DOKUZ EYLUL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

RESPONSE OF LAMINATED COMPOSITES TO THE IMPACT LOADING

by
Levent Sacit AKBOY

October, 2012
İZMİR

RESPONSE OF LAMINATED COMPOSITES TO THE IMPACT LOADING

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by
Levent Sacit AKBOY

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled "**RESPONSE OF LAMINATED COMPOSITES TO THE IMPACT LOADING**" completed by **LEVENT SACIT AKBOY** under supervision of **Assoc.Prof.Dr. BÜLENT MURAT İÇTEN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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RESPONSE OF LAMINATED COMPOSITES TO THE IMPACT LOADING

ABSTRACT

The purpose of this thesis is the examination of damage and deformation of fiber reinforced laminated composites with varying stacking sequences under impact loading in order to figure out the best combination.

Specimens were built in the Composite Research Laboratory at Dokuz Eylül University with vacuum infusion method. After the manufacturing process the thickness of the composite was measured as 2.2 mm and cut into as 100 x 100 mm dimensions. Specimens were placed inside the Fractovis Plus test machine to apply the impact loading with various impact energies.

Conclusions were made according to Contact Force – Time, Energy – Time, Deflection – Time, Contact Force – Deflection graphs. Further, visual inspection was undertaken by photographs. Results indicated that fiber and ply orientation effects the resistance under impact loading.

Keywords: Laminated composite materials, VARIM method, impact loading.

TABAKALI KOMPOZİTLERİN DARBE YÜKLEMESİ ALTINDAKİ DAVRANIŞLARI

ÖZ

Bu tezin amacı fiber takviyeli lamine kompozitlerin darbe yüklemesi altında farklı tabaka dizilimleri ile oluşan hasar ve deformasyonun incelenerek en iyi tabaka dizilim kombinasyonunun anlaşılmasıdır.

Numuneler Dokuz Eylül Üniversitesi Araştırma Laboratuarında vakum infüzyon metodu ile üretilmiştir. Üretimden sonra tabakalar 2.2 mm olarak ölçülmüş ve 100 x 100 mm ebatlarında kesimi yapılmıştır. Numuneler Fractovis Plus test cihazına yerleştirilerek farklı darbe enerjilerinde darbe yüklemeleri uygulanmıştır.

Sonuçlar Temas Kuvveti – Zaman, Enerji – Zaman, Deformasyon – Zaman, Temas Kuvveti – Deformasyon grafikleri ve hasar fotoğrafları üzerinden değerlendirilmiştir. Alınan sonuçlarla fiber ve plaka diziliminin darbe yükleme altında dayanıklılığa etkisi incelenmiştir.

Anahtar sözcükler: Tabakalı kompozitler, VARIM metodu, darbeli yükleme.

CONTENTS

CHAPTER ONE
INTRODUCTION

1.1. Introduction

Impact loading is a force which is applied for a very short time period. However, impact loading causes much more deformation (or stress) than a lower force which affects for a long time period.

Most of the time mechanical equipments, especially the critical ones, sustain impact loadings during their operation time. Metallic materials can endure these loadings easier than laminated composites. Metallic materials have a capability to plastic strain, thus they absorb most of the energy during the impact. However, composite materials do not have this capability so the deformation becomes faster and unpredictable. Especially for the laminated composites, in proper conditions damage after the impact occurs as internal damage which can not be observed visually. For instance assume that a plane wing is hit during the take off by debris. During the maintenance inspection the damage can not be observed from the surface and the damage under surface gets longer until reaches the surface or a sudden failure of material. For reasons like this, dynamics inside the impact loading should be understood well and this understanding should lead the design limits accordingly. Due to the low performace of composite materials under impact loading significant theoretical and practical interest is needed.

Initial studies in order to understand dynamics under impact loading were done by Rotem (1971), Lifshitz (1976) amd Sierakowski et al. (1971) . Further theoretical calculations were done by Dobyns (1981) by using the equations of plate referred to past study carried out by Whitney & Pagano (1970) in order to analyse an orthotropic plate subjected to central impact. Lifshitz (1976) worked on a drop weight equipment in order to calculate mechanical properties especially tensile strength of angle ply laminate plates made from glass fibers and epoxy matrix. Response of composite laminates under low velocity impact loading was experimented by Naik & Sekher

(1998) with the use of three dimensional transient finite element code. With this work it was understood that woven composites have higher resistance on impact loading then unidirectional composite plates. Kim and Sham (2000) took this study one step further and proved that fracture toughness is higher on woven fabric laminates. That makes the maximum load and area damage relatively smaller then cross ply composite laminates. Delamination of laminated composites after impact loading was studied by Jih and Sun (1993). Experiments of drop weight impact showed that static interlaminar fracture toughness in static linear beam model (Aslan, Karakuzu, Okutan 2002) can be used to figure out low velocity impact affected delamination.

Scholars investigated many impact models in order to understand dynamics of impact loading. For instance according to Classical Laminate Theory Tsai & Hahn (1980) stacking order can change the stiffness of the composite. Icten (2002) studied diversified combinations of laminated plates which consists of woven glass fibers and epoxy resin in approximately twenty different order, for improving behavior of deflection.

Stitching (a single turn of thread) process is very common and studied by many scholars, on behalf of improving laminated composites mechanical properties among thickness. (Kang & Lee 1994, Reeder 1995, Sharma & Sankar 1997). From these stuides it is understood that stitching has a positive affect on deflection under impact. On the other hand due to diversified fiber positioning strength under compression decreases. Mouritz & Cox (1997) work exposed that stitching lowers the strength and fatigue resistance of a laminate around %10 to %20. Also in some cases mechanical properties remain steady or increase slightly.

In order to see the difference between stitched and unstitched woven Hosur, Vadiya et al (2004) studied the resistance of stitched and unstitched woven carbon and epoxy composite laminates that are loaded with high velocity impact. This study showed that impact releases its energy within unstitched composites more than stitched ones. Lopresto et al (2006) indicated that stitch application does not make a crucial difference in Force – Displacement curves, first failure load and deflection. Also penetration energy through material is 30% lower than the unstitched composites. Stitch application can also be advantageous in terms of impact resistance with relatively thick specimens. Kang and Lee (1994) study was not only about mechanical properties but also about impact properties of stitched woven composites. They demonstrated that if the wowen was stitched with an optimum density, then the mechanical properties were slightly improved. Also penetration energy through stitch composites was reiforced more than unstitched composites. In addition to that stitching makes the damaged area narrower then unstitched surfaces (app. %10 less damaged area).

Impact on composite materials has been studied by many scholars since 1990s. Review articles on the subject covering contact laws, impact dynamics, stress analysis, damage initiation and propagation, failure modes, damage tolerance, and improvements in damage resistance and tolerance can be found in literature (Abrate, 1991, 1994, 1998; Cantwell & Morton, 1991).

Impact effect is commonly known by three names low velocity, high velocity and hyper velocity impact. Yet in some cases it is not so certain to define the limits of these concepts. Sjoblom et al. (1988), Shivakumar (1985) and Cantwell & Morton (1991) defined the low velocity impact as up to 10 m/sec. Abrate (1991) presented in his study that 100 m/sec for the impacttor speed as low velocity impact. Liu & Malvem (1987) and Joshi & Sun (1987) suggested that type of impact can be classified according to the damage occurrence so low velocity is characterized by delamination and matrix cracking while high velocity is defined by penetration induced fiber breakage.

Chang and Choi (1992) used a module of finite element method that makes it possible to perform failure analysis in order to observe the treshold of impact damage. They examined impact loading effect on laminated composites by an external object. The object was chosen as a point nose impactor which creates matrix crackings and further delaminations. With the finite element method they developed, it is possible to push forward damage by the function of material properties, laminate configuration and impactators’ mass for final damage. This finite element method model formed by a stress and a failure analysis module. A transient dynamic finite element analysis was formed for calculating the stresses and strains inside the material during impact loading by impactor. With the criteria of failure it is possible to observe matrix cracking by the size of interface delaminations in material.

Jih and Sun (1993) examined plies of composite laminates under impact loading. They studied a method in order to use heavy impactors for low velocity impact. Fracture toughness of static ply was used to determine ply cracks evolution due to impact loading. Thermal stresses at curing process is also debated and aided for improving the resistance of fracture. In order to get the impact force history peak force is used with crack length of plies in laminated composite.Results illustrated that it is proper to use static fracture toughness in order to determine delamination size. (Aslan, Karakuzu, Okutan 2002)

This thesis examines the deformation of specimens with different stacking sequences under impact loading. The purpose of the study includes to determine the combination of composites which is suitable under predefined effects.

CHAPTER TWO
COMPOSITE MATERIAL

This chapter discusses the context of the composite materials. The chapter delves into the properties, uses, benefits as well as the drawbacks of the composites. The chapter also elicits many of the manufacturing methods such as hand lay up, filament winding, pultrison, resin transfer moulding and vacuum assisted resin infusion molding.

2.1 History & Definition

Examples of the utilization of composites are abundant in the history of humankind. For instance, the first human settlers developed a novice form of a composite material for construction purposes. The settlers would make bricks out of clay and reinforce these bricks with straws. The individual substances, clay and straw, could not perfom the task by themselves as seperated but did when put together in proper way. Therefore, they used straw to keep the clay from cracking, otherwise there would be sharp cracks in the dry clay. The resistance of the bricks were better so both of the suggestions are acceptable.

In the literature there are many other historical examples of composites. Significant examples include the use of reinforcing mud walls for housing with bamboo sticks, attached as laminated wood by Egyptians (1500 BC) , Mongolian composite bows that are made from wood, bone and animal glue as binded with special techniques around 1200 AD and laminated metals in forging swords or for decoration is used firstly by Japanese artisans around 17th century.

In the beginning of the 20th century plastics were found which as resins. But without the matrix their strength was not enough. In the 1930s first matrix material fiberglass was introduced and with this invention modern composite era began. By the second world war innovations on the composite material indicated a significant shift in the industry. Its light weight and relatively good strength encouraged engineers to use them on military aircrafts. By the end of war, composite material was introduced as boat hull a commercial material of daily use for common people. Meanwhile manufacturing processes were expanding such as pultrison. By 1970's a new matrix material aramid was found by Dupont company which is known as Kevlar. Around the same time carbon fiber came as an alternative of metal with its similiar mechanical properties and light weight. Since the beginning, composite industry has evolved by the development of new matrix and resin materials and new manufacturing methods.

Generally speaking the composite is made of two inherently different materials to produce a new material which exceeds the constituent materials. The process can be defined as the merge of materials, which are different in composition in many ways, to form a new structure with different characteristics and mechanical properties. Components inside the compositon is not a homogenous solution. If the composition is in macroscale then the materials can be identified physically otherwise they can be identified by microscope. If the material is combined in a microscopic scale, then it can becomes homogenous.

The structure has two main sections; matrix and reinforcement. Reinforcement can be fibers, flakes, particles etc. and matrix can be polymers, metals, seramics. Matrix covers the reinforcement and forms the physical shape. During this process reinforcement holds the matrix in shape like a backbone by improving mechanical properties of structure. It transfers load to the reinforcement, it effects the temperature and chemical resistance. Consequently the reinforcement handles the tensile properties, stiffness and impact resistance of the new material. In some conditions combination of reinforcement and matrix has better mechanical properties then their individual properties. If designed properly, the new combined materials will have better strength than their past individual properties.

Properties that can be improved by forming a composite material is shown in Table 2.1.

Table 2.1 Properties that can be improved by composite materials

Strength	Fatigue life
Stiffness	Temperature – dependent behavior
Corrosion resistance	Thermal insulation
Wear resistance	Thermal conductivity
Attractiveness	Acoustical insulation
Weight	

In practice, these properties are not improved at the same time or there is any requirement to do so. In fact, some of the properties are in conflict with each another, such as thermal insulation versus thermal conductivity. The objective of the production of a composite is to create a material that has only the characteristics needed to perform the desing task.

Classification of the composite materials are listed in Table 2.2;

Table 2.2 Classification of composite materials (Hull, 1981)

Natural Composite Materials
Wood Bone Bamboo Muscle & other tissue structures
Microcomposite Materials
Metallic alloys like steels Toughed thermoplastics like polystyrene, ABS Sheet moulding compounds (Laminated) Reinforced thermoplastics
Macrocomposite Materials
Galvanised steel Reinforced concrete beams Helicopter blades

2.2 Mechanical Behavior of Composite Materials

Composite materials have diversified mechanical behaviors that are different from those of more common engineering materials. Some characteristics are just modifications of the conventional behavior. Figure 2.1 shows the mechanical body forms.

Most common engineering materials are both homogeneous and isotropic;

- A homoheneous body has uniform properties throughout the body. The features of the material are independent from a position in the body.
- An isotropic body has uniform properties for one point in every direction. The features of the material are independent of the orientation at a point in the body.

If the body is sensitive among temperature change so isotropic material properties will not be homogeneous. With this in mind:

- An inhomogeneous body does not have the same material properties among the whole body. It depends on the position of body.
- An orthotropic body has, in general, different material properties through each axis. So the material properteis are changing according to the point that is chosen in the body.
- An anisotropic body is a material that does not have same material properties in any direction so there is no material symmetry between surfaces.

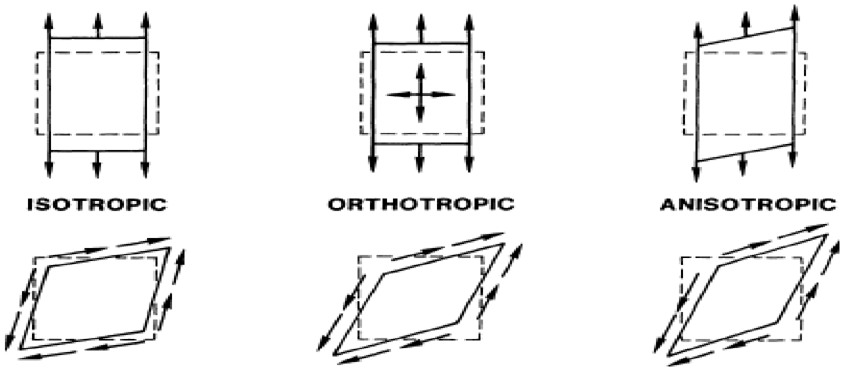


Figure 2.1 Mechanical body forms (Jones, 1998)

In this framework fiber reinforced composite materials typically exhibit anisotropy. In other words some properties vary on the position of measurement by axis or plane.

Due to the macroscopic anisotropy and the presence of two diverse materials with unfitting characteristics at the microscobic level, the mechanics of non linear deformation and fracture of fiber reinforced polymers present drastic difficulties. This situation culminates in the exposure of FRP laminates of five different physical mechanisms of fracture depending on the loading mode.

2.2 Advantages and Disadvantages of Composite Materials

The main advantage of the composite material is its strength and hardness with its light weight. By the combinations of matrix and reinforcement requirements for particular purposes can be achieved.

Civil and military aviation illustrates the importance of composite materials. Thanks to its hardness and strength with its light weight, aviation is much more efficient nowadays. Industries need new materials that are light and strong. That demand pushed engineers to develop better composites and manufacturing methods. If you observe an aircraft designed these days you can see that tail and wing structure (not all of the body) and even engine parts and common fittings are all products of advanced composites. Furthermore some small planes frames and body structure are nearly just made from composite materials.

Composite materials are less likely to break up completely under stress than metals (such as aluminium). Thus, in the case of an aircraft, this characteristic of composite materials becomes vital. Prevention of any crack on the metal body constitutes the primary goal of an engineer. Under any kind of stress or impact, cracks on the surface or inside the material can occur. In metallic materials most of the time these cracks gets longer or bigger until fracture ends with serious consequences. However composite materials do not spread these cracks and they holds them partially. Due to the inner design of composites fibers, they block the crack route and holds as it is.

The congruent arrangement of the composites components also points to their resistance under high temperature and corrosive conditions. Hence, they are very stable. These advantages make composites suitable for equipments that are used in corrosive conditions, for handling chemical materials and even in space.

On the other hand design flexibility is a very big odd. For instance, for manufacturing complex designs moulding is possible as in sea crafts bodies or even safety helmets.

The major drawback of the composites constitutes the high cost per unit. This is because of the high costs of fiber and resin prices that are used in composite. In the end, expensive raw materials, relatively not practical manufacturing methods and complicated repair applications make the composites not the number one material but just the second after traditional ones. However because of the new innovations there is a strong hope that someday composites can pass traditional materials.

The advantages of the composite materials can be summarised as:

- Low density (lower than aluminium)
- High strength (as strong as high – strength steels)
- High stiffness (stiffer than titanium, yet much lower in density)
- Good fatigue resistance
- Good creep resistance
- Low friction coefficient and good wear resistance
- Toughness and damage tolerance (as enabled by using appropriate fiber orientations)
- Chemical resistance (chemical resistance controlled by polymer matrix)
- Corrosion resistance
- Dimensional stability (can be designed for zero CTE)
- Low electrical resistivity
- High electromagnetic interference (EMI) shielding effectiveness
- High thermal conductivity

The disadvantages of the composite materials can be summarised as:

- Cost of materials
- Lack of well proven design rules
- Metal and composite designs are unique
- Long development time
- Manufacturing difficulties
- Fasteners
- Low ductility
- Solvent / moisture attack
- Temperature limits
- Damage susceptibility
- Hidden damage

2.4 Classification and Characteristics of Composite Materials

Due to the fact that the reinforcement material has the primary effect on mechanical behavior of the composite so it is proper to classify composites by these materials. Table 2.3 demonstrates the composite classifications. The most common four types of composite materials is listed below;

- Fibrious composite materials have fibers that are spreaded through matrix. They can be in properly lined up or just random.
- Laminated composite materials are formed by plies of diversified materials.
- Particulate composite materials consist of particles that are spread in matrix.
- Hybrid composite materials.

Table 2.3 Diagram of composite classifications (Roy, 2012)

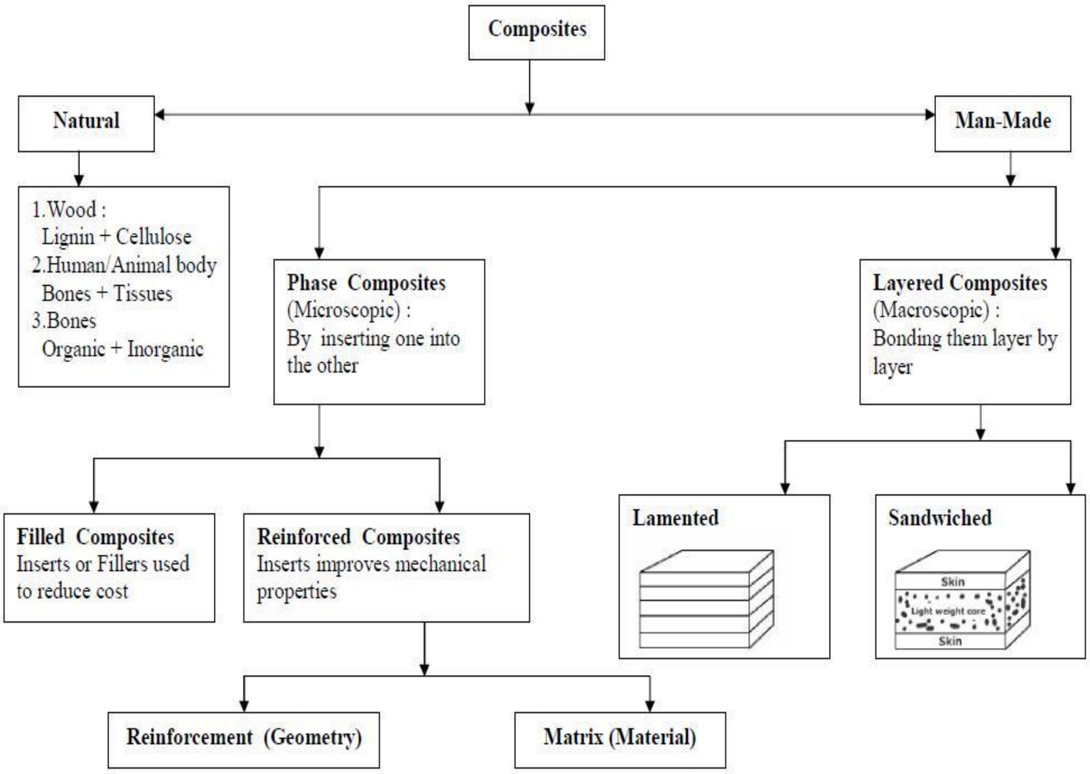
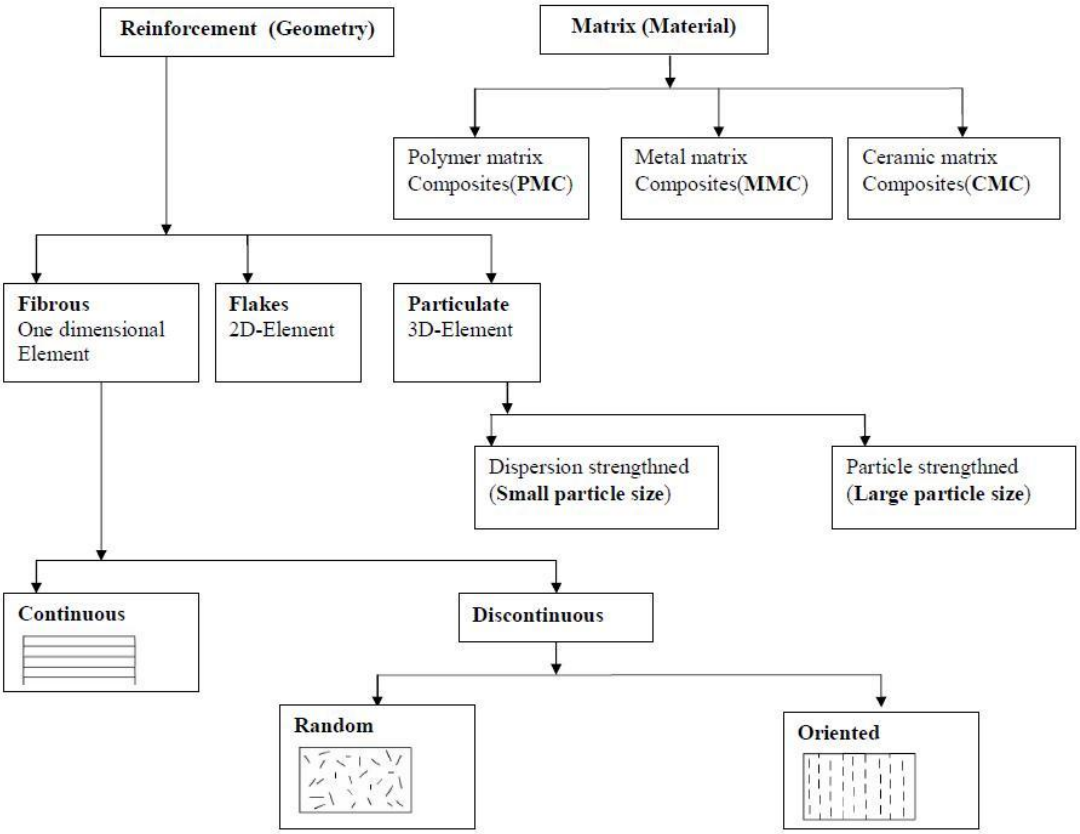


Table 2.4 General diagram of matrix and reinforcement (Roy, 2012)



2.4.1 Fibrious Composite Materials

Fibrous composite is a material consisting of fibers embedded in a matrix. (Parker, 2004)

As discussed before fibers inside matrix can be found as properly lined up (continuous) or random (discontinuous). By combining with fibers, ductile matrix materials such as polymers and metals become harder and brittle matrix materials such as ceramics are made stronger. Fiber ratio in matrix effects the mechanical properties. With respect to the length and diameter ratio of fiber, upcoming load is effectively directed from matrix to the fiber.

