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Characterization of Mechanical and Physical Properties Of Polyurethane Cored Sandwich Structure

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Abstract: In this modern era, most of the conventional engineering materials are replaced by composite materials. Composites are widely used in automobiles, aircraft and marine applications because they are related to light weight, high strength to weight ratio, corrosion resistance flexibility, high impact strength. In its most basic form the composite material is one which is composed of at least two elements working together. A sandwich structured composites is a special class of composite materials that is fabricated by attaching two thin but stiff skins to a light weight but thick core. This project study focuses on the fabrication and characterization of sandwich composite panels using glass fiber composite skin, polyurethane foam as a core material and epoxy resin as an adhesive material. The main objectives are to characterize the physical and mechanical properties and to elucidate the effect of face sheet thickness and core thickness on the flexural strength of a sandwich structure under three point bending and also attempt will be made to characterized reinforced sandwich composites in terms of water absorption. The images of the fractured specimens showed, crack propagation starts from the interface between the core material and face sheet and moves towards the centre of the core to the lower face of the face sheet.
Key Words-- Epoxy, glass fibre, rigid polyurethane foam, Flexural Strength, water absorption.

I. INTRODUCTION

the use of composite sandwich structures in aerospace and civil infrastructure applications has been increasing especially due to their extremely low weight that leads to reduction in the total weight and fuel consumption, high flexural and transverse shear stiffness, and corrosion resistance. In addition, these materials are capable of absorbing large amounts of energy under impact loads which results in high structural crashworthiness. In its simplest form a structural sandwich, which is a special form of laminated composites, is composed of two thin stiff face sheets and a thick lightweight core bonded between them. A sandwich structure will offer different mechanical properties with the use of different types of materials because the overall performance of sandwich structures depends on the properties of the constituents. Hence, optimum material choice is often obtained according to the design needs. Various combinations of core and face sheet materials are utilized by researchers worldwide in order to achieve improved crashworthiness.

In a sandwich structure generally the bending loads are carried by the force couple formed by the face sheets and the shear loads are carried by the lightweight core material. The face sheets are strong and stiff both in tension and compression as compared to the low density core material whose primary purpose is to maintain a high moment of inertia. The low density of the core material results in low panel density; therefore under flexural loading sandwich panels have high specific mechanical properties relative to the monocoque structures. Therefore, sandwich panels are highly efficient in carrying bending loads. Under flexural loading, face sheets act together to form a force couple, where one laminate is under compression and the other under tension. On the other hand, the core resists transverse forces and stabilizes the laminates against global buckling and local buckling. Additionally, they provide increased buckling and crippling resistance to shear panels and compression members. The critical properties of sandwich structures vary according to the application area of the structure. In automotive industry the out of plane compressive properties are more critical, whereas in wind turbines the in plane compressive properties are more important. Therefore, depending on the application area, different properties or characteristics of sandwich panels are needed to be evaluated. In order to select the correct configuration for the sandwich structures according to the design specifications these structures are tested. The objectives of this study are to produce 50/50 ratios of both polyether polyol (PEP) and methyl di isocyanate (MDI) were taken to produce the rigid polyurethane foam. This project is focused on developing a new composite sandwich structure with rigid polyurethane foam(50/50) as a core material and glass fibre with epoxy resin as a facing material were used fabricated by hand layup method. Then mechanical flexural

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properties are tested by using three point bending (3PB), compression, water absorption and density tests were conducted on composite sandwich specimens and also on polyurethane foam. A sandwich structure is a special form of laminated composites. A typical sandwich structure consists of two thin, high strength face sheets bonded to a thick, lightweight core. Face sheets are rigid and core is relatively weak and flexible, but when combined in a sandwich panel they produce a structure that is stiff, strong and lightweight.

