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Glass Fibers/ Epoxy PVC Sandwich Composite for Train Body Structure

حشوة المواد المركبة من الياف الزجاج / ايبوكسي بولي فينيل كلورايد لهياكل القطارات

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الآية

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

قال تعالى:

ا لله نُورُ السَّمَاوَاتِ وَالْأَرْضِ مَثَلُ نُورِهِ كَمِشْكَاةٍ فِيهَا مِصْبَاحٌ الْمِصْبَاحُ فِي زُجَاجَةٍ الزُّجَاجَةُ كَأَنَّهَا كَوْكَبٌ دُرِّيٌّ يُوقَدُ مِنْ شَجَرَةٍ مُبَارَكَةٍ زَيْتُونَةٍ لَا شَرْقِيَّةٍ وَلَا غَرْبِيَّةٍ يَكَادُ زَيْتُهَا يُضِيءُ وَلَوْ لَمْ تَمْسَسْهُ نَارٌ نُورٌ عَلَى نُورٍ يَهْدِي اللَّهُ لِنُورِهِ مَنْ يَشَاءُ وَيَضْرِبُ اللَّهُ الْأَمْثَالَ لِلنَّاسِ وَاللَّهُ بِكُلِّ شَيْءٍ عَلِيمٌ (35)

صدق الله العظيم

سورة النور الآية (35)

Dedication

I dedicate my work
To

My beloved mother soul of my father and my brothers
and
Sisters

To my faith full friends
To all those who teach me a letter

Acknowledgements

Thanks first and last to ALLAH who enabled me to conduct this study by grace of him and donated strength and patience my special thank, grate fullness and profound gratitude to my Supervisor

Assistant Professor**: Ramadan Mohmmed Ahmed**

Who made this study possible by his valuable guidance, effort and patience also very special thanks to my lovely uncle

My colleagues at the Ministry of Industry

Finally, I wish to express my great thanks to all members of College of Engineering and Industrial Technology especially department of Textile Engineering and who helped me in this work.

Abstract

Sandwich composites materials are of interest in industrial applications due to their high strength-to-weight ratio and tolerable mechanical properties. This study to describes the use of composite sandwich materials in train vehicles bodies to achieve requirements of performance increased speed, comfort to passengers, increased number of passengers , reduce high consumption of fuel and reduce weight of train. Material selection to railway vehicles bodies requirements includes E-glass fibers (woven type), matrix thermoset epoxy and poly vinyl chloride (PVC) foam. Fabrication process involves hand-lay-up methods, vacuum bag and curing by autoclave. Manufacturing sheet of composite material sandwich structure isotropic, flat sample configuration top face (-45^0 / $90^0/45^0/0^0$), in core Sandwich structure (poly vinyl chloride (PVC) foam type) and back face (-45^0 / $90^0/45^0/0^0$), sample with (6 and 3mm core thickness).Testing according to standard (ASTM C393-00 standard, ASTM D 7136 M-12 standards and ASTM C365-03 standard).From the above we can conclude that in 3 point pending test the specimen with (6 and 3 mm core thickness) in comparison with the specimen with (6 mm core thickness) has a higher flexural stiffness and in comparison to the specimen with (3 mm core thickness), a higher maximum load as well Through load- displacement curve we noticed that the specimen with (6 mm core thickness) has higher energy absorbed than specimen with (3 mm core thickness).On the other hand at drop-weight impact event it is found that the specimen with (6 mm core thickness) has batter energy absorption beaver than specimen with (3 mm core thickness).

مستخلص

تعتبرحشوة المواد المركبةذات أهمية في التطبيقات النصاعية نظرآلارتفاع نسبة القوةإلي الوزن وخواص ميكانيكية ملائمة، تصف هذه الدراسة استخدام حشوة المواد المركبة المستخدمة في هيكل عربات القطار لتحقيق متطلبات زيادة السرعة،راحة الركاب ، زيادة عددالركاب ، تقليل الاستهلاك العالي للوقود فضلاً عن تقليل وزن القطار.أختيار المواد وفقآ متطلبات هيكل مركبات السكة حديديةباستخدام الألياف الزجاجية (E)النوع المنسوج ، مصفوفة الايبوكسي المعالج بالحرارة ورغوة بولي كلوريد الفينيل (PVC)،تشمل طريقة التصنيع الطريقة اليدوية واستخدام اكياس مفرغة من الهواء واستخدام الفرن للتجفيف و المعالج ،تصنع حشوةمواد مركبةمسطحة موحدة الخصائص لتكوين وجهالعينةالاعلي($0^0/45^0/90^0/45^0$-)،في كورهيكل الحشوة رغوة بولي كلوريد الفينيل(PVC) و الوجه لاسفل، ($0^0/45^0/90^0/45^0$-)سمك العينة 6 و3ملم،يتم الاختبار وفقآ للمعيار (ASTM C939-00standard,ASTM D7136 M-12standards and ASTM C365-03 standard).بتطبيق اختبار الثني علي 3 نقاط أنه في العينتين(6 و 3 ملم سمك الكور)بالمقارنة مع صلابة الانثناء فانالعينية (6 ملم سمك الكور)لديها صلابة إنثناء أعلي ، مقارنة مع العينية (3 ملم سمك الكور)،كذلك أرتفاع الحمل الاقصي، من خلال منحني الحمل – الازاحة الانضغطي لوحظ أن العينة (6 ملم سمك الكور)لديها طاقة أمتصاص أعلي للحمل من العينة (3 ملم سمك الكور)،من ناحية أخري ، عند حدوث تاثير بالصدمات (باسقاط اوزان)،وجد أن العينة ذات سمك (6 ملم سمك الكور) تتميز بامتصاص افضل للطاقة مقارنة بالعينة (3 ملم سمك الكور).

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CHAPTER ONE

1. INTRODUCTION

1.1Background

For rail to compete with other transportation modes there are several factors that have to be taken under consideration, e.g. travel time, ride comfort and price Advantages that are often pointed out for rail transportation are for example the ability to work or read during travel, that connections often place the passenger in good proximity to city centers and for shorter to intermediate travels (Weinberg, 2011).

As designer in railways industry strive to reduce fuel consumption, environmental pollution and improve safety, composites are becoming an attractive alternative to standard metallic solution for mass transport applications. Lightweight composite materials are primarily specified because they can be used to produce cost- effective (Galoone et al., 2012).

Sandwich structures have important applications in the naval, railway and aerospace industry. Their high strength/weight ratio and high Stiffness/weight ratio plays a vital role in their applications, especially when they are subjected to high-intensity impulse loadings such as air blasts. Their properties assist in dispersing the mechanical impulse that is transmitted into the structure and thus protect anything located behind it (Song and Paulino, 2006).

Polymer foams are widely used in lightweight structures, such as core material for sandwich structures, due to their superior blast mitigation and impact resisting behavior. Currently, sandwich structures are among the lightweight structures widely used in aerospace, navy, and other related industries. Polymer foams have shown promising results as core material

for sandwich structures due to their high energy absorption capabilities, especially in the case of impact loading (Kidane, 2013).
On author hand Car body function definition the car body of a rail vehicle refers to the load carrying structure, doors, windows, interior with seats etc, inner lining and so-called comfort systems for lighting, heat, ventilation and sanitation(Wennberg, 2011).

Figure 1-1: Module composite sandwich car body structure

The car body must meet a number of requirements, including: safety requirements set up for crash scenarios, derailment, re, projectiles impacts, pressure waves in tunnels, etc. The car body must also be within the specific construction profile of the operated line. It must be strong enough as not to fail during typical maximum loads or during cyclic loading. A large amount of these requirements are, for example, covered by the norm prEN 12663-1(JIRRU, 2015).

1.2 Research problem

The problem of research concentrated on the problems that related to the train vehicle problems such as, low speed of the train, uncomfortable for passengers, obstacles during the travel, and high consumption of fuel all these problems lead the researcher to try find some solutions.

1.3 Research objective

- The objective of this study is increase speed of train and reduces energy power (fuel) by reducing the weight of train.
- Aim of this research is manufacture sandwich composite from E-glass fiber, matrix thermoset epoxy with poly vinyl chloride (PVC) foam for the different foam thickness.
- To obtaining static and dynamic properties of sandwich composite by using different mechanical tests.
- To analyzed interring and extorting damage used microscope.

1.4 Research hypotheses

Using composite material sandwich structure will lead to

- Reduce the weight.
- Increase train speed.
- Make train more comfortable.
- Reduce consumption of fuel.
- Increase the number of passengers.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Materials used for Body train structure Light weights

Since the first-ever high-speed train, the Japanese Tokaido Shinkansen, started operation at the maximum speed of 210 km/hr. in 1964, railway systems have gone through a rapid evolution and improvement with significant growths, mainly in Japan, France, Germany, Italy, Britain and, lately, China. The world speed record today is 574.8 km/h achieved by the French TGV POS train Hunder test conditions on the railway network LGV Est, reported in 2007. Noticeably, the TGV record for the fastest scheduled rail journey with a start-to-stop average speed of 279.4 km/h was already surpassed by the Chinese CRH (China Railway High-speed) service, called Harmony Express, on the Wuhan–Guangzhou High-speed Railway in 2009(Dong et al., 2010).

The materials used during this period from 1964 to 2006 metallic materials (steel, aluminum).And from 2007 till now which used composite materials can be divided into the following:-

2.1.1 Metallic materials

Rail vehicle bodies were made of stainless steel and constituted by stainless steel sheets welded onto a strength-providing structure.

In a study by Takeichi, M., et al Railway car body structures. 1992. 1- A railway car body structure has a panel assembly forming at least part of a side, the roof, an end or the floor plate, each panel has inner and outer spaced metal sheets and a cellular metal core bonded to the sheets and maintaining them spaced apart. To join the panels, a metal connecting member is joined to at least one of the inner and outer sheets by continuous metal-to-metal bonding and has a projection for use in welding the panel to the neighboring panel. The projection extends in the lateral direction of the panel and is of material thicker than the general sheet thickness of the sheets. A frame member of the body structure may be welded to the panels at the joint (Takeichi et al., 1992).

On author hand in a study by Tieberghien, P., et al., Rail vehicle body made of stainless steel. The side faces comprises sheets of stainless steel that are smooth and thin relative to the thickness of the section. The elements of the strength-providing structure are assembled together by weld fillets, and likewise the metal sheets are assembled to strength-providing structure by weld fillets (Tieberghien et al., 1995).

Development of materials used in the train cars bodies structure according to Saranac, R. Started in the 1970's by using Aluminum Railcar Design and Useful Life–Fatigue Assessment. The use of aluminum in the construction of rail passenger cars was a departure from traditional materials (e.g. stainless steel and steel) due to its strength to weight ratio and aesthetics. Various transit authorities adopted the aluminum rail vehicles for widespread use. These early designed aluminum rail cars are now more than 30 years old and are slowly approaching the end of their predicted useful life (Sarunac, 2010).

The purpose of the use of aluminum was in the rail vehicles according to Zangani, D, M. Robinson, and G. Kotsikos, improving the crashworthiness of aluminum rail vehicles The use of aluminum alloys in rail vehicle manufacture has introduced a number of advantages, namely good corrosion resistance, lightweight and superior surface finish. Furthermore, the use of double skinned aluminum extrusions that can be welded together to form the vehicle body has enhanced the efficiency of the manufacturing and assembly methods. Double skinned closed cell extruded sections have an inherently excellent resistance to impact loading that contributes to the crashworthiness of modern rail vehicles (Zangani et al., 2009).

Aluminum is used improve quality of joints in railway vehicles body structure that according to Gay, R., M. Robinson, and D. Zangani, Crashworthiness of Joints in Aluminum Rail Vehicles. On the crashworthiness of joints in aluminum rail vehicles later has been intensified since the rail accident at Ladbroke Grove. This paper addresses the issues of weld unzipping and looks at alternatives to fusion welding. Existing joints have been characterized to determine the effects of the weld filler material, the type of aluminum and the heat affect (Gay et al.).

In the study of structural diagnosis of rail vehicles and method for redesign by Mauricio, Jaime L, German, Leonel, Bogdan Design of new structural elements for rail vehicles, (e.g. car body and bogie frame), usually seeks a useful life of 30 years . However, due to the different conditions that arise in normal operation, it is common to require corrective maintenance procedures on structural elements in order to safely guarantee the established design life. Normal operation of the vehicle represents complex loading conditions for the structural elements. Its dynamic behavior represents a very load-alternating environment for the different parts, so that fatigue problems are usual in rail vehicles, especially in those with aluminum structures. Fatigue problems are represented by formation of cracks. Although some cracks might be admissible for a safe operation of the vehicle, continuously growing cracks, located in critic connections are not admissible and requires corrective actions, such as refurbishment procedures (Aristizabal et al., 2014).

2.1.1.1 Disadvantages of the use of metallic materials

1) The weight of the mass of steel and aluminum in the body design of the train vehicles has a large mass volume compared to other materials (composite materials) used in the construction or design body of railway vehicles. Thus the weight of train vehicles is very heavy.

2) Due to very heavy weight of train body structure, the speed of train slow (about 210 km/hr) compared to composite material that speeds faster than (574.8 km/hr.).

