Finite Element Modeling of Laser Drilled Micro Hole on CFRP Composites

Asst. Prof. Hema Kalyana Sahu[1], Prof. Dr. Jitendra Kumar Sahu[2]

[1]*Faculty Dept. of Mech. SMIT, DEC, Chandipadar, Berhampur, Odisha, India*
[2]*Mech. HOD and Head T&P office SMIT, DEC, Chandipadar, Berhampur, Odisha, India*

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Abstract: *In recent time as world is more and more interconnected than ever before, in terms of developing technology with advanced machining process and material. our objective is to develop a multilayer composite material by using an epoxy resin (60% in volume), in our experiment we had selected a composite (FRP) fiber reinforced polymer with high strength polymer (Plastic) matrix has been reinforcing for achieving high strength. Since CFRP machinability is a major concern to attain surface finishing at micro level for which finite element method has been used for analysis of FRP laminated based micro drill hole by laser drilling. For the result we had used ANSYS 15.0 and scanning electron microscope (SEM). To optimum parameters has been obtained for better quality surface finish by minimizing the amount of heat accumulated zone which has been arise by laser drilling.*

Keywords: Laser drilling, finite element method, CFRP Composite material.

1. INTRODUCTION

In recent years use of composite material is increasing to produce product for the use in different segment as it has greater advantage in mechanical properties. As the years passes development in modeling of product has been improved by using numerical modeling, which describes the material deportment and development of defects during machining. With uninterrupted development of composite material, carbon fiber composite has a greater affinity to be used in different sector to produce precession and high strength product to fulfill the purpose. From the properties it has been conclude that carbon fiber composite material is having high strength, resistance to corrosion, fatigue resistance, damage tolerance, acoustic and thermal insulation power, thermal conductivity is less and other characteristics which we could not find while comparing with different alloy and material. In case of composite material fabrication or joining, machining which required hole which can be obtained by drilling by removing excess material, but in case of composite material because of its mechanical properties cutting performance is poor due to this a large plastic deformation arises during process resulting defects like micro-cracking, fiber-deboning, fiber pull out & buckling, cracking and delamination, burrs etc., which leads to tool wear and affecting precision machining and efficiency. Since composite material are non-homogeneity in their properties, major bother for industry is to machining of these material conventionally. In order to overcome the machining, non-conventional machining process has been opted for better result. Hole is a major part in each product and which can be obtained by drilling, there is several processes but most optimum is the laser machining (drilling). Generally in Laser drilling high complex dynamic process is involved with complicated geometrical interconnection and friction.

1.1 PREPARATION METHODS OF COMPOSITE

The most common method of manufacturing for large structures such as ship hulls is contact molding in an open female mould using cold curing polyester resin and E-glass reinforcement.

- The varies techniques are:
- Spray-up and Hand lay-up lamination
- Die moulding
- Injection moulding
- Pultrusion process
- Vacuum forming

2. LITERATURE REVIEW

Polymer- based composite material, by their very nature; pose a challenge during secondary machining operations. Even through in most applications involving composite materials, parts are made to their near net shapes, they required some final machining to bring the components to their required dimensional accuracy for final assembly. Thus an importance aspect of manufacturing technology in machining is to obtain parts that confer with the required geometrical and dimensional tolerances. Some of the final machining operation involves drilling, sawing, trimming and grinding. The most important kind of surface damage observed in machining polymer based composite materials is delamination. Many methods for drilling composite material suggested. These include conventional and non-conventional processes. Laser assisted drilling, water jet, EDM and ultrasonic machining are some of the most extensively investigated non-conventional method. However, their disadvantages include a heat-affected zone and lower rate of production. Considering these shortcomings, conventional machining processes still find a wider acceptance for machining composite material and in particular, polymer-based matrix materials.

Hintze et al. [1] a post-machine step, such as milling and drilling, is necessary after curing to create the shape with the required tolerances. For components made of carbon fibre reinforced polymers (CFRP), common problems that occur during manufacturing like fibre pull-outs, delamination, and putrefaction of the material matrix can a_ect the consistency and properties of machined surfaces.