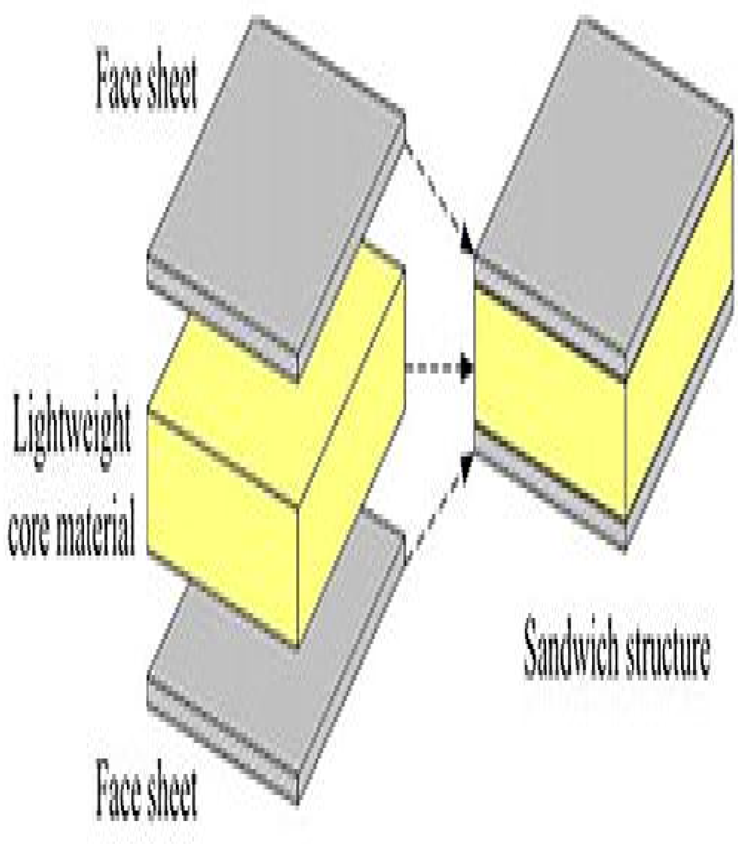

Fig 1.Components of sandwich structure

In structural sandwiches, face sheets are mostly identical in material and thickness and they primarily resist the in-plane and bending loads. These structures are called symmetric sandwich structures. However, in some special cases face sheets may vary in thickness or material because of different loading conditions or working environment. This configuration is named as asymmetric sandwich structures. In general sandwich structures are symmetric; the variety of sandwich constructions basically depends on the configuration of the core. The core of a sandwich structure can be almost any material or architecture, but in general they are classified in four types; foam or solid core, honeycomb core, web core and corrugated or truss core. The adhesion of face sheets and core isanother important criterion for the load transfer and for the functioning of the sandwich structure as a whole.

The basic concept of a sandwich structure is that the face sheets carry the bending loads while the core carries the shear loads. The face sheets are strong and stiff in tension and compression compared to the low density core material whose primary purpose is to keep the face sheets separated in order to maintain a high section modulus. The core material has relatively low density, which results in high specific mechanical properties, in particular, high flexural strength and stiffness properties relative to the overall panel density. Therefore, sandwich panels are efficient in carrying bending loads. Additionally they provide increased buckling resistance to shear panels and compression members. Sandwich construction results in lower lateral deformations, higher buckling resistance and higher natural frequencies than monocoque constructions.

II. LITERATURE REVIEW

A. Isaac and Jundro [2]

determine experimentally the flexural behaviour of composite sandwich beams and compare the results with prediction of theoretical models Sandwich beams are fabricated by bonding unidirectional carbon/epoxy face sheets (laminates) to aluminium honeycomb cores with an adhesive film. All constituent materials (composite laminates, adhesive and core) were characterized independently. Special techniques were developed to prevent premature failures under loading pins and to ensure the failure in the test section. Sandwich beams were tested under four-point and three-point bending. Strains to failure in the face sheets were recorded with strain gauges, and beam deflections, and strain in the honey comb core were recorded by using more techniques. The beam face sheets exhibited a softening non linearity on the compression side and stiffening non linearity on the tension side. Experimental results were in good agreement with prediction from simple models which assume the face sheets to behave like membranes, neglecting the contribution of the honey comb core, and accounting for the non linear behaviour of the face sheets.

B. Johnson and Sims [3]

reported the design and mechanical properties of sandwich materials. Sandwich materials consisting of a low density core with stiff skins offer considerable potential for weight savings in panel applications, where the main loads are flexural. Sandwich materials of interest for car and van body panels, seat shells, etc include steel/plastic laminate, integral skinned plastic foams and glass fibre-reinforced polyester skin with foamed plastic cores. In the work, basic design formulae for the flexural stuffiness and strength of such sandwich materials are reviewed and a method for designing optimum sandwich structure for last weight or cost is given. Mechanical property data are presented on a range of sandwich materials of potential interest for vehicle panel applications.