3) Routine maintenance operations, especially shell body of train vehicles, need more man power.

4) Welding operations especially in aluminum.

5) As a result very heavy train vehicles the consumption of fuel increased during operations and which lead to an environmental impact resulting from fossil fuel combustion and energy consumption that pollute the surrounding environment.

6) The train vehicles body structure dynamic is heavy so the load carried by train vehicles including load of passenger is greater than the load carried by train body structure used composite materials.

7) Mechanical properties (impact, stress, strength….ete) resulting an air pollution during operating of train.

8) The heavy weight of large train vehicles lead to vibration in the train vehicles body coming from friction between the train wheels and railway line according to this generates cracks and fatigue in the side of train vehicles body shelly.

9) As the result of the vibration of train vehicles and inconvenience, the train vehicle is not comfortable and safe.

10) Fatigue problems are represented by formation of cracks.

11) The heavy weight vehicles and low speed decreases the number of passenger (Takeichi et al., 1992, Aristizabal et al., 2014).

2.1.2 Composite materials

Composite materials have been used in a wide range of applications due to their superior specific mechanical properties over conventional materials such as metals. For example, in aerospace and automotive industries, several structures are built from composite materials in order to have high strength and stiffness to weight ratios. Also in the railway industry composites are becoming an attractive alternative to standard metallic solution. Applications of the composite materials in railway vehicles include front cab, roof, sidewall and interior components, such as seats and paneling (Grasso et al., 2015).

Use composite materials of traditional materials according to Ning, H, et al. Structure design for the body panel of mass transit vehicle use thermoplastic, create weight savings in vehicles enhances fuel efficiency and decreases maintenance costs, especially in mass transit systems. Lightweight composite materials, such as glass fiber reinforced polymers, have been used to replace traditional steel and aluminum components. Amass transit bus side body panel was designed, analyzed, and manufactured using thermoplastic composite materials. The design featured a sandwich composite with E-glass fiber/polypropylene (glass/PP) face sheets and PP honeycomb core as constituents that provide low weight, high strength and energy absorption benefits. The panel was designed and analyzed using Pro/Engineer 2001 (Pro/E), Altair® Hypermesh® 6.0 (Hypermesh) and ANSYS 7.0 (ANSYS). A single diaphragm forming process was used to manufacture the glass/PP face sheets. This process provides excellent consolidation, which was confirmed by microstructural analysis of the face sheets. The face sheets and core material were adhesively bonded and tested to validate the model. The failure of the body panel occurred by adhesive failure when the load reached 11.7 kN. The static loading requirements of the American Public Transportation Association (APTA) for the body panel were met. The thermoplastic composite body panel exhibited excellent weight saving of more than 55% compared to a conventional bus with aluminum skin and supporting steel bars (Ning et al., 2007).

Use composite materials in the design of train vehicle body; reduce weight, according to Belingardi, G., M. Cavatorta, and R. Duella, the structural design of the front shield for a high speed train made of composite material. A sandwich structure was considered, made of glass fiber epoxy face sheets with a polymeric foam core. Initially, the material properties and the rate sensitivity of the skin and core materials were investigated through a series of static and quasi-static tests. Static and dynamic impact tests were then run on the sandwich structure. For all materials tested, no significant strain-rate effects were observed over the range of test conditions investigated in the study. Results show that the structural response of the sandwich depends primarily on the strength properties of the foam core material. The dynamic impact resistance of the sandwich structure was then substantially improved by adding a net of resin walls within the foam (Belingardi et al., 2003).

2.1.3 Mechanical properties of sandwich composite use in train vehicle body:-

Use composite materials proves impact of the railway vehicle in study by Schubel P.M,J-J. Luo, and I.M. Daniel, Low velocity impact behavior of composite sandwich panels. Stated Composite sandwich structures are susceptible to low velocity impact damage and thorough characterization of the loading and damage process during impact is important. The objective of this work is to study experimentally the low velocity impact behavior of sandwich panels consisting of woven carbon/epoxy factsheets and a PVC foam core. Instrumented panels were impacted with a drop mass setup and the load, strain, and deflection histories were recorded. Damage was characterized and quantified after the test. Results were compared with those of an equivalent static loading and showed that low velocity impact was generally quasi-static in nature except for localized damage. A straightforward peak impact load estimation method gave good agreement with experimental results. A contact force–indentation relationship was also investigated for the static loading case. Experimental results were compared with analytical and finite element model analysis to determine their effectiveness in predicting the indentation behavior of the sandwich panel (Schubel et al., 2005).

Use of composite materials to improve fire resistance according to Kim, J.-S., et al., and Fire resistance evaluation of a train vehicle body made of composite material by large scale tests. Fire resistance tests of a train vehicle body made of composite materials. In this study, fire performance tests using specimens and a large scale mock-up were performed to evaluate the fire safety of the composite train car body. From the specimen tests, it was seen that the interior panels met the fire safety for the flame propagation, toxicity and smoke density performance. In addition, the fire resistance of the composites car body was verified by the larger scale tests under the real fire accident scenario. From the results, both the surface temperature of the interior and the composite car body were lower than the ignition temperature (Kim et al., 2008).

Use of composite materials to reduce weight according to Seo, S., J. Kim, and S. Cho, Development of a hybrid composite body shell for tilting trains. A concept of a hybrid body shell for a tilting train is proposed and a prototype model has been developed. Tilting trains require lightweight structure and stability on curves. To satisfy these requirements, the upper body shell of the prototype model was made of composite honeycomb panels and the lower under frame of stainless steel. The composite honeycomb panel was composed of carbon fiber reinforced skins and an aluminum honeycomb core. The hybrid structure made it possible to reduce the car body weight by almost 30 per cent. The hybrid body shell was tested for the static and fatigue strength and fire safety was also verified by testing. The hybrid body shell was proved to be good enough for commercial use. As a result, the conventional manufacturing process for the rolling stock could be changed by introduction of this new structure (Seo et al., 2008).

2.1.3.1 Disadvantages of the use of composite materials:-

1) The methods of choosing materials used in manufacturing composite and methods of manufacturing process are very crucial in reducing problems raising during fabrication of train vehicle body structure shelly.

2) High initial investment costs.

3) Welding and joining operation cannot easily be achieved.

4) Environment problems, especially when composite are made from thermosets materials after complete life cycle of the part from train vehicle body (Grasso et al., 2015, Seo et al., 2008).

2.2 Composite materials

2.2.1 Definition of composite materials

A composite material is generally defined as a material made from two or more constituent materials, which remain separate and distinct from one, another on a microscopic level (Zenkert and Battley, 2006). Each material brings its own specific properties to the union, and for a well-designed composite, the resulting material has superior properties to those of each of the constituent materials on their own.

Composites are found everywhere. An example of a natural composite is wood; a combination of cellulose fibers and lignin. One of the oldest man made composites is a combination of mud and straw, a primitive form of building brick. Herein composite refers to a specific group of composites called fiber Reinforced Polymers (FRP) Figure (1.2) show the composites fiber reinforced polymers (Wennberg, 2013).In the composite materials the function of the fibers is carrying the load exerted on the composite structure, and providing stiffness, strength, thermal stability and other structural properties. Matrix material carries out several functions in a composite structure, some which are binding the fibers together and transferring the load to the fibers, and providing protection to reinforcing fibers against chemical attack, mechanical damage and other environmental effects like moisture, humidity, etc.(Mazumdar, 2001).

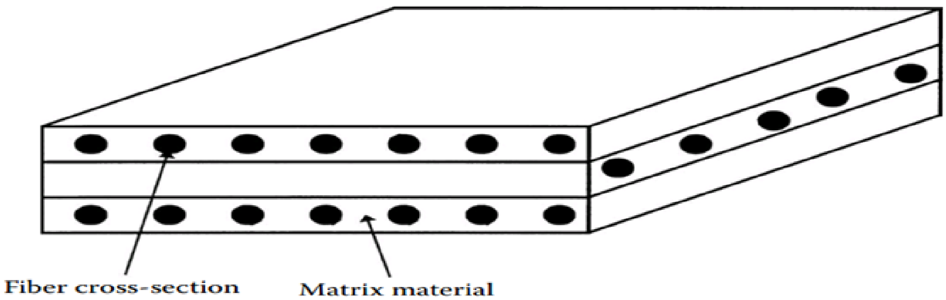


Figure 2-1: show composites fiber reinforced polymers.

2.2.2 Composite lamina

It is made up of a number of fibers, i.e. the reinforcement (e.g. carbon fibers or glass fiber), and a matrix material, commonly a polymer. The matrix surrounds the fibers and keeps them in place. This results in high strength and rigidity in the fiber direction, while in the transverse direction; it is the strength and stiffness of the matrix that dominates the mechanical properties of the laminate. This lamina is therefore a highly orthotropic component.in the figure (2.2) show composite lamina with reinforcement fibers and matrix materials example of a unidirectional lamina's directional strength.

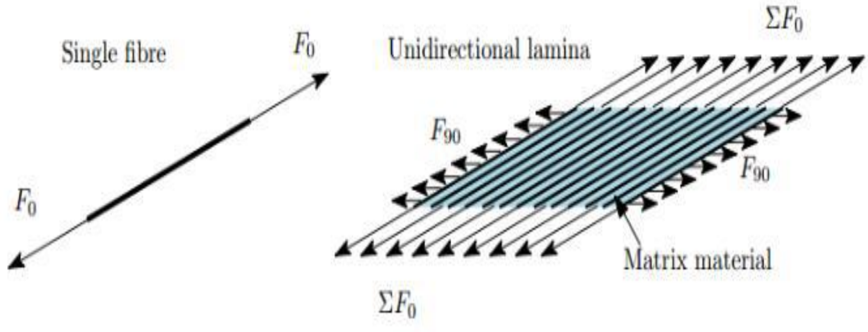


Figure 2-2: show example of a unidirectional lamina's directional strength.

A number of this lamina can be stacked on top of each other, creating composite laminate. The laminate can be created to further increase the strength and stiffness in a certain direction, or the stacking sequence, the lamina lay-up, can be varied as shown in figure 2.3 In this figure four lamina, of various thickness are stacked together to create a laminate with the lay-up $0^0/-45^0/45^0/90^0$. The lay-up angles are defined from some predetermined 00 -direction. This laminate has enhanced shear stiffness and transverse stiffness as compared to the unidirectional lamina, however, the stiffness in the 0^0-dir is reduced (in unit per area).

Adding composite face sheets to the sandwich structure gives added complexity to the problem but also added design space. The composite face sheets can be engineered to optimize the directional properties of the component. For a structure like the load carrying structure of a high-speed train's car body, this has to carry many different loads in various directions it is important to have a somewhat balanced ply lay-up (Kim et al., 2005).

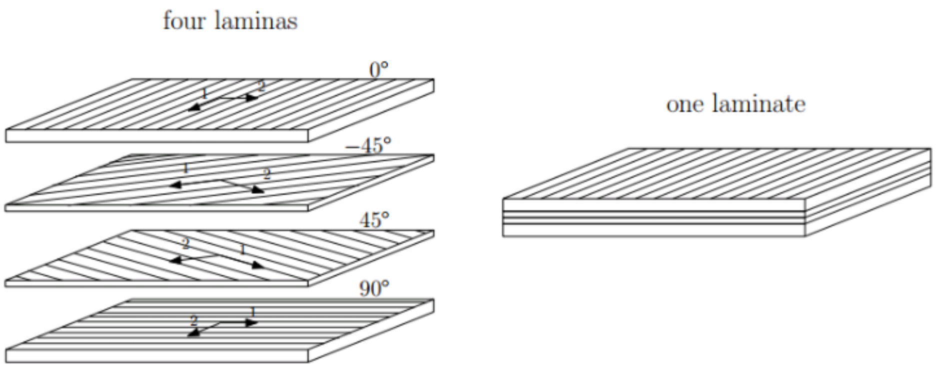


Figure 2-3: example of number of lamina creating laminate.

2.2.3 Concept of Sandwich structures

The Definition of Sandwich Structures is a special form of laminated composites. A typical sandwich structure consists of two thin, high strength face sheets boned to a thick, light weight core (Figure 2.4).

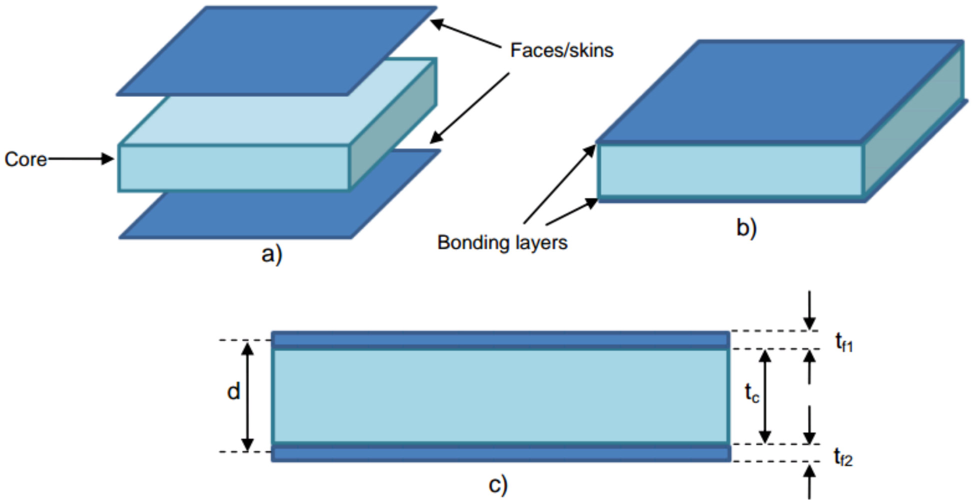


Figure 2-4: typical sandwich structure, a) Sandwich elements,
b) Bonded structure, c) Side view of the sandwich structure.