Abrate and Walton [2] emphasise that laser cutting is challenging as component thickness increases, because the layer being extracted prevents the laser beam from cutting. The laser cutting of plastics is very e_ective because of the high absorption rate and low heat conductivity of infrared radiation, which keep the thermal energy highly localised .

Reza and Li [3] examined the use of 1 kW fibre laser IPG YLR-1000-SM for laser cutting in carbon fibre reinforced polymer composites at the University of Manchester's Laser Processing Research Centre (LPRC). The thermal damage caused by various gases and pressure assisting forms, as well as focal plane positions (FPP), were investigated through experimental studies. They concluded that the essential factors in single-pass mode are beam power and scanning speed. Based upon the analysis, the results of the FPP scan showed that these optimal conditions successfully reduced CFRP in a one-pass procedure under the surface of the workpiece with a laser power of 340 W and a scan speed of 20 mm/s. The fibre laser system used a beam focused below the material for the cutting experiments, and which, according to the authors, was used for thermal damage reduction. They noted that even at low scanning rates of 1 mm/s, the material in the piece could not be cut at power levels below 230W.

Klotzbach et al [4] They stated that it is essential to understand the interaction between a laser beam and workpiece because laser cutting quality is strongly influenced by laser power and cutting speed/feed rate, as highlighted by conducted laser machining of CFRP experiments by using three high brilliant laser beam sources—a single-mode fibre laser, a multi-mode fibre laser and CO2 slab laser. They identified that the number of cycles plays a significant role in terms of HAZ reduction when increasing the laser spot velocity during the remote processing. The higher the velocity applied, the higher the required cyclic rate to reach the desirable kerf width.

Wahab et al. [5] to develop A experiment also indicated the superiority of a fibre laser's beam focusing position compared to the experiments of CFRP composites machining by using CO2 and Nd: YAG lasers. The laser cutting of CFRP by Nd: the YAGlaser was examined and They concluded that the pulse Nd: YAG laser can be e_ectively reduced to 30 mm/m with a pulse duration of 0.5 ms. Furthermore, the significant ects on kerf width, HAZ and taper angle are a_ected by the pulse energy and the pulse repetition rate, where a high pulse energy leads to a high HAZ, and a high pulse repetition rate produces a narrow kerf width. As the authors suggested, laser cutting plays a significant role in pulse energy and repetition rate. However, given the fact that the authors were able to attain the optimal parameters, they succeeded in reducing a 1.5 mm thickness of CFRP, which is challenging. This result shows that the operation of pulse mode needs more parameters, including pulse duration, pulse energy and pulse repetition rate to optimise the laser beam e_ciency and power density. Additionally, full penetration cuts are almost impossible due to the available energy supplies during the laser machining process.

Hu et al [6] used the Nd:YVO4 picosecond pulse system to conduct experimental research on CFRP cutting, andachieved a HAZ size of 13~44 _m at a scanning speed of 1500 mm/s. The study showed that HAZ has a minimum value at lower laser power and larger hatch distance. Compared with the picosecond laser, the femtosecond laser has a smaller pulse interval, which can realize the processing of carbon fiber materials with higher precision and less thermal effect.

Alessandro Abena et.al [7] shows that wide range of parameters must be considered when developing FE simulation of machining composites. Model scale has influence on material modelling and failure mechanism. For last 15 years material properties of composites is represented in FEA as equivalent homogeneous material (EHM). This technique is applied at macroscopic level where material is anisotropic and homogeneous. This provide useful information regarding bulk chip formation but lack in interaction between fiber-matrix, which is important to understand defect formation and propagation. But is relatively straight forward to implement at reasonable computational cost. New modelling technique was presented in paper is microscopic simulation methodology (fiber, matrix, and interface). These models have more computational cost, but they provide a comprehensive understanding of cutting mechanics.