C. Wit Witkiewicz et al. [9]

investigated properties of polyurethane light foams. Mechanical properties of foams have been measured in compression tests for two foams of 16 kg/m3 and 62 kg/m3 density, and in tension and shearing tests for foam of 62 kg/m3 density. PU foams have shown anisotropic properties as measured in parallel and perpendicular direction to the foam rise. Reduction in buoyancy for both foams after 7 and 30 days of immersion in water has been shown to occur some extent. The burning tests were performed for foam of 62 kg/m3 density showing good behaviour.

D. Anton [11]

has reported polyurethane rigid foam, a proven thermal insulating material for applications between +130°C and -196°C. Polyurethanes are high molecular Weights polymers based on the poly addition of poly-functional hydroxyl group containing compounds and poly isocyanates. Rigid polyurethane foams perform well in most areas of low-temperature insulations. Products in the density ranging from approximately 30 kg/m3 to 200 kg/m3 withstand temperatures down to -196°C. Typical applications are refrigerated Vehicles, road and rail tankers, vessels for refrigerated cargo, pipelines, liquid gas for LPG and Cryogenic wind tunnels.

E. G.S. Langdon et al. [5]

reported a preliminary experimental investigation into the response of sandwich panels comprising E glass fibre reinforced vinyl ester face sheets and closed cell PVC foam cores to localized blast loading. A failure progression pattern was identified, with increasing impulse: front face sheet delamination, core compression, back face sheet delamination, fibre fracture, core fragmentation, plastic deformation and debonding of the back face sheet followed by complete core penetration. No back face sheet rupture was observed.

F. Problem formulation

Based on above literature, it is very much clear that not much investigation is carried out on sandwich composites with glass fibre as a skin material. Indeed, ecological considerations such as recyclability an environmental friendly products are the new driving forces in our society where pollution and global warming issues have become almost incontrollable hence the present research was devoted to the development of polyurethane foam with 50/50 proportion of the MDI and PEP. Polyurethane foam is used as a core and the skin material used are glass/epoxy and then combination of these for the development of sandwich structure. The experimental studies of three point bending, compression, water absorption and density test were carried out to study the material property of sandwich structures.

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G. Objectives

1) Develop the rigid polyurethane foam in 50/50 proportion.
2) Characterisation of rigid polyurethane foam for mechanical property by subjecting it to three point bending test.
3) Characterisation of rigid polyurethane foam for physical property.
4) Developing rigid polyurethane foam cored sandwich structure with using glass fibre as a face skin material.
5) Characterisation of developed sandwich structure for mechanical properties.
6) Characterisation of developed sandwich structure for physical property.
7) Characterisation of developed sandwich structure for water absorption property.
8) Examine the effect of core thickness and face sheet thickness on the bending strength of sandwich structure.

H. Methodology

To achieve the above mentioned objectives, following methodology is adopted and followed carefully so as to get the accurate reliable results

1) Rigid polyurethane foam is prepared by moulded method.
2) Hand lay-up method is used to fabricate the skin of the sandwich structure and composite laminates.
3) Characterization of the rigid polyurethane foam.
4) Characterization of sandwich structure.

III. MATERIALS SELECTION AND EXPIREMENTATION

It is intended to present in this chapter an account on materials used, fabrication and various test methods employed in the present investigation for studying the rigid polyurethane foam and foam cored sandwich structures. Details of experimental procedures followed for the fabrication and instrumental techniques are adopted for mechanical characterisation such as mechanical testing, physical testing.

In this work rigid polyurethane foam is produced with 50/50 proportions of both MDI and PEP. Sandwich panel skins are made from laminates glass and epoxy resin. And combination of these with rigid polyurethane foam as a core material forms the sandwich structure for this mechanical and physical tests were carried out. Water absorption for core and sandwich structures is conducted.

