Weight Reduction of Heavy Commercial Vehicle Using Advanced Materials

M.Tech. Thesis

By

Ram Poojan Yadav

(1502103006)

Discipline of Mechanical Engineering

INDIAN INSTITUTE OF TECHNOLOGY INDORE

JULY 2017

Weight Reduction of Heavy Commercial Vehicle Using Advanced Materials

A Thesis

Submitted in partial fulfillment of the

requirements for the award of the degree

of

Master of Technology

in

Mechanical Engineering

with specialization in

Production and Industrial Engineering

by

Ram Poojan Yadav

Discipline of Mechanical Engineering

INDIAN INSTITUTE OF TECHNOLOGY INDORE

July 2017

Indian Institute of Technology Indore

Candidate's Declaration

I hereby certify that the work which is being presented in the thesis entitled **Weight reduction of heavy commercial vehicle using advanced materials** in the partial fulfillment of the requirements for the award of the degree of **Master of Technology** in **Mechanical Engineering** with specialization in **Production and Industrial Engineering** and submitted in the **Discipline of Mechanical Engineering, Indian Institute of Technology Indore**, is an authentic record of my own work carried out during the time period from **(May 2016 to July 2017)** under the supervision of **Professor Neelesh Kumar Jain** and **Dr. I. A. Palani** of Discipline of Mechanical Engineering.

The matter contained in this thesis has not been submitted by me for the award of any degree from any other institute.

(Ram Poojan Yadav)

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

(Prof. Neelesh Kumar Jain) **(Dr. I.A. Palani)**

Ram Poojan Yadav has successfully completed his M.Tech Oral Examination held on **……….**

Signature of Thesis Supervisors
Date:

Signature of Convener, DPGC
Date:

Signature of PSPC Member 1
Date:

Signature of PSPC Member 2
Date:

Acknowledgement

I take this opportunity to express my deep sense of respect and gratitude for, **Prof. N. K. Jain** and **Dr. I.A.Palani**, for believing in me to carry out this work under their supervision. His constant encouragement and constructive support have enabled this work to achieve its present form. His innovative perspective towards things and his continuous pursuit for perfection has had a profound effect on me and has transformed me majorly. I feel greatly privileged to be one of his students.

My gratitude is also extended towards my PSPC members **Dr. Devendra Deshmukh** and **Dr. Ram Bilas Pachori** for their guidance and cooperation. I am grateful to the **Prof. Pradeep Mathur, Director**, **IIT Indore** and **faculty members** of Discipline of **Mechanical Engineering** for providing the essential facilities and guidance.

I would like to express my recondite thanks to Mr**. Rajeev Kumar Jain and Aditya Birla Group** for providing epoxy resin and hardener as a part of research in development of composite material. I am also obliged to **Mr Santosh Kumar Sharma** for his moral support and the not-so-serious moments shared between us have been highly beneficial during the hardships of this project. I am highly grateful to **Inox Wind Power Plant and its engineers and workers** for providing material and knowledge about fabrication of composite material. I express my deep sense of gratitude to **Sujeet Choubey**, **Mayur Sawant**, **Sagar Nikam** for bearing with me and always maintaining a homely atmosphere in the lab. Special thanks are extended to my colleagues **Vijay Choyal, Rajat Kasliwal, Rahul Kashyap, Gaurav Kumar** for their help, suggestions whenever I needed and for always giving me company, and to all the M. Tech 2017, Production and Industrial Engineering (PIE) batch.

I am also thankful to Lab staff of Mechanical Engineering Labs and Central Workshop, specially **Mr.Anand Petare ASW, IIT Indore, Mr. Santosh Sharma and Mr. Sandeep Gour, Mr. Satish Koushal, Mr. Deepak Rathore, MrVinay Misra** for their cooperation in fabrication of my experimental setup.

Last, but not least, I would like to dedicate this thesis to **my parents**, **sisters, brothers** and **my friends**, for their love, patience, and understanding, because without their support, I would have never reached where I am today.

Ram Poojan Yadav

Dedicated to my Guide –

my mother,

my father,

my teacher,

and my friends

ABSTRACT

The rapidly increasing economic growth leads to advancement in the automotive sector. Concept of road vehicles have changed drastically based in terms of on their design and other functional aspects. Vehicle manufacturers are continuously improving the design of the heavy load carrying vehicles .The developed countries started manufacturing heavy commercial vehicle(HCV) which can carry more load than ordinary vehicle without hampering the mileage of vehicle. These HCV are having lower weight than ordinary vehicle. Leading HCV manufacturing companies looking for more technical enhanced, fuel efficient and economically viable HCV. The best way to increase efficiency of the HCV is to reduce the weight of vehicle. Mileage of a vehicle is related to the fuel consumption of the vehicle. When the load on the vehicle increases, its engine has to do more work to generate the thrust required to propel the vehicle. It results in excessive fuel consumption i.e. increase in load on the vehicle increases its fuel consumption. When the load (weight of the goods) on the engine increases it increases the mean effective pressure of the engine cycle and friction power (difference between indicated power and brake power). If a vehicle requires same brake power, which is available at its wheels, then it has to accelerate more which increases fuel consumption as compared to the unloading condition for same distance of travel. Because weight directly affect the mileage of vehicle so weight should be less. VECV (Volvo Eicher Commercial Vehicle) which is the joint venture between the Valvo group (Volvo) and Either Motors Limited is facing the problem of heavy weight of vehicle due to which vehicles are not able to perform well. So to eradicate this problem VECV Ltd. made collaboration with IIT Indore and ask how to reduce the weight of vehicles.

