



ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

Effect of internally and externally ply drop on Energy absorption of Glass fiber reinforced epoxy composite analyzed using numerical methods

A Thesis submitted to the Graduate school of Addis Ababa University in partial fulfillment of the Requirement for Degree of Masters of Science in Mechanical Engineering (Mechanical Design Stream)

By

Mulugeta Eshetu

Advisor: Daniel Tilahun (PhD)

Co Advisor: Mulugeta H/Mariam (PhD)

Addis Ababa, Ethiopia

June 2020



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By

Mulugeta Eshetu

Approved by

Dr. Daniel Tilahun (Associate Professor)

Advisor

Signature

Date

Dr. Mulugeta H/Mariam

Co-Advisor

Signature

Date

Dr. Samuel Tesfaye

Internal Examiner

Signature

Date

Behailu Mamo (Ph.D. Candidate)

External Examiner

Signature

Date

Dr. Yilma Tadesse

Chairman of the school

Signature

Date

DECLARATION

This is to certify that **Mulugeta Eshetu** has carried out his project work on the topic of “Effect of internally and externally ply drop on Energy absorption of Glass fiber reinforced epoxy composite analyzed using numerical methods” under my supervision. This work is original in its nature and it is suitable for Submission in partial fulfillment of the Degree of Masters of Science in Mechanical Engineering (Mechanical Design Stream).

Mulugeta Eshetu

Signature _____

Date _____

Dr. Daniel Tilahun (Ph.D.)
(Advisor)

Signature

Date

Dr. Mulugeta H/Mariam (Ph.D.)
(Co-Advisor)

Signature

Date

Acknowledgement

First, I would like to express my deepest gratitude to the almighty God and Saint Arsema for everything they gave me and make all things are possible.

Second, I would also like to thank Mr. Tadele he helped me starting from the first year by supporting to find a reference material for the study. Especially for my advisor Dr. Daniel Tilahun and Co-advisor Dr. Mulugeta H/Mariam and also for all AAiT staffs who helped me a lot in finalized this research.

Finally, I have to express my gratitude to my family for their support and continuous encouragement throughout my life. And also to my friends I would like to say thank you.

Abstract

In a Ply dropped composite structures, Plies must be terminated or dropped off at discrete location over the part that improve the deformation and energy absorption capacity. In tapered structural parts thickness tapering cannot be achieved during a continuous way. Because of this tapered structures use either internally or externally ply drop types to create a required structural shape. Ply dropped composite used as impact absorption material for different application such as bumpers, armors, crush box, helmets, and disposable barrier shells and structures protection. However, the improvements of the capacity of impact energy absorption need a research to study the effect of different parameters and mechanisms on impact absorption capacity of composite materials. The main objective of this investigation is to study the effect of internally and externally ply dropped on the impact energy absorption of unidirectional glass fiber reinforced epoxy composite materials. Impact energy, load carrying capacity and deformation of the flat, internally and externally dropped ply was analyzed. Based on the numerical approach using ABAQUS CAE software based on ASTM standards, at three different Impactor velocities of 2.51 m/s, 5 m/s and 10 m/s. From the analysis the specific energy stored on flat, internally ply drop, and externally ply drop was 13.23 KJ/Kg, 1.56 KJ/Kg and 25.74 KJ/Kg at 10 m/s respectively. The amount of peak load also recorded 54601.8 N, 10255.7 N and 50871.6 N and deformation of 0.0163 m, 0.012 m, and 0.022 m was recorded on flat, internally and externally dropped ply respectively. As compared the result of all ply arrangements by considered mass of the specimens' external ply drop specimen had a better specific energy absorbed capacity of 25.74 KJ/Kg and load carried capacity of 50871.6 N at 10 m/s velocity impactor and deformation of 0.022 m. From this the analyses recommended that externally ply drop specimen has a better specific energy absorbed capacity.

Key words: Flat Specimen, Internally-ply drop, externally ply drop, Energy absorption capacity, Deformation, Reaction Force, Numerical approach

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Nomenclature

U- Displacement

V- Velocity

E- Energy

S- Second

Wt- Weight

E11, E22: - elasticity modules in longitudinal and transverse

G12, G23: - shear stiffness

ν_{13}, ν_{23} : - Poisson's ratio

X_t, X_c : - Tensile and Compressive strength at longitudinal direction

Y_t, Y_c : - Tensile and Compressive strength at transverse direction

S_{12}, S_{13} : - Shear stress at longitudinal and transverse direction

G_{ft}, G_{fc} : - Tensile and Compressive fracture toughness at longitudinal direction

G_{mt}, G_{mc} : - Tensile and Compressive fracture toughness at transverse direction

List of abbreviations

ASTM -American Society for Testing and Materials

GFRP -Glass Fiber Reinforced Polymer

CFRP- Carbon-Fiber-Reinforced Polymer

MMCs- Metal-Matrix Composites

CMCs- Ceramic-Matrix Composites

PMC's- Polymer Matrix Composites

GRP- Glass Reinforced Polymer

FRP- Fiber Reinforced Polymer

ECCM- European Conference on Composite Materials

TDTBC- two-dimensional tri-axially braided composite

GPa: - Giga Pascal

MPa: - Mega Pascal

IE -Internal Energy

RF -Reaction Force

ABAQUS FEA - ABAQUS Finite Element Analysis

SYM -Symmetric

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CHAPTER ONE

1. INTRODUCTION

1.1 Background

Composites used during the past to early twentieth century. In 1940, fiberglass was first accustomed reinforce epoxy. Fiber reinforced polymer matrix composite materials are being introduce in ever-increasing quantities in military systems and became a key element within the Department of Defence's effort to lighten the force. The hot temperature alternative to high-density metals is ceramics, offering weight savings further hot temperature capability and oxidation resistance [1].

Composite materials are spreading the bounds of engineer's altogether divisions of engineering, and yet the degree to which this can be trendy can easily pass unperceived. The eye, after all, doesn't see beyond the glossy outdoor or the race performance of a GRP1 yacht, nor does it sense the problem of the building of a composite helicopter air foil or of a contemporary CFRP2 racquet. Nevertheless, this family of synthesized materials offers the chance of exciting new solutions to difficult engineering problems [2]. In composites, constituents are combined in such some way on allow us to create enhanced use of their features while reducing to some extent the results of their lacks. This process of optimisation can release a designer from the constraints related to the choice and manufacture of conventional materials. He can make use of tougher and lighter materials, with properties which will be tailored to suit particular design requirements. Moreover, due to the convenience with which complex shapes will be manufactured, the entire rethinking of a long-time design in terms of composites can often result in both cheaper and better solutions. The 'composites' concept isn't a person's invention. Nature makes a way better job of design and manufacture than we do, although Man was able to recognize that the way of overcoming two major disadvantages of natural wood that of size (a tree contains a limited transverse dimension), which of anisotropy (properties are markedly different within the axial and radial directions) — was to create the stuff that we call plywood. Man was aware, even from the earliest times, of the concept that combining materials may well be advantageous, and therefore the down-to-earth procedures of wattle-and-daub (mud and straw) our own era. However, it's only within the half century that the science and technology of composite materials have developed to produce the engineer with a completely unique class of materials and therefore the necessary tools to enable him to use them advantageously[2].

The term 'composites' gives slight suggestion of the large range of singular mixtures that are comprised during this class of materials. Figure 1.1 provides a clearer awareness of the possibility for originality, which is obtainable to the Materials Scientist and his customer, the look Engineer. First, in individually group of materials-metallic, ceramic and polymeric — there are already certain

familiar materials, which might be described as composites. Many members of the most common and largest group of engineering materials, the family of steels, incorporate combinations of particles of hard ceramic compounds in a very softer metallic matrix. Polymers, too, are often two-phased, comprising of a matrix of 1 polymer with dispersals of harder or softer particles contained within it; wood may be a perfect example of this, as we've seen. Additionally, concrete may be a classic example of a ceramic/ceramic composite, with particles of sand and aggregate of graded sizes in a very matrix of hydrated Portland cement. These materials are well-known for several years, and Materials Scientists have learned to regulate their properties by controlling their microstructures; that's to mention, the number, the form, and therefore the distribution of what we would seek advice from because the 'reinforcing phase'. the thought of blending components across the materials class boundaries may be a natural extension of this idea. Making additions of hard, or fire-resistant, or just cheap, ceramic powders to plastics to create filled [2].

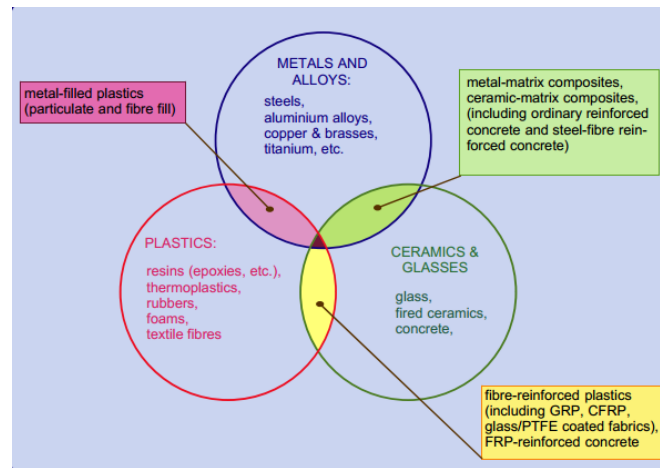


Figure 1-1: Relationships between classes of engineering materials

polymers; and making additions of very hard, or abrasive, or thermally stable ceramic particles to metals to create the category of materials called 'cermet' to supply machine tips capable of cutting hard metals at high speeds or high temperatures; are only two samples of important developments in our exploitation of those materials. But even more significant is that the extension of this principle to include filamentary metals, ceramics and polymers into the majority sorts of any of those three classes of materials to create fibre composites — reinforced plastics, like CFRP and GRP, metal-matrix composites (MMCs) like silicon-carbide-fibre-reinforced aluminum, and ceramic-matrix composites (CMCs) like carbon fibre-reinforced glass. Superlatively, the possessions of engineering ingredients should be reproducible and precisely known. Additionally, since satisfactory exploitation of the composite principle depends on the look flexibility that results from tailoring the properties of a mixture of materials to suit a specific requirement, we also must be able to predict those properties

successfully. At the current time a number of the more important engineering properties of composites will be well predicted on the premise of mathematical models, but many cannot.

The increasing applications of carbon fiber reinforced magnesium matrix composites make it more important to grasp and predict their mechanical properties. Many attempts have mainly focused on the results of the fiber volume fraction and therefore the interfacial adhesion between the fiber and matrix, which guaranteed the effective transfer of stress. However, it had been discovered that the mechanical properties of composites also depended strongly on the fiber orientation and fiber aspect ratios[3].

In composite structures, thickness tapering cannot be achieved during a continuous way. Plies must be terminated or dropped off at discrete location over the part. Additionally, as an impact of the manufacturing process, a triangular-shape resin-rich pocket is usually present at the tip of a dropped ply [4]. The composite tapered beams are gradually being used in engineering presentations, such as turbine blades, helicopter blades and yokes, robot arms and satellite antennas wherein the stiffness of the structure needs to be varied along the length of the beam. Such tapered structure is made by terminating selected plies at discrete locations along the length of the beam to alter the stiffness of the beam. differing kinds of ply drop-off configurations is achieved in practice. a number of the foremost common forms of tapered configurations shown in Figure 1-2 [5].

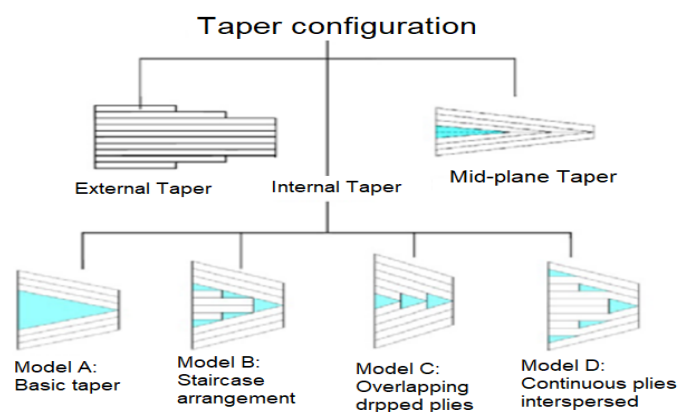


Figure 1-2: Schematic illustration of taper configuration

Energy absorbing elements, used as bumpers, armors, Passenger-vehicle crash box, helmets, disposable barrier shells and structures protection etc..., [6]. Such elements are made up of different quite materials like metals, foams, and composites. The metal energy absorbing elements have larger mass than the weather of other forms. this is often the explanation why they will be utilized in the branch during which the extra mass of elements isn't critical buildings and structures protection. The foams and composites elements have smaller mass than comparable elements made up of metals. It

results in take the advantage of aviation and vehicle [7]. The foremost important material requirement is that the capacity to soak up an oversized amount of energy under impact conditions before reaching fracture. Impact resistance could be a material's ability to resist the force of a sudden impact. Compared to static loading, materials are more prone to a shock force applied over a brief duration. Escaping the tragic failure during impact events is the key task in the proposal of impact resistant material. Various approaches are applied to extend the material's impact resistance. One approach is to mix two or more materials with distinguished physical or chemical properties to supply a replacement material with better performance without changing the characteristics of the constituents [8].

Most composites are inelastic then can only absorb energy in elastic distortion and over damage mechanisms, and not via plastic deformation. Basically five mechanical failure modes which will occur during a composite after the initial elastic deformation [9]: i) fiber fracture, ii) resin crazing, micro cracking iii) debonding between fiber and matrix, iv) fiber pull out from the matrix, and v) delamination of adjacent plies during a laminate. In general, each of the above-mentioned mechanisms may contribute to the energy dissipation process under impact conditions. Delamination is that the most significant damage mechanism in impacted composite laminates[10].

Ply drops in composite materials are applicable design consideration in many structures, especially those with varying loads all over the structure. As an example, each ply during a composite laminate without bending must carry the identical amount of strain when a ply is dropped. The reduction in area that places the thinner section under a better stress, transitioning via shear lag. These thickness variations are required to optimize the look of recent laminated composite structures. This ends up in a structure, which is matched to stiffness and loading requirements[11].

So to urge an improved impact energy absorbing material and for tapered structures, it's better to crate ply drops either internally or externally on the laminated stuff. Then either to decide on it's better internally or externally this sort of research is very important. Therefore, this work presents the effect of internally and externally ply drops on energy absorption capability of fibre reinforced plastic composite materials using numerical analysis techniques and preparing specimens for testing on ABAQUS.

1.2 Statement of the problem

The use of composite materials for Energy-absorbing application is gradually increased in the recent periods because of their advantageous properties when compared with metal and foam type energy absorbing material. Specially for Tapered layered structures, which are formed by dropping off some

of the plies at discrete locations over the laminate, have established much devotion from researchers because of their structural tailoring capabilities, damage tolerance, and their potential for creating significant weight savings in engineering applications additional to its Impact energy absorbing capability. Beside of those advantageous, glass fiber reinforced plastic composite materials impact energy absorbing capability is not that much satisfied. One of the most is their vulnerability response to the transverse path impact damage during the time of impact. This damage is the main problem in the design of laminated composite materials with different arrangement of Tapered structures. The various damage such as matrix cracks, delamination's, fiber fracture, fiber-matrix debonding, fiber pull out and penetration can occur during transverse impact event. These damage reason for extensive reduction in mechanical stiffness, prominent to the development of damage, tragic damage and final fracture [12].

Different authors and literatures are studied Energy absorbing capability of composite using different layers and arrangement [13] [14], varying composite material, fiber orientation [15], changing ply thickness [16] [17] and the ratio of hardener and resin and other techniques, it shows that still demands on the need to analyze the impact energy capacity of the composite materials by using other mechanism. Hence, the basic question answered on these works is the effect of internally and externally ply drops on energy absorption capability of glass fiber reinforced epoxy composite materials numerically using ABAQUS software.

1.3 Objectives of the study

1.3.1 Main objective

The main objectives of this study were to investigate the influence of internally and externally ply drops on energy absorbing capability of glass fiber reinforced epoxy plastic composite using a numerical approach.

1.3.2 Specific Objectives

- ✓ To analyze the energy absorption for flat plate, internal ply drops and external ply drops
- ✓ To analyze amount of deformed displacement for flat plate, internal ply drops and external ply drops
- ✓ To analyze amount of reaction forces for flat plate, internal ply drops and external ply drops
- ✓ To investigate the effect of impact speed on energy absorption, reaction forces and deformations.
- ✓ To compare the specimens with the in terms of specific energy absorbing capacity, reaction force and deformation

1.4 Scope of the research

The research covered numerical modeling of flat, internally plies dropped and externally ply dropped unidirectional GFRP impact absorbed capacity and compared the impact resistance of the 3 specimens based on the amount of specific energy absorbed. The numerical analysis was done by using ABAQUS CAE and modeling was done based on ASTM D736 standard.

1.5 Organization of the paper

This paper focused on Numerical analysis of the influence of internally and externally ply drop on energy absorption of glass fiber reinforced plastic composite materials. This study consists 5 chapters.

The first chapter, concern on the basic introduction and history of composite material related to the thesis concept like about ply drops and energy absorbing capacity of different composite materials related to their properties. Additional to introduction it included objectives of the study and main problem statement of the paper also covered in this chapter.

The second chapter is covers a review of different literatures related to the topic and general concepts of composites analysis methods with the software's that used the researchers to study their papers. In chapter three the numerical analysis is done based on the given standard, geometry and boundary conditions. After the numerical analysis, it goes to result and discussion in chapter 4. The result of all model was discussed and results are express in graphs and table formats.