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Fig 2.Materials used for specimen fabrication

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A. specimen fabrication

The sandwich specimens were fabricated according to mold box specifications. The specimen consists of glass fibre/epoxy and polyurethane foam as core. Table 6.1 shows the material specification. The primary chemicals used to produce the polyurethane foam where methyl di-isocyanate (MDI) and polyether polyol (PEP).

Type of rigid polyurethane foam	Weight in grams	
	MDI	PEP
50/50	190	190

Table 1.Composition of rigid polyurethane foam

B. Preparation of rigid polyurethane foam

The procedure of preparation of rigid polyurethane foam summarized as follows:

1) Amount of MDI and PEP liquids were taken in separate clean and dry glass cups.
2) Inner surface of wooden die (250 mm * 250 mm * 24 mm) was covered with a Teflon sheet.
3) MDI and PEP were mixed using stirring rod in a separate glass vessel.
4) The mixture was poured in to die.
5) The die was covered with wooden plate at top and pressure of 5 tons was applied using hot press.

C. Sandwich panel preparation

There are different manufacturing methods used in the production of structural composites. We made use of hand lay-up process for production of structural composites.

Hand lay-up process is a manual approach in which layers of fabric and resin are successively applied onto a mould. This method is perhaps the simplest, oldest and least complicated. The mold is firstly designed to the shape of the final composite structure.

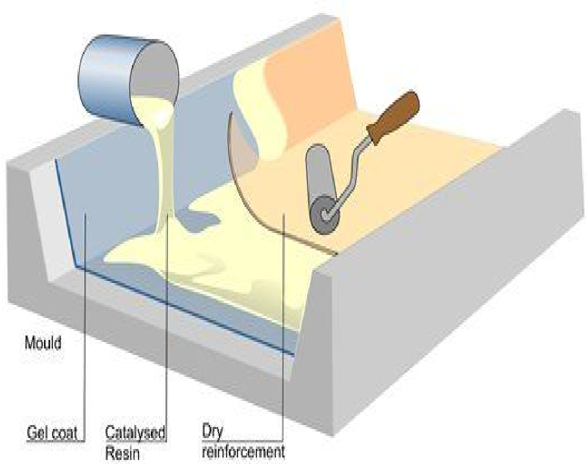

Fig 3.Sandwich panel preparation

The fibre layers are oriented in such a way as to develop the desired strength and stiffness. After each layer of fabric is placed, a roller is used on the composite so that a strong bond results and excess resin is squeezed out. The stacking of fabric materials and resin is done until the required thickness is achieved. This method is laboured intensive and only suitable for production in low volume. It also has a disadvantage of low quality control and inconsistency in properties of various parts of the finished product. However, with this method, complicated shaped composites can be manufactured, such as the complex core configuration of the sinusoidal honeycomb panel. In recent years, the advances in manufacturing technology have resulted in some improvement in this manual process. Today, the hand lay-up has become automated in several applications. Hand lay-up is used for fabricating laminates made of skin material glass for polyurethane core sandwich panels.

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1) *These includes following steps:*
   a) A glass fibre mat was laid-up on PUF core.
   b) A resin and hardener on each face of the glass fibre mat was laid up.
   c) Reinforcement fibres on each side of the rigid foam were laid up.
   d) The specimens were cured at ambient temperature for 2 to 3 hours applying pressure using hot press.

Material composition	Weight fraction (%)		
	Glass fibre	Epoxy resin	Hardener
Glass/epoxy composites	50	50	40

Table 2.Material composition of skin

D. Experimentation

The following tests are carried-out for sandwich structure

1) Compression Test
2) Three Point Bending Test
3) Water Absorption Test
4) Density Test

1) *Compression test:* Compression test of sandwich structure is carried out in UTM machine. The length, width, depth of core is 50 mm, 50 mm, 27 mm respectively. During testing the specimen is kept in between the jaws of universal testing machine and load is applied as shown in below figure.