In this research main aim is to develop advanced new composite material for bus flooring and suggest alternate material for hatrack assembly which is having lesser weight than what they are currently using without compromising the strength of material. They are anticipating weight reduction about approximately 50% in bus flooring and hatrack assembly.

After suggesting and developing advanced material the main aim is to check out the desire mechanical, chemical and other different properties of these new materials. After developing composite material it can be concluded that weight reduction in case of

single layer fiber and double layer on balsa wood as core material reduces weight about 63%. And 42.93% respectively and in case of SAN foam as core material weight reduction in double layer and single layer fiber is about 49.6% and 32.92% respectively. The results obtained after performing the experiment on double layer fiber meeting the expectation while results obtained on single layer fiber are not much significance. For hatrack assembly the suggested alternate material reduces the weight significantly.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1

Introduction

1.1 Commercial Vehicle

Faster and higher load transportation in shorter duration of time is the present requirements of the road transport vehicles. Consequently, concept of road vehicles have changed drastically based in terms of on their design and other functional aspects. Vehicle manufacturers are continuously improving the design of the heavy load carrying vehicles. But, safety of such vehicle is very important because of the load and speed of transportation. The European Union defines a ***commercial vehicle*** as any motorized road vehicle which according to its type of construction and equipment is designed for and is capable of transporting more than nine persons including the driver and/or goods and is fitted with a standard fuel tank. This implies that the fuel tank permanently fixed by the manufacturer to the motor vehicles of the similar type and which allows the fuel to be used directly both for propulsion and for providing power to the refrigeration system, if any.

1.2 Weight and Dimensions of Heavy Commercial Vehicles

European Union directive 96/53/EC defines weight and dimensions of the heavy commercial vehicles (HCV). Figure 1.1 depicts two older modules of HCV giving details of their dimensions. Concept of European Modular System (EMS) classifies the HCV into three categories (i) Street class 1; (ii): Road class 2; and (ii) Road class 3 as illustrated in in Fig. 1.2. The concept of EMS leads to efficient logistics which is shown in Fig. 1.3 for Class 2 and class 3 of HCV.

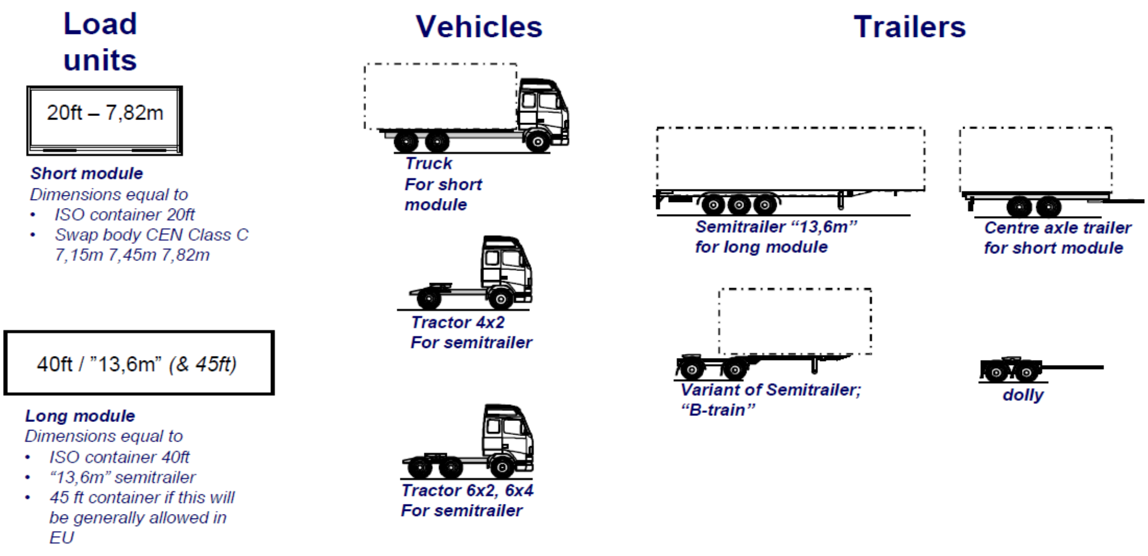


Fig. 1.1: Two older modules of HCV (**Larsson, 2009**).

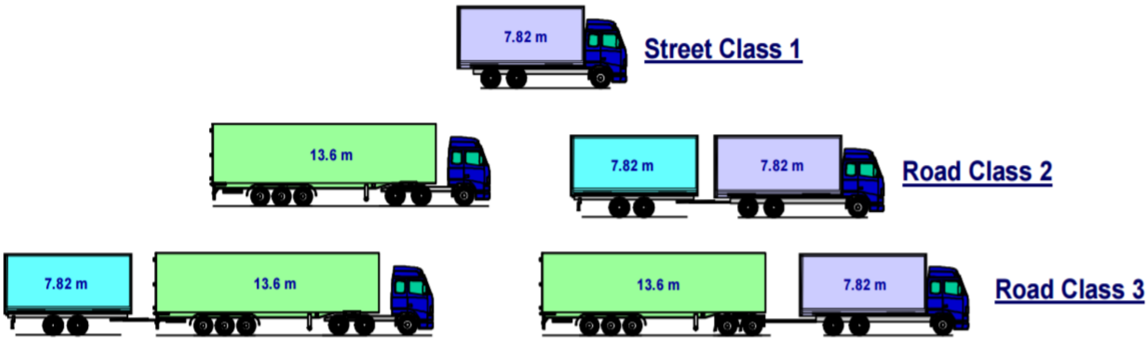


Fig.1.2: Three types of HCV according to the European Modular System (EMS) (**Larsson, 2009**).