Finally, all results and discussions are summarized and concluded in chapter 5. For the future work the recommendation also place in this chapter.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Composite Material

Advanced composite materials Associate in nursing structures area unit an outgrowth of the bolstered industry and has, since 1965, shown a gentle increase in augmenting metals for structural applications. The main improvement of advanced composites over bolstered plastics is in stiffness and therefore this material and structures factory-made therefrom will be additional economical than metals each from a strength and stiffness viewpoint. Part styles and ideas were at the start developed by the region trade. Early material forms and method parameters were dilated and simplified for sporting goods. Second-generation composite styles and advanced ideas were developed for space vehicle structures. Chopper and advanced craft structures introduced hybrid composites that were additionally applied to industrial elements in an endeavor to attenuate the first high prices.

Trends for future composite styles and ideas area unit expected to maximize cheap weight savings alongside mixtures of materials that area unit sturdy and accessible. Style options for composite structures of the long run can embody issues of:

- ✓ Damage tolerance
- ✓ Impact resistance
- ✓ Crashworthiness
- ✓ Environmental durability
- ✓ High volume reducibility

It is expected that the advanced composites community can still give effective materials and structures solutions to a number of the worldwide desires for additional economical, low energy overwhelming sturdy structures[18].

2.1.1 Definition of composite material

Composite materials area unit made up of two or additional macro constituent materials with considerably totally different physical or chemical properties and that area unit insoluble in one another, that once combined, manufacture a cloth with characteristics totally different from the individual elements. The individual elements stay separate and distinct inside the finished structure. the 2 constituent's area unit fiber (reinforcement) and matrix. That leads to higher properties than those of the individual elements used alone.

➤ **Reinforcements:** -The role of reinforcement in composite materials is primarily to feature mechanical properties to the fabric like strength and stiffness. Reinforcements primarily are available 3 forms: [19].

- Particulate
- Discontinuous Fiber
- Continuous Fiber

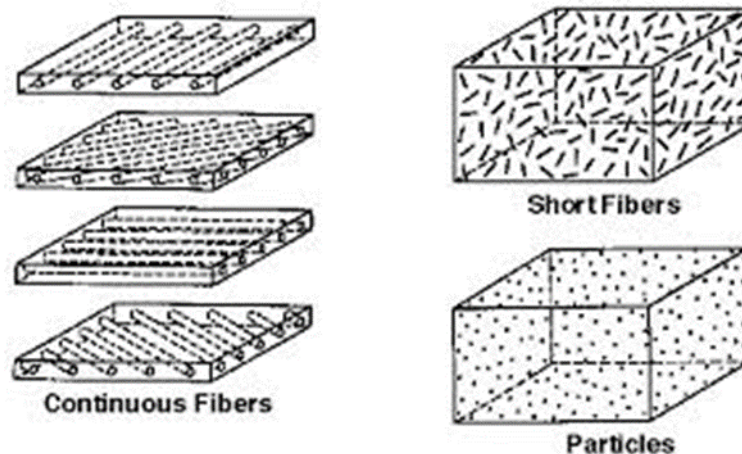


Figure 2:- type of reinforcement

➤ **Matrix:** - The role of the matrix is to bind the reinforcement along in order that the applied stress is distributed among the reinforcement and to guard the surface of the reinforcement from being broken. Composites are classified in keeping with their matrix phase:

- Polymer Matrix Composites (PMC's)
- Ceramic Matrix Composites (CMC's)
- Metal Matrix Composites (MMC's)

2.1.2 Advantages of composite materials

Composite materials are different advantages as compare to other material the followings are some of them

- **Substantial Weight Reduction:** FRP composites are typically 30-40% lighter than steel parts of equal strength. Composite parts can be designed to carry the same loads as steel. Parts are generally molded at minimum thickness to reduce weight and minimize molding cycle time. Structure is achieved through proper section design to add increased strength and stiffness to localized areas as required. Automotive closure panels are generally two-piece designs consisting of a Class "A" cosmetic skin backed by a non-appearance structural reinforcement panel.

- Lower Manufacturing Complexity: Finished assemblies with fewer parts cut manufacturing costs and often accelerate design completion and model introduction. A single composite molding can take the place of up to 15-20 individual steel components and fasteners. With fewer components to procure, inventory and assemble the net result is tighter tolerances, better fit& finish and reduced labor cost.
- Reduced tooling cost: Tooling for composite parts can be as much as 80% less than comparable metal parts. Steel parts often require a series of stamping dies to produce a desired shape in addition to multiple components that must be subsequently assembled. In most cases, one or two molds and presses take the place of entire multi-station stamping lines. Bottom line: lower cost, tighter tolerances and less assembly required.
- Unparalleled damage resistance: Composites' dent and ding resistance is far superior to that of steel, aluminum and thermoplastic panels. Composites do not dent nor ding. Their coefficient of linear thermal expansion (CLTE) is very similar to steel that allows them to maintain excellent fit & finish over a wide range of temperatures. They do not brittle when exposed to cold temperatures nor will they melt in the presence of extreme heat as do thermoplastics.
- Unrivalled corrosion resistance: FRP composites are superior in corrosion resistance for any application. Composites do not rust nor corrode when exposed to moisture and road salt and will literally outlast most of the steel components on a vehicle. Their inherent chemical resistance and dimensional stability make them well suited for engine components such as valve covers and oil pans.
- Better internal damping: Leads directly to reduced noise, vibration, and harshness (NVH). Fewer parts mean fewer chances for squeaks and rattles. Composites are inherently better sound insulators than steel.
- Improved design flexibility: Unlike metals, composites offer a limitless "depth-of-draw" range. Stamped metals get thinner as they are drawn to form vertical walls; whereas, composites offer the ability to maintain a constant cross-sectional thickness over the entire part. Many shapes that are impossible or economically prohibitive to form in steel and aluminum can be produced with relative ease in composites.
- Cost-effective solutions: Lower composite investment costs satisfy automakers' trends toward reduced builds per model. With the current trend towards niche marketing and frequent design "freshening" production runs of closure panels are typically shorter. Thus, it is advantageous to minimize both the number and cost of the tooling, as it will be amortized over fewer units.
- Comparable aesthetics: Toughened SMC resin provides "first-time through" processing comparable to steel. The surface smoothness of most composites is equal or better than the steel

parts surrounding them. Composite panels are generally assembled onto the vehicle and painted on-line with their steel counterparts. Recent advances in formulation chemistry first run capability is now considered to be equal or better than steel by some original equipment manufacturers (OEM). On the finished vehicle, composite parts are visually indistinguishable from steel and aluminum.

2.1.3 Application area of composite

Glass-fiber reinforced composites possess good mechanical properties, due to the high mechanical strength and rigidity of the glass fibers they contain, which can be adjusted to suit particular static requirements (e.g. directionality) and which, for light construction in particular, can meet up to stringent requirements. Composite structures used in aerospace, mechanical and automotive industries, marine industries and defense due to their high strength-to-weight and stiffness-to-weight ratios, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part. The reinforcing phase provides the strength and stiffness. In most cases, the reinforcement is harder, stronger, and stiffer than the matrix [1].

- ✓ aircraft hulls, bicycle bodywork,
- ✓ Military and heavy goods vehicles use composites in both bodywork and engine and transmission systems.
- ✓ Mass transit systems in trains, subways and buses use composites for ceilings, walls, floors and seating.

Composite products range from skateboards to components of the space shuttle. The industry can be generally divided into two basic segments:

- Industrial composites: - The industrial composites industry has been in place for over 40 years in the world. This large industry utilizes various resin systems including polyester, epoxy, and other specialty resins. These materials, along with a catalyst or curing agent and some type of fiber reinforcement (typically glass fibers) are used in the production of a wide spectrum of industrial components and consumer goods: boats, piping, auto bodies, and a variety of other parts and components.
- Advanced composites: -Advanced composites industry is characterized by the use of expensive, high-performance resin systems and high-strength, high-stiffness fiber reinforcement. The aerospace industry, including military and commercial aircraft is the major customer for advanced composites. The sporting goods suppliers who sell high-performance equipment to the golf, tennis, fishing, and archery markets have also adopted these materials for use. While aerospace is the predominant market for advanced composites

today, the industrial and automotive markets will increasingly see the use of advanced composites.

- Aerospace: - A wide range of load-bearing and non-load-bearing components are already in use in both fixed-wing and rotary wing aircraft. Many military and civil aircraft now contain substantial quantities of lightweight, high-strength carbon-, Kevlar- and glass-fiber composites, as laminated panels and moldings, and as composite honeycomb structures with metallic or resin-impregnated paper honeycomb core materials. They are used in air frames, wing spars, spoilers, tail-plane structures, fuel tanks, drop tanks, bulkheads, flooring, helicopter rotor blades, propellers, and structural components, pressured gas containers, nose and landing gear doors, fairings, engine nacelles (particularly where containment capability is required for jet engines), air distribution ducts, seat components, access panels, and so forth. Many modern light aircraft are being increasingly designed to contain as much lightweight composite material as possible.
- Automotive Engineering: - There is increasing interest in weight reduction in order to permit both energy conservation and increased motoring economy. Reduction in the weight of an automobile structure achieves primary weight saving and if carried to sufficiently great lengths enable the designer to use smaller power plants, thus achieving substantial secondary improvements in fuel economy. The majority of automotive applications involve glass-reinforced plastics because the extra cost of carbon or aramid fiber is rarely considered acceptable in this market. Even so, the cost of using GRP is usually being weighed Against the much lower cost of pressed steel components, and the substitution is often rejected on purely economic grounds, leaving aside the question of energy saving.
- Bioengineering Carbon-fiber-reinforced plastic and carbon components are in use for prosthetic purposes, such as in orthopedic fracture fixation plates, femoral stems for hip replacements, mandibular and maxillary prostheses (jaw remodeling, for example), and for external orthotic supports in cases of limb deformity etc. Pyro lytic carbon is used to manufacture heart valve components, and the substitution of a carbon/carbon composite is not unlikely.
- Chemical Engineering: - A substantial amount of GRP is currently in use in chemical plant for containers, pressure vessels, pipe-work, valves, centrifuges etc. These may be filament-wound or molded components for containment of process fluids.
- Civil/Structural Engineering: - Again, the bulk of composites used in this field are glass-reinforced plastics. The low inherent elastic modulus of GRP is easily overcome in buildings by the use of double curvature and folded-plate structures: thin GRP panels also offer the

advantage of translucency. A good deal of GRP is used in this industry for folded-plate structures, cladding panels, decorative ‘sculptured’ panels (like those in the doors of the Roman Catholic cathedral in Liverpool), services moldings and ducting, racking, pipework, rainwater moldings, domestic and industrial water tanks, form-work for concrete, and complete small structures like foot-bridges. Light-weight composite paneling for partitioning and similar applications have also been tried. CFRP have been less used until recently because of the cost, but are increasingly being considered for building lightweight structures, including a number of bridges.

In recent years, there has been a major surge of interest in the use of structural composites in civil engineering infrastructures. At least two major composites journals have run Special Issues on the subject in 1996/99, and the 1998 European Conference on Composite Materials, ECCM8, ran a series of well-attended sessions on civil engineering uses for the first time. A good deal of upgrading of existing bridge structures by externally applied composite components is being carried out. Domestic Injection-molded reinforced thermoplastics and polyester molding compounds are perhaps the most common composites used in consumer items for the domestic market, and the range is vast. Moldings of all kinds, from kitchen equipment of all kinds to casings for the whole gamut of domestic and professional electrical equipment, motor-cycle crash helmets, television and computer casings, and furniture.

- Electrical Engineering: -Typical applications are radomes, structural components for switch gear, power generator coolant containment and large-diameter butterfly valves, high-strength insulators (e.g. for overhead conductor systems), printed circuit boards, and casings for electronic equipment. The majority of applications in this field again use GRP, although the use of composites which are more thermally stable and more moisture-resistant is increasingly predicated for sensitive, small-scale electronic components. Many prototype and practical wind-generator designs incorporate GRP or hybrid blading.
- Marine Engineering: - Marine applications include surface vessels, offshore structures and underwater applications. A vast range of pleasure craft has long been produced in GRP, but much serious use is also made of the same materials for hull and superstructure construction of passenger transport vessels, fishing boats and military (mine-countermeasures) vessels. Seawater cooling circuits may also be made of GRP as well as hulls and other structures. Off-shore structures such as oil rigs also make use of reinforced plastics, especially if they can be shown to improve on the safety of steel structures, for fire protection piping circuits, walkways, flooring, ladders, tanks and storage vessels, blast panels, and accommodation

modules. High specific compression properties also make composite materials attractive for submersibles and submarine structures, both for oil exploration and for military purposes, and for towed transducer arrays for sea-bed sonar mapping.

- Sport: - GRP vaulting poles were perhaps the earliest of the composite sports gear, but one can now obtain tennis rackets, cricket bats, golf clubs, fishing rods, boats, oars, archery equipment, canoes and canoeing gear, surf boards, wind-surfers, skateboards, skis, ski-poles, bicycles, and protective equipment of many sorts in composite materials of one kind or another. In an industry that is often less directly subject to controls exercised in other areas of engineering there is often a tendency to dupe customers with the use of names which incorporate the words 'carbon' or 'graphite' to describe expensive, black colored items which may at the present time legitimately contain little or no carbon fiber [2].

2.1.4 Properties of composite material

Composite materials produce combination properties of two or more materials that cannot be achieved by either fiber or matrix when they are acting alone. Fiber-reinforced composites were successfully used for many decades for all engineering applications. Glass fiber-reinforced polymeric (GFRP) composites were most commonly used in the manufacture of composite materials. The matrix comprised organic, polyester, thermos table, vinyl ester, and phenolic and epoxy resins. The mechanical behavior of a fiber-reinforced composite basically depends on the fiber strength and modulus, the chemical stability, matrix strength and the interface bonding between the fiber/matrix to enable stress transfer. Suitable compositions and orientation of fibers made desired properties and functional characteristics of GFRP composites was equal to steel, had higher stiffness than aluminum and the specific gravity was one-quarter of the steel.

Mechanical performance of composite material is depending on different factors the basic four fiber factors are: the first factor is length; the fibers can be long or short. Long, continuous fibers are easy to orient and process, but short fibers cannot be controlled fully for proper orientation. Long fibers provide many benefits over short fibers. These include impact resistance, low shrinkage, improved surface finish, and dimensional stability, the second is Orientation: Fibers oriented in one direction give very high stiffness and strength in that direction. If the fibers are oriented in more than one direction, such as in a mat and woven, there will be high stiffness and strength in the directions of the fiber orientations. The third factor is Shape: The most common shape of fibers is circular because handling and manufacturing them is easy. The material is the fourth and the material of the fiber directly influences the mechanical performance of a composite. Fibers are generally expected to have

high elastic moduli and strengths. This expectation and cost have been key factors in the graphite, aramids, and glass dominating the fiber market for composites.

The various GF reinforcements like long longitudinal, woven mat, chopped fiber (distinct) and chopped mat in the composites have been produced to enhance the mechanical and tribological properties of the composites. The properties of composites depend on the fibers laid or laminated in the matrix during the composites preparation. The figure below describes the methodology of the GFRP matrix composites preparation and characterization, and its application [20].

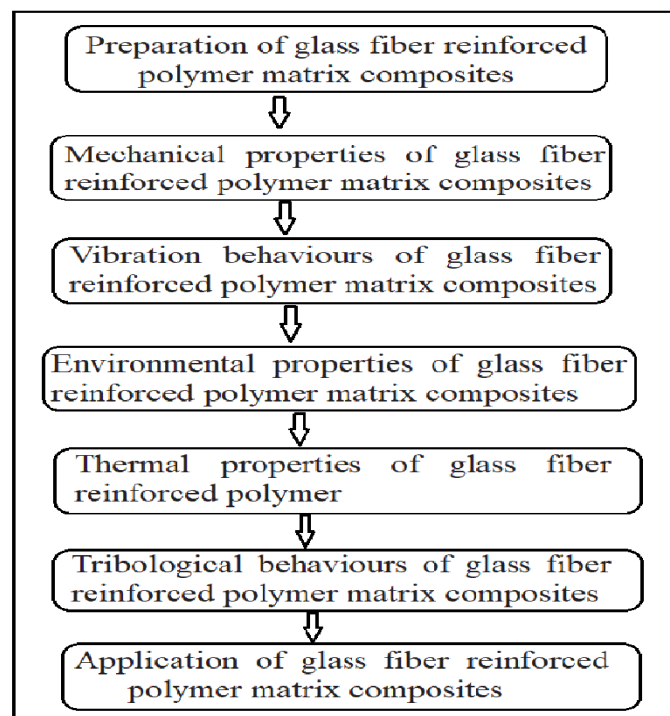


Figure 2-1: Flowchart of the GFRP matrix composites preparation and characterization.

For applications where more than one fiber orientation is required, a fabric combining 0° and 90° fiber orientations is useful. Woven fabrics are produced by the interlacing of warp (0°) fibers and weft (90°) fibers in a regular pattern or weave style. The fabric's integrity is maintained by the mechanical interlocking of the fibers. The following is a description of some of the more commonly found weave styles.

Plain

Each warp fiber passes alternately under and over each weft fiber. The fabric is symmetrical, with good stability and reasonable porosity. However, it is the most difficult of the weaves to drape, and the high level of fiber crimp imparts relatively low mechanical properties compared with the other

weave styles. With large fibers (high Tex), this weaving style gives excessive crimp and therefore it tends not to be used for very heavy fabrics [21].