Lissek et al [8] noticed reduced thrust force measurements by pre-drilling the holes first. The results concluded that the magnitude of the thrust force critically affects the delamination damage of the CFRP. The progression of damage experienced by an element is influenced by the cutting speed. The stable time increment in a FE analysis is governed by element size, bulk modulus, and material density. The fine mesh and high stiffness of CFRP develops rigid elements that propagate a stress front through the CFRP, creating premature damage. The bulk viscosity parameter can more accurately represent the material response by facilitating dampening; otherwise, it is not well represented in the model.

Isbilir et al [9] to develop a model in this model the drilling process, including the inter-laminar damage, comparing a standard twist drill and step drill geometries. Ply damage was modelled using Hashin's theory, and delamination was based on a cohesive contact relationship. Isbilir et al. described better model prediction capabilities with the inclusion of inter-laminar cohesive modelling. The objective of this work was to progress the development of a macro FE drilling model to be used as a tool to accurately test various drill geometries with reasonable computation time. To substantially reduce computational time, numerical analysis was preformed to investigate the influence of mass scaling, bulk viscosity, friction, strain rate strengthening, and cohesive surface modelling, building on intra-ply and inter-ply progressive failure modelling techniques developed a Experimental work was carried out to investigate the effect of of drill tip geometries on drilling forces and hole quality and to validate FE model prediction capabilities.

Giasin et al [10] created a 3D drilling model of a hybrid material made of stacked glass fibre/epoxy prepreg with aluminum sheets. The model predicted torque within 0.83–17.9% and thrust force within 3.2–53.2%. However, no delamination was identified and was deemed negligible. The effect of including a cohesive surface in finite element modelling on the cutting of CFRP was investigated.

3. FIBRE REINFORCED POLYMER(FRP) PLASTICS:

Fiber-reinforced polymers plastic material consist of fibers of significant strength and stiffness embedded in a matrix with distinct boundaries between them. It is used as reinforcement for making components of structural construction. Material in fiber form are stronger and stiffer then that used in a bulk form. There is a likely presence of flaws in bulk material which affects its strength while internal flaws are mostly absent in the case of fibers.

The commonly used fibers and resins are Carbon fibers, Glass fibers and Agamid fibers and the resins are polyester, vinyl ester and epoxy.

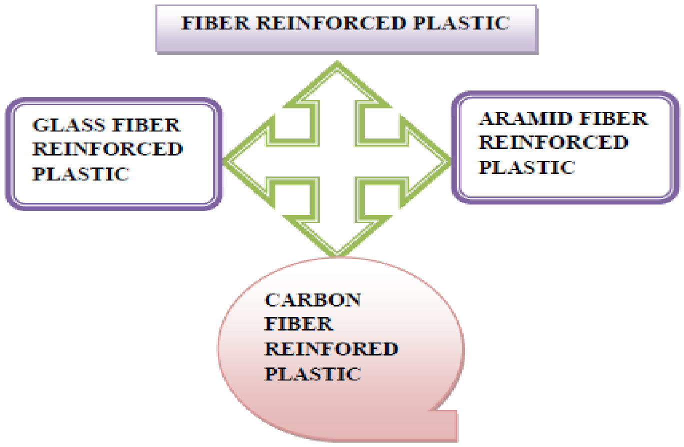


FIG -1. Classification of FRP

3.1 MACHINING AND METHODOLOGY OF CARBON FIBER REINFORCED PLASTICS

Hand lay-up technique is the most widely and the method to prepared composite. The fabrication process of FRP composites are generally used in the near-net-shape; however the trimming, drilling, grinding and slotting operation are still required to remove excess material and meet dimensional tolerances and requirements during cutting process.