Depending on the shape / physical form of the fiber, it can be harder or stronger. For instance a thin plate of glass can be shattered around 20 Mpa but glass fibers can stand up to 2800 to 4800 Mpa. (Some special glass fibers, which are built in laboratory conditions, can also stand up to 7000 Mpa.)

Obviously, the geometry and physical makeup of a fiber are important crietaeria for increasing its strength and must be considered as a design discipline. Figure 2.4 shows the schematic view of fibrious composites.

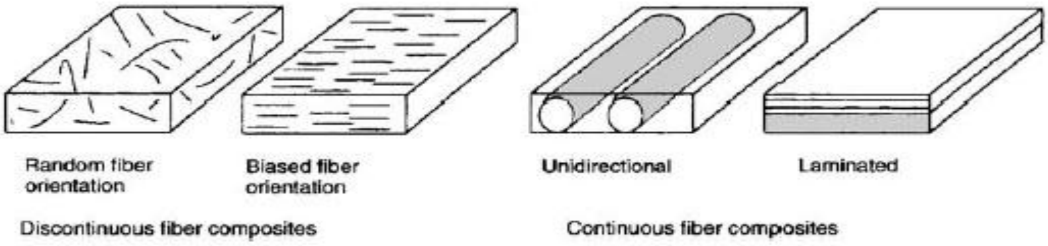


Figure 2.4 Fibrious composite materials (Staab, 1999)

2.4.2 Particulate Composite Materials

Particulate composite is a form that has scattered particles inside matrix. Concrete is a good example. The aggregate of coarse rock or gravel is embedded in a matrix of cement. The aggregate provides stiffness and strength while the cement acts as the binder to hold the structure together.

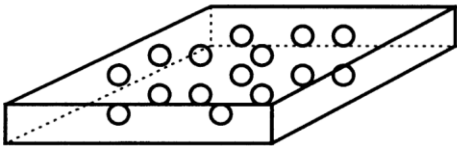


Figure 2.5 Particulate composite (Kaw, 2006)

2.4.3 Hybrid Composite Materials

Hybrid composites consist of the combination of two or more different reinforcement fibers as shown in Figure 2.6.

The individual components of hybrid composites have a great influence on the behavior of the composites. In fact, the overall behavior of the composites is a weighed sum of inherent advantages and disadvantages of each of the component material. Considering a hybrid composite that includes two or more types of fibres, one type could complement the material property which is lacking in the other ones. In other words, a balance in cost and performance can be achieved through efficient material design. The characteristics of a hybrid composite is often based on the fibre content, length of individual fibres, orientation, extent of intermingling of fibres, fiber to matrix bonding and arrangement of the fibres. Furthermore, the strength of the hybrid composite is based on the failure strain of individual fibres. In the cases where fibers are highly strain compatible, maximum hybrid results can be achieved. (Sabu, 2008)

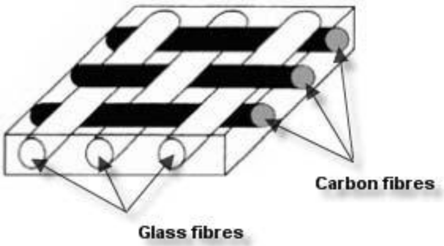


Figure 2.6 Hybrid composite (Uysal, 2009)

2.4.4 Laminated Composite Materials

Laminated composites consist of stacking two or more thin layers of fiber covered by matrix until they reach desired thickness. Positioning fiber in each layer and stacking sequence provides oppurtunity to get a wide range of physical and mechanical properties. Fibers inside the matrix can be in short, long, woven or even braided.

In order to analyze the laminates x,y,z coordinate system is used. z is used as perpendicular to the plane of laminate. The orientation of continuous, unidirectional layers is exposed with the angle θ with respect to the x axis. The angle θ is positive in the counter clockwise direction. Figure 2.4.4.1 The number of layers within a stacking sequence is shown by a schematic phrase in Figure 2.7.

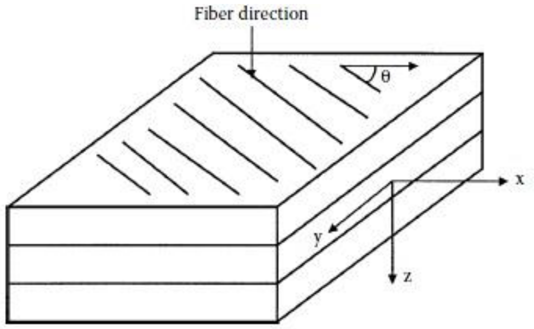


Figure 2.7 Schematic view of a laminate
(Kaw, 2006)

0^0
45^0
90^0

Figure 2.8 Example of a laminate
with three ply layers

Figure 2.8 [0/45/90] represents the laminated composite noted above. It contains three ply groups. First ply has 0^0 direction, second ply contains 45^0 direction and the last one makes a 90^0 with x axis.

In order to classify the ply formation and fiber angles between x axis, there are four types of laminates; symmetric laminates, non-symmetric laminates, angle ply and cross ply.

2.4.4.1 Symmetric Laminates

When the laminate plies are symmetric to each other, they are called symmetric laminates as shown in Figure 2.9.

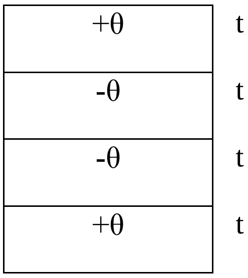


Figure 2.9 Symmetric laminate ply formation

2.4.4.2 Non-Symmetric Laminates

In non symmetric laminates, for every ply, there is a +θ direction and the opposite will be in –θ direction as shown in Figure 2.10

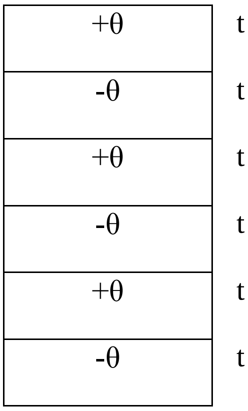


Figure 2.10 Non-Symmetric laminate ply formation

2.4.4.3 Angle Ply

When the plies have +θ and –θ directions in their sequences, it is called angle ply. That is shown in Figure 2.11. It can be both symmetrical and non symmetrical.

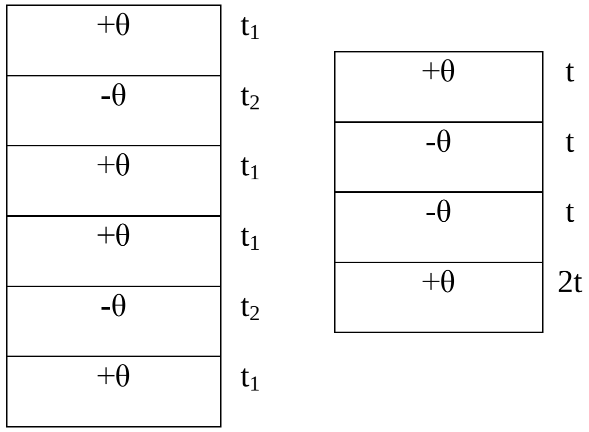


Figure 2.11 Angle ply formation – symmetric (left),
non-symmetric(right)

2.4.4.4 Cross Ply

If the plies consist of only as 0^0 or 90^0 so it is called as cross ply. Same as angle ply it can be both symmetrical and non symmetrical.

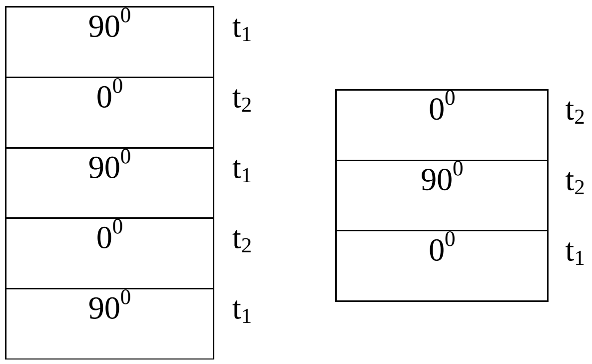


Figure 2.12 Cross ply formation – symmetric(left),
non-symmetric(right)

2.5 Manufacturing Processes

A key element for the succesful production and application of a material is a cost effective and reliable manufacturing method. Cost effectiveness depends largely on the rate of production and reliability requires a uniform quality from part to part. (Kaw, 2006)

Fiber reinforced composites are manufactured by hand layup which is a reliable process. However the necessity of labor force and too long process time makes it less feasible for specimen manufacturing. In the past decades, due to substantial demand of the industry, for mass production and uniform quality on innovative materials, engineers have developed new methods or advanced ones that are already operating on manufacture. Processes such as compression moulding, pultrison and filament winding have come up with these demands. For instance RTM (Resin Transfer Molding) is an innovative manufacturing method which aerospace and automative industries are interested in due to its production rate even for complex shaped parts. Automation, fast curing resins, fiber types with better mechanical properties, and computer aided precise control systems make this process even better, faster and more uniformal.

2.5.1 Lay-Up

The process of stacking several layers together simply named as Lay-Up is shown in Figure 2.13. If the process is done (Stacking) by hand then it is called as hand lay-up. This method is the first and the simplest “open molding” method. However it is a labor intensive process, so it takes too much time to manufacture. Reinforcing material placed manually inside the open mold and then resin is poured, brushed or sprayed through and over the plies. Trapped air is removed by squeegees or rollers for homogenous penetraion of resin troughout reinforcing material. On the other hand disadvantages of hand lay up can be avoided by using prepreg tape rolls on some gantries or automated arm systems. However in any case trapped air and penetration of resin should be in control by manually during the process.

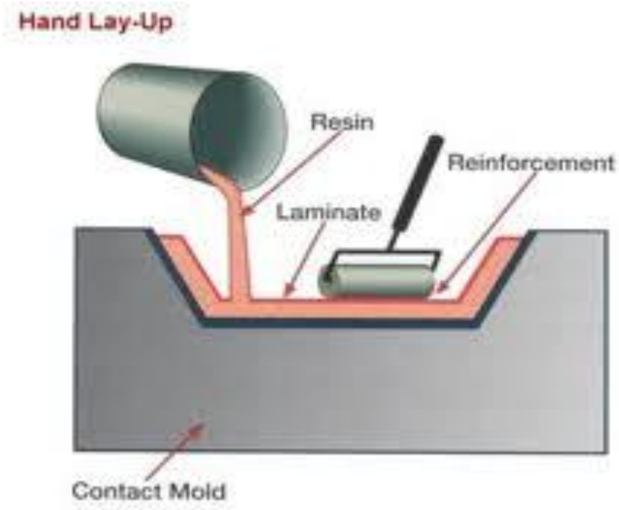


Figure 2.13 Hand lay-up (Hand Lay-Up (n.d.), 2012)

2.5.2 Filament Winding

A rotating mandrel or a male mould pulls fibres from fibre spools through resin impregnation which is guided by a pay-out eye and a carriage that determines the axis and length of material on mandrel or male mould. Carriage is eglible to move while mandrel / male mould rotates. Fiber materials are chosen carbon or glass in general and they are coated by synthetic resin. At the moment that mandrel reaches desired thickness it is placed in an oven until it has cured. After the curing process final product is taken out from the mandrel/male mould.

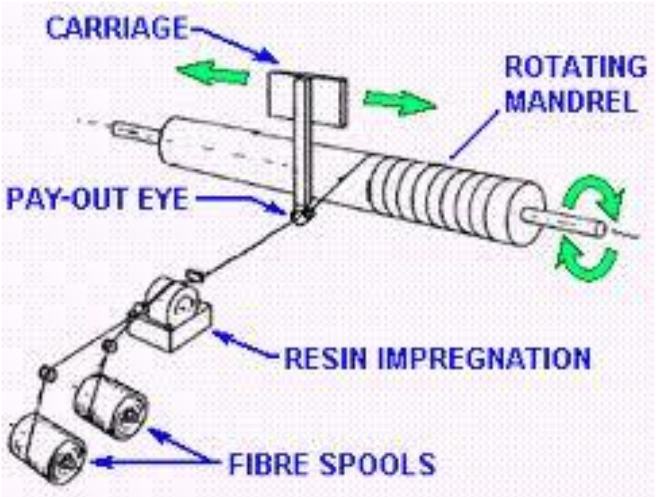


Figure 2.14 Filament winding (Filament Winding (n.d.), 2012)

2.5.3 Pultrusion

This is an automated process which pulls fibers through pressurized resin injection for impregnation. If prepreg material is used instead of fibers then resin bath is not necessary so it is called as dry pultrison. After the resin bath reinforcement is guided into a kind of mould which is heated. During this process resin changes from liquid to gel and then to its final form as rigid plastic. The main advantage of the pultrison is the very high production rate.

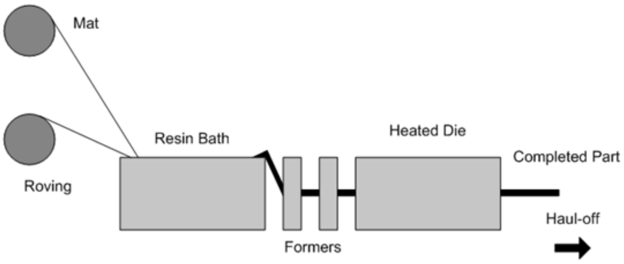


Figure 2.15 Pultrusion (Pultursion (n.d.), 2012)

2.5.4 Resin Transfer Moulding

This is a closed molding process under low pressure. Resin is injected through the mold by covering reinforcement until the end. At the other side of the mould, vacuum pump assists the penetration of resin through dry reinforcement. When the resin is cured the mold can be opened and the finished component can be removed.

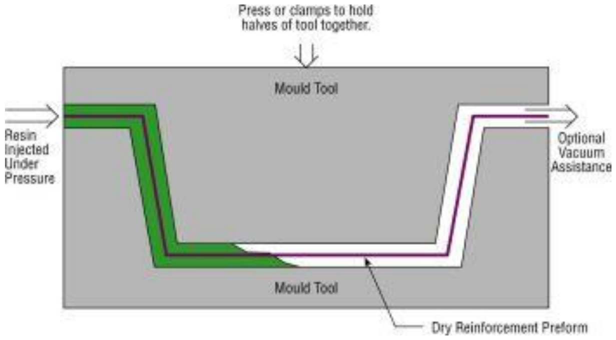


Figure 2.16 Schematic view of RTM (Resin Transfer Moulding (n.d.), 2012)

2.5.5 Vacuum Assis ted Resin Infusion Moulding

VARIM (Vacuum Assisted Resin Infusion Molding) is a manufacturing process for composite structures. In the literature, vacuum infusion has many acronyms such as (Ragondet, 2005)

VARTM-Vacuum Assisted Resin Transfer Moulding (Koefoed, 2003),
VARIM-Vacuum Assisted Resin Infusion Moulding (Khattab, 2005),
SCRIMP™-Seemann Composites Resin Infusion Moulding Process (Boh et al., 2005),
VBRTM-Vacuum Bag Resin Transfer Moulding (Kang et al., 2001),
VARI-Vacuum Assisted Resin Infusion Process (Tzetzis et al., 2008)

All the processes noted above involve similar technology and production methods based on the impregnation of a dry reinforcement by liquid thermoset resin driven under vacuum (Goren, Atas, 2008)

Prior to delving into the details of VARIM, it is a useful exercise to go through the basic terminology of which is very common and taken from SAE AIR 4844 Glossary as listed below;

Bagging : A leakproof thin layer covers the sealing and all the uncured part
Bagging Film Sealant Tape : This is a soft plastic tape which is slightly tacky and is used to seal bagging film to repair area or to join parts of the bagging film if two sheets are used.
Bag Side : Cured side of the vacuum bag
Bleeder : An equipment that allows to exhausts the excessive air and resin during cure section. This part is removed after curing, it is not a part of composite at all.
Bridging : 1) A phrase that represents that shows fiber penetration problems till the very end of corners. After curing process this is comeover with dimension or radius problems and also some areas filled by only resin. 2) A condition in which one or more plies of a pre-preg span a radius step of the fluted core of a radome without full

contact. 3) A condition where part of a vacuum bag does not go down into a radius and thus no pressure can be applied at that point. When making up a vacuum bag, it is important to avoid this.

Debulking : A process that is done to avoid wrinkles for thick laminates by using heat and vacuum (non curing conditions.) Debulking should be done for a few layers at a time, in a series of debulking operations, rather than by debulking the whole lay-up in one operation.

Mold Release Agent : A material that is preventing composite material to stick to the table after curing process. They can be found in solid, liquid or powder.

Parting Agent : A material, liquid or solid film used on the tool surface to ease removal of the assembly. Teflon film is an example.

Peel Ply : This is a textile material that is made from fiberglas or heat set nylon. After the curing process it is removed with haste. It provides a clean, uncontaminated and smooth surface which is subsequent or painting.

Release Film : A leakproof thin layer that does not stick to the resin during cure process.

Resin Distribution Medium : A highly permeable layer that is put on the release film which spreads and leads the resin to the side parts of uncured stack.

Separator : A permeable layer which is similar as a release film. This is a barrier between laminate and distribution medium. On the surface there are holes for exhausting trapped air for improving the laminate quality.

Vacuum Bag : The plastic or rubber layer used to cover the part to enable a vacuum to be drawn.

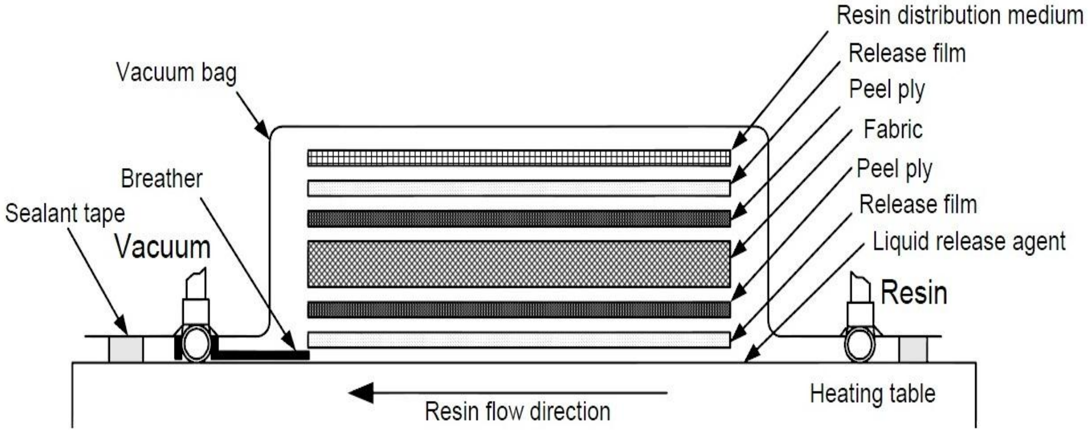


Figure 2.17 Vacuum assisted resin moulding (Goren, Atas 2008)

The components of the VARIM process is shown on the drawing above in Figure 2.17.

In order to create a closed system, a vacuum bag is sealed with sealant tapes at the outer layer. In this sealed area, resin impregnation is possible. Release film enables to exhaust the trapped air with the aid of vacuum. Fabric and peel ply are put at the surface of laminated composite. Release film form a shiny finish with fabric and peel plies weave pattern impression. Also peel plies generate a clean surface for further bonding or painting.

2.5.5.1 Introduction to the VARIM Equipments

The VARIM system used during manufacturing consists of 1800 mm x 1500 mm table that is capable to control both of temperature and vacuum.

Temperature is controlled by heating resistances under the table. There are thermocouples below the table surface which is divided into eight sections so temperature is known simultaneously. Data acquired by thermocouples is used in PLC so a decent reaction can be given for completing curing precisely. For getting the optimum mechanical properties curing conditions should be uniformal in all sections.

PLC gives opportunity to set two to three temperature values in a cure process. Temperature – Time and Vacuum pressure – time diagrams are shown at below. Cure process instructions generally depend on recommendations of resin suppliers.

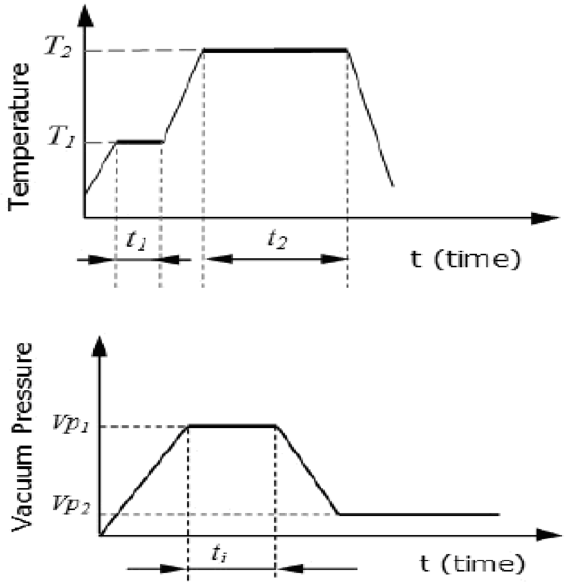


Figure 2.18 Cure process temperature – vacuum pressure steps (Goren, Atas, 2008)

In the figure 2.18, T_1 and T_2 temperatures represents correct cure values during t_1 and t_2 time intervals in relation with vacuum – time relations as vp_1 during t_1 time and vp_2 until the very end of curing process.

Besides the temperature control system, the VARIM system is also includes a vacuum pump and a vacuum regulator with a vacuum gauge. The operator can initilize and halt the vacuum pump using the touch screen. The user can tune the vacuum value manually before or during the production. A host of parameters such as the permeability of the reinforcement stack, the resin viscosity and inlet geometry may cause unpredictable cases or problems affects resin flow in the resin infusion moulding process and hence the quality of the production. Therefore, the vacuum regulation system is included in PLC program as an open loop control. It enables to control vacuum manually during the infusion moulding process (Goren, Atas, 2008)

CHAPTER THREE
MANUFACTURING OF SPECIMENS AND IMPACT LOADING TESTS

In this study manufacturing of specimens were executed by VARIM (Vacuum Assisted Resin Infusion Moulding) method. This chapter discusses VARIM and explains all the steps taken.

