FRACTURE ANALYSIS OF SYNTHETIC FIBER WITH PVC BASED MATERIAL

A PROJECT REPORT

Submitted by

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BONAFIDE CERTIFICATE

Certified that this project report "**FRACTURE ANALYSIS OF SYNTHETIC FIBER USING PVC BASED MATERIAL"** is the bonafide work of **"NARESH KUMAR .S (211419114183), NAVEEN .K (211449114186), PRADEESH .P (211419114203), RAGHUL RAJA .R (211419114225)"** who carried out the project work under my supervision.

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ABSTRACT

Composite materials have made a major impact in the area of engineering material research. Sandwich composites are used in aerospace, automobile, shipbuilding, and structural applications in civil engineering and also in the making of lightweight materials with absolute dimensions, reducing noise, control of the heating, and cooling process. Sandwich composite materials are prepared by a combination of reinforcement and matrix for the fabrication of stiff and lightweight composite materials. Theyare fabricated using different foam materials with different foam orientations. In this research work, two or more constituent materials of foam and fiber with different orientations have been combined.

In hybrid sandwich composite materials, a distinct reinforcement of fiber, polypropylene, and PVC foam is distributed in a matrix. A hybrid sandwich composite is fabricated with polyurethane foam, PVC foam as reinforcement with epoxy resin as matrix, and carbon as a skin material. Sandwich composites of polyurethane, PVC, and hybrid sandwich composite fabrication are fabricated using the hand lay-up method. Polyurethane, PVC, and hybrid composite have different orientations.

Epoxy resin was used as a matrix material in the fabrication of the composite. Mechanical tests conducted on this sample included tensile, flexural, impact, double shear, inter delamination, and hardness. For the analysis of the temperature property of the sandwich composites, Thermo Gravimetric Analysis (TGA) test was conducted. The morphological structure of the mechanically tested sandwich composite was analyzed through the use of SEM images.

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CHAPTER 1

INTRODUCTION

Sandwich foam composites have proved their quality with their less weight and the recent challenge to reduce the cost of fabrication of the composites. Efforts are given to the manufacture of sandwich composites for a reduction in cost. Composite manufacturing companies have initiated more business opportunities in the aerospace zone due to the absolute dimension, lightweight, and high strength of the transport applications.

Developments in sandwich foam composite materials in the aerospace industry are moving very fast. Peng Yang et al [74] had conducted test on polyurethane sandwich foam material. Sandwich composites have more strength and least mass ratio and good hardness characteristics. So they have been found to the suitable materials to replacing the materials like metals, wood, etc. A composite intellectual from the whole world is concentrating on sandwich composite materials to minimize the cost of the materials and reuse the ability of the sandwich composite.

1.1 DEFINITION OF THE SANDWICH COMPOSITES

Figure 1.1 shows the sandwich composite is composed of two face sheets combined with one foam core material. The sandwich composite may be defined as a combination of two or more different foam core elements that are not soluble in each and having different chemical properties. It is a mixture of two components in which one is known as the reinforcing phase and it is the form of foam that is implanted in other materials known as the matrix resin phase.

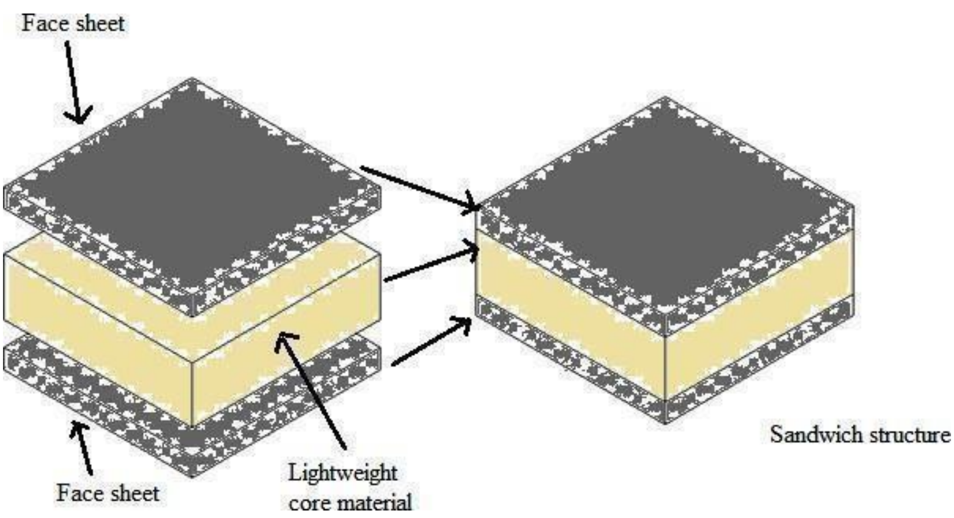


Figure 1.1 The sandwich composite plate structure

Foam with artificial or natural fibers combined to form a strong sandwich composite reducing the weakness of each material. Sandwich composites are generally used in replacing metals due to their strength and lightweight. The matrix is metal, plastic, or ceramic material that has been used for binding the fibers and the foam together like an adhesive and makes them more resistant to external damage.

Foams, matrix, and fibers are generally manufactured from different sources of materials. Foams used mostly are polyurethane, PVC, polypropylene, honeycomb, aramid, and balsa wood. Fibers effectively used in the fabrication of composites are carbon, silicon carbide, glass, or asbestos. Fibers make the matrix stiffer and stronger and help the sandwich composites resisting cracks and fractures. Sandwich composites are used mostly in aerospace, automobiles, marine, and structural applications.

1.2 HISTORY OF COMPOSITES

In the 1870s, a polymerization process was generated to allow new synthetic resin for phase transformation to form a chemical structure. The synthetic resins used in the early stages are bakelite, celluloid, and melamine. In the 1920s, carbon fibers were introduced as the main reinforcement in aircraft industries and sports equipment.

In the 2000's sandwich composite materials were widely used in automotive, consumer appliances, textile, railways, defense, marine, building, electronic industries, etc. The primary concern of the sandwich composite is related to the good performance with reduced cost becomes the entry to the advanced foam composites.

1.3 CHARACTERISTICS OF COMPOSITES

Various fiber-reinforced polymers and sandwich composite provide a combination of strength and modulus better than old metallic composite. On account of less density, the ratio of modulus to weight, and high strength to mass ratios these sandwich composite materials are higher level than the metallic composites.

Fatigue strength and fatigue damage of the sandwich composite laminates are specified the outstanding performance. These are the reasons; the polymers and the sandwich foam composites have emerged as majorelements in the use of structural materials considered as a substitution for metal components in the aerospace, automotive, and other industries.

1.3.1 Fibers

Fibers are important elements in fiber plates and sandwich foam composite materials fabrication. Fiber materials are a major volume fraction of the sandwich composites. In the sandwich laminates reinforcing fiber usually show maximum tensile loads applied to the structures. The additional matrix helps the fibers sharing the major part of the mechanical load when used in fiber-reinforced composites. The applied mechanical loads are tensile, compressive, and flexural or shear strength to the reinforced polymer structures.

1.3.2 Polymeric Matrix

Thermoplastic and thermoset plastic are the two types of polymers. The natural properties of the thermoplastic polymers are softening materials with the ability to melt and reshape them many times when heated. But thermoset polymers cannot be reshaped by the application of heating, melting, and change in pressure.

Thermoplastic matrix components can be used in temperatures ranging from 100° c to 300° c depending on the material used. The advantage of thermoplastic composites is improved fracture tolerance. The manufacturing cost of the thermoplastic is low compared to the thermoset matrix.

Traditionally, in structural applications, thermoset polymers are used as matrix materials in sandwich fabrication with stronger chemical resistance and thermal stability. The reduced storage life at low temperature and the time delay in fabrication are the disadvantages.

Strains to failure of the composites are very low. The types of thermosets are polyester resin, epoxy resin, vinyl ester resin, phenolic resin, and high-performance resin.

1.3.2(a) Polyester Resin

Polyester resin commonly used in the manufacturing of glass-reinforced plastic shows excellent characteristics. The reaction of the saturated or unsaturated condition of the polymers with di-functional acid and glycols is used for forming the unsaturated polyester resin. Reasonable cost and ease in manufacture are the polyester resins' advantages.

1.3.2(b) Epoxy Resin

Epoxy resins are used in aerospace structural applications. Resin and the hardener are used for forming the epoxy resins. Epoxy resin is a copolymer used in marine construction also monomers or short-chain polymers are mixed with the epoxy group to form the resin.

The reaction between epichlorohydrin and bisphenol-A can produce the epoxy resins and is also substituted by related 45 chemicals. Triethylenetetramine is a polyamine monomer mostly used as a hardener. Covalent bonds are formed due to the reaction of the epoxide group with amine groups. So, the final results of the polymer are highly cross-linked. Due to this cross-link reaction, the polymers become very tough.

1.3.2(c) Vinyl Ester Resin

Epoxy and polyester resins are mixed together to form the vinyl ester resin. The epoxy resins are chemical coincidence with the vinyl ester resin.

Vinyl ester resins are higher-ranking to polyester resin becausevinyl ester resin produces excellent resistance to H_2o and has excellent chemical resistance and superior retention properties. Also, they have more strength and stiffness at elevated temperatures.

1.3.2(d) Phenolic Resin

Phenolic resins have better fire resistance properties. They were introduced for high-temperature applications of the composites and possess mechanical properties of polyester resins and epoxy resins. The phenolic resins are utilized as a cold-cure for molding of the structural applications.

They can withstand maximum operating temperatures, reduced smoke, and toxic gas emission characteristics. They find applications are internal bulkheads, greater flame retardation, decoration, and also used in ships mostly phenolic resins are used.

1.3.2(e) High Performance Resin

High-performance resins are developed in the composite matrices to achieve excellent performance at intense heat. The processing characteristics of the high-performance resin are decreased when an increasein the thermal strength.

1.4 PREPEGS

Combined materials of fiber and matrix can get one entity; may help to avoid the getting of matrix and fiber individually. Prepegs are semi-cured matrix resins which act as a binder to well-dropped fiber structure.

They are available in both twists and unidirectional structures. They are easy to handle and are mostly applied in the molding of intricate geometrical structures.

1.5 FILLER AND OTHER ADDITIVES

Fillers used in the polymeric matrix for the following reasons

- Cost concession
- High modulus
- Viscosity control
- Smooth surface

Polyester and vinyl ester resins are mixed with calcium carbonate fillers. Calcium carbonate minimizes the cost of the fillers and also reduces mold depreciation. Other fillers used in composite fabrication are the clay, mica, and glass microspheres. Though fillers have increased the unreinforced matrix modulus and lowered the impact resistance and matrix strength.

1.6 CLASSIFICATION OF COMPOSITES

Figure 1.2 shows the classification of polymer composites based on the matrix. Composites are classified into three types depending on the matrix material. The composite types are explained below.

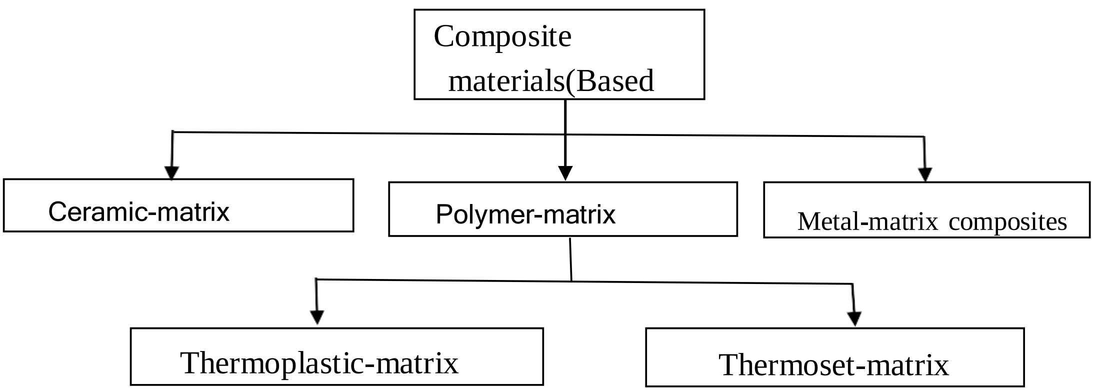


Figure 1.2 Composite types based on matrix

1.6.1 Metal Matrix Composites (MMCs)

They possess a metal matrix and the examples are composites comprising magnesium, titanium, and aluminum. The fiber holds the particle of silicon carbide and carbon. MMCs are manufactured for meeting the need for composite part fabrication.

The thermal and electrical conductivities of the MMCs are increased when increasing the strength and elastic stiffness of the metals. The addition of fillers such as silicon carbide to the MMC may minimize the coefficient of thermal expansion.

1.6.2 Ceramic Matrix Composites (CMCs)

CMC contains calcium, alumina silicate combined with the silicon carbide. Silicon carbides can withstand maximum heat. High strength, chemical inertness, hardness, and high service temperature at low density are the benefits of CMC. The ceramic materials may set-off brittle and get fractured.

1.6.3 Polymer Matrix Composites (PMCs)

Now a day, PMCs composites are mostly used in the composite industries. PMC contains the polymer thermoplastic mixed with natural boron. It can be made into different dimensions depending on the requirement of the component.

It provides excellent stiffness, strength, and resistance to corrosion of the composite. Polymer matrix composites are most commonly used due to their high strength, low cost, and easy fabrication. PMC has magnificent specific characteristics due to the lower density of the ingredients.

1.7 CLASSIFICATION OF POLYMER MATRIX COMPOSITES

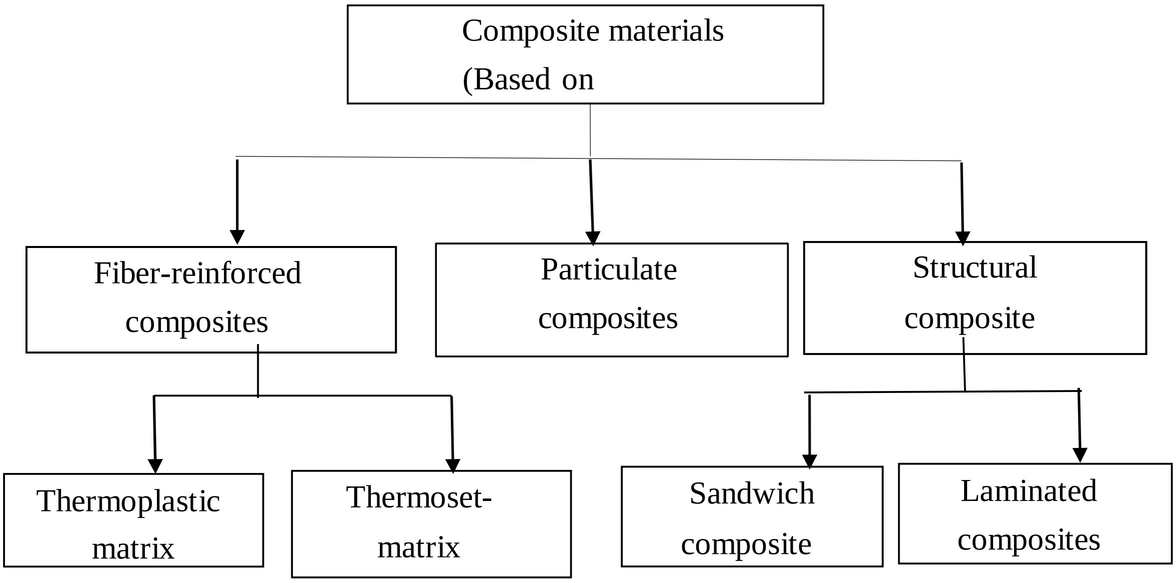


Figure 1.3 Types of polymer composite

Figure 1.3 depicts the composite types depending on reinforcement. There are three types of composites used details are given below. Structural composites are further sub-divided into two types. They are laminated composite and sandwich composites.

1.7.1 Particulate Composites

Reinforcement of particles produces the composite. The different sizes of the particle are cubic, spherical, platelet, and tetragonal, regular, and irregular structure. But the particles are roughly equal in shape. So particle mixtures are seen in spheres, flakes, rods, and different sizes are approximately the same percentages.

Generally, particles improve the stiffness in the composite to some limit and increase the characteristics of the composites such as modification of the thermal and electrical stability. They help to reduce friction and good performance at a higher temperature. The other properties to increase abrasion and wear resistance, improve machinability, and surface hardness.