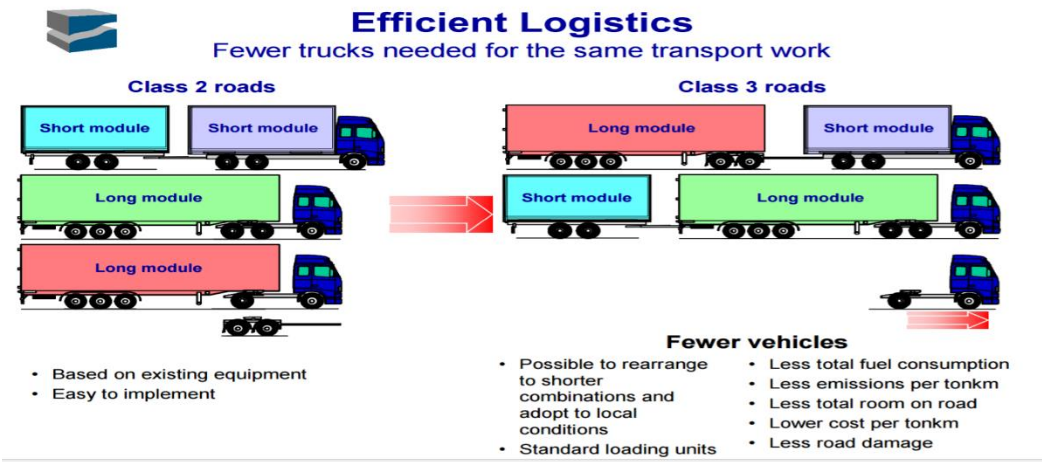


Fig. 1.3: Concept of efficient logistics for two categories of HCV in the EMS (**Larsson, 2009**).

1.3 Importance of Weight Reduction of HCV

Heavy commercial vehicles have received increased demand in recent years because of their immense potential in revolutionizing automobile engineering applications. Leading HCV manufacturing companies looking for more technical enhanced, fuel efficient and economically viable HCV. The best way to increase efficiency of the HCV is to reduce the weight of vehicle. Mileage of a vehicle is related to the fuel consumption of the vehicle. When the load on the vehicle increases, its engine has to do more work to generate the thrust required to propel the vehicle. It results in excessive fuel consumption i.e. increase in load on the vehicle increases its fuel consumption. When the load (weight of the goods) on the engine increases it increases the mean effective pressure of the engine cycle and friction power (difference between indicated power and brake power). If a vehicle requires same brake power, which is available at its wheels, then it has to accelerate more which increases fuel consumption as compared to the unloading condition for same distance of travel. Fuel consumption of an HCV can be reduced by reducing its dead weight which will also help in increasing its thermal efficiency. Reduced weight of HCV helps in achieving following benefits in addition to fuel economy:

- **Reduction in Emissions: Fan et al (2016)** has described about use of lightweight materials in automotive applications. Lightweight has become more prevalent as transport vehicle manufacturers strive to reduce vehicle weight to improve performance, to lower the fuel and oil consumption, and to reduce emissions. Mass reduction, manufacturing process, and recycling are paramount in the transport sector in achieving reduction of emission of carbon monoxide and other pollutant gasses. The lighter the mass, the lower the acceleration required. The weight reduction of a vehicle is an effective way of reducing emission of harmful gases from any source of energy whether oil (petrol, diesel, etc.), electric, biofuels, or fuel cells.
- **Development of sophisticated vehicles:** Consumer demand for more relaxed, luxurious and reliable travelling by vehicle is continuously growing. But, this requires addition of new auxiliaries, accessories and components which eventually increases the weight of the vehicle. Therefore, weight reduction of HCV by using light weight material assumes lot of significance.
- **Aesthetics:** New components and accessories are added to make a vehicle more attractive and competitive. It also increases the weight of vehicle. Therefore, weight reduction provides opportunity for addition of such components and accessories without affecting power and mileage of the vehicle. .

Use of composite material as light weight in automobile an aviation industry has been growing continuously increasing since 1990s. **Gubencu et al (2010**) have mentioned that composite material is having specific strength typically in the range of 3 to 5 times that of steel and aluminum alloys. Therefore, substitution of existing materials by existing composites or developing new composite in HCV will result in higher strength-to-weight ratio and consequently reduction in its weight. Strength of any composite material strongly depends on fiber type, fiber length, fiber orientation, and fiber content (60 to 70% is strongest, as a rule).

Chapter 2

Review of Past Work

2.1 Motivation of Present Work

The growing push towards 'smart' systems with adaptive and/or intelligent functions and features has necessitated increased use of the advanced technologically driven vehicle. To make vehicle more sophisticated more auxiliaries are being added continuously in HCV. Increased number of accessories increases weight of the vehicle and consequently reduction in its mileage and thermal efficiency. To solve this problem, automobile manufacturers and experts are searching for advanced material that has low weight and higher strength-to-weight ratio.

Traditionally, bus floors of HCV are made of wood which is expensive and unsafe due to being prone to fire hazards. Consequently, HCV manufacturers started using either metals or alloys such as aluminum sheets, stainless steel, etc. Though these floorings are more cost-effective than wood but they poses risk to the safety of the passengers traveling in HCV because metallic materials attract static electricity. Some HCV manufacturers started using combination of metallic, non-metallic and thermosetting material. Some HCV manufacturers used vinyl flooring which is referred as homogeneous vinyl flooring or vinyl flooring in combination with either wood or metals which are known as heterogeneous flooring. But, these also did not help in significant weight reduction of the flooring in HCV without affecting their design requirements.