A sandwich structure is characterized by three distinct layers: two outer layers so called skins or faces, and a center core. The faces, which are commonly made of high performance material such as sheet metals or fiber Reinforced Polymers (FRPs), are separated by a certain distance from each other by the core that is made of lower performance and light weight material, e.g. balsa wood, honeycomb structures or polymer foams. These structures can greatly increase the stiffness and strength of the without increasing its weight (Grasso et al., 2015).

Modern structures employ elements consisting of three or a much greater number of layers. These multilayered elements can contain special-purpose layers, which, for example, damp the structure or protect it from thermal or corrosive effects. At present, three- and multilayered plates are widely used in various fields of engineering, as presents the positive and negative features associated with application of these materials (Altenbach, 1998). It is important to produce a sandwich structure having required properties according to the working environment. In order to employ the proper components the following conditions must be satisfied:-

1) Determination of the absolute minimum weight for a given structural geometry, loading and material system.

2) Comparison of one type of sandwich construction with others.

3) Comparison of the best sandwich construction with alternative structural configurations (monologue, rib-reinforced, etc.).

4) Selection of the best face sheet and core materials in order minimizes structural weight.

5) Selection of the best stacking sequence for faces composed of laminated composite materials.

6) Comparison of the optimum construction weight with weights required by some restrictions; i.e., the weight penalty due to restrictions of cost, minimum gage, manufacturing, material availability, etc.(Vinson, 1999).

2.2.3.1 Composite Sandwich designs in vehicles

Composites and sandwich structures are not new building elements in the transportation industry and they can be found in all areas of transport. Figure (2.5) gives three examples of what are some of the most ambitious uses of composite sandwich design in vehicle body structures.

Figure 2-5: Examples of composite sandwich vehicle bodies.

Composite sandwich designs found in different modes of transportation as well as what the benefits of these designs, different modes of transportation, the benefits of these designs have been.

Sandwich structures are especially popular in aerospace and naval applications. Kokum's AB has specialized in sandwich hull structures for naval ships made of FRP skins and light weight foam cores. The main advantages of this design are, according to Kokum's: low weight, versatility, long life-cycle, flexible production and simple maintenance. The typical production is vacuum infusion.

Another innovative design is the Advanced Composite Cargo Aircraft made by Lockheed Martin, which, unlike most composite aircraft structures, was manufactured without the use of an autoclave (Gardiner, 2011). The almost 20 m long fuselage is comprised of two large "skins" and a number of frames. These skins are sandwich panels fabricated using out-of-autoclave carbon/epoxy laminates on a honeycomb core (Russell, 2010).

Another example of sandwich design is the metro train C20 FICAS, running in Stockholm’s underground since 2003. The FICAS train unit is a prototype and the only one of its kind. Like for the TTX the FICAS sandwich panels are supported by an underlying steel frame.

The sandwich construction is itself based on steel face sheets on a PMI core (Knutton, 2003). A 33% increase in aisle space was achieved with the sandwich panel design as compared to the conventional steel car body, which gave room for an additional 35 passengers per car (Skoglund and Lagerås, 2002). A large difference between the FICAS and TTX are the requirements placed on the car bodies. Metro cars have a shorter span between bogies reducing the stiffness requirements on the car body. Furthermore load case requirements from norms are significantly lower as compared to high speed trains (e.g. the maximum buffer load for high speed trains 1500 KN and for underground vehicles 800 KN (Standard, 2000), furthermore, several other load cases are not even considered for underground operations). Comfort requirements are also significantly lower on metro trains as compared to high speed trains, e.g. thermal insulation, sound level, etc.

2.3 Railway vehicle functions and requirements

Arial vehicle's car body is a relatively long and slender tube like structure, Figure (2.6). The main functions of the car body are to provide passengers with sufficient comfort and safety. To achieve these two main functions, the car body must provide a number of lower level functions, e.g. strength, internal sound level and fire safety. For these lower level functions it is often possible to define requirements which must be fulfilled in order to design and manufacture a viable vehicle. A number of these are summarized below:

1) The vehicle structure should not collapse, or show any damage during typical operational loads, for example inertia forces between two adjacent car bodies.

2) The allowed weight of rail vehicles is limited. Train exerts forces on the infrastructure due to their weight which results in wear of the tracks. High weight also increases the wear on wheels, axles, breaks, shocks, etc.

3) The car body should be sufficiently stiff. From a safety perspective the car body should not flex outside the track gauge during operations or show significant vertical displacement due to the passenger load. From a comfort perspective vibrations, excited from the track and bogies, can lead to severely reduced comfort, where it is desired to separate the natural frequencies of the car body from those of the track and bogies.

4) The sound level in the passenger compartment should be limited. For high speed trains the sound level on the outside of the train can be above 100dB. The car body has to isolate the passenger compartment from these sound levels.

5) The car body should be designed to limit the risk of fire ignition due to both electrical malfunction and arson. In addition, in case this fails and there is an ignition point, the fire spread should be slow and limited. The car body should be able to retain structural integrity, at least for enough time to safely evacuate passengers.

6) Rail vehicles operate in many different climates and temperatures, from temperatures as low as -40C^{O} during winter to above 50C^{O} in the summer. Passengers, however, want an "indoor feeling" in-side the train. Why the car body must provide sufficient thermal insulation?

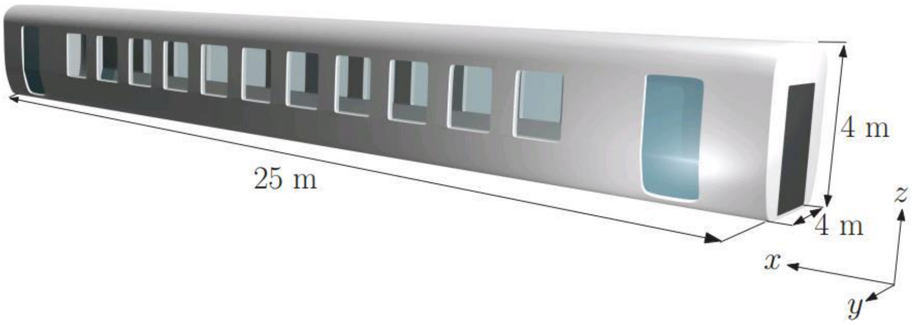


Figure 2-6: General car body appearance, long and slender structure in X direction.

All of these functions, and more, have to be incorporated into a structure which occupies a limited amount figure (2.7).

The outer profile of the design space illustrated in figure (2.7) is limited by the track gauge, i.e. the amount of space available along the track, while manufacturer's and operator's want to maximize the interior space to provide the right comfort for passengers. The result is a complex, thin, shell like structure comprised of a load carrying component, almost exclusively made of steel or aluminum, with the function of providing strength and stiffness to the structure, different layers of insulation to provide, or add to the thermal and acoustic insulation of the structure and finally an inner lining with aesthetic and protective functions. Typically the functions are gradually added to the structure throughout the design phase, steadily increasing the weight of the vehicle.

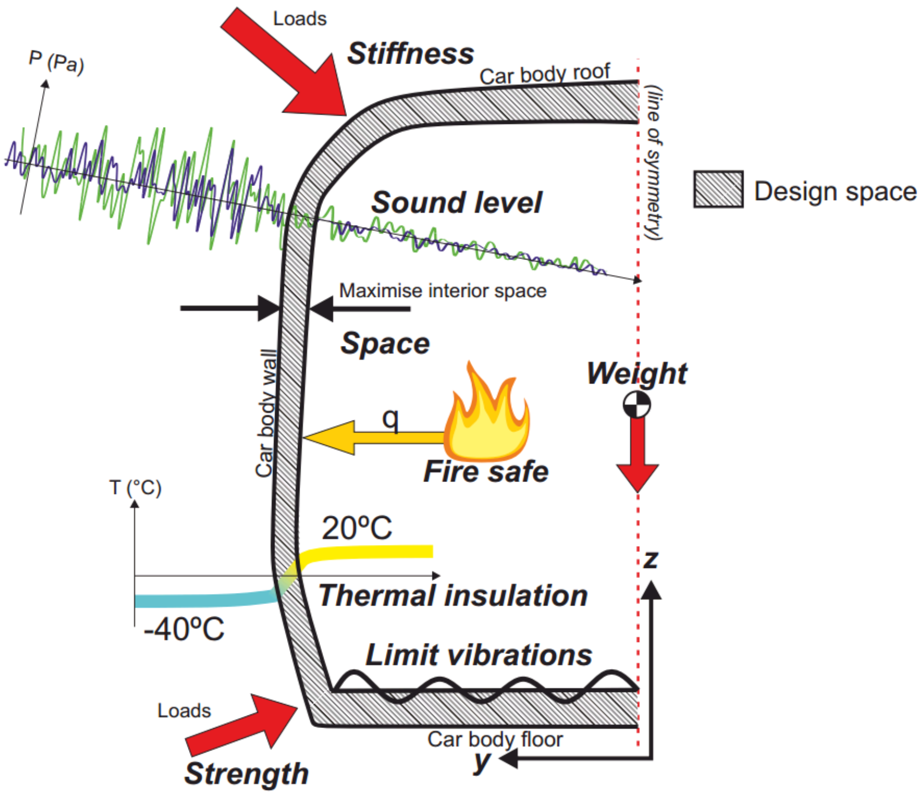


Figure 2-7: Cross-sectional view of car body design space.

There are several other functions that the vehicle body should provide such as easy entrance and exiting, aerodynamic shape, ease of maintenance (Wennberg, 2013). However, due to the scope of this thesis, the car body functions and requirements considered and discussed are limited to the ones summarized in Table (2.1).

Table 2-1: Functions and requirements considered within this thesis

Low weight	Strength	Stiffness	Ride comfort
Interior space	Sound transmission	Thermal insulation	Fire safety
Energy consumption	Manufacturability	Recyclability	

2.4 Railway vehicle design

The technical equipment for propulsion, breaking etc. is by definition not included in the vehicle body, even though this equipment usually is attached/hinged on this (commonly under the car body). Sometimes the concept vehicle body is limited to only the load carrying structure of the vehicle.

The vehicle body must meet a number of requirements, including: safety requirements set up for crash scenarios, derailment, fire, projectiles impacts, pressure waves in tunnels, etc. The car body must also be within the specific construction profile of the operated line. It must be strong enough as not to fail during typical maximum loads or during cyclic loading (Wennberg, 2010).

2.4.1 Load carrying structure

The loading specifications to which passenger vehicle body structures are designed seek to fulfill two basic requirements.

Firstly, normal service loads experienced over the life of the vehicle must be met without loss of serviceability.

Secondly, passengers and crew must be afforded protection against loads outside the normal service experience (Scholes, 1987).

2.4.2 Train vehicle body dynamics

From a space and loading perspective, it is beneficial to have the car body as long and as wide as possible. However, as a consequence of the loading profile, which sets limits on the size of the car body cross-section, the structure can become rather long and slender with relatively low rigidity.

A too flexible car body can lead to significant structural motion during operation, resulting in poor ride comfort or even structural damage of the vehicle body.

During operation the vehicle body is continuously excited due to the dynamic interaction between track, wheels, bogie and vehicle body. To avoid resonances, the principle of separating frequencies is employed Figure (2.7), this is also briefly mentioned in (Wennberg, 2011).

Component frames∼18 Hz   Inner floor with chairs∼18Hz

Floor between side sills∼14 Hz

↑

Car body vertical bending mode∼10 Hz

↑

Bogie 5-7 Hz

↑

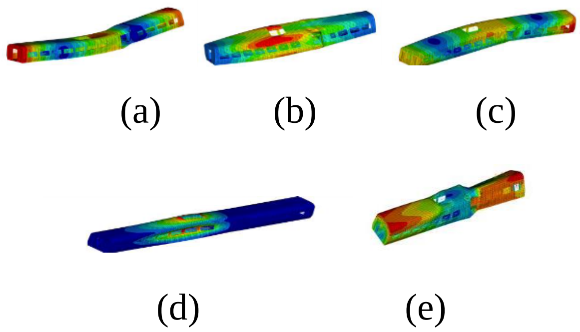
Track

Figure 2-8: the principle of separating frequencies.

A common design principle is to keep the first natural frequency of the car body as high as possible, typically above 10 Hz. The first five natural frequencies and modes of a high-speed vehicle body are presented in figure (2.8). These are the typical natural modes of a high speed vehicle body, however, the order and frequencies may differ from this specific example.