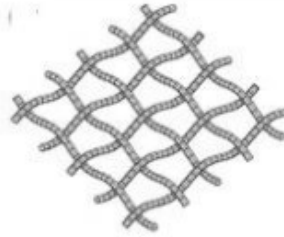


Figure 2-2: Plain weave

Twill

One or more warp fibers alternately weave over and under two or more weft fibers in a regular repeated manner. This produces the visual effect of a straight or broken diagonal 'rib' to the fabric. Superior wet out and drape is seen in the twill weave over the plain weave with only a small reduction in stability. With reduced crimp, the fabric also has a smoother surface and slightly higher mechanical properties.

Table 2-1: Chemical compositions of glass fibers in wt. %

Chemical composition of glass fibers in wt. from literature [20]

Type	SiO ₂	Al ₂ O ₃	TiO ₃	B ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	Fe ₂ O ₃
E-glass	55.0	14.0	0.2	7.0	22.0	1.0	0.5	0.3	-
C-glass	64.6	4.1	-	5.0	13.4	3.3	9.6	0.5	-
S-glass	65.0	25.0	-	-	-	10.0	-	-	-
A-glass	67.5	3.5	-	1.5	6.5	4.5	13.5	3.0	-
D-glass	74.0	-	-	22.5	-	-	1.5	2.0	-
R-glass	60.0	24.0	-	-	9.0	6.0	0.5	0.1	-
EGR-glass	61.0	13.0	-	-	22.0	3.0	-	0.5	-
Basalt	52.0	17.2	1.0	-	8.6	5.2	5.0	1.0	5.0

Table 2-2: composite material properties
 Different types of composite material Properties of [[22],[23],[24],[25],[26]]

Materials		T700GC/M21 Composite laminates	unidirectional composite.	Unidirectional Tape (UT)	graphite/epoxy unidirectional laminate	Fibre dux HTA/6376 C material properties
Properties						
Density	P	1600 kg/m ³	1600	1510	1600	1590
Young's modulus	E ₁₁	130 GPa	153	116.73	143.4	145
	E ₂₂	7.7 GPa	10.3	8.31	9.27	10.3
	E ₃₃	7.7 GPa	10.3	-	9.27	12.1
	G ₂₃	3.8 GPa	3.7	-	3.2	3.95
	G ₁₂	4.8 GPa	6	4.67	3.8	5.3
	G ₁₃	4.8 GPa	6	-	3.8	5.3
Poisson's ratio	v ₂₃	0.35	0.4	-	0.52	0.495
	v ₁₂	0.33	0.3	0.26	0.31	0.3
	v ₁₃	0.33	0.3	-	0.31	0.5
Strength	X _t	2080 MPa	2537	1477.09	2945	2000
	X _c	1250	1580	708.46	1650	1600
	Y _t	60	82	55.47	54	64
	Y _c	140	236	170	240	290
	S ₁₂	110	90	117.45	-	98
Fracture toughness	G _{ft}	133 N/mm	10	248.50	91.6	-
	G _{fc}	40	10	10000	79.9	-
	G _{mt}	0.6	1	0.62	0.22	-
	G _{mc}	2.1	1	3.02	0.76	-

2.2 Literatures on impact energy absorption properties of composite material

In the development of composite-manufacturing techniques, an increasing number of carbon fiber and glass-fiber-reinforced polymer (CFRP & GFRP) materials are used in the aerospace and automotive industries to meet crash and lightweight-design requirements. Because of this, energy absorption characteristics have become more important in recent years. [27] Studies shown the list of limitations, which modify Crushing and energy absorption performance of different geometrical

shapes of small-scale glass/polyester composite tubes under quasi-static loading conditions. This paper presents the quasi-static crushing performance of nine different geometrical shapes of small-scale composite tubes. The idea is to understand the effect of geometry, dimension and triggering mechanism on the progressive deformation of small-scale composite tubes. Different geometrical shapes of the composite tubes have been manufactured by hand lay-up technique using uni-directional E-glass fabric (with single and double plies) and polyester resin. K. Kairouz, J. Ball [28] showed impact testing of ply drop features, using T300/914C carbon fiber/epoxy resin non-crimp fabric with nominal fiber volume fraction of 0.55 composite material arranged in (-45/+45/0) and (0/+45/-45) stitched ply stacks, with a (0/+45/-45) ply stack drop-off specimen. It has been found that, whilst the energy to initiate damage may vary, the threshold force for damage initiation is constant. It has been shown that the impact performance of ply drop specimens is more critical than the equivalent flat laminate.

Article [29] presented a comprehensive review of different strategies dealing with development of new composite materials investigated by several research groups that can be used to mitigate the low velocity impact damage in laminated composites. Hybrid composites, composites with tough thermoplastic resins, modified matrices, surface modification of fibers, trans-laminar reinforcements, and interlaminar modifications such as interleaving, short fiber reinforcement, and particle based interlayer are discussed in this article. A critical evaluation of various techniques capable of enhancing impact performance of laminated composites and future directions in this research field are presented in this article.

The response of E-glass/epoxy laminated plates subjected to low velocity impact loading also studied on [30] paper. In this paper, Impact tests were performed using a specially designed vertical drop-weight testing machine. The samples used for this study were 8 plies symmetric laminated composites. These composites were characterized by three different stacking sequences, [0/90]_{2s}, [-30/30]_{2s}, [-45/45]_{2s}, and they were compared with each other. [4] In this work, specimens with multiple dropped plies are considered to match with industrial type structures and finally, the effects on the damage mechanism of drop-off disposition, configuration and the taper angle are analyzed using a drop weight-testing rig. A guided 4 kg-mass with a hemispherical indenter of 16 mm diameter is dropped from a specific height onto the specimen placed below. Specimens were impacted on the flat face; the opposite side being simply supported by a tapered base with a rectangular opening of 75*125 mm². Finally, the author compared and concludes the result to plain laminates; permanent indentation of tapered laminates is reduced due to the delay in fiber rupture. From a damage tolerance point of view, this difference can make tapered laminates more critical to impact. In the future, this research will be pursued to investigate the compression after impact of

tapered laminates. Additionally, numerical analysis will be carried out to investigate the impact behavior of tapered laminates, The energy absorption capability of carbon- fiber rain forced (CFRP) square tubes with overlapping discontinuous plies covered on [7]. Quasi-static axial compression tests were conducted to investigate the failure process, crashworthiness and the corresponding energy-absorption mechanism. Lastly, the result shows Increasing the cutting angle increases the specific energy absorption from 50.8J/g to 74.1J/g.

Few studies [23, 24, 25, 26] are use crushable foam core and polymer foam filled composite conical element aiming to achieve large strains (due to unfolding of the skins) and energy absorption (due to crushing of the foam core) under tensile loading.[24] Study is performed on a single-element loaded in the principal direction: tension and compression, both in the fiber and matrix direction. By using LS-DYNA's MAT54, the quasi-static crushing of a composite specimen, consisting of a semi-circular sinusoid and manufactured with carbon/ epoxy unidirectional prepreg tape, is then modeled. Based on the research the higher the degree of curvature of the specimen, the more efficient it is in crushing by fragmentation rather than frond formation. The formation of large intact fronds is highly inefficient from an energy absorption standpoint, and is accompanied by the formation of long delamination in the specimen ahead of the crash front itself. Hong and Liu [25] showed that there is an almost linear relationship between the impact energy and the total delaminated area in glass/epoxy laminates. Therefore, an efficient way to improve the energy absorption capacity of laminate composites in the through-thickness direction is by promoting controlled delamination by weakening the interlaminar bond strength or interlaminar fracture toughness. [11] Explore various factors for design of composite structures with ply drops. These factors include thicknesses, ply stacking sequences, and ply drop geometries and manufacturing considerations. In addition, fatigue loading is considered with respect to delamination initiation and growth.

[26] Conducted the impact energy absorbing ability of sandwich materials that have different skin and honeycomb core. The test is simulated by drop-weight and constant velocity impact experiments. These studies assess the energy absorbing damage at all stages of the impact and relate this to the impact conditions in terms of impact energy, size and shape of Impactor as well as fiber directionality and skin structure.[33] Stated alternative experimental test setup for studying compression failure of the composites with an embedded ply drop. This setup introduces a combined compression and bending loading to a unidirectional glass reinforced composite tube, which contains ply drops. This combined loading state is achieved by applying eccentric compression force to the tube. Furthermore, the far field stress state of the composite tube is studied to examine the similarities/discrepancies from the typically used "flat type specimen". It was found that even the far

field stresses are slightly more complex compared to the alternative "flat type specimen" and the tube setup could possibly be used as benchmark case for compression models of composite material with embedded ply drops.

Some of [30, 31] papers performed on circular tubes to examine their axial crushing behaviors. Stable progressive crushing processes with brittle fracturing crushing mode observe during the experiments. The interaction of the fundamental symmetric Lamb wave mode S_0 with delamination's in 8-layered glass fiber reinforced polymer (GFRP) laminated composites, using numerical models validated against experiments was also studied [36].

2.3 Literatures on numerical analysis of composites using ABAQUES software

The paper [37] conducted to predict the damage behaviors of composite sandwich structures with a honeycomb core subjected to low-velocity perforation impact, a numerical model was developed addressing the intra-laminar damage, inter-laminar and adhesive delamination and strain rate effect of the materials. For this analyses the impact test was implement using a drop weight machine coded ITR 2000. Hemispherical steel Impactor with the diameter of 12.5 mm was utilizing. The height from the Impactor tip to the specimen after fixing completely for the test was 45 mm. The specimen was uniformly clamped by a fixture, which spared a consistent area for the impact test. During testing, impact force and deflection were recorded by a data collection computer. From this, the results demonstrated that the proposed methods could predict the low-velocity impact damage of composite sandwich structures with honeycomb core. The results demonstrated that the proposed methods could predict the low-velocity impact damage of composite sandwich structures with honeycomb core.

[38] Investigated and presented the impact dynamic response and energy dissipation mechanism of composite multilayer array structures using ABAQUS/Explicit to develop numerical simulations of the composite multilayer array structures under low-velocity and large mass impact loading. The four constituent materials, that is, the Q235B steel, the solid buoyant core, the glass fiber composite and the bonding interface, clearly present very different mechanical responses. The author conclude that Comprehensive analysis results shows that this new structure has good energy absorption efficiency and provide a new way for the design of warship protective structures.

[39] This paper introduces a shell based finite element (FE) model for predicting the impact response and dominant failure mechanisms of fiber reinforced polymer matrix composites subject to low velocity impact. The commercially available FE solver ABAQUS Explicit is used. The model utilizes eight noded plane-stress continuum shell elements with reduced integration (SC8R element

in ABAQUS) for modeling each lamina individually. Continuum shells provide the benefit of having nodes on the top and bottom surface of the ply. The shell based impact FE model has been shown to be successful at predicting the response and damage of FRPC laminated composites subject to low-velocity impact. Future work on improving the model would include capturing the rebound response more accurately. The model has proved to be robust and highly applicable to solve industry level problems. The model was successful at predicting the impact response of composite laminates of various different non-traditional layups.

The impact resistance of new resin-based fiber composite materials for electric vehicle battery PACK box also studied on paper [40]. The dynamic simulation for fiber composite laminates is carried out based on ANSYS ACP module and Explicit Dynamics module. From the analysis the researcher, conclude that the basic strength of the carbon fiber board is slightly larger than that of the glass fiberboard. When the impact energy is small, carbon fiber board has a better performance than glass fiber; When the energy grows stronger, at the same impact conditions, because the carbon fiber board deformation area is smaller and the deformation is larger, so the load capacity is weaker than the glass fiber board. In the battery PACK box, glass fiberboard must be placed outside the carbon fiber board, which can improve the impact resistance of the box.

The dynamic mechanical response and damage development in cross-ply composite laminates subjected to transverse low velocity impact also conducted using finite element package ABAQUS/Explicit on cross-ply composite specimens with different impact energies to study the impact force-time, force displacement and energy-time histories curves as well as the damage evolution behaviors of matrix cracking and interface delamination. From the study, the author used 'Surface to Surface Contact', it is available in ABAQUS/Explicit, to define the contact response between the Impactor and composite laminates. Finally, the author concludes that, the current numerical model is able to analyze the impact damage response of intra-laminar behavior and interface delamination, and the damage formulations presented is naturally general. In addition, he recommended that this model could be an appropriate tool in future to study the damage development behavior in other types of composite laminates under large mass and low velocity impact [23].

The paper [41] deals with the finite element analysis of effect of cutout of different shapes in laminates and influence of fiber orientation on the strength of the woven Glass/Epoxy - Carbon/Epoxy hybrid composite laminate. Investigations have been carried out on laminated composites with and without cutouts of different shapes and for different fiber orientation.

Simulation of tensile tests was carried out in system using Abaqus software. From analysis, it was noticed that straight-ply oriented composite laminates possess the maximum strength as compared to other types of fiber orientations. In addition, it is noticed that the maximum load carrying capacity increases with introduction of carbon fiber insert and it decreases with the introduction of cutout.

The author [42] studied High velocity impact on laminated composite panels is investigated by modeling, simulation, and experiments based on Impact velocities of 100 m/s, 200 m/s, and 300 m/s are considered and normal as well as oblique impacts using the explicit FEM solver Abaqus/Explicit v6.14 (Assault Systems Simulia Corp., Providence, RI, USA). The Material used for analysis is glass fabric/epoxy plies. Lastly, the result confirmed that the modeling approach is capable to simulate the high velocity impact response of composite laminates within reasonable computation time and resources. Eventually, such advanced computational simulations contribute to improvements in the design of impact loaded composites and help in reducing the experimental effort associated with their design.

2.4 Literatures on the study of ply drops in composite material

Tapered laminated structures, were formed by dropping off some of the plies at discrete positions over the laminate, and had received much attention from researchers because of their structural tailoring capabilities, damage tolerance, and their potential for creating significant weight savings in engineering applications. The inherent weakness of this construction is the presence of material and geometric discontinuities at ply drop region that induce premature interlaminar failure at interfaces between dropped and continuous plies. Because of this [11] studied the finite element analysis of composite laminates with externally and internally ply drop-off is presented. The effect of different lay-ups and different ply drop-off ratio T_h/L (where T_h is total thickness of ply drops and is ply drop of length) under tensile load was studied. Finally, the researcher conclude that internally ply drop-off composite laminates have more strength compare to externally ply drop-off composite laminates.

Tapered laminated composite structures formed by terminating or dropping off some of the plies in some primary structures, create geometry and material discontinuities that act as sources for delamination initiation and propagation. Because, of their structural tailoring capabilities, damage tolerance, and their potential for creating significant weight savings in engineering applications it received much attention from researchers and a large number of investigators have been engaged in conducting research on this subject [43]. The following figure shows schematic of taper with internal dropped plies [44].

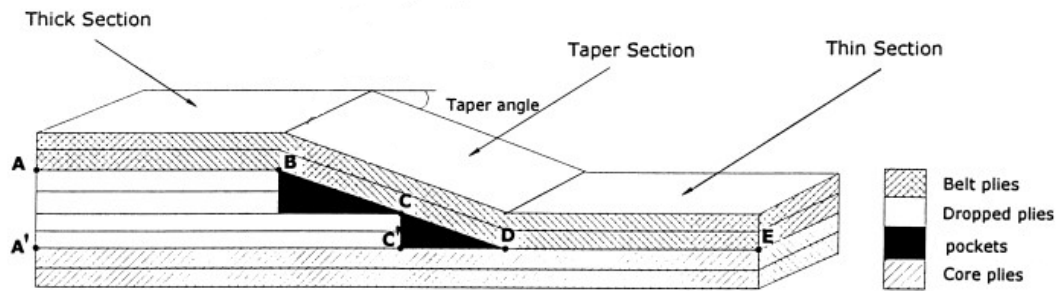


Figure 2-3: Schematic of taper with internal dropped plies

On [45] The author investigate to developing a few guidelines for the design of tapered laminated composites. The tapering in laminated composites is introduced by terminating (dropping-off) plies at different locations. The main objective in designing a drop-off is to reduce stress concentration. At present, some thumb rules are used to design the drop-off. However, these guidelines have been developed by studying the effect of important parameters that determine the strength of the laminate. After the analysis, the numerical study shows that some of the thumb rules used at present are rather conservative and may be relaxed to an extent.

The effects of ply drops and resin pockets on the tensile behavior of tapered laminates considering certain important parameters like taper angle, the number of plies dropped, and the fiber orientations are also covered on [46]. The authors use for analysis is CFRP with multiple ply dropping n plies at a single station, with n varying from 1–4 and at the same time by changing tapering angle α . Finally, the authors summarize that, the size of the resin pocket is shown to be a crucial parameter affecting the nature of the stress distribution. The effect of dropping plies with different fiber orientations was also illustrated. Dropping of off-axis plies leads to higher failure factors due to the presence of significant in plane shear stresses, whereas the dropping of 90° plies has negligible effect on the stress distribution.

[47] Studied compressive strength of composite laminate with internally ply drops experimentally. For this experimental analysis, all specimens for the direct compression tests comprised unidirectional 0° laminates made from 0.125 mm thick T300/914C carbon fiber–epoxy prepreg. The specimens were laid up by hand and autoclaved using the recommended schedule with two ply-drop regions arranged symmetrically about the mid-plane. Four specimen geometries were manufactured and tested in order to vary the physical size and the taper angle of the ply drop. Lastly, by observing the experimental analysis like number of ply drops, tapering angle and resin rich pocket dimension the authors conclude that Composite laminates with terminated internal plies fail either by micro-

buckling of the longitudinal fibers near the toe of the resin pocket governed by the induced fiber waviness of longitudinal fibers in the vicinity of the ply drop. Micro buckling is active for shallow angles of taper while delamination dominates in steeply tapered specimens. Both the delamination model and the micro-buckling model give adequate predictions of compressive strength in their respective regimes of dominance.