1.7.2 Fibrous Composites

Length and cross-sectional areas decide the fiber characteristics. The long dimension of the fiber is used in the fabrication of the composite to reduce crack enlargement. Fibers of non-polymeric manufactured show very good performance towards the fiber length. Defects present in the bulk material are minimized due to the reduced area of the fibers.

Arrangement of particle structures can achieve increased stiffness and strength for the polymeric composite. The fibers are low cost, sustainable, partially or completely recyclable, and biodegradable. Formerly they were collected from the nature of cotton, hemp, jute, flax, kenaf, sisal, ramie,bamboo, banana, pineapple, and wood as a source of lignocellulosic fibers. These natural fibers are widely used in the fabrication of composites.

Availability, low density, renewability of the fibers enables good mechanical performance they also excellent substitutes for carbon, glass, and man-made fibers. The natural fiber is easily biodegradable and the applications are in aerospace, building, construction industries, railway coaches, automobiles, consumer products military applications, and packaging, etc.

1.7.3 Structural Composites

Structural composites are used in aerospace industries, automobile body constructions, and civil engineering constructions, etc. Structural composites are grouped into two types of composites. They are explained below in detail.

1.7.3.1 Laminate Composites

A laminate composite is obtained by a mixture of a more number of fibers in a matrix. Layers of fibers are continuous or discontinuous, organized in a random or specified direction. Random orientation of the fibers can help to obtain an equal mechanical strength in all directions of the composite. The fibers may be arranged in parallel to one another in a specific direction for unidirectional lamina.

A laminate can be created by stacking layers of several laminas. Laminate composites are widely used in the fiber-reinforced structure. A convenient shape and size of the laminate can be set up to support the applied load and to withstand the deflection. For the achievement of the desired mechanical property of the composite, the orientation of fibers, and the sequence of the fibers are modified.

1.7.3.2 Sandwich Composites

Intermediate foam materials act as a key material for the sandwich composites. The variety of design of sandwich composite is done to reduce noise, weight, fire resistance to control heating and cooling performance. This sandwich composite gives higher bending stiffness-to-weight ratio than single plate solid composites.

1.8 FABRICATION TECHNIQUES

Composite specimens are fabricated among various methods depending on the shape and size required for the end product. The fabrication techniques for composites are explained in detail below.

1.8.1 Hand Layup Method

The hand layup technique is one of the oldest and most widely used methods for the construction of fiber composite plates. Component requirements are reduced in the preparation of the composites in these methods. The processing steps in the fabrication of composites are quitesimple.

Liquid paraffin is sprayed on the top of the mold surface at the start of the fabrication for avoiding the fiber plunge into the mold. Thin plastic sheets are covered at the bottom and top of the mold for getting uniform surface finish of the composite plate. The fibers which are in the form of woven are cut according to the required size of the fabrication. After all the preparation now the composite plates are applied and prepared manually.

1.8.2 Compression Molding

Compression molding is used for the transfer of sheets into the required final product. The complex shape of any part can be manufactured in a short period of time. The parts of non-uniform thickness, bosses, ribs, holes, flanges, and shoulders, etc. are manufactured through the compression molding method.

Such moldings are used to eliminate the probability of another operation such as forming, drilling, and welding. The compression molding method can be automated. So this process is suitable for the more volume manufacturing of components.

1.8.3 Pultrusion Process

Straight and long structural members with a standard area of the cross-section are produced using this pultrusion method. The components of hollow tubes, solid rods, angle plates, beams of different areas, channels, flat sheets, hat sections, are manufactured from this process. Product of different width and the length along with curved shapes can be made using this method.

1.8.4 Filament Winding

Resin and fibers are wound over a rotating mandrel in a standard pattern. In this filament winding process, void-free parts are manufactured with a maximum fiber volume ratio. The fibers catch the low viscosity resin in the wet process and in the dry method, the pre-impregnated reinforcement is used. When the winding is completed, the defined shape and size components are disconnected from the mandrel after cured.

The filament winding process is helpful in getting pressure vessels, golf club shafts, fishing rods, tanks, and ducting, and rocket motor casings. Thermoset resins applied in the filament wound include epoxies, polyesters, vinyl esters, and phenolic. These filament windings may be an automated process and can produce more components. High-strength products are obtained from this filament winding method due to fiber order control. Various directions to control the strength of the component are also possible inthis method.

1.8.5 Resin Transfer Molding

Resin transfer molding is also called the liquid molding process. It is used in the manufacturing of medium-volume of composites. Mixed strand mats and woven are applied to the mold. Complex mold shapes are produced from glass reinforcements. Inside the mold, the catalyzed resin is pumped through the placed vents, and the pressure is maintained between 0.70-7.0 bars.

1.8.6 Vacuum Bag Molding

The pump generates a vacuum which is passed into the lay-up. It is a complex process in the making of components. Bag porosity may produce a porous contained component. Different tools are required to fold the bag in the proper places. The vacuum should be maintained until the resin gels. Wrinkles may appear in the manufactured components due to improperly positioned fold.

1.8.7 Spray Layup Method

It is an open mold method used in the making of complicated components at a low cost. Chopped fiberglass mixed with resin and the filler sprayed on the mold through the spray gun. Rollers are used for the removal of entrapped air. Woven fabrics are added in the needed places to obtain more strength of the components. The gel coats are applied to the components to get good quality colored surfaces.

1.9 WEAR BEHAVIOUR

The wear of sandwich composite plays the main role in the study and understanding of the tribological behavior of materials. More studies of wear shall be associated with five-decade, which are developed from the basic method of surface contact.

Friction and wear consume one-third of our global energy. Besides the primary saving of energy, more care should be given to minimize the manufacturing cost required alongside the exchange of prematurely exhausted parts. The dissipated heat energy by scratch has weakened the national economic growth. Hence, concentration on the reduction and control of wear property of sandwich composite are mostly desired.

Wear results in large annual spending to the organization and in consumer services. A majority of the wear analysis helps in replacing or repairing machine parts that have been worn out to the extent where they can no longer play a major role. For many machine parts, this may occur in the aftermath by a very small percentage of total volume. For some industries, such as agriculture, 40% of the parts that were continuously changed have failed continuously due to abrasive wear.

Wear characteristic is not an inherent material property but mainly depends on hardness, temperature, load, environmental condition, speed, and the presence of unwanted material. Surface damages need the removal of material on either side of the solid surfaces due to rolling, sliding, or impact motion between the surface contacts. Normally, wear was formed through surface interactions at the high sharpness of the surface contact.

During the motion of parts, the material on the contacting surfaces may be removed. Resulting in wear particles lost on the mating surfaces. Wear resistance depends on the microstructure generated during the component running condition. The wear of components relies on more factors; hence research on wear requires systematic planning. From the researcher's more useful information we can observe.

Wears are classified into five types. They are adhesive, abrasive, surface fatigue, erosive, and corrosive.

1.9.1 Abrasive Wear

Abrasive wear is produced during the contact of hard and soft surfaces. Most failures of the components are in abrasive wear. Hard surfaces of one component cause rubbing the other surfaces producing abrasive wear.

1.9.2 Adhesive Wear

Local bonding between contacting solid surfaces results in producing adhesive wear. When the surfaces are in close contact with other surfaces adhesive wear is produced. Lubricant and oxide film must be applied between the contacting surfaces for reducing adhesive wear.

1.9.3 Erosive Wear

It is a process of metal removal from the solid particles that have contact. Erosion is generated through a gas or a liquid form of solid particles. When the collision angle is less, similar wear is generated. When the collision angle is normal, the plastic flow of the material occurs causing the failure of the surfaces may come to in a brittle manner.

1.9.4 Surface Fatigue Wear

Fracture generated on the contact surfaces leads to surface fatigue. Cyclic loading is applied to the contact surfaces like tension and compression generating micro-cracks. These failures are produced below the surfaces and give weakened components.

1.9.5 Corrosive Wear

Most of the metals react with oxygen in the air. Oxides formed in the air develop a layer on the surface. Finally, corrosive wear is developed. It gradually eats into the unprotected surfaces of the metal, due to the effect of the metal, gases, alkalis, atmosphere, etc. This type of wear produces pits and perforations are formed due to this corrosive wear and dissolve the components continuously.

1.10 ADVANTAGE AND DISADVANTAGE OF SANDWICH

Sandwich composites are used in many applications. Sandwich composite has more advantages and disadvantages according to the practical usage of the product. They are explained in detail below.

1.10.1 Advantage

1. Sandwich composites can be made stronger than metal composites. Sandwich plates can be made stronger in a specific direction only.

2. Sandwich composites are of smaller weight, compared to most woods and metals, making them apt for automobiles, aircraft, and marine applications and enabling better fuel economy to vehicles.

3. The sudden force from a bullet can be absorbed from the sandwich materials. The bulletproof, shield airplanes, buildings, and military vehicles are made from sandwich materials.

4. Sandwich plat act as good insulators because they never transmit cold or heat easily.

5. An entire assembly can make from a single piece of sandwich parts. So it reduces the more parts required and also saves time to manufacture the other part.

6. Sandwich composite minimizes the maintenance time and cost of repair.

1.10.2 Disadvantage

1. Foam materials and skins not properly mixed can produce a common sandwich composite property.
2. Sandwich composites are not easily bending and make a curved shape like an aluminum composite material.
3. Sandwich composite materials do not break effectively due to the applied load.
4. Sandwich composite's life is too high so it needs a recycling process.
5. To purchase foam and fibers is too expensive.
6. After fabrication, the strength of every sandwich composite is varying.
7. To produce new parts of composite, a pattern is required.

1.11 APPLICATION OF SANDWICH COMPOSITE

Sandwich materials find wide use in many engineering applications. They should be carefully applied in the required places, for design practice and process to develop improved mechanical, thermal, and physical properties. Major applications include the aircraft industry, military vessels, marine, space, sporting goods, and building infrastructure, etc. which are briefly discussed below.

1.11.1 Aircraft Application

The foam is based on polyurethane applied in aircraft applications. Bearing components of rotary-wing aircraft are fabricated from sandwich materials. They are used in fiber composite airframes, fuel tanks, tail-plane structures, wings, flooring, helicopter rotor blades, bulkheads, and propellers.

They are also used as sandwich composites in pressured gas containers, structural components, nose and landing gear doors, air distribution ducts, seat components, access panels, etc.

1.11.2 Military and Aerospace Application

Sandwich structure helps to make a hanger for military and aerospace applications. Many civil and military aircraft components are made of carbon, glass-fiber, and kevlar composites as laminated in the form of panels and moldings. The nation and manufacturers are working on highstandard quality composite components to protect soldiers from enemies.

The rising use of sandwich composite materials and the advancement in materials mixed and their fabrication have helped sandwich composite manufacturers in meeting increasing demands from military vehicle parts. Composite cryogenic tanks are major components used in space travel. Lockheed Martin, Northrop Grumman, and Boeing are introduced inthe fabrication of the components based on this composite.

1.11.3 Automotive Application

The polypropylene seat is used in a car back seat in automobile applications. Weight reduction in automobile parts and concentration on energy saving are the main requirements in automobile applications. Glass fireplastics composite materials are used due to the increased cost of aramid and carbon fiber in the market.

The cost of glass-reinforced plastics (GRP) is usually much lower than the cost of steel metals, and the replacement has increased nowadays.

The components used in the car body moldings, panels, and bumper moldings, which are changing into composite materials.

1.1.1 Sporting Goods Application

The use of sandwich composite-based components is increased in the sports goods industry. Manufacturers are using the potential advantages of new hybrid composite materials. The conventional wood and metals are getting replaced by carbon and boron fiber composites based on sports equipment bought by the sportsman.

GRP vaulting poles are found useful in the composite sports gear, but now anyone gets the cricket bats, golf clubs, tennis rackets, fishing rods, boats, ski-poles, bicycles, and shielding sports components are fabricatedfrom the sandwich materials.

1.1.2 Marine Application

Foam and balsa lightweight sandwich composites find use in marine applications. The components used are offshore structures, surface vessels, and sea-water materials. Pleasure crafts are manufactured from the GRP composite. Components of hulls, other structures, and cooling circuits in sea-water are also made from the GRP composites.

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

The survey relates to the research work conducted by various researchers on sandwich composite. Sandwich foam composite along with their mechanical, thermal, and machining behavior are explained in detail in this review. This gives useful ideas relating to the fabrication of the composites and tests done on this sandwich foam composite. A review of the various foam materials used in the sandwich composites is also made.

1. Various sandwich composites
2. Various reinforcement materials used
3. Different types of fabrication of the composite.
4. Mechanical, thermal, and structural behavior of sandwich composites.
5. Machining characteristics of the sandwich composites.

Satay & Nirmal (2016) have studied the effects of core design that belongs to the bending test. They examined the problem of the mechanical behavior of honeycomb panels. They selected jute fiber in a hexagonal and circular shape through compressing molding techniques, and conducted an optical three-point bending test circular jute fiber and found it withstood 10

MPa and hexagonal jute fiber up to 9 MPa of higher bending strength compared to hexagonal jute fiber.

Sameh & Khaled (2017) made a study of fiber-reinforced polymer sandwiches subjected to blast resistance. They studied the problem of the sandwich panel subjected to blast effect. Selected polyurethane and dytherm foam as core materials and sand as a filling material. They conducted blast loads and finite element simulation and observed a maximum deflection of 260 mm for the W2 plate and the numerical results were correctly matched with experimental results.

Yicheng *et al.* (2012) investigated the lightweight honeycomb core panels having bio fiber fabrication and evaluation. They analyzed the problem of bio fibers. They selected phenolic-coated aramid nomex paper honeycomb and the whatman filter paper as a bio-fiber and polyurethane adhesive. In the creep test, the sandwich panel withstood maximum stress of 25 MPa, and the load-deflection of lab-made sandwich structure matches with results obtained using the Timoshenko model.

Belouettar *et al.* (2009) have experimentally investigated fatigue and static characteristics of honeycomb foam from a bending test. They analyzed the static and fatigue behavior. They selected aramid fiber as a face sheet and aluminum as a core material. In a four-point bending test, L- configuration was seen withstanding a maximum 6 KN load and maximum deflection of 95 mm. In W-configuration withstand 4.5 KN and a deflection of 25 mm and the aluminum core with L-configuration was more suitable for structural fatigue.

Dipak *et al.* (2013) experimented on sandwich composites. They studied the problem of optimizing the mass of composite materials. They selected aluminum foam and polyethylene sheets. Tensile tests without hexagonal structure withstood 13.54 KN and with hexagonal structure withstood 12.21 KN. In the bending test, without hexagonal structure, observe 14.47 KN and with hexagonal structure 13.92 KN and the tensile and bending capacity of hexagonal shapes are less compared to withouthexagonal composite materials.

Tochukwu *et al.* (2014) analyzed the fabrication and mechanical effects of a hybrid core for carbon fiber sandwich panels. They fabricated sandwich panels of the CFRP truss. They selected carbon fiber as a face sheet, and the core materials were kevlar fiber stitched to 3D woven and PVC divinycell foams, syntactic foam, and polyurethane foam. They were prepared via a vacuum-assisted resin transfer process. They conducted tensile and compression tests and analytical calculations and X-CT images. The average tensile strength was 640 MPa. In the compression test, hybrid CFRP attained 17 MJ/m^3 and foam attained 12 MJ/m^3 and honeycomb attained 2 MJ/m^3.

Flores-Johnson & Li (2011) made a study of the depression of the sandwich composite. They analyzed the quasi-static depression of sandwich structures. They selected carbon fiber as a face sheet and the core is polymeric foam. They conducted a quasi-static indentation test. The maximum stress observed in tensile was 684 MPa. In a flat indenter, 71WF plate observed maximum energy of 10.5 KN. Mm, and 51WF plate was observed minimum energy of 7.3 KN. mm. For more density core, the indentation resistance of both sandwich and core materials are the same.

Yicheng *et al.* (2013) conducted an experimental study of the creep behavior of natural fibers. They analyzed the creep response of natural fiber thermoset polymer. They selected bio fiber face-filter paper and phenolic-coated aramid. In a tensile test, the maximum stress obtained by PRP composites was seen as 75 MPa, and in a flexural test, the maximum stress obtained by PRP composites was 60 MPa, and the PRP sandwich panels were a high creep-rate compared to other sandwich materials.