3.1 Manufacturing of Specimen

Specimens were been manufactured as 8 plies with orientations as $[0]_s$, $[0/15/0/15]_s$, $[0/30/0/30]_s$, $[0/45/0/45]_s$, $[0/90/0/90]_s$, $[0/15/30/45]_s$. Those plies were manufactured from epoxy matrix and fibers and cut as 100 x 100 square.

For the specimen specimen, reinforcement material is chosen as e-glass unidirectional fabric with a density of 509 g/m2. Matrix material is prepared with Duratek 1000 which is a mixture of DTE 1000 resine and DTS 1100 hardener by mixing them in a proper container. After the mixing process there will be 30 to 40 min for penetration.

Manufacturing process can be summarised with the photos below, (process is completely same for all orientations).

Figure 3.1 Mould table with heating and vacuum equipment. (Uysal, 2009)

The mould is coated by a release agent then eight plies of fibers are placed on table surface then peel ply placed on fiber plies. Then release film is put among the surface and finally resin distribution medium is put on release film in Figure 3.1 and Figure 3.2.

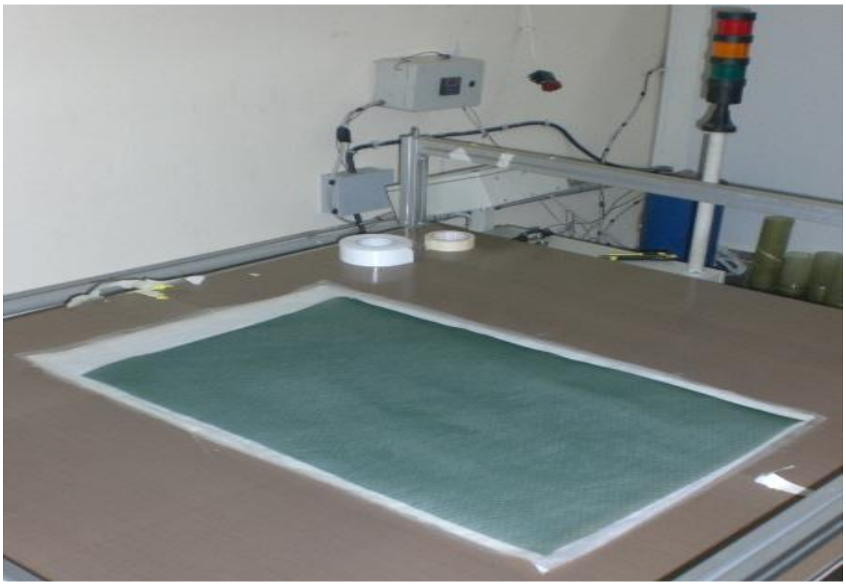


Figure 3.2 Plies are placed for the next step (Uysal, 2009)

Layers of materials for manufacturing and plastic hoses that are connected by a T connection to form a resin inlet and outlet are shown in Figure 3.3 and Figure 3.4

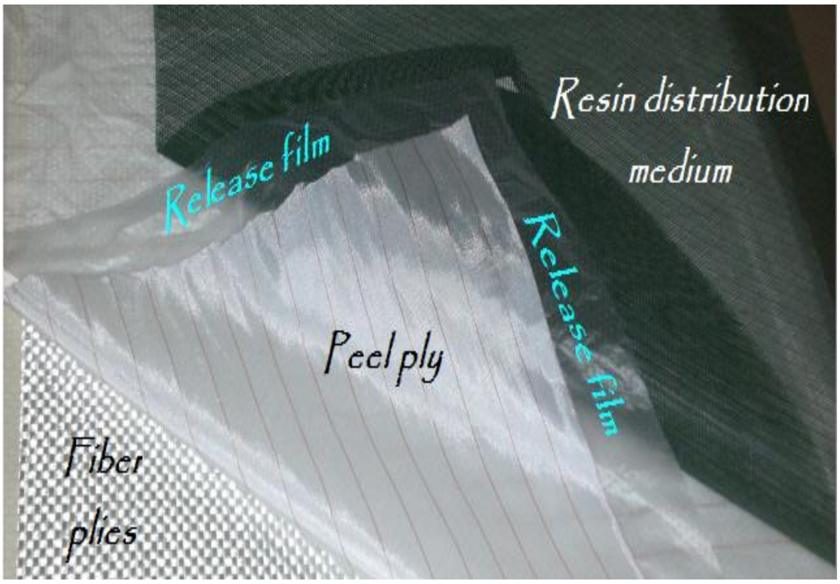


Figure 3.3 Layers of plies (Uysal, 2009)

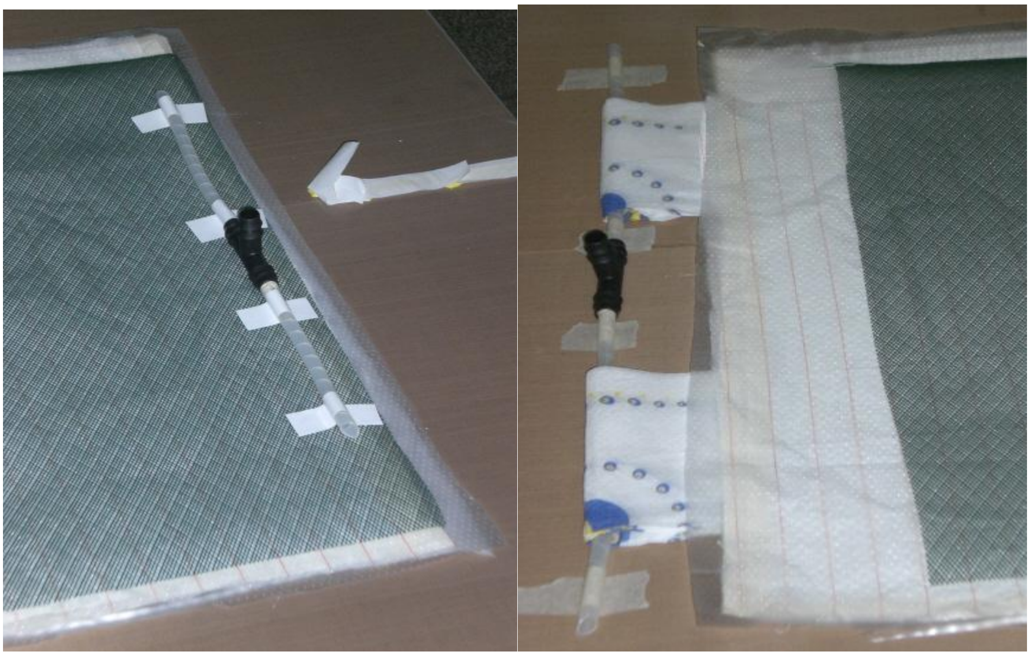


Figure 3.4 Vacuun inlet and outlet connection (Uysal, 2009)

The vacuum bag is placed on top of plies and sealed without leaving any air gap in Figure 3.5. Yellow sealent tape is placed around (only resin inlet and vacuum outlet are in touch by ambient)

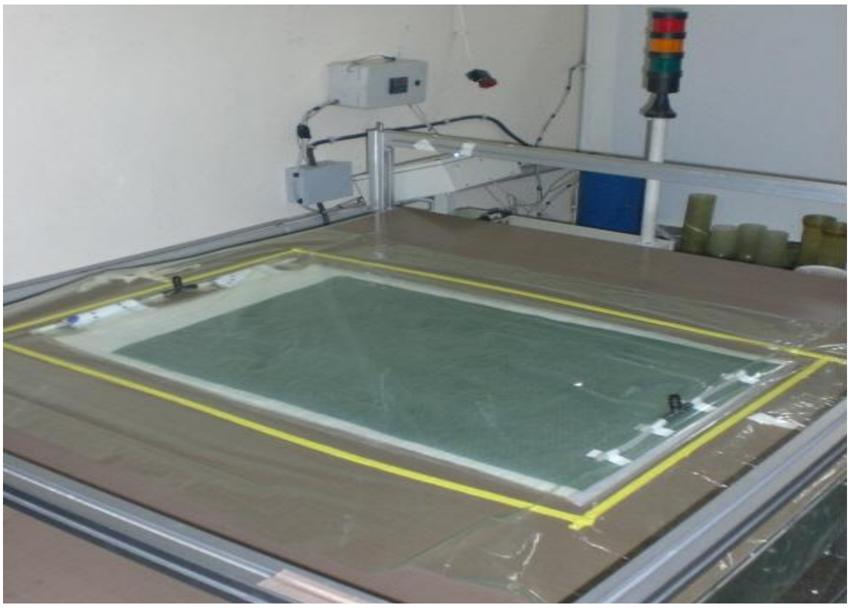


Figure 3.5 Sealed plies just before hose connections (Uysal, 2009)

Resin inlet and vacuum output are assembled to hoses by T connections. For further sealing sealant tape is used around T connections as it is shown in Figure 3.6.

Figure 3.6 Hose connections of vacuum and resin inlet (Uysal, 2009)

Vacuum pump starts after sealings are properly done. (Figure 3.7) After reaching the predefined vacuum pressure, a leakage test is performed. Then a PLC curing process is chosen. There are two alternatives, one takes 30 minutes at 50^0C and the other 120 minutes at 90^0C.

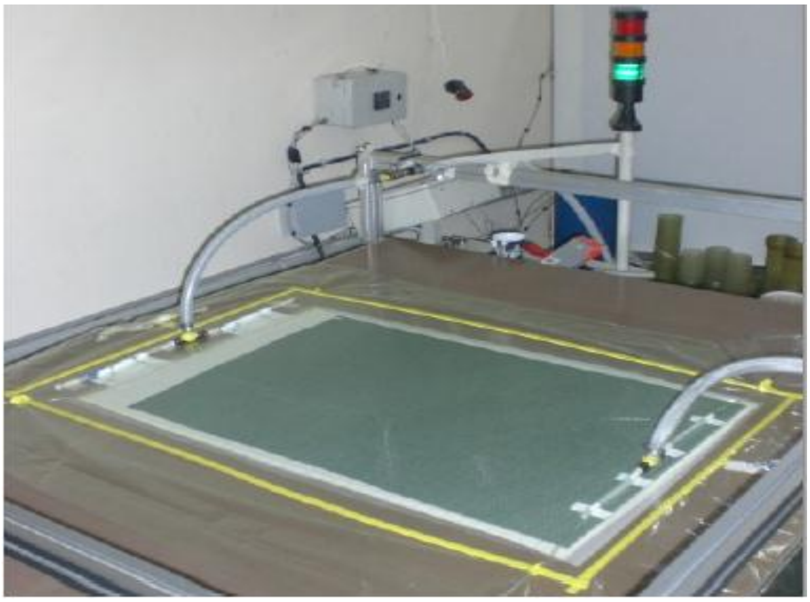


Figure 3.7 Just before curing phase (Uysal, 2009)

As it is mentioned before Mould Table has 8 independent resistances. Temperature is set to 50^0C for resistances. In the catalogue of DURATEK it is discussed that DTE 1000 resin and DTS 1100 hardener should be mixed in a predifined ratio so DTE1000 and DTS1100 is put in a proper bucket and scrambled by a “past driller” in 3/1 weight ratio.

As soon as the temperature reaches to 50^0C at PLC screen, prepared mixture is taken from the bucket by the resin inlet. The flow of the resin can be seen in Figure 3.8.

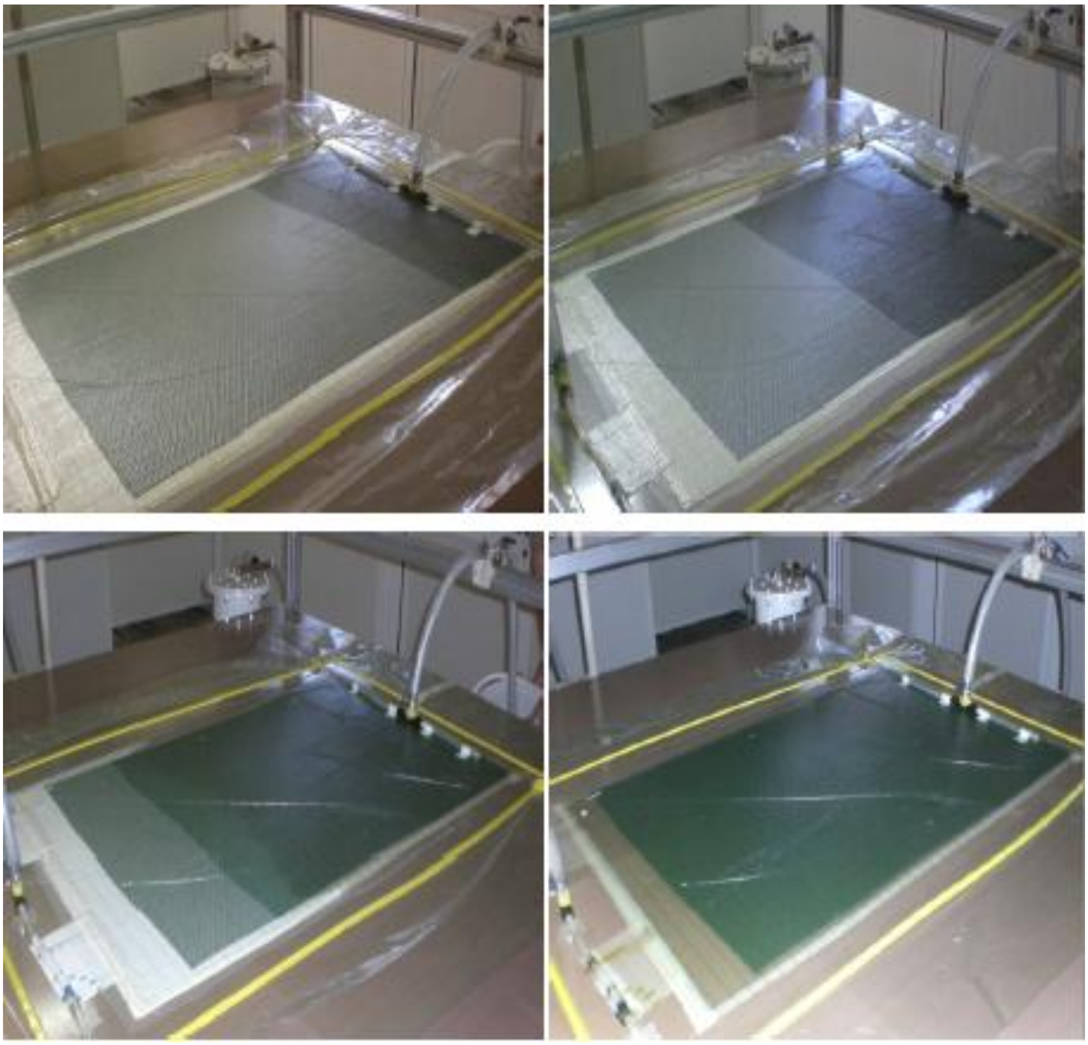


Figure 3.8 Resin infusion while air is going out from other side (Uysal, 2009)

After ther mixture reaches every corner of the plies without any gap the resin inlet is closed and then a periodical check in every 10 minute starts, in order to follow the curing process precisely. As soon as the curing completes sealing tapes and other vacum bag equipments are taken out. Eventually our freshly cooked composite is ready for impact.

3.2 Impact Loading Test

Composites are materials of choice of light-weight structures due to their excellent weight/strength and weight/stiffness properties. Composite structures may be subjected to low-velocity impacts. Under the dynamic loading of the material, these unseen damages can become larger and even can cause the loss of the material. Hence on a layered composite build, anticipating the damage caused by the impact is very important on design and usage. (Akın, Senel, 2010)

3.2.1 Impact Test Equipment

Impact loading tests were done with Fractovis Plus test machine in Figure 3.2. This machine works with "Dropping Weight" principle which is a modular machine, so it is inevitably configurable to fulfill the demands.

Drop speed can be up to 4.6 m/s and also potential energy of weight unit can holds 755 J energy(with the aid of springs keeping of potential energy can be up to 1800J as well as 24m/sn). At the bottom there is a closed chamber due to need to be heated or cooled in between -70^{0}C to 150^{0}C.

A bounce blocker system and automatic weight calculator is also installed. Impactor design consists of two types Piezoelectric and Strain-Gauge.

Figure 3.2 Fractovis plus tester (A), impactor nose(B_1), piezoelectric(B_2), data acquisition system(DAS)(C), specimen holding mechanism(D), springs(E)

The test starts with the release of impactor. As soon as it reaches the composite specimen time trigger occurs with the signal of time sensor. At this point impact velocity is calculated by the time it takes to pass the two triggers. Immediately the impact starts and force the transducer on the impactor gets data about the contact forces. The data is sent trough the Data Acquisition System to the computer. Impactor velocity can be found by integrating contact force after dividing the mass of impactor. After calculating the velocity, displacement can be found by integrating this value. Eventually with these values Force – Displacement (practically also force – deflection) and energy relations (curves) can be established.

Depending on the impact energy level and the type of specimen investigated, either a partial or the total amount of impact energy can be absorbed by the composite specimen in forms of damage, heat and others. (Liu, Raju, Dang, 2000)

If the heat and energy loss is ignored during impact, the energy that is produced by impactor is directly transferred to the specimen.

CHAPTER FOUR
RESULTS

All the tests were performed at the room temperature. The inner diameter of the clamping apparatus was 76 mm Hemispherical Nose diameter of the impactor was 12.7 mm with a force transducer at 22.24 kN loading capacity. The mass of the impactor was 4,906 kg and not changed during the experiment. The specimens for each stacking sequences parameters and having 100 x 100 mm square shape with 2.2 mm thickness were impacted at 35J, 30J, 25J, 20J, 15J, 10J for three times. (35J loading is tried as 1 per each fiber orientation.) Specimens configurations are given in Table 4.1.

Table 4.1 Specimen configuration and number of specimens

	Specimen	Number of Specimen
1	$[\ 0\ ]_8$	16 pieces
2	$[\ 0 / 15 / 30 / 45\ ]_s$	16 pieces
3	$[\ 0 / 15 / 0 / 15\ ]_s$	16 pieces
4	$[\ 0 / 30 / 0 / 30\ ]_s$	16 pieces
5	$[\ 0 / 90 / 0 / 90\ ]_s$	16 pieces

Under impact loading the composites behave in three different ways, rebounding, penetration and perforation. Rebounding is a state that velocity of impactor decreases until zero then suddenly it starts to increase its speed in negative. That is a proof of absorbion of all the impact energy by specimen when its started to speed up in negative. In penetration velocity of impactor decreases until zero, same as in rebounding but it is suddenly stucked inside specimen and stays as it is. There is still a thickness of material holding the impactor to proceed more. The third case is perforation which is observed with contact force. Force reaches to its biggest (critical) value and suddenly decreases to a minimum value. At that moment it is understood that perforation is happened on specimen. Perforation is the supreme damage that can the impactator can do. All of the layers are passed through by impactor and there is still some more kinetic energy, which could do some more damage if there were additional layers within. It can be physically described as a hole that starts from the top till the bottom. It can be observed better by a series of general graphs as shown below;

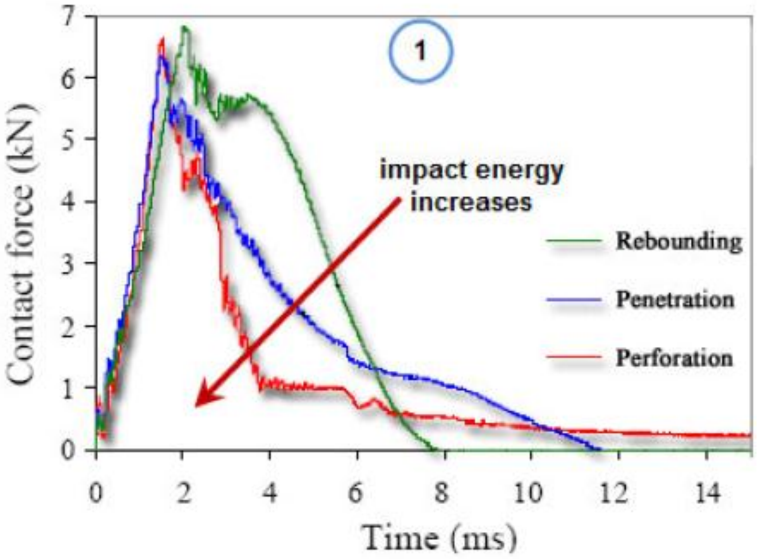


Figure 4.1 Contact force(kN) – Time(ms) (Aktas, 2007)

Figure 4.1 indicates that as impact energy increases penetration shifts to perforation. After perforation friction between hole and the impactor hinders contact force for reaching zero.

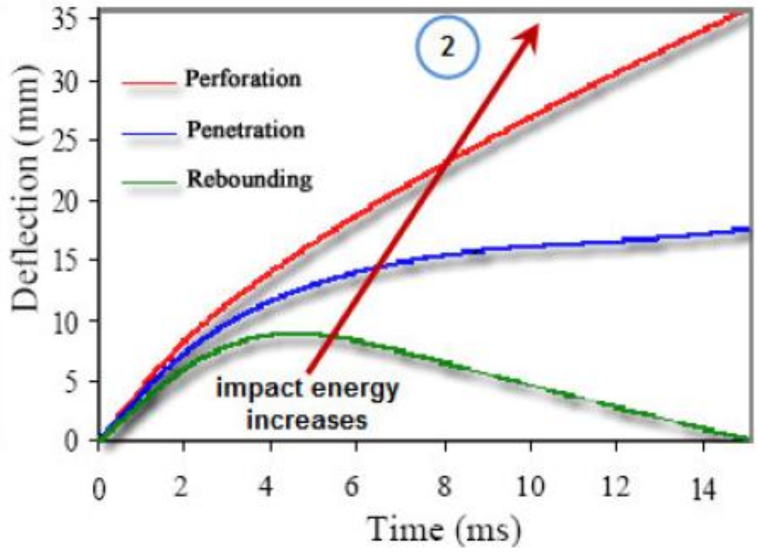


Figure 4.2 Deflection(mm) – Time(ms) (Aktas, 2007)

The calculation of deflection is done according to the displacement of impactor as time passes Figure 4.3 shows that impact energy rises deflection gets bigger. However only when rebounding state reaches zero, negative values were calculated for deflection. This green line would continue to negative values. Penetration deflection value holds as it is after some time. This critical moment points out the stuck moment of impactor inside specimen. On perforation state value of deflection goes to an uncertain point so friction force inside the hole was not enough to hold the impactor.