Fig 4.Specimen during compression test

2) *Bending test of sandwich structure:* The flexural test is conducted by using three point bending test using universal testing machine. The objective set for this project is to study the effect of core thickness and face sheet thickness on the flexural strength of glass/epoxy polyurethane cored sandwich polymer matrix composite. In this project the parameters selected for the study are face sheet thickness and the core thickness. The list of parameters and their levels are shown in table below

Parameter	Face sheet thickness in mm		
	Level 1(2mm)	Level 2(4mm)	Level 3(6mm)
Core thickness in mm	10	10	10
Core thickness in mm	20	20	20

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Table 3.Bending parameters and levels

Experiment No.	Face sheet thickness, mm	Core thickness, mm
1	2	10
2	2	20
3	4	10
4	4	20
5	6	10
6	6	20

Table 4.Experimental Plan

On the basis of above selected parameters and Experimental plan specimens are prepared and Sandwich structures are then cut to the size 250 mm * 30 mm and tested in universal testing machine as shown in figure.

Fig 5.Specimen during bending test

3) *Bending test of foam:* The flexural test conducted by using three point bending test using universal testing machine. The objectives of this test are to determine the flexural strength of foam core. For this test, the specimen dimensions were 250 mm * 30 mm * 24 mm. During testing the specimen is kept in between the jaws of universal testing machine and load is applied as shown in below figure.

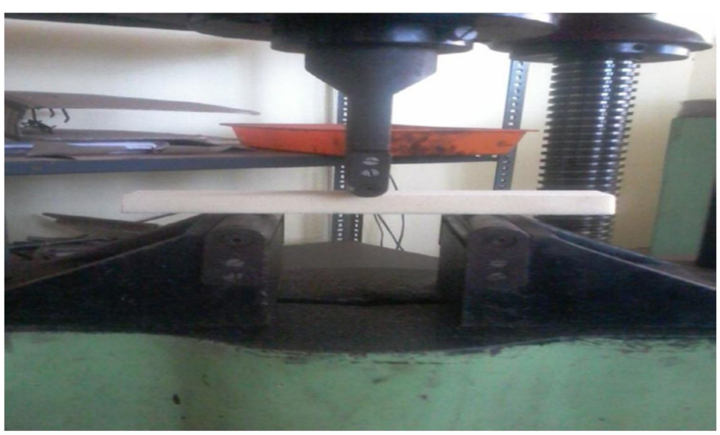

Fig 6.Specimen during bending test

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4) *Water absorption test:* The prepared specimens are tested to water absorption property by placing the specimens in water for about 24 hours and their weight is tested before and after putting into water there by knowing the water absorption property.

Fig 7.Specimen during water absorption test

5) *Density test*

The objective of this test is to determine the density of core materials. The samples dimensions were 250 mm * 50 mm * 24 mm. In this test, panels were tested to determine the panel's density. The density was measured as the mass of the panel divided by its volume.

Specimen	Specimen details		
	Dimension	Weight	Density
Foam	250 mm * 50	0.018 kg	60 kg/m^3
Sandwich	250 mm * 40 * 27	0.09 kg	333 kg/m^3

Table 5. Details of specimens used for density test

IV. RESULTS AND DISCUSSIONS

The physical and mechanical properties evaluated to analyse the comparison of between polyurethane foam cores and sandwich composites. The purpose of this analysis is to determine the ability of sandwich composites in enhancing the material properties. Sandwich composites offer excellent properties due to the way of skin and core deal with load applied.

A. *Compression test*

Compression test is carried out in UTM with a specimen size of 50 mm * 50 mm. The result of compression test is shown below.