The paper [48] also presented that The influence of ply-drop position along thickness direction under fatigue loading ($R = -1$) had been studied for a highly oriented composite laminate dropping from 20 to 12 plies. Compressive and tensile strengths had been determined for several configurations of ply-drop locations. Fatigue tests at a load ratio of $R=-1$ had been performed up to rupture. The final result shows that the first damages clearly identified were delamination close to the drop-offs. Their initial locations and propagations kinetics before final failure were observed. Finite element simulations were performed to find out initiation spots of delamination.

Study of [49] discussed the effects of ply drops and resin pockets on the tensile behavior of tapered laminates considering certain important parameters like taper angle, the number of plies dropped, and the fiber orientation is reported here. Estimation of the tensile strength of tapered laminates necessitates accurate determination of the state of stress near the ply-drop region, which is, in general, three-dimensional (3-D) in nature. Recognizing the fact that full 3-D finite-element analysis becomes computationally exorbitant, special layered 3-D finite-element analysis is carried out. Laminates with ply drops along only one direction are analyzed to elicit the nature of the local bending effects occurring near the ply drops. Complete 3-D Tsai–Wu criterion considering all the six stress components is used to obtain a quick and comparative assessment of the tensile strength of these laminates. High stress concentration zones are identified and the effects of number of plies dropped at a station and resin pocket geometry are illustrated. The mechanism of load transfer near ply drops and the local bending that occur are described. Susceptibility of ply drop zones to the onset and subsequent growth of delamination is also brought out.

(Dhurvey, 2013) Review various studies on composite laminates with ply drop-off was presented. Tapered laminated structures, which are formed by dropping of some of the plies at discrete positions over the laminate, had received much attention from researchers because of their structural tailoring capabilities, damage tolerance, and their potential for creating significant weight savings in engineering applications. Generally, it devoted to static and dynamics analysis, buckling analysis, vibration analysis, delamination and interlaminar stress analysis of laminated composite plates and beams, tapered laminated structure with ply drop-off [5].

2.5 Research gap

Different authors and literatures were studied Energy absorbed capability of composite using different layers and arrangement for different types of composite materials. Based on the literatures, most of the researcher done impact analysis of composite by varying composite material, fiber orientation, changing ply thickness and the ratio of hardener and resin and other techniques, it shows that still demands on the need to analyze the impact energy capacity of the composite materials by using other mechanism. Hence, in the present work the effect of internally and externally ply drops on energy absorbed capability of glass fiber reinforced plastic composite materials numerically investigated in three different Impactor velocity by using ABAQUS software.

CHAPTER THREE

3. MATERIAL AND METHODS

3.1 Material Description

As a material, this research uses unidirectional GFRP (glass fiber reinforced epoxy plastic) composite materials for impact analysis. The mechanical property of the material and all input variables are selected from the literature [23].

Table 3-1: Material properties of modeled specimen

Density (ρ)=1600 Kg/m ³			
Young's modulus (GPa)	Poisson's ratio	Strength(Mpa)	Fracture toughness(N/mm)
$E_{11}= 153$	$\nu_{23} = 0.4$	$X_t= 2537$	$G_{ft}= 10$
$E_{22}= 10.3$	$\nu_{12}= 0.3$	$X_c=1580$	$G_{fc}= 10$
$E_{33}= 10.3$	$\nu_{13}= 0.3$	$Y_t= 82$	$G_{mt}= 1$
$G_{23}= 3.7$		$Y_c= 236$	$G_{mc}= 1$
$G_{12}= 6$		$S_{12}=S_{13}= 90$	
$G_{13}= 6$		$S_{23}= 40$	

Where;

E_{11}, E_{22} : - longitudinal and transverse stiffness

G_{12}, G_{23} : - shear stiffness

ν_{13}, ν_{23} : - Poisson's ratio

X_t, X_c : - tensile and compressive strength at longitudinal direction

Y_t, Y_c : - tensile and compressive strength at transverse direction

S_{12}, S_{13} : - shear stress at longitudinal and transverse direction

G_{ft}, G_{fc} : - tensile and compressive fracture toughness at longitudinal direction

G_{mt}, G_{mc} : - tensile and compressive fracture toughness at transverse direction

GPa: - Giga Pascal

MPa: - Mega Pascal

3.2 Modeling procedures

3.2.1 Creating parts and define model geometry

The composite model was modeled based on ASTM D7136/D7136M – 12 standards designed for measuring the damage resistance of a fiber-reinforced polymer matrix composite to a drop weight impact event. The Abaqus FEA package also provides built in composite modeling capabilities. The general geometry of the test specimen was a rectangular uni-directional E-glass fiber laminate with a

thickness of 0.75 mm, a length of 175 mm, width of 125 mm and for gripping 25 mm each on each end is taken, for impact test and impactor as shown in figure 3-1 below.

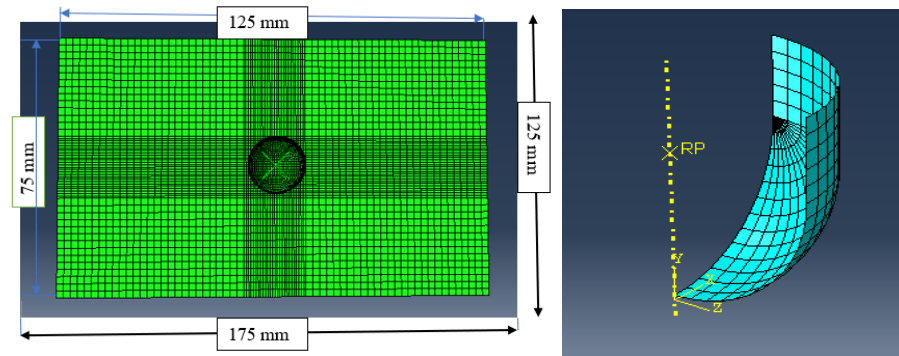


Figure 3-1: Abaqus Model Geometrical properties of the simulation specimen and impactor

Using the above general dimension and geometry all 8 individual layers were modeled on the part module and assembled together on assembly module. The composite plies were created as a three-dimensional deformable solid part and the impactor as a three dimensional discrete rigid. The geometry of plies was varied for each layer because of the ply drop effect, because of this the dimension of all layers are listed below on table

Table 3-2: Dimension of flat (without) ply drop modeled specimen

No of plies	Width of ply (mm)	Length of ply (mm)	Thickness of ply (mm)
8	37.5	62.5	0.75

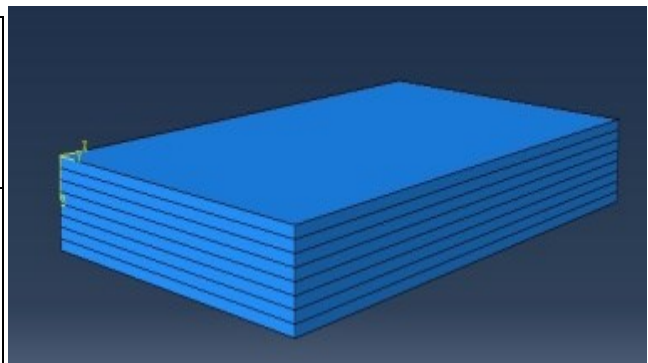


Figure 3-2: Flat (without ply drop) modeled specimen

Table 3-3: Dimension of external ply drop modeled specimen

No of plies	Width of ply (mm)	Length of ply (mm)	Thickness of ply (mm)
1.	37.5	30	0.75
2.	37.5	33.125	0.75
3.	37.5	36.25	0.75
4.	37.5	39.375	0.75
5,6,7,8	37.5	62.5	0.75

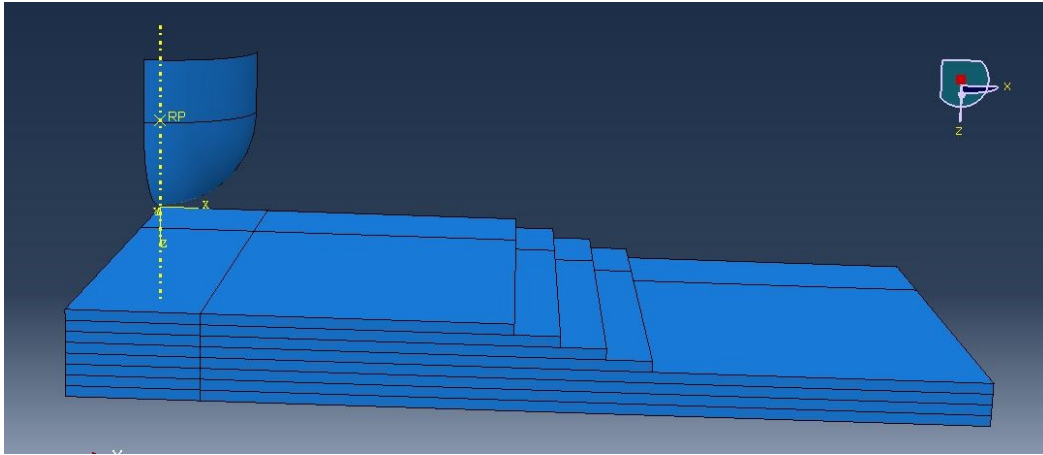


Figure 3-3: External ply drop modeled specimen

Table 3-4: Dimension of internal ply drop modeled specimen

No of plies	Width of ply (mm)	Left Flat Length of ply (mm)	Tapered length of ply (mm)	Right flat length of ply (mm)	Thickness of ply (mm)
1, 2	37.5	30	12.5	20	0.75
3,	37.5	30	3.125	-	0.75
4.	37.5	33.125	3.125	-	0.75
5.	37.5	36.25	3.125	-	0.75
6.	37.5	39.375	3.125	-	0.75
7,8	37.5	62.5	-	-	0.75

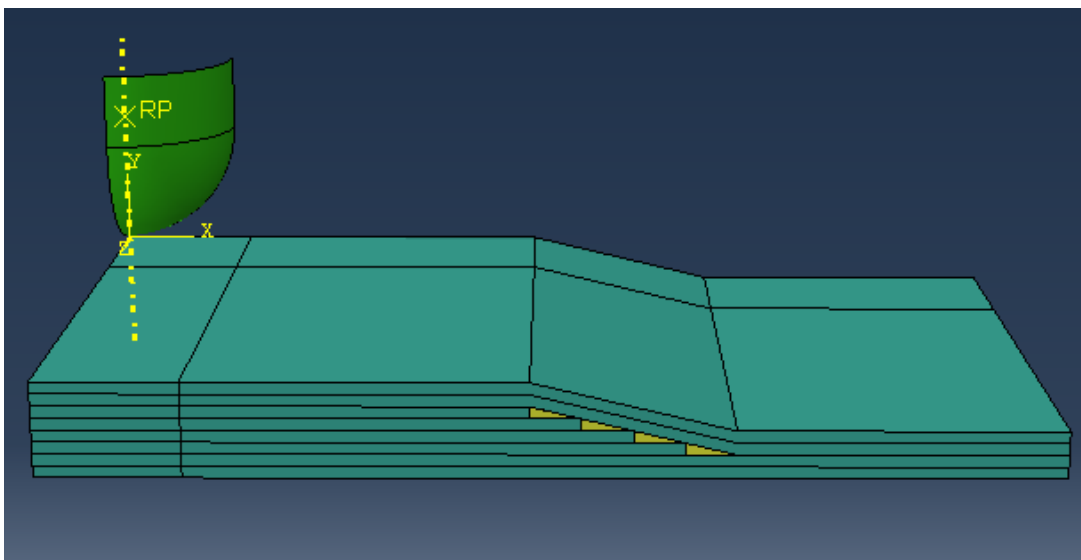


Figure 3-4: Internal ply drop modeled specimen

3.2.2 Interaction properties

The interaction module was one of the most important part of the finite element analysis when two or more objects were in contact. In this study the interaction properties were created using the general contact algorithm. The interaction property between the impactor and the composite laminate was defined using frictional coefficient of 0.3 and hard contact normal behavior [50]. The cohesive material properties also used for the interaction between the plies layer to layer from the literature used for the general analysis [23].

Table 3-5: Material properties of interface cohesive elements.

K (N/mm ³)	N(MPa)	S=T (MPa)	G _{IC} (N/mm)	G _{IIC} =G _{IIIC} (N/mm)	Density (kg/m ³)
2*10 ⁵	62.3	92.3	0.28	0.79	1200

3.2.3 Boundary condition and constant variables

The prescribed initial boundary conditions and the predefined velocity in the transverse direction (in Y-direction) is applied at this module. Four basic initial boundary conditions were applied on the analysis. The first boundary condition was clamped boundary condition or the fixed side boundary condition. It was created by pinned the face of thickness ($U_1=U_2=U_3=0$) at fixed side. The second condition was symmetry boundary condition, there were 3 types of symmetry sections for symmetrical models those are (X-SYM, Y-SYM and Z-SYM). Out of those symmetry types based on the direction of the modeled specimen plies arrangement and the direction of the impactor X-SYM and Z-SYM were used as shown on the figure below fig 3-5 for internally ply dropped and X-SYM and Y-SYM for flat and externally ply dropped specimen. The third boundary condition was the impactor movement that only allowed in the Y direction ($U_1=U_3=UR_1=UR_2=UR_3=0$) for internally ply drop and in the Z direction for flat and externally ply dropped specimen using displacement/ rotation boundary condition. The last boundary condition was the velocity/angular velocity boundary condition. In this section only the speed of the impactor was fixed at Y-direction ($V_1=V_3=VR_1=VR_2=VR_3=0$) for internally ply dropped and in the Z direction for flat and externally ply dropped specimen.

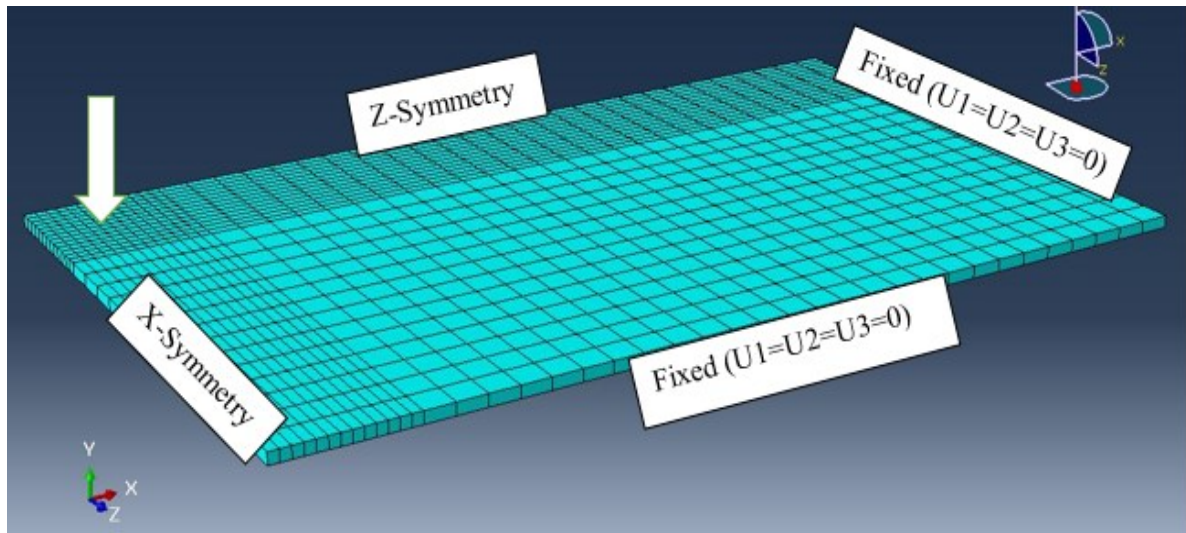


Figure 3-5: Boundary conditions of the modeled specimen

Table 3-6: Boundary conditions

BC	Pinned	Symmetry	Velocity/angular velocity	Displacement/rotation
Flat	$U1=U2=U3=0$	X-SYM and Y-SYM	$V3=2.51, 5$ and 10 $V1=V2=VR1=VR2=V$ $R3=unselected$	$U1=U2=UR1=UR2=UR3=0$
Internally ply drop	$U1=U2=U3=0$	X-SYM and Z-SYM	$V2=2.51, 5$ and 10 $V1=V3=VR1=VR2=V$ $R3=unselected$	$U1=U3=UR1=UR2=UR3=0$
Externally ply drop	$U1=U2=U3=0$	X-SYM and Y-SYM	$V3=2.51, 5$ and 10 $V1=V2=VR1=VR2=V$ $R3=unselected$	$U1=U2=UR1=UR2=UR3=0$

From the general ASTM D7136M-12 standard guide line for drop weight impact testing the impactor shall have had a mass of 5.5 ± 0.25 Kg, and shall have a smooth hemispherical striker tip with a diameter of 16 ± 0.1 mm was used throughout the quasi-static indentation and impact tests. Laminate construction shall consist of the appropriate number of unidirectional plies to achieve a total cured thickness nearest to 6.0 mm. the minimum and maximum ply thickness and number of ply related with layup sequence is listed on the following table [51]. With a stacking sequence of $[45/0/-45/90]_{NS}$ where N is a whole number.

Table 3-7: Recommended Layups Nominal Cured Ply Thicknesses, Unidirectional Tape

Nominal cured ply thickness			
Minimum, mm	Maximum, mm	Ply count	Layup
0.085	0.1	48	[45/0/-45/90] _{6S}
0.10	0.13	40	[45/0/-45/90] _{5S}
0.13	0.18	32	[45/0/-45/90] _{4S}
0.18	0.25	24	[45/0/-45/90] _{3S}
0.25	0.50	16	[45/0/-45/90] _{2S}
0.50	0.75	8	[45/0/-45/90] _S

Based to this standard, the drop weight impact simulation was performed by using a balanced, symmetric unidirectional laminated glass/epoxy composite with a dimension of 125 x 75 mm² as shown the above 3.1. Damage in the composite plate is imparted through out of the plane, concentrated impact (perpendicular to the plane of the laminated composite plate) using a drop weight rigid impactor with a hemispherical striker tip. In this work the 5.5 Kg of the impactor mass with smooth hemispherical striker tip of 16 mm diameter was used. In this simulation a clamp boundary conditions were also implemented in the Abaqus software, and by using the advantage of symmetry, only the quarter pars (1/4) of the composite plate is modeled and simulated in order to reduce the simulation time.