Ariel *et al.* (2014) made a study of the manufacture and testing of the sandwich panel. They analyzed a novel honeycomb made of natural-fibers. They selected the jute fabric as a face sheet and honeycomb as core material. They were manufactured using compression molding. They conducted lateral compression and flatwise compression. Jute-vinyl ester 6 mm-cell core got a high compressive strength of 15.5 MPa and 10 mm-cell core got low compression strength of 13.5 MPa. Finally, Jude- reinforced core as an alternative core could withstand compressive staticloads.

Kress & Winkler (2009) analyzed the honeycomb structure residual stress deformation pattern. They analyzed the problem of face-sheet undulation. They selected nomex honeycomb core and face sheets of glass- fiber reinforced with epoxy resin. They conducted periodic deflection and parametric studies. The maximum amplitude of 0.23 mm for the core height of 10 mm was attained at 60º and the moisture enlargement of the aramid createsa higher free-strain contradiction.

Nayeem *et al.* (2013) conducted flexural strength of the hybridpanel. They analyzed the problem of multiple types of materials to set the desired strength. They selected the LY5052 matrix material and LY556 matrixmaterial. Resin LY5052 took a maximum bending load of 1.8 KN for 4 mm thickness with a displacement of 9 mm and the minimum bending load of 0.65 KN. They had a movement of 14 mm. Finally, the mixing of multiple materials increases in mechanical and thermal behavior.

Insub Choi *et al.* (2016) studied the effect of cyclic loading on a concrete sandwich wall. They analyzed a concrete wall under monotonic loads and wind-induced cyclic loads. They selected glass-fiber-reinforced polymer grids and GELO1-M and GXLO1-M specimens. In the cyclic loading test, the specimen GXL01-M withstood the highest load of 155 KN and the corresponding deflection of 65 mm and the cyclic test provided the least degree of composite action compared to the monotonic test at a constant rate.

Ajay K Misra *et al.* (1994) made a study of the modification of the interface aluminum-based intermetallic matrix. They analyzed the problem of an interface in intermetallic matrix composites, using the NiAl/Sic system. They conducted cyclic thermal conditions and logical analysis. Radial and longitudinal fiber cracks were created considering cyclic applied thermal load and the interfacial coating on ductile material was well bonded to fiber and the matrix.

Mileiko *et al.* (1995) made a study of the fabrication structure and mechanical behavior of carbon fiber/titanium silicide. They identified the problem of carbon fiber fabrication and strength properties. They selected titanium foils and carbon fiber as materials. They conducted the tensile, creep strength, and high-temperature strength tests. They measured mechanical strength to withstand up to 900º c and the rupture strength maintained at 800º c. Finally, the model results in insufficient thermal conductivity, sufficientheat capacity, and the time-dependent response of the composite test.

Skvortsov *et al.* (2003) examined the energy separation for ballistic perforation of the sandwich structure. They identified the problem of ballistic effect and penetration in the sandwich material. The selected material was glass fiber reinforced polymer as a face sheet and H80 foam as a core material manufactured by the hand lay-by method. They conducted bending and shear deformation and also developed an analytical model. They saw the agreement of the experimental data with the theoretical values.

Matthew & Lorna (2007) analyzed the optimization of spherical shells. They identified the problems to provide a more excellent analysis of isotropic, round shells with complaint cores. Selected material for a thin wall round structure is made from honeycomb or foam-like cellular core. They manufactured thin-wall by hand lay-up methods. They conducted tests on optimization based on modules of the core to the modulus of shell ratio for best design and the honeycomb core provided a better effect than a foam core.

Guan *et al.* (2014) conducted experiments on the blast resistance of stitched composite structures. They analyzed the effect of blast withstanding on the composite structure. Selected materials are a panel made of woven s-glass/epoxy skin and they are made cross-link of PVC core materials. The stitch-bonded was made using kevlar 129 yarn. They are manufactured using vacuum-assisted resin in the fusion process. They conducted tests through the finite element model and numerical analysis. Finally, the stitched laminates have greater blast resistance.

Soroosh & Giovanni (2017) investigated the design of a sandwich-based roof of the vehicle structure. They analyzed a model of the roof builds configuration, using sandwich materials. The selected carbon/epoxy compositeswere used as face sheets. Material use of polypropylene foam was made as core material. They conducted a test for rollover crash analysis and structural analysis using numerical simulation. In the end, they reduced the vehicle roof structure mass by 68%.

Rajaneesh *et al.* (2014) conducted a test on the performance of metal and polymeric foam structures at the velocity impact. They selected aluminum material as faceplates. Aluminum alloy foam was selected as core material and metal foam was constructed using polyvinyl chloride as a foam core material manufactured manually. They conducted a finite element model for a study of the impact behavior and also analytical modeling. They conducted experiments on tensile, compression, and the analytical methods agree with experimental measurement.

Xin & Wen (2015) made a study of continuous damage design for reinforced plastic composites under impact load test. Their work showed the effect and damage to plastic laminates. They conducted an impact load test. Selected materials were 2 mm and 4 mm deep carbon fiber reinforced polymeric laminates. They prepared this material manually. They conducted a mechanical test of impact loading-continuous damage mechanism (CDM) and the results under the numerical values.

Zhiqiang Fan *et al.* (2016) experimentally investigated the blast resistance of the metallic sandwich structure under the water explosion. They analyzed the problem of blast withstanding the metallic sandwich structure. The materials selected were two aluminum alloy face sheets and the honeycomb core was the core material. They prepared the sandwich structure manually. They conducted the water blast test and Anti-shockwave performance. The blast withstood shows a higher compared with the monolithic plate's results and the better performance can be obtained from the sandwich structure.

Yu Wang *et al.* (2014) made a study of the experiment characteristics structure under an impact test. They analyzed the impact the behavior of ultra-lightweight cement. They selected hollow steel pipes and ultra-lightweight cement as materials. They prepared the specimen manually. They conducted the test at a low velocity in a drop-weight impact test. They conducted a finite element mode also and the sandwich pipes have better impact performance with maximum impact resistance when compared to steel hollow pipes.

Abdul *et al.* (2015) conducted the experimental solution of CNT nano-fluids in the form of single-face flow. They analyzed the thermal- hydraulic behavior of carbon nanotube (CNT). They selected the material as a multi-walled carbon nanotube in distilled water prepared manually. They conducted the experimental test of heat transfer and the behavior of pressure drop. The nano fluids showed pressure drops higher than those of the base fluid and increased the pumping capacity by 10%.

Karagiozova *et al.* (2010) analyzed the simulation of the response of fiber metal panels to the blast loading test. They analyzed the behavior of Fiber Metal Laminates (FML) under localized blast loading. They selected aluminum alloy sheets for the face sheet and 1 to 3 layers of glass-fiber polypropylene and a polypropylene interlayer. They prepared the materials using the hand lay-up method. They conducted a test of numerical simulation, they used ABAQUS/Explicit, and also, they conducted localized pressure pulse loading. They saw the numerical results of the plate showed withstanding of larger localizedimpulse without high damage to the materials.

Bin Yang *et al.* (2015) made a study of the impact test response foam contained a sandwich with a hybrid face sheet. They analyzed the impact effect and residual compressive properties. Selected materials were C2/G2/foam core and carbon face sheet. They were prepared using a vacuum- assisted resin injection. They conducted a velocity drop weight, compression test, and also they observed microscopic morphology. Finally, the panel with a pure carbon face sheet structure had the highest residual compressive strength.

Karthick Ram *et al.* (2014) made a study of the response of the block copolymer and the nano-reinforcement on the velocity impact behavior and the dynamic effect of the sandwich panel. They selected the kevlar fiber- reinforced epoxy skin and took polymethacrylmide foam and added the triblock copolymer M25N nanostructure. The manufacture was made in a wet lay-up process. They conducted a low-velocity impact test and used the optical microscope. They saw M52N Elastomeric progressively improved the resistance of the kevlar material.

Zdenek *et al.* (2003) investigated the size variation and asymptotic fitting estimation of fracture of the polymeric structures. They analyzed the response of structure shape on the nominal strength of the PVC foam. They selected the material of PVC-foam (Diviny cell H100) they had prepared manually. They conducted the tensile test and compression tests and the numerical value has a close match near to Bazant's law and the tested values.

We Xu & Guogiang Li (2010) analyzed the constitutive modeling of the shape memory. They made this study to form a thermodynamics based constitutive model and to find the behavior of the small foam. They selected the material as synthetic foam SMP based they manufactured from a series of chemical reactions. They conducted the test of dynamic mechanical analysis and the Fourier transform infrared spectroscopy analysis and coefficient of thermal expansion. Finally, the finalized model is the bestmatch with the 1D test.

Kevin *et al.* (2016) analyzed the model of highly contrasted plates with experiments on laminated glass materials. They analyzed the problem of a theoretical and experimental characterization of Highly Contrasted Stratified (HCS) plates. Selected materials are the highly contrasted stratified plates and they are manufactured manually. They conducted a theoretical analysis, three points bending, a cyclic bending test, a creep bending test, and a shear test, andthe theoretical value of the temperature and frequency are in exact match with the experimental results.

Gielen *et al.* (2008) experimentally investigated the failure, and the crushing of a PVC-foam structure depending on a thermo dynamically elastoplastic-deform. They analyzed the problem of PVC foam in a thermo dynamically consistent framework undergoing damage and plastic effect. The selected material isPVC foam they prepared manually. They conducted stress and strain tests, compression, and tension tests. Finally, the structure got the required crushingresponse and damage response including the reloading effects.

Abdi *et al.* (2014) analyzed the flatwise position of flexural and compression characteristics of foam core and polymer foam core sandwich materials and found the response of the polyester foam. They selected the sandwich materials as polyester laminates face sheet, and they took polyurethane and polymer pin as a foam core material. They manufactured the structures through the vacuum infusion process. They conducted three-point flexural, flatwise compression, and tensile tests. They saw the diameter of the polymer pin as more important in the flexural stiffness.

Erheng Wang *et al.* (2009) made a study of stepwise graded cores of sandwich panels in the blast resistance. They analyzed the problem of the dynamic response of sandwich panels. They selected E-glass Vinyl ester compositesas a face sheet material and the stepwise graded styrene foam as

the core material. They manufactured the sandwich panel’s using the Gurit SP technologies. They conducted the dynamic behavior of the structure through the shock tube apparatus for shock-wave loading of these panels and the total energy difference of the reflected energies was almost identical.

Henrik *et al.* (2014) investigated the development of the bending strength of scarf-bonded carbon fiber panels. They analyzed the problem of bending surface animation for the scarfed rebuilding bonds. They selected a carbon-reinforced polymer specimen as the material and prepared the composite manually. They conducted laser activation of the bonding surface and they did the tensile test and the microscopic testing. Finally, the shown optimization steps to increase the bonding strength and then lowering the rebuilding with cost considerably.

Rasoul & Ali (2014) conducted a study of the changes in foam density in composite sandwich structures when applying high-velocity impact loading. They analyzed the problem of the effect of foam density charges. They selected glass fiber woven roving reinforced as the face sheet and rigid polyurethane foam as the core material. They manufactured the sandwich panels defined by gas gun target holders. They conducted the high-velocity impact test and scanning electron microscope. So that the maximum foam core density result in total foam collapse in a brittle manner.

Arora *et al.* (2017) analyzed the damage to composite structures exposed to multiple and single blasts. They analyzed the problem of blast resistance of the sandwich in increasing shock intensity. They selected glass fiber reinforced polymer as a skin material and styrene acronitrile (SAN) foam with epoxy resin as a core material. They manufactured the structures in the hand layup method. They conducted single blast loading and multiple blasts loading and also, analyzed in finite element modeling and these experimental data can be used for both the analytical andcalculation models.

Egidio *et al.* (2000) conducted the mechanical characteristics of asyntactic foam from experimental results and modeling. They analyzed the mechanical characteristics. They selected syntactic foam materials. They were prepared through the mixing of materials with the matrix. They conducted uniaxial tension/compression, biaxial compression, and a three-point bending test. Finally, the uniaxial tension and three-point bending test results exactly match the experimental findings.

Shashank & Pradyumna (2015) investigated the C^o higher-order layer-wise finite element formulation to analyze the sandwich plates. The analysis was based on C^o higher-order for static and free vibration analysis. They selected higher-order displacements for the middle layer and first-order displacement for the top and bottom layers. They conducted mathematical formulations, finite element formulations, and free vibration analysis. The higher-order layer-wise finite element method was convenient for finding the static and dynamic response of sandwich structures.

Vincent *et al.* (2015) analyzed moisture absorption created inside stresses in balsa core composite. They selected woven E-glass fiber/polyester resin as the skin and balsa wood as the core material. They were prepared by the hand lay-up method. They conducted diffusion behavior, hygroscopic expansion, and analytical and numerical analysis. The finalized diffusion of single balsa is higher than a sandwich structure.

Antoine & Batra (2014) made a study of the slow speed impact of laminated polymethylmethacrylate/adhesive polycarbonate plates. They analyzed the problem of deformation of transport laminates, impacted at low speed. They selected PMMA adhesive and polycarbonate (pc) as a core material prepared manually. They conducted the impact load simulation in LS-DYNA and created the mathematical model. Finally, the plastic deformation of the polycarbonate was seen as more than that of cracks created in the PMMA.

Vyacheslav & Tomasz (2010) analyzed de-bonding on the free vibrations characteristics of foam and honeycomb sandwich structures. They analyzed the problem of the dynamic behavior of partially delaminated sandwich structures. They selected glass fiber reinforced polymer as the skin material and aluminum honeycomb, PVC foam H100, and PVC foam H200 as core materials prepared using the ABAQUS software. The rectangular sandwich with a circular shape is more sensitive for free oscillations.

Khalili & Ghaznavi (2011) conducted a numerical analysis of T-joints and sandwich panels. They analyzed the problem of the effect of fillet geometry and core materials. They selected vinyl ester infusion as the skin material and divinycell HD250 PVC, H100 PVC, HCP70 PVC, and hardwood as core materials and prepared them using the automatic mesh. They conducted a numerical model using tensile load and damage and core shear failure by ANSYS and the failure load found by the finite element method is within 5% of the experimental values.

Madhukar & Singha (2013) made a study of the dimensionally nonlinear finite analysis of the sandwich structure using normal deformation theory. They analyzed the nonlinear bending and vibrational characteristics of the core sandwich structure. They selected a soft-core sandwich plate. They used higher-order FEM and first and third-order shear deformity theories. The shear and normal failure increased with the increase of thickness to span ratio and core materials to the skin thickness ratio.

Hamid & Ashkan (2013) experimentally investigated metal sandwich structures under multiple intense shocks. They analyzed mechanical response and fracture of metal under shock loads. They selected a square honeycomb core and also selected cores of folded plates, these materials are AH36, HY80-high strength steel, AL6XN-stainless steel, and DH36. They conducted multiple intense shocks and numerical simulations and at the end ofexperiments, a square honeycomb structure made from steel has more strengthand strain hardening and ductility values.

Zhou *et al.* (2013) made a study of numerical and experimental analyses on hail impact on composite structures. They analyzed the damage behavior of high-velocity hailstone’s impact on composite panels. They selected aluminum alloy plates and hailstone for support so, they took polyurethane sabots. They conducted numerical simulations and SPH method and 3D digital image correlation and increase in delamination following an increase in velocity. An HT3/421 composite structure was having excellent resistance to the impact of the hailstones.

Heimbs *et al.* (2009) conducted the velocity impact of carbon fiber reinforced polymer applied with compressive preload. They analyzed the problem of a compressive fore load on velocity behavior. They selected materials of type-A non-crimp fabric and typed B&C symmetric layup, both as 12K HTS carbon fibers. They manufactured it through Hexcel's RTM6 resin with the help of a vacuum-assisted process. They conducted low- velocity impact tests and compressive preloading and C-scan and simulation- LS-DYNA.

Salvo *et al.* (2010) made a study of connecting carbon/carbon composite. They analyzed the problems in bonding technology for manufacturing space instruments. They selected carbon/carbon as the skin materials and honeycomb carbon/carbon as the core material and joining materials are TicuNi brazing alloy and silicon powder. They produced the skin by the Chemical Vapor Infiltration (CVI). They conducted a wetting test, mechanical testing, et. Finally, both the thermal growth and moisture growth are better mechanical strength.

