DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

INVESTIGATION OF SEA WATER EFFECT ON IMPACT BEHAVIOR OF LAMINATED COMPOSITE PLATES

by
İsmail Cihan ÇALIK

July, 2010
İZMİR

INVESTIGATION OF SEA WATER EFFECT ON IMPACT BEHAVIOR OF LAMINATED COMPOSITE PLATES

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **“INVESTIGATION OF SEA WATER EFFECT ON IMPACT BEHAVIOR OF LAMINATED COMPOSITE PLATES”** completed by **İSMAİL CİHAN ÇALIK** under supervision of **PROF. DR. RAMAZAN KARAKUZU** 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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INVESTIGATION OF SEA WATER EFFECT ON IMPACT BEHAVIOR OF LAMINATED COMPOSITE PLATES

ABSTRACT

The aim of this study is to investigate the sea water effect on impact behavior of glass-epoxy laminated composite plates. Therefore, 135 pieces of specimens were prepared in dimensions of 100 x 100 mm with thickness of 3 mm. Impact tests of specimens were conducted by the Fractovis Plus Impact Test Machine.

The experimental phase of this study consists of five stages. In each stage 27 specimens were used. In first stage, dry specimens were used and in last four stages, wet specimens were used. In these specimens, seawater immersion times were chosen as 1, 3, 6, 9 months. Before the impact test, the masses of dry and seawater immersed specimens were measured by sensitive weighing machine to calculate the amount of water absorption. Specimens were impacted at impact energies, 10J, 20J and 30 J and impactor masses, 5 kg, 10 kg and 15 kg.

The absorbed energy, maximum contact force, maximum deflection and maximum contact time were obtained according to the seawater immersion time. From the obtained results, it’s observed that the specimen that has longer immersion time, the absorbed energy of the specimen has decreased but the contact time has increased.

Keyword: Glass-epoxy composite plate, Sea water effect, Impact energy.

DENİZ SUYUNUN TABAKALI KOMPOZİTLERİN DARBE DAVRANIŞI ÜZERİNDEKİ ETKİSİNİN ARAŞTIRILMASI

ÖZ

Bu çalışmanın amacı, cam lifi-epoksi tabakalı kompozit plağın darbe davranışı üzerine deniz suyunun etkisini araştırmaktır. Bu sebeple 100 x 100 mm boyutlarında, 3 mm kalınlığında 135 adet numune hazırlanmıştır. Numunelerin darbe deneyleri Fractovis Plus darbe test makinesinde gerçekleştirilmiştir.

Tez çalışmasının deney fazı beş aşamadan oluşmaktadır. Her bir aşamada 27 numune kullanılmıştır. İlk aşamada deniz suyu görmeyen numuneler kullanılmıştır. Geri kalan dört aşamada ıslak numuneler kullanılmıştır. Bu numunelerde deniz suyunda bekletilme zamanları 1, 3, 6 ve 9 ay olarak seçilmiştir. Darbe deneyinden önce, su emme miktarını tespit etmek için kuru ve deniz suyu emmiş numunelerin kütleleri hassas tartı ile tartılmıştır. Numuneler 10J, 20J, 30J darbe enerjilerinde ve 5 kg, 10 kg, 15 kg vurucu kütlerinde darbeye maruz bırakılmıştır.

Absorbe edilen enerji, maksimum temas kuvvet, maksimum çökme ve maksimum temas süresinin deniz suyunda bekletilme zamanına bağlı değişimleri elde edilmiştir. Elde edilen sonuçlardan; numunenin deniz suyunda bekleme süresi arttıkça absorve ettiği enerji miktarı düşmüş, temas süresinde ise artış gözlenmiştir.

Anahtar Sözcükler: Cam lifi kompozit plak, Deniz suyu etkisi, Darbe enerjisi.

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CHAPTER ONE

INTRODUCTION

There has been a growing interest, particularly in the few last decades, in the use of composite materials in structural applications ranging from aircraft and space structures to automotive and marine applications.

Glass-fiber reinforced polymer composites are often used in marine craft such as canoes, fishing trawlers, patrol boats and naval mine hunting ships and in the non-pressure hull casing, sonar dome and masts of submarines. Fiberglass composites are also used in offshore drilling platforms for deck grates, low-pressure pipes and storage tanks, and in civil infrastructure for the repair, strengthening and rehabilitation of ageing pylons to bridges and piers.

When the boats built in recent years are compared to the boats of former years; it can be seen that the hull structures are produced to meet the demands related to higher loads; no matter whether the boat is a motorboat or a sailing yacht. This can be attributed to the competitive attitude of people; boat owners driving motorboats favor ever-faster boats, installing more powerful engines. On the other hand, owners of sail yachts favor larger sail areas, stainless steel rigging, synthetic sail fabrics, shorter fin keels, etc., even though the waves and wind have not changed for millennia. These preferences have resulted in increased stresses on hull material. Therefore, the designer has to deal with higher structural loads and / or increasingly lighter structures. More accurate calculations are made with smaller margins of error or smaller factors of safety. What has made those lighter structures available is the use of advanced composite materials technology.

Many industries have adopted a virtual design methodology where the majority of design and development is achieved using computer simulations; verification testing being conducted only at the end of the design process. This substantially reduces the design cost by decreasing the need for expensive full scale physical tests.

In service aircraft loads commonly include impact events such as a dropped tool or debris from runways. This may result in a large internal damaged area of the laminate that is not detectable from visible observation. Fluctuating in-service loads, in particular compression, can continuously grow the damage area, possibly resulting in complete structural collapse of the damaged part. The development of the current analytical methods resulting in a viable virtual design capability will significantly reduce the cost and speed up development of damage tolerant composite structures in industry. Both damage mechanics and fracture mechanics methods have been employed in the literature to predict the debilitating effects of inter-ply delamination due to low velocity impacts composite laminates.

Material damage is associated with a stress or strain regime, while fracture is the fragmentation of material by cracking and is determined by energy considerations. Fracture will occur if the growth of a crack results in a lower energy state of the system. That is to say the energy required to overcome the cohesive force of the atoms is equal to the dissipation of the strain energy that is released by the crack.

In homogenous metals, material damage and fracture are generally considered to be independent of each other. Although the formation of fracture may occur in conjunction with plasticity at the crack tip, the energy associated with this plasticity can be included in the energy equations and is considered a part of the fracture process. This is not true for composites where the discrete components of the composite may experience damage and fracture concurrently. Typically a low speed impact will overstress the matrix material, producing local sub-critical cracking (micro- cracking). This does not necessarily produce fracture; however it will result in load redistribution and the concentration of energy and stress at the inter-ply regions where large differences in material stiffness exist. These conditions are ideal for a fracture based inter-ply delamination to initiate and grow. The onset, and rapid propagation of a crack, results in sudden variations in both section properties and load paths within the composite local to the impactor. This requires an adaptive method to track the progression of damage and fracture growth. (Elder, Thomson, Nguyen, Scott, 2004) In this study, the changes in impact parameters are tracked with DAS (Data Acquisition System) that connected to the impact testing machine.

The first attempts to characterize composite materials under dynamic loadingwere carried out by Rotem (1971) and Lifshitz (1976) and Sierakowski et al. (1971) Sun and Chattopadhyay (1975), Dobyns (1981), and Ramkumar and Chen (1983) employed the first-order shear deformation theory developed by Whitney and Pagano (1970) and used in conjunction with the Hertzian contact law to study the impact of laminated composite plates. Sankar (1992) presented semi empirical formulae for predicting impact characteristics such as peak force, contact duration, and peak strain on back surface. By solving a one-parameter differential equation, Olsson (1992) obtained an approximate analytical solution to the first phase of impact, or wave propagation dominated, response of composite plates. Various researchers have developed the three dimensional finite element models to investigate impact. Yang and Sun (1982), Tan and Sun (1985) and Sun and Chen (1985) studied impact on laminates under initial stress using the finite element method with a Newmark time integration algorithm. The merit of this three-dimensional numerical model is that it can provide detailed information about the local stresses and strains, which are key factors to produce initial damage in materials. Thereby, it is possible to capture the formation impact-induced damage, if a very fine mesh is used. The disadvantage of this approach is that its computational demands can be exorbitant as pointed out by Davies and Zhang (1995). Some simple, but efficient theoretical and energy-based approximation methods have also been presented to deal with this problem. Choi et al. (1991) used the dynamic finite element method coupled with failure analysis to predict the threshold of impact damage and initiation of delamination. Numerous researchers have used instrumented impact test apparatus to study the impact characteristics of different laminated composites. Chang and Sun (1989) determined the dynamic impact forces on a composite laminate by using experimentally generated Green’s functions and signal deconvolutions. Jih and Sun (1993) studied experimentally prediction of delamination in composite laminates subjected to low-velocity impact. They found that the results of the drop-weight impact tests indicated that low-velocity impact-induced delamination could be predicted by using the static interlaminar fracture toughness in conjunction with the static linear beam model. (Aslan, Karakuzu, Okutan, 2002)

Zhang, Zhu, & Lai (2004) published an approach to predict the initiation and propagation of damage in composite laminated plates, which is based on contact constraint introduced by penalty function method. The numerical analysis computed with ABAQUS, and its user subroutine VUINTER. Another research is performed by Cesari, Re, Minak & Zucchelli (2006) that deals with the characterization of damage in quasi-isotropic carbon fiber reinforced epoxy resin laminate loaded at the centre. They applied the problem into ANSYS software to predict the first ply failure (FPF) and the ultimate ply failure (UPF) of laminate. The one another investigation of the low velocity impact on laminated composite thin disks of epoxy resin reinforced by carbon fiber is presented by Tita, Carvalho, & Vandepitte (2007). They used the Hill’s model and material models implemented by UMAT (User Material Subroutine) into ABAQUS FEA software, in order to simulate the failure mechanisms under indention tests.