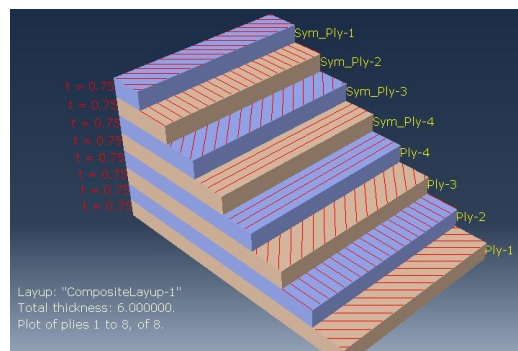


Figure 3-6: Fiber arrangement of composite

Measured Impact Energy—If the impact device is capable of detecting the velocity of the impactor, calculate the actual impact energy using Eq 1 and report the results to three significant figures. This calculation is performed automatically by most systems with velocity detection capability, but may be performed manually if necessary.

$$E_i = \frac{m \cdot V_i^2}{2}$$

1

Where;

E_i = measured impact energy, J and

m = mass of impactor, kg.

Units in Abaqus: - Generally Abaqus has no units built into it except for angle and rotation measurements. Therefore, the considered unit must be self-consistent, which means that derived units of the chosen system can be expressed in terms of the fundamental units without conversion factors. A consistent system of units is chosen within the design, as following:

Table 3-8: Basic Abaqus parameters and units

Parameters	Units
Time	Second (s)
Mass	Kilogram (Kg)
Length	Meter (m)
Energy	Joule (J)
Stress	Pascal (Pa)
Force	Newton (N)

3.2.4 Mesh module

The mesh module provides a variety of the tools that allows specifying different mesh characteristics, such as mesh density, element shape, and element type. For this study the composite plies meshed with SC8R element type which describes an 8-node quadrilateral in plane general-purpose continuum shell. The impactor region was meshed with $(0.5*0.5 \text{ mm}^2)$ and the other region was meshed with $(0.7*0.7 \text{ mm}^2)$. The metal Impactor also meshed with $(1*1 \text{ mm}^2)$ mesh size. Generally, the analysis holds different number of elements for each specimen and those numbers of elements were selected after mesh convergence study.

A mesh convergence study was conducted to ensure that the results obtained from ABAQUS simulation are reliable and accurate. The formal method of establishing mesh convergence requires a curve of a critical result parameter in a specific location, to be plotted against some measure of number of elements. As the number of elements increases the numerical solution will tend toward converged values. Five different mesh sizes and number of elements were used and the influence of number of elements on absorbed energy and reaction force particular result was plotted in Figure 3-7.

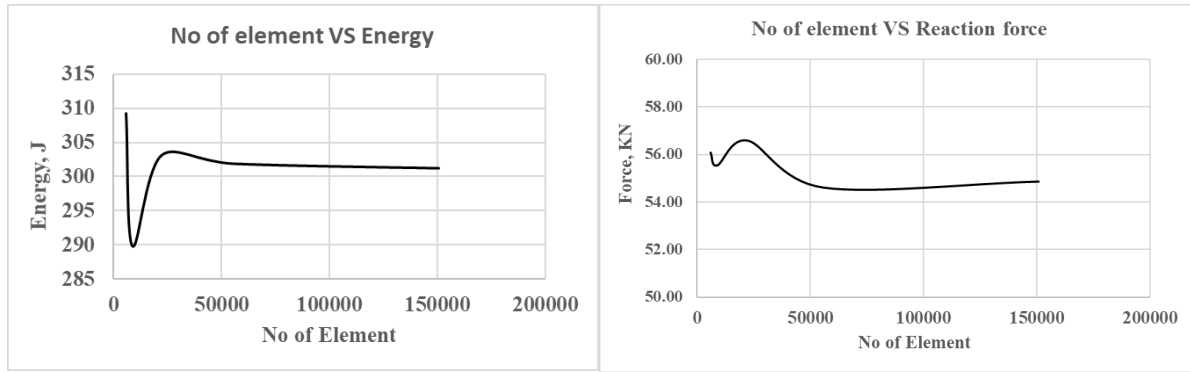


Figure 3-7: Number of elements vs. Energy and Reaction Force

The mesh size predicts inaccurate results but as the meshes sizes were decreased the number of elements was increased at this time all predict similar results. All the results were normalized with respect to the values predicted by the number of elements. From the study, 0.5 mm mesh size for fine mesh and 0.7 mm for course mesh and totally more than 55,825 numbers of elements had been chosen to produce reliable results throughout the analysis.

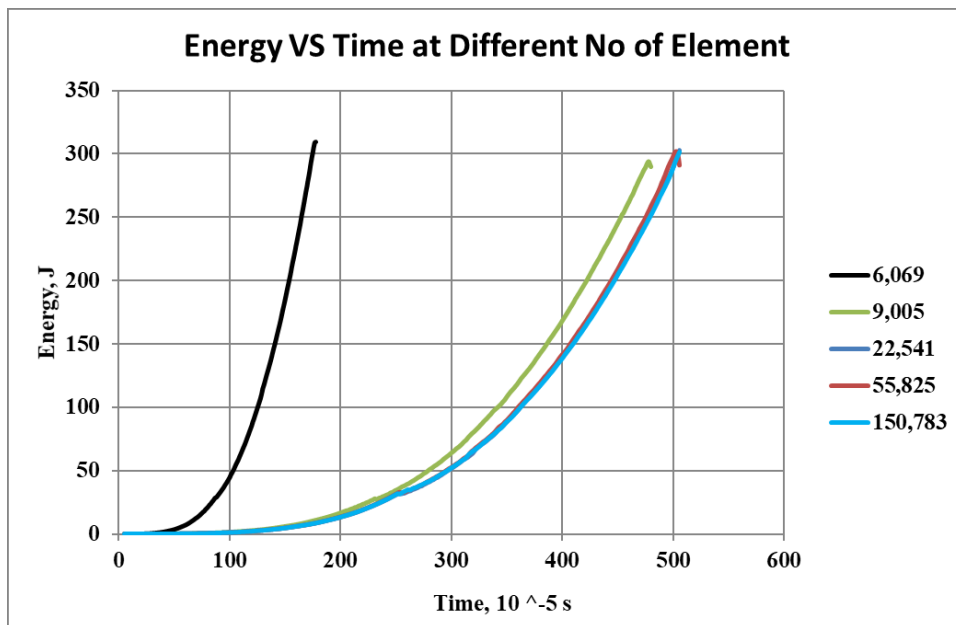


Figure 3-8: Internal energy vs. time at different number of elements

Table 3-9: Number of elements for different type of ply drop

Type of drop	No of element	Mesh size
Internal ply drop	61,949	0.5 mm for fine and 0.7 mm for course
Flat specimen	55,825	0.5 mm for fine and 0.7 mm for course
Externally ply drop	71,865	0.5 mm for fine and 0.7 mm for course

To create node to node interaction of each plies specially for internal and external ply drop specimen different section was applied on each plie and finally meshed all sectioned area by the same mesh size and it results perfect node to node mesh.

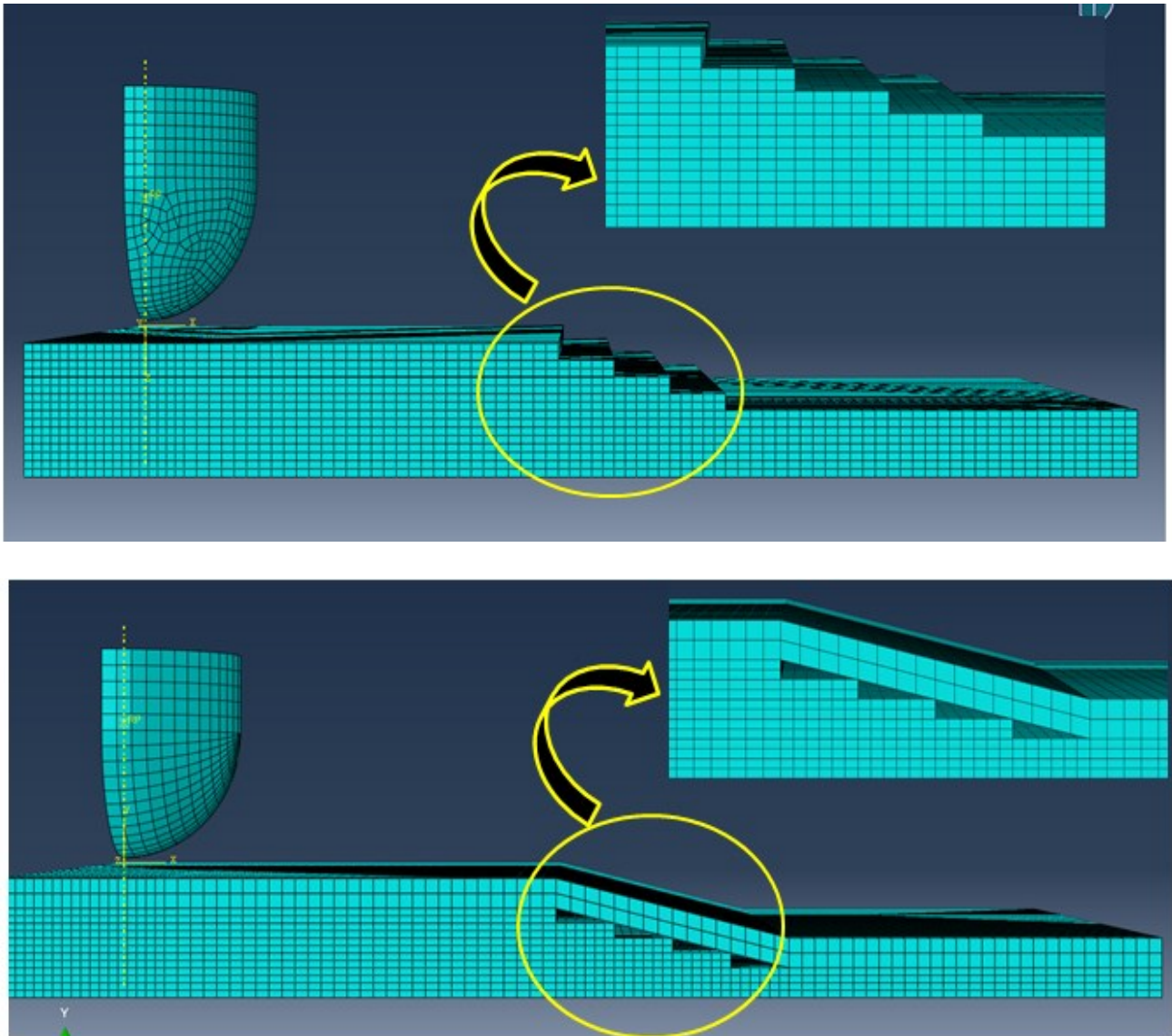


Figure 3-9: Node to node interaction for internally and externally ply dropped specimen

3.3 Numerical modeling and analysis

The drop-weight tests were carried out according to ASTM D7136 and the simulation was undertaken in framework of ABAQUS workbench commercial packages. Abaqus/CAE allows the user to define composite layups for three types of elements: conventional shells, continuum shells, and solids. ABAQUS/CAE is an engineering tool that is used to solve various engineering problems ranging from linear to non-linear problems that are complex. The software is used all over the world in industries and also in academic purpose it also enables models to be solved as quickly as possible

by simply creating the geometry under investigation with the right physical and material properties associated to it, loading and also by applying the boundary conditions to the material to be modeled. This versatility is facilitated by the user defined material card within the ABAQUS input deck, which gives control over the elastic material constants used by the analysis. The type of element that should be used to model a component is based on the component's geometry and the results desired [51].

The objective of this ABAQUS analysis and simulation of uni-directional E-glass is to predict the impact properties of composite material with internally and externally ply drop effect and compression will be done verified with the flat composite material without ply drop. The model of the test specimen for ABAQUS simulation dimensions and design as shown in figure 3.2-3.4. First, the model with 3D was created for each layer individually and assembled in assemble section. After all plies were assembled the required output results set on the step section. For type of loading, there are several categories of impact loading, and specifically these are: low velocity (large mass), intermediate velocity, high/ballistic velocity (small mass), and hyper velocity impact. Low velocity impacts occur at a velocity below 10 m/s, intermediate impacts occur between 10 m/s and 50 m/s, high velocity (ballistic) impacts have a range of velocity from 50 m/s to 1000 m/s, and hyper velocity impacts have the range of 2 Km/s to 5 Km/s [52].

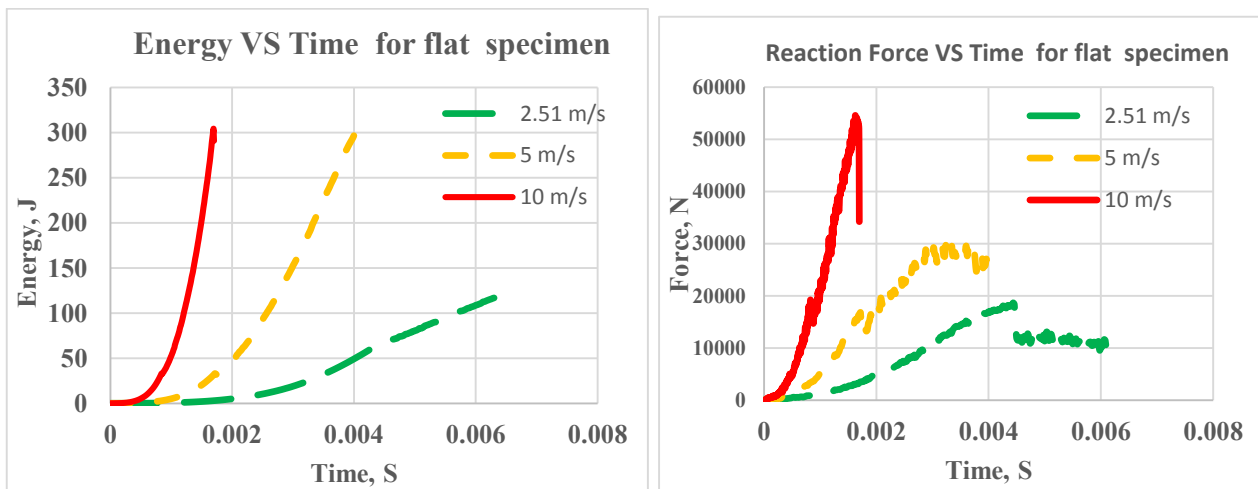
CHAPTER 4

4 RESULT AND DISCUSSION

In the previous chapter the numerical impact simulation procedure of fiber reinforced composite laminate using Abaqus/CAE was discussed. In this chapter the result of numerical simulation was presented and discussed briefly in the form of graphs. These results were given an information about the general behavior of the three different laminated composite models subjected to impact load with different velocity impactor, and finally the result comparison is done between the three different layup laminated composite. From all the graphs listed below the peak energy absorbed and the peak force were the main result obtained from the drop weight impacted composite laminated model analysis. Peak force is the maximum force of the impactor impacted on the laminate model over the entire impact time, although the absorbed energy is the energy at the maximum impact load and it obtained from the load-displacement graph integration.

4.1 Flat specimen results

Fig. 4-1: shows internal energy, reaction force and deformation curves for 2.5m/s, 5m/s and 10m/s impactor velocity respectively. Absorbed energy is the energy that stored on the specimen due to the deformation of the specimen caused by the applied impactor weight and speed. This impactor mass and velocity had created a reaction force on the edge of the specimen support; at this time the specimen resist the given load up to its maximum load capacity reaches. After that the specimen maximum load carrying capacity is pass load resistance of the material is reduced because of deformation occurred inside the composite material and the properties of the composite is not the same as the first material due to the additional mass and speed of the impactor.



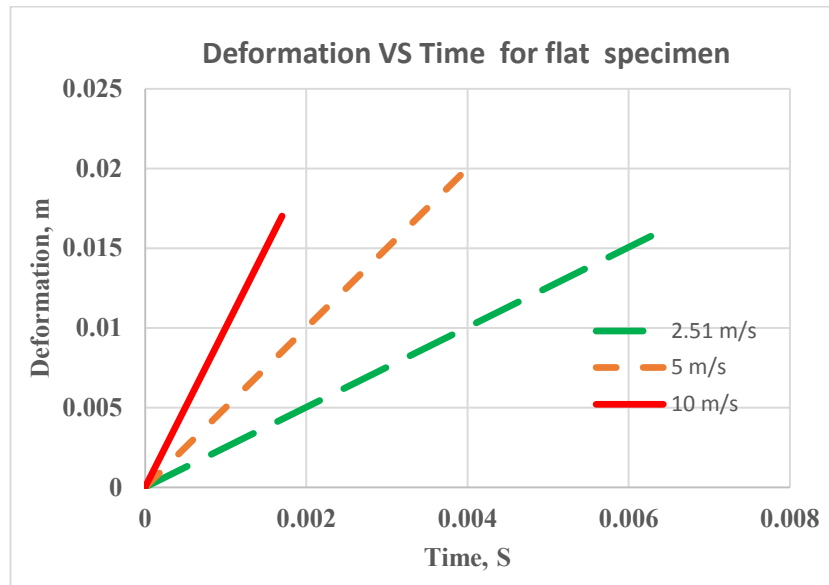


Figure 4-1: Flat specimen IE, RF and deformation at different impactor velocity

From fig 4-1 it shows that impact analysis of flat specimen within 0.01 s of analysis time at different impactor velocity. From the graph at 2.5 m/s impactor speed the maximum Internal energy was 116.76 J and maximum peak load was 18674 N occurred at 0.011 m deformation. This shows that the modeled flat specimen has capacity of storing Internal energy of 116.76 J with the deformation level of 0.011 m at peak load of 18674 N. similarly for impactor speed changed to 5m/s and 10m/s the response of the flat specimen was shown on the figure 4-1. From the observation when the speed was at 5 m/s, maximum peak load reach 29980.9 N at 0.016 m deformation. This shows that the energy stored due to the reaction force at the support of modeled flat specimen and the deformation of the specimen displacement was 296.6 J. 304.397 J stored energy at 0.0016 sec and 54601.8 N reaction forces at 0.0163 m deformation were also recorded at 10 m/s impactor speed.