Alberto *et al.* (2011) analyzed an integrated assembly technic of sandwich panels for ceramic matrix composites. They studied the ceramic sandwich structure for higher temperature applications. They selected ceramic matrix composites laminates and SIC and ERBISIC-R foams as a core material. They prepared the hand layup method. They conducted an assembly method of SIC, CMC, and three-point bending tests and this method permits the production of composite shapes at a low cost. And also the shear is ordinarily constant throughout the core.

Zhibin Li *et al.* (2016) investigated local indentation of aluminum core composite beams at elevated temperatures. They analyzed a rigidly supported and simply supported beam. They selected aluminum as the core component and commercial pure aluminum as a face sheet. They conducted a quasi-static indentation test and analyzed of the model. In indentation test displacement is 6 mm and the maximum load withstands is 6.5 KN at the temperature of 300ºc. Finally, the indentation of a load of a beam i s reducedwith increasing temperature.

Weihong *et al.* (2010) conducted an impact test of a composite panel with aluminum core material. They analyzed ballistic performance. They selected two aluminum pieces of (Al-5005H34) as a face-sheet andaluminum foam material as a core material. They conducted Quasi-static impact performance (flat end, hemispherical nosed end, and conical nosed). The maximum energy observed was 45J when they used the projectile. For conical projectile was observed 25J energy and the resulted in more extensive tearing damage on the back face.

Zhong Tao *et al.* (2004) experimentally investigated the characteristics of stub columns and beam-columns. They conducted experiments on double skin steel tubular. They selected outer steel CHS and inter steel both CHS and concrete. They used a theoretical model and strain gauge stub column and beam-column in a universal testing machine. The maximum axial load applied was 600 KN and the fiber strength was 20,000. The final result of load and displacement are in an excellent match with stub column and beam-column value.

Abbadi *et al.* (2010) studied fatigue characteristics of honeycomb materials using a four-point bending test. They analyzed fatigue characteristics through experiments. They selected aluminum $Almg_3$ as a face sheet and aramid fiber (ECA) as a core material. They manufactured the composite through a hand lay-up method. They conducted a fatigue test, four points bending, and an analytical method. In fatigue deflection when thenumber of cycles reaches 18,000 the maximum deflection occurred.

Olurin *et al.* (2001) investigated fatigue crack propagation. They analyzed the fatigue behavior of the closed-cell aluminum alloy foams. They selected Al-mgl-si0.6 as a face sheet and Al-mgl-si10 as a foam core material. They conducted Linear Elastic Fracture Mechanism (LEFM) and Fatigue Crack Propagation (FCP). The maximum crack extension is 8 mm and the fatigue crack growth rate is controlled through progressive degradation of crack bridging.

Bayomy & Saghir (2017) made an experimental study of nano-fluid flow into the aluminum foam. They analyzed the new cooling methods for the fast removal of heat generated from electric components. They selected aluminum foam subjected to Gama-Al_2O_3-water nano-fluid flow. They used an experimental method and the numerical method and the average Nusselt number was enhanced up to 20% when they used ARGaluminum foam as a core material.

Crupi *et al.* (2012) investigated collapse mode in the aluminum sandwich panel. They analyzed static and low-velocity impact responses. They selected AA5052 aluminum alloy as skin materials. They conducted a static three-point bending, impact test, and theoretical approach. The maximum applied impact force was 20,000 N for GFR-AFS SCHUNK with a maximum displacement of 35 mm.

Yayun Zhao *et al.* (2017) experimentally investigated the aramid oneycomb panel undergoing impulse loading. They analyzed damage modes and the impact withstand of the composite structure. They selected the plates manufactured of titanium and honey core manufactured of aramid materials.

They conducted velocity interferometer systems for a reflector and analytical solution approach. The maximum velocity applied was 550 m/s and the time was 35 microseconds. Finally, the clamped boundary decreases the damage of the front plate but extends the local plastic deformation of the plate.

Jilin Yu *et al.* (2008) conducted the impact and static characteristics of composite beams. They analyzed the failure of aluminum core fabricated beam material. They selected aluminum alloy as skin material and aluminum as the core material. They conducted 3-point bending tests, low-velocity impact tests, and theoretical analyses. In the impact test, they applied a maximum 4.5 KN load and a maximum displacement of 10 mm.

Jiayi Liu *et al.* (2013) examined the mechanical characteristic of the carbon composite type of pyramidal core panel after the thermal exposure. They analyzed the thermo-mechanical behavior of pyramidal truss core subjected to axial compression. They selected carbon/epoxy as a face sheetand truss core as a carbon fiber struts manufactured by molding the hot-press method. They conducted thermo gravimetric analyses and compressive tests after thermal exposure and analytical method. The maximum compressive value of the sandwich was 165 MPa at -60ºc and the least strength of the composite was 10 MPa at 125ºc.

Leng Yu-Bing & Song Xiao-Bing (2017) investigated the shear and flexural behavior of the SCS composite. They made the analysis using the concentrated load. They selected steel-concrete-steel and steel-concreter as the materials and made the manufacture using a tie bar welded to the steel plate. They conducted flexural, shear, and analytical methods. In the flexural test, they applied a maximum of 2,200 KN load and the maximum displacement is 90 mm and the explained method could sharply find the capacities of steel- concrete-steel slabs.

Mojtaba & Mohammad (2016) analyzed the aero-elastic behavior of the magneto-rheological fluid sandwich beam. They analyzed supersonic aero-elastic instability of three-layered composite beams. They selected the constraining layer, the MR layer, and the primary layer. They conducted Hamilton's principle and the assumed mode technique. A maximum natural frequency of 1,000 λ was used and the magnetic intensity and depth ratios had essential effects.

Jiayi *et al.* (2008) investigated the compressive behavior of pyramidal truss core at various temperatures. They used a new method in the fabrication of the glass fiber composite sandwich method. They selected E-glass, pyramidal truss, epoxy resin, and pore at 60 degrees Celsius, which they prepared through vacuum-assisted transfer modeling technology. They conducted a scanning electron microscope and out-off-plane compressive test with the temperature limit of -60 degrees Celsius to 150 degrees Celsius. In a compression test, they applied 1.5 KN maximum loads and the maximum displacement was 20 mm. Finally, the cryogenic heat affects the increase of compressive value.

Manalo *et al.* (2010) conducted the flexural properties of composite beams in edgewise and flatwise positions. They selected polymer as the skin component and modified phenolic as the core material. They conducted the four-point static bending test, using the analytical method, and finite element modeling. They conducted a four-point position damaged at a maximum load with small deflection. They applied 8 KN maximum loads and they got a maximum displacement of 30 mm.

Pei Gu & Asaro (2008) investigated the wrinkling of the sandwich structure subjected to a transverse thermal gradient. They analyzed the problem of transverse thermal gradients. They selected E-glass/vinyl ester as skin materials and PVC as the core material prepared manually. They conducted an analytical solution and material degradation law. The thermal gradient in the outer layer has higher contributions to the wrinkling load than in the core materials.

Martin *et al.* (2017) analyzed the rheological characteristics and the thermal dilation effect of alumino-silicate. They examined inorganic adhesive layers for higher-temperature use. They selected ceramic matrix composite as the face sheet and pyrolysed polymethylsiloxane as a resin and Si-o-c as a foam material prepared manually. They conducted high-temperature bending and double cantilever beam, and the shear test.

Hulme & Goodhead (2003) investigated the reprocessing of polyurethane using hot compression molding. They analyzed a method for mechanical recycling. They selected polyurethane granules and polyester resin they manufactured through hot compression-molded by a hydraulic press.They conducted flexural, tensile strength, and dart impact tests. Finally, the functional filler in the thermoset molding compounds to increase the impact oftoughness.

Peng Yang *et al.* (2015) conducted a temperature effect on low-velocity impact damage. They analyzed the problem of low-velocity impact at various temperatures. They selected polymeric as the core material and carbon plate as the face sheet. They manufactured using hand lay-up vacuumed sealed. They conducted a scanning electron microscope, drop weight impact, numerical method, and simulation analyses. The maximum exposure temperature results in higher damage zones.

Alibeigloo *et al.* (2016) did thermo elasticity evaluation of the sandwich plate using the generalized differential quadrature method. They analyzed the bending behavior of the sandwich circular plate. They selected FGM as the core material and ceramic as the face sheet. They prepared manually. They used differential coordination methods, numerical methods, and generalized differential quadrature methods. The radial displacement increases and the transverse displacement continuously reduce when the surface temperature variations increase.

Wong *et al.* (2015) investigated the interfacial stresses of a sandwich panel under temperature and mechanical loads. They analyzed the problem of interfacial shearing, peeling stresses for symmetric and non- symmetric materials. They selected the sandwich structure. They conducted an analytical solution and finite element analysis. The differential thermal, mechanical stretching and bending had excellent quality research streams.

Amir *et al.* (2014) conducted thermal conduction and contact withstand of silica. They analyzed the problem of the thermal conduction of the silica gel. They selected silica bounce with a PVP sample andmanufactured a chemical composition. They conducted thermal conductivity and thermal conduct resistance tests using hot plate equipment subjected to a vacuum monitor. They saw 26% of the bulk resistance as the final rate.

Boldrin *et al.* (2014) made a study regarding the thermal conductivity of iso-volume center-symmetric honeycombs. They analyzed the problem of the equivalent thermal conductivity of iso-volume periodic honeycomb. They selected the thermal conductivity of tessellation for finding solutions and numerical results. The iso-volume topologies in sandwich structures had tunable thermal properties and lightweight performance.

Allan *et al.* (2016) investigated the flexural characteristics of the FRP sandwich at elevated in-service temperature. They analyzed the problem of elevated temperature. They selected phenolic as the core material and glass fiber reinforced polymer as the skin material. They prepared a hand lay- up method. They conducted dynamic mechanical analysis and flexural behavior. Finally, the full composite action was lost between skin and core at a higher temperature.

Cetkovic *et al.* (2015) conducted the thermo-mechanical bending of the sandwich through a layer-wise displacement model. They analyzed the thermo-mechanical behavior. They used the mathematical model and made the analysis using the principle of virtual displacement. They conducted a numerical model, a finite element model, and MATLAB programs. Finally, they extracted the applicability and constraints of layer displacement.

Xiaolei *et al.* (2015) analyzed the thermal vibration behavior of a sandwich with a ceramic foam core. They analyzed with the maximum temperature and higher gradient temperature. They selected a mullite composite as the face sheet and ceramic foam as a core material, prepared manually. They conducted a finite element model and numerical simulation. They concluded that the natural frequency and damping loss factor had a steady-state with an increased temperature of up to 800ºc. Also, structural stiffness and damping behavior showed excellent performance.

Soohyun *et al.* (2014) investigated fracture toughness increase in polyurethane adhesive joints. They analyzed the problem of the reliability of polyurethane adhesive heated at 180˚c. They selected polyurethane combined with glass fibers, aluminum, and steel adherent. They manufactured using an automatic bonding machine. They conducted a fracture toughness test at the cryogenic temperature of 150°c. An optimal reinforcement method was advisable from the analysis.

Krzysztof *et al.* (2017) made a study of vibration analysis of a composite plate including temperature effect. They analyzed the thermo-mechanical properties of the plate material. They selected multi scale fiber-reinforced composite plates. They conducted a numerical investigation of freevibration using a Halpin-Tsai model. At a maximum temperature the critical transport speeds of the investigated plates are different from each other.

Nadia & Ping (2014) investigated the effect of thermal treatment up-to 2200ºc. They did post-deposition annealing on the Sic coating.

Selected materials are TRISO particles, pyrolytic carbon, and Sic they prepared through chemical composition. They conducted scanning electron microscope tests, and crush tests. At the end of experiments, high-temperatureresistance provided an increased safety margin.

Li Chen *et al.* (2015) conducted the combined effect of high temperature and high strain rate subjected to standard weight concrete. They made an experimental study of the combined effect. They selected Portland cement, fly ash, basalt rubble, and river sand prepared manually. MATSHPB apparatus was manufactured and a microwave oven was used. F i n a l l y , the strength and stress-strain curve of ordinary concrete experienced excellent strain rate effects.

Arezoo *et al.* (2013) analyzed the effects of the strain rate and the temperature of rohacell foams. They did compression experiments on four different densities of rohacell foam. Selected materials were copolymer of meth acrylonitrile and methacrylic acid and alcohol as a foaming agent test prepared using chemical foaming. They conducted compressive tests and foam sensitivity and all foams reached mild strain rate sensitivity.

Jaehyeuk Jeon *et al.* (2014) analyzed the thermal stress and deformation of the sandwich subjected to heat conduction and mechanical loading. They analyzed the time-dependent response of the sandwich. They selected a unit cell model consisting of the glass of the MF model with several fibers. They conducted the micro-mechanical test, finite element framework, and calculation of thermal stress.

Martin *et al.* (2008) conducted experiments and theoretical methods for finding thermal stress. They analyzed thermal stress in advanced carbon fiber using reinforced polymer foam as a core sandwich panel. They selected polymethacrylimide as the foam core and NCF carbon fiber as the face sheet material manufactured through an open mold vacuum infusion process. They used the Timoshenko theory and did experiments in temperature ramp and finite element analysis.

Pengfei Wang *et al.* (2014) investigated the temperature effects on the mechanical characteristics of aluminum foam subjected to dynamic loading. They analyzed the problem of impact loading at different temperatures. They selected aluminum foam as the core material prepared manually. They conducted a thermal effect at room temperature of 773° K anddynamic stress and also, they used high-speed photography. So the strain rate sensitivity of aluminum foam is higher as the temperature improves.

Anjang *et al.* (2015) analyzed the post-fire mechanical behavior of sandwich panels and found the residual strength of the fire exposed structure. They selected woven E-glass/vinyl ester laminates as a skin material and balsa wood as core material prepared manually. They conducted the thermal analysis, tension, and compression tests. The compression and tension behavior of the sandwich decreases as a result of temperature decomposition.

Anurag *et al.* (2018) made a study of jute and glass fiber wear performance. They conducted wear tests on the disc machine and the values were analyzed using the Taguchi method. They are taking into account various velocities, loads, and distances. The analysis showed velocity of 1 m/s, load 10 N, and distance 1000 m is the best condition for the S/N ratio andjute/glass composite shows better wear performance.

Sudeepan *et al.* (2014) analyzed the frictional wear of acrylonitrile-butadiene-styrene sandwich. The experiment was done in a dry environment on the tribo tester at room temperature. They were conducted based on the Taguchi method. The best parameter for the lowest coefficient of friction was 5 wt. % filler, 120 rpm, and 35 N loads. The verification test showed the development of COF as 18.60% and the wear rate as 14.43 and the tribological properties improved with the addition of micron-sized ZnO.

Emad Omrani *et al.* (2015) studied the strength and tribological performance of the carbon-fabric plate. The effect of carbon fiber on the mechanical and wear characteristics was analyzed. The cure effect was studied using DSC and the tribe-surface was studied using SEM micrographs. The Taguchi technique was used in the analysis of the experimental data. Finally, adding the volume fraction of carbon in the sandwich resulted in a lower coefficient of frictional wear loss.

Shaghayegh *et al.* (2019) conducted tests on texturing for ice friction of sandwich composite and found the optimization of surface-texture with a better resistance on ice. The hybrid thermoplastic polyurethane (TPU) composite coefficient was calculated using slip-resistance testing equipment. They used the Taguchi experiment and finalized the fiber content at 8% with the heat at 120° c having excellent ice friction behavior after abrasion (COF=0.61).

Jitendra *et al.* (2019) did an experimental investigation of the short fiber wear performance. Short glass fiber (SGF) having synthetic graphite and polyaryl ether thermal, wear, and mechanical characteristics were used in the analysis. They made analysis using the fracture surface morphology, Micro hardness, Differential Scanning Calorimetry, and did thermo gravimetric analysis, Dynamic mechanical analysis, and wear performance. The mechanical behavior of the plate with 40 wt. % GF confirmed better than a composite with 30 wt. % GF.