Zheng & Binienda (2007) had investigated the small mass impacts on composite structures that are common cases caused by hailstones and runway debris. Small mass impactors usually result in a wave controlled local response, which is independent of boundary conditions. This response occurs before the reflection of waves from the boundaries and cannot be modeled by large mass drop weight tests. An elasto-plastic contact law, which accounts for permanent indentation and damage effects, was used here to study small mass impact on laminated composite plates. By comparing with results from the Hertzian contact law, it was found that damage can resistance of laminated composite helicopter blades subjected to impact loading. In their study, dynamic stress intensity factors are determined for composite laminate change the dynamic response of the structure significantly with increasing impact velocity. Due to smaller contact force generated for the case of using elasto-plastic contact, the central displacement of the plate is also less than the one using Hertzian contact law. The linearized version of the contact law was then used to derive the closed-form approximations of the contact force, indentation and plate central displacement for the impact loading of composite laminates. The threshold velocity for delamination onset under small mass impact was predicted analytically based on the obtained peak contact forces by combining with an existing quasi-static delamination threshold load criterion. A good agreement was found between the predicted threshold values and published experimental results. (Zheng & Binienda, 2007)

A methodology aiming at taking into account delaminated composite structures behavior has been developed by Coutellier, Walrick, & Geoffroy (2005). Their study falls into two parts. The first one tackles the delamination detection within damaged thin laminated structures. In the finite element method (FEM) computational code, those laminated structures have been modeled using multi-layered shell elements. The methodology uses post-process criteria, based on fracture mechanics linked with damage mechanics, of computational code by the effective stress tensor. In the second place, the influence of delamination over the overall behavior of the structure is taken into account. This influence is introduced by locally changing material characterization, quite progressively during the loading phase. These integrated effects change the numerical behavior on loading and energy curves. The validation is carried out with experimental low velocity impact tests on the bending tests. A satisfactory coherence is shown for damage mechanisms and delamination shapes, in different examples. The methodology developed is recognized a predictive process for several laminates under study. It can be used as a potential tool to size laminated structures at design stage. They presented the different aspects of this delamination approach in their journal.

In this study; 135 composite specimens are tested in experimental platform. The experimental results are examined with comparing the similarities and differences between them. Three experiments are performed for each case and the mean values are used, to reach an appropriate result and to avoid exorbitant values in graphs. The effects of the sea water on impact behavior of laminated composite plates were investigated. During the experiments, the velocity and mass of the impactor were systematically varied. Each 27 specimens had 1, 3, 6, 9 immersing period in sea water.

CHAPTER TWO

COMPOSITE MATERIALS

2.1 Introduction

In this chapter, giving essential information about composite materials is aimed. The types and characteristics of composite materials, and where are they used. There are several comments that define composite materials. Some of them are:

- "A composite material is a macroscopic combination of two or more distinct materials, having a recognizable interface between them." (Miracle & Donaldson, 2001)

- "Generally speaking any material consisting of two or more components with different properties and distinct boundaries between the components can be referred to as a composite material." (Valery V. & Evgeny V, 2007, p. 9).

- "The word composite in the term composite material signifies that two or more materials are combined on a macroscopic scale to form a useful third material." (Jones, 1999, p. 2)

- "A composite more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituents is called the *reinforcing phase* and the on e in which it is embedded is called the *matrix*." (Kaw, 2006)

- "Fiber-reinforced composite materials consist of high strength and modulus embedded in or bonded to a matrix with distinct interfaces (boundaries) between them." (Mallick, 2007)

- “Engineered materials which consist of more than one material type. Fiberglass is a familiar example, in which glass fibers are embedded within a polymeric (plastic) material. A composite is designed to display a combination of the best characteristics of each of the component materials. Fiberglass acquires strength from the glass and flexibility from the polymer.” (Brazil, 2008)
- ‘‘ A combination of two or more materials (reinforcing elements, fillers, and composite matrix binder), differing in form or composition on a macro scale. The constituents retain their identities; that is, they do not dissolve or merge completely into one another although they act in concert. Normally, the components can be physically identified and exhibit an interface between one another.” (Fiberglass Warehouse, 2008)
- “Composite materials (or composites for short) are engineered materials made from two or more constituent materials with significantly different physical or chemical properties and which remain separate and distinct on a macroscopic level within the finished structure.” (Wikipedia, 2008)

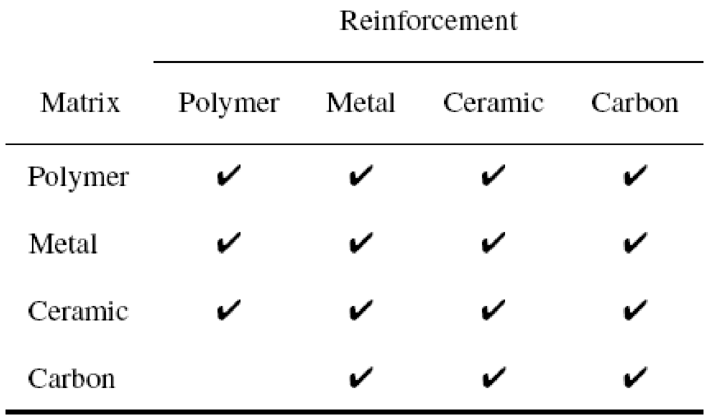
- “Strong lightweight material developed in the laboratory; fibers of more than one kind are bonded together chemically.” (WordNet® 3.0, 2008)

Traditional engineering materials (steel, aluminum, etc.) contain impurities that can represent different phases of the same material and fit the broad definition of a composite, but are not considered composites because the elastic modulus or strength of the impurity phase is nearly identical to that of the pure material. The definition of a composite material is flexible and can be augmented to fit specific requirements. In this text a composite material is considered to be one that contains two or more distinct constituents with significantly different macroscopic behavior and a distinct interface between each constituent (on the microscopic level). This includes the continuous fiber laminated composites of primary concern herein, as well as a variety of composites not specifically addressed.

2.2 Classification of Composite Materials

There are four types of composite materials; polymer (PMC), metal (MMC), ceramic (CMC), and carbon (CAMC) matrix composites. The carbon-carbon matrix composite (CCC) is the most important type of CAMCs. The matrix and fiber materials that can be mixed to compose composite material have shown in Table 2.1.

Table 2.1 Types of composite materials. (Harper, 2004)



	Reinforcement			
Matrix	Polymer	Metal	Ceramic	Carbon
Polymer	✓	✓	✓	✓
Metal	✓	✓	✓	✓
Ceramic	✓	✓	✓	✓
Carbon		✓	✓	✓

Polymer matrix composites (PCM) include thermoset (epoxy, polyimide, polyester) or thermoplastic (poly-ether-ether-ketone, polysulfone) resins reinforced with glass, carbon (graphite), aramid (Kevlar), or boron fibers. They are used primarily in relatively low temperature applications.

Metal matrix composites (MMC) consist of metals or alloys (aluminum, magnesium, titanium, copper) reinforced with boron, carbon (graphite), or ceramic fibers. Their maximum use temperature is limited by the softening or melting temperature of the metal matrix. The principal motivation was to dramatically extend the structural efficiency of metallic materials while retaining their advantages, including high chemical inertness, high shear strength, and good property retention at high temperatures.

Ceramic matrix composites (CMC) consist of ceramic matrices (silicon carbide, aluminum oxide, glass-ceramic, silicon nitride) reinforced with ceramic fibers. They are best suited for very high temperature applications. Ceramic-matrix composite development has continued to focus on achieving useful structural and environmental properties at the highest operating temperatures.

Carbon/carbon composites (CCC) consist of carbon or graphite matrix reinforced with graphite yarn or fabric. They have unique properties of relatively high strength at high temperatures coupled with low thermal expansion and low density (Daniel & Ishai, 1994).

In another way, composite materials can be regrouped according to their appearance rather than their matrix. They are:

- Fibrous composites: Obtained by putting long fiber groups or whiskers into a matrix with a predefined angle (Figure 2.1) or in random order, and curing at a specified temperature. The fibers can be straight or woven, and they can be continuous or discontinuous (Figure 2.2).

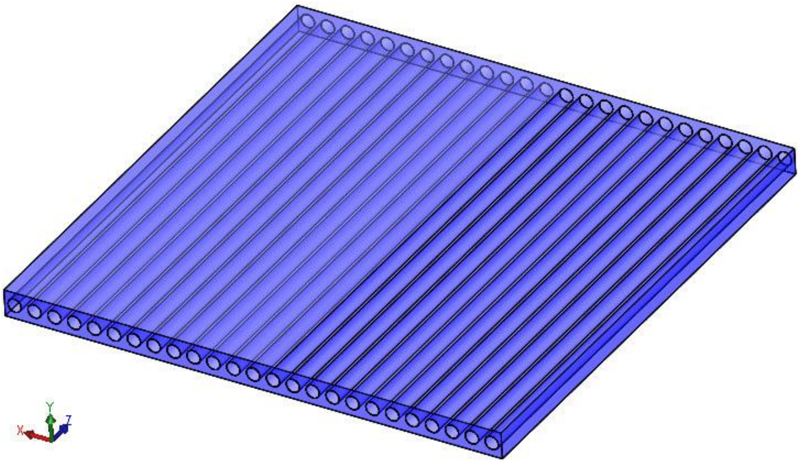


Figure 2.1 A lamina with longitudinal fibers. (E. Erbil, Impact Loading in Laminated Composites 2008, Dokuz Eylul University)

There is a difference between fibers and whiskers. Fiber is characterized geometrically not only by its very high length-to-diameter ratio but by its near-crystal-sized diameter. A whisker has essentially the same near-crystal-sized diameter as a fiber, but generally is very short and stubby, although the length-to-diameter ratio can be in the hundreds. Thus, a whisker is an even more obvious example of the crystal-bulk-material-property-difference paradox. That is, a whisker is even more perfect than a fiber and therefore exhibits even higher properties. Whiskers are obtained by crystallization on a very small scale resulting in a nearly perfect alignment of crystals. Materials such as iron have crystalline structures with a theoretical strength of 2900000 psi (20 GPa), yet commercially available structural steels, which are mainly iron, have strengths ranging from 75000 psi to about 100000 psi (570 to 690 MPa). (Jones, 1999)

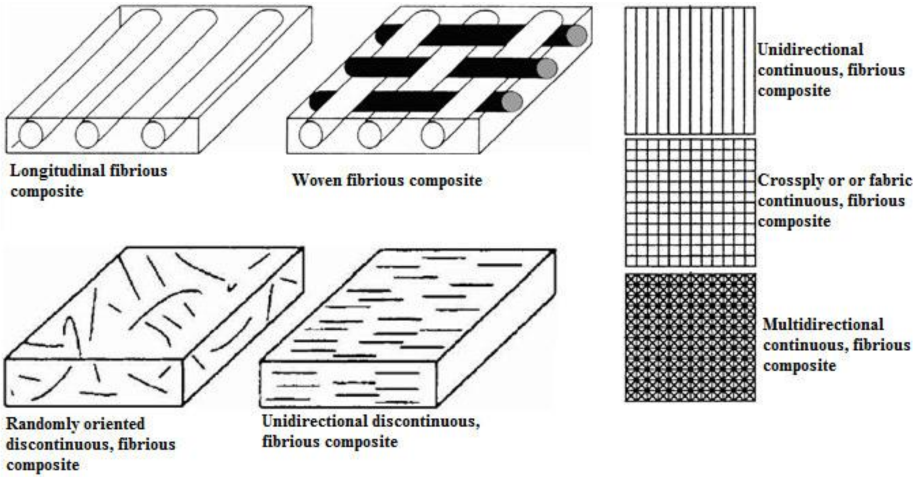


Figure 2.2 Types of fibrous composites. (E. Erbil, Impact Loading in Laminated Composites 2008, Dokuz Eylul University)

Laminated composites: Two or more composite layers are bonded together. (Figure 2.3) Lamination achieves the mechanical properties in composite. Mechanical properties can be changed with the angle of fibers in laminate.