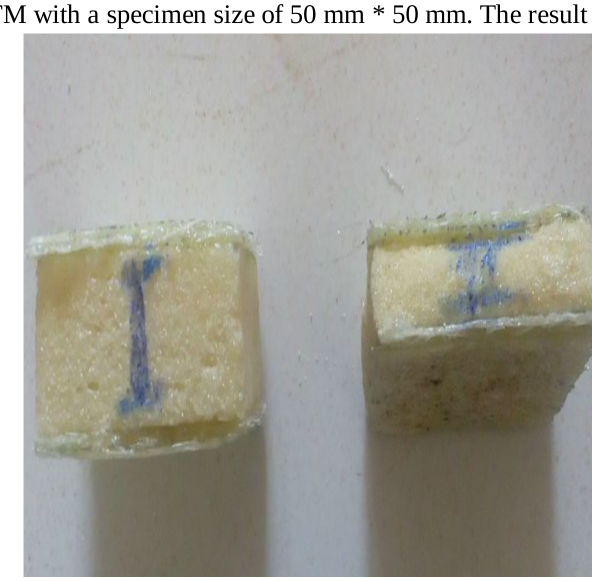

Fig 8.Specimen before & after the compression test

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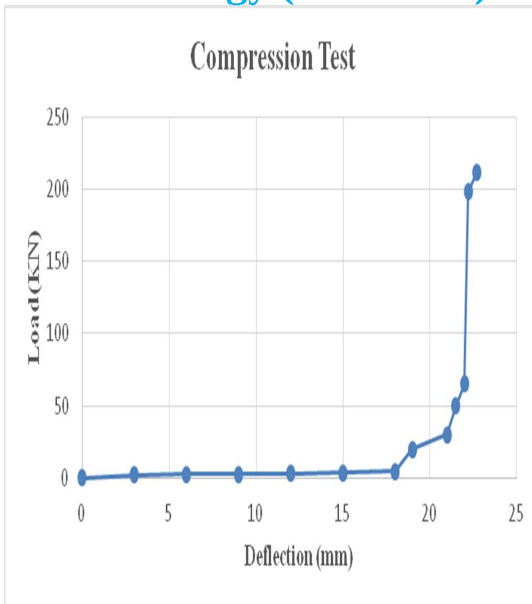

Fig 9.Graphical representation of compression test

The above graph shows the Load v/s Deflection for compression test. As we go on applying load on specimen Initially Uniform deflection takes place up to 20 KN and the deflection is recorded as 19 mm. After 20 KN rapid deformation takes place. Finally peak load is applied up to 212 KN. The compression strength is calculated and is obtained as 157.07 N/mm². After the test thickness of specimen is reduced to 14 mm.

B. Bending test of foam core

Specimen of 50 mm width, 24 mm thickness and 250 mm length is used. Three point bending test of foam is carried out by placing the specimen on the jaws of bending arrangement as shown in the above figure. Initially a small amount of load is applied using data acquisition machine. Immediately after applying the load initial cracking of foam takes place. Lastly the foam will brakes at 0.12 KN. The bending strength is calculated as 1.17 N/mm² and the deflection is recorded as 9.1 mm. According to the result the foam will sustain only 0.04 KN of load. The result of bending test for foam is shown below.

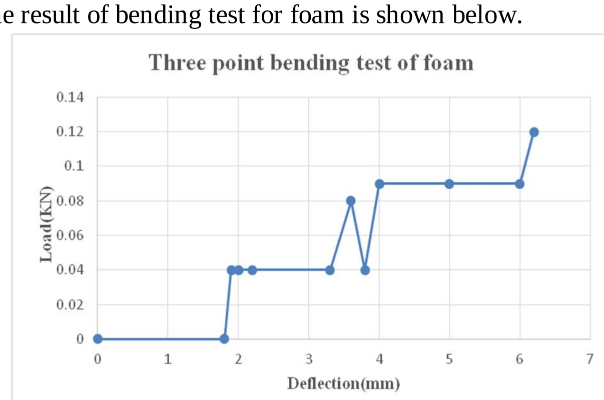

Fig 10.Graphical representation of three point bending test of foam

C. Bending test for sandwich structure

It is well known that the strength of closed cell foam derives from its edges, walls, faces and entrapped gas. In particular, two phenomena will dominate the foam failure during flexural. One of them is cell stretching in the tension side of the specimen, which is initiates the multiple cracking at the edge of the specimen just below the central loading point, and the other is coalesce into a dominant crack causing the eventual failure of the foam. It is seen during testing that crack propagation starts from the interface between the core material and face sheet and moves towards the centre of the core to the lower face of the face sheet. The specimens after testing are shown below