The natural frequencies of the vehicle body give a good impression of how stiff the construction is. Especially the vertical bending mode gives a hint of how well the vehicle body will manage the payload.

To construct a vehicle body that has sufficient stiffness with respect to vertical and lateral bending, has a stiff cross-section as well as being stiff in torsion is a challenge for the designer. There are several functional design aspects of the vehicle body that severely reduce the stiffness of the structure. As an example, the first vertical bending frequency is especially sensitive to the door openings, which are sometimes as many as 2-3 per side.



(a)Vertical bending, (b) Shearing of the cross, (c) Lateral bending

(d) Breath-mode 11.1Hz. (e)Torsion 12.8Hz.

Figure 2-9: Modal analysis of high-speed vehicle car body.

The best place for door openings, with regard to high vertical bending frequencies, is at the ends of the vehicle body or in the middle. Here, on a large scale, these results in the least shear of the door openings as illustrated in the vertical transverse forces are at minimum.

Looking from an operational point of view, however, optimal door placement may be to place the doors one third of the way in from each end to optimize passenger flows.

Other aspects that affect the rigidity of the car body are for example window size, car body length and cross-section geometry, boggie placement, etc. (Freiholtz, 2008).

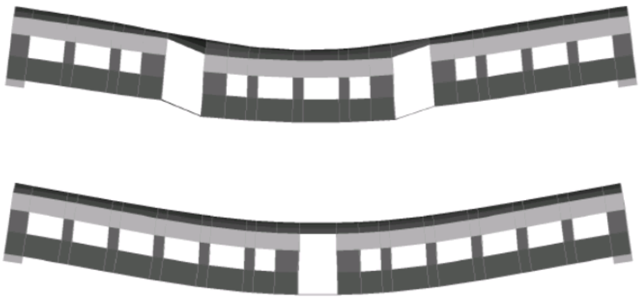


Figure 2-10: Influence of door placement on the vertical bending behavior of the car body.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1Introduction

In this chapter the experimental work involved four main phases and they were:

1) Material selection according to railway applications involves not only the assessment in terms of stiffness and crashworthiness but also other requirement as fire protection insulation and comfort.

2) Fabrication processing involved hand-lay-up methods, vacuum bag and curing by autoclave.

3) Laboratory testing according to flatwise Compressive Properties of Sandwich Cores ASTM C 356-03, flexural Properties of Sandwich Constructions 3point bending / ASTM 393-00 standard and measuring the damage resistance of a fiber- reinforced polymer matrix composite to drop- weight impact ASTM D 7136/ D7136 M -12.

4) Calculation as follows:

a) Core Shear Stress (Single-Point Midspan Load).

b) Obtain the ultimate shear strength.

c) Facing Bending Stress (Midspan Load).

d) Core shear stress (two-point load; one-quarter or one-third span).

e) Facing bending stress (two-point load; one-quarter span)—calculate the facing bending.

f) Sandwich panel deflection (two-point load, one-quarter span) — calculate the mid span deflection.

g) Flexural Stiffness and Core Shear Modulus.

h) Calculate the flatwise compressive strength.

3.2 Material selection

Mechanical characterizations of the selected composite material have been assessed in order to define the basic material properties that can be used as input in structural design. In this study materials used are as following:

1) E-glass fibers (woven type) reinforcement.

2) Matrix thermoset epoxy.

3) Poly Vinyl Chloride (PVC) foam.

3.2.1 E-glass fibers (woven type) reinforcement

Woven E-glass fibers reinforcement (0.2 high strength glass fabrics) Specification of fabric is shown in the below table given by supplier (Changzhou Xingao insulation materials Co. Ltd).

Table 3-1: Specification of fabric

Quality index			Value
1	Fabric weave		Plain weave
2	Warp number × strand number		133
3	Weft number × strand number		131
4	Width (CM)		100
5	Thickness (CM)		0.235
6	Mass per unit area (g/m2)		195
7	Density (cm)	Warp	8
		Weft	7
8	Tensile breaking strength (MPa)	Warp	2865
		Weft	2559
9	Moisture content %		0.09
10	Oil content %		0.71
11	Combustible content %		0.6

3.2.2 Thermoset Epoxy Matrix

Thermoset epoxy in polymer matrix composites, epoxy resins are a family of thermoset plastic materials which do not give off reaction products when they cure and so have low cure shrinkage. They also have good adhesion to other materials, good chemical and environmental resistance, good chemical properties and good insulating properties, specification in table below given by supplier (Linhai Xinxiangrong Decoration Material Co. Ltd).

Table 3-2: Specification of thermoset epoxy

Quality index		Value	
		Epoxy resin	Hardener
1	Mixing proportion	3	1
2	Specific gravity	1.14±0.1	1.02±0.1
3	Color	Colorless	Brown
4	Viscosity (Maps)	550±50	
5	Pot life (min)	30±10 at 23C^0	
6	Hardening time (hr)	24-36 at 23 C^0	

3.2.3 Poly Vinyl Chloride (PVC) foam

Poly vinyl chloride (PVC) foam was used to make sandwich (core) with the following properties:

Table 3-3: Specification Poly vinyl chloride (PVC) foam

Quality index		Value
1	Code	02310111
2	Name	20 mm foam board H45
3	Specifications	H45
4	Characteristics	- Excellent heat resistance. - Light material Easy installation. - Excellent mechanical properties Significant heat Insulation. - Good resilience and high impact energy absorption. - Good chemical corrosion resistance. - Good resistance to cracking under stress.

3.3 Fabrication of the composite

Manufacturing of composite material sandwich structure isotropic flat sample configuration face (-45^0 / $90^0/45^0/0^0$), in core Sandwich structure (PVC foam) and back (-45^0 / $90^0/45^0/0^0$), sample dimensions (80*40cm with 6mm core thickness and 60*40cm with 3mm core thickness), with clarification (marking) direction of warp and weft yarns.

3.4 Fabrication methods

Materials were selected, the molds were prepared done, and prepared fiber glass clothing is pleased according to the angle sequence ($0^0/45^0/-45^0/90^0$). Mix the epoxy matrix, mixed is performed in the mixed containers with the mixed stick should be done slowly so as to not entrap any excess air bubbles in the thermoset epoxy matrix. Place fiber glass clothing in mold surface with angle (0^0), next deposited epoxy matrix over fiber glass in the mold use a brush to spread it around all surface (it is important not to add too much epoxy), the first layer of fiber reinforcement is then laid (lamina), this layer must be wetted with epoxy and then softly pressed using a brush make the epoxy that was added in the previous step pick up through the fiberglass cloth. At this stage a second layer with angle (45^0) of glass fiber cloth is added and special care must be taken to eliminate all air bubbles. Bald up the layer with angle (-45^0 and 90^0) in the same way at the moment it is complete face. Poly vinyl chloride (PVC) foam to make sandwich (core) added up epoxy, then make the back layer according to the way make face layer. Put weight from above composite materials sample (wetted) in systematic manner to expel air. Distribute epoxy in good way in composite materials sample. Curing sample in oven at temperatures around (160 degrees C^0), bearing outside cool.

Weight of fibers glass is the 1560 (g/m^2), weight of epoxy is the 752.4 (g/m^2), foam (PVC) weight is the (45 g/m^2 specimen with 6 mm thickness and 40 g/m^2 specimen with 3 mm thickness) and sandwich composite materials weight is (specimen with 6 mm thickness 2357.4 g/m^2 and specimen with 3 mm thickness 2352.4 g/m^2).

Figure 3-1: Composite materials sample (80*40CM).

Figure 3-2: Composite materials sample with 6mm core thickness.

Figure 3-3: Composite materials sample (60*40CM).

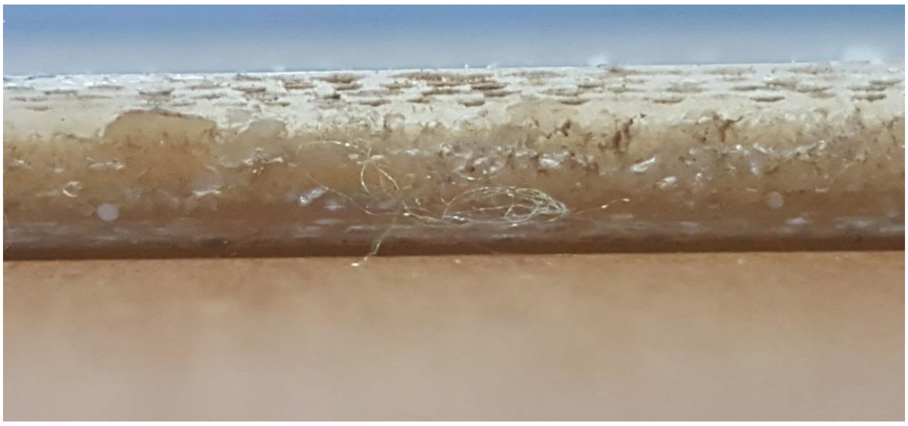


Figure 3-4: Composite materials sample with 3mm core thickness.

3.5 Laboratory testing

3.5.1 Flexural Properties of Sandwich Constructions tests

Flexural Properties of Sandwich Constructions tests were performed on six composite coupons. Three specimens were tested with 6mm core thickness and three with 3mm core thickness according to ASTM C393-00 standard (ASTM, 2000). This test method covers determination of the properties of flat sandwich constructions subjected to flatwise flexure in such a manner that the applied moments produce curvature of the sandwich facing planes, used machine Zwick / Roell tester with zwick z010 load cell 10 KN with single arm extensometer at pre-load (0.1 MPa) and speed 1mm / min.

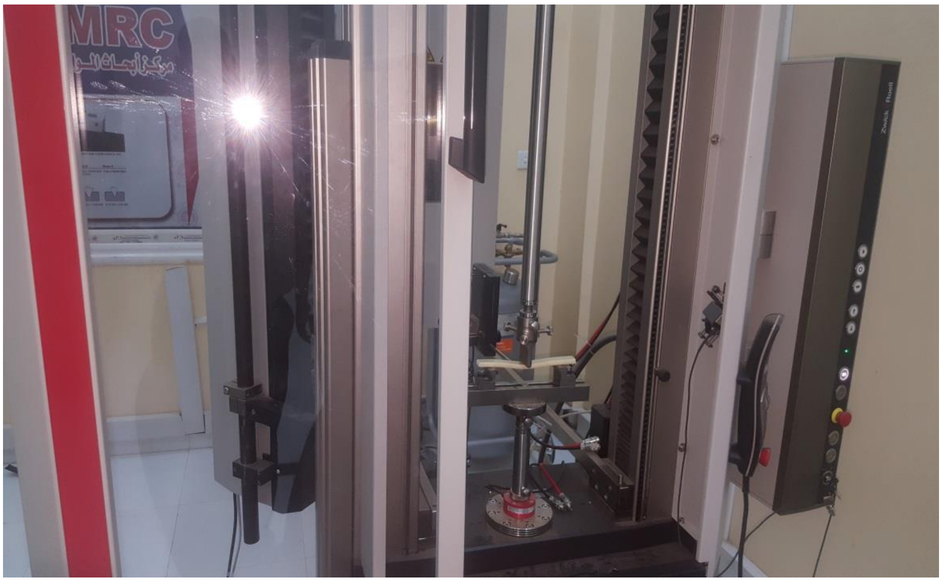


Figure 3-5: Zwick / Roell tester machine for (3 point bending teats).

3.5.2 Flatwise Compressive Properties of Sandwich Cores

Compressive tests were performed in accordance with the ASTM C365-03 standard (ASTM, 2011). Eight coupons were tested: four with 6mm core thickness and four with 3mm core thickness. This test method covers the determination of the compressive strength and modulus of sandwich cores. These properties are usually determined for design purposes in a direction normal to the plane of facings as the core would be placed in a structural sandwich construction. The test procedures pertain to compression in this direction in particular, but also can be applied with possible minor variations to determining compressive properties in other directions, used machine Zwick / Roell tester with zwick z010 load cell 10 KN with single arm extensometer at pre-load (0.1 MPa) , speed compression modulus 1mm / min and test speed 0.5mm/min.