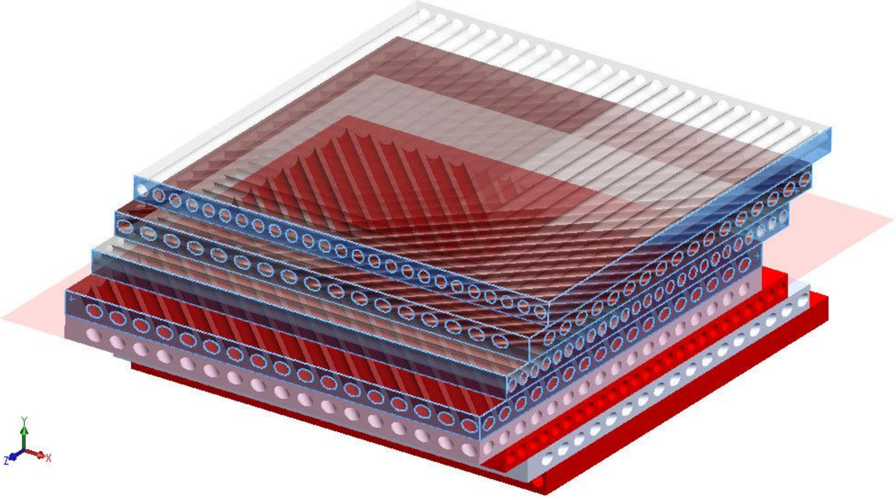


Figure 2.3 A laminated composite with the fiber angle of [90/+45/0/-45] (E. Erbil, Impact Loading in Laminated Composites 2008, Dokuz Eylul University)

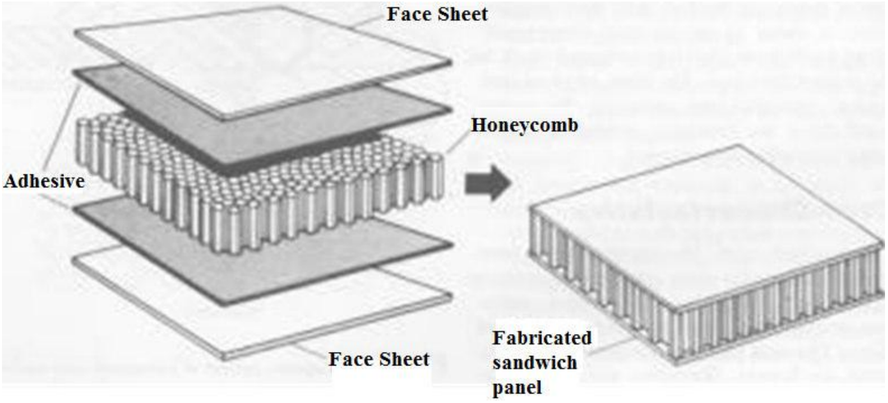


Figure 2.4 Honeycomb sandwich constructions. (E. Erbil, Impact Loading in Laminated Composites 2008, Dokuz Eylul University)

Laminated composites can be in the sandwich structural form. Structural sandwich is a layered composite formed by bonding two thin facings to a thick core (Figure 2.4). It is a type of stressed-skin construction in which the facings resist nearly all of the applied edgewise (in-plane) loads and flat wise bending moments. The thin spaced facings provide nearly all of the bending rigidity to the construction. The core spaces the facings and transmits shear between them so that they are effective about a common neutral axis. The core also provides most of the shear rigidity of the sandwich construction. By proper choice of materials for facings and core, constructions with high ratios of stiffness to weight can be achieved.

Laminated composites can be different from fiber-matrix form. For instance, bimetals, clad metals, laminated glass or plastic-based laminates are the laminated composites, too. Bimetals consists of two different types of metals that are bonded together. In this form, the advantage of thermal expansion coefficient differences between the metals that forms the bimetal can be used. An example of bimetals has shown in Figure 2.5.

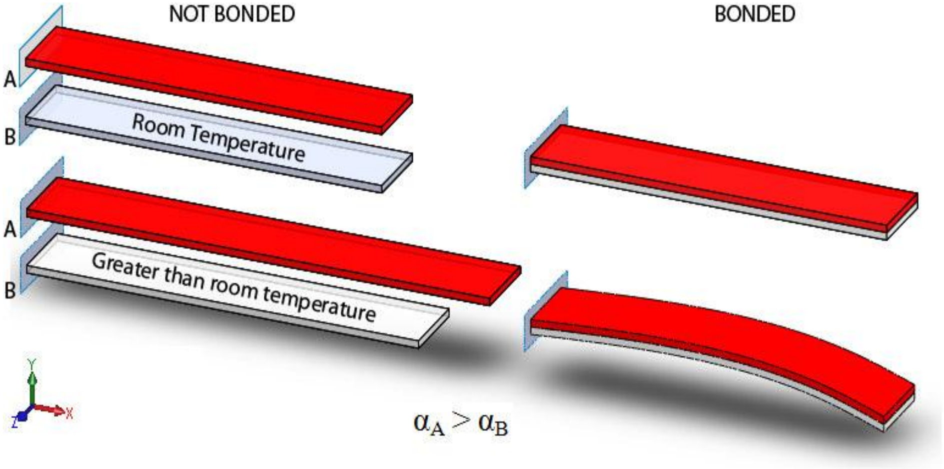


Figure 2.5 A thermostat that is obtained by bonding two different metals. (E. Erbil, Impact Loading in Laminated Composites 2008, Dokuz Eylul University)

Clad metals obtained by sheathing a metal with another. For instance, copper wires can be clad with aluminum. So it becomes lighter and durable in fatigue loading. Other example is a laminated glass. Glass is brittle and can break into many sharp pieces. To solve this problem, a thin plastic film can clad with glass. So stiffness and durability in laminated glass can be gained. And a good example of plastic-based laminates is Formica. It is merely layers of heavy kraft paper integrated with a phenolic resin overlaid by a plastic-saturated decorative sheat that, in turn, is overlaid with a plastic-saturated cellulose mat. Heat and pressure are used to bond the layers together. A useful variation on the theme is obtained when an aluminum layer is placed between the decorative layer and the kraft paper layer to quickly dissipate the heat of, for example, a burning cigarette or hot pan on a kitchen counter instead of leaving a burned spot. (Jones, 1999)

- Particulate composites: They consist of particles immersed in matrices such as alloys and ceramics. Particular composites can group into nonmetallic particles in nonmetallic matrix composites, metallic particles in nonmetallic matrix composites, metallic particles in metallic matrix composites and nonmetallic particles in metallic matrix composites. They are usually isotropic because the particles are added randomly. Particulate composites have advantages such as improved strength, increased operating temperature, oxidation resistance, etc. Typical examples include use of aluminum particles in rubber; silicon carbide particles in aluminum; and gravel, sand, and cement to make concrete. (Kaw, 2006) There are three types of particulate composites as shown in Figure 2.6.

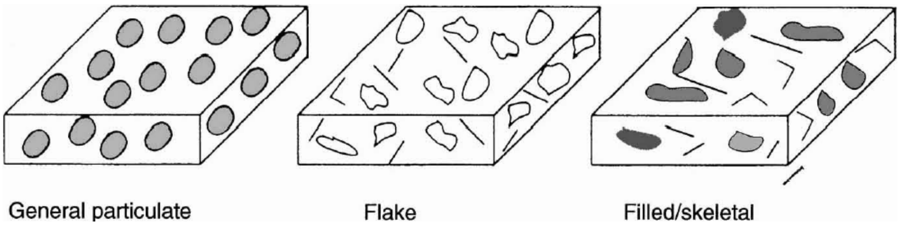


Figure 2.6 Types of particulate composites. (Staab, 1999)

Flake: A flake composite is generally composed of flakes with large ratios of platform area to thickness, suspended in a matrix material (particle board, for example).

Filled/Skeletal: A filled/skeletal composite is composed of a continuous skeletal matrix filled by a second material: for example, a honeycomb core filled with an insulating material. (Staab, 1999)

Combinations of composite materials: They are the mixture of fibrous, laminated, or particulate composites. In this classification method, this type can conflict with the two or three other types of composite classes. For instance, fiber-reinforced concrete is both particulate (the composite is composed of gravel in a cement-paste binder) and fibrous (due to the steel reinforcement). And also, laminated fiber-reinforced composite materials are obviously both laminated and fibrous composite materials. Thus, any classification system is arbitrary and imperfect.

2.3 Manufacturing Process of Composite Materials

The mixture of reinforcement/resin does not really become a composite material until the last phase of the fabrication, that is, when the matrix is hardened. After this phase, it would be impossible to modify the material, as in the way one would like to modify the structure of a metal alloy using heat treatment, for example. In the case of polymer matrix composites, this has to be polymerized, for example, polyester resin. During the solidification process, it passes from the liquid state to the solid state by copolymerization with a monomer that is mixed with the resin. The phenomenon leads to hardening. This can be done using either a chemical (accelerator) or heat. (Daniel & friends, 2003) The discussion of manufacturing of laminated fiber- reinforced composite materials is restricted in this section to how the fibers and the matrix materials are assembled to make a lamina and how, subsequently lamina are assembled and cured to make a laminate.