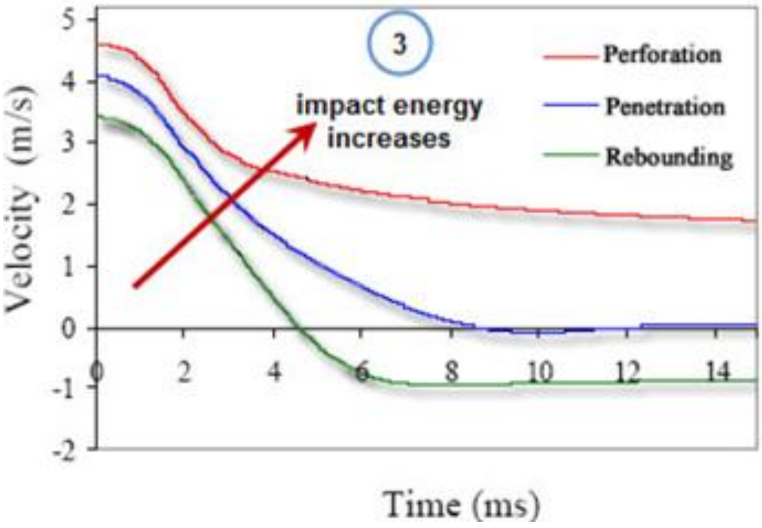


Figure 4.3 Velocity(m/s) – Time(ms) (Aktas, 2007)

In figure 4.3, for rebounding state impactor is halted for a moment on the surface of material until all the energy is absorbed by specimen. Then suddenly it starts to go back in negative velocity values. However penetrated impactator is halted inside the material and velocity value stays. On the other hand, perforation impactor loses some of its velocity during impact and friction while passing through specimen as it continues its journey until an uncertain point.

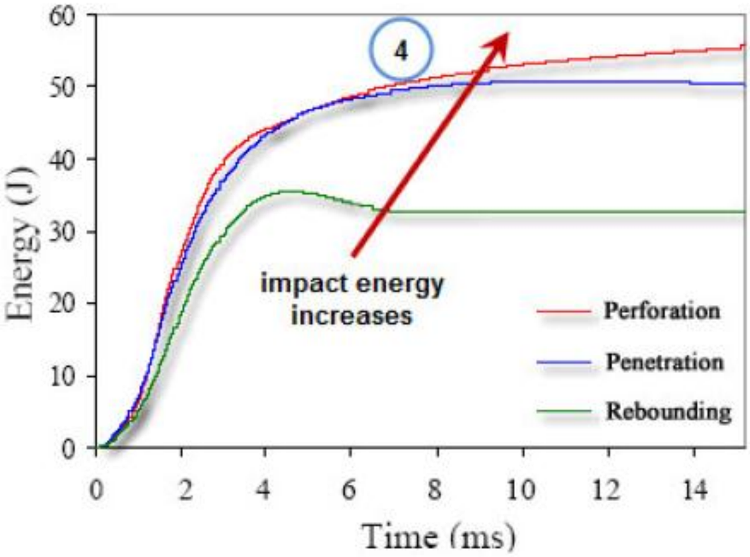


Figure 4.4 Energy(J) – Time(ms) (Aktas, 2007)

In figure 4.4 it is understood that if impact energy is equal with the absorbed energy then this state is called rebounding. However if it is higher than absorbed energy it can be called both penetration or perforation. Perforation energy is increases after the impact as the other states stay stable.

Absorbed – impact energy relation is given at Figure 4.5 for all. From the figure it is understood that until 20J impact loading all the orientations encountered rebounding and absorbed impact energy partially. Rebounding, penetration or preferation state can not be observed with this figure. However by increasing the impact energy, each laminate orientation reacts differently.

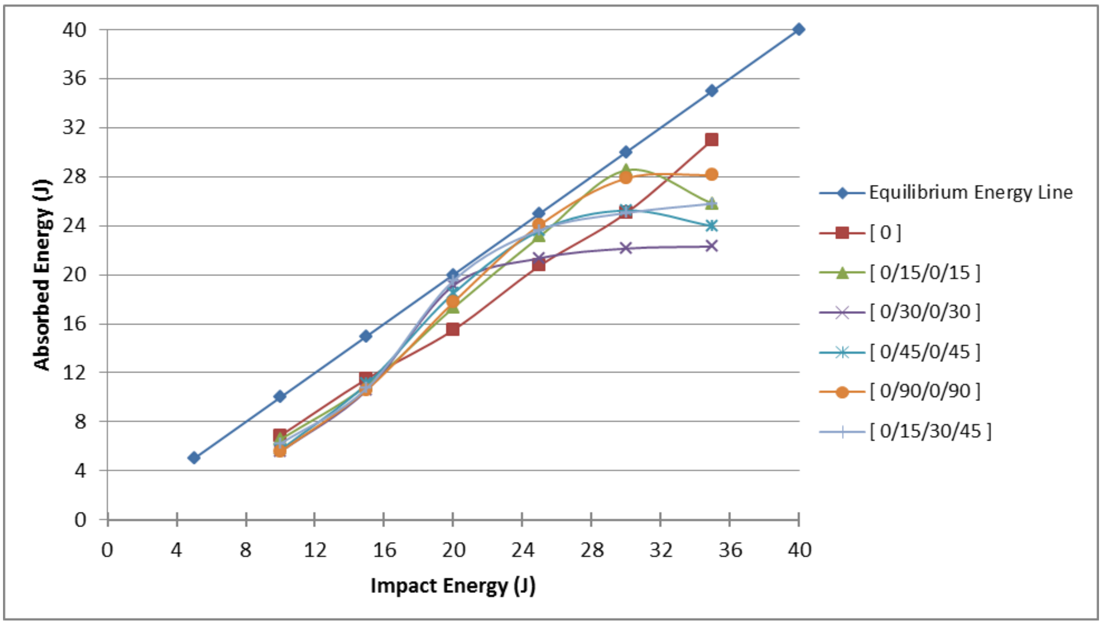
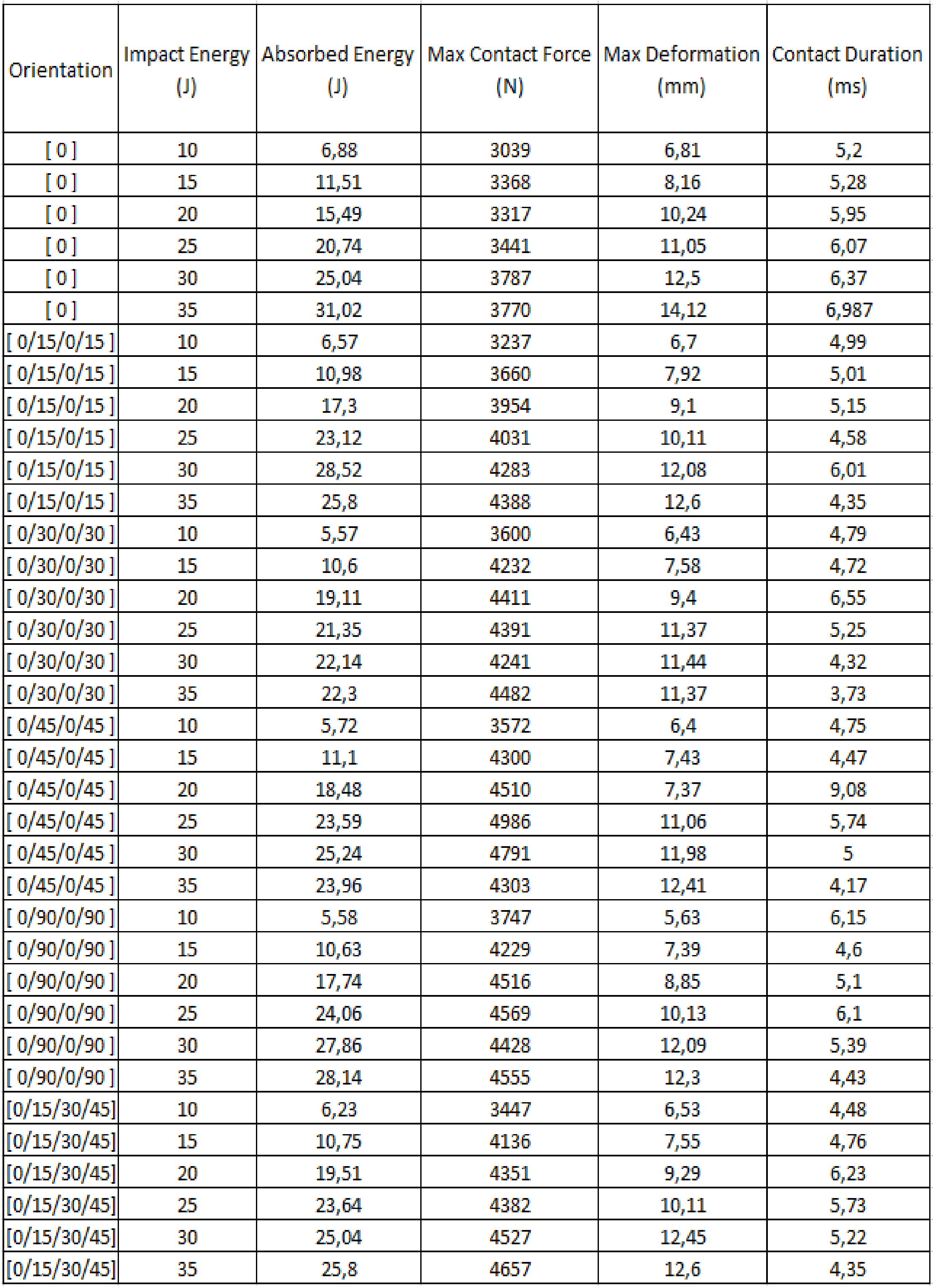


Figure 4.5 Absorbed – Impact energy history for all orientations with equilibrium energy line

To understand the reactions of different orientation under diversified loading values six different impact energy levels (10J-15J-20J-25J-30J-35J) were used. For all levels from 10J to 30J are performed three times just 35J is perfomed one time in order to get the values more precise. Information that was taken during impact is listed below at table.

Usually by increasing impact energy, the contact force and deformation increases, but the impact time drops. Contact Force – Time, Energy – Time, Deflection – Time, Contact Force – Deflection graphs are listed below in order to show impact dynamics.

Table 4.2 Results of orientations under different impact energies



Orientation	Impact Energy (J)	Absorbed Energy (J)	Max Contact Force (N)	Max Deformation (mm)	Contact Duration (ms)
[0]	10	6,88	3039	6,81	5,2
[0]	15	11,51	3368	8,16	5,28
[0]	20	15,49	3317	10,24	5,95
[0]	25	20,74	3441	11,05	6,07
[0]	30	25,04	3787	12,5	6,37
[0]	35	31,02	3770	14,12	6,987
[0/15/0/15]	10	6,57	3237	6,7	4,99
[0/15/0/15]	15	10,98	3660	7,92	5,01
[0/15/0/15]	20	17,3	3954	9,1	5,15
[0/15/0/15]	25	23,12	4031	10,11	4,58
[0/15/0/15]	30	28,52	4283	12,08	6,01
[0/15/0/15]	35	25,8	4388	12,6	4,35
[0/30/0/30]	10	5,57	3600	6,43	4,79
[0/30/0/30]	15	10,6	4232	7,58	4,72
[0/30/0/30]	20	19,11	4411	9,4	6,55
[0/30/0/30]	25	21,35	4391	11,37	5,25
[0/30/0/30]	30	22,14	4241	11,44	4,32
[0/30/0/30]	35	22,3	4482	11,37	3,73
[0/45/0/45]	10	5,72	3572	6,4	4,75
[0/45/0/45]	15	11,1	4300	7,43	4,47
[0/45/0/45]	20	18,48	4510	7,37	9,08
[0/45/0/45]	25	23,59	4986	11,06	5,74
[0/45/0/45]	30	25,24	4791	11,98	5
[0/45/0/45]	35	23,96	4303	12,41	4,17
[0/90/0/90]	10	5,58	3747	5,63	6,15
[0/90/0/90]	15	10,63	4229	7,39	4,6
[0/90/0/90]	20	17,74	4516	8,85	5,1
[0/90/0/90]	25	24,06	4569	10,13	6,1
[0/90/0/90]	30	27,86	4428	12,09	5,39
[0/90/0/90]	35	28,14	4555	12,3	4,43
[0/15/30/45]	10	6,23	3447	6,53	4,48
[0/15/30/45]	15	10,75	4136	7,55	4,76
[0/15/30/45]	20	19,51	4351	9,29	6,23
[0/15/30/45]	25	23,64	4382	10,11	5,73
[0/15/30/45]	30	25,04	4527	12,45	5,22
[0/15/30/45]	35	25,8	4657	12,6	4,35