Generally, composite have lesser weight than metallic materials and can be engineered to have more strength than metallic materials in the direction of loading. **Panthapulakkal et al. (2017)** have mentioned several advantages including weight reduction achievable by use of composite materials. **Karthikeyan et al. (2017)** have mentioned weight reduction in aircraft components by using composite materials. Therefore, development and use of light weight composite material having higher strength-to-weight ratio can significantly reduce weight of those parts of an HCV which constitute dead weight such as bus flooring, hatrack, seating, etc. without affecting their design requirements. Unfortunately, no HCV manufacturing company is presently using such composite materials.

Volvo Eicher Commercial Vehicle (VECV) Ltd. Pithampur is a joint venture between the Volvo group and Eicher motor limited. The company is facing problem of poor mileage performance of the Buses manufactured by VECV and shown in Fig. 2.1 due to their increased weight caused by provision of more sophisticated accessories. It motivated to set the goal of the present work as achieving significant weight reduction of the flooring and hatrack used in the VECV manufactured buses by developing a light weight fire resistant and easy-to-use composite material without affecting their design requirements.

Fig. 2.1: Photographs of some of the buses manufactured by Volvo Eicher Commercial Vehicles (VECV) Ltd at Pithampur (MP).

2.2 Objectives of Present Work

Following objectives were identified to accomplish the goal of the present work.

- Analysis of the material and weight used in the existing flooring and hatrack assembly used in the buses of VECV
- Analysis of the design requirements of the flooring and hatrack in buses of VECV
- Identifying scope for weight reduction of flooring and hatrack
- Identification and development of light weight material for bus flooring
- Identification and development of light weight material for hatrack assembly
- Fabrication of light weight composite material
- Mechanical testing of the developed material

2.2.1 Material and Weight of the Existing Flooring of the Buses

Fig. 2.2 represents weight distribution on bus flooring and Fig. 2.3 shows existing flooring and exterior roof materials:

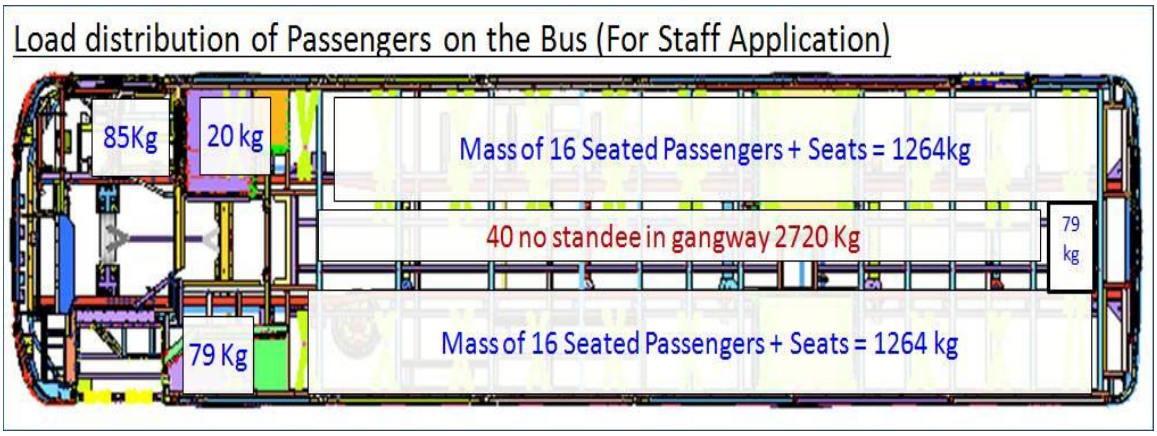


Fig. 2.2: Distribution of passengers' load in bus manufactured by VECV Ltd.

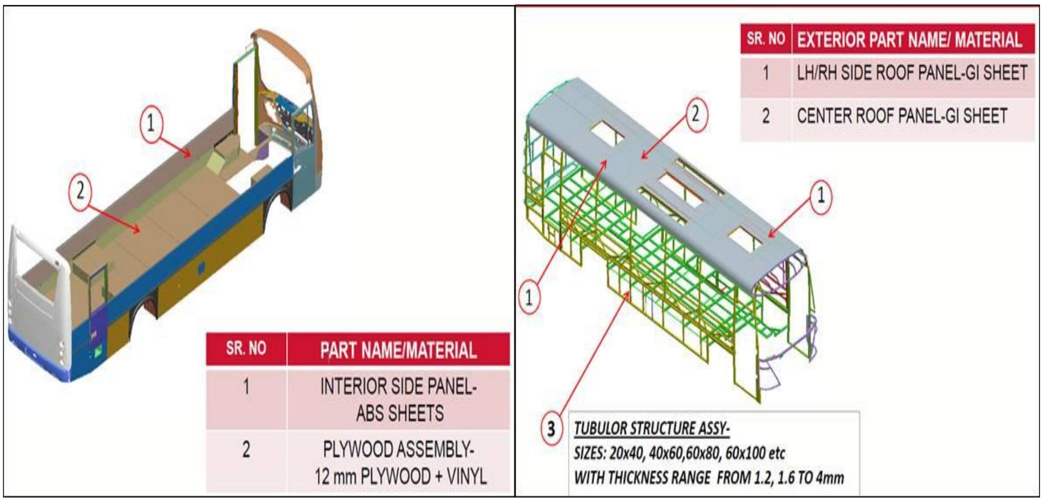


Fig. 2.3: Currently used floor and exterior roof material by VECV Ltd.

In existing design plywood and vinyl materials are being used for bus flooring by VECV Ltd.