Fibers are available individually or as roving which is a continuous, bundled, but not twisted, group of fibers. The fibers can be unidirectional or interwoven. A fabricated carbon fiber has shown in Figure 2.7.

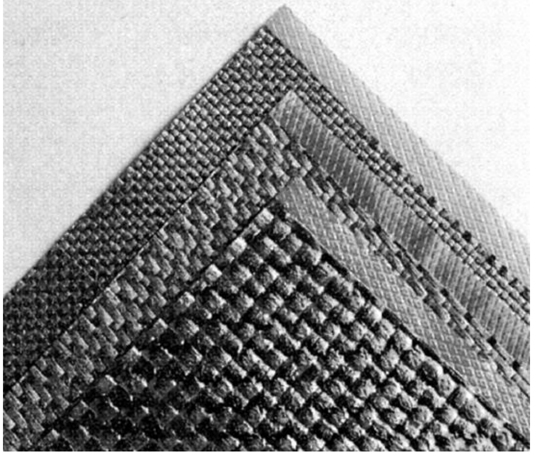


Figure 2.7 Carbon fiber fabrics. (Mazumdar, 2002)

Fibers are often saturated or coated with resin material such as epoxy which is subsequently used as a matrix material. The process is referred to as preimpregnation, and such forms of preimpregnated fibers are called 'prepregs'. For example, unidirectional fibers in an epoxy matrix are available in a tape form (prepreg tape) where the fibers run in the lengthwise direction of the tape (shown in Figure 2.8). The fibers are held in position not only by the matrix but by a removable backing that also prevents the tape from sticking together in the roll. The tape is very similar to the widely used glass-reinforced, heavy-duty package strapping tape.

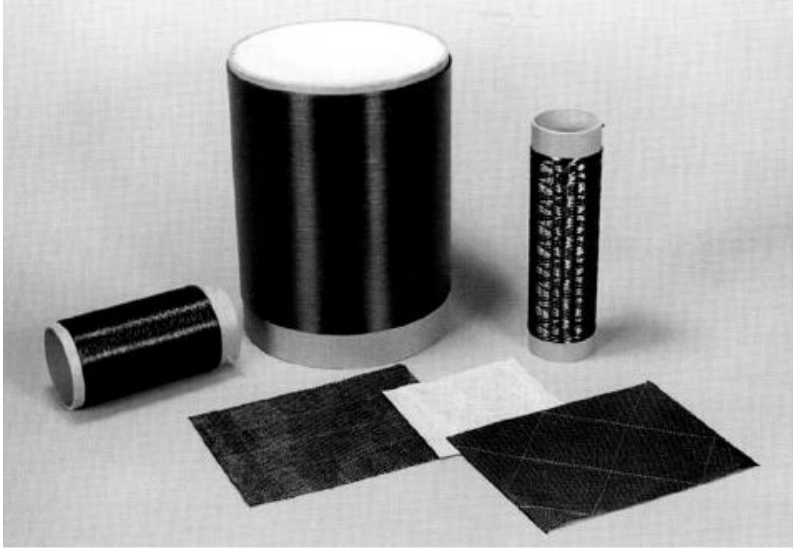


Figure 2.8 Prepreg types: unidirectional tape, woven fabric prepregs, and rovings. (Mazumdar, 2002)

Similarly, prepregs cloths or mats are available in which the fibers are interwoven and then preimpregnated with resin. Other variations on these principal forms of fibers and matrix exist. (Jones, 1999)

2.3.1 Layups

There are three layup processes for fiber-reinforced composites. They are winding, laying and molding. Winding and laying operations include filament winding, tape laying or wrapping, and cloth winding or wrapping. (Jones, 1999)

Filament winding: Filament winding is a process for fabricating a composite structure in which continuous reinforcements (filament, wire, yarn, tape, or other), either previously impregnated with a matrix material or impregnated during winding, are placed over a rotating form or mandrel in a prescribed way to meet certain stress conditions. When the required number of layers is applied, the wound form is cured and the mandrel can be removed or left as part of the structure.

Laying: Originally performed by hand, the lay-up process was labor intensive, and inconsistency with hand lay- up caused quality problems with the cured laminates. After 1980s, automated computer numeric control tape-laying machines developed and decrease the production costs and time. Tape laying starts with a tape consisting of fibers in a preimpregnated form held together by a removable backing material. The tape is unwound and laid down to form the desired shape in the desired orientations of tape layers. In the late 1980s, the use of automated tape laying began to focus on commercial aircraft applications. Throughout the 1990s, the equipment, programming, lay-up techniques, and ATL-grade composite materials were further developed to make the tape-laying process more productive, reliable, and user friendly. As of 2001, there are approximately 40 to 45 commercially produced tape- laying machines in the field.

Molding: There are many types of molding. They are compression molding, vacuum molding, contact molding, resin-transfer molding (RTM), structural reaction injection molding (SRIM), sheet molding compound (SMC), thick molding compound (TMC), bulk molding compound (BMC), injection molding. Molding operations can begin with hand or automated deposition of preimpregnated fibers in layers. Often, the prepreg layers are also precut.

Subsequently, the layers are compressed under elevated temperature to form the final laminate in a press. Radar antenna houses or radomes are obtained by molding method to close thickness tolerances.

2.3.2 Curing

Curing is the irreversible change in the physical properties of a thermosetting resin brought about by a chemical reaction, condensation, ring closure, or addition. Cure may be accomplished by the addition of curing or cross- linking agents, with or without the addition of heat and pressure. Curing of resins can also be accomplished using ultraviolet radiation and electron beams, but these methods are used for very specific applications and are not commonly used for composite manufacturing. Processing materials must be added to a composite ply lay-up before autoclave curing. These materials control the resin content of the cured part and ensure proper application of autoclave pressure to the lay-up. In selecting materials for use in preparing a laminate for curing, cure temperatures and pressures must be considered, as well as compatibility of the processing materials with the matrix system.

2.4 Applications of Composite Materials

Composite materials have lots of applications in industry. Commercial and industrial applications of fiber-reinforced polymer composites are so varied that it is impossible to list them all. In this study, only the major structural application areas, which include aircraft, space, automotive, sporting goods, marine, and infrastructure will be discussed. Fiber- reinforced polymer composites are also used in electronics (e.g., printed circuit boards), building construction (e.g., floor beams), furniture (e.g., chair spring s), power industry (e.g., transformer housing), oil industry (e.g., offshore oil platforms and oil sucker rods used in lifting underground oil), medical industry (e.g., bone plates for fracture fixation, implants, and prosthetics), and in many industrial pro ducts, such as stepladders, oxygen tanks, and power transmission shafts. Potential use of fiber-reinforced composites exists in many engineering fields. Putting them to actual use requires careful de sign practice and appropriate process development based on the understanding of their unique mechanical, physical, and thermal characteristics.

Aerospace Applications: The major structural applications for fiber-reinforced composites are in the field of military and commercial aircrafts, for which weight reduction is critical for higher speeds and decreased payloads. With the introduction of carbon fibers in the 1970s, carbon fiber-reinforced epoxy has become the primary material in many wing, fuselage, and empennage components. The structural integrity and durability of these early components have built up confidence in their performance and prompted developments of other structural aircraft components, resulting in an increasing amount of composites being used in military aircrafts. The outer skin of B-2 (Figure 2.9) and other stealth aircrafts is almost all made of carbon fiber-reinforced polymers. The stealth characteristics of these aircrafts are due to the use of carbon fibers, special coatings, and other design features that reduce radar reflection and heat radiation.

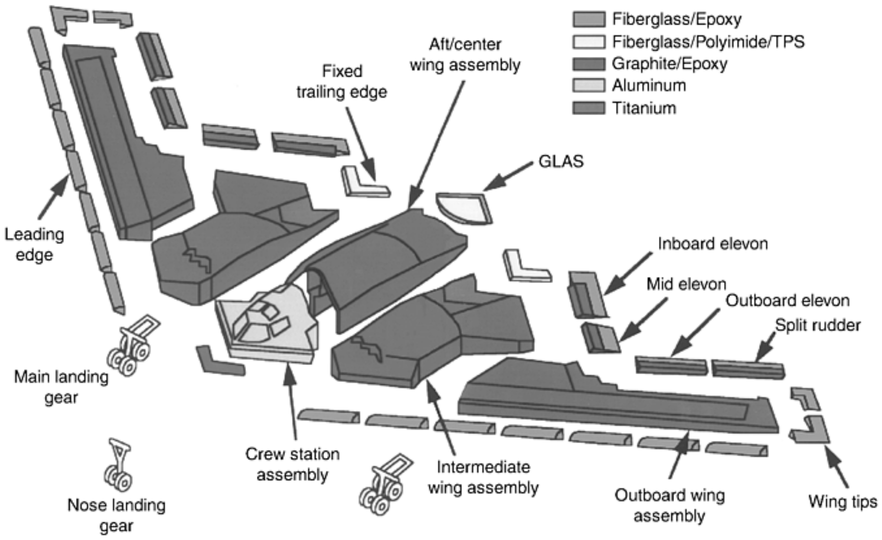


Figure 2.9 The B-2 stealth bomber aircraft, which is made of advanced composite materials. (Miracle & Donaldson, 2001)