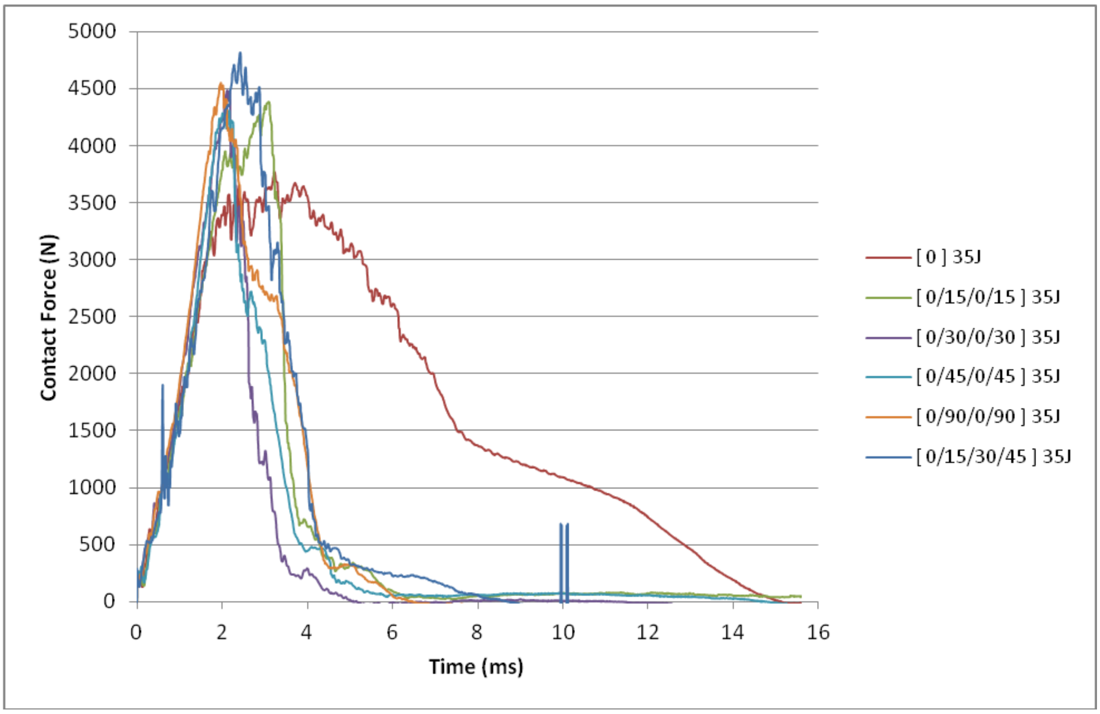


Figure 4.6 Contact force – Time history under 35J impact energy

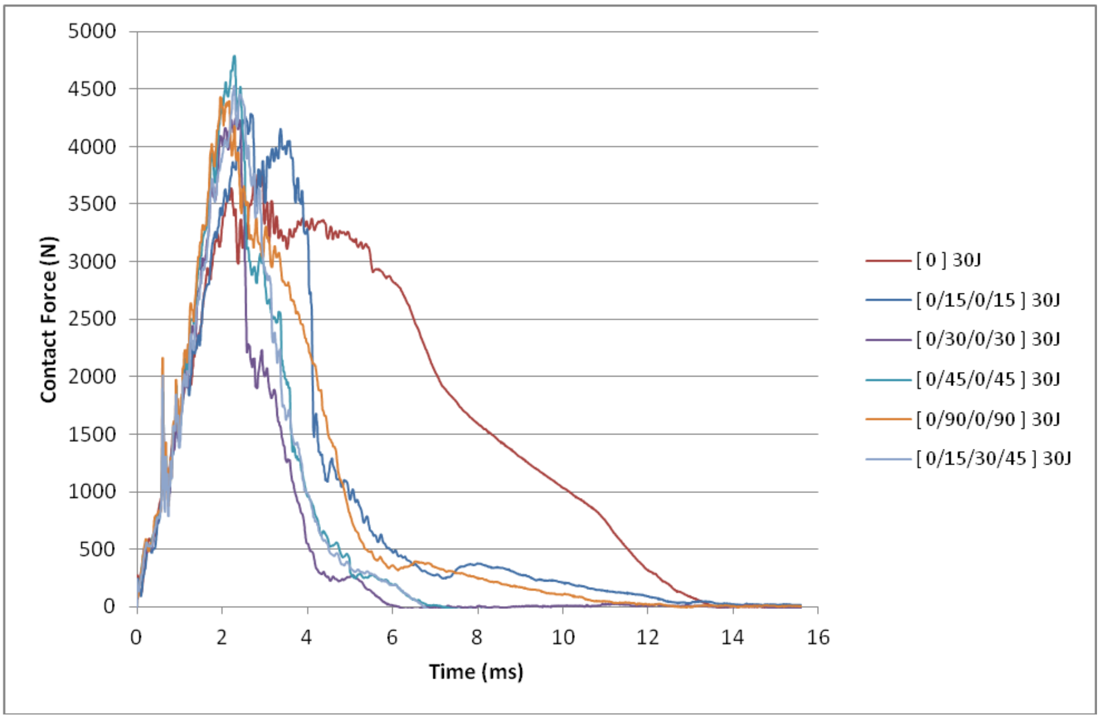


Figure 4.7 Contact force – Time history under 30J impact energy

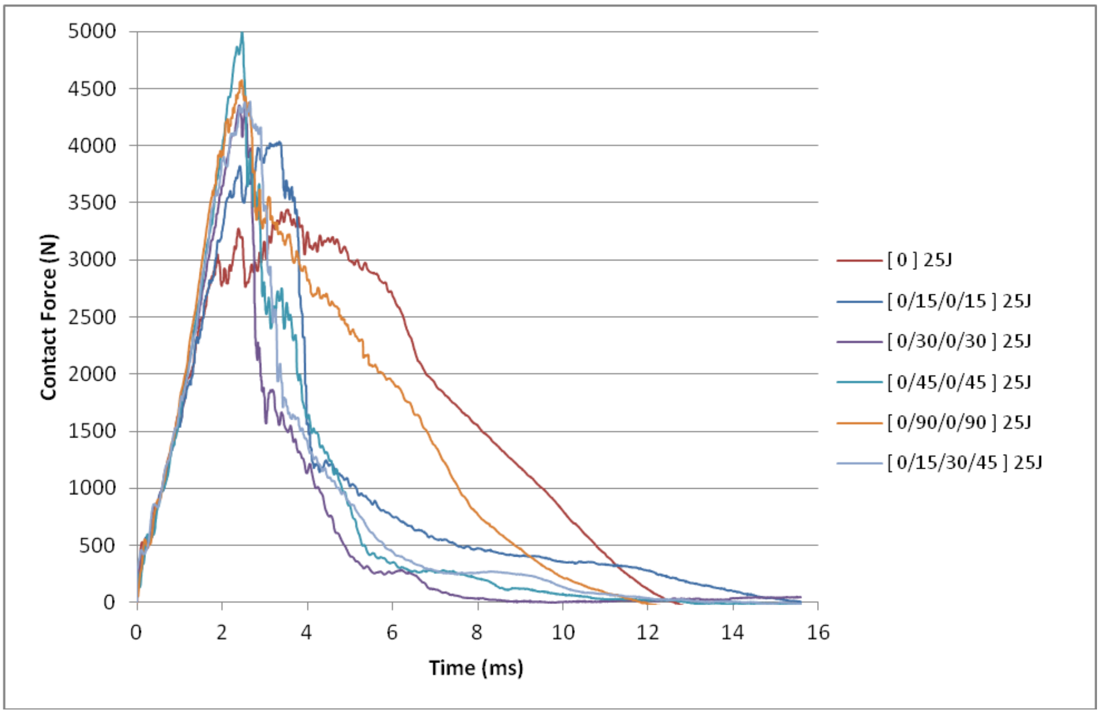


Figure 4.7 Contact force – Time history under 25J impact energy

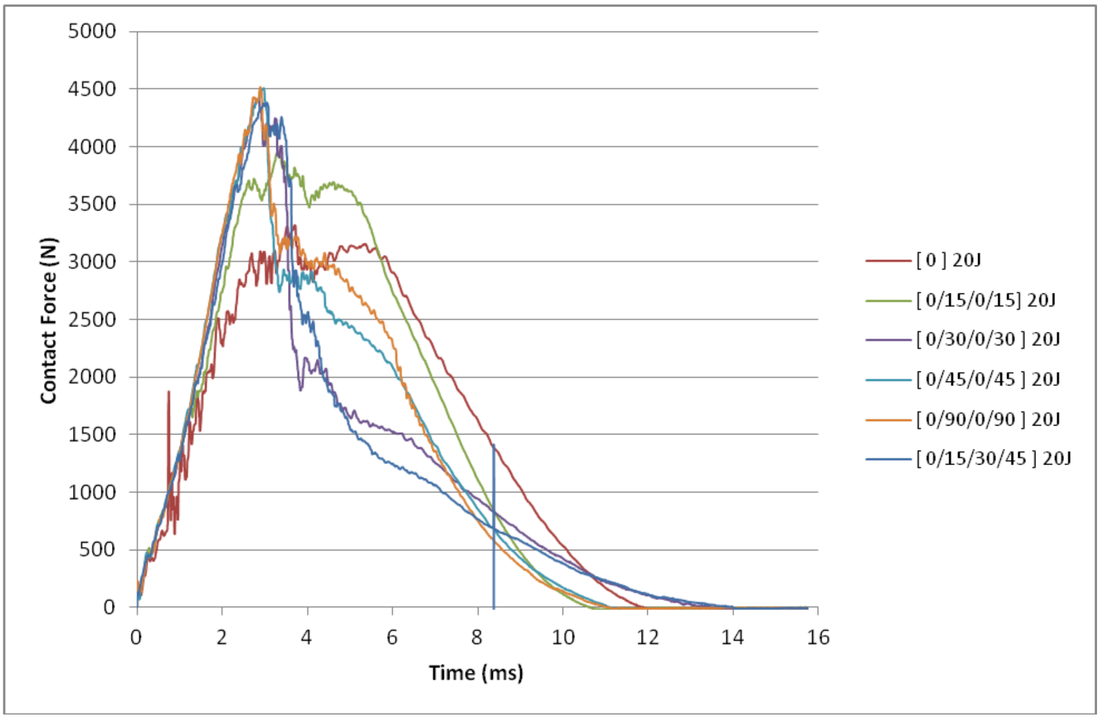


Figure 4.8 Contact force – Time history under 20J impact energy

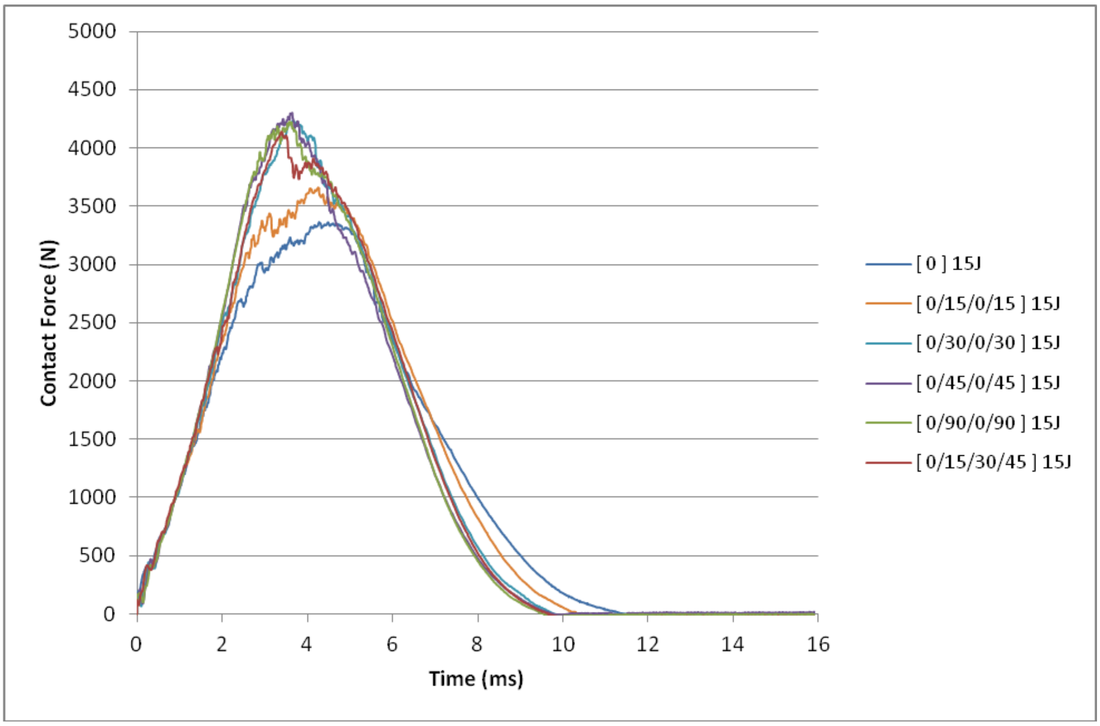


Figure 4.9 Contact force – Time history under 15J impact energy

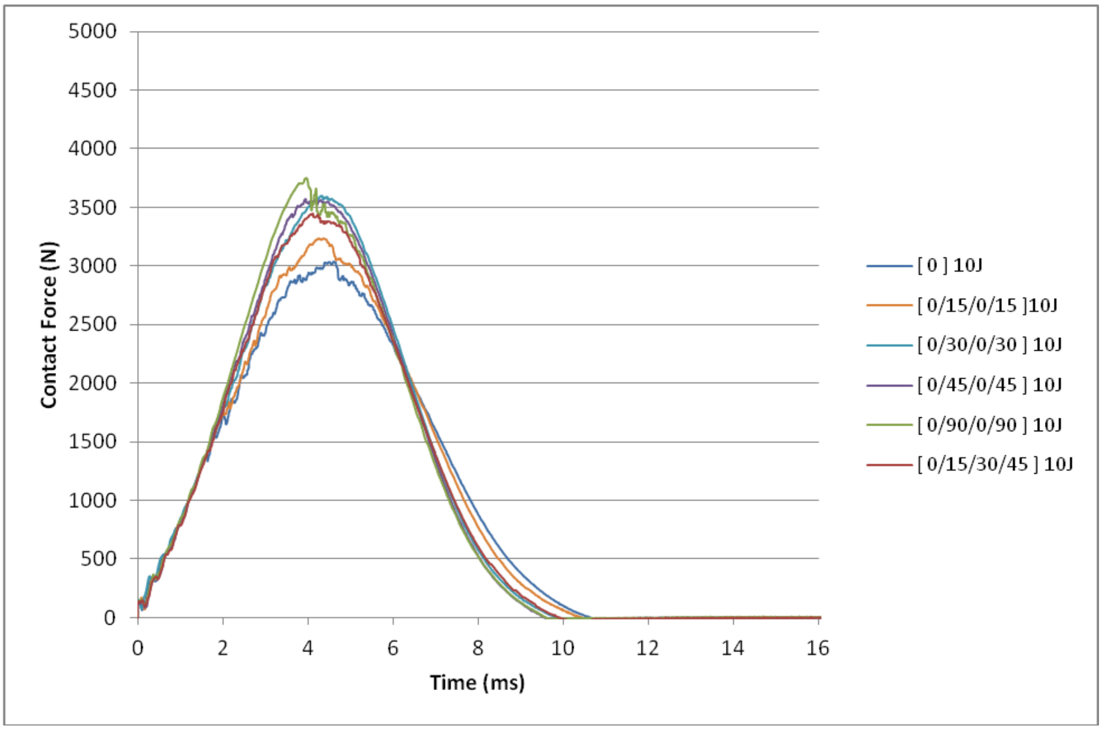


Figure 4.10 Contact force – Time history under 10J impact energy

Figures show that as impact energy increases contact force increases accordingly. Rising slope is nearly same for all orientations during loading. However after the peak contact force, unloading slope differs due to fractures inside plies such as penetration or perforation.

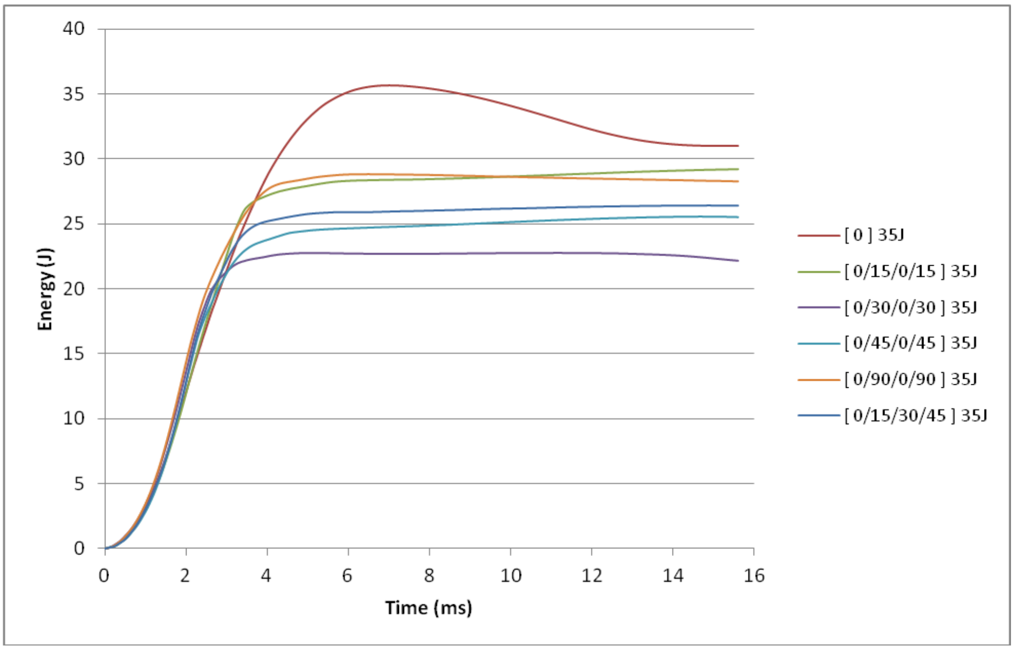


Figure 4.11 Energy – Time history under 35J impact energy

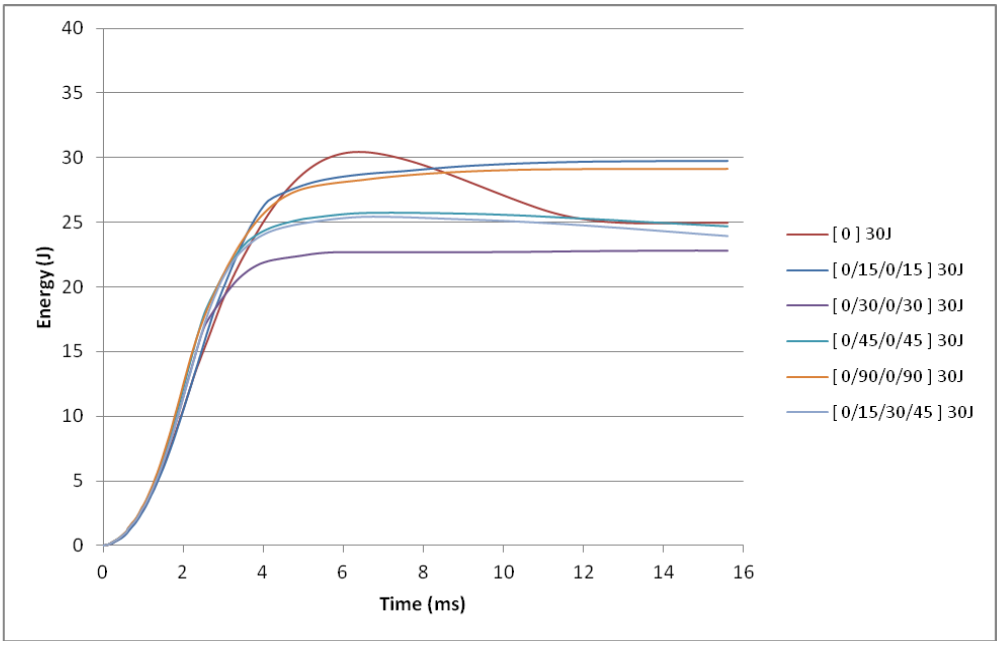


Figure 4.12 Energy – Time history under 30J impact energy

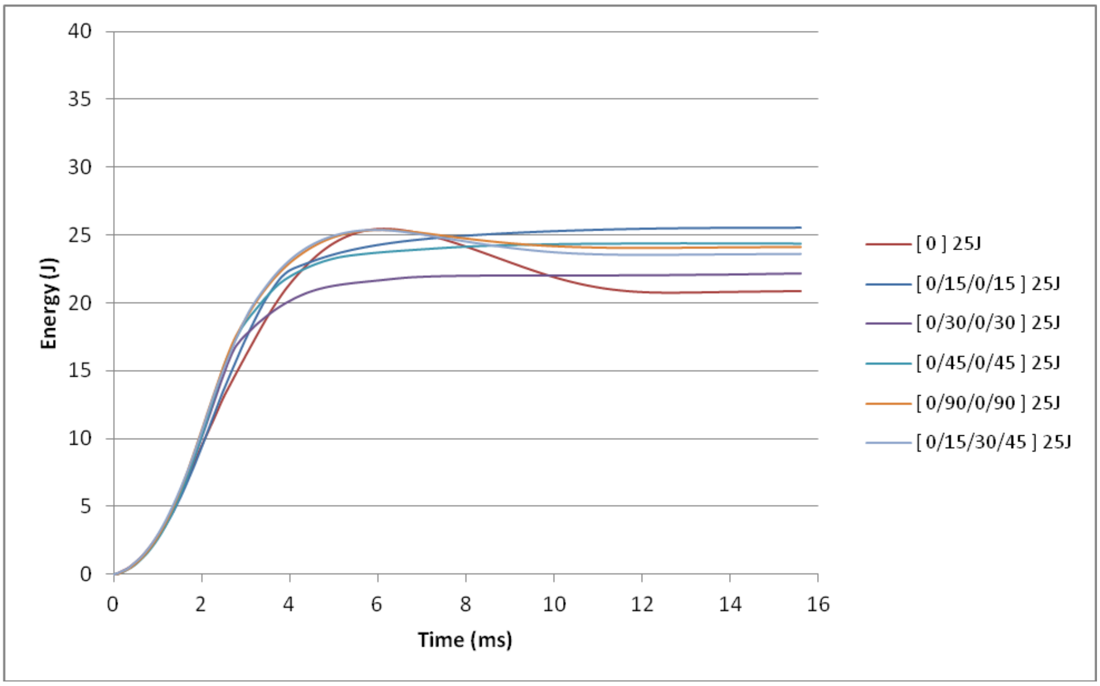


Figure 4.13 Energy – Time history under 25J impact energy

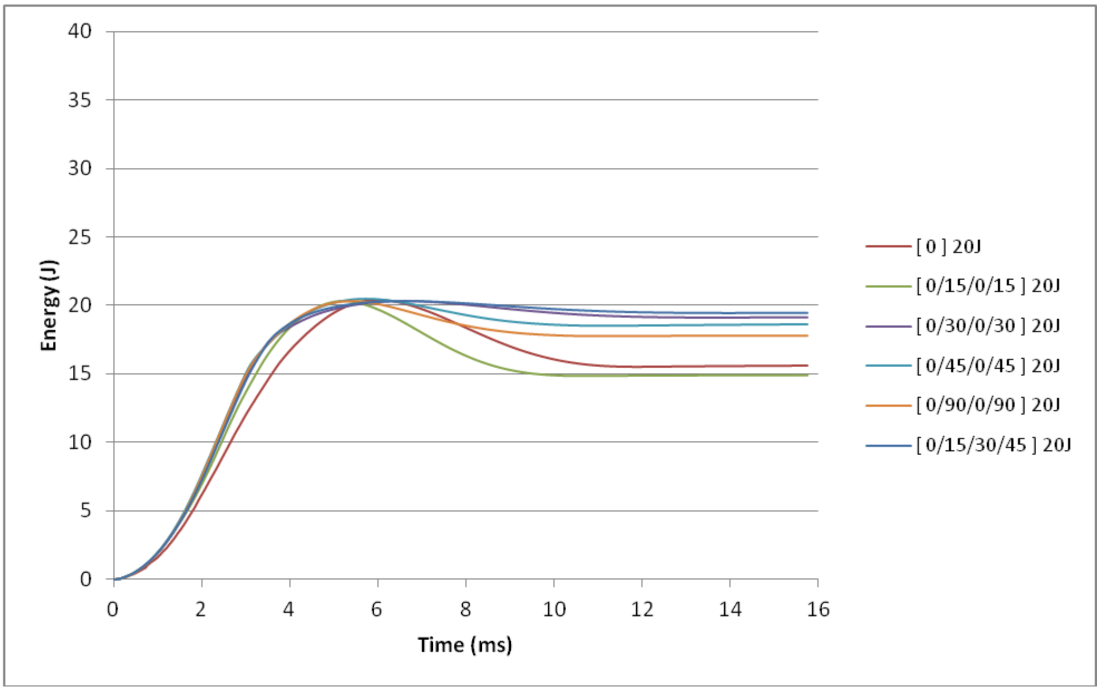


Figure 4.14 Energy – Time history under 20J impact energy

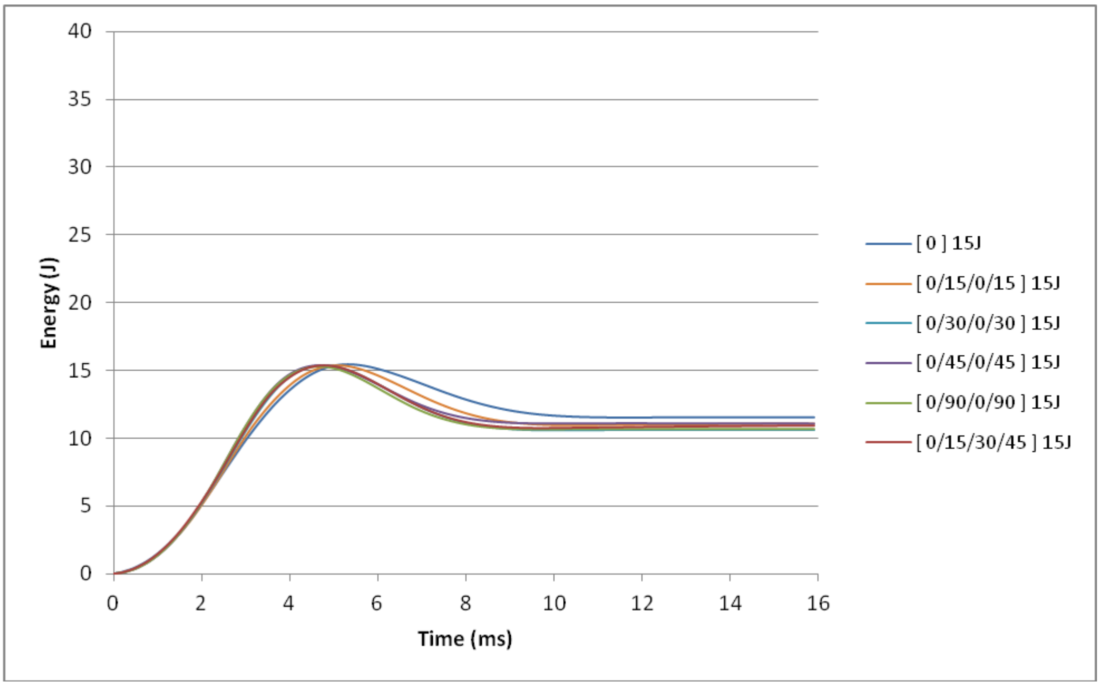


Figure 4.15 Energy – Time history under 15J impact energy

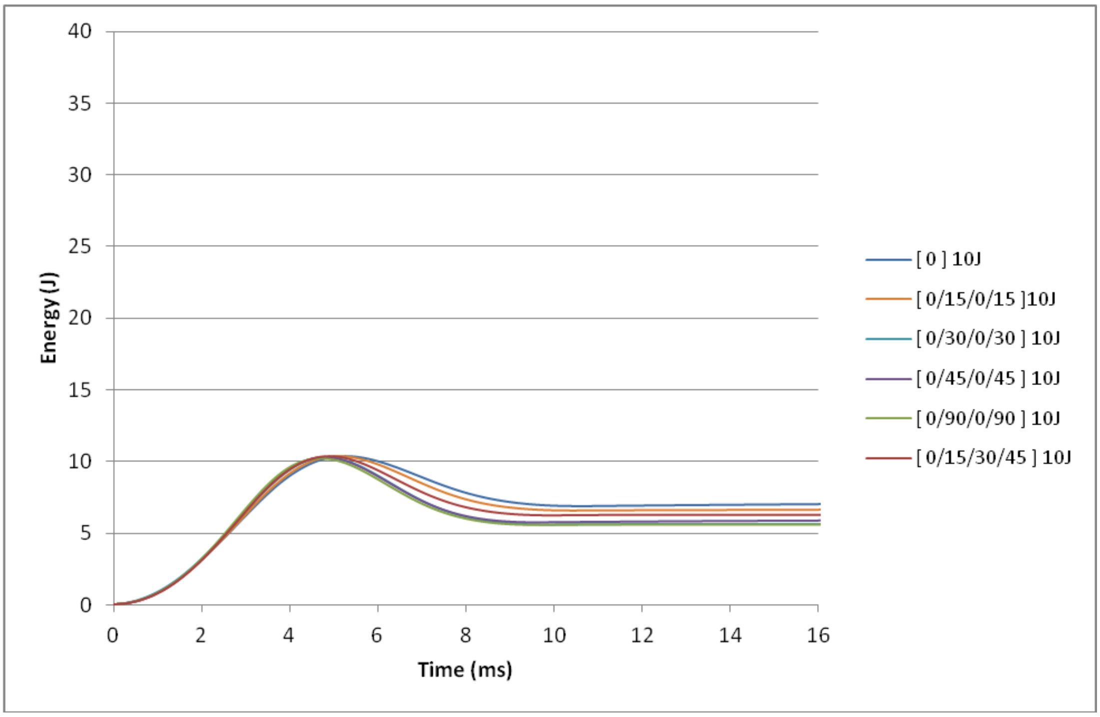


Figure 4.16 Energy – Time history under 10J impact energy

From 0 J to impact energy, value slopes in figures are similar. Indeed that they are in different orientations and impact energies so in some conditions curves are bending and going straight to an insignificant value. The point that changed its curve slope demonstrates the last fibers of fracture, the end of penetration and the start of perforation. During perforation between impactor and fractured fibers or cracked matrix has a friction at surfaces which can not absorb all but very little of its kinetic energy.