Details of assembly:

- Materials: Plywood (12 mm thick) + Vinyl (3 mm thick)
- Weight: assembly weight (120 kg)
- Density: 0.65 g/cc

2.2.2 Design Requirements of Bus Floor

Following are the design requirements for the bus flooring of HCV manufacturing by VECV:

- Weight reduction about 50%:
- Should sustain the dynamic loading 2G
- Easily mountable with the screw on structure
- Better fit and finish

- Fire and water resistance
- Operating temperature range: 90°C
- Aesthetically neat and clean

2.2.3 Material and Weight of the Existing Hatrack Assembly

Fig.2.4 depicts hatrack assembly consisting of different parts having different materials in VECV Ltd.:

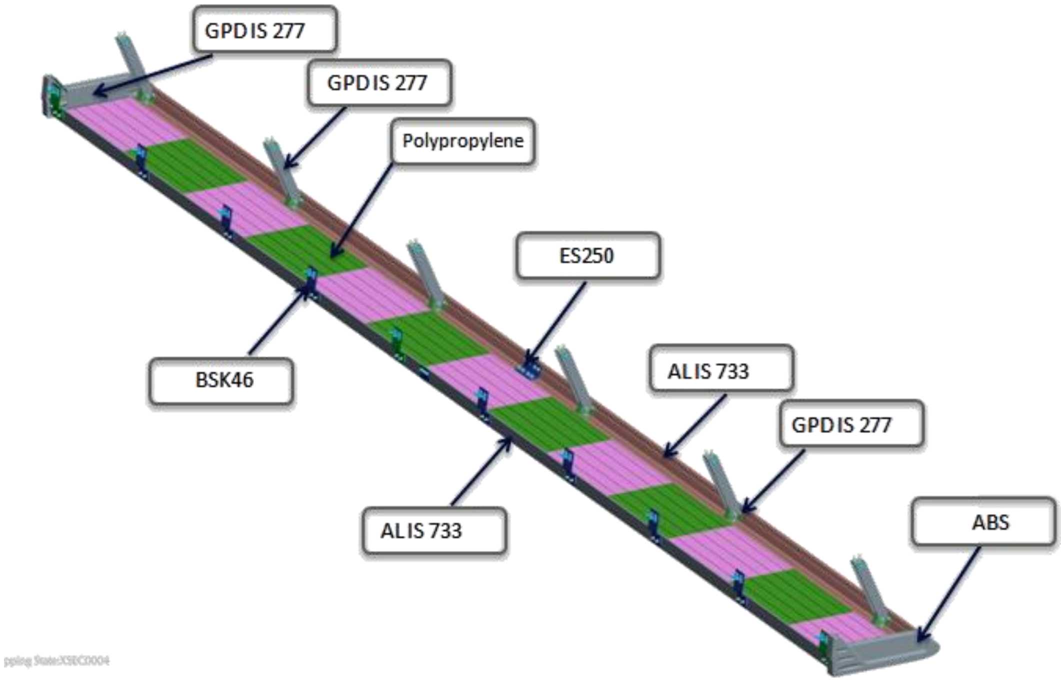


Fig.2.4: Hatrack assembly of buses manufactured by VECV Ltd.

(Weight of above assembly: 40 Kg)

2.2.4 Design Requirements of the Hatrack Assembly

- The length of the hatrack: 7.6 m
- Total load on hatrack: 308 kg i.e. load carried per hatrack: 154 kg
- The first mode of natural frequency of the hatrack should be more than 25 Hz
- The life of the hatrack in fatigue mode should be at least six lacs kilometre.
- Loading should be of 0 to 50 Kg
- Hatrack able to sustain compressive loads

2.3 Research Methodology

Figure 2.4 presents the research methodology used in the present work to meet the identified research objectives.

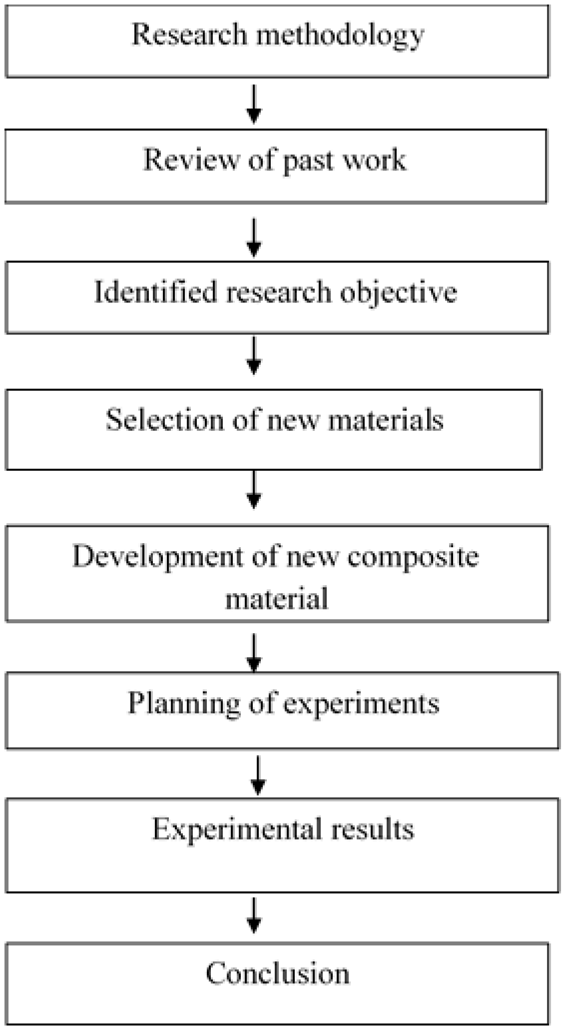


Fig.2.5: Research Methodology of the present work.