Kuo *et al.* (2005) did an investigation on the wear behavior of phenolic based carbon/carbon composite. They used sliding wear-tested in the analysis of the wear properties. The different carbonization rates are (1, 100, 1000°c/min) they used. The results showed pitch group samples having the least wear more than furan group samples. Finally, the pitch treatment could make speedy increases in the wear characteristics of carbonized c/cspecimens.

Michita Hokao *et al.* (2000) did the wear and friction performances of graphite-carbon composites with a study of the wear behavior of G/GC materials. A rubbing test was conducted in the surrounding air with the help of a wear machine. The G/GC plates with graphite are the minimum friction and the graphite showed the least wear and the G/GC plats are could use as self-lubricating components.

Mei Lv *et al.* (2015) investigated the wear and friction behavior of aramid and carbon fibers in a reproduce space surrounding. They tested the specimen using ball-on-disc equipment under a vacuum surrounding and the start-stop method. The test carbon fiber reinforced polyimide showed very good wear behavior in the irradiation domain. The introduction of carbon fibercan cause a decrease in friction and withstand wear resistance of the polyimide materials.

Soma Dalbehera & Acharya (2015) took up a study of the jute and glass fibers, wear, and erosion characteristics of the composite. Jute and glass composites were filled with various sizes of ceramic rich cenosphere weight percentage as 5% to 20% was fabricated in the hand layup method. For this experiment, a test rig and the Taguchi method were used to analysis of the data. They saw the added filler exhibiting excellent erosion wear characteristics.

Aslan *et al.* (2018) analyzed the wear and mechanical characteristics of sisal, carbon, and glass fiber hybrid mixture. He analyzed the use of natural fiber possible replacement for synthetic fibers in tribo-mixture. They conducted flexural, hardness, and tensile tests for sisal and carbon fiber composite in different ratios. The hybrid ratio of 35/75 %wt. for s-c and s-g composite shows good friction and mechanical characteristics and increasing the sisal fiber increase the coefficient of friction.

EI-Tayeb &Yousif (2007) investigated the glass fiber combined polyester mixture for abrasive wear usages. The multi-pass wear behavior of chopped was tested using a pin-on-ring machine with the use of Sic abrasive paper. The different grades of abrasive papers are 1500, 1000, and 4000 and the applied normal loads were 5-25 N. The rotational speed used was 100 and 500 rpm for various orientations of the abrasive grains. The wear rate increases when the value of the rotational speed and abrasive increases.

Jacobs *et al.* (2002) studied the wear and creep characteristics of ethylene-butene combined with polyethylene fiber. They used of ball-on- prism tribo meter against steel balls, they used to conducting the experiment. They concluded that the creep resistance of the matrices decreases whenincreasing the branching of the copolymer. Also, the composites had an equal wear rate and powerful fibrillation of the compositewas noticed.

Gai Zhao *et al.* (2013) conducted wear and friction tests for fiber combined polyimide sandwiches. Friction and wear of polymides in combination with the glass, carbon, and aramid fiber were evaluated under sliding with steel rig and sandpaper as well as under an abrasive environment. They concluded that brittle glass fiber was not good for wear resistance in the three-body abrasive condition. The reason they said is due to insufficient support from the polyimide matrix.

Benyan Liu *et al.* (2017) analyzed carbon nanotube-based polymer electrodes in the electrocardiographic measurements (ECG) prepared by ultrasonically stirring and heat stirring. The polymer electrode was prepared using the doctor blade technique. Continuous monitoring was done for 14 days. Wearable electrodes were qualified for medical devices using ECG measurements. The CNT-based electrodes were seen as flexible and suitable for long term wear. These devices could be used as a medical instrument for practical applications.

Abu Samah *et al.* (2017) investigated pressure sensors with the help of various wall carbon nanotubes. They studied the response of porosity in MWCNT/PDMS nano composites on its pressure observing behavior. A multi-functional MWCNT/PDMS nano composite foam sensing element was created. MWCNT/PDMS nano composites foam exhibited negative pressure of the coefficient of resistance showing a decrease in the resistance with applied pressure. Sports gloves were used in Jamar dynamo-meter and Martin vigor-meter showed the maximum grip strength.

Zhao-Zhu Zhang *et al.* (2008) conducted carbon fiber wear performance with polyurethane foam composites. Polyurethane coated withCF was analyzed using a ring wear machine under a sliding environment. PU coating was analyzed by an optical microscope and SEM. The deformations become higher when the applied load was up to 820 N. Finally, the least content TDI-CF gave the PU coating showing the maximum wear characteristic.

Mei Lv *et al.* (2019) investigated the wear performance of thecarbon-fiber sandwich exchanged by proton irradiation. The tribological property was analyzed before and after irradiation. Proton irradiationdecreases the surface energy and the irradiations deep up to 820 nm arecalculated using the SRIM software. The wear resistance was increased after the proton ray of light and this improvement can be applied to aeronautics and smart medical materials.

Satish & Srikiran (2018) made a study of the wear characteristics of palm kernel composites for brake pad usage. Palm kernel (0-50%) and wheat (0-10%) with added aluminum oxide, graphite powder, Nile roses, and the phenolic resin of 35% were used as couplers. The experiment was carried out in a disc, and the hardness and oil absorption tests were conducted. Finally, the palm kernel shells will be the best alternative for asbestos in friction coating materials.

Xiaoshuang *et al.* (2018) made an experimental investigation of the abrasive and mechanical wear properties of woven flax fabric combinations. They conducted a mechanical test of tensile and flexural tests. They conducted a wear test with the help of pin and disc equipment. Composite B depicts good mechanical and wears characteristics along with the plates A, B, and composite C. They saw the flax composites having good mechanical and wear withstanding capacity.

Yucheng Liu *et al.* (2019) investigated the power of silane tests on the wear, mechanical, and morphological characteristics of corn stalk fiber. They conducted a mechanical test of density, apparent porosity, and water absorption test. Friction and wear characteristics of plates were tested with the help of a tester. The silane-treated corn stalk fiber (CSF) should be responsibly applied in a biopolymer mixture.

Jie Fei *et al.* (2015) conducted carbon fiber friction and wear performance of the paper-based frictional composite. They prepared four kinds of micron-level materials. They conducted wear and friction on QM1000-II on friction analyzing tester. From the experiment, they concluded that the porosity of composites decreases with the improvement of carbon.The carbon fiber content of 55% was seen as having good friction ability and anti-shudder behavior subjected to an oil-lubricated state.

Deepak *et al.* (2017) investigated the wear characteristics of banana combined with molybdenum disulphide mixture. Molybdenum disulphide was mixed to the resin at different weight values of 5 to15 percentage to improve the wear behavior of the mixture. They conducted experiments on flexural, tensile, impact, and wear. The morphology of the sample was monitored using a scanning electron microscope test. A mixture of molybdenum sulphite and resin increases the wear characteristics of the mixture.

Ashwin *et al.* (2018) conducted experiments on the wear and mechanical behavior of kenaf-aloevera-jute combined natural fiber plate. They fabricated composite using the compression molding method. They conducted a mechanical test of tensile, flexural, and impact strength. They conducted a wear test using the wear test machine and the stacking order of the fiber and interaction of fiber and matrix shows major changes in the wear and mechanical characteristics of the plate.

EI-Tayeb (2008) conducted a wear test on sugarcane fiber composites. They prepared sugarcane polyester and glass-polyester plates using a compression mold and the hand-lay-up technique. They analyzed the effect of load, fiber orientation, and wear. They studied the morphological properties of the worn-out surfaces using a scanning electron microscope.They saw an improvement in wear resistance for sugarcane/polyester composites compared to glass/polyester composites.

Arash *et al.* (2015) investigated the wear performance of polyphenylene sulfide (PPS) mixture in water-lubricated conditions. They used carbon fillers, namely, short carbon fibers, carbon nanotubes, and graphite as reinforcement. They conducted experiments using a pin-on-disc tribo-meter. Morphological performance was studied using SEM and EDS.The short carbon fiber was more responsible for outstanding tribological performance.

Shreemoy Kumar *et al.* (2014) performed different machining factors during the turning of SS with the help of GRA. They selected an L_{27}

orthogonal array design with different machining factors of V_C, f, and t. Machinability performance of cutting force, material removal rate, and surface roughness (R_a) was observed. The parameters used were V_C = 45 m/min, f = 0.1 mm/rev, and t = 1.25 mm. In the second confirmation test, they attained a development of 88.78 % in the GRA.

Prakash *et al.* (2015) investigated the best condition of drilling behavior with the help of Grey Relational Analysis. They considered thedrilling parameters of feed rate, spindle speed, drill diameter. Grey Relational Analysis level-1 was taken for drill diameter, feed rate, and level-3 was taken for spindle speed they exposed. F i n a l l y , the feed rate confirmed as highly important the unevenness of the surface and delamination.

Amit Sharma *et al.* (2018) analyzed the different effects of optimization of Al2024 MMC using the GRA-Entropy optimization method. GRG data were analyzed with the help of the Taguchi method. The process parameters-A represents at level 3, the B represents grain shape at level 1 and C re-presented the angle of the blade. A confirmatory test showed the normal values of micro hardness and tensile strength coming within 95% confirms level and this method was definitely put into the multi- response system.

Arun Kumar & Sathiya (2016) investigated different responses considered most suitable for process factors for TIG welding using the GRA method. Their experiments were subjected to L_9 array and the input factors were voltage, welding current and welding speed. They concluded that the optimal parameters determined were $A_2B_1C_2$, that is the voltage at 10 V, current at 110 A, and welding speed at 1.5 mm/s. The output mechanical performance for the excellent and lowest GRG was evaluated by the metallurgical performance.

Reddy Sreenivasulu & Srinivasa Rao (2013) have experimentally conducted the design and the best condition of torque and thrust force subjected to the drilling of Al alloy using GRA. Drilling parameters were clearance angle, point angle, feed rate, speed, and drilling diameter on the torque and thrust force using GRA. They used a drill tool dynamometer for monitoring torque and thrust force. The optimal values for cutting speed from GRA orthogonal array as 750, the feed rate 0.3, and drill diameter 8, the point angle 136, and the clearance angle 4 were used.

2.2 SUMMARY OF THE LITERATURE REVIEW

Processing methodologies, advantages, disadvantages, and limitations of the sandwich foam composites have been narrated these by the various researcher have been listed below.

1. Different types of fibers are used for lightweight and high mechanical strength though they have some disadvantages.
2. Different types of foam materials are fabricated and used for a lightweight purpose and also for easy disposal.
3. Fiber orientation, machining, preparation, and performance of the fiber along with foam materials have a major effect on the mechanical characteristics' of the sandwich composite.
4. Polyurethane and PVC foams have more advantages and mostly used in the structural applications.

2.3 KNOWLEDGE GAP

1. Research works carried on pp mesh and PVC foams are only very few in the hybrid sandwich composite materials.
2. Particularly on fabrication with different orientations of the foams testing carried out are less in the sandwich materials.
3. Varieties of foam materials are available; these foam materials can be used for making different composite structures.
4. A study of machining characteristics has not been much to speak of in these sandwich composite materials.

2.2 PROBLEM STATEMENT

Good interest has been shown in the use of natural fiber instead of glass fiber in a composite. Most of the works carried out on mono fiber materials. Hence, in this research work, two types of foam materials have been used, namely, polyurethane foam and PVC foam. They were used as reinforcements along with synthetic carbon fiber as skin material. Hybrid composite using these foams were fabricated with different foam orientations and their mechanical, thermal, and machining characteristics were evaluated.

The wear properties were analyzed using the Taguchi L_{27} orthogonal array analysis for the hybrid sandwich composite.

2.3 SUMMARY

This chapter has dealt with various foam materials used in the fabrication of the sandwich composite materials as seen from literature. The experiments were conducted on the mechanical, thermal, and machining behavior of the different foam materials is very few. So, we have selected polyurethane and PVC foam material and conducted tests on these foam materials. The literature review report gives a clear vision based on the literature review and also a problem statement of this research work.

CHAPTER 3

SCOPE AND OBJECTIVES

3.1 INTRODUCTION

The scope and objectives of the research conducted on sandwich material are discussed in this chapter. The sandwich composites were made with polyurethane foam and PVC foam reinforced with a matrix. PP fibers were used as face sheets for the fabrication of composite. The main objective of this research work is to make a sandwich composite that is suitable for industrial application with proper strength and optimal machining characteristics.

Also, to conduct experiments relating to the mechanical, thermal, and wear properties of the sandwich composite. To attain the objective, we have prepared the research methodology.

3.2 SCOPE OF THE RESEARCH

Mechanical properties like tensile, flexural strength, impact, For the assessment of the suitability of the composites for various industrial applications.

It is known that the major survey of the PP and the PVC foam- based fiber composite is a valid problem. The mechanical, thermal, and machining character of polyurethane and PVC foam were evaluated in this research work. To understood sandwich foam mechanical characteristics, thermal behavior, and machining parameters of the wear performance.

CHAPTER 4 MATERIALS AND METHODS

4.1 INTRODUCTION

Fiber and foam used for fabrication of the sandwich specimens were polyurethane, PVC foam as the core materials, and carbon fiber as the skin material. The hardener and polyester resin were applied in the fabrication of the composite plates. The various manufacturing methods of fabrication of the composites are explained in this chapter also the method of fabrication of hybrid sandwich composite to this research work.

4.2 MATERIALS USED

Table 4.1 Properties of polyurethane, PVC foam, and carbon fiber

Foam and fiber	Density (Kg/m^3)	Tensile strength (N/m^2)	Young's Modulus (N/m^2)	Elongation (%)
PP MESH	55	$650x10^3$	$120\ x10^6$	40
PVC foam	100	$20x10^6$	$142.5\ x10^6$	32

Table 4.1 shows the properties of polyurethane, PVC foam, and carbon fiber. The density, tensile strength, young's modulus, and the percentage of elongation of the polyurethane, PVC foams, and PP fiber are presented. PVC foam has more tensile strength, young's modulus, and

density than polyurethane foam. However, the percentage of elongation of PVC foam is less than that of polyurethane foam. The skin surface of the carbon material has better mechanical properties than PVC and polyurethane foam materials.

The following is the list of materials used in the fabrication of the sandwich hybrid composites:

1. PP
2. PVC foam
3. Epoxy resin
4. Hardener

Foams belong to lightweight materials in the shape of a square plate. They are mostly used as a core for the sandwich material in the areas of automotive and aerospace. Since the foams are bio-degradable, less cost, and eco-friendly. Examples of foam materials are polyurethane foam, flax foam, wood foam, latex rubber foam, reflex foam, gel foam, and memory foam.

4.2.1 PP MESH

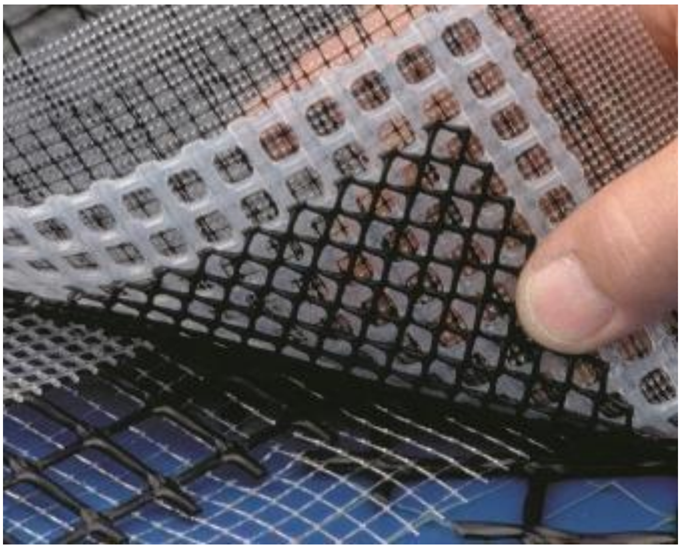


Figure 4.1 PP

4.2.2 PVC Foam

Figure 4.1 and Figure 4.2 above shows the polyurethane foam and the PVC foams used in the fabrication of the sandwich hybrid composite. In this research polyurethane and PVC foams were used in the fabrication of the sandwich composites. Polyurethane foam and PVC foams were prepared using chemical treatment. The foam offered a high level of dimensional accuracy and stability where the need for repeatability and consistency is essential.