4.2 Internal ply drops specimen results

Similarly, Fig. 4-2 shows absorbed internal energy -time curves, reaction force-time and displacement-time curves at 2.5 m/s, 5 m/s and 10 m/s impactor velocity. Where observation indicated that the result of energy contrary the peak of force where noted the maximum absorbed energy is appearing for internally ply drop specimen. Therefore, increasing in the reaction force leads to increasing in absorbed energy.

From the figure below fig 4-2a the dropped plies were not freely deformed and moved because of the first 2 layers are constraint and fixed on the top section. As a result of this the amount of energy absorption was reduce and the stress distribution also small at the first 2 layers and high at dropped section shows on the image below.

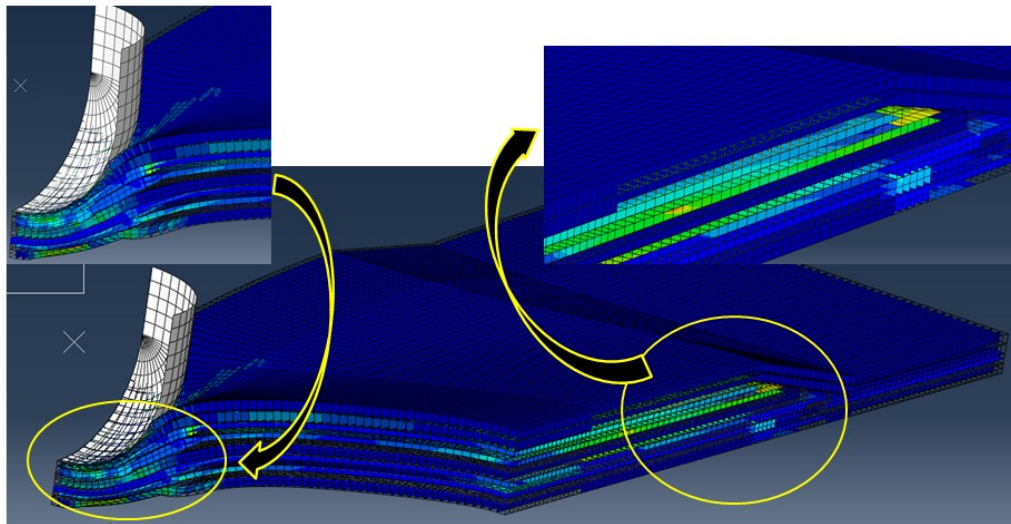


Figure 4-2a: Deformed part of internally ply drop specimen after impact

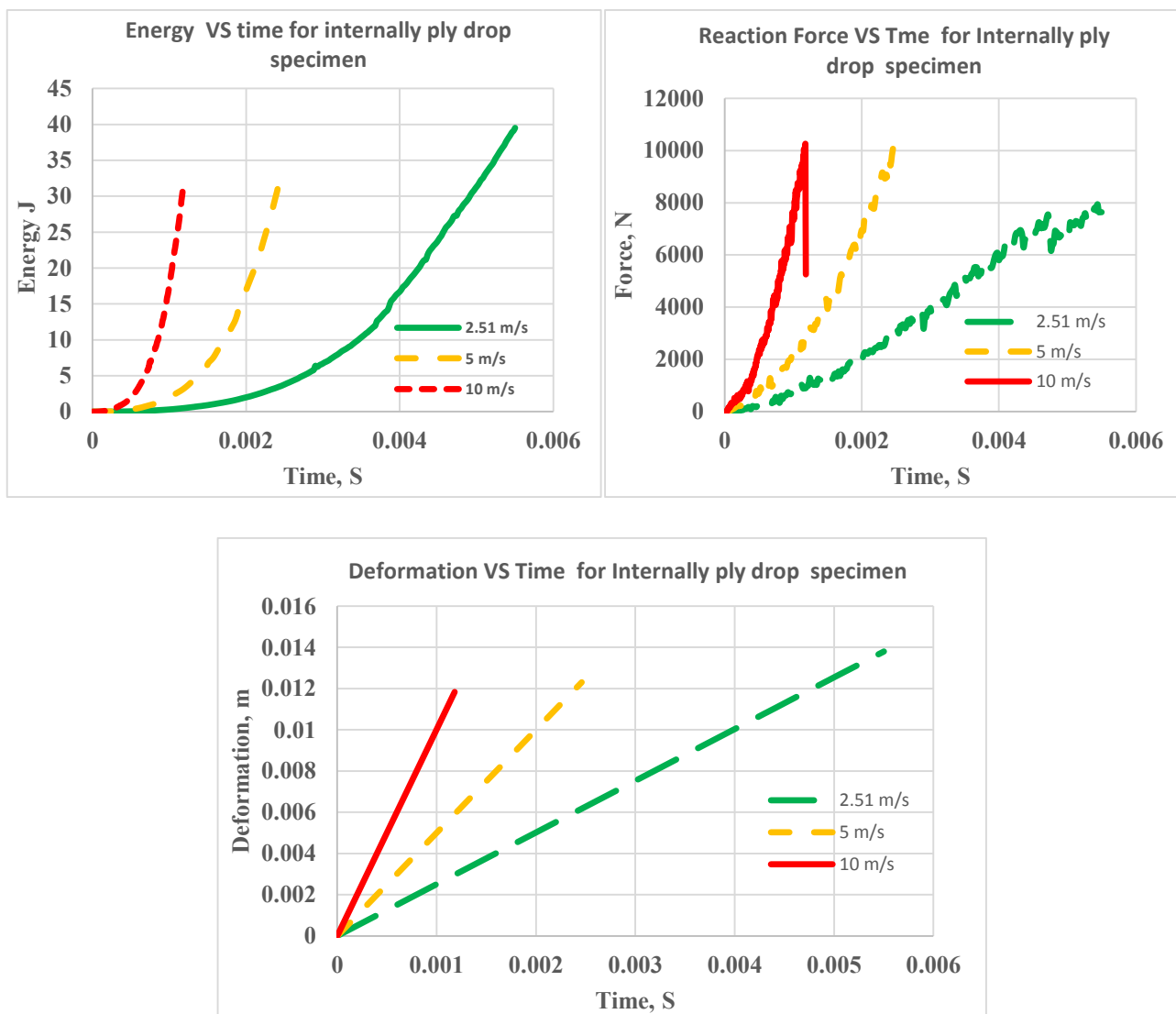


Figure 4-2: Internal ply drop specimen IE, RF and deformation at different impactor velocity

From fig 4-2 at 2.51 m/s impactor speed the maximum peak load is 7948.35 N and maximum Internal energy is 39.53 J at displacement value of 0.01365 m. This shows that the modeled internally ply drop specimen has capacity of stored of 39.5229 J Internal energy, because of the reaction force creating around the support and amount of displacement at 2.51 m/s. The maximum Internal energy when the impactor speed changed to 5 m/s was 33.4047 J at the deformation of 0.0123 m and the maximum reaction force is 10143.8 N. This shows that the modeled internal ply drop specimen has capacity of resisting load of 10143.8 N within 0.0123 m deformation.

When the impactor speed was 10 m/s maximum internal energy and reaction force of 30.84 J and 10255.7 N recorded respectively at deflection of 0.011764 m. This shows that the energy stored due to the reaction force at the support of modeled internally ply drop specimen and the deflection of the specimen displaced is 30.84 J.

4.3 External ply drops specimen results

Fig. 4-3 and Shows the internal energy, reaction force and displacement curves for 2.5 m/s, 5 m/s and 10 m/s impactor velocity respectively. From the figure below fig 4-3a the first 4 dropped plies were freely deformed and moved rather than the other 4 plies, because there is no constraint and fixed point at the top layer like internally ply dropped specimen. As a result of this the amount of energy absorption was increased and the stress distribution also high around the dropped section due to this reason the amount of energy absorbed around high stress concentration area was maximum as compared to normal flat specimen shows on the image below.

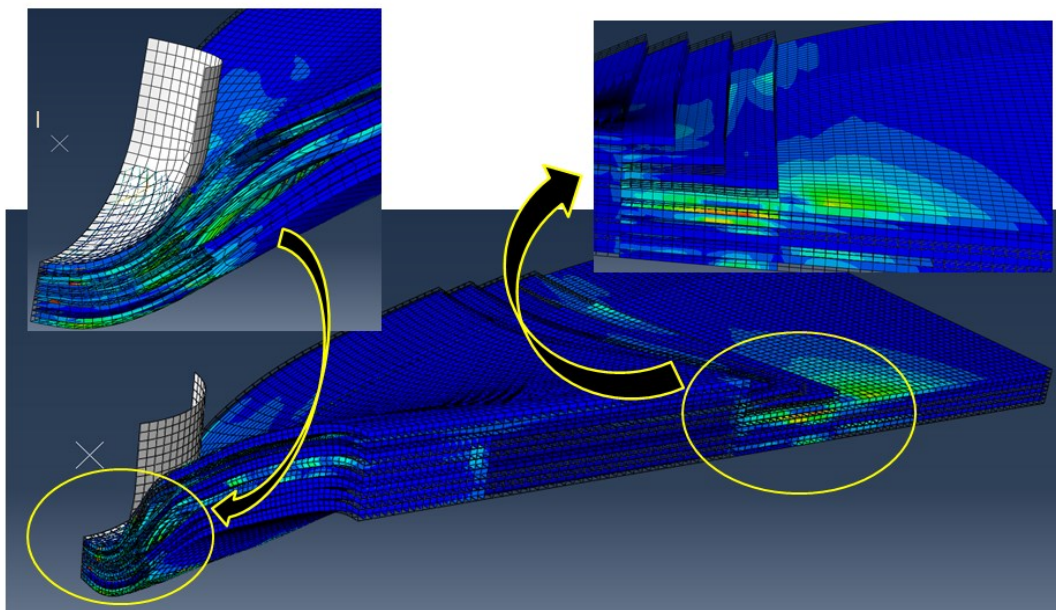


Figure 4-3a: Deformed part of externally ply drop specimen after impact

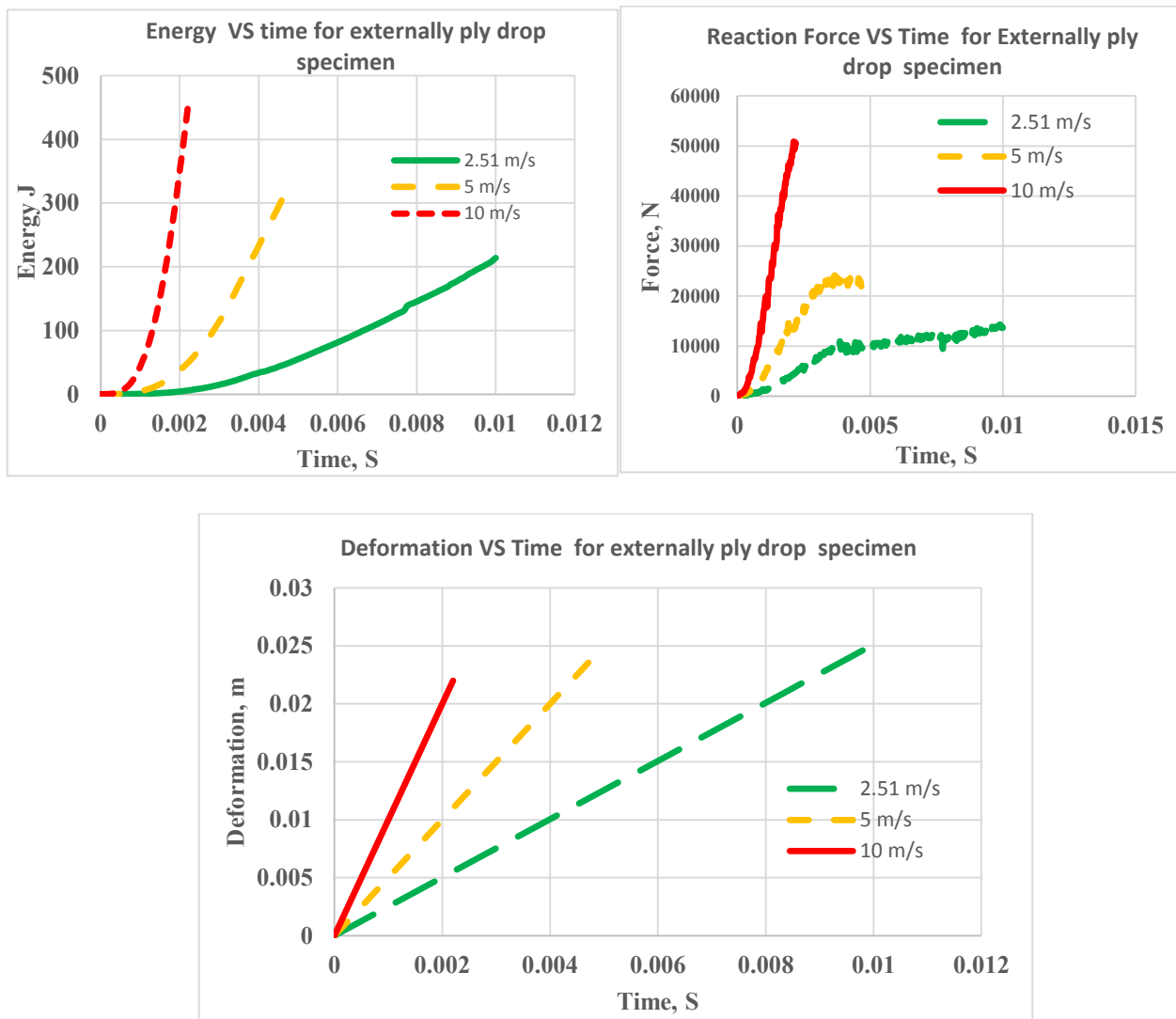


Figure 4-3: External ply drop specimen IE, RF and deformation at different impactor velocity

From fig 4-3 at 2.51 m/s the maximum Internal energy is 213.87 J occurred at 0.01 sec and 0.025 m. this shows that the modeled external ply drop specimen had stored Internal energy of 213.87 J, because of the reaction force creating around the support and amount of displacement. The maximum Internal energy when the speed was at 5 m/s, 291.93 J occurred at 0.0213 m. this shows that the energy stored due to the reaction force at the support of modeled external ply drop specimen and the deflection of the specimen displacement was 291.93 J. At 10 m/s absorbed energy was 447.89 J and amount of displacement recorded was 0.022 m. This shows that the energy created due to the reaction force at the support of modeled external ply drop specimen and the deflection of the specimen displacement is 447.89 J.

Similarly, at 2.51 m/s the maximum reaction force was 14277.6 N occurred at 0.0099 sec. This shows that the modeled external ply drop specimen had capacity of resisting load of 14277.6 N with

deformation value of 0.025 m. The maximum reaction force of 24029.1 N and displacement of 0.0213 m also recorded at 5m/s impactor speed. This shows that the modeled external ply drop specimen had capacity of resisting load of 24029.1 N within 0.0213 m displacement deflection. At the impactor speed was 10m/s maximum reaction force reached 50871.6 N at 0.00212 sec and at the same time displacement was reached 0.022 m. this shows that the modeled external ply drop specimen had capacity of resisting load of 50871.6 N at 0.022 m displacement deflection.