Chapter 3

Selection and Development of the Composite Material

3.1 Selection of Type of Material

Few researchers have reported on use of advanced materials in transport sector. **Khalil (2017**) and **Martinzer et al. (2015)** have mentioned that composite material can be used as floor material for heavy commercial vehicles due to special features possessed by them. Composite materials have high specific stiffness (stiffness-to-density ratio) which enables different vehicles to move faster with better fuel efficiency. Therefore, it was decided that development of a light weight carbon fibre reinforced composite (CFRP) material with appropriate sandwich structure and possessing following properties can be a better alternative for replacement for existing materials in bus floor and hatrack. CFRP composite material is one of the most abundantly used composite material.

- It should reduce weight of floor by at least 50%
- It should have good weldability.
- Good resistance to fire, chemical reaction, and wear
- Should have better mechanical properties than the existing material and they should not degrade appreciably at an elevated temperature
- Its cost should be less than or comparable with the existing material being used in floor and hatrack of VECV buses
- Good shock and impact resistance
- Aesthetically more neat and clean

A sandwich structure with glass fibre as the reinforcement material can be the best material to replace the existing material of bus floor and hatrack. Designers and manufacturer of the composite opine that sandwiching a low-density, lightweight core material between thin face sheets can increase a laminate's stiffness with little added weight. A sandwich structure is relatively cost-effective in comparison to more expensive composite reinforcement material and it can be cured with the skins in one-shot processes like resin infusion. Lighter sandwich structure requires less supporting structure than a solid laminate. Sandwich structure also helps in distribution of loads and stresses on the skins which makes a cored sandwich an excellent design for absorbing impact stresses. Compressive strength of core prevents the thin skins from buckling failure, while its shear modulus keeps the skins from sliding independent of each other when subjected to bending loads. Equally important is the adhesive (epoxy resin) that bonds the core to the skins. It must be strong enough to withstand the constant compressive or tensile forces of dynamic loading. The coefficients of thermal expansion of the core, the laminate material and the adhesive are compatible to ensure that thermal cycling does not cause failure of composite material.

3.2 Proposed Composite Material for Bus Flooring

Following constituent were selected for developing sandwich type composite material for bus floor considering the above-mentioned requirements and considerations. Table 3.1 presents mechanical properties of the selected constituents along with another alternative for core material.

- **Glass fibre as reinforcing material:** The arrangement or orientation of the fibers relative to one another, the fiber concentration, and the distribution all have a significant influence on the strength and other properties of fiber-reinforced composites. Following two orientations of glass fibre are possible:
  (i) A parallel alignment of the longitudinal axis of the fibers in a single direction with continuous fiber, or
  (ii) Perpendicular or cross-orientation for continuous fiber and random orientation for discontinuous fiber

Since, strength observed in cross-orientation fiber is more therefore it was selected for bus floor.

- **Balsa wood:** was selected as core material for sandwich structure. Balsa wood is the one of the lowest weighting material. It is a natural cellular material with an excellent stiffness-to-weight and strength-to-weight ratios as well as excellent energy absorption property. It has these properties due to its microstructure, which consists of long slender cells with approximately hexagonal cross-sections that are arranged axially. It can be easily shaped, sanded, glued, and painted. It is also non-toxic, biodegradable, and absorbs shocks and vibrations well. ***Styrene Acrylo Nitrile (SAN) foam*** is a high performance foam which is ideal for marine applications, high shear strength and low-density compatible with sandwich structure of the composite material.
- **Epoxy Resin and Hardener:** Mixture of an epoxy resin and hardener in ratio of 100:35 is proposed to be used as an adhesive to bind the glass fiber and core material. Epotec YD 535 LV grade epoxy resin has been selected in the present work. It is a low viscosity, a modified bisphenol based epoxy resin. This has very good wetting resistance and exhibits excellent adhesion to all types of reinforcements such as glass,

polyester, carbon and Kevlar etc. It provides an excellent combination of chemical, mechanical, physical and thermal properties when it is used with suitable aliphatic or aromatic amine hardeners. Fully cured components prepared by this resin are recommended to operate 112° C temperature. ***Epotec TH 7257*** was selected as hardener which can provide working time more than 5 hours at 25^{o}C with low exothermic reactions. It has rapid curing character and can be used to produce small components that are demoldable in just a few hours at 25°C. Its low viscosity guarantees fast and complete impregnation of reinforcing fibers such as glass, carbon, and polyaramide and allows laminates to be produced by contact pressure, vacuum or pressure bag techniques, filament windings, and vacuum assisted resin injection. The laminates cured at room temperature provide excellent strength. Optimum properties, however, will only be reached after post-curing at temperature more than 40°C. Fully cured components prepared by this system are recommended to operate up to 110°C temperature. Table 3.1 present properties of the proposed material.

Table 3.1: Mechanical properties of the selected constituents of the sandwich composite for bus flooring of HCV along with SAN foam.

Property	Balsa wood	Epoxy resin	Glass fibre	SAN foam
Density (g/cc)	0.163	1.25	2.11	0.12
Tensile strength (MPa)	32.2	130	4137	15
Modulus of elasticity (GPa)	1.28	413.68	206.84	1.5
Stiffness (GPa)	0.23	55.15	8.27	9

3.3 Proposed Composite for Bus Hatrack Assembly

Following two materials are proposed as alternate material for ABS and polypropylene in hatrack assembly. Table 3.2 present their mechanical properties. Fig.3.1 depicts hatrack assembly made of the proposed material for buses of VECV Ltd.