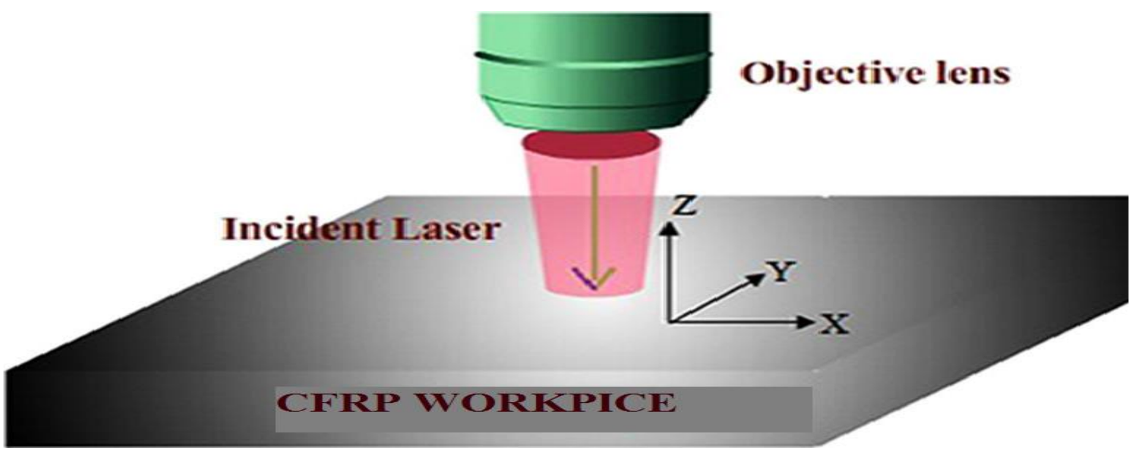


Fig- 2. Physical Model of Laser Drilling

The physical model for laser drilling in shown a fig.2 .This model involved in laser drilling is basically the nature of thermal. When a laser pulse irradiates like lighting a material, a multitude of highly dynamic coupled in physical processes occurring within a limitation of time. Given that a Gaussian laser beam generated by a nanosecond laser is incident at the center of the titanium sheet surface, heat is absorbed in the sheet it is based on the absorptivity of the material. The surface temperatures of several hundred CFRP are reached almost instantly because of the high intensities of the pulsed laser. As the temperature of the local material exceeds the melting point of the material, a three-phase state, i.e. solid, liquid, and a mixture of solid and liquid, is formed. The temperature increases to the boiling point, a portion of the material vaporizes, and extreme pressures occur from CFRP sheet.

3.2 FINITE ELEMENT MODEL AND MESH GENERATION

In finite element analysis, the meshing model of laser drilling was established using ANSYS software is a technique in which the entire domain is discretized in to small division these divisions are called “Elements” and the elements are connected through each other by “Nodes ” the meshed structure of the CFRP sheet is simplified transient sheet. The dimensions of the model (CFRP sheet) were 10 mm×10 mm×0.2 mm. Given that the laser drilling process can be simplified as an axisymmetric problem in physics, we used half of the workpiece for simulation process. The fig.3shows that the calculation process of the transient finite element through thermal analysis during laser drilling. The element size was 1/4 to 1/5 times that of the laser spot. The mesh was refined to determine the sensitivity of the Computational solution and reduce the computation time. Figure 3 shows a graphical model of rectangular plate through laser drilling in th x-y plane.

