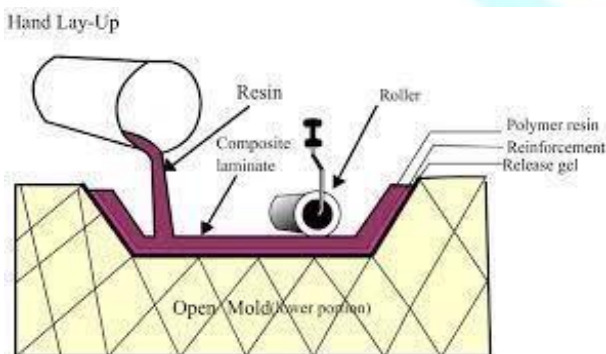


Table 1: MATERIAL PROPERTIES

S.NO	PROPERTIES	AL-2024-T3	GLASS FIBER	CARBON FIBER
1	Modulus of elasticity	70-80	50-80	228
2	Ultimate tensile strength	300	1500	1600
3	Density	2.7	2.5	1.6
4	Poisson's ratio	0.33	0.22	0.1
5	Elongation(%)	8-13	4-5	3

6	Shear modulus (Gpa)	27.06	29.7	5
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**Carbon Fiber Based Fiber Metal Laminate(C-Fml)**



The above mentioned figure is a carbon fiber based fiber metal laminate in which it is fabricated by seven layers of materials. Three layers are aluminum 2024-T3 and remaining four layers are carbon fiber.

The layers are arranged in an order of carbon fiber, AL 2024-T3, carbon fiber, AL 2024-T3, carbon fiber, AL 2024-T3, carbon fiber in a sandwich form.

The first layer is carbon fiber, second layer is AL 2024-T3, third layer is carbon fiber, fourth layer is AL 2024-T3, fifth layer is carbon fiber, sixth layer is AL 2024-T3 and seventh layer is carbon fiber.

Carbon fiber	0.25mm
AL2024-T3	0.5mm
Carbon fiber	0.25mm
AL2024-T3	0.5mm
Carbon fiber	0.25mm
AL2024-T3	0.5mm
Carbon fiber	0.25mm

**Glass Fiber Based Fiber Metal Laminate (G-Fml)**

The above mentioned figure is a glass fiber based fiber metal laminate in which it is fabricated by seven layers of materials. Three layers are aluminum 2024-T3 and remaining four layers are glass fiber.

The layers are arranged in an order of glass fiber, AL 2024-T3, glass fiber, AL 2024-T3, glass fiber, AL 2024-T3, glass fiber in a sandwich form.

The first layer is glass fiber, second layer is AL 2024-T3, third layer is glass fiber, fourth layer is AL 2024-T3, fifth layer is glass fiber, sixth layer is AL 2024-T3 and seventh layer is glass fiber.

Table 2: Different orientation layer of G-FML

Glass fiber	0.25mm
AL 2024-T3	0.5mm
Glass fibre	0.25mm

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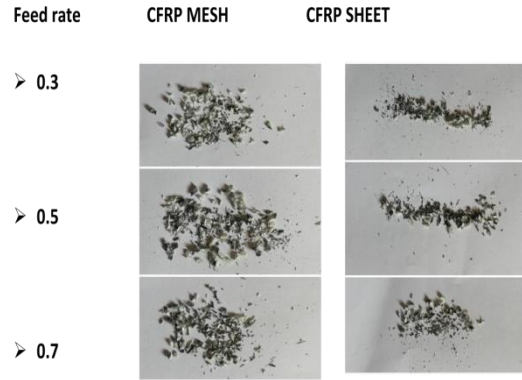
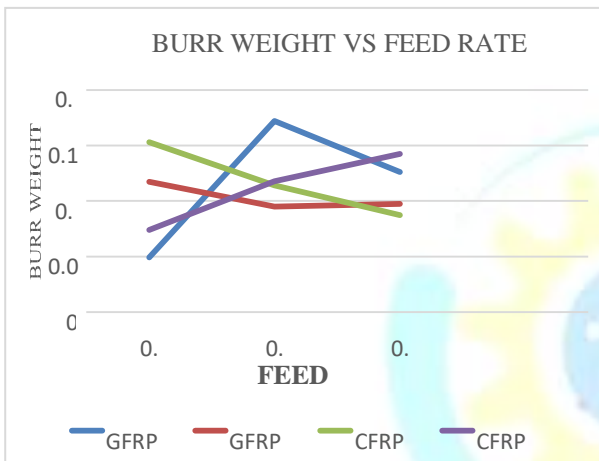
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AL 2024-T3	0.5mm
Glass fiber	0.25mm
AL 2024-T3	0.5mm
Glass fiber	0.25mm