- **Acrylic-styrene-acrylonitrile (ASA):** This material can be better alternative to replace acrylonitrile butadiene styrene (ABS) because it is having better, mechanical, physical and thermal properties properties than ABS. It offers improved weather ability over ABS. Having better stability when exposed to ultraviolet light. ASA is alloyed with either poly-vinyl chloride (PVC) or AES (Centrex). These materials offer good retention of properties and appearance after prolonged exposure to sunlight. It exhibits excellent properties at low temperature.
    - Tensile strength: 23.43-41.36 MPa

- Flexural modulus: 1.378-2.06 GPa
- Impact strength: 103 kJ/m^2
- Maximum operating temperature: 90 °C

- **Polycarbonate**: Polycarbonate can be used to replace polypropylene which is major contributor to weight of hatrack assembly Polycarbonate is an amorphous material with excellent impact strength, clarity and optical properties. It is widely used and a wide variety of compounds are available. Polycarbonate is a victim of its own success as worldwide production capacity is not enough and there are currently long lead times for this material. Polycarbonate has excellent mechanical properties, and can be moulded to tight tolerances.
  - Tensile strength: 62.04-158.5 GPa
  - Flexural Modulus: 2.34-9.65 GPa
  - Impact Strength: 94 kJ/m^2
  - Maximum Temperature: 190 °C

Table 3.2: Properties of the proposed materials for bus hatrack.

Property	Acrylic-styrene-acrylonitrile (ASA)	Polycarbonate
Density (g/cc)	0.163	1.55
Tensile strength (MPa)	41.36	40
Flexural modulus (GPa)	2.06	9.65
Impact strength (kJ/m^2)	103	94

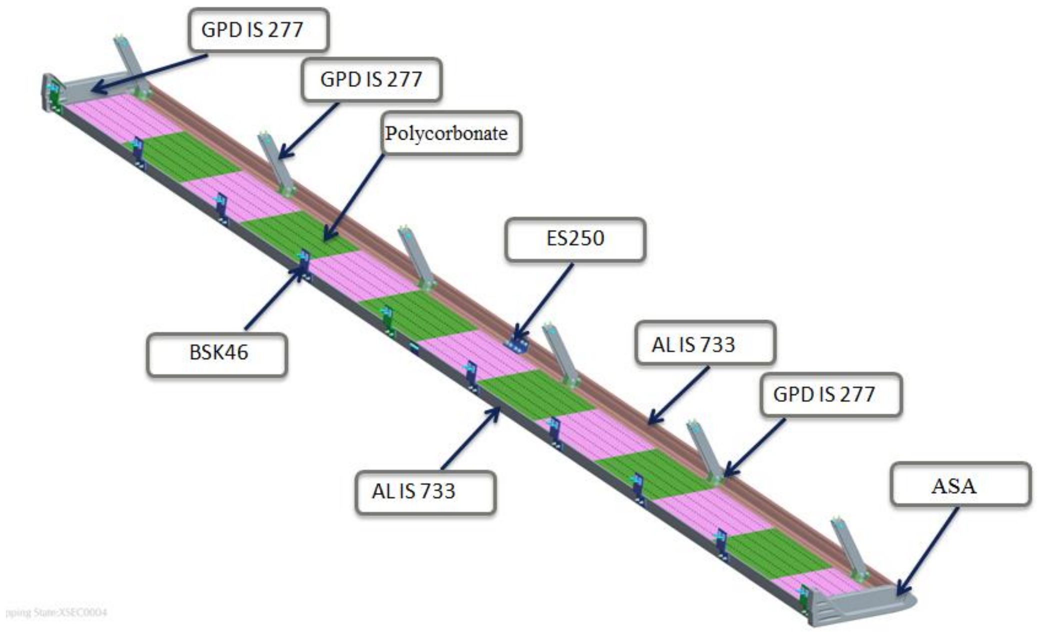
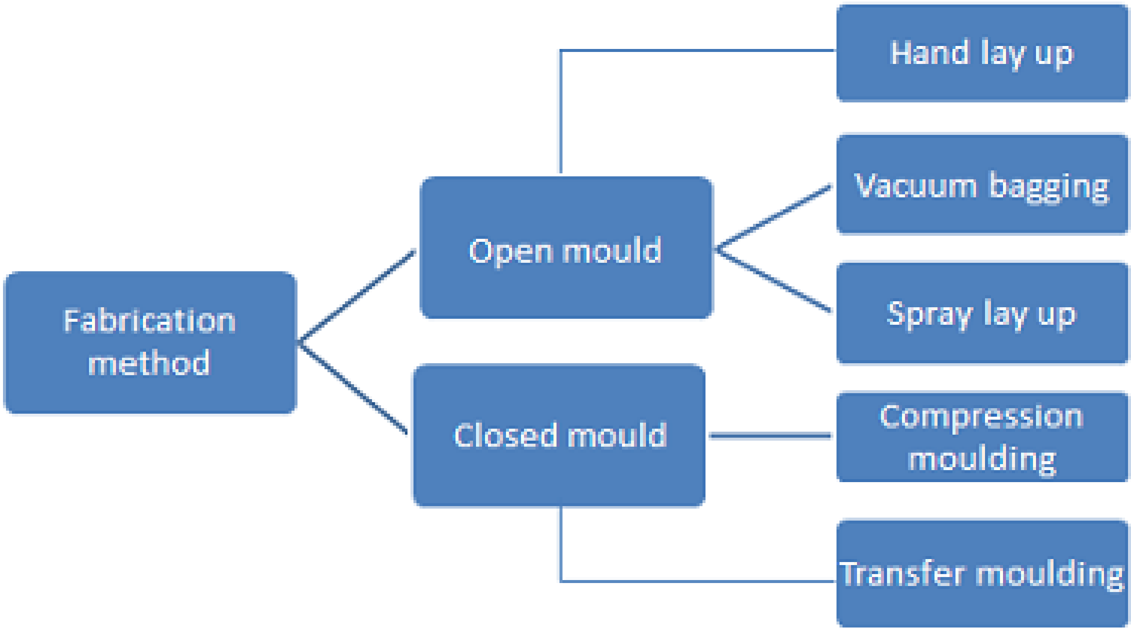


Fig. 3.1: Proposed hatrack assembly of the buses manufactured by VECV Ltd.