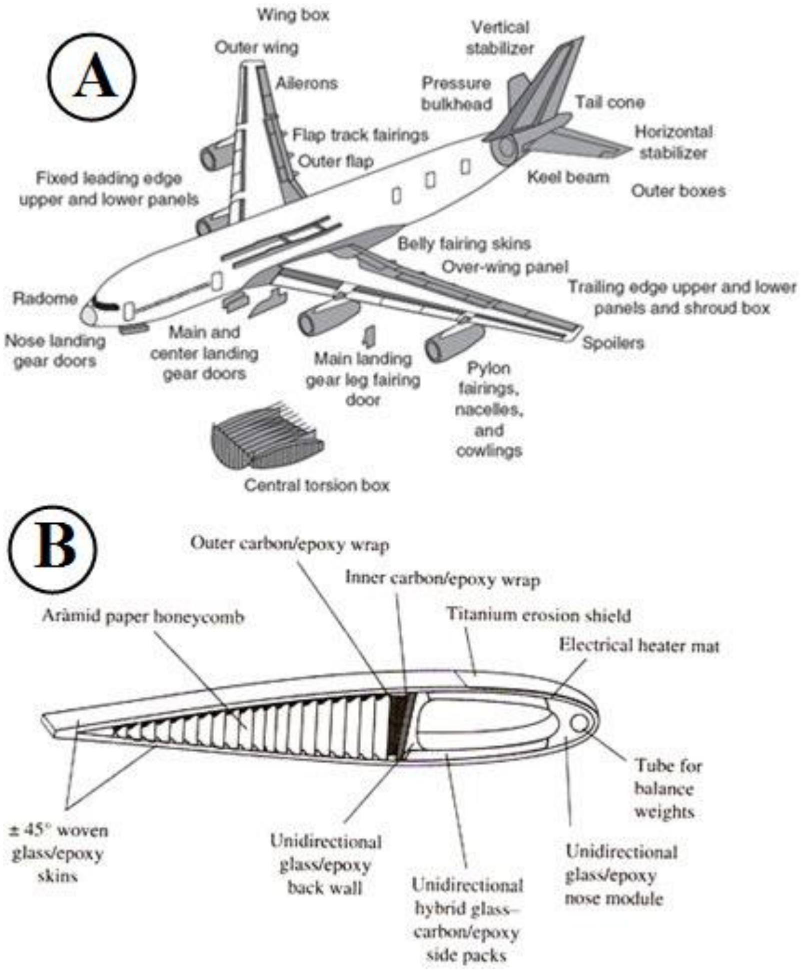


Figure 2.10 Use of fiber-reinforced polymer composites in Airbus 380 (A) (Mallick, 2007)and a helicopter rotor blade section (B) (Gibson, 1994).

Advanced composites are used in air defense and civil applications that shown in Figure 2.10 (A). And in Figure 2.10 (B), composite construction of a helicopter rotor blade has shown.

Space applications: Among the various applications in the structure of space shuttles are the mid-fuselage truss structure (boron fiber-reinforced aluminum tubes), payload bay door (sandwich laminate of carbon fiber-reinforced epoxy face sheets and aluminum honeycomb core), remote manipulator arm (ultrahigh-modulus carbon fiber-reinforced epoxy tube), and pressure vessels (Kevlar 49 fiber-reinforced epoxy). Fiber-reinforced polymers are used for support structures for many smaller components, such as solar arrays, antennas, optical platforms, and so on. A major factor in selecting them for these applications is their dimensional stability over a wide temperature range. A space application of composites has shown in Figure 2.11.

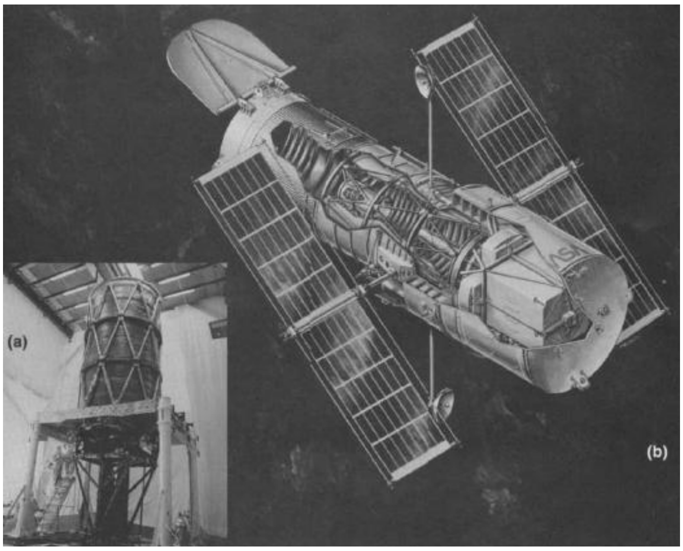


Figure 2.11 Composite structural truss (a) aboard Hubble Space Telescope (b) aligns primary and secondary mirrors (Peters, 1998)

Automotive applications: Applications of fiber-reinforced composites in the automotive industry can be classified into three groups; body components, chassis components, and engine components. Composites have proven to be very successful in a wide range of exterior body panels and are used in hundreds of vehicle applications. Exterior body components, such as the hood or door panels, require high stiffness and damage tolerance (dent resistance) as well as a ‘‘Class A’’ surface finish for appearance. Excellent surface finish, light weight, and a thermal coefficient of expansion near that of steel have made these applications successful. Customers appreciate the dent and corrosion resistance of composite panels. The composite material used for these components is E-glass fiber-reinforced sheet molding compound (SMC) composites. Another manufacturing process for making composite body panels in the automotive industry is called the structural react ion injection molding (SRIM). The fibers in these parts are usually randomly oriented discontinuous E-glass fibers and the matrix is a polyurethane or polyurea.

Sporting goods applications: Tennis rackets, golf club shafts, fishing rods, bicycle frames, snow and water skis helmets, athletic shoe soles and heels, and the most of the other sporting goods are made of composites. Fiber-reinforced polymers are extensively used in sporting goods and are selected over such traditional materials as wood, metals, and leather in many of these applications. The advantages of using fiber-reinforced polymers are weight reduction, vibration damping, and design flexibility.

Marine applications: Use of composites in marine applications is widespread. The two major advantages of fiber reinforced plastics over metals are resistance to the marine environment, particularly the elimination of galvanic corrosion and the ease of tailoring structures, which are fabricated by molding processes. In addition, composites have high strength-to-weight ratios. (Peters, 1998) Glass fiber-reinforced polyesters have been used in different types of boats (e.g., submarines, sail boats, fishing boats, dinghies, life boats, and yachts) ever since their introduction as a commercial material in the 1940s. Today, nearly 90% of all recreational boats are constructed of either glass fiber-reinforced polyester or glass fiber-reinforced vinyl ester resin.

Infrastructure: Fiber- reinforced polymers have a great potential for replacing reinforced concrete and steel in bridges, buildings, and other civil infrastructures. The principal reason for selecting these composites is their corrosion resistance, which leads to longer life and lower maintenance and repair costs.

CHAPTER THREE

PRODUCING THE LAMINATED COMPOSITE SPECIMENS AND EXPERIMENT PREPERATIONS

In this chapter, the production process of the specimen explained with pictures. Our specimens have same orientation and same thickness with each other. They are nearly identical. This 8 plies laminate consist of epoxy matrix, and glass fibers. And, the measurement of the square specimen is 100 x 100 mm.

Unidirectional E-glass fabric having weight of 509 g/m2 was used as reinforcing material. The first step of the manufacturing process is determining the optimum plate size that will be cut to obtain specimens. The edge length of this square is obtained as 898 mm. Then, the square is drawnto the glass fiber in 30^{0} angle and cut with a scissor. Four pieces have been cut at this angle to provide the requirements. The 60^{0} is needless, because this angle can be obtained by flipping and rotating the fiber. Then 4 copies of other pieces have been cut in 0^{0} angle (similarly, 90^{0} fiber angle can be obtained by rotating).

In the second step, the epoxy (CY225) and hardener (HY225) curing resin are prepared by mixing them in a heater. The mixing ratio is 1/1. Then, the heater has set to a temperature of 90 ^{0}C. While the oven was heating the resin, the next step has been performed.

In third step, a sheet metal is laid down at the middle of the doubled nylons before orienting the plies. Then, the lowest ply at 0^{0} angle is laid down. Meanwhile, the resin is blended at the elevated temperature. Then, the resin is applied to the first ply with rollers. The rolling speed is neither fast nor slow; it’s at a speed which does not let the resin to dry.

When the lowest ply finished, the following two plies have lay down with the angle of in 30^0 and 60^0 respectively. The resin is applied to the single ply only at the bottom and top plies. At the other plies, the resin is applied to the doubled fiber plies. After the last fiber ply is resined, the laminate is covered with nylon. Then, the second sheet metal had put before curing, and covered with nylon to avoid resin leakage. At the fourth step, the laminate is covered by sheet metals and covered by nylons, and then put into the hot press. Curing process materialized at the pressure of 150 bars and the temperature of 120 °C for 2 hours.

After the curing process, 135 pieces of laminates are cut into the squares that each laminates have the edge length of 100 mm. A finished specimen has shown in Figure 3.1. The final thickness of the composite specimen is about 2.9 mm.

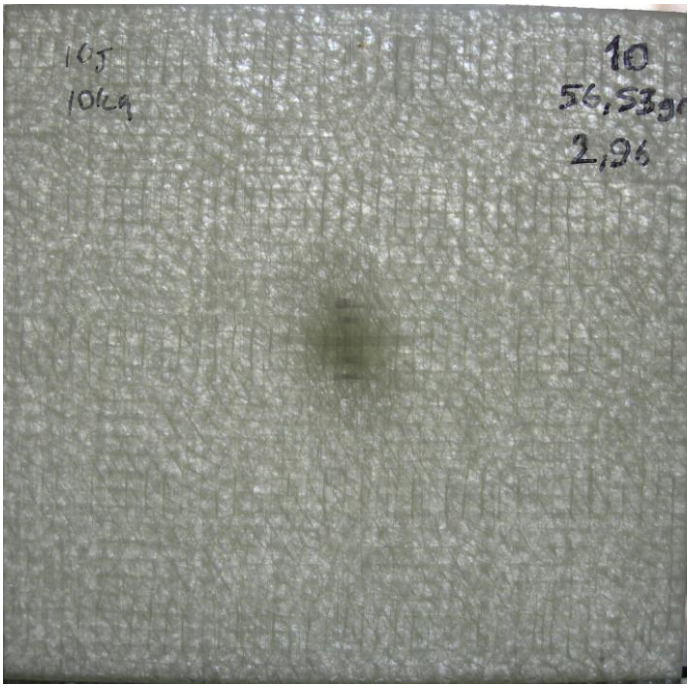


Figure 3.1 Laminated Composite Plate.