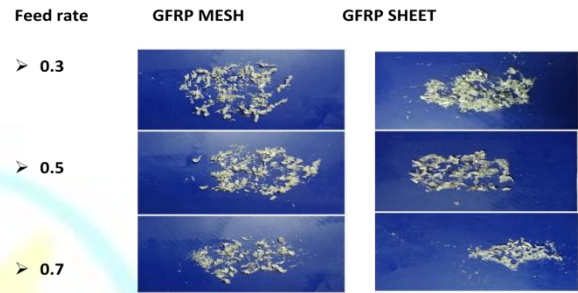
We have done a drilling process on the composite laminate sheet at various feed rates of 0.3mm/rev, 0.5mm/rev and 0.7mm/rev respectively. In GFRP mesh and CFRP sheet the weight of the chip increases as the feed rate increases. But in the GFRP sheet and CFRP mesh the weight of the chip decreases as the feed increases.

Chip removal composite

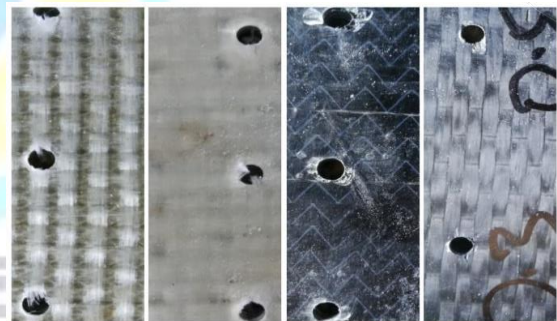
### GRAPH



Chip formation of CFRP mesh and CFRP sheet



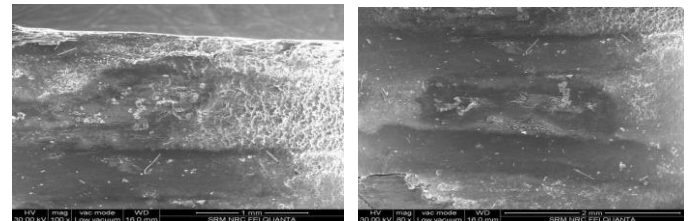
Chip formation of CFRP mesh and CFRP sheet AFTER DRILLING PROCESS



HSS drill of composites

The above indicates the drill holes of different composite laminates of AL-mesh with E-glass fiber, AL-perforated sheet with E-glass fiber, Carbon fiber with AL-perforated sheet.