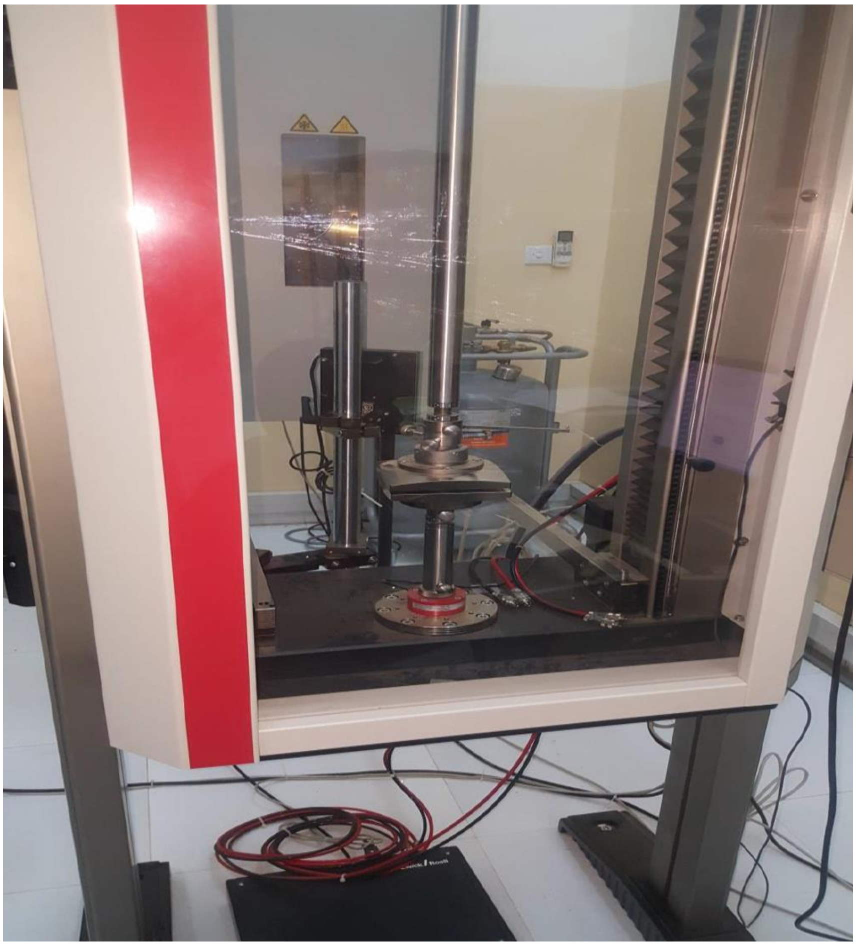


Figure 3-6: show Zwick / Roell tester machine for (compression teats).

3.5.3 Measuring the Damage Resistance of a Fiber-Reinforced Polymer Matrix Composite to a Drop-Weight Impact Event

Impact tests were performed in accordance with the ASTM D 7136 M-12 standard (D/DM-12, 2015). Sex samples were tested: three with 6 mm core thickness at 5, 15, and 30 Jules and with 3 mm core thickness. Compare specimen with 6 and 3 mm core thickness to determent behavior of specimen at different level of energy (5, 15 and 30 Jules). This test method determines the damage resistance of multidirectional polymer matrix composite laminated plates subjected to a drop-weight impact event. The composite material forms are limited to continuous-fiber reinforced polymer matrix composites. The test method may be used to screen materials for damage resistance, or to inflict damage into a specimen for subsequent damage tolerance testing.

Figure 3-7: show tester machine for (impact teats).

3.6 preparation specimen

According to standard (ASTM C393-00, ASTM C365-03 and ASTM D7136M – 12) to cut specimens used computer programs (coloration) programs with machine CNC.

Table 3-4: Specimen preparation

Test specimens	Dimensions			Standard
	L(mm)	b(mm)	d(mm)	
6 mm core thickness	130	8.7	20.5	ASTM D 7264-7
3 mm core thickness	90	5.5	20	ASTM C 393-00
6 mm core thickness	25	8.7	25	ASTM C365-03
3 mm core thickness	25	5.5	25	
6 mm core thickness	150	8.7	100	ASTM C365-03
3 mm core thickness	150	5.5	100	

The tested is done in conditioning should be made in room under the same conditions, temperature of 23± $3C^0$ (73± $5C^0$) and relative humidity of 50± 5% are recommended for standard control conditions, Machine used zwick /roell to tested flexural , compressive and impact tested used machine.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Result and discussion

4.1.1 Flexural Properties of Sandwich Constructions

This test method covers determination of the properties of flat sandwich constructions subjected to flatwise flexure in such a manner that the applied moments produce curvature of the sandwich facing planes. The main results obtained of force and displacement values, which were processed in order to produce graphs of Force Displacement Curves.

4.1.1.1 Load-displacement curves

Table 4-1: Force sample maximum load, displacement 3mm core thickness

Sample	Maximum load (N)	Displacement (mm)
1	160	22.5
2	150	21.9
3	140	22.9

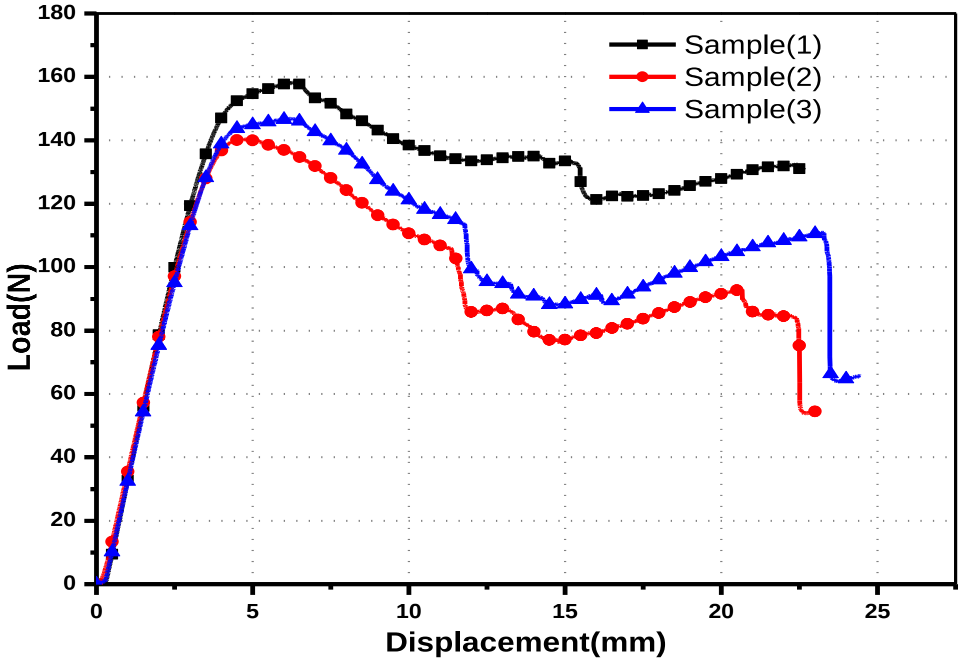


Figure 4-1: The Load- Displacement curve of samples with 3mm core thickness.

Table 4-2: Force sample maximum load, displacement 6mm core thickness

Sample	Maximum load (N)	Displacement (mm)
1	180	13.0
2	170	17.5
3	130	14.0

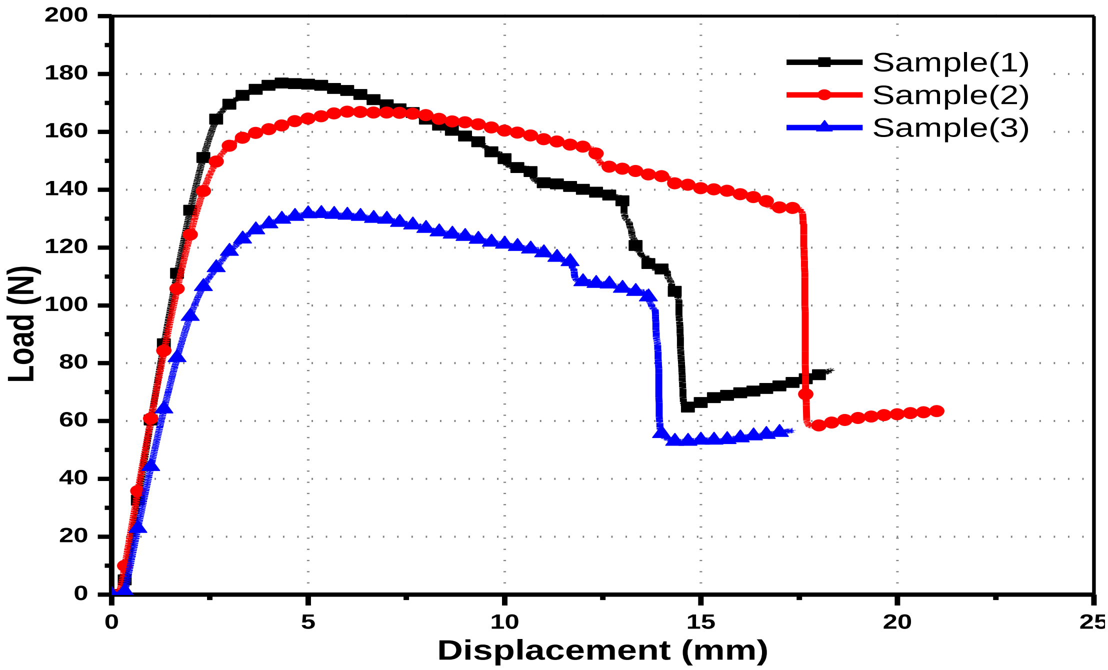


Figure 4-2: The Load - Displacement curve of samples with 6mm core thickness

These graphs relate the force applied on the test specimen with the displacement of the machine header (which is considered to represent the deflection in the middle span length of the upper face of specimen where the force is applied).

Can be divided load displacement curves in figure (4.1) and (4.2) three distinct regions.

The first region is primary region of compressive behavior of skin laminates. This region initially corresponds to reversible linear behavior and initiation, progression and development of transverse cracking in 90° plies of the skin.

The second region exhibits the compressive behavior of core due to bending of the top skin and leads to non-linear behavior of load-displacement curve that is mostly dependent on the properties of core. In the third region, with the further increase in force, there is initiation and development of delamination between skin and core which leads to the fracture of the skin. The fracture of skin corresponds to sudden drop of approximately 40% of the maximum load in the load displacement curve. After the fracture of skin, load is transferred to the core material leading to crushing under concentrated loading.

The PVC foam in the central region of the specimen experiences the compressive stresses, which is reflected in the specimen a long plateau region in the curve. At the end of this plateau, all failure mechanisms combine and resulted in the complete failure of the specimen.

4.2.1.2 Comparison of specimen with 3 and 6 mm core thickness load – displacement curve

Table 4-3 and figure 4-3 shows comparison of specimen with 3 and 6 mm core thickness load – displacement curve. Can be divided load displacement curves in figure 4-3 three distinct regions.

Table 4-2: Campari force sample maximum load, displacement 6mm and 3mm core thickness

Sample	Cod	Maximum load (N)	Displacement (mm)
6mm core thickness	SANB	180	13.0
3mm core thickness	SANS	160	22.5

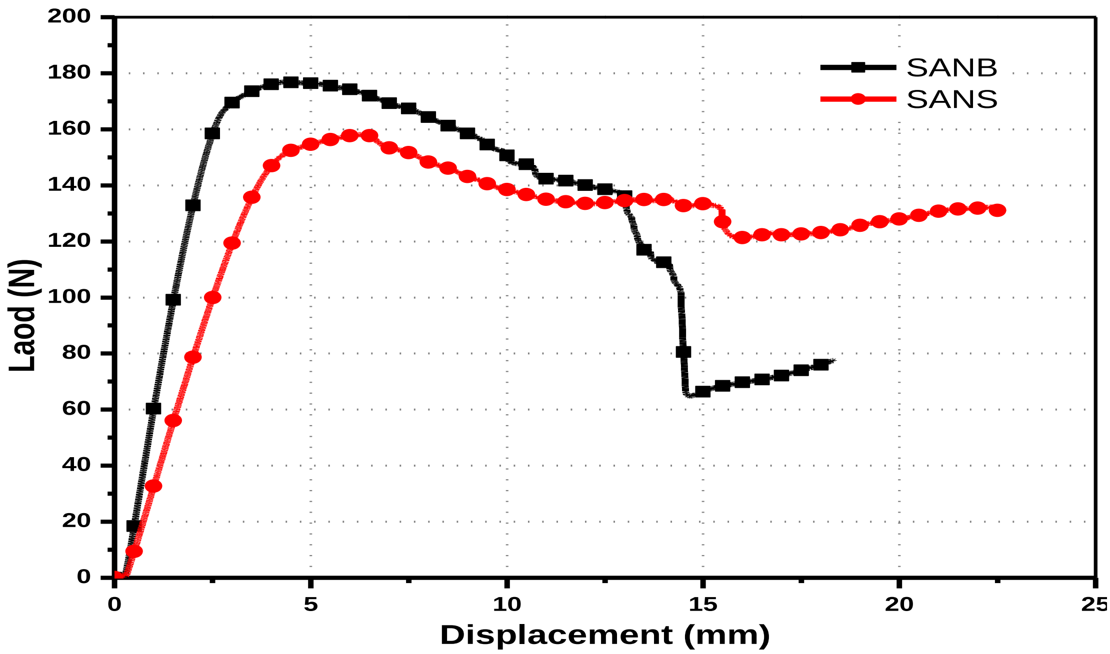


Figure 4-3: the load-displacement curve of specimen with 3 and 6 mm core thickness.

In specimen with 3 mm core thickness (SANS) pick force linear speed to reach yield point at (160N), shortness distant linear region, after this point start nonlinear region and failure. In specimen with 6 mm core thickness (SANB) pick force linear speed to reach yield point at (180N), long distant linear region, after this point start nonlinear region and failure.