CHAPTER FOUR

IMPACT EXPERIMENT AND RESULTS

4.1 Introduction

In this chapter, the impact tester will be introduced, and then the experimental conditions will be given. Subsequently, the mechanical properties of specimen and the impactor will be given. Finally, the experimental results will be given.

4.2 Impact Test Machine and Test Conditions

The guided falling weight technique is applied for all specimens with the tester machine called *“Fractovis Plus”* as shown in Figure 4.1. The impactor consists of three components: a dropping crosshead, an impactor rod or striker, and an impactor nose. The steel impactor rod has a diameter of 12.7 mm and is attached to the dropping crosshead. A piezoelectric head striker is used in the experiments. It is characterize by higher robustness which makes it more suitable for testing very hard materials like advanced composites. A force transducer having a capacity of 22.24 kN was mounted on the front end of the impactor striker and encapsulated by a hemispherical nose. The impactor was set at a dropping height of 30 ~ 1100 mm to give a constant impact velocity at 0.75 ~ 4.6 m/s for tests.

Figure 4.1 Fractovis Plus Low velocity impact tester (A) and its equipments; impactor nose (B^1), piezoelectric impactor nose (B^2), Data Acquisition System (DAS) (C), the specimen clamp mechanism (D), and the springs (E). (E. Erbil, Impact Loading in Laminated Composites 2008, Dokuz Eylul University)

The total mass of the impactor, however, ranged from 2 to 70 kg (by adding various deadweights to the crosshead), resulting in impact energy from 0.6 to 755 J. For impact energy higher than 755 J, an additional energy system (springs have shown in Figure 4.1 (E)) can be integrated which supports up to 1800J. The tester has also a built-in heater and cooler (if a nitrogen tube is connected) which are connected to the computer through advanced data acquisition system (DAS) (shown in Figure 4.1 (C)).

In each impact test, a composite specimen with dimensions of 100 mm x 100 mm was placed between two steel plate holders.

The composite specimen thus had a fixed (22500 N clamping force) boundary condition. In impact testing, the impactor contacted the center of composite specimens, resulting in so-called central impact.

As the impactor dropped and approached the composite specimen, its time trigger passed through a time sensor right before contact-impact occurred. The initial impact velocity was then calculated from the distance between two edges on the tim trigger and the time interval they passes through the sensor. Once impact began, the contact forces at many consecutive instants were detected by the force transducer attached to the impactor. The force history data was send through DAS and downloaded to a computer for graphical processing.

The corresponding velocity history of the impactor could then be calculated from integrating the force history (after being divided by the mass of the impactor) and using the initial impact velocity.

Subsequently, the corresponding displacement history of the impactor could be calculated from integrating the velocity history. Based on the force and displacement histories, the force - displacement relation and the energy history of the impactor could be established.

Assuming the impactor was perfectly rigid and the energy loss on the contact-impact interface between the impactor and the specimen was negligible, the force-displacement relation of the impactor could be considered as the force - deflection curve of the composite specimen.

And the kinetic energy of the impactor right before contact-impact took place, i.e. the *impact energy*, would be the energy transferred to the composite specimen. However, depending on the impact energy level and the type of specimen investigated, either a partial or the total amount of impact energy could be absorbed Liu, Raju & by the composite specimen in forms of damage, heat and others. (Dang, 2000)

4.3 Experimental Results

The impact tests are performed with Fractovis Plus tester at the temperature of 20 C° and at about 1 bar air pressure. In the test machine, the impactor with a hemispherical nose of 12.7 mm in diameter, and a force transducer with the capacity of 22.24 kN is used. The specimens are square with a 100 mm. in length per edge. The different impactor masses are used; 5 kg, 10 kg, 15 kg, that impactor mass and the crosshead mass are included.

The experiments are performed in three main titles which consist of constant impact energy, constant impactor mass, constant impact velocity. The effect of mass, energy and velocity are aimed to find out. If a table was drawn to explain the experiment done, that was similar as the Table 4.1.

Table 4.1 Experiment specifications that objected to the specimens.

	10 J	20 J	30 J
5 kg	2 m / s	2,83 m/s	3,46 m/s
10 kg	1,41 m/s	2 m / s	2,45 m/s
15kg	1,15 m/s	1,63 m/s	2 m / s

According to the Table 4.1, 9 main experiments have been performed. Each experiment had been repeated with three times and the mean values are selected to comment on them. The values are marked to represent constant impactor mass, constant impact energy, and constant impact velocity conditions for discussing the effect of impactor mass, velocity and energy more easily. After that point of this study, constant (or equal) mass represents the 5 kg impactor mass, constant (or equal) energy represents the 10 J impact energy, and constant (or equal) impact velocity represents the 2 m/s impactor velocity (in the gravity direction) in the diagrams, figures, tables and writings.

Before giving the graphs, explaining the three main deflection types are important. Impact damage occurs in three ways which are rebounding, penetration, and perforation. In the first two damage types, the specimen subjected to the impact damage reflects some of the energy from its body. This reflected energy spends on rebounding or negative penetration. In a perfect penetration, the impactor’s velocity becomes zero and it knits with the specimen. In the rebounding condition, impactors’s velocity becomes zero for a while, and then it accelerates in the opposite direction of the initial velocity vector. For the third case, the contact force increases to a critical value, then it reduces to a minimum value. At that moment, the specimen is perforated. In our experiments, the first two types of impact damage occurred.

With the energy profiling method (EPM), penetration and perforation threshold values can be seen more clearly. In the Figure 4.2, AB region represents the rebounding case, BC represents the penetration case, and CD represents the perforation case.

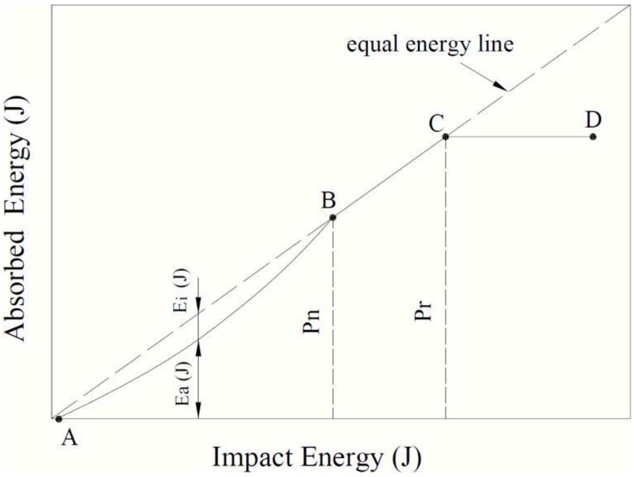
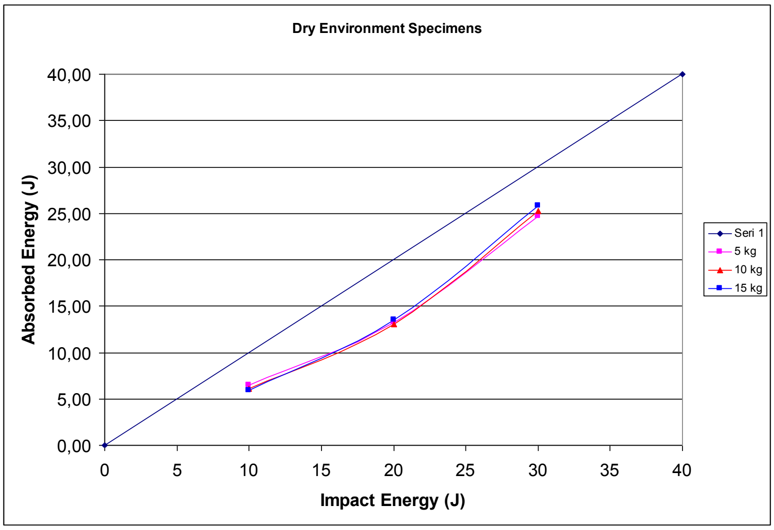


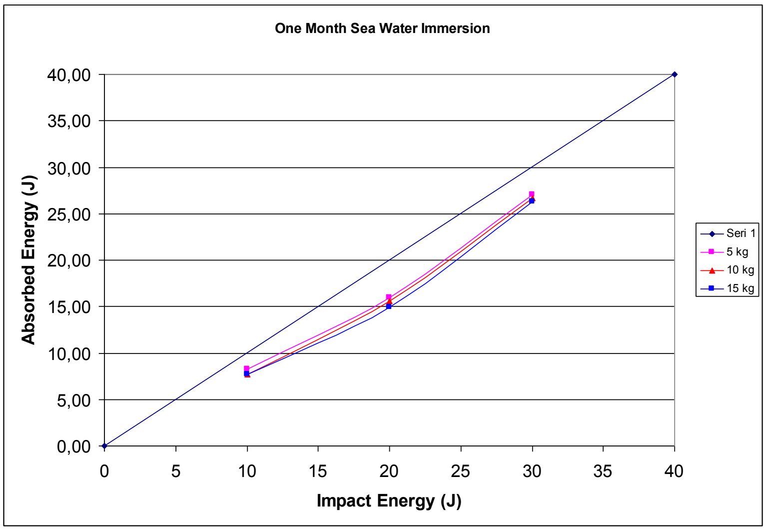
Figure 4.2 Three cases of damage types in EPM (E. Erbil, Impact Loading in Laminated Composites 2008, Dokuz Eylul University)

(Ei) represents the impact energy, and *(Ea)* represents the absorbed energy. *P*n and *Pr* represent the penetration and perforation thresholds, respectively.

After the experiments, the energy profiling diagram in Figure 4.3 shows that the experiments are performed in the first case, rebounding. But none type of test specimens has reached the penetration threshold.

In maximum penetrated specimens are the heaviest and have the maximum impact energy in the whole experiments. This shows that mass is the most effective parameter in penetration damage after impact energy. But on the other hand, the minimum mass specimens' absorbed energy curves are nearly congruent from 10 Joule to 30 Joule impact energy levels. In higher impact energy levels, the difference between eq. mass and eq. velocity curves increases rapidly. But in general, light and fast impactors rebound more than the heavy and slow impactors for constant energy.