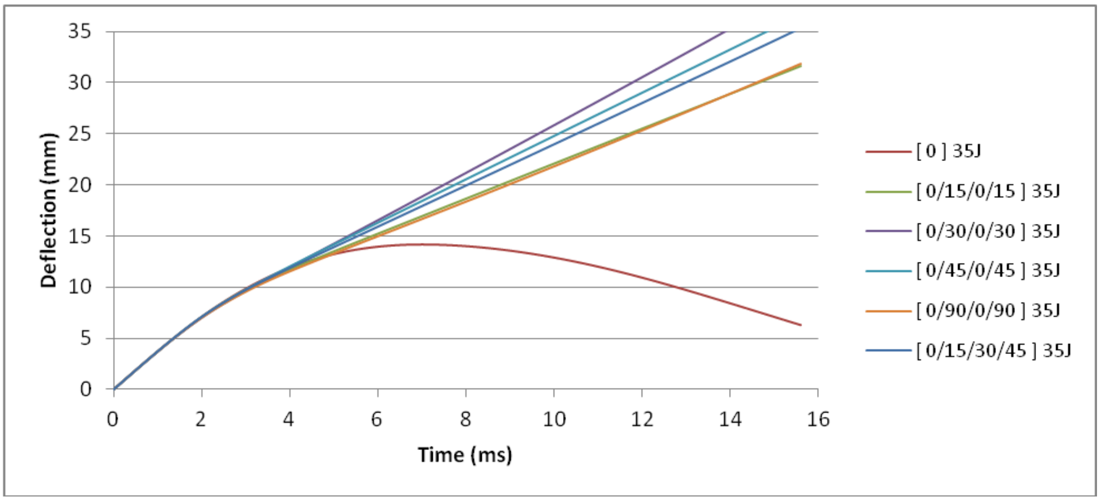


Figure 4.17 Deflection – Time history under 35J impact energy

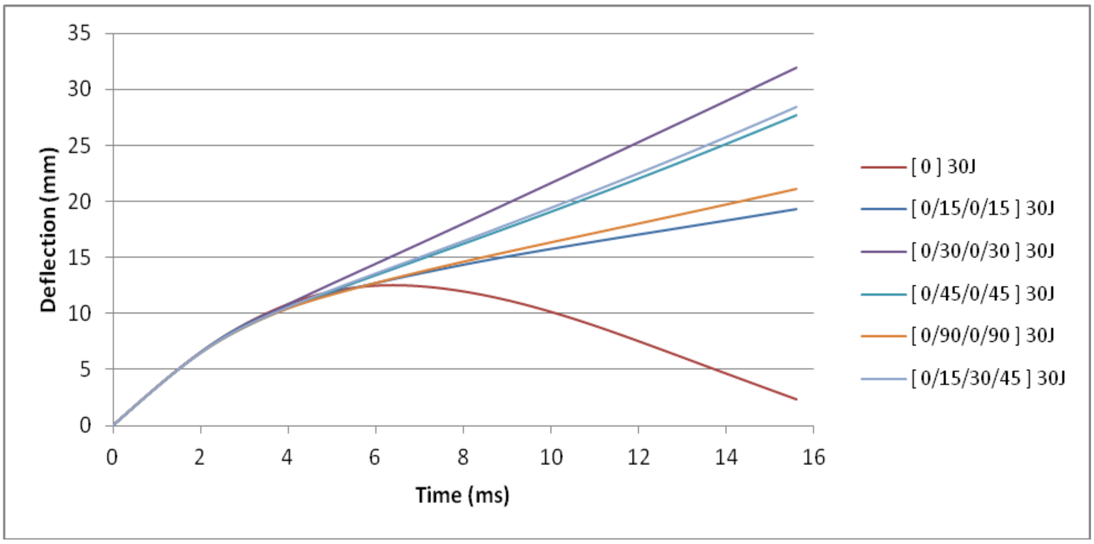


Figure 4.18 Deflection – Time history under 30J impact energy

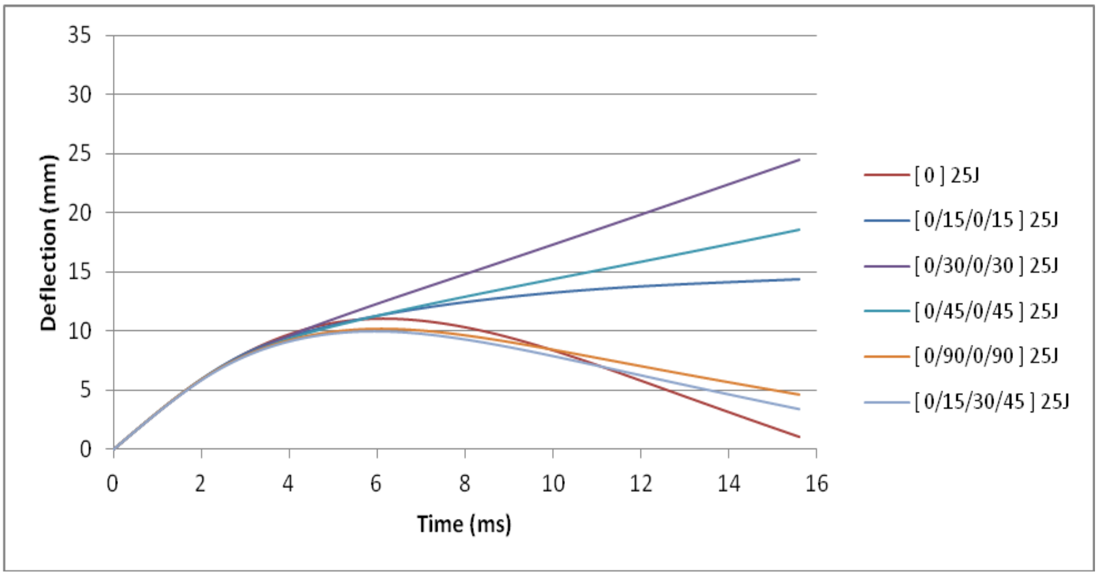


Figure 4.19 Deflection – Time history under 25J impact energy

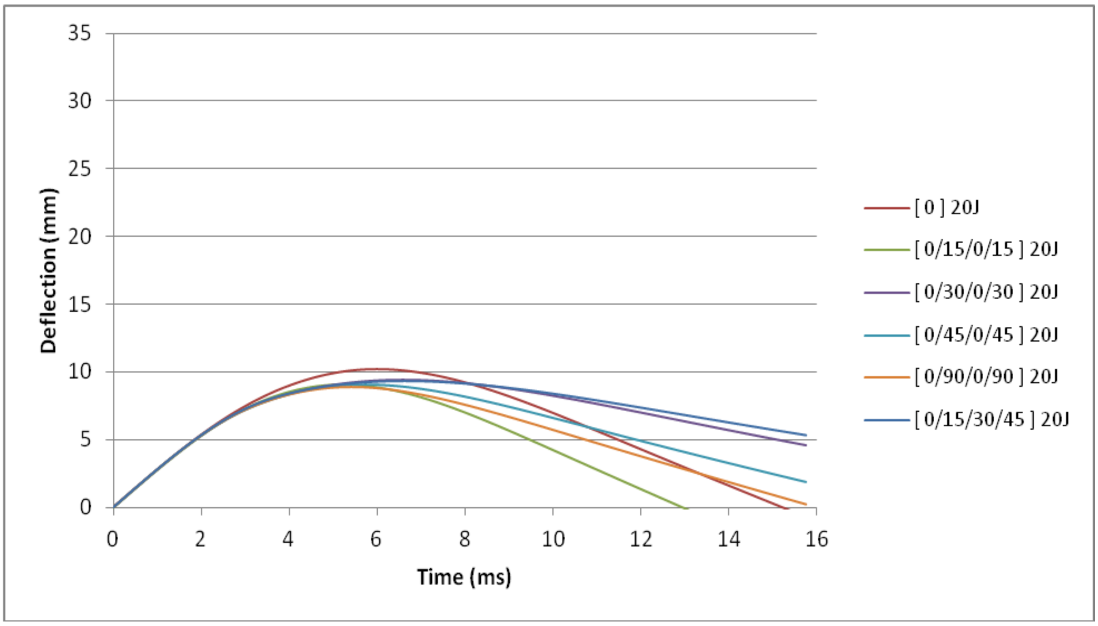


Figure 4.20 Deflection – Time history under 20J impact energy

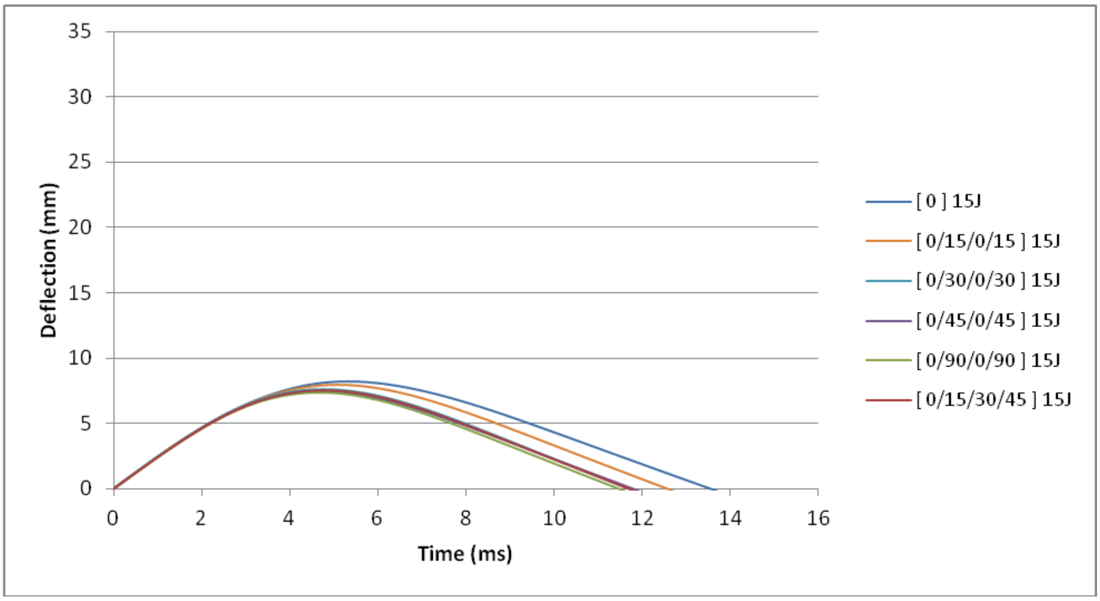


Figure 4.21 Deflection – Time history under 15J impact energy

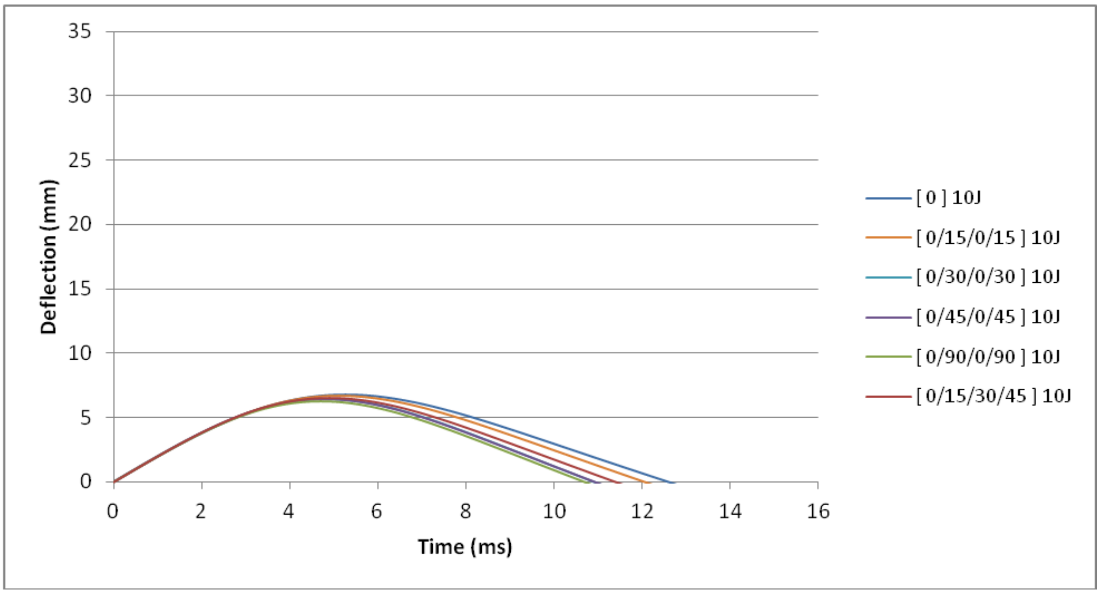


Figure 4.22 Deflection – Time history under 10J impact energy

Under 35J impact, $[0]_8$ oriented specimen deformation occured as only as penetration. However other specimens were continued to deform until perforation. Rebounding is observed for all orientations in between 10J to 15J.