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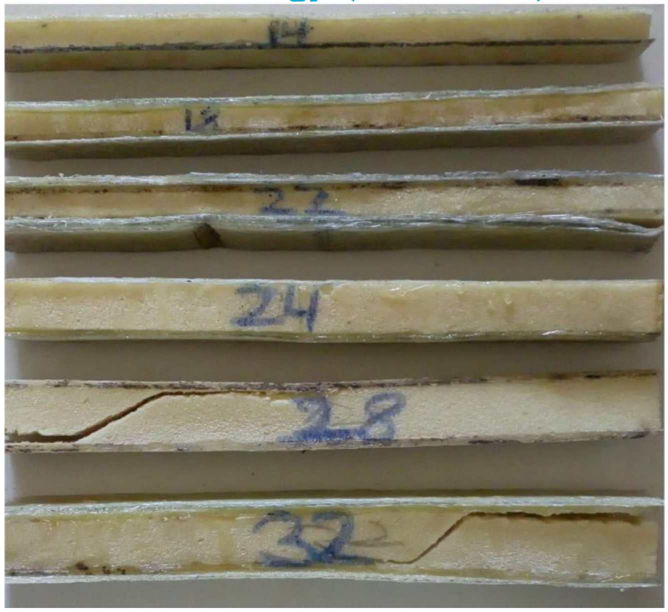

Fig 11.Specimens used for bending test

The bending strength is calculated by values recorded during three point bending test using the formula

$$\text{Bending Strength} = \frac{3WL}{2bd^2}$$

Where

W = Peak Load in N
b = Width of the specimen in mm
L = Length of the specimen in mm
d = Depth of the specimen in mm

Material	Flexural strength in N/mm^2 (σ)
Sandwich Structure (2 mm Face sheet & 10 mm core thickness)	222.62
Sandwich Structure (2 mm Face sheet & 20 mm core thickness)	108.03
Sandwich Structure (4 mm Face sheet & 10 mm core thickness)	265.01
Sandwich Structure (4 mm Face sheet & 20 mm core thickness)	140.20
Sandwich Structure (6 mm Face sheet & 10 mm core thickness)	318.60
Sandwich Structure (6 mm Face sheet & 20 mm core thickness)	188.15

Table 6.Bending strength for Sandwich samples of different face sheet and core thickness

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The effect of PU core thickness and face sheet thickness on the flexural strength of PU/glass/epoxy sandwich structure is studied with the help of bending test results of prepared specimens.

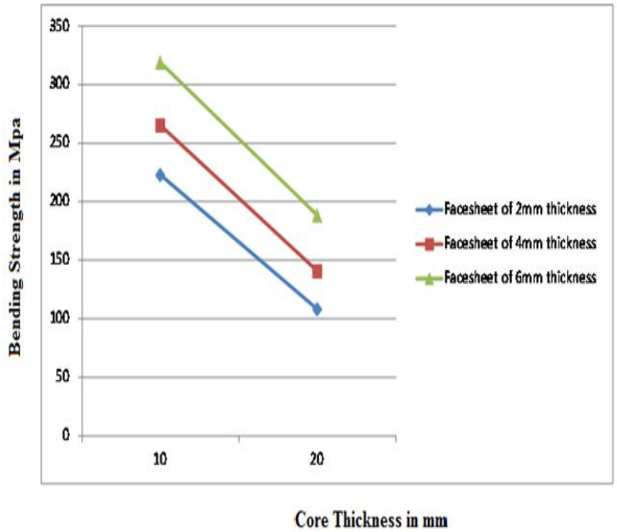

Fig 12.Effect of core thickness on flexural strength

From the graph 8.3b it is observed that, the flexural strength decreases with increase in core thickness. That is, flexural strength is inversely proportional to the core thickness.