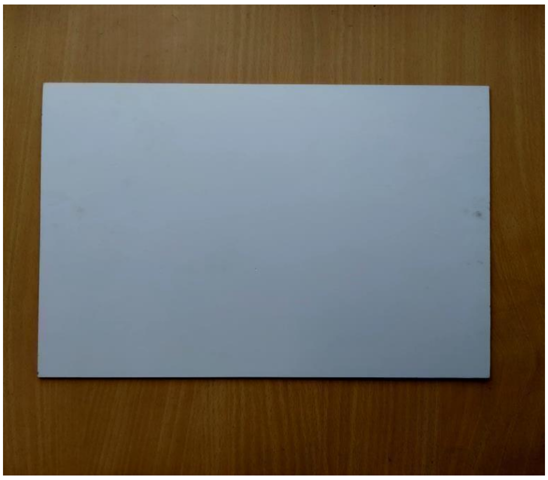


Figure 4.2 PVC foam

Polyurethane foams are light green in colour while PVC foams are white these are available in square meters. They have good tensile and flexural properties. Polyurethane and PVC, foams were fabricated in this research work were in the sizes of 30mmx30mm and 9mm thickness. Foam materials are good reinforcement in the sandwich composite. The foam volume of 40% (0.4VF) is adopted while fabricating the composite. Because, the foams were contained good mechanical and flexural properties.

4. 2. 4 Polyester Resin

Figure 4.4 Polyester resin and hardener

Figure 4.4 shows the polyester resin and hardener used for the fabrication. Binding agent polyester resins are easy to handle, cheap, and used most commonly in sandwich composite and structural applications. Polyesters are classified on the basis of structures; examples are orthophthalic, isophthalic, dicyclopentadiene, and bisphenol fumarate resins. The polyester resin used in this work was epoxy resin LY556 are purchased from M/s Sakthi fiberglass, Chennai, India.

4.2.5 Hardener

Figure 4.4 shows the hardener used in the sandwich composite fabrication. The hardener is used as a curing component acted as a catalyst in chemical reaction during the mixing process. Hardener HY951 was mixed with epoxy resin in 10:1 proportion.

4.3 MANUFACTURING PROCESS OF COMPOSITE MATERIALS

The following are the commonly used methods adopted for the fabrication of sandwich composite materials.

1. Pultrusion process
2. Resin Transfer Molding (RTM)
3. Filament winding process
4. Spray up method
5. Hand layup method
6. Vacuum bag molding

4.3.1 Pultrusion Process

Figure 4.5 shows the pultrusion process. This is the simplest of all the processes for the manufacture of the composites of similar cross-section area. It can produce very long, continuous fiber-reinforced polymers. Pultrusion is derived from a combination of two different words, namely, pull and extrusion. Extrusion is achieved by pulling the fiber glass materials along with resin through the required shape of the heated die.

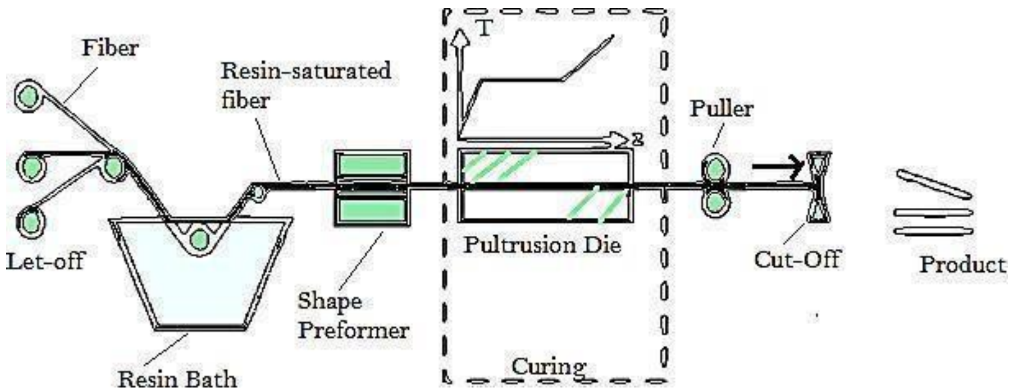


Figure 4.5 Pultrusion process

Various resins used are epoxy resin, polyester resin, and vinyl ester resin, etc. They are used with reinforcement for the pultrusion process. Initially, the fibers are combined to feed in a resin bath mixture for impregnation and then further processed to remove excess resin. Through different steps, the impregnated fibers are passed through various continuous feeders thereby the fibers get tension lengthwise.

The tension in the fibers in the rollers acts as performing guides to feed correctly into the heating die while resin mixture, various additives, and fillers are added for improvement of the physical appearance. Care can be taken to see that, the mixture was not exposed to sunlight, UV rays, or other cosmic rays during the processing time. Now, the tension fibers are fed into the steel hot forming dye. Now, the dyes are framed into the final shape of the product.

Then the cured profile from the hot die was pulled out with the help of a gripping and pulling mechanism and finally, it was cut into the required shape and size of the product. Thus, the composite was prepared as the end product using the pultrusion process.

4.3.2 Resin Transfer Molding (RTM)

Figure 4.6 shows the RTM for fabricating the composite. It is the best technique for the mass production of composite material.

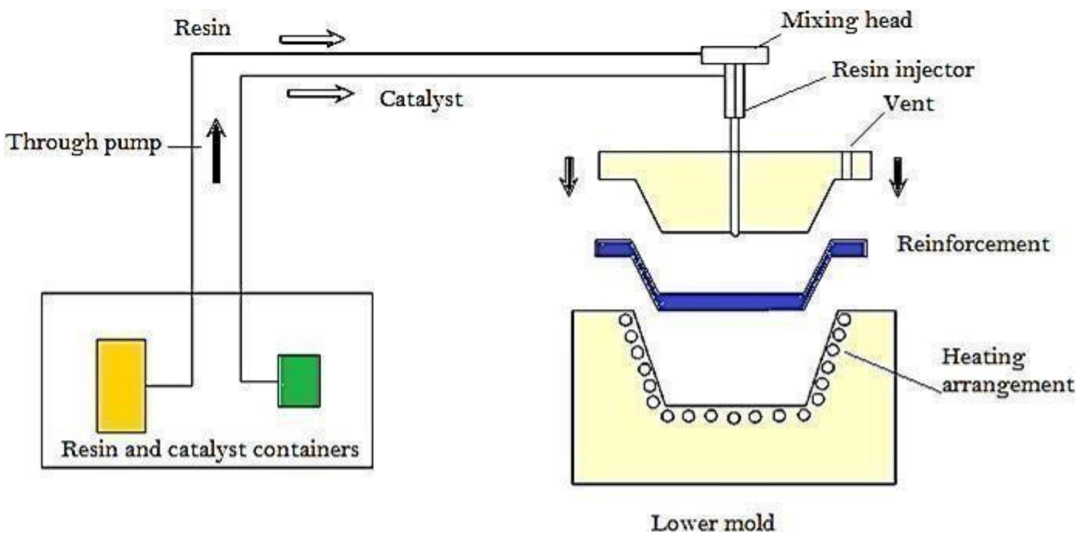


Figure 4.6 Resin Transfer Molding

The resin transfer molding process creates smooth surfaces in the outer layer. RTM can produce complex sizes and shapes with a large surface area. The woven roving was used in the determination of the outer layer of the end product which had to be laid. Then the resin was injected into the system. Care was taken to ensure proper maintenance of the flow of the resin.

The mold was prepared according to the required shape of the end product. It was closed to ensure precise thickness and a smooth finish. Gel coating was applied for the high quality and good durability of the product. The resin was inserted inside the mold through a heated dye under pressure up-to the mold is filled. The resin gets dried with curing temperature and turn into a rigid plastic. The product was ejected finally through ejector pins.

4.3.3 Filament Winding Process

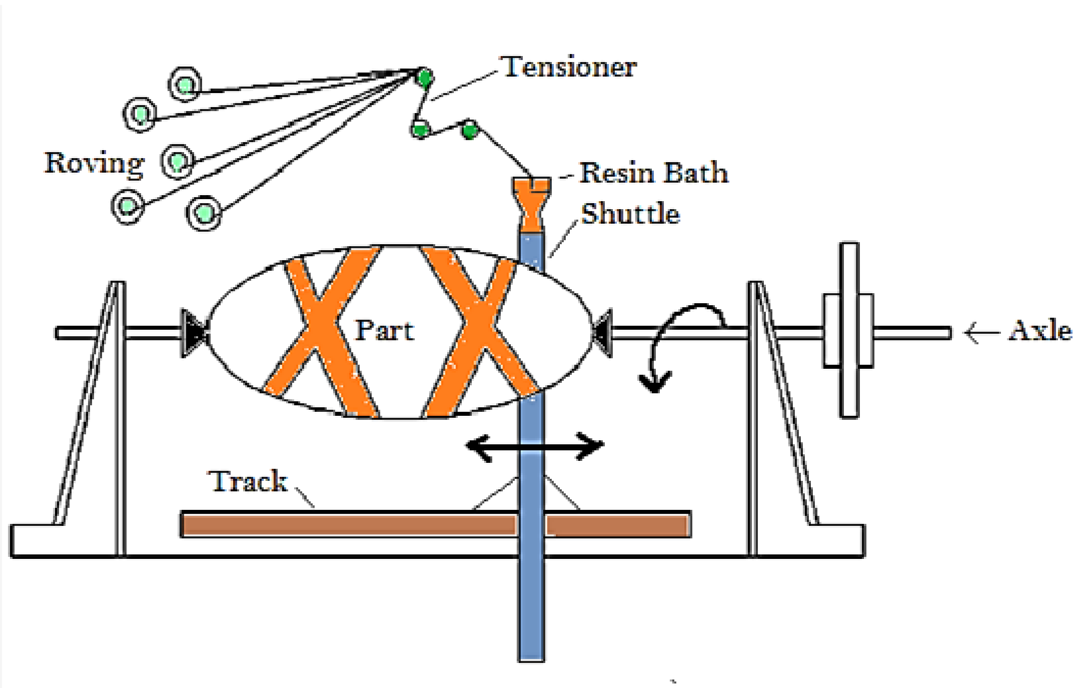


Figure 4.7 Filament winding

Figure 4.7 shows the filament winding process. This involves impregnated resin along with fibers wrapped around the rotating mandrel which decides the internal shape of the composite product. The fibers were dragged across a resin and wound in a helical pattern. The process wasrepeated to getting the desired thickness of the fabrication. Finally, the exact parts were obtained and taken out of the mandrel. The winding cost of this process was low compared to other processes.

4.3.4 Spray up Method

Figure 4.8 shows the spray up method. This is the normal method of fabricating the composite product. This method is suitable for open mold large composite products. The mold was placed on the floor and the resins with chopped fibers were sprayed into it with uniform velocity and pressure. The fibers stuck with each other into the mold.

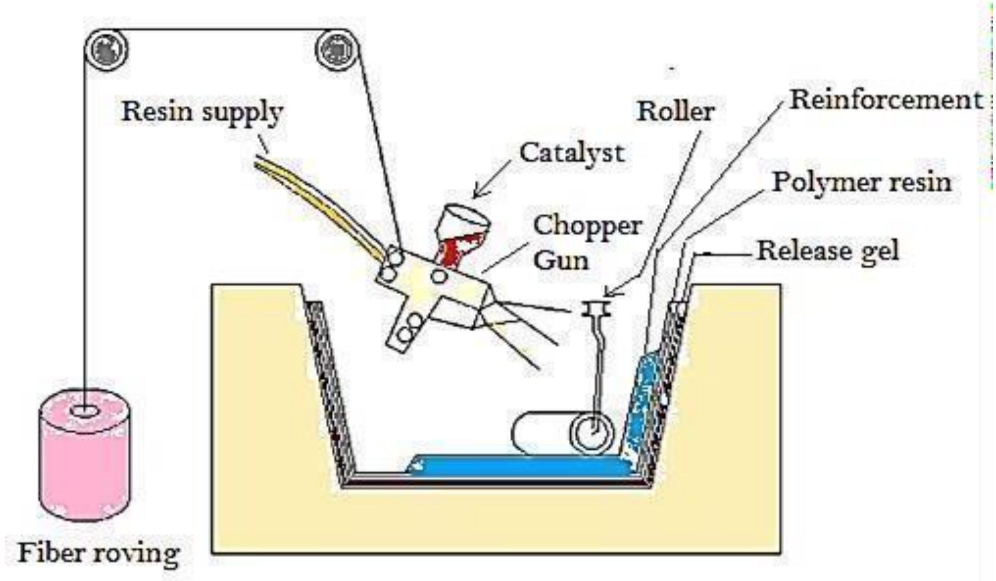


Figure 4.8 Spray up method

The process was repeated in the mold until it gets filled. The layering of the resin fiber mixture was mechanized to ensure reduction of the manual layup time. After getting the required shape and thickness, the productwas dried up and the product was taken out of the mold, and the process was repeated.

4.3.5 Hand Layup Method

Figure 4.9 shows the hand layup method. It is an uncomplicated and easier method. This method is used for making sandwich composite laminates. Foam cores were impregnated into the resin with the help of rollers. Usually, steel rollers are used for the impregnation of resins. For better impregnation nip-rollers are used. In this hand layup process, after fabrication, the composites were permitted to cure under normal conditions.

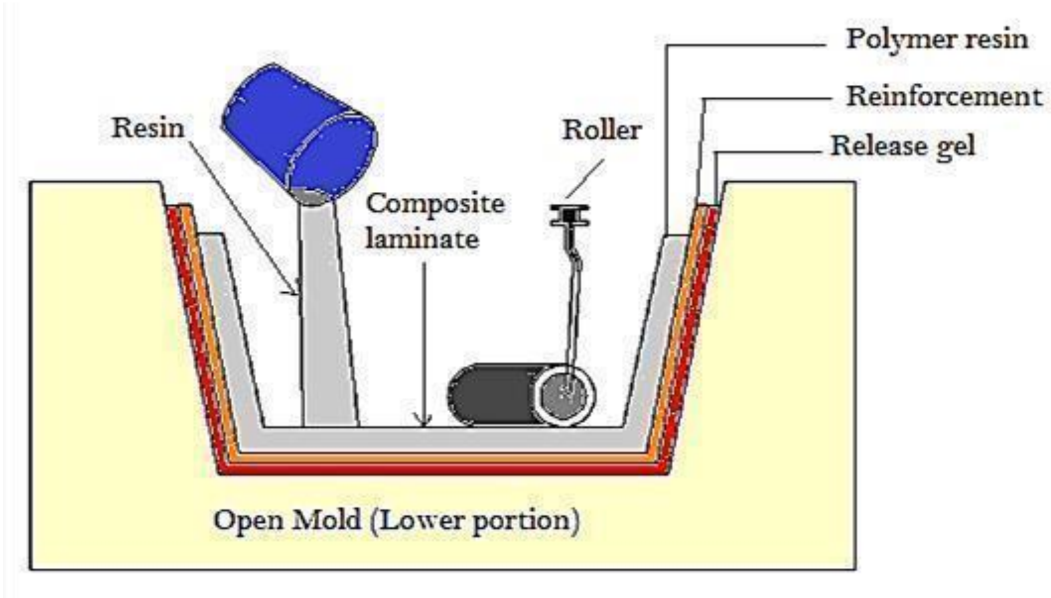


Figure 4.9 Hand layup method

Carbon fibers were placed in the mold after a roll out of the thinner on the mold surface. Then, the mixture of hardener and resins are polished above the carbon fiber surface was polished. Next, the foams were inserted into the mold. Now, the carbon fiber was put above the foam and the resin is applied. Foam and carbon fibers were placed on the topmost layers, with a mixture of resin. A known weight of 180 N was covered above the mold and allowed 24 hours for the curing of the sandwich composite. Similarly, PVC and hybrid composites were fabricated.

4.3.6 Vacuum Bag Molding

Figure 4.10 shows the vacuum bag molding process. It is a modification of a hand layup process. This method finds application in aerospace and marine components and the high surface finishes are achieved. Initially, the mold was kept in an enclosed sheet, and the air bubbles and voids present inside the mold were completely removed by applying pressure.