Specimen with 6 mm core thickness (SANB) it has the ability to carry high force level compared to other specimen with 3 mm core thickness (SANS), absorption force displacement in specimen with 3 mm core thickness (SANS) have larger displacement estimated at (around 7 mm) and specimen with 6 mm core thickness(SANB) have absorption force displacement estimated at (around 3 mm) lees than other specimen, indications indicate better in specimen with 6 mm core thickness than specimen with 3 mm core thickness.

4.2.1.3 Failure modes

Figure 4-4 and 4-5 shows failure modes in static tests for sandwich composite of different thickness (3mm and 6 mm core thickness) failure modes can explain by an initially linear response region, all curves reveal a substantial nonlinear response. The nonlinear response is attributed to plastic deformation of the cell walls under extensional and bending loads. The failure process and load-displacement responses were indicative of ductile material behavior. The properties of the core material, the thickness in particular are also found to control the static strength of the sandwich composite. higher core thickness have higher static strength, all the sandwich Composite show that after maximum force, there is no increase in force, while displacement increases until failure. The failure was characterized by almost vertical crack that initiated on the tension side of the beam and rapidly propagated on compression side. The failure process and the force deformation response are indicative of ductile failure. These cracks it is observed that that cracks are of similar shape for tow thickness (3and 6 mm core thickness), thus assuming a similar kind of failure mechanisms for specimen.

Figure 4-4: Shows surfaces of specimen with 3and 6 mm core thickness pending test.

Figure 4-5: Shows cross-sectional view of specimen with 3and 6 mm core thickness pending test.

4.2.1.4 Calculation face bending stress

Table 4-1 shows the evaluated of face bending stress with specimen 3and 6 mm core thickness. This can be seen from this figure 4-1 and 4-2 the Load - Displacement curve of samples with 3and 6mm core thickness.

Face bending stress increases with the decreasing in the core thickness due to the short distance between the top and back face, because the two layers face and back work to gather to peck load. From the above can be said that the specimen with 3 mm core thickness is better in bending stress than specimen with 6 mm core thickness.

$$\sigma = \frac{PL}{2t(d+c)b} \qquad (1)$$

Where:

σ = facing bending stress, MPa (psi);

P= load, N (lb.);

L= span length, mm (in);

t= facing thickness, mm (in.);

d= sandwich thickness, mm (in.);

c= core thickness, mm (in.); and

b= sandwich width, mm (in.).

Table 4-3: Core face stress specimen with 3and 6 mm core thickness

No	Specimen	Load(N)	Stress(MPa)
1	3mm core thickness	160	21.08
2		150	19.76
3		140	18.45
4	6mmcore thickness	180	19.86
5		170	18.76
6		130	14.34

4.1.2 Compressive Properties of Sandwich Constructions

This test method covers the determination of the compressive strength and modulus of sandwich. These properties are usually determined for design purposes in advection normal to the plane structural sandwich construction.

4.1.2.1 Load – displacement curve

Table 4-5, table 4-6, figure 4-6and4-7 shown the load – displacement curve specimen with 3and 6 mm core thickness energy absorbing behavior can be divided in three distinct regions:

Table 4-4: Sample maximum load, displacement
3mm core thickness

Sample	Maximum load (N)	Displacement (mm)
1	180	2.3
2	220	0.3
3	210	0.3

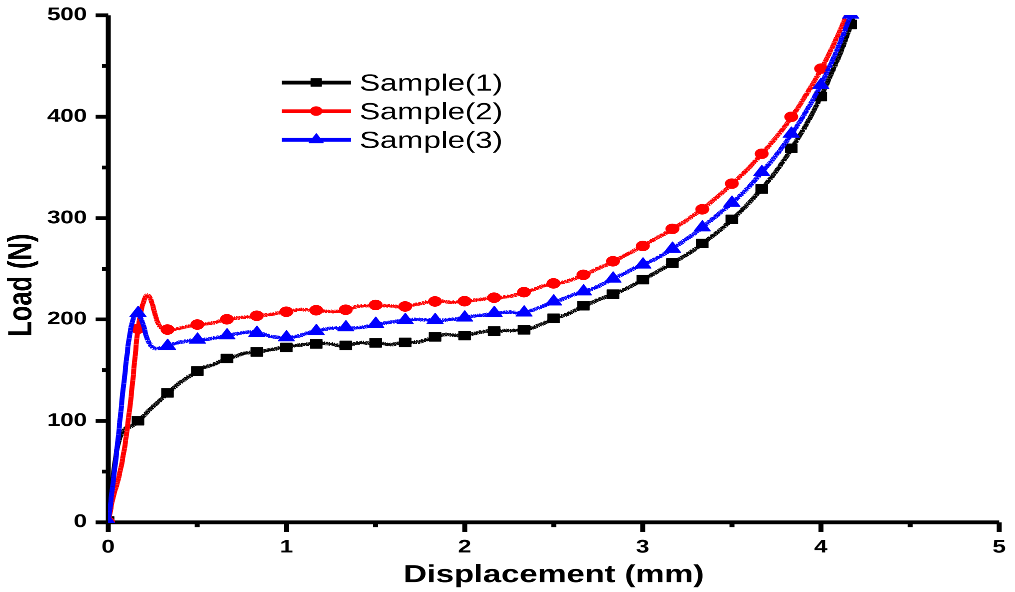


Figure 4-6: The Load - Displacement curve of samples with 3mm core thickness.

Table 4-5: Sample maximum load, displacement
6mm core thickness

Sample	Maximum load (N)	Displacement (mm)
1	520	0.2
2	490	0.3

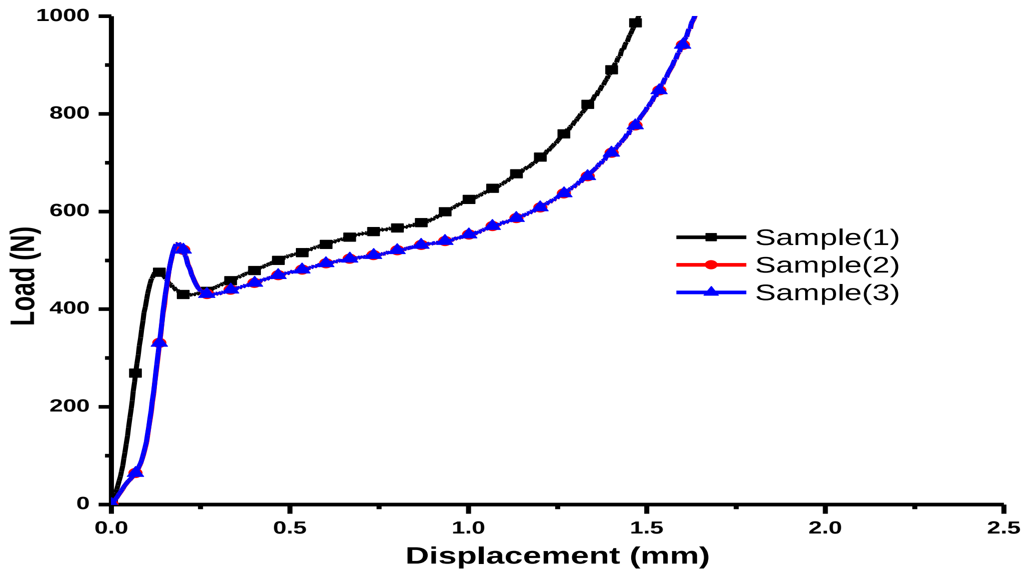


Figure 4-7: The Load - Displacement curve of samples with 6mm core thickness.

The first region is linear region behavior of skin laminates. The second region exhibits behavior of core due to bending of the top and back skin and leads to non-linear behavior of load-displacement curve that is mostly dependent on the properties of core and a start creak in core. There is initiation and development of delamination between skin and core which leads to the fracture of the skin. The fracture of skin corresponds to sudden drop of approximately of the maximum load in the load displacement curve. After the fracture of skin, load is transferred to the core material leading to crushing under concentrated loading.

With increasing the core thickness, which offer more resistance in the deformation of the specimen thus more energy is needed in compression in specimen with 3 mm core thickness (around 220 N) and in specimen with 6 mm core thickness (around 520 N) . Increasing the thickness of the specimen core increases the slope of the linear elastic part, raises the plateau and reduces the strain at which densification starts.

4.2.2.2 Comparison of specimen with 3 and 6 mm core thickness load – displacement curve

Figure 4-8 shows comparison of specimen with 3 and 6 mm core thickness load – displacement curve. Aloes can be divided load displacement curves in three distinct regions, compressive behavior of skin laminates for each specimen, the second region exhibits the compressive behavior of core, there is initiation and development of delamination between skin and core which leads to the fracture of the skin.

Table 4-6: Campari force sample maximum load, displacement 3mm core thickness, 6mm core thickness

Sample	Cod	Maximum load (N)	Displacement (mm)
3mm core thickness	SANB	220	0.3
6mm core thickness	SANS	520	0.2

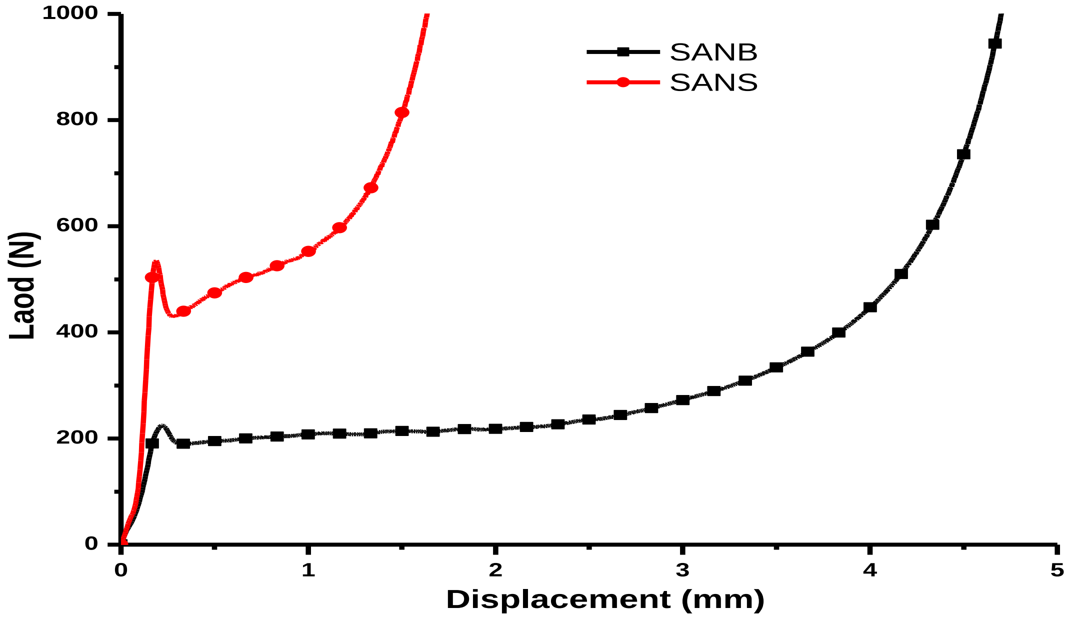


Figure 4-8: The Load - Displacement curve of glass fiber sandwich composite with 6mm and 3mm core thickness.

In specimen with 3 mm core thickness pick load linear speed to reach yield point at (220N), shortness distant linear region, after this point start nonlinear region and failure. In specimen with 6 mm core thickness pick load linear speed to reach yield point at (520N), long distant linear region, after this point start nonlinear region and failure. Specimen with 6 mm core thickness it has the ability to high absorption energy level compared to other specimen with 3 mm core thickness, specimen with 6 mm core thickness than specimen with 3 mm core thickness have good absorption energy due to large core thickness wine increases in thickness increase in absorption energy because the test machine move the distant smaller to core thickness.

4.2.2.3 Failure modes

Figure 4-9 and 4-10 shows failure modes in static tests for sandwich composite of different thickness (3mm and 6 mm core thickness). Failure modes can explain by failure was considered to have occurred when the specimen could not withstand any additional increase in load to failure; the first area is nearly linear with no damages, then, the load-displacement curve the second area non-linear behavior due to damages, the ultimate failure load was defined as the specimen peak load. The behavior looks like that of a perfectly plastic material and seems due to the penetration of the fastener head before the catastrophic failure. Failure modes as there are many failure modes existing in the specimen. Skin face peak load, core foam under pressure from face (lamina) and bonding between face, core foam disintegrates due to started core foam crushing, increase load (pressure) in top face increase crushing core foam, after that catastrophic failure in core foam was broken by compression and shear and applies tow face (top and back) in the second stop test because fiber strong than foam.

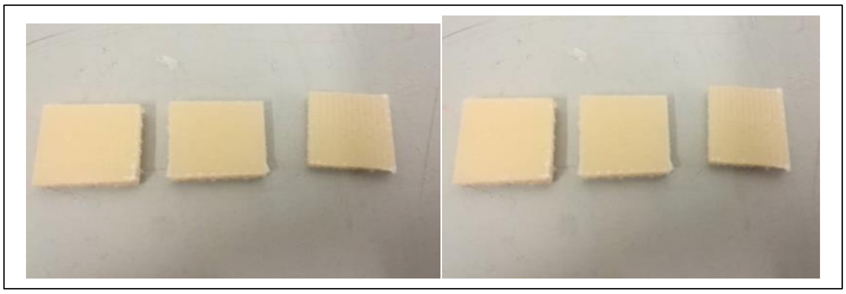


Figure 4-9: Surfaces of specimen with 3and 6 mm core thickness Compressive test.