4.4 Overall results comparison

All results of IE (internal energy) and RF (reaction force) of the analysis at different velocity impactor gives a good information about the three type of ply arrangement specimens energy absorbed capacity and maximum applied load resistance related to displacement. Generally, the amount of absorbed energy and reaction force created inside the specimen was varied when the impactor speed and type of ply drop changed. Based on this to compare the result of absorbed energy for each specimen the mass and volume of the specimen must be the same, but in case of this analysis due to the ply drop effect the mass of the three specimens was different. Because of this to compare the result of those different mass specimen’s specific energy absorption capability must be calculated. On [53] Specific energy absorption capability E_s , defined as the energy absorbed per unit mass of material and given by

$$E_s = \frac{IE}{M} \dots\dots\dots 2$$

Where;

E_s : - Specific energy absorption capability

IE: - Internal energy

M: - mass of the specimen

The mass of the specimen was calculated by using volume of the specimen and the density of the composite.

$$M = \rho * V$$

Where;

ρ : - density of composite material

V: - Volume of the tested specimen

For flat specimen

$$V_F = 8 * 0.75 * 62.5 * 37.5 = 1.41 * 10^4 \text{ mm}^3$$

$$M_F = 1600 \left(\frac{Kg}{m^3} \right) * 1.41 * 10^{-5} = 0.023 \text{ Kg}$$

For internally ply drop

$$V1 \text{ and } V2 = 2 * 0.75 \text{ mm} * 37.5 \text{ mm} * (30 + 20 + \sqrt{12.5^2 + 3^2}) \text{ mm} = 3535.9 \text{ mm}^3$$

$$V3 = 0.75 \text{ mm} * 37.5 \text{ mm} * 30 \text{ mm} = 843.8 \text{ mm}^3$$

$$V4 = 0.75 \text{ mm} * 37.5 \text{ mm} * 33.125 \text{ mm} = 931.6 \text{ mm}^3$$

$$V5 = 0.75 \text{ mm} * 37.5 \text{ mm} * 36.25 \text{ mm} = 1019.5 \text{ mm}^3$$

$$V6 = 0.75 \text{ mm} * 37.5 \text{ mm} * 39.375 \text{ mm} = 1107.4 \text{ mm}^3$$

$$V7 \text{ and } V8 = 2 * 0.75 \text{ mm} * 37.5 \text{ mm} * 62.5 \text{ mm} = 3515.6 \text{ mm}^3$$

$$VT_I = (3535.9 + 843.8 + 931.6 + 1019.5 + 1107.4 + 3515.6) = 1.10 * 10^4 \text{ mm}^3$$

$$M_I = 1600 \left(\frac{\text{Kg}}{\text{m}^3} \right) * 1.10 * 10^{-5} \text{ m}^3 = 0.0176 \text{ Kg}$$

For externally ply drop

$$V1 = 0.75 \text{ mm} * 37.5 \text{ mm} * 30 \text{ mm} = 843.8 \text{ mm}^3$$

$$V2 = 0.75 \text{ mm} * 37.5 \text{ mm} * 33.125 \text{ mm} = 931.6 \text{ mm}^3$$

$$V3 = 0.75 \text{ mm} * 37.5 \text{ mm} * 36.25 \text{ mm} = 1019.5 \text{ mm}^3$$

$$V4 = 0.75 \text{ mm} * 37.5 \text{ mm} * 39.375 \text{ mm} = 1107.4 \text{ mm}^3$$

$$V5 \text{ to } V8 = 4 * 0.75 \text{ mm} * 37.5 \text{ mm} * 62.5 \text{ mm} = 7031.25 \text{ mm}^3$$

$$VT_E = (843.8 + 931.6 + 1019.5 + 1107.4 + 7031.25) = 1.09 * 10^4 \text{ mm}^3$$

$$M_E = 1600 \left(\frac{\text{Kg}}{\text{m}^3} \right) * 1.09 * 10^{-5} \text{ m}^3 = 0.0174 \text{ Kg}$$

Where

V1, V2...: - Volume of 1st ply, volume of 2nd ply...

VT_F: - Total volume of flat specimen

M_F: - Total mass of flat specimen

VT_I: - Total volume of internally ply drop specimen

M_I: - Total mass of internally ply drop specimen

VT_E: - Total volume of externally ply drop specimen

M_E: - Total mass of externally ply drop specimen

By using the above total mass of the three specimens the specific energy absorption capability was calculated and the results were compared as follows.

At 2.51 m/s;

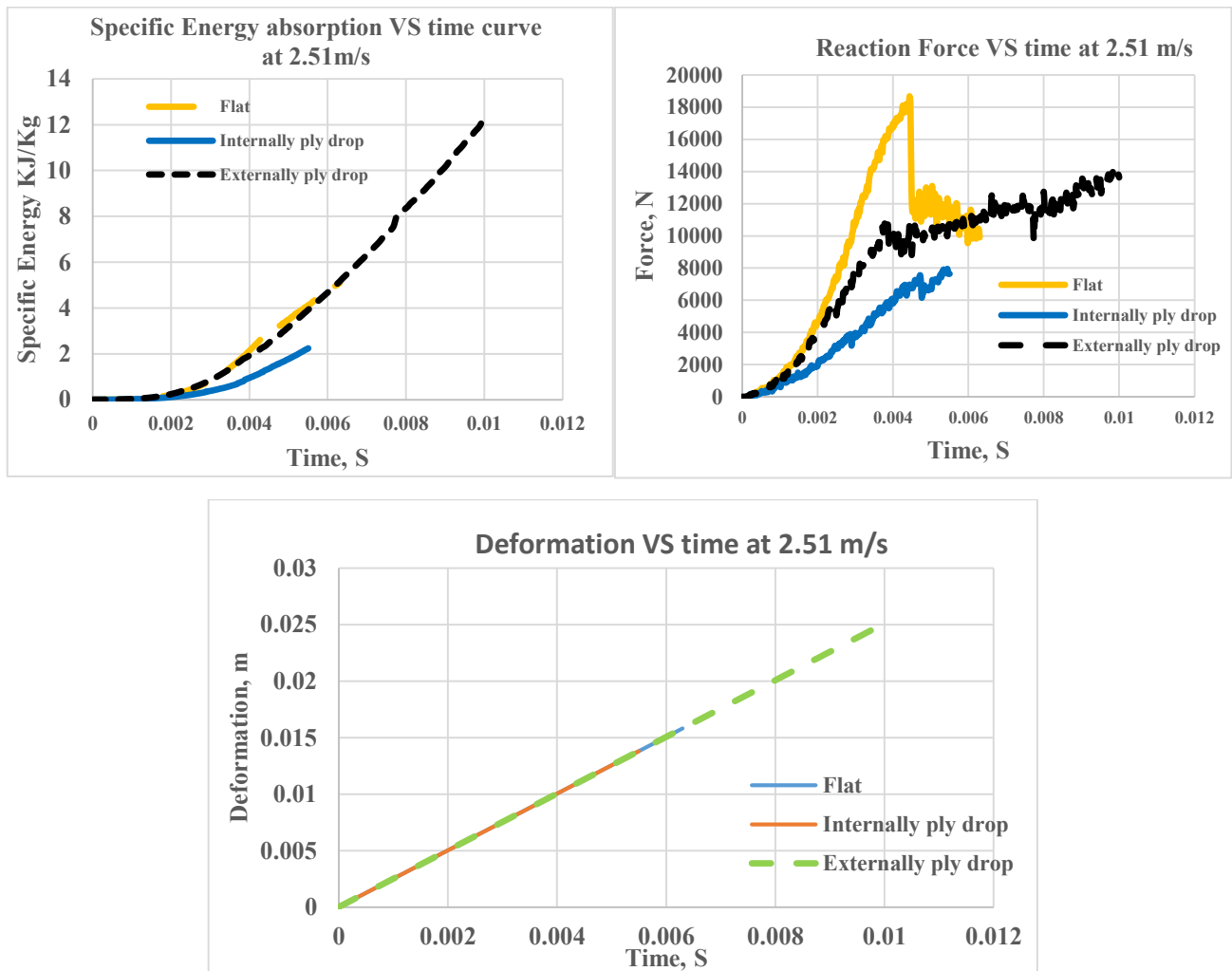
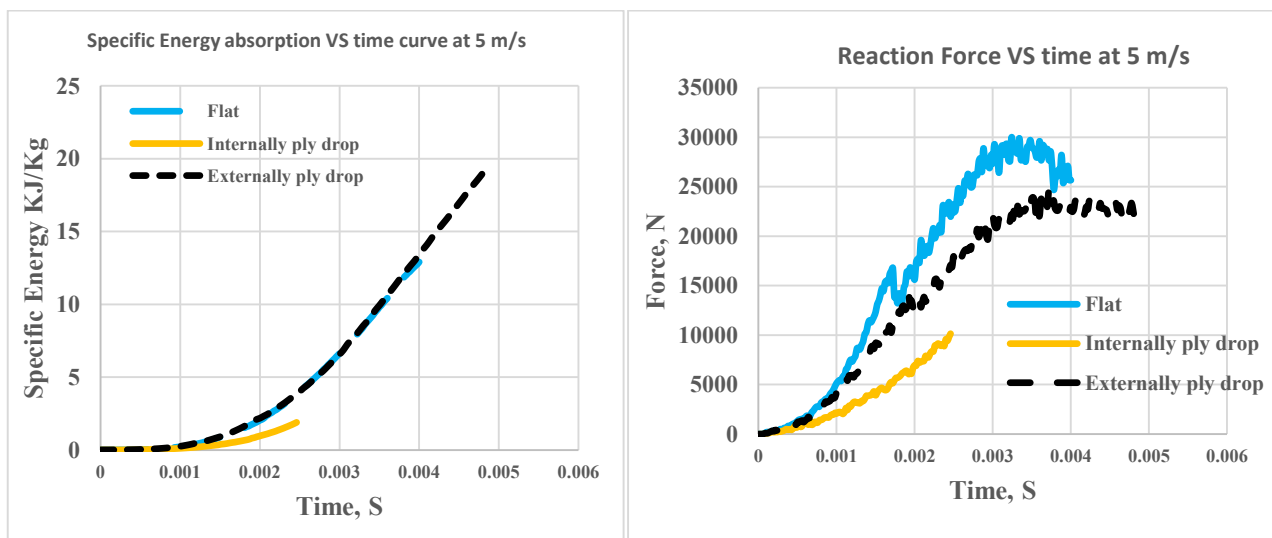


Figure 4-4: Specific energy, reaction force and deformation results at 2.51 m/s

At 5 m/s;



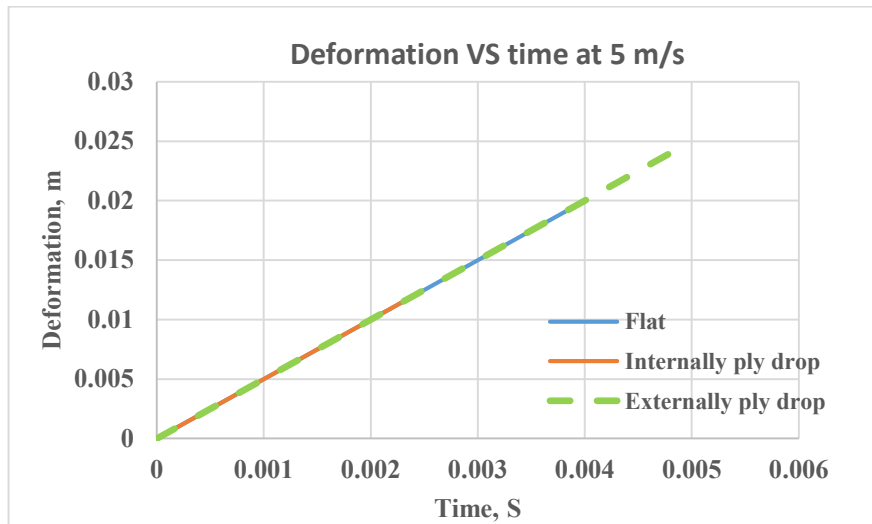


Figure 4-5: Specific energy, reaction force and deformation results at 5 m/s

At 10 m/s;

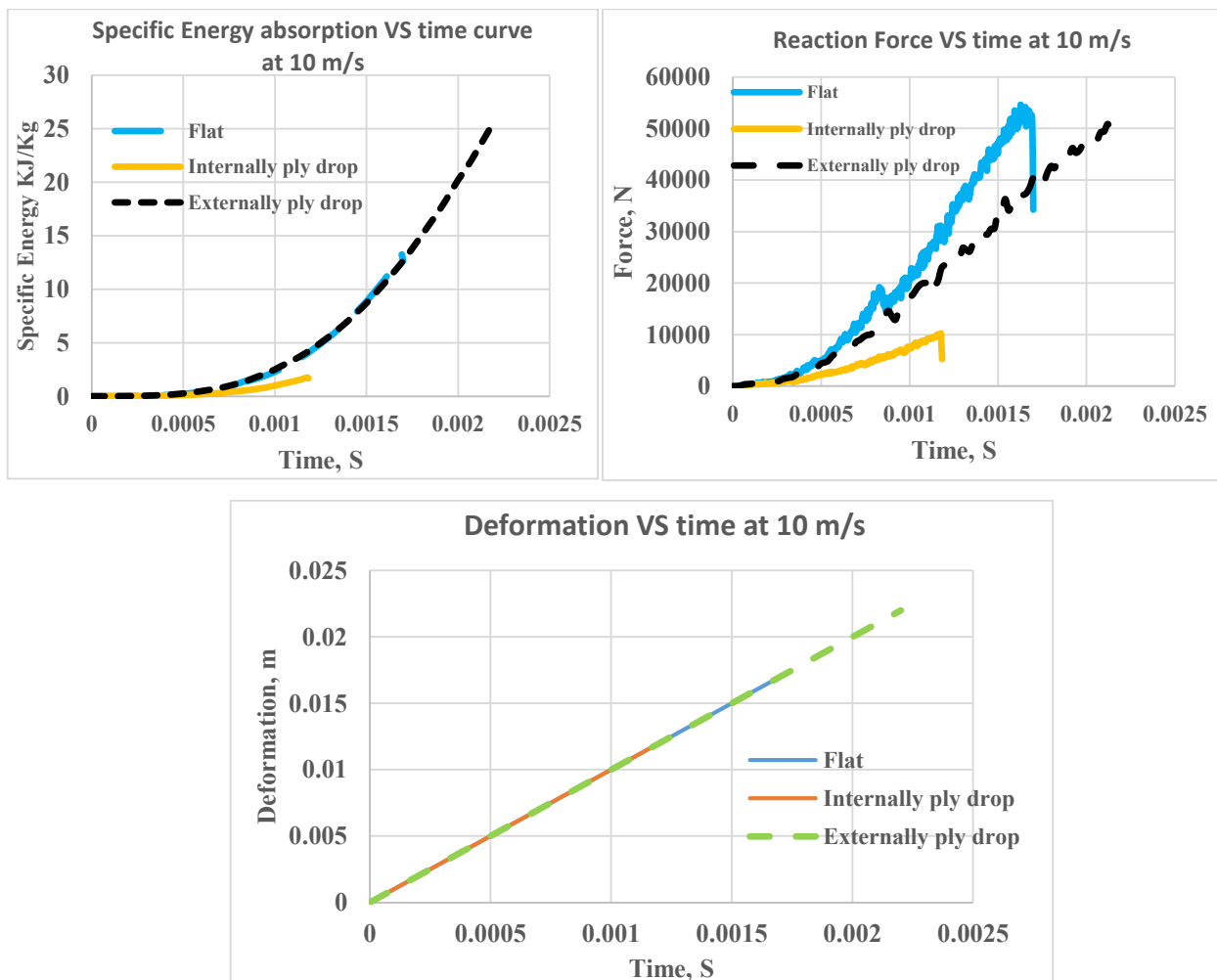


Figure 4-6: Specific energy, reaction force and deformation result at 10 m/s

Table 4-1: Overall Specific results comparison

Type of specimen	Parameter	At 2.51 m/s	At 5 m/s	At 10 m/s
Flat (without ply drop) $M_F=0.023\text{Kg}$	E_s	5.07 KJ/Kg	12.89 KJ/Kg	13.23 KJ/Kg
	Reaction Force	18674 N	29980.9 N	54601.8 N
	Deformation	0.011 m	0.016 m	0.0162 m
Internally Ply Drop $M_I=0.0176\text{Kg}$	E_s	2.25 KJ/Kg	1.84 KJ/Kg	1.56 KJ/Kg
	Reaction Force	7948.35 N	10143.8 N	10255.7 N
	Deformation	0.014 m	0.0123 m	0.012 m
Externally Ply Drop $M_E=0.0174\text{Kg}$	E_s	12.29 KJ/Kg	16.78 KJ/Kg	25.74 KJ/Kg
	Reaction Force	14277.6 N	24029.1 N	50871.6 N
	Deformation	0.025 m	0.021 m	0.022 m

On the first stage at 2.51 m/s impactor speed the maximum specific absorbed energy of 12.29 KJ/Kg at maximum deformation of 0.025 m on externally ply drop specimen was recorded and the maximum peak load was recorded on flat specimen 18674 N but due to the small amount of deformation it absorbed less energy than externally ply drop specimen on the analysis. On the second stage flat ply drop specimen absorbed a better specific energy of 5.07 KJ/Kg at the same impactor speed. When the impactor speed changed to 5m/s specific energy absorption of externally ply drop specimen also increased in to 16.78 KJ/Kg and 12.89 KJ/Kg for flat specimen was recorded. Similarly, the maximum deformation 0.021 m on externally ply drop specimen was recorded. Finally, at 10 m/s on the flat specimen 13.23 KJ/Kg, 1.56 KJ/Kg for internally ply drop and 25.74 KJ/Kg for external ply drop was recorded. From this the maximum specific energy absorption was found on externally ply drop specimen of 25.74 KJ/Kg at 10 m/s impactor speed. And the amount of peak load was 54601.8 N on flat specimen and 50871.6 N on externally ply drop. Similarly, the amount of deformation also 0.0162 m on flat specimen, 0.012 m on internally ply drop specimen and 0.022 m on externally ply drop specimen was recorded. It shows the amount of absorbed energy per a give mass of each types of ply dropped specimens were different because of the additional ply drop feature.

CHAPTER 5

5. Conclusion and Recommendation

5.1 Conclusion

From the numerical ABQUS analysis the impact resistance behavior or impact energy absorbing capacity of flat (without ply drop), internally ply drop and externally ply drop unidirectional GFRP composite specimens are done in three different velocity impactor. The result indicates that, the stored energy is varying as ply arrangement and impactor speed varying. Based on this the maximum specific absorbed energy stored on flat, internally ply drop, and externally ply drop unidirectional Glass fiber epoxy composite material become 13.23 KJ/Kg, 1.56 KJ/Kg and 25.74 KJ/Kg at 10 m/s respectively. The result shows the maximum specific energy stored at all speed was on externally ply drop specimen, it means externally ply drop had a good specific energy absorbed capacity as compare to the other flat and internally ply drop arrangements. Therefore, for the tapered structural part and other impact resisting material impactor speed on the range up to 10 m/s externally ply drop specimen was better to store impact energy.