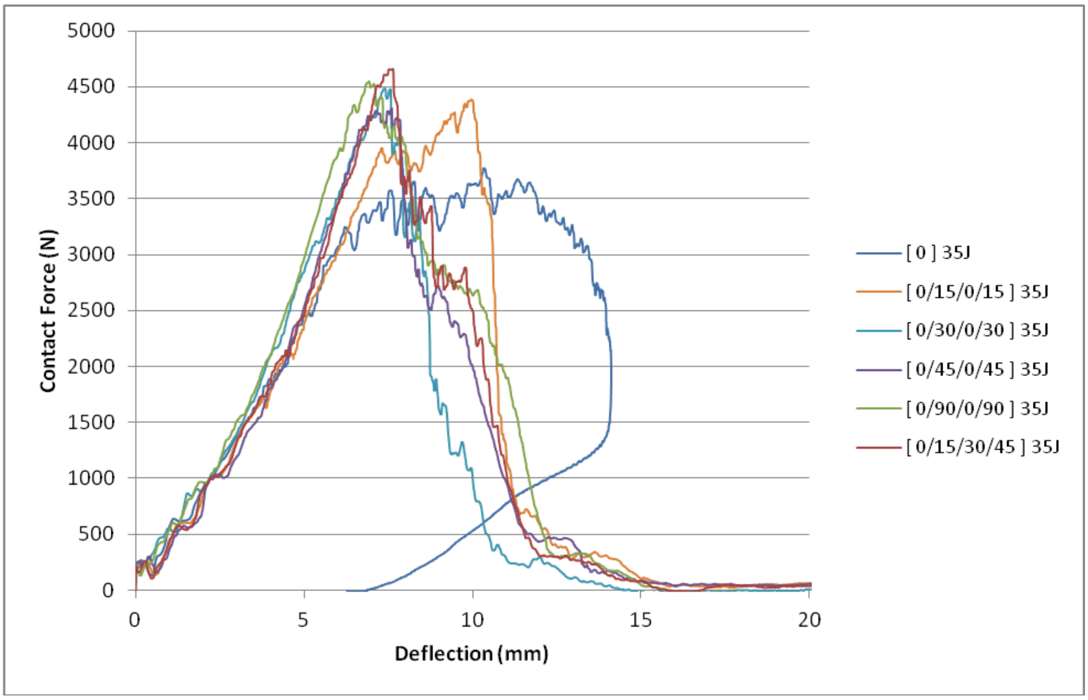


Figure 4.23 Contact force – Deflection history under 35J impact energy

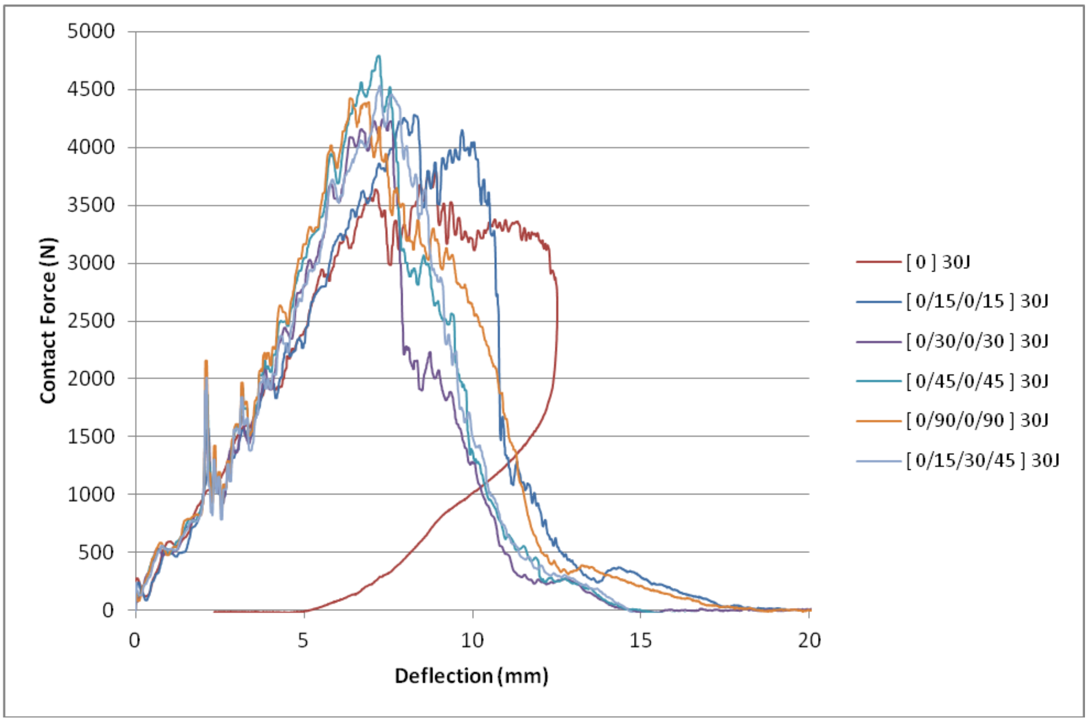


Figure 4.24 Contact force – Deflection history under 30J impact energy

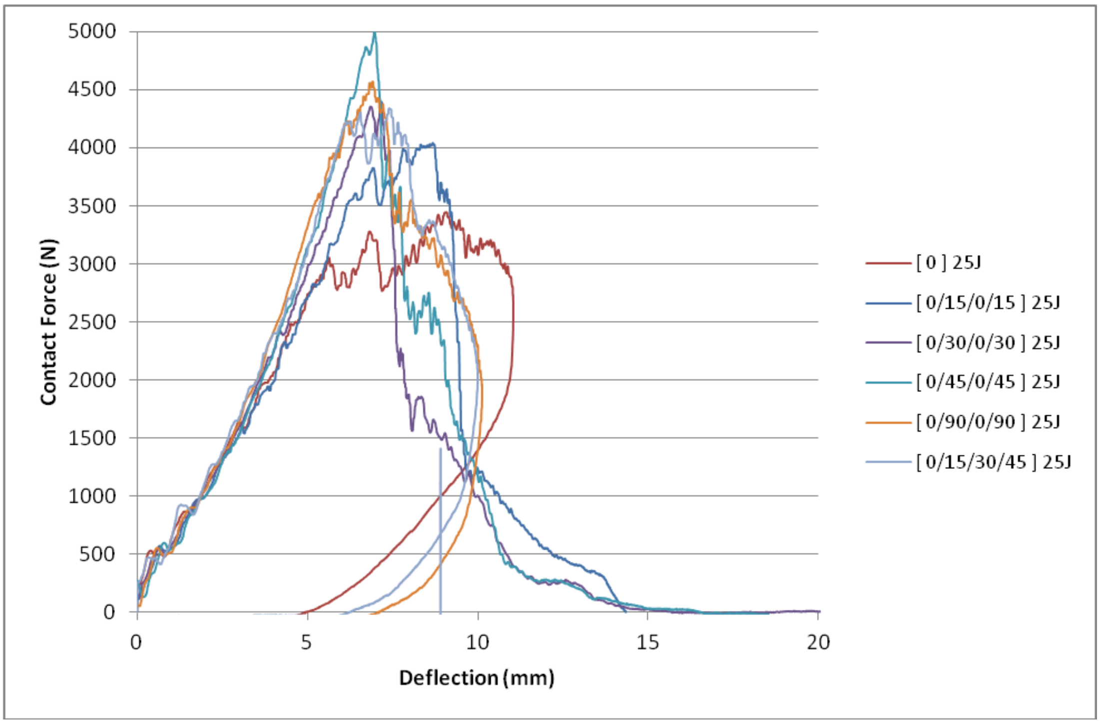


Figure 4.25 Contact force – Deflection history under 25J impact energy

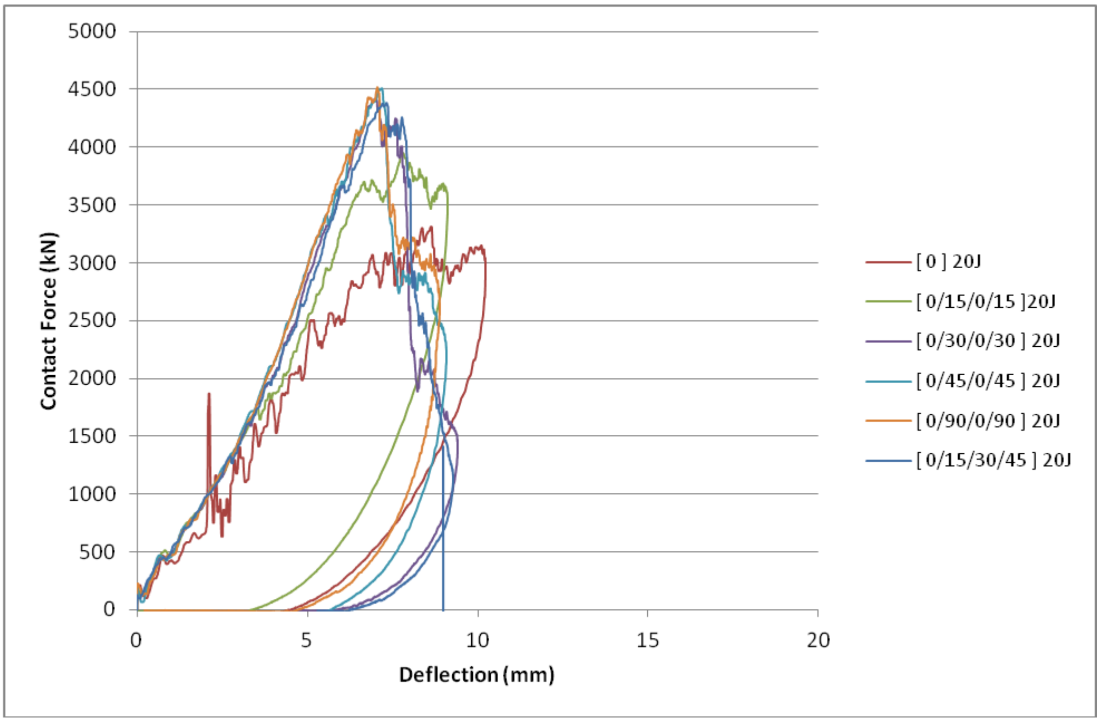


Figure 4.25 Contact force – Deflection history under 20J impact energy

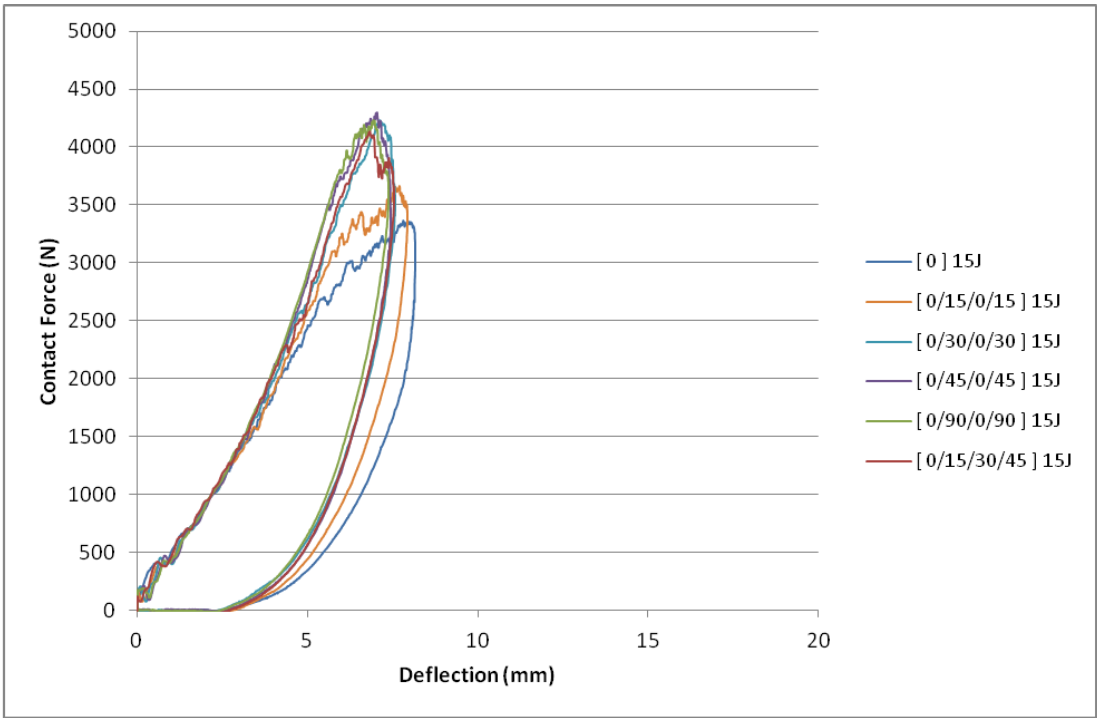


Figure 4.26 Contact force – Deflection history under 15J impact energy

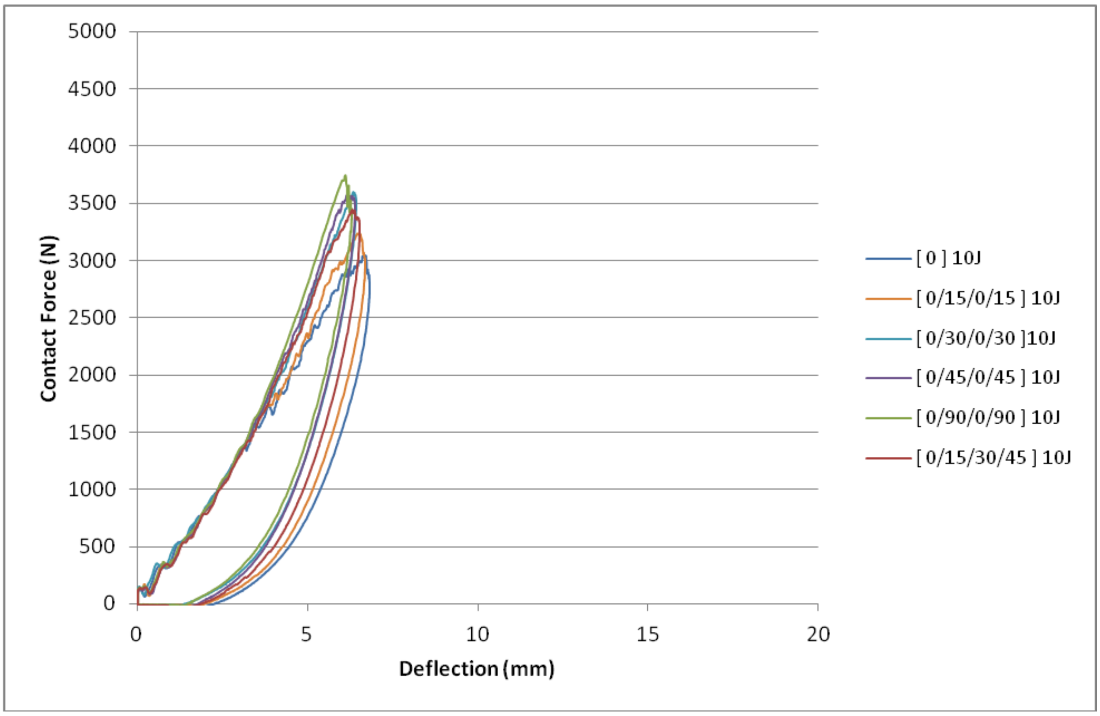


Figure 4.27 Contact force – Deflection history under 10J impact energy

Penetration, Rebounding and Perforation states are easier to observe in contact force – deflection histories. Rebounding is clearly shown in Figure 4.17 where slopes are smooth and make a proper curve until absolute zero. On the other hand as impact energy increases slope begins to form some peaks and break points such as shown in Figure 4.16. Those remarkable points shows that penetration is started. Probably matrix is cracked and fibers started to fracture but there is still some plies or at least fibers to hold the impactor. Furthermore as impact energy increases more as in Figure 4.15 preforation starts. Only [0] orientation could stand 35J impact energy. Also slope of this orientation shows that penetration happened on the surface.

After this point specimen photos are listed in order to see the effect of impact energy by visiual inspection. Orientation is shown on right corner at top and impact energy is shown at left corner at below.