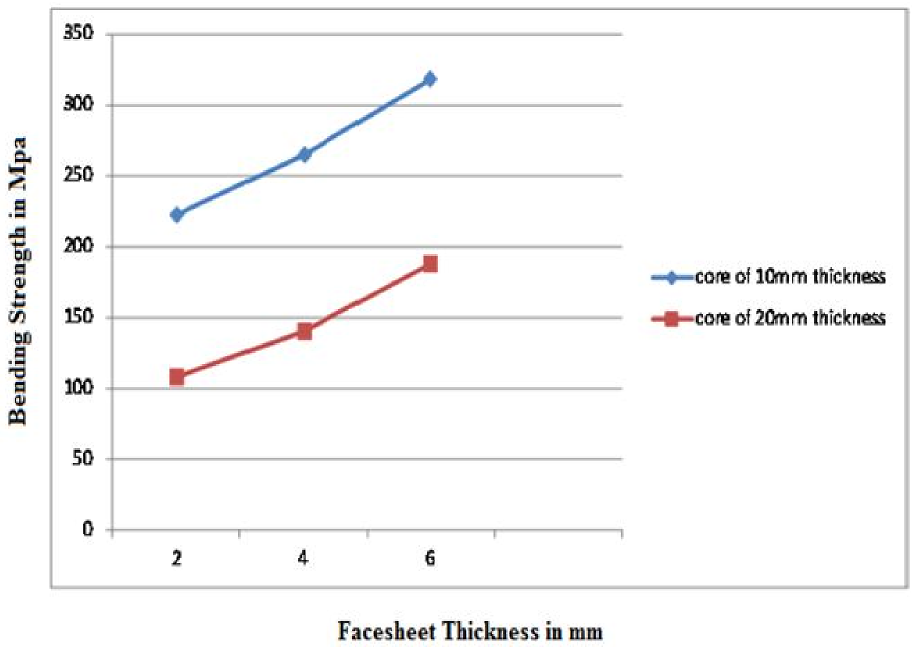

Fig 13.Effect of face sheet thickness on flexural strength

Form graph 8.3c it is observed that the flexural strength increases with increase in face sheet thickness. In general the flexural strength can be related as

$$\sigma \,\alpha\, \frac{Tf}{Tc}$$

Where,

Tf = Thickness of face sheet

Tc = Thickness of core material.

The maximum value of flexural strength is found to be 318.6 Mpa for 6 mm face sheet and 10 mm core thickness.

D. Water absorption test

The specimen of size 250 mm * 50 mm is placed in water, before placing its weight is measured and after taking the specimen from water it is weighed to test the water absorption.

Details of specimen used:
Dimension of specimen = 250 mm*50 mm* 24 mm
Weight of specimen before putting in water = 104 gm
Weight of specimen after placing in water for 1 day = 104.06 gm

E. Density test

Physical properties of sandwich composites and polyurethane foam cores were determined by conducting density test. Polyurethane foam offered better density with lowest average value at 60 kg/m^3 compared to sandwich composite that have higher average density which is 333.3 kg/m^3. Sandwich composites density was increased compared to polyurethane foam cores. This increment is due to sandwich composite cores attachment to fibre glass composite skins. However the excellent properties contribution offered by the role of fibre glass composites skins in sandwich composites, make the density increment worth.

V. CONCLUSION

The mechanical and physical properties of rigid polyurethane foam, sandwich structure composite laminates have been experimentally determined. Water absorption testing and physical properties are noted. Based on the results of the experimental analysis the following conclusions derived.

A. It is seen from results that the most significant factor for flexural strength is face sheet thickness.
B. The maximum value of flexural strength can be achieved for the sandwich structure having greater face sheet thickness and lower core thickness values. In this project the maximum value of flexural strength achieved is 318.6 Mpa.
C. During the flexural loading, the complete load is first taken by the face sheet and gradually transferred to the core material.
D. It is seen from results that it will not absorb water, it shows good floatation property and also it is corrosive resistance property of material makes it possible to use in marine applications.
E. Polyurethane core material has a very low thermal conductivity of about 0.022 W/mk to 0.028 W/mk. The sandwich structure made by using this PUF as core material is used in heat insulation applications such as pipe insulations and for constructing storage reservoirs.
F. It can Seen from various mechanical and physical tests polyurethane foam of 50/50 proportion of MDI and PEP posses properties that are suitable to various applications such as marine and heat insulations.

VI. SCOPE FOR THE FUTURE WORK

In the present analysis, rigid polyurethane foam is made in 50/50 proportion and sandwich structure is made with making use of glass/epoxy laminate and various mechanical and physical tests are conducted on composite made from glass/epoxy laminate. There is a scope for carrying future experimentations and analysis they are:

A. Since the material is susceptible low and high velocity impacts, an experimental analysis on the impact on the impact behaviour can be performed.
B. In the present work, the duration of exposure for water absorption is in terms of days, the same can be extended by increasing the exposure time.
C. FEM analysis can be carried out for this material, for the same characterising parameters with the aid of suitable software's.
D. The project can be continued to study with different composition of face sheet materials and core materials. The mechanical properties such as tensile and fatigue can be studied for different orientation of the fibres for face sheet thickness.

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