Additionally, when compared the reaction force of the three specimens at impactor speed increasing the reaction force also increasing for all ply arrangement. From table 4-1 the maximum resistance of reaction force occurred at 10 m/s on flat specimen of 54601.8 N at displacement of 0.0162 m deformation and externally ply drop of 50871.6 N at 0.022 m deformation. From the displacement-time graph the amount of displaced/deformed size of the specimen was vary similarly when the impactor speed and type of ply drop changed. Due to this the deformation recorded on flat, internally and externally ply drop was 0.0162 m, 0.012 m and 0.022 m respectively. This show that the externally ply drop specimen deforms more because of this it absorbed more energy as compared to internally ply drop and flat specimen. Then as general the analysis conclude that externally ply drop type of ply arrangement had a good energy absorbing capacity due to its externally dropped plies and a good load carrying capacity.

5.2 Recommendation

For the future and generally suggested that:

- For a use of tapered geometry cross section externally ply drop arrangement prefers than the flat arrangement for a better load carrying capacity and energy absorbing ability.
- If the experimental set up of drop weight impact analysis is available, it's better to do experimental work. And studying the following effects also important for the future
 - The effect of dropped ply length and number of drops on impact energy absorption

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Appendix: A Flat specimen deformed part after impact

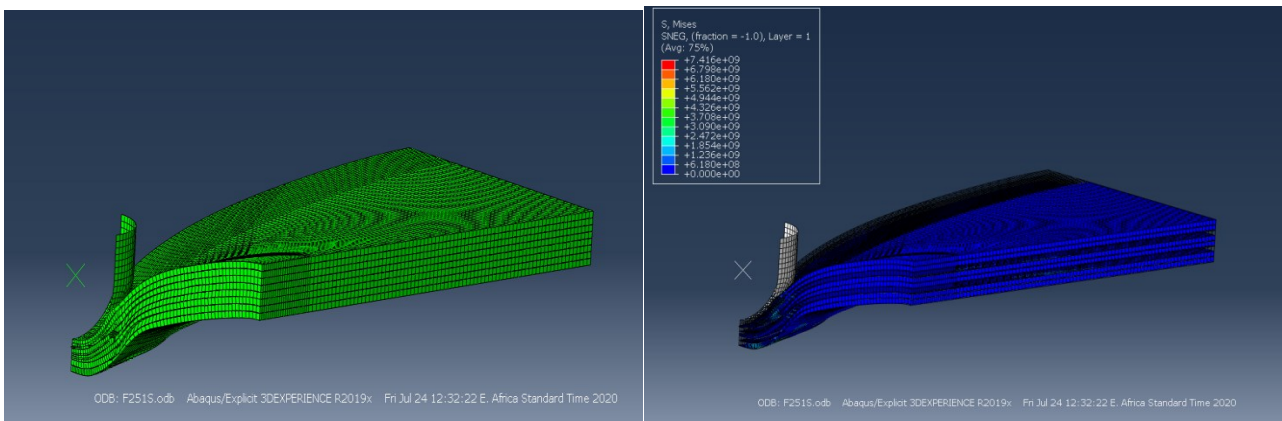


Figure A1: Deformed part of flat specimen at 2.51 m/s after impact

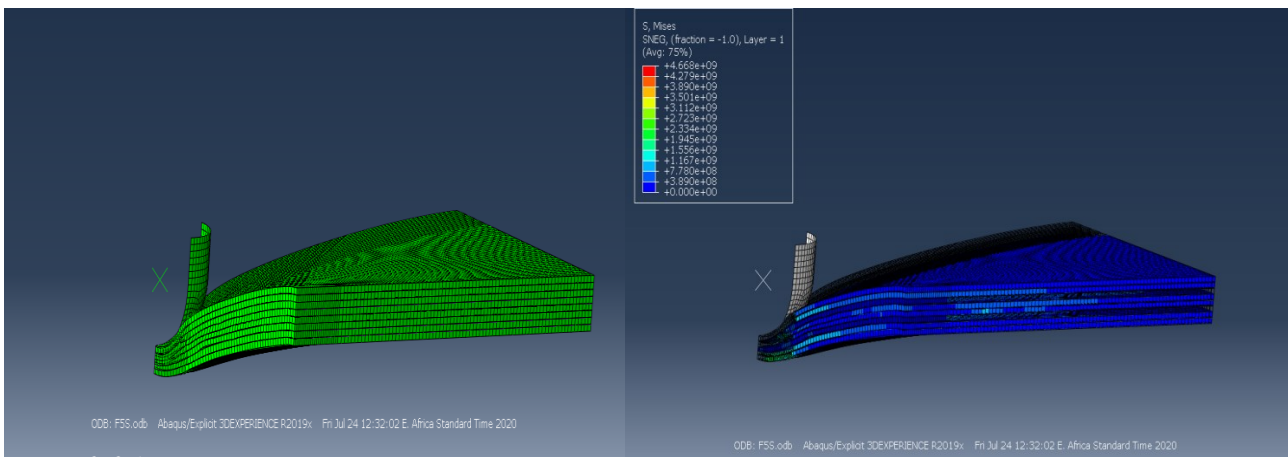


Figure A2: Deformed part of flat specimen at 5 m/s after impact

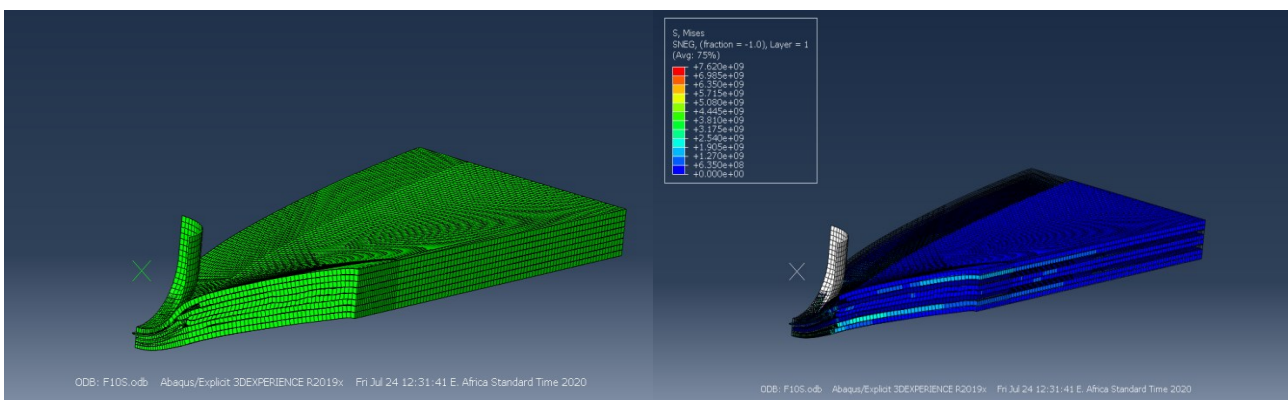


Figure A3: Deformed part of flat specimen at 10 m/s after impact

Appendix: B Internally ply drop specimen deformed part after impact

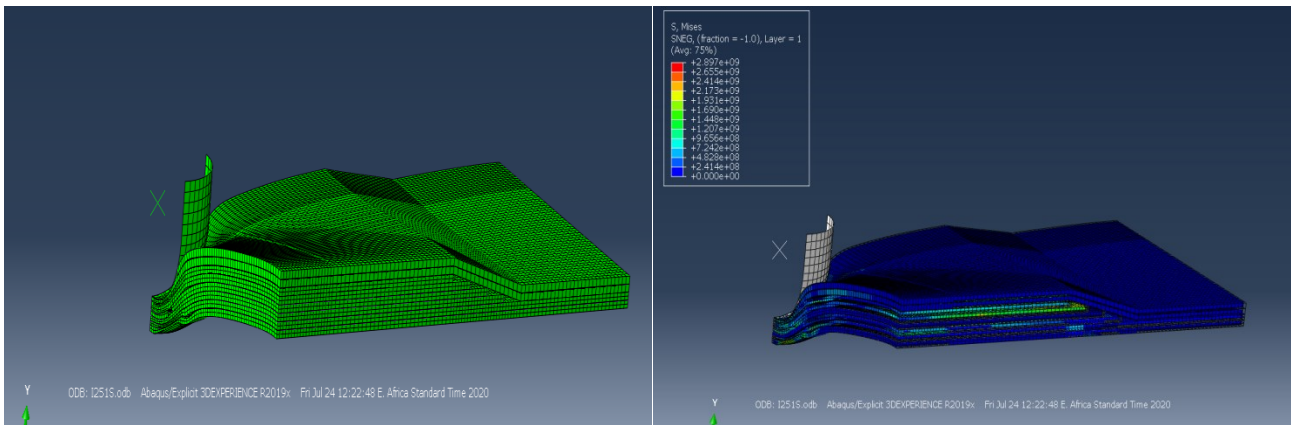


Figure B1: Deformed part of internally ply drop specimen at 2.51 m/s after impact

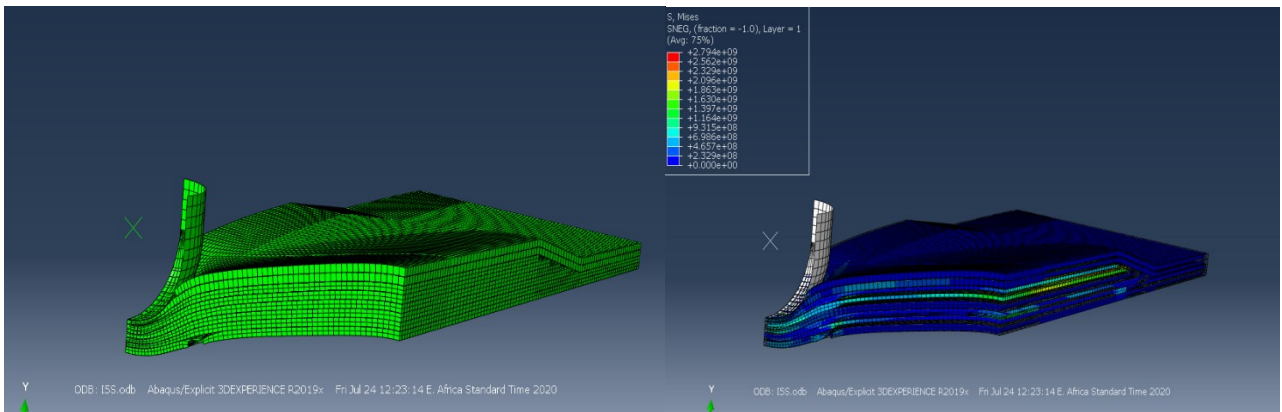


Figure B2: Deformed part of internally ply drop specimen at 5 m/s after impact

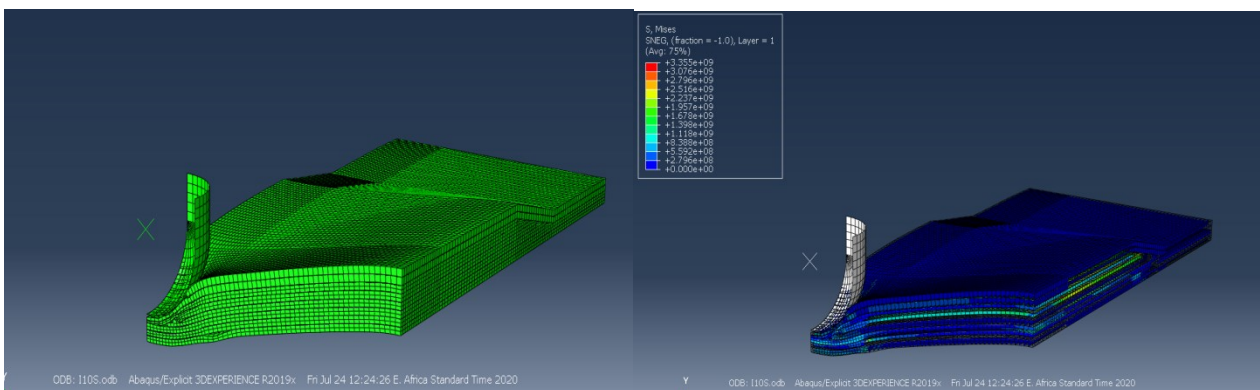


Figure B3: Deformed part of internally ply drop specimen at 10 m/s after impact

Appendix: C Externally ply drop specimen deformed part after impact

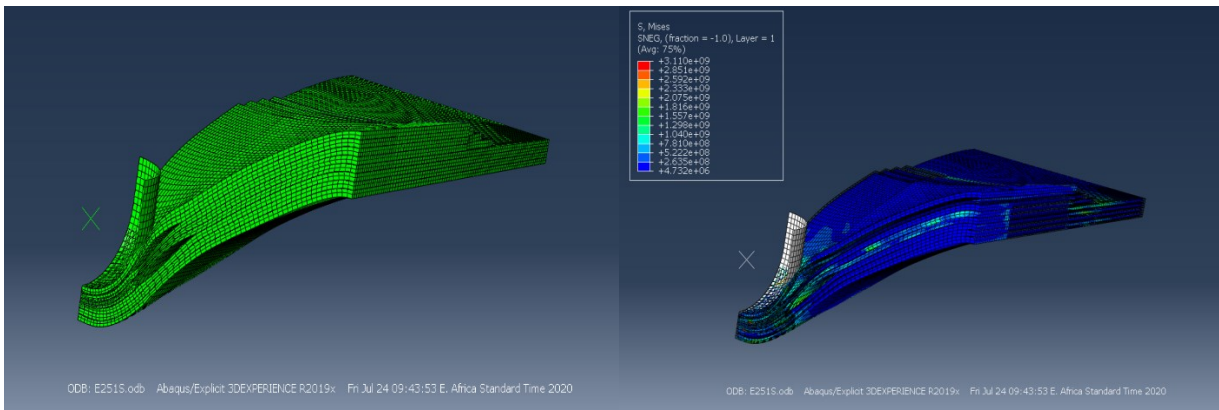


Figure C1: Deformed part of externally ply drop specimen at 2.51 m/s after impact

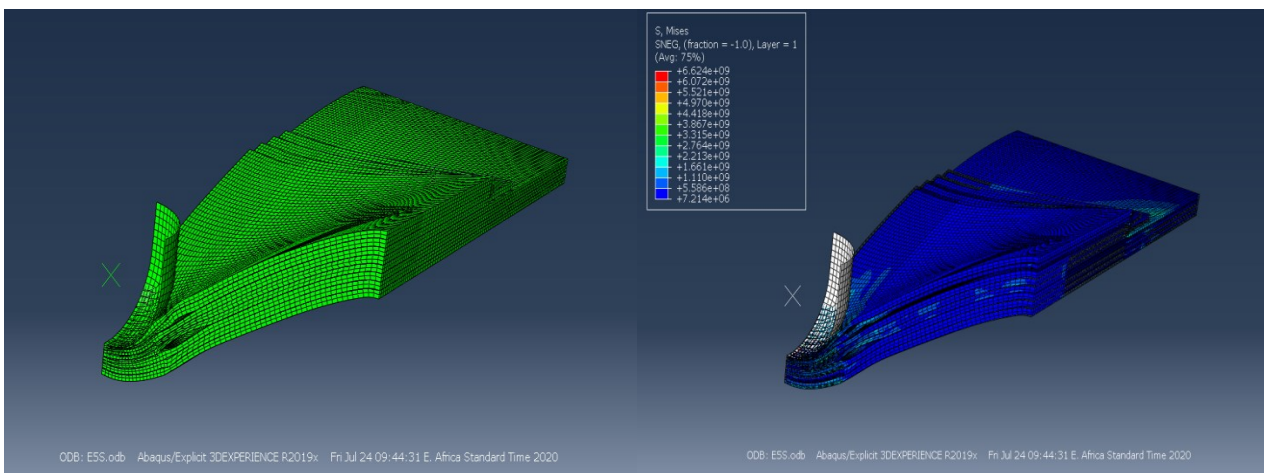


Figure C2: Deformed part of externally ply drop specimen at 5 m/s after impact

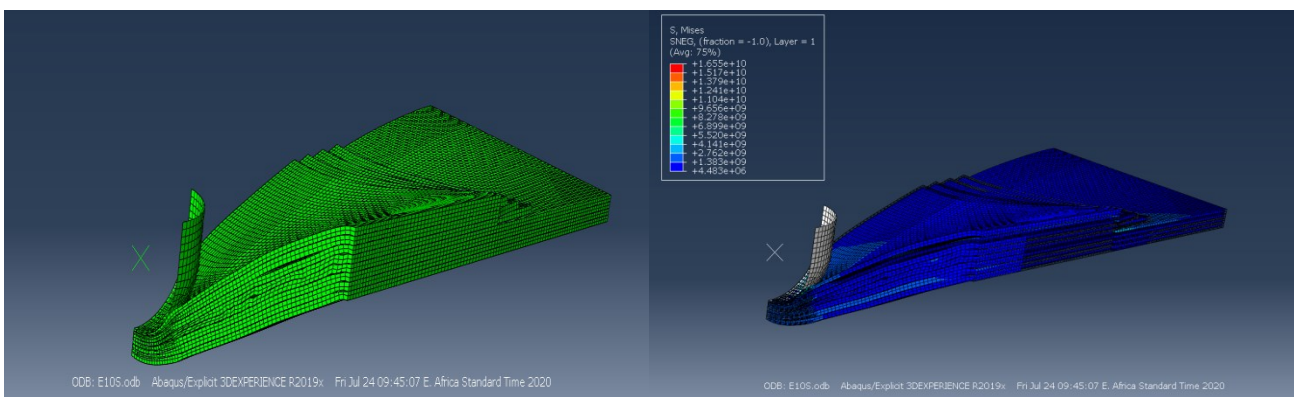


Figure C3: Deformed part of externally ply drop specimen at 10 m/s after impact