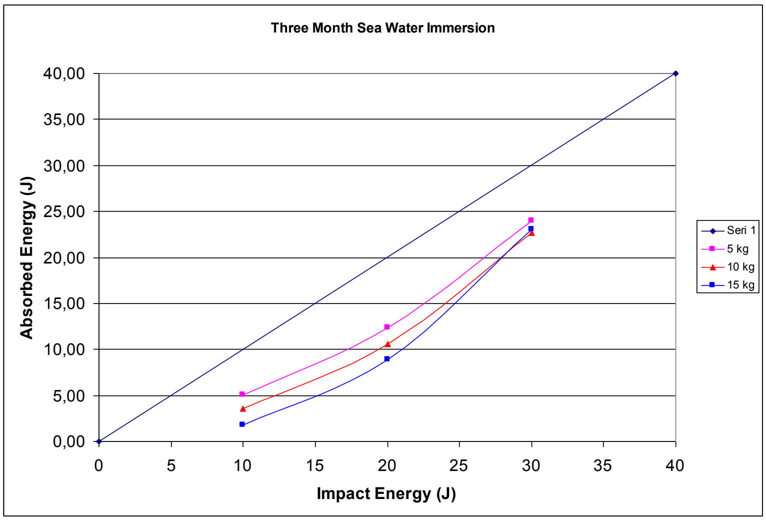
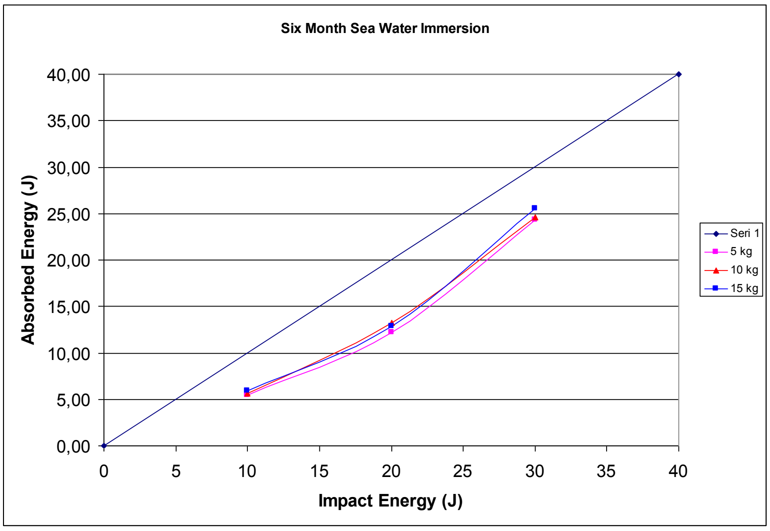


Figure 4.3 Energy profiling diagram of the experimental results. Continues…



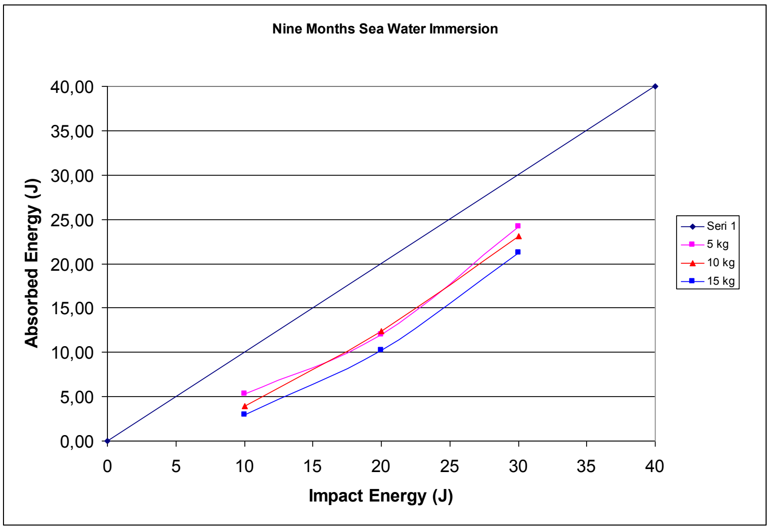


Figure 4.3 Energy profiling diagram of the experimental results

4.3.1 Effects of Impact Energy, Impact Velocity and Impactor Mass

The experimental results are classified in three main titles. After that, the results are classified in two cases again for each effect. The first case is the effect of impact energy at constant impactor mass, and the second case is at constant impactor velocity.

Constant Impactor Mass:

As shown in Figure 4.4. ; Absorbed energy of the specimens in first month is greater than the other months.

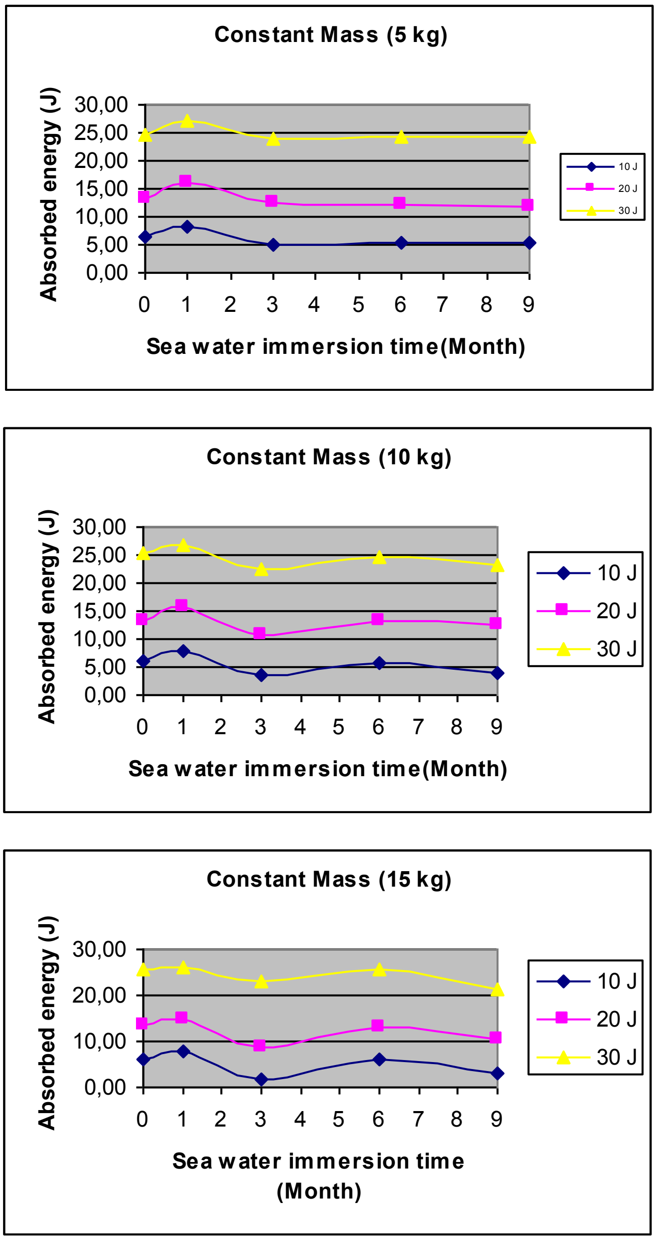


Figure 4.4 For 5-10-15 kg (constant impactor mass) absorbed energy - sea water immersion time history for various impact energies

It's seen that the most deflection occurred in the 30 Joule 15 kg specimens. This means that the 30 Joule 15 kg specimens absorbed the most energy in constant impactor mass case. (Figure 4.5) And this situation can be obtained from Figure 4.4 (Absorbed energy - Sea water immersion time history for 15 kg).

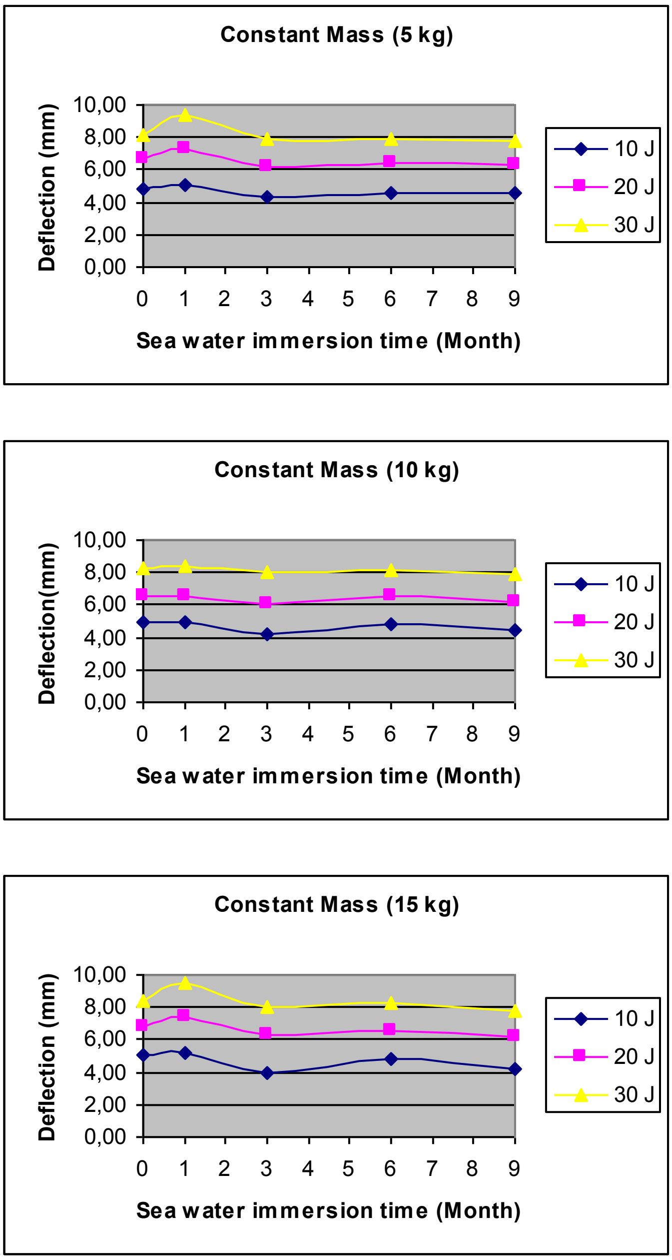
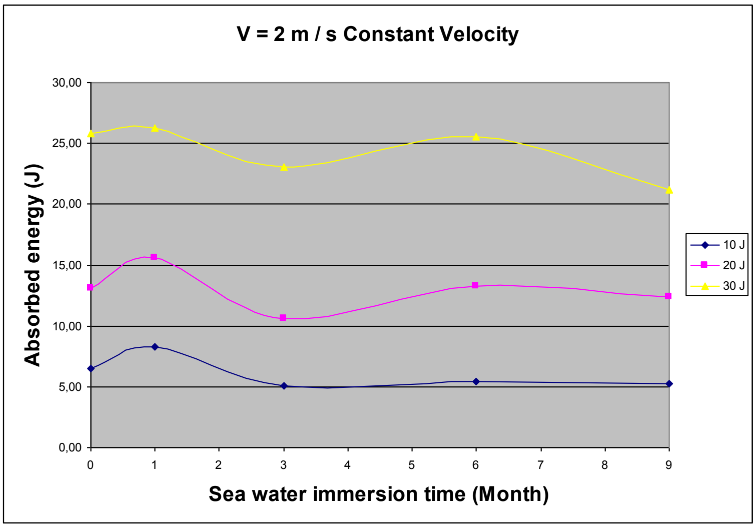


Figure 4.5 For 5-10-15 kg (constant impactor mass) deflection - sea water immersion time history for various impact energies

Constant Impactor Velocity:

As shown in the Figure 4.6. at constant impactor velocity 2 m/s absorbed energy at first month is at the highest degree, Due to this situation , deflection on the specimen has the highest values.