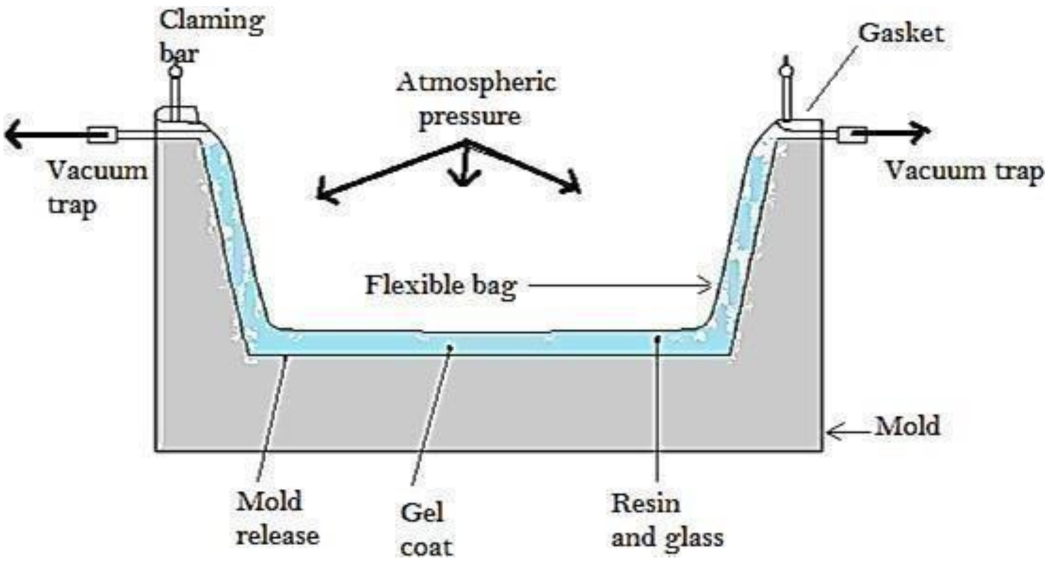


Figure 4.10 Vacuum bag molding process

High pressure increased the surface finish and the adhesion of resin in the fibers for a higher concentration. The required number of stages of curing directly depends on the volatile molecules removed from the system. After the curing process, the bag was removed and the final product of the composite was taken out from the mold. The only disadvantage of this methodis that it needs a labour skill for the initial bagging setup compared to the manual hand lay-up method.

4.4 FABRICATION OF COMPOSITE

In this hand lay-up method of fabrication, the mold was constructed using silicon rubber. The base of the mold was enclosed by aluminum stiff plates. The mold was placed above the aluminum rigid plate. Now, the fabrication processes was initiated.

Table 4.2 PVC WITH PP MESH sandwich composite

Polyurethane foam (Horizontal orientation)	Polyurethane foam (45° orientation)	Polyurethane foam (Vertical orientation)
PP MESH	PP MESH	PP MESH

4.5 SUMMARY

In this chapter, various materials used in the sandwich composite fabrication and the various manufacturing process of composite materials have been discussed. The fabrications of poly PP Mesh, PVC, and hybrid composites in three different orientations have been explained. The hand lay- up process of making a sandwich composite has been discussed in detail.

CHAPTER 5

TESTING OF COMPOSITE

5.1 INTRODUCTION

The experiments carried out for finding the thermal and mechanical behavior of the sandwich composites are discussed in this chapter. It also deals with the morphological analysis done using an SEM for a study of the internal microstructure of the tested samples. The machinability of the sandwich composite specimen has been done using the Grey Relational Analysis (GRA).

5.2 MECHANICAL TESTS

Various mechanical tests were conducted in the study of the effects of fabricated sandwich materials. These include the mechanical tests of flexural, tensile, impact; inter delamination, double shear, and hardness experiments. The various standards used for conducting the mechanical tests are given in this chapter.

5.2.1 Tensile Test

Tensile experiments were conducted using a universal testing machine. During the experiment, a one-directional load was applied to the sandwich composite. Composite specimens were cut to the required size as per ASTM: D 638 standard in the conducting of the tensile test. Details are shown in Figure 5.1.

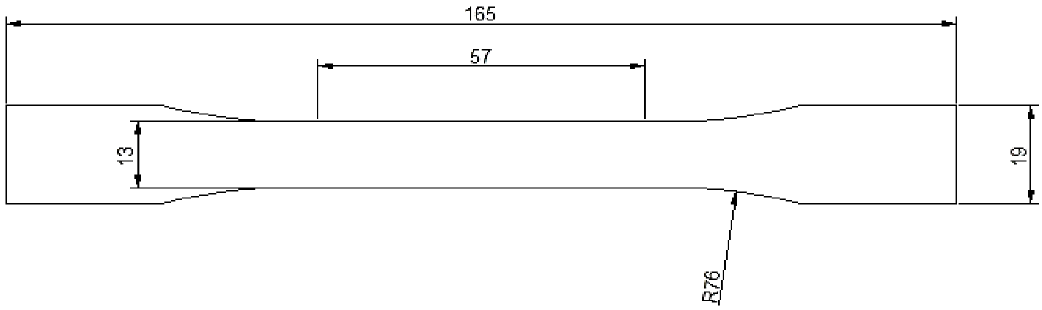


Figure 5.1 Schematic diagram of the tensile test

Figure 5.2 Tensile test set up

In the tensile test, the stress is observed to increase the strain. A test sample was fixed in the UTM gripper simultaneously; the tensile load was applied gradually till the sandwich failure. The deformation of the specimen length was noted. Figures 5.2 depict the tensile experiment arrangement of the specimen.

Figure 5.3 shows the examined specimen in the tensile test. The sandwich composites C1, C2, and C3 have different orientations of 0°, 45°, and 90° respectively each specimen is tested and presented in Figure 5.3.

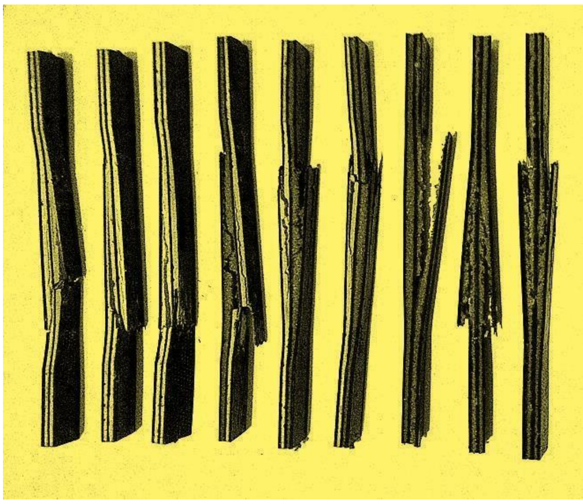


Figure 5.3 Tensile tested specimen

5.2.2 Flexural Test

A flexural test was performed as per the ASTM: D 790 grade. The ability of the material to resist deformation when applying loads perpendicularly is called flexural strength. In this research work, a three-point bending test was conducted, in which most failures have seen inter-laminar shear. Flexural strength was calculated and expressed in MPa. The ASTM specimen picture of the flexural test is shown in Figure 5.4.

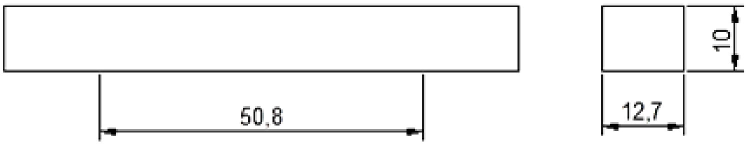


Figure 5.4 Schematic diagram of the flexural test

Figure 5.5 shows the flexural tested specimen used in three points bending tests. A flexural test was conducted at 40 % of the humidity under normal temperature. In this flexural test, the composite was held between the fingers of the Universal Testing Machine and tested. Flexural weight was supplied to the sandwich composite with the middle length of the specimen until the fracture.

Figure 5.5 Flexural tested specimens during failure

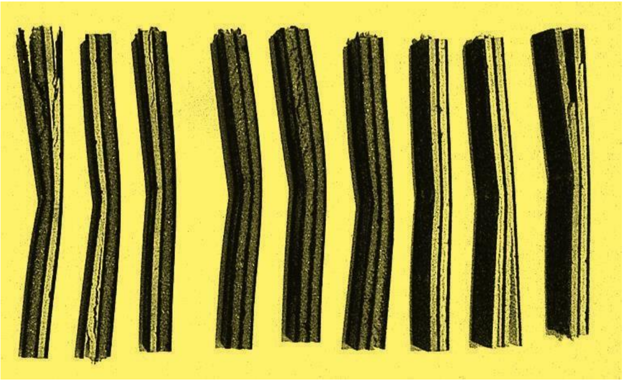


Figure 5.6 Flexural tested specimen

Figure 5.6 shows the flexural tested samples of the sandwich composite used in three points bending test. This test shows the maximum stress developed in the outermost fibers on the composite. The tested samples are presented in the figure.

5.2.3 Impact Test

The charpy impact test ASTM standard picture is shown in Figure 5.7. The impact test is conducted as per the ASTM: D 256. The impact analyses are very important in deciding the quality of the sandwich component.

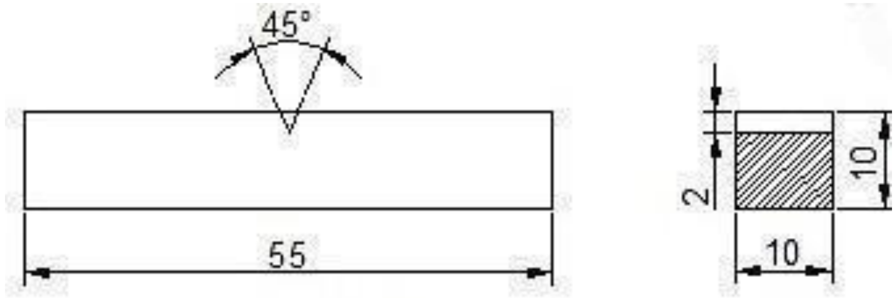


Figure 5.7 Schematic diagram of the impact test

Figure 5.8 Impact test machine

Impact tested specimens and setup are shown in Figure 5.8. The specimens were placed on the Charpy impact machine and the loads were applied suddenly. The impact energy observed by the sandwich specimen was recorded and the energy observation of the composites was analyzed.

Figure 5.9 shows the Charpy impact tested sandwich composite specimen. The sandwich composite was subjected to a suddenly applied blow by the pendulum and material ability to observe the energies was noted.

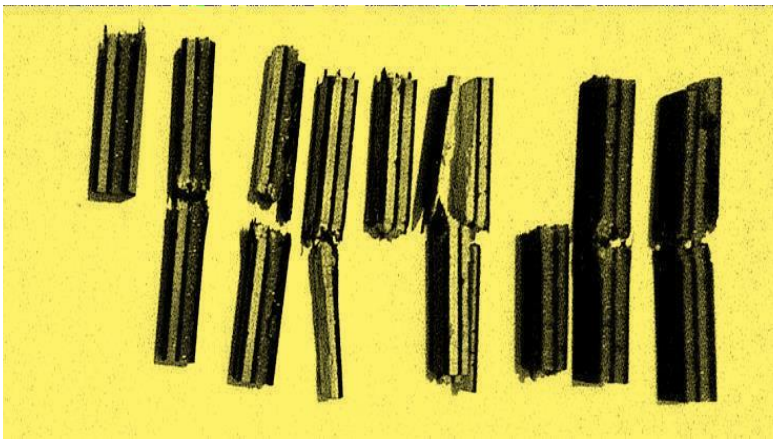
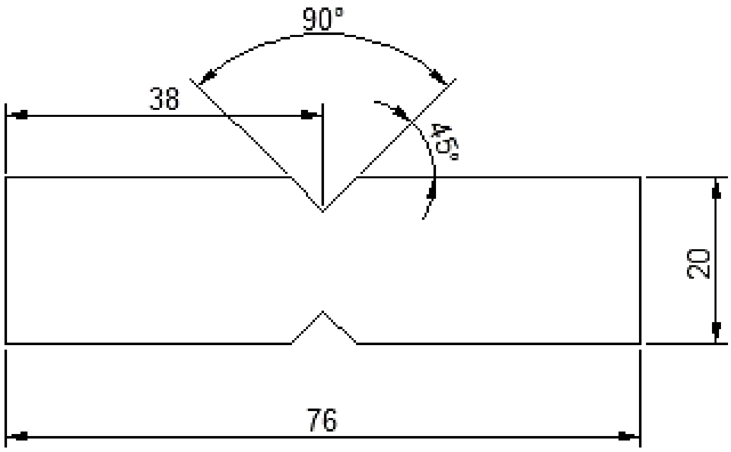


Figure 5.9 Impact tested



CHAPTER 6

RESULT AND DISCUSSION

6.1 INTRODUCTION

The results of various mechanical and thermal tests conducted on the sandwich composite of sample-1 to sample-9 for polyurethane, PVC, and hybrid composites are discussed. Also, the result of the machining characteristics of the sandwich composite was discussed in this chapter.

6.2 RESULT OF MECHANICAL TEST

6.2.1 Tensile Test Result

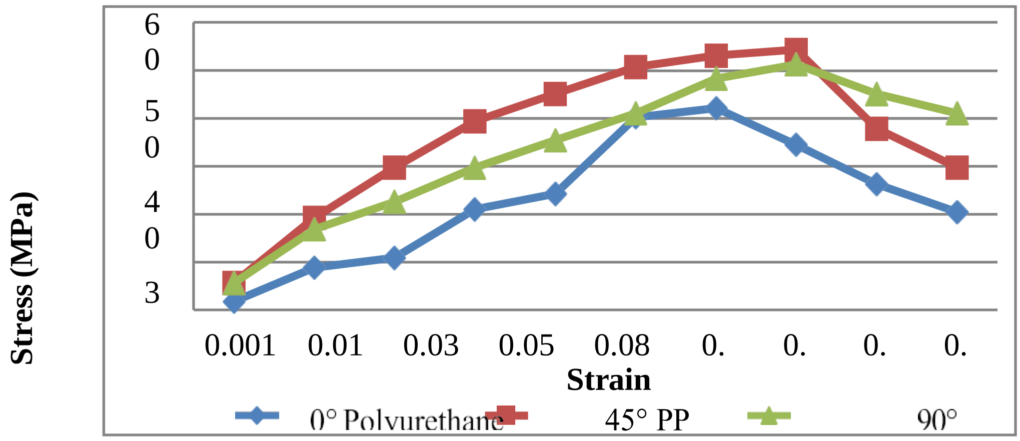


Figure 6.1 Stress-strain relation of the PP WITH PVC foam composite (C1)

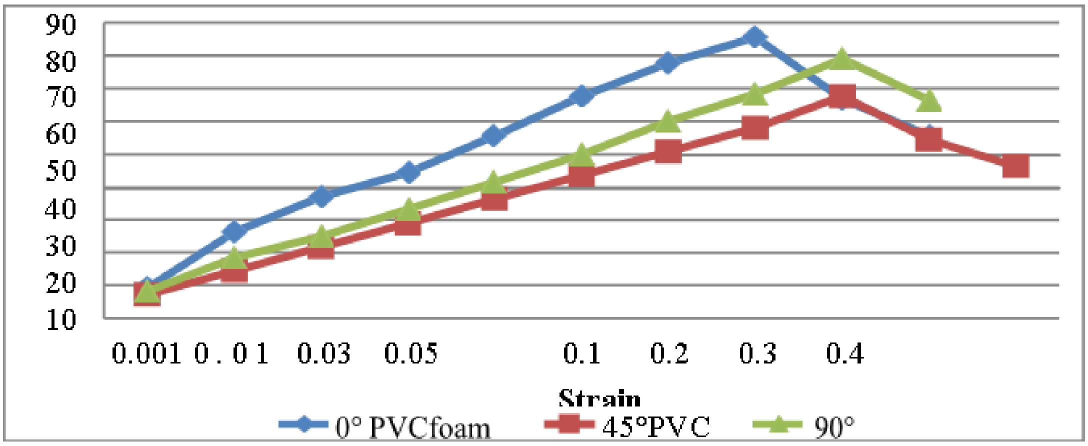


Figure 6.2 Stress-strain relation of the PP WITH PVC foam composite (C2)