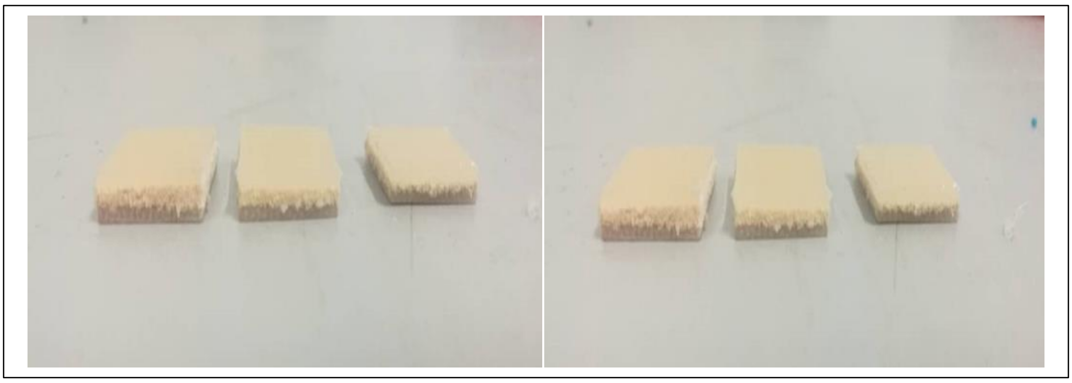


Figure 4-10: Cross-sectional view of specimen with 3and 6 mm core thickness Compressive test.

4.1.3 Drop-Weight Impact of Sandwich Constructions

This test method deters 'mines the damage resistance of multidirectional polymer matrix composite laminated plates subjected to a drop-weight impact event; the composite material forms are limited to continuous-fiber reinforced polymer matrix composites. Impact energy levels of 5, 15 and 30 J were being used.

4.2.3.1 Load displacement curve

Table 4-8: Different level Joel's, load and displacement 6mm core thickness

No	Joel's	Peak load-1(N)	Peak load-2(N)	Displacement (mm)
1	5	1.2	-	7.4
2	15	1.5	2.0	15.0
3	30	1.6	2.5	27.0

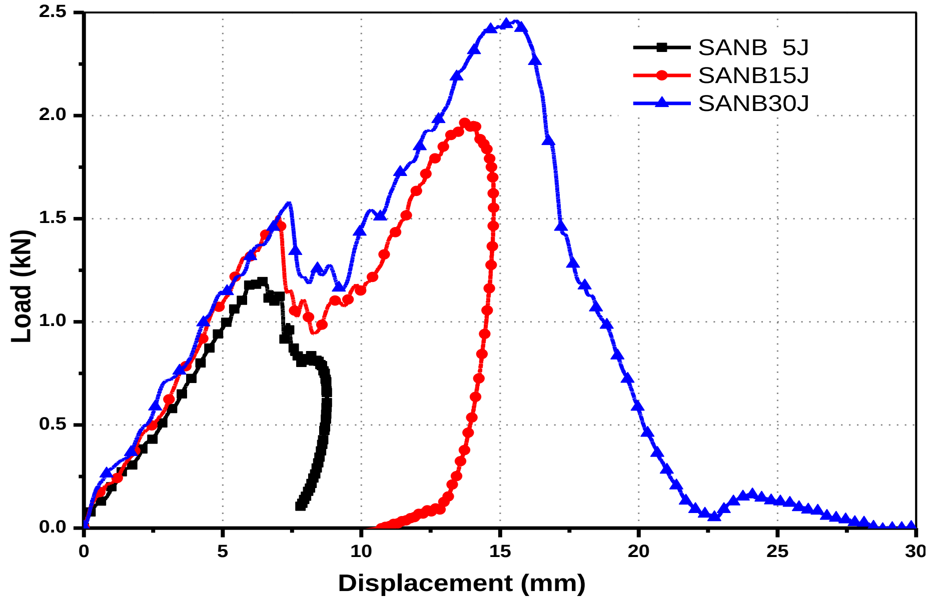


Figure 4-11: Load - Displacement curve impact test specimen with 6 mm core thickness.

Table 4-8: Different level Joel's, load and displacement 3mm core thickness

No	Joel's	Peak load-1(N)	Peak load-2(N)	Displacement (mm)
1	5	1.5	-	7.0
2	15	2.7	-	13.0
3	30	3.0	-	20.0

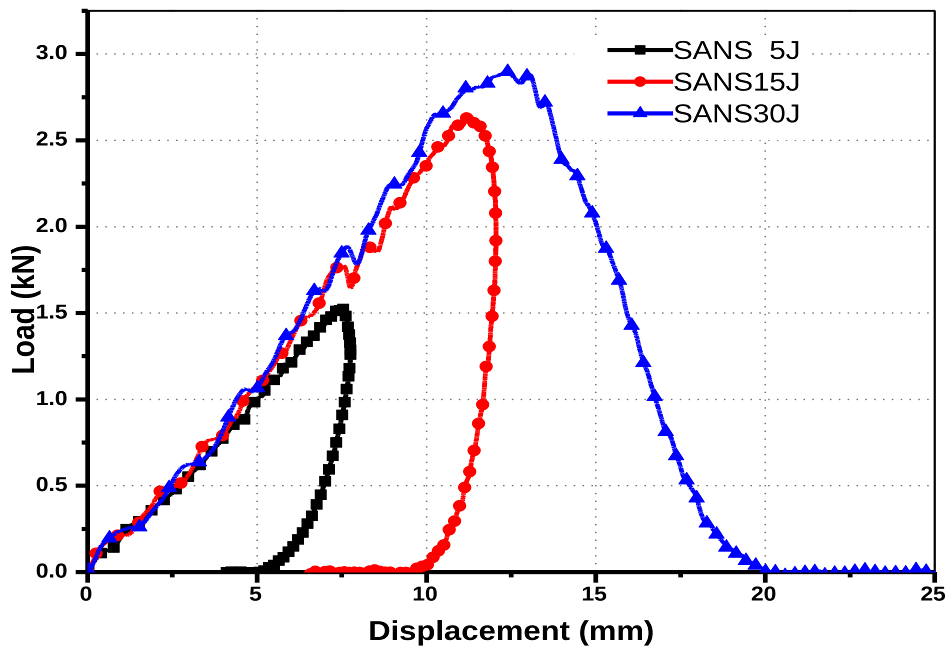


Figure 4-12: Load - Displacement curve impact test specimen with 3 mm core thickness.

Display figure (4-11 and 4-12) load displacement curve impact tests specimen with 3 and 6 mm core thickness respectively.

The curves can be divided into three regions: the first region, linear in appearance could explain the elastic deformation of the specimens. The deformation was noticeable when the displacement of the indenter was affected in the upper surface. The second region after the load reached a peak value, a significant drop of about 50% in the peak load was seen and a displacement curve was observed in the specimen's structures. This sudden drop would be due to fiber reinforcement cracking. After the crack initiated in the tensile side, it propagated to the compressive side within all types of specimens before the final failure occurred.

After the load drop, the specimen continued to sustain the load, but never exceeded the previous peak load as only the fiber reinforcement carrying, the load which is reflected in the third region. In this region, a plateau region was observed until reaching final failure. The final failure occurs when the upper skins crush due to compressive failure or in some case the skin and the foam deboning occur due to core shear failure.

Dynamic tests comparators between specimens with 3and6 mm core thickness.

The load-displacement curve at different energy levels have been obtained by using the drop weight testing method in order to analyze the impact damage and failure model of the sandwich composite with different thickness core. The failure modes involved in impact damage under varied impact energies of sandwich composites with different thickness core. These modes were being described and characterized by the, face skin failure, core shear failure, back skin failure, penetration depth and the deboning between the face and core materials.

4.2.3.2 Comparison of specimen with 3 and 6 mm core thickness load – displacement curve with different load (5,15and30J)

Table 4-9: Campari of sample at 5(J), load and displacement
3mm core thickness, 6mm core thickness

Sample	Cod	Peak load-1(N)	Peak load-2(N)	Displacement (mm)
3mmcore thickness	SANB	1.5	-	7.0
6mm core thickness	SANS	1.2	-	7.5

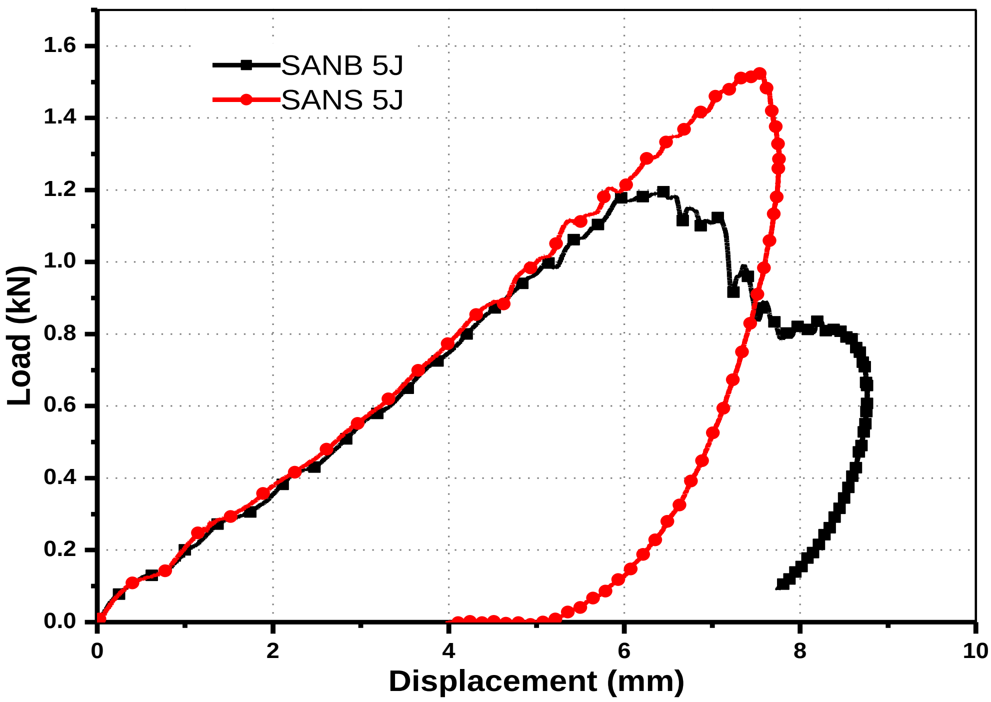


Figure 4-13: Load - Displacement curve impact test at (5 J) glass fiber sandwich composite with 3and 6mm core thickness.

The peak load does not vary much within all sandwich structures (different thickness and quasi-isotropic face/back sheets) and at all impact energy levels (around 1.2 to 1.5 KN). Figure (4-13) illustrate the load displacement curve for sandwich composites with 3and 6mm core thickness at 5J, respectively.

The displacement was found to be increased with an increase in the thickness (around 7.4 and 7.0 mm), the load does not absorption in all sandwich structures especially specimen with 3mm core thickness, in specimen with 6mm core thickness also not completed because energy used is less than density and thickness of foam core (6 mm).

Table 4-10: Campari of sample at 15(J), load and displacement

3mm core thickness, 6mm core thickness

Sample	Cod	Peak load-1(N)	Peak load-2(N)	Displacement (mm)
3mmcore thickness	SANB	2.7	-	13.0
6mm core thickness	SANS	1.5	2.0	15.0

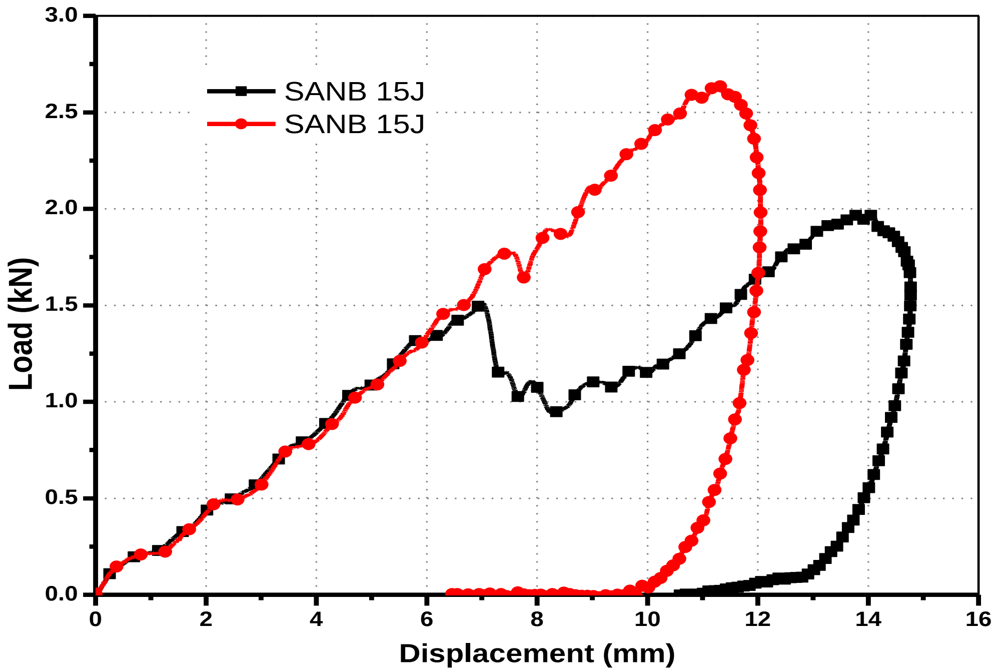


Figure 4-14: Load - Displacement curve impact test at (15 J) glass fiber sandwich composite with 3mm and 6mm core thickness.