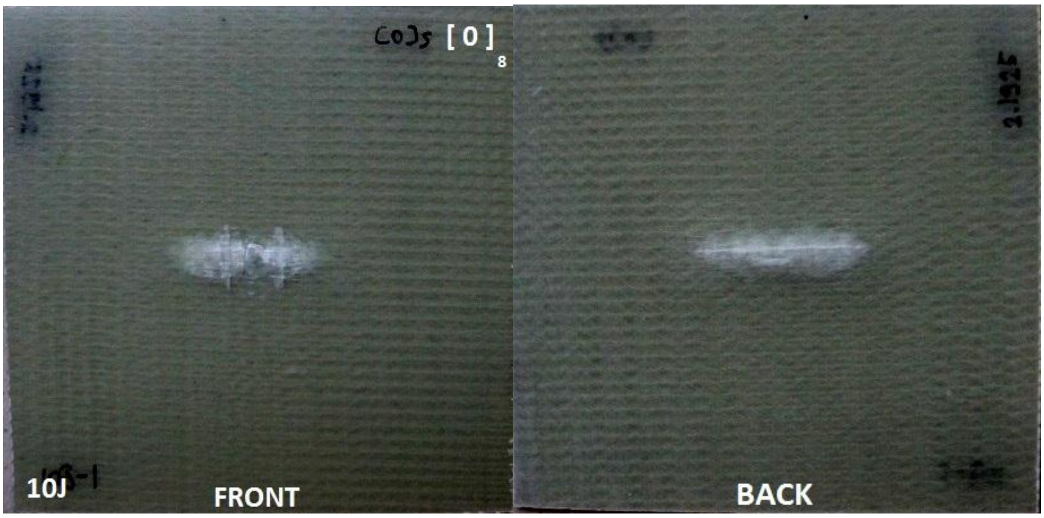


Figure 4.28 $[0]_8$ After 10J impact

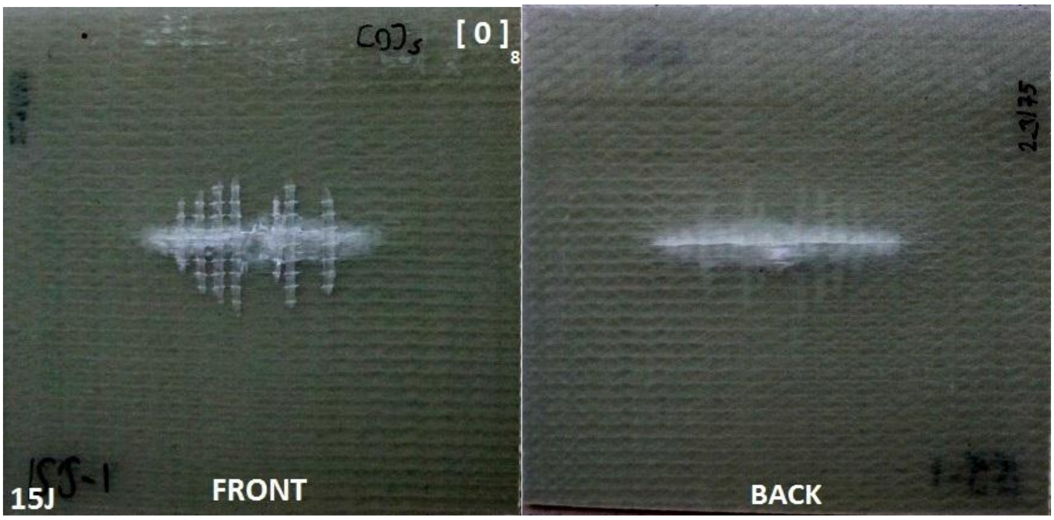


Figure 4.29 $[0]_8$ After 15J impact

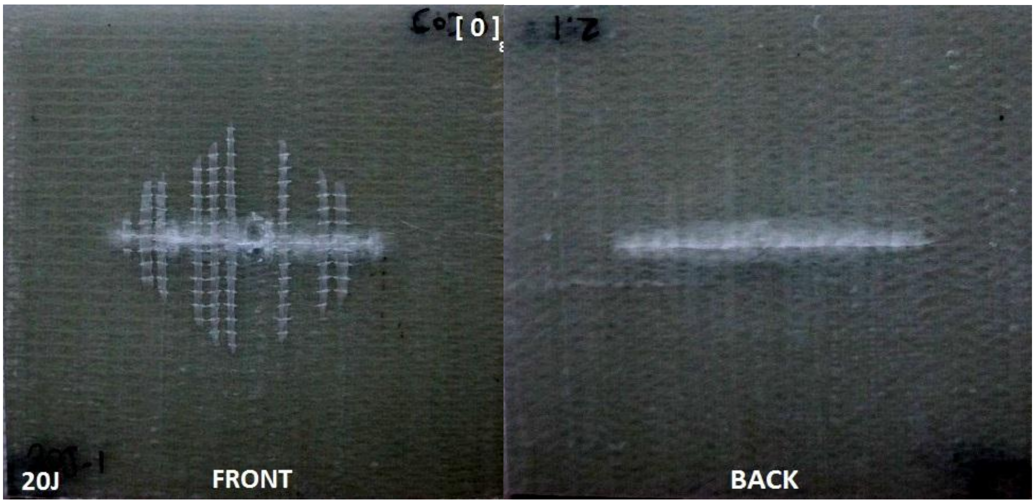


Figure 4.30 $[0]_8$ After 20J impact

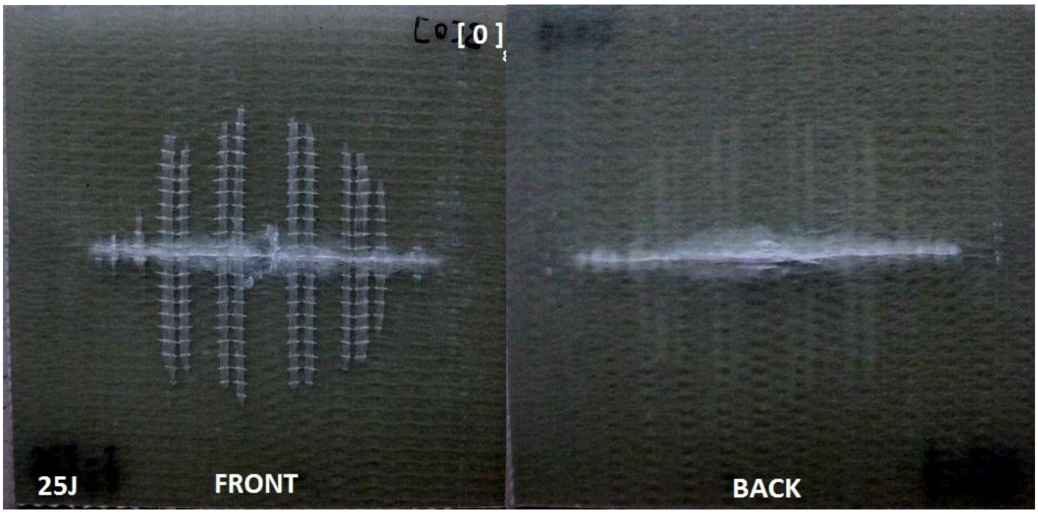


Figure 4.31 $[0]_8$ After 25J impact

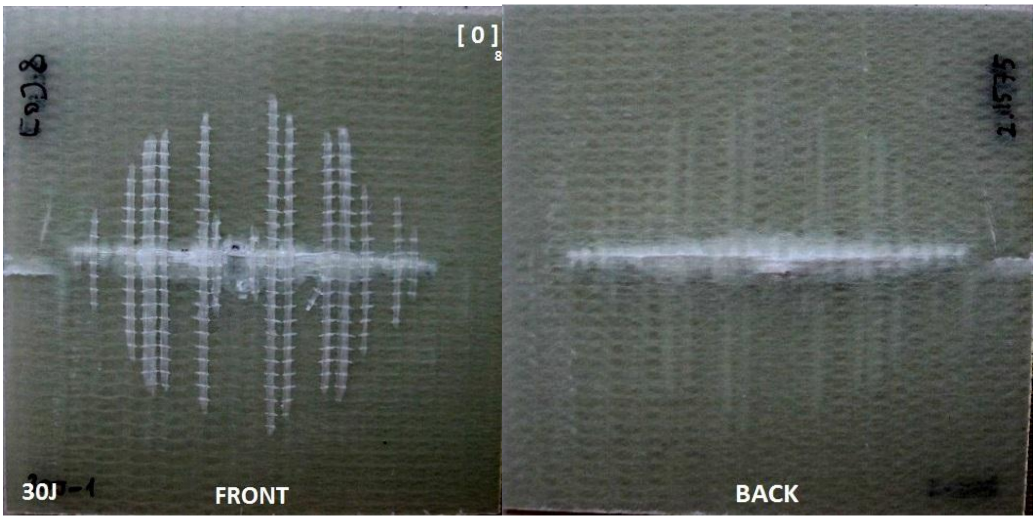


Figure 4.32 $[0]_8$ After 30J impact

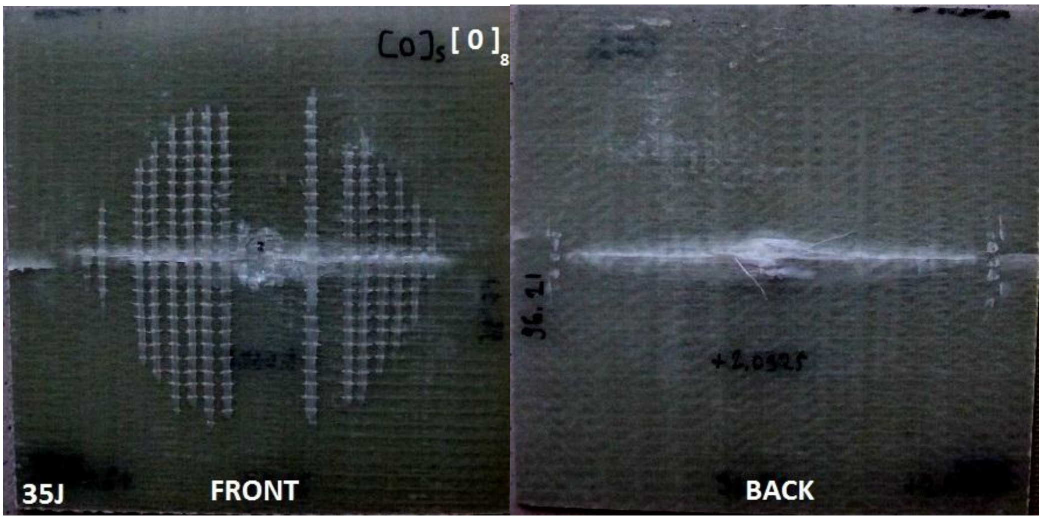


Figure 4.33 $[0]_8$ After 35J impact

Figure 4.34 $[0/15/0/15]_s$ After 10J impact

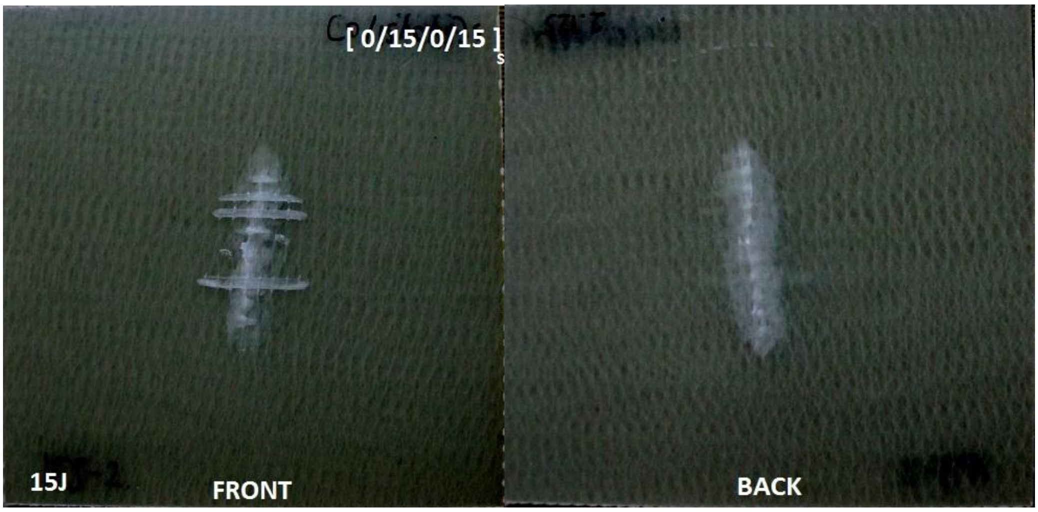


Figure 4.35 [0/15/0/15]$_s$ After 15J impact

Figure 4.36 [0/15/0/15]$_s$ After 20J impact

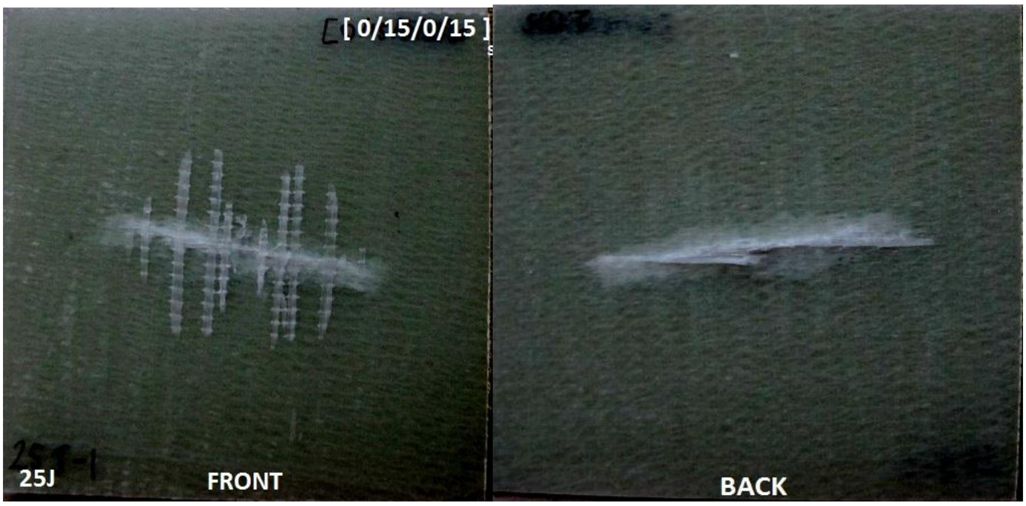


Figure 4.37 [0/15/0/15]$_s$ After 25J impact

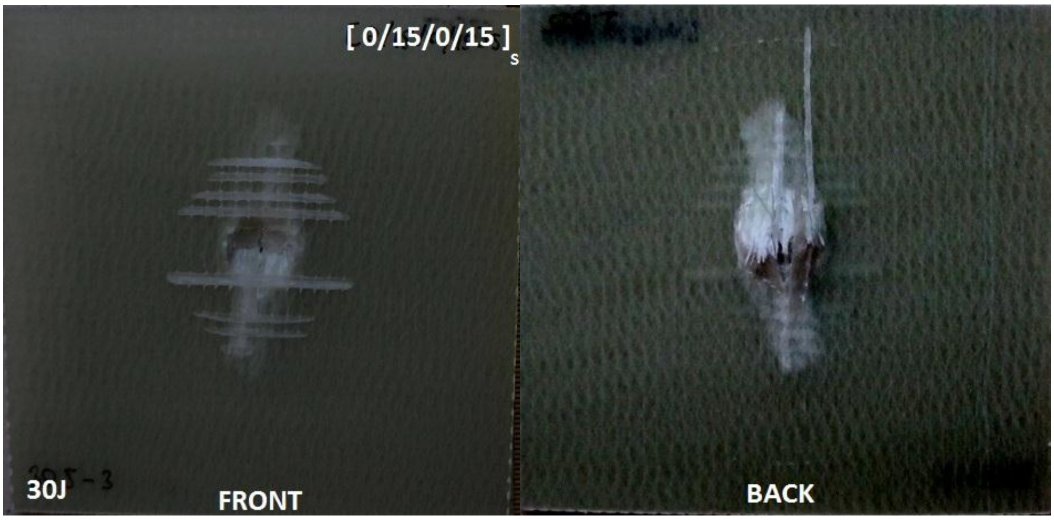


Figure 4.38 [0/15/0/15]$_s$ After 30J impact

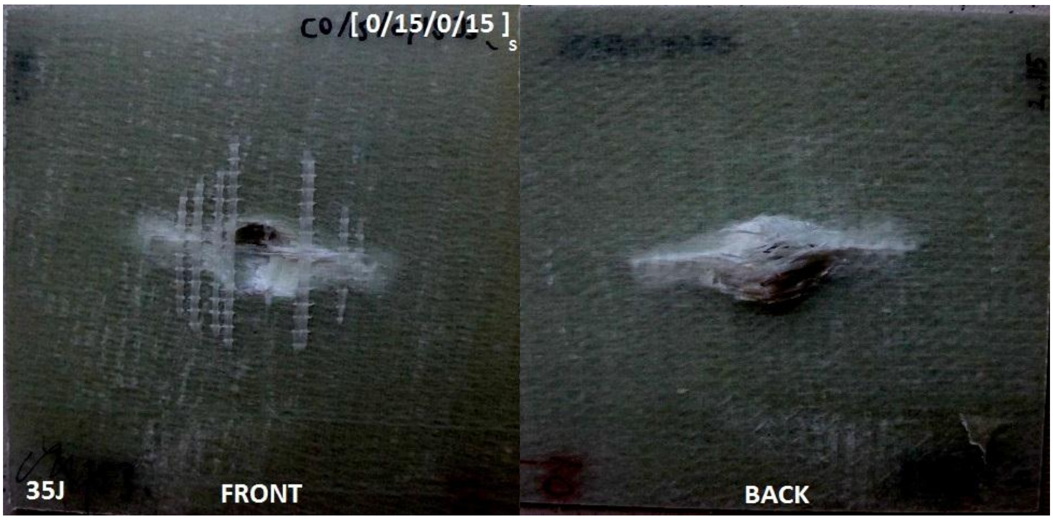


Figure 4.39 [0/15/0/15]$_s$ After 35J impact

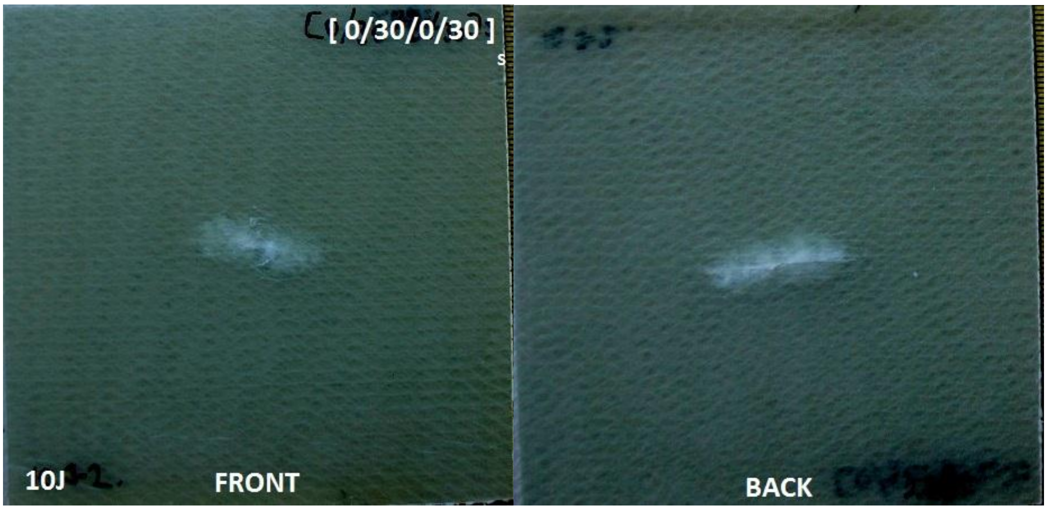


Figure 4.40 [0/30/0/30]$_s$ After 10J impact

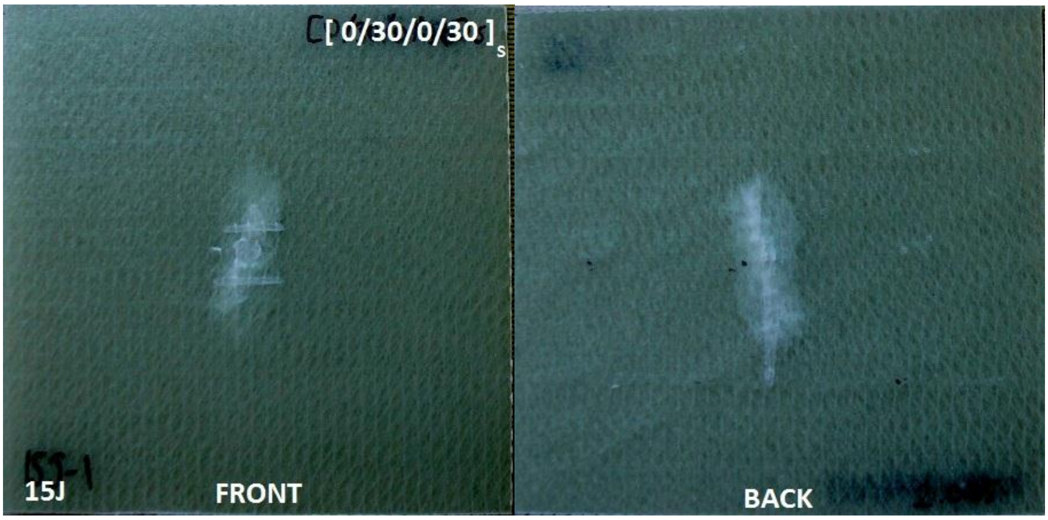


Figure 4.41 $[0/30/0/30]_s$ After 15J impact

Figure 4.42 $[0/30/0/30]_s$ After 20J impact

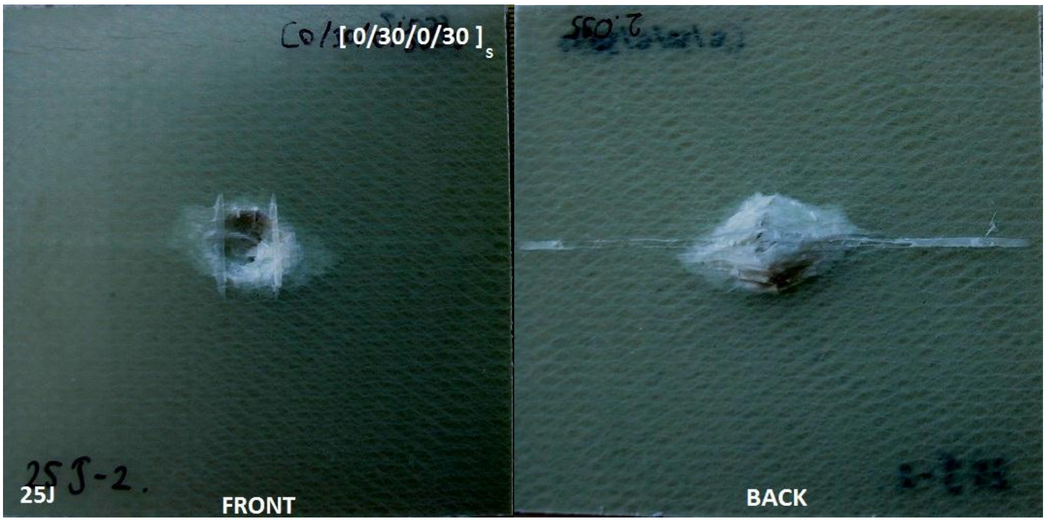


Figure 4.43 $[0/30/0/30]_s$ After 25J impact

Figure 4.44 [0/30/0/30]$_s$ After 30J impact

Figure 4.45 [0/30/0/30]$_s$ After 35J impact

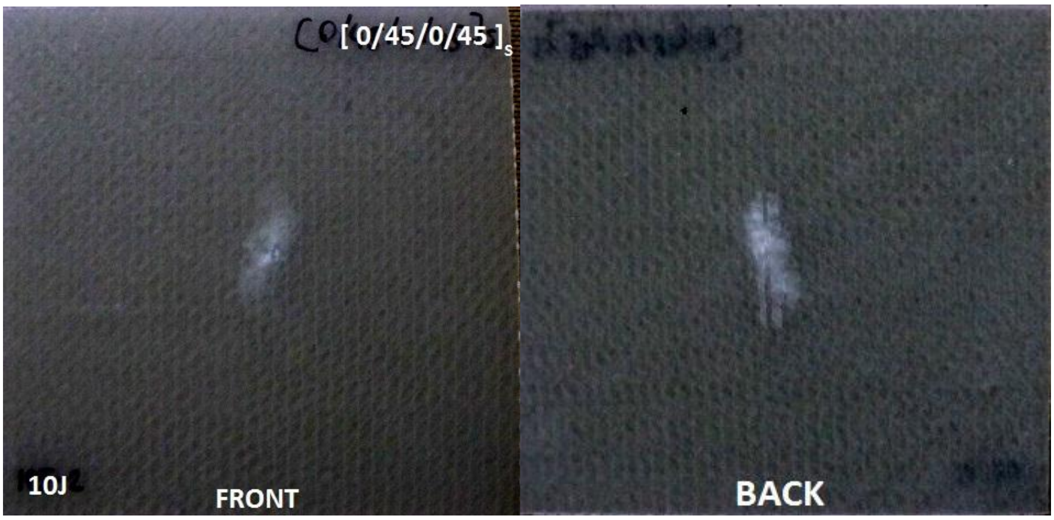


Figure 4.46 [0/45/0/45]$_s$ After 10J impact

Figure 4.47 [0/45/0/45]$_s$ After 15J impact

Figure 4.48 [0/45/0/45]$_s$ After 20J impact

Figure 4.49 [0/45/0/45]$_s$ After 25J impact

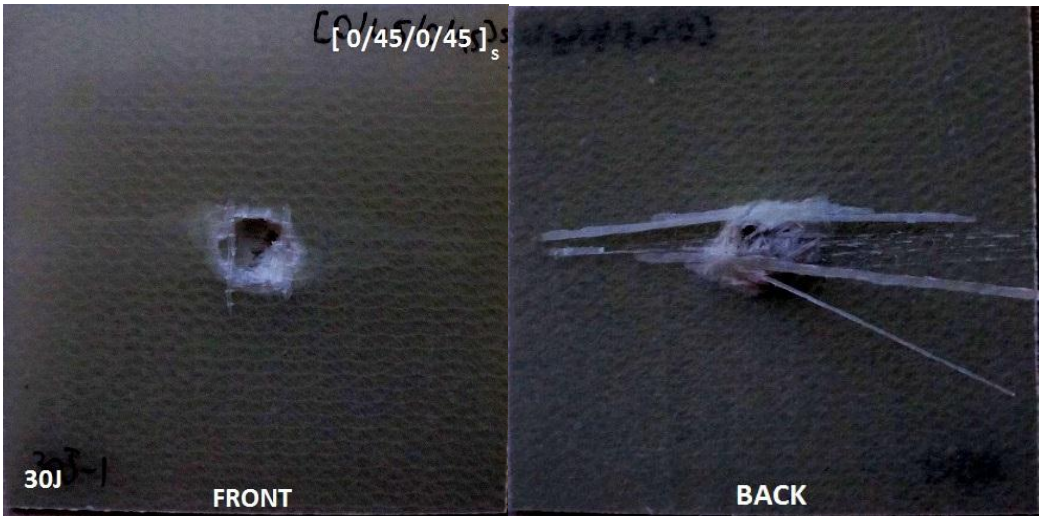


Figure 4.50 [0/45/0/45]$_s$ After 30J impact

Figure 4.51 [0/45/0/45]$_s$ After 35J impact

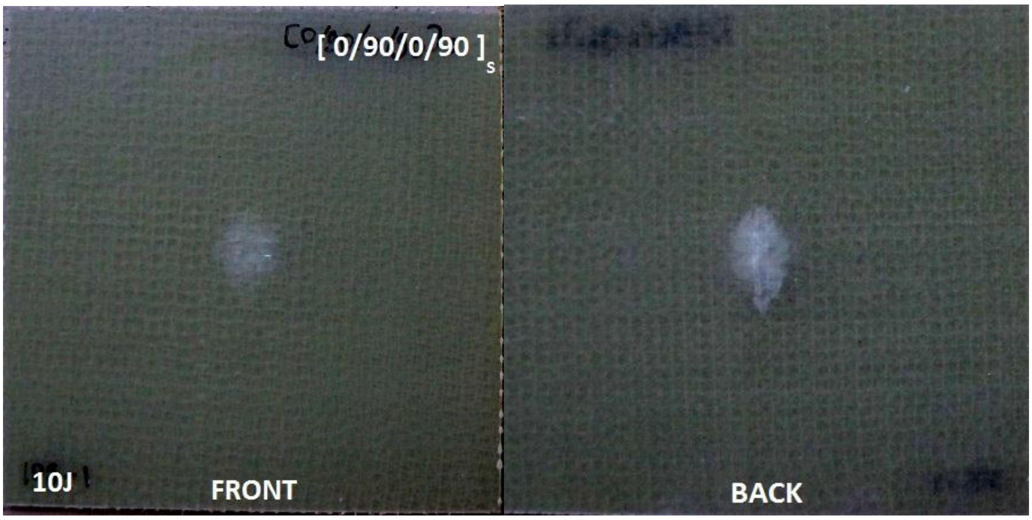


Figure 4.52 [0/90/0/90]$_s$ After 10J impact

Figure 4.53 [0/90/0/90]$_s$ After 15J impact

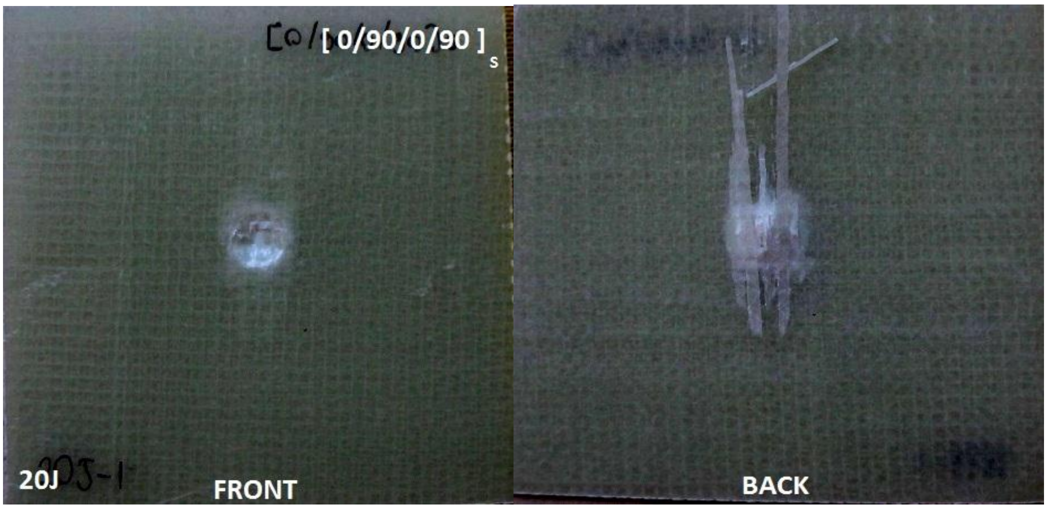


Figure 4.54 [0/90/0/90]$_s$ After 20J impact

Figure 4.55 [0/90/0/90]$_s$ After 25J impact

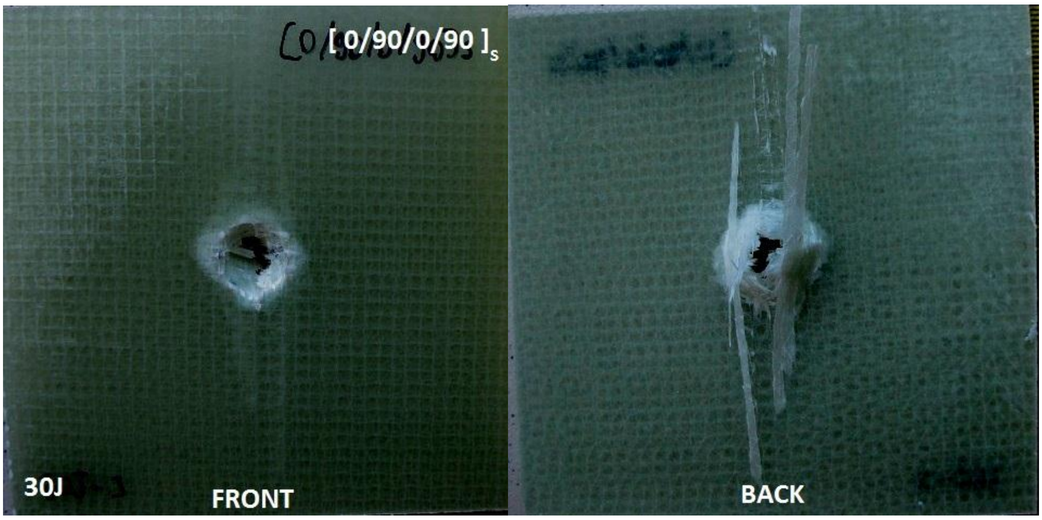


Figure 4.56 [0/90/0/90]$_s$ After 30J impact

Figure 4.57 [0/90/0/90]$_s$ After 35J impact

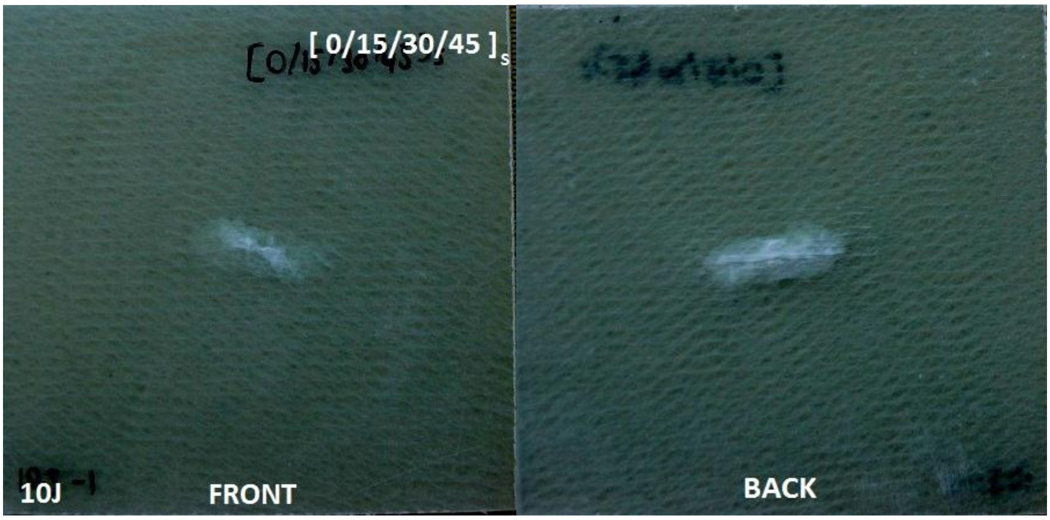


Figure 4.58 [0/15/30/45]$_s$ After 10J impact

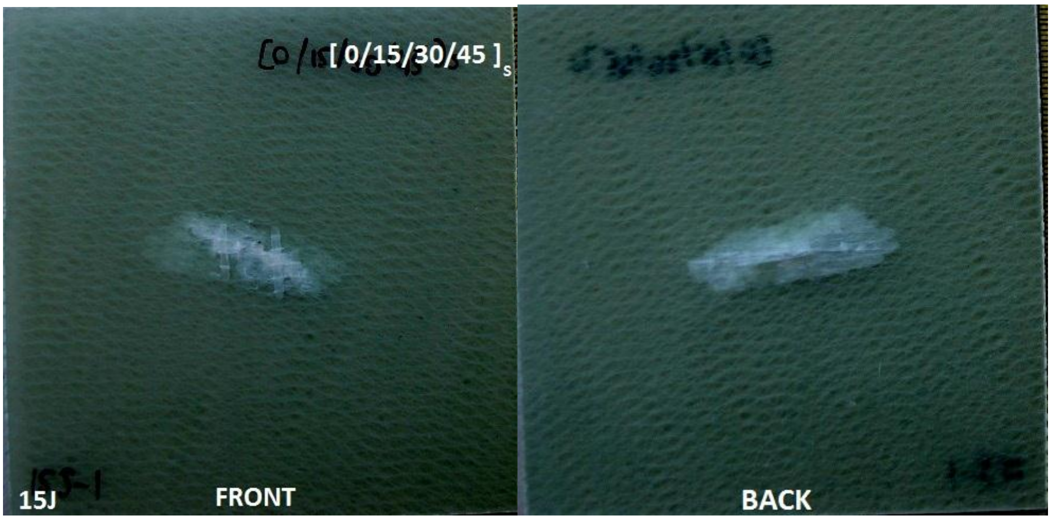


Figure 4.59 [0/15/30/45]$_s$ After 15J impact

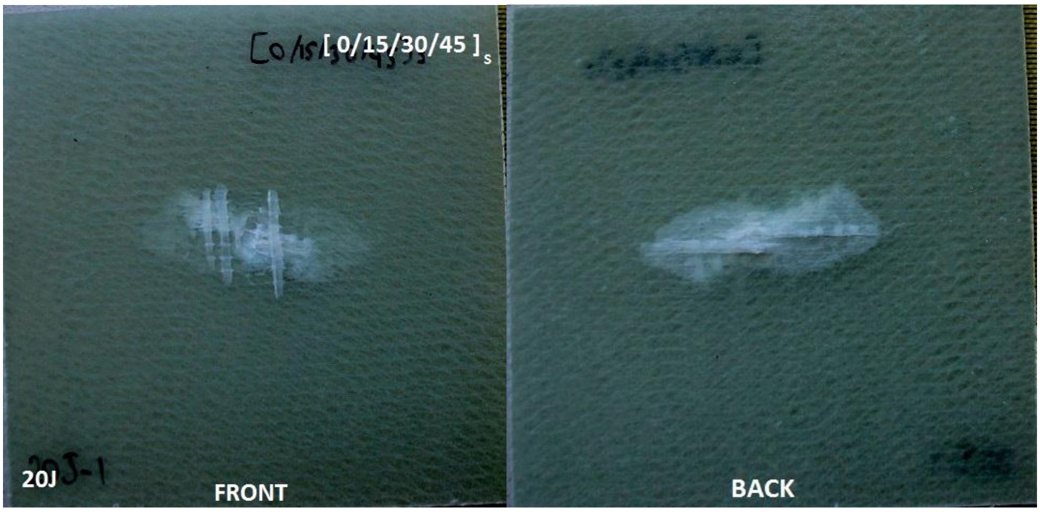


Figure 4.60 [0/15/30/45]$_s$ After 20J impact

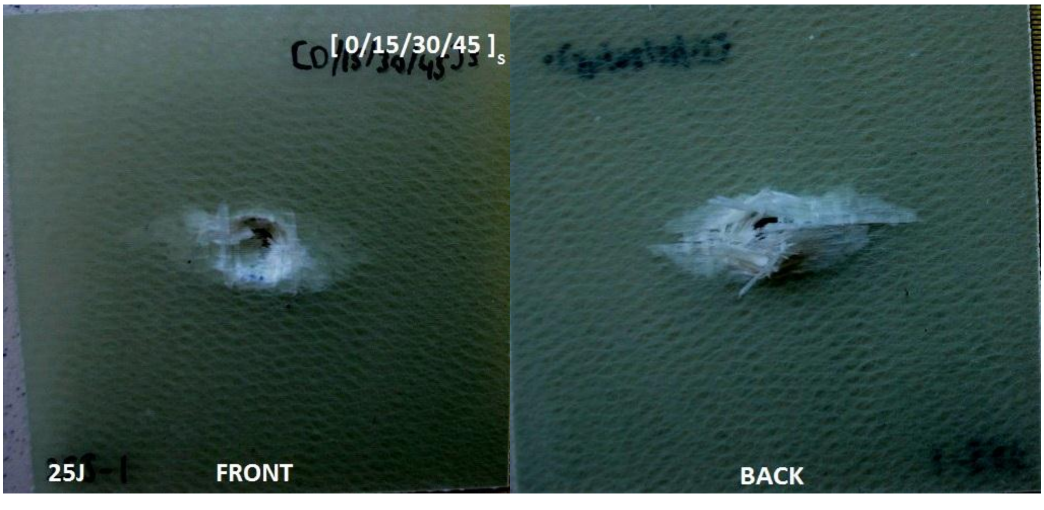


Figure 4.61 [0/15/30/45]$_s$ After 25J impact

Figure 4.62 [0/15/30/45]$_s$ After 30J impact

Figure 4.63 [0/15/30/45]$_s$ After 35J impact

CHAPTER FIVE

CONCLUSIONS

With this thesis impact loading is observed under different impact energies such as 10J, 15J, 20J, 25J, 30J, 35J on divesified orientations. As it is discussed before laminated composites consists of 8 plies and made of epoxy /glass material. Contact force, contact time, absorbed energy and deformation histrories are observed by values that are gathered with fractovis plus during test. Also photographs of specimens were taken in order to check effects of loading by visual inspection. All three states were observed such as rebounding, penetration and perforation on specimens. The results of the study were produced with the visual and analytical data gathered during the work. The conclusions are listed below:

- Contact force and deformation gets higher in accordance to the impact energy increase.
- Absorbed energy by specimen increases until perforation limit. After perforation starts absorbed energy drops by time.
- By the visual inspection of specimens, it is understood that loading side damage is smaller then the back side. This is happened beacuse of the bending of the contact of impactor on specimen surface.
- As impact energy decreases fiber fractures shifts to delaminations and matrix cracks.
- Examining the results show that $[\ 0\ ]_8$ orientation's resistance to impact loading is the highest but $[\ 0/30/0/30\ ]_s$ orientation performance was the lowest one.

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