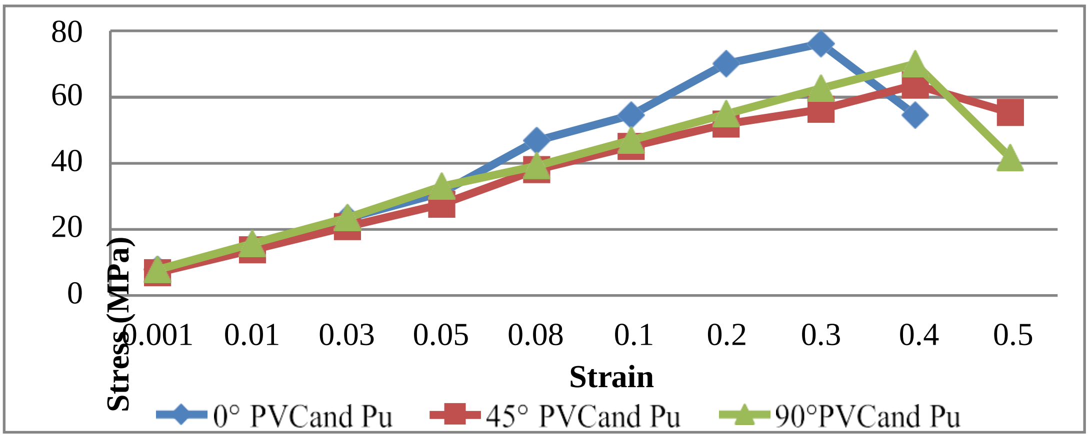


Figure 6.3 Stress-strain relation of the hybrid foam composite (C3)

Table 6.1 Tensile properties of the composites

Composite specimen	Break load [KN]	Maximum Displacement (mm)	Elongation (%)	Ultimate tensile strength (MPa)	Tensile modulus (MPa)
Category-1					
Sample1	5.245	5.2	9.1	42.12	462.86
Sample2	6.755	3.7	6.5	54.30	835.39
Sample3	6.370	6.0	10.5	51.22	487.81
Category-2					
Sample1	9.240	5.4	9.5	85.62	901.26
Sample2	7.460	4.9	8.6	67.64	786.51
Sample3	8.565	6.5	11.4	79.09	693.77
Category-3					
Sample1	8.805	4.7	8.3	76.11	916.99
Sample2	7.365	3.5	6.1	63.63	1043.12
Sample3	8.050	4.4	7.7	70.02	909.35

Figure 6.4 Comparison result of tensile test

Flexural Test Result

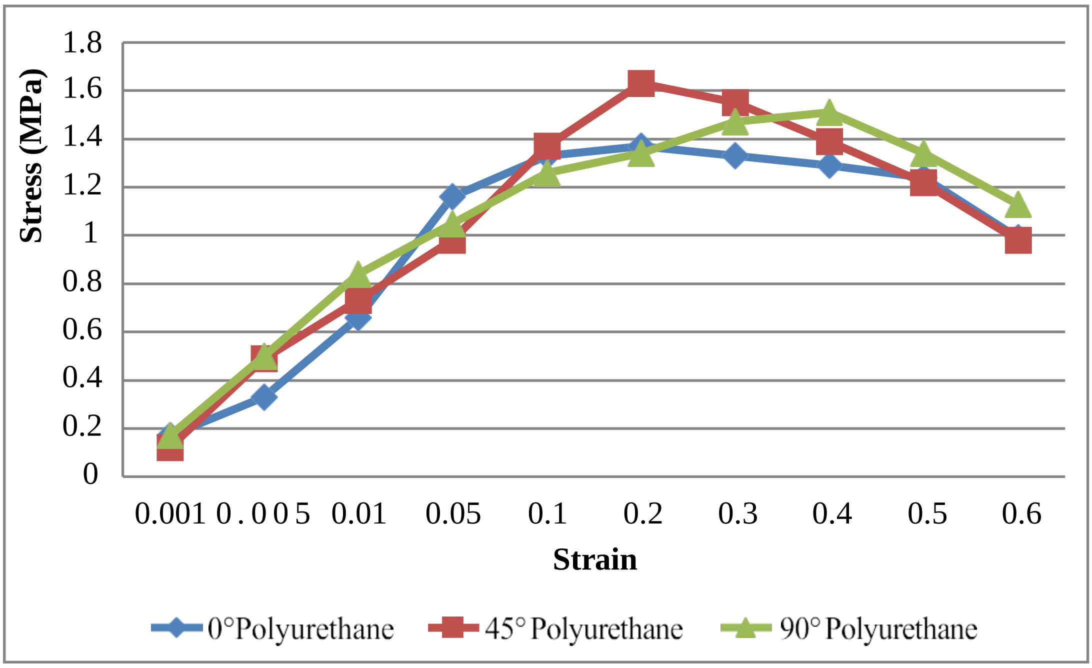


Figure 6.7 Stress-strain relation of the PP AND PVC foam composite (C1)

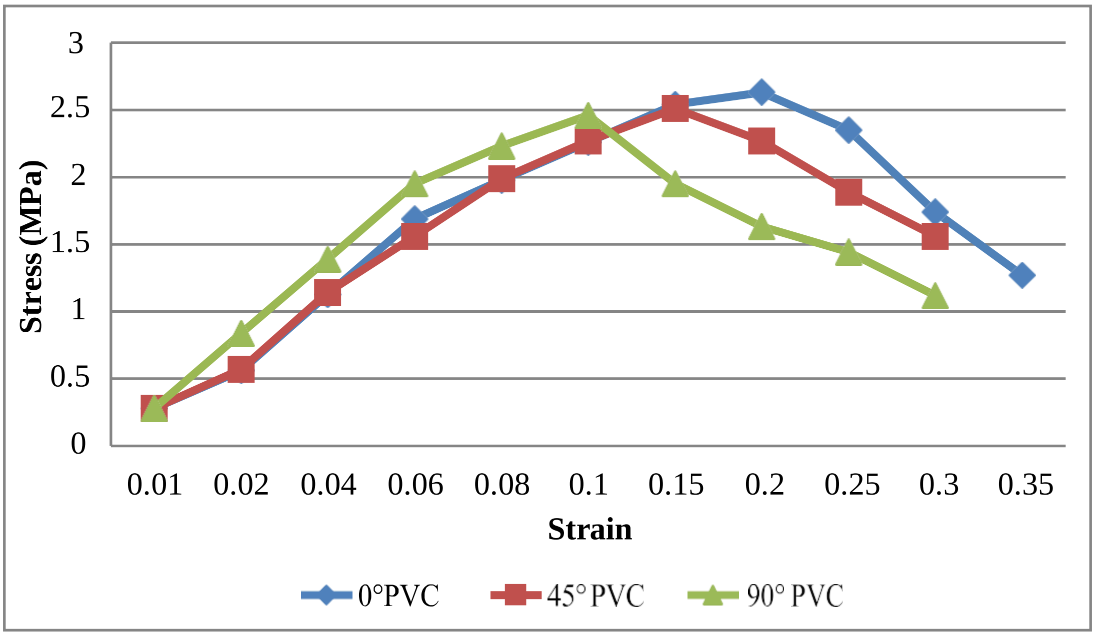


Figure 6.8 Stress-strain relation of the PVC WITH PB foam composite (C2)

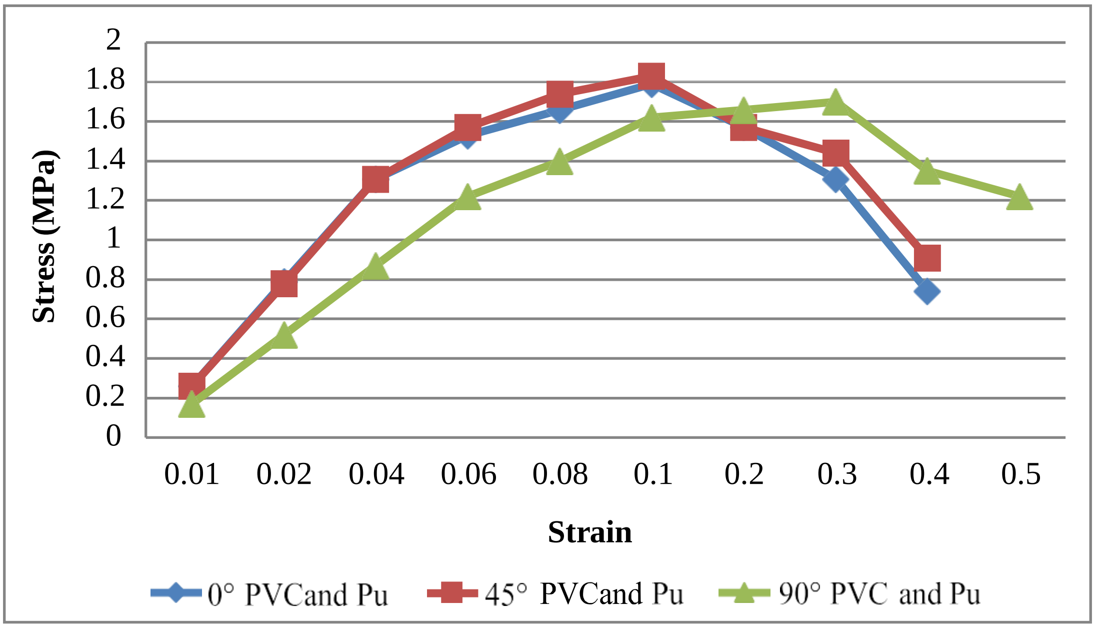


Figure 6.9 Stress-strain relation of the hybrid foam composite (C3)

Table 6.2 Flexural properties of the composites

Composite specimen	Break load [KN]	Maximum Displacement (mm)	Elongation (%)	Ultimate flexural strength (MPa)	Flexural modulus (MPa)
Category-1 Sample1	0.165	7.5	16.7	1.37	8.20
Sample2	0.200	6.0	13.3	1.63	12.26
Sample3	0.180	15.0	33.3	1.51	4.54
Category-2 Sample1	0.280	4.5	10.0	2.63	26.30
Sample2	0.265	5.25	11.7	2.51	21.45
Sample3	0.265	5.20	11.6	2.46	21.21
Category-3 Sample1	0.205	13.0	28.9	1.79	6.19
Sample2	0.210	12.6	28.0	1.83	6.54
Sample3	0.195	12.8	28.4	1.70	5.99

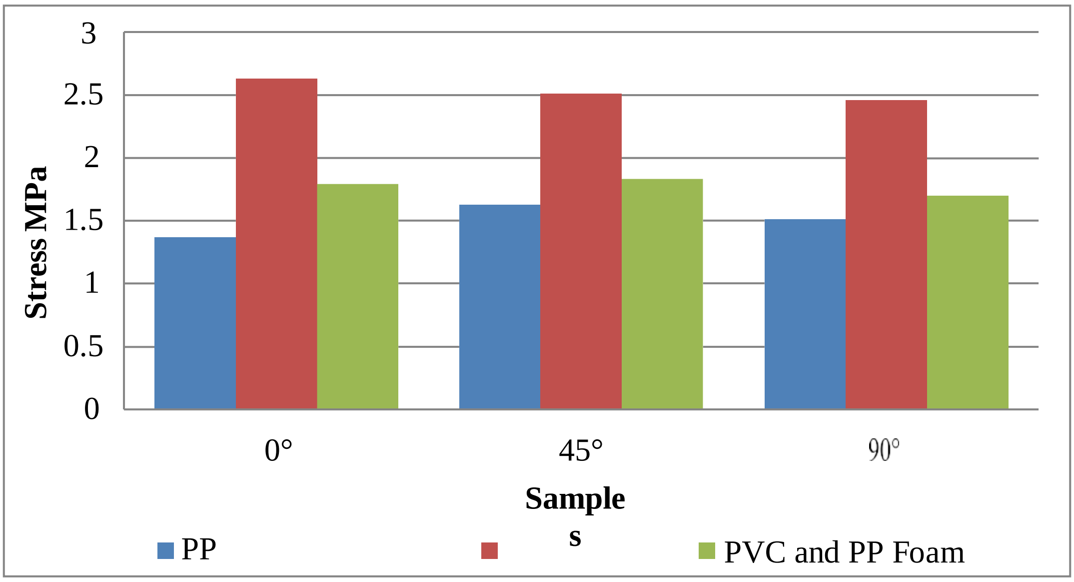


Figure 6.10 Comparison result of flexural test

Table 6.3 Impact test properties of the composites

Composite specimen	Energy observed (J)
Category-1	
Sample1	3.90
Sample2	3.85
Sample3	3.80
Category-2	
Sample1	4.10
Sample2	4.00
Sample3	3.90
Category-3	
Sample1	4.05
Sample2	3.95
Sample3	3.85

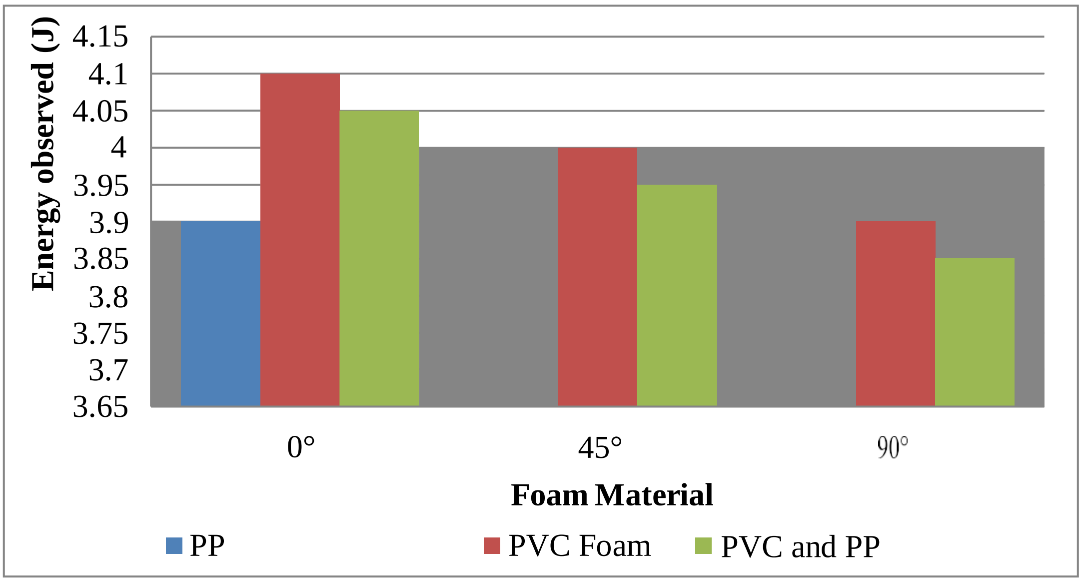


Figure 6.13 Comparison result of the impact test

CHAPTER 7

CONCLUSION

In this research work, sandwich composite materials were fabricated with PP and PVC foam as a core component and carbon fiber as a skin material. The fabricated samples were tested to enable an analysis of the mechanical, thermal, and wear tests for their machining characteristics. The following conclusions are presented from this research work.

7.1 CONCLUSIONS BASED ON MECHANICAL PROPERTIES OF THE SANDWICH COMPOSITE MATERIALS

In this, sandwich composite materials with different orientations of 0º, 45º, and 90º polyurethane and the PVC foams were fabricated. The mono structure of PP and the PVC foam, and also the hybrid polyurethane and PVC foams were fabricated. The samples were tested for their tensile, flexural, impact, shear, delamination strength, and hardness test.

1. The results of tensile tests show the PVC foam composite attaining higher tensile strength of 85.62 MPa. The 0° foam-oriented PVC foam composite plates (C2-S1) showed higher strength in the tensile test. The SEM images of the polyurethane foam show the more fractured surfaces. So, the PVC foam composites have more tensile strength than polyurethane foam composites.

2. The results of the flexural test show the PVC foam composite having a maximum flexural strength of 2.63 MPa. Themaximum stress was attained by the PVC composite plates (C2-S1) at the 0° orientation. The fractured areas were seen as particularly even for the PVC foam composite shown in theSEM images. Because the flexural strength of the PVC foams is higher than polyurethane.

3. The results of the impact tests show the PVC foam composite having maximum energy of 4.1 J. The 0° oriented PVC foam composite plates (C2-S1) were seen taking maximum energy. The SEM images of the impact test show the polyurethane and PVC foams as more damaged on account of the suddenly applied load.

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