Figure (4-14) illustrate the load-displacement curve for sandwich composites with3and 6mm core thickness at 15J, respectively. The peak load have very much within all sandwich structures vary much within all sandwich structures (different thickness and quasi-isotropic face/back sheets) and at all impact energy levels (around 1.5 to 2.7 kN), as mentioned earlier was found to be increased with an increase in the thickness (around 15.0 and 13.0 mm), also in specimen with 3mm core thickness load absorption incomplete because the distance between the face and back is small (foam sandwich structures 3 mm) For this reason, the face and back layers work together. On the other hand in specimen with 6mm core thickness the load-displacement curves at medium impact energy level (15 J) exhibited a prolonged plateau region. In this case, the foam undergoes certain damage, whereas the indenter comes in contact with the bottom face sheets without damage, the sample at 15 J; the top face sheet completely failed leading to foam penetration and cracking.

Table 4-12: Campari of sample at 30(J), load and displacement 3mm core thickness, 6mm core thickness

Sample	Cod	Peak load-1(N)	Peak load-2(N)	Displacement (mm)
3mmcore thickness	SANB	3.0	-	20.0
6mm core thickness	SANS	1.5	2.5	27.0

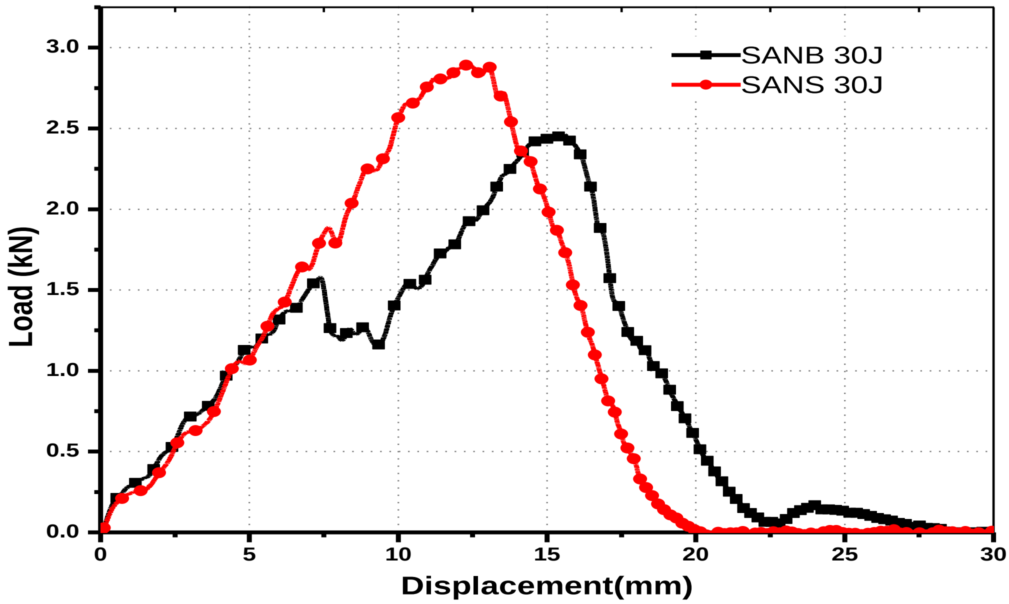


Figure 4-15: Load - Displacement curve impact test at (30 J) glass fiber sandwich composite with 3mm and 6mm core thickness.

Figure (4-15) shows the load-displacement curve for sandwich composites with3mm and 6mm core thickness at 30 J, respectively. The peak load have very much within all sandwich structures vary much within all sandwich structures (different thickness and quasi-isotropic face/back sheets) and at all impact energy levels (around 2.5 to 3.0 KN).

Specimen with 3mm core thickness the same behavior is previous when used 5Jand 15J.But in specimen with 6mm core thickness In the case of 30 J energy level, sudden peak load drop has led to a prolonged plateau region which indicates the interaction of the indenter through the foam core. The indenter penetrates the foam and makes contact with the back face. A secondary peak value was also observed could be due to the load carried by the back face.

4.2.3.3 Failure modes

Failure modes in specimen with 3and6 mm thickness core, comparing the failure modes of different thickness it can be observed that sandwich structures have similar behavior of failure in same thickness. At low-impact energy levels, the top face failure and for the medium impact energy levels, the top face completely failed, leading to the penetration of the indenter within the foam and contact with the back face. Whereas in the case of high-impact energy levels, the three layers of the foam sandwich composites were failing due to the indenter penetration within the three faces. Whereas in the case of high-impact energy levels, the three layers of the foam sandwich composites were failing due to the indenter penetration within the three faces. The damage size increased with an increase in the impact energy levels within all sandwich structures, also in increase in core thickness.

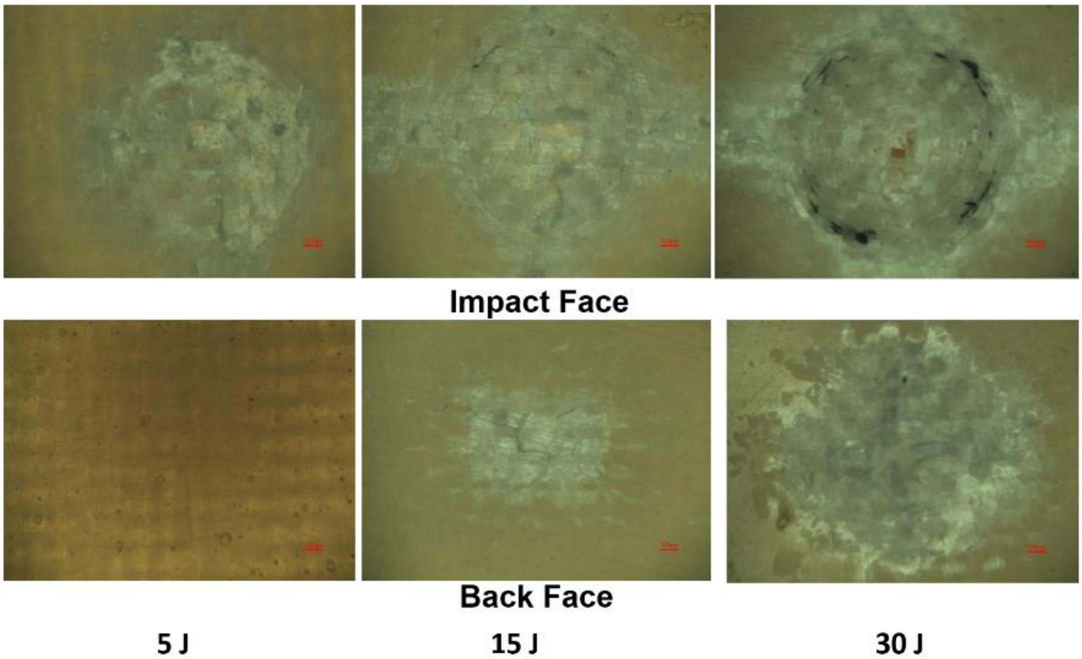


Figure 4-16: the top and bottom surfaces of specimen with 6 mm core thickness under 5,15and 30 J.

Figure 4-16 shows the view of top and bottom surface of the foam sandwich composites with 6 mm core thickness. For the low-impact energy level (5 J), small damage observed in the top face laminate consists primarily of delamination and matrix cracking. For the medium-impact energy level (15 J), the top face laminate is completely failed, which create significant damage in the top face sheet and consists of delamination with matrix crack and fiber breakage. In the high-impact energy level (30 J), the top laminate has the same damage like the medium impact level (15 J) damage in the form of delamination and in the back layer.

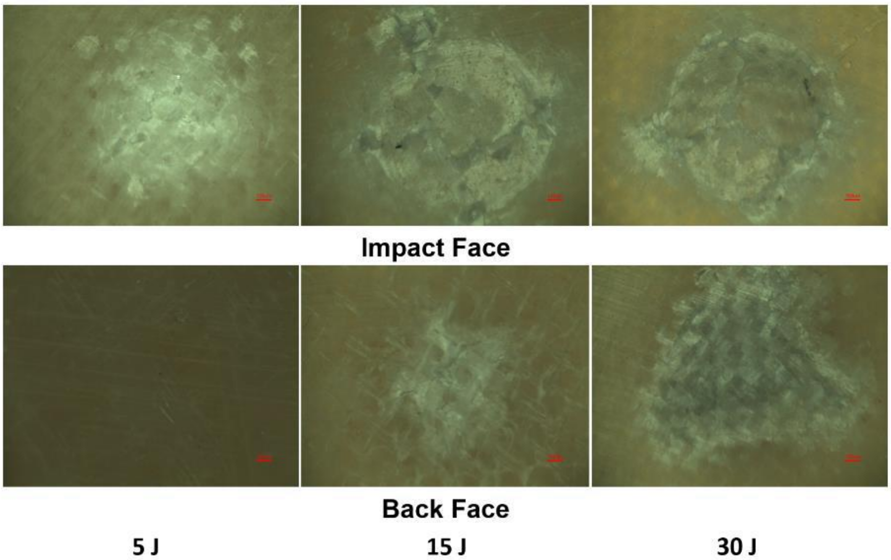


Figure 4-17: the top and bottom surfaces of specimen with 3 mm core thickness under 5,15and 30 J.

Figure 4-17 shows the view of top and bottom surface of the foam sandwich composites with 3 mm core thickness. At the low impact energy level (5 J), small damage observed in the top face laminate consists primarily of delamination and matrix cracking. For the medium-impact energy level (15 J), the top face laminate is completely failed, which create significant damage in the top face sheet and consists of delamination with matrix crack and fiber breakage, But the damage is less than the specimen with 6 mm core thickness at the same joule. . In the high-impact energy level (30 J), the top laminate has the same damage like the medium impact level (15 J) damage in the form of delamination and in the back layer also have small than specimen with 6 mm core thickness.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In the present thesis the design procedure, involving both experimental and computational studies, has been presented for the case of study light weight composite sandwich for train body. The experimental activities allow characterizing the basic stiffness and strength parameters of the selected composite material.

The fabrication and testing of light weight composite sandwich for train body (glass fiber reinforced epoxy skin and core poly vinyl chloride foam) with different core thickness demonstrated the following:

1) The sandwich design would significantly lower the mass (sandwich around 2357.4 gm^2 and iron 7072.2 m/g2) of any structure, and it is easy to get blindsided by its apparent potential.

2) Care should, have utilized reinforcing steel frames within the body structure.

3) Common practice is to assume a perfect bond between face and core in the sandwich panel, thus enabling dimensional plate modeling with effective material properties.

4) All sandwich beams tested in 3points bending exhibited a linear-elastic behavior; this initial response was followed with stiffness softening prior to failure.

5) The specimen with 6mm core thickness (around 180 N) construction exhibited better strength when peck load than the other specimen with 3 mm core thickness (around 160 N) and in bending face stress the specimen with 3 mm core thickness have values bending stress (21.08 MPa) higher than specimen with 6 mm core thickness (19.86 MPa), investigated in this research, this is due to the remarkable effect of

thickness. Also, excellent bond was observed between the poly vinyl chloride (PVC) foam core and the facings in the beams.

6) Compressive properties of sandwich constructions similar failure behavior but specimen with 6 mm core thickness has (around 220 N) better resisting to compressive than specimen with 3 mm core thickness (around 220 N). It was found that compressive models in flatwise compression increased with increase in thickness. With change in thickness there was a marginal increase in compressive models.

7) Drop-weight impact of sandwich constructions fond in both experimental and computational studies that cracks initiate from the tensile side and propagate to the compressive side within the core in all sandwich structure specimens, the final failure occurs when the upper skin crashed and the skin-foam faced deboning. Specimen with 6 mm core thickness tapes better absorption different level energy and specimen with 3 mm core thickness they have less absorption level energy.

5.2 Recommendations

1) The applications of this specimen are use be used as a viable alternative to train body structural system since it meets structural performance requirements and has many desirable properties, specimen with 6mm core thickness used at train body and specimen with 3 mm core thickness at breaks between train vehicles and doors, due to result of their experimental use in this reaches.

2) This help in technology transfer process especially in railway sector , this the beast techno-transfer vehicles as describe above, in the future, we will work on the manufacture of railway vehicles using composite sandwich materials.

3) Helps in reducing the cost of maintenance in the Nile and Al Jazeera train, by taking advantage of this these.

Are aspect that has not been touched throughout this these is the cost of the manufacture process and simulation with result according to real environment.

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