But on the Contact time and contact force diagrams the values stays stable during the experiment, just changes by the impactor energy (10-20-30 J).



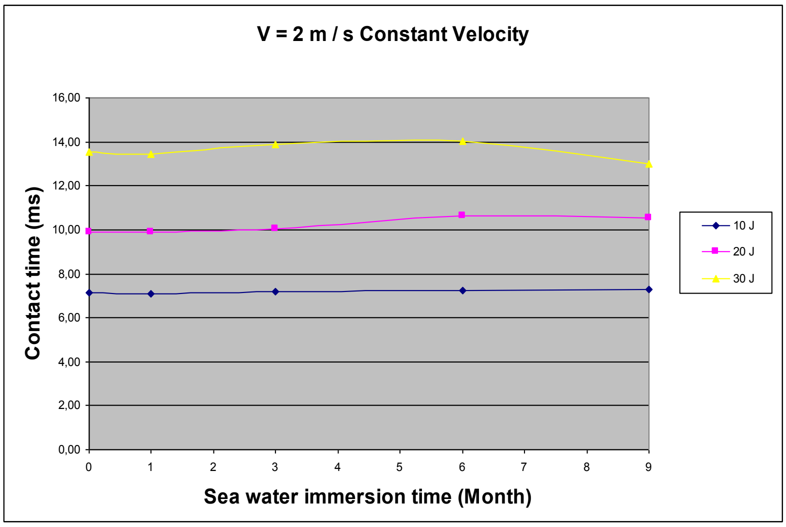
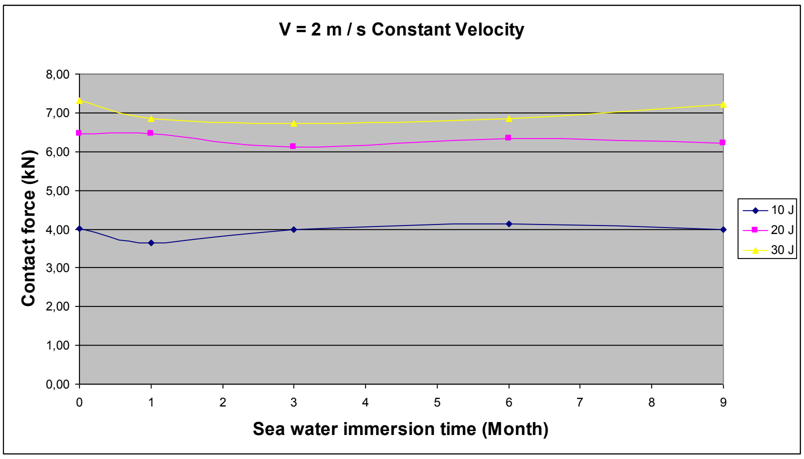


Figure 4.6 For 5-10-15 kg (constant impactor velocity) absorbed energy, contact time, contact force, deflection - sea water immersion time history for various impact energies. Continues…



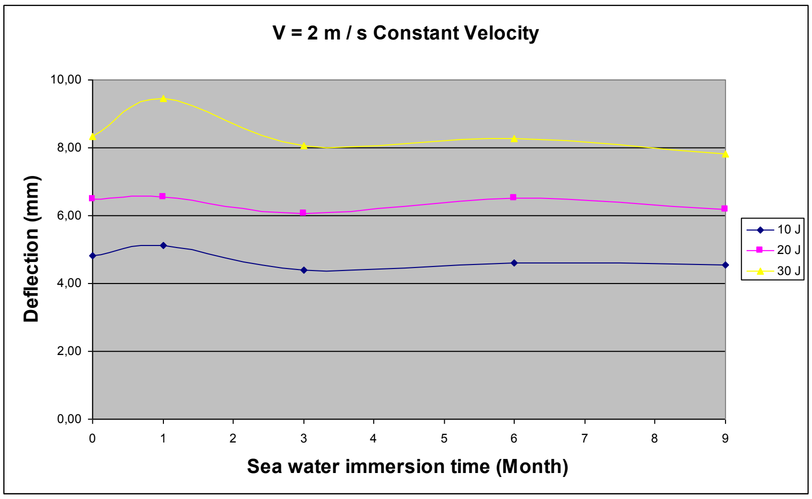


Figure 4.6 For 5-10-15 kg (constant impactor velocity) absorbed energy, contact time, contact force, deflection - sea water immersion time history for various impact energies

4.3.2 The Damaged Area of the Specimen after the Impact

To discuss the damage areas, giving the damage mechanisms is important. When a foreign object impacts on a composite laminate, several damage modes occurs. These are matrix cracks, delaminations and the fiber breakage. One or more damage modes can occur alone or together according to the impact parameters. In this study, at the higher impact energy levels and impactor mass, splitting between fiber and matrix with fiber fractures are dominant damage modes around the impact point. Also, the delaminations are greater because of debonding delaminations at the bottom interface layer.

For this study the constant velocity (2 m/s) specimens, 45 pieces of specimens has been chosen and the photos of these pieces has been taken. After taking the photos digital pictures of specimens were imported to Auto CAD 2009 drawing program to measure the damaged areas. The measurements are shown below (Table 4.2);

Table 4.2 The Absolute damage areas of the impacted specimens

Specimen No:	Delamination Area (mm²)	Specimen No:	Delamination Area (mm²)	Specimen No:	Delamination Area (mm²)
1	147,64	28	96,47	55	139,94
4	520,68	31	436,74	58	535,12
7	1.210,01	34	1.062,63	61	1.283,48
10	217,30	37	230,09	64	296,70
13	507,30	40	377,91	67	584,95
16	1.756,51	43	1.471,39	70	1.504,24
19	119,65	46	242,26	73	127,96
22	413,82	49	450,16	76	532,50
25	1.460,88	52	1.437,16	79	1.295,01

Specimen No:	Delemnation Area (mm²)	Specimen No:	Delemnation Area (mm²)
82	94,39	109	191,93
85	355,71	112	561,33
88	1.790,10	115	1.390,89
91	316,71	118	307,82
94	564,28	121	484,31
97	898,46	124	1.135,77
100	335,98	127	293,46
103	450,59	130	1.197,03
106	789,70	133	1.851,82

According to the values on Table 4.2 the graphic on Figure 4.7 is drawn. The area of the surface gets the highest value at 15 kg-30 J at ninth month.

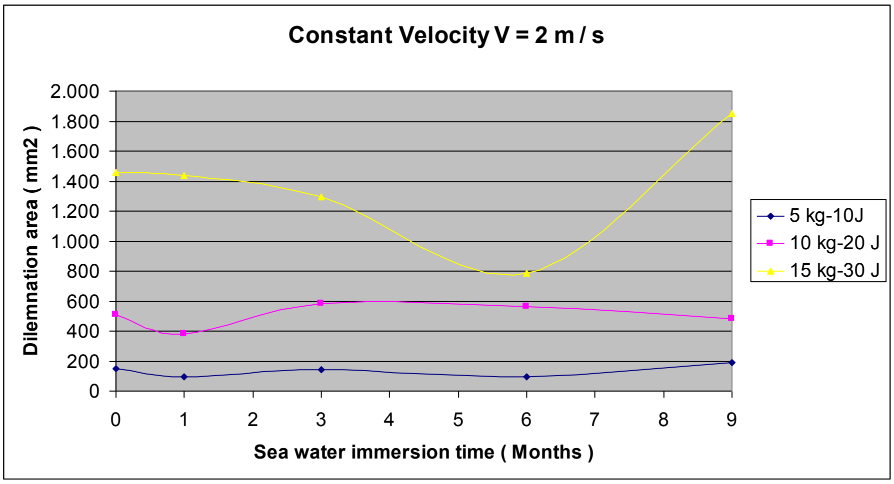


Figure 4.7 Delamination area - sea water immersion time graphic at constant velocity.

CHAPTER FIVE

CONCLUSIONS

Sea water effect on impact behavior of laminated composite plates was investigated experimentally. Specimens were cut and drilled from the composite plates. The dimension of the specimens was 100 x 100 mm. Specimens were put into an aquarium which include sea water to immerse. The specimens were kept into sea water 1, 3, 6 and 9 month periods. On each experiment time 27 pieces of specimens were tested by Fractovis Plus Low velocity impact tester. After that the specimens were tested and the following results were obtained. The results can be sort into three for constant impactor mass, constant impact energy and constant velocity for 2 m/s.

At constant impactor mass; absorbed energy reached the maximum point on first month. Contact time between impactor and the specimen increased as reaching the ninth month. Deflection of the specimen had the highest value on first month as the absorbed energy.

At constant impact energy; contact time between impactor and specimen did not show a big change during the immersing period. But contact force for the first month had the lowest value.

At constant velocity for 2 m/s; absorbed energy and in parallel with the deflection of the specimen had a peak value on first month.

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