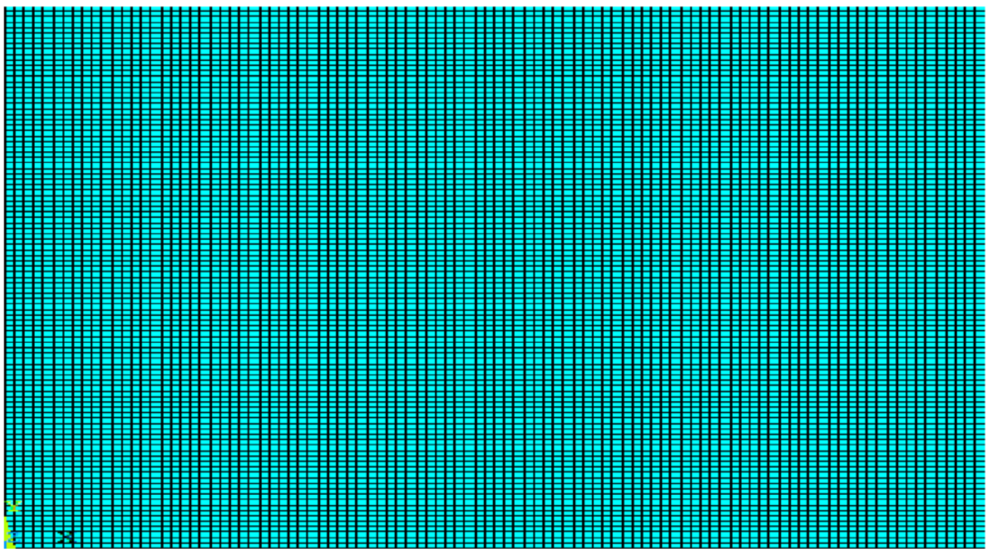


FIG-3 Meshed Model of CFRP Sheet in X-Y Plain

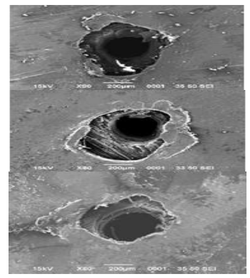
4. RESULT AND DISCUSSION

Table -1: Heat Affected Zone Values obtained of CFRP sheet in laser drilling

Sl.no	Thickness (A)	Hole of Diameter (B)	Frequency (C)	HAZ
1	3.0	0.4	100	0.4022
2	3.5	0.4	100	0.4022
3	4.0	0.4	100	0.4022
4	3.0	0.6	200	0.6033
5	3.5	0.6	200	0.6033
6	4.0	0.6	200	0.6033
7	3.0	0.8	400	0.8044
8	3.5	0.8	400	0.8044
9	4.0	0.8	400	0.8044

In the above table -1 having the no of corresponding frequency it is clear that the greater the diameter of the hole, the more the HAZ induced into the material.

Table -2: laser Drilled Holes for 0.4 mm Diameter

Sr. No.	Thickness	Diameter	HAZ	Broken Status	HAZ Effect
1	3.0	0.4		NO	LESS
2	3.5	0.4		YES	MORE
3	4.0	0.4		LESS	MODERATE

5. CONCLUSIONS

This paper object is to develop a FE model in order to investigate the Laser drilling behavior of CFRP composites. The following conclusions were drawn on the basis of the present investigation:

The finite element model proposed in this paper can predict accurately the Processing Parameters of Laser Drilling of both Thin and Thicker composite materials is possible and the Scanning Electron Microscope Analysis shows that it is possible to micro-texture the surface of carbon composites to promote the bond strength.

- It is clearly exhibited that in Laser machining process induces heat in the composite material and may alter the properties of the material due to the creation of HAZ in the localized areas.
- The most remarkable laser drilling the HAZ in the localized areas results in inducing of stress, thus the structural integrity of the material gets compromised due to improper machining.
- The heat is accumulated in material during Laser processing especially in the case of carbon fibers, so minimum HAZ can be achieved in machining of CFRP composites by minimizing pulsed rate of Lasers.

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BIOGRAPHIES

Mr. Hema Kalyana Sahu is the Assistant professor of Department of Mechanical Engineering Sanjay Memorial Institute of Technology, Degree Engineering College, Chandipadar, Berhampur, Odisha. He has completed M-Tech, and Bachelor in Engineering. He is having an excellent 5 years teaching experience. Two published papers in reputed journals along with six International/National conferences attended.

Dr. Jitendra Kumar Sahu is the professor , in-charge of Department of Mechanical Engineering (Head)and Training & Placement Office, Sanjay Memorial Institute of Technology, Degree Engineering College, Chandipadar, Berhampur, Odisha. He has completed Ph.D, MBA, M-Tech, and Bachelor in Engineering. He is having an excellent 20 years teaching experience and an impressive 4 years professional experience in reputed industries. He has served nation being an many honorable posts including the Honorary Secretary of Institute of Engineers and organized many International and National events in the field of Academics and Engineering. There are 17 UGC recognized International papers. 2 books, 1 book chapter and a Patent in his Credit, along with Participation in a dozen of conference, seminar and workshops. He is also resources person for many university and Industry.