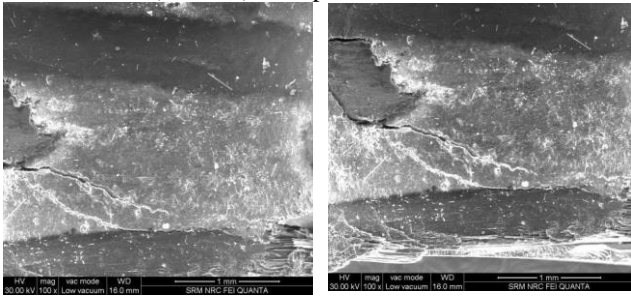
### V. RESULTS & DISCUSSION



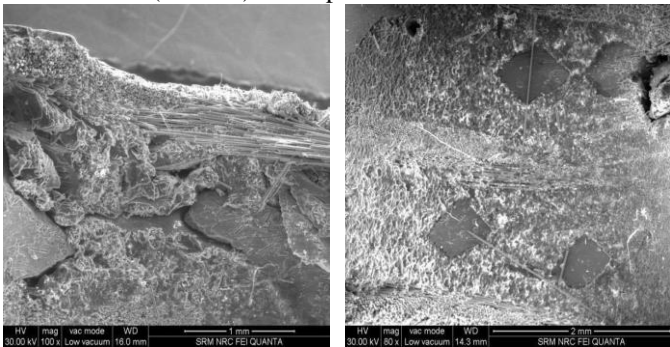
Drilled Carbon fibre with Al mesh

S.NO	MATERIAL	FEED RATE (m/rev)	CUTTING SPEED (m/min)	DRILL BIT ANGLE (DEG)	BURR WEIGHT (g)
1.	GFRP MESH	0.3	100	118	0.0491
		0.5			0.1722
		0.6			0.1262
2.	GFRP SHEET	0.3	100	118	0.1174
		0.5			0.0949
		0.7			0.0975
3.	CFRP MESH	0.3	100	118	0.1529
		0.5			0.1141
		0.7			0.0873
4.	CFRP SHEET	0.3	100	118	0.0740
		0.5			0.1178
		0.7			0.1423

The above shows the Scanning Electron Microscopic view of carbon fiber laminated with aluminium mesh and noticed that the material undergone the drilling process at the rate of 0.3(mm/rev) with pessimisible level cracks

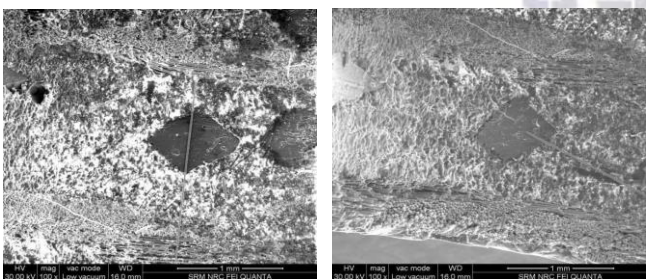


The above shows the Scanning Electron Microscopic view of carbon fiber laminated with aluminium sheet and noticed that the material undergone the drilling process at the rate of 0.3(mm/rev) with optimistic level of cracks



Al sheet with E-glass fiber

The above shows the Scanning Electron Microscopic view of E-glass fiber laminated with aluminium sheet and noticed that the material undergone the drilling process at the rate of 0.3(mm/rev) with very lesser amount of cracks.



Al mesh with E-glass fiber

The above fig.19 shows the Scanning Electron Microscopic view of E-glass fiber laminated with aluminium mesh and noticed that the material undergone the drilling process at the rate of 0.3(mm/rev)with very lesser amount of cracks From the above analysis of the scanning electron microscopic study, it clear that the cracking is very high in the aluminium sheet with E-glass fiber composite laminate and the cracking is moderate in the aluminium

mesh with E-glass fiber composite and carbon fiber with aluminium sheet composite material. It is also seen that the crack is very less in the carbon fiber with the aluminium mesh composite laminate material. So the composition of carbon fiber with Al mesh laminate material is better composite material than any other composite materials.

#### VI. CONCLUSION

Here we study the drilling characteristics of fiber metal laminates such as E-glass fiber, carbon fiber, aluminium sheet and aluminium meshes. The carbon fiber and glass fiber based composites have been fabricated by hand layup process. We laminate E-glass fiber with Al sheet, E-glass fiber with Al mesh, Carbon fiber with Al mesh and Carbon fiber with Al sheet. We drill this laminate sheet on various feeds and cut this drills into semi halves as, we have to take the SEM image of this semi half drills. As a result we acquire cracks while lamination of carbon fiber with aluminium sheet whereas we acquire pessimistic cracks, when we use E-glass fiber with Al mesh and E-glass fiber with Al sheet. We acquire a crystal clear image on drilling the lamination of carbon fiber with Al mesh.

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