3.4 Development of the Composite Material

Following are methods to fabricate sandwich type of composite in which Balsa wood or SAN foam is to be used as core material. In the present work, vacuum bagging method was used to fabricate the selected composition of the composite.



3.4.1 Vacuum Bagging Method

This process uses atmospheric pressure to hold the adhesive or resin-coated components of a lamination in place until the adhesive cures. Modern room-temperature-curable adhesives help to make vacuum bag laminating techniques available to the average manufacturer by eliminating the need for the sophisticated and expensive equipment required for fabricating the composites. Effectiveness of the vacuum bagging process permits the laminating of a wide range of materials from traditional wood veneers, vinyl, balsa wood, PVC foam to synthetic fibers and core materials.

3.4.2 Advantages of Vacuum Bagging:

- ***Maximization of fibre-to-resin ratio:*** The reason that composites are used increasingly is the strength-to-weight advantages that they offer. Key to obtaining this advantage is maximizing the fibre-to-resin ratio. If excess resin exists in the laminate, the laminate will have more of the properties of resin only. If too little resin exists, places where the reinforcement is dry will cause weak spots. To optimize the resin content, the entire reinforcement must be saturated with resin with as little excess as possible. The technique of squeezing out excess resin to obtain a maximized fibre-to-resin content is the concept of bagging. Hand laminate may use in excess of 100% fabric weight by resin. A refined aerospace composite lamination will obtain as little as 40%. The perfect combination for a given lamination in a sophisticated engineering composite fabrication is about 60% resin content.

- ***Uniform distribution of holding pressure:*** Vacuum bagging process provides uniform distribution of pressure over the entire surface regardless of the type or quantity of material being laminated. This allows a wider range and combination of materials as well as a superior bond between the materials. Uniform clamping pressure in the vacuum bagging process across the laminate results in thinner, more consistent glue lines and fewer voids. Since, atmospheric pressure is continuous, it evenly presses on the joint as the adhesive spreads evenly within. Mechanical clamping or stapling applies pressure only to concentrated areas and can damage fragile core materials in one area while not providing enough pressure for a good bond in another. When placed in a closely spaced pattern, staples exert less than 5 psi of clamping force and then only in the immediate area of the staple. They cannot be used at all if lamination has to be done to foam or honeycomb core because of the core's lack of holding power. In addition, extra adhesive is often required to bridge gaps that result from the uneven pressure of clamps and staples.
- ***Resin content optimization:*** Vacuum bagging also provides the means to control excess adhesive in the laminate, resulting in higher fiber-to-resin ratios. This translates into higher strength-to-weight ratios and cost advantages for the composite manufacturer
- ***Simple molds:*** Another advantage of vacuum bagging process is the simplicity and variety of the molds used. The atmospheric pressure is not only pushing down the top of the envelope, but it is also pushing up equally the bottom of the envelope or mold. Since, atmospheric pressure provides equal and even clamping pressure to the back of the mold, the mold only has to be strong enough to hold the laminate in its desired shape until the epoxy has cured. Therefore, most molds can be relatively light weight and easy to build.
- ***Efficient laminating:*** Because all of the materials in the laminate are wet and laid up at the same time, vacuum bagging allows to complete the laminating process in one efficient operation.
- ***Health and safety:*** The vacuum bag reduces the number of volatiles emitted during cure.

3.4.3 Vacuum Bagging Equipment

The vacuum bagging system consists of the airtight clamping envelope and a method for removing air from the envelope until the epoxy adhesive cures. This process requires following equipment:

- ***Vacuum pump:*** The heart of a vacuum bagging system is the vacuum pump. Powered vacuum pumps are mechanically similar to air compressors, but work in reverse manner so that air is drawn from the closed system and exhausted to the atmosphere. The size and shape of the mold and type and quantity of the material being laminated determines the minimum pump requirements. For laminating the flat panels consisting of a few layers of glass, flat veneers or a core material, 2.5–3 psi vacuum pressure can provide enough clamping pressure for a good bond between all of the layers. Fig.3.2 shows vacuum pump used for fabrication of composite material:

Fig. 3.2: Vacuum pump (from **Value Vacuum Technology**).

Table 3.3: Specifications of vacuum pump.

Free air Displacement	2.0 CFM
Ultimate Vacuum	150 microns
Voltage/Frequency	230V/50 HZ
Power	1/4 HP

- ***Vacuum bagging materials:*** A variety of other materials are needed to complete the vacuum bagging system and assist in the laminating process. The required materials were procured from the domestic market or readily accessible through hardware or automotive supply stores.
- ***Release fabric or peel ply:*** Release fabric is a smooth woven fabric that will not bond to epoxy. It is used to separate the breather and the laminate. Excess epoxy can wick

through the release fabric and be peeled off the laminate after the laminate cures. It will leave a smooth textured surface that, in most cases, can be bonded to without additional preparation. Surfaces which are subjected to highly-loaded bonds should be sanded. A variety of release materials are produced specifically for vacuum bagging process. They may be known as release fabric, peel ply or release film. Many are designed for use at higher temperatures or to control the amount of resin that can pass through them.

- **Perforated film**: A perforated plastic film may be used in conjunction with the release fabric. This film helps to hold the resin in the laminate when high vacuum pressure is used with slow curing resin systems or thin laminates. Perforated films are available in a variety of sizes of holes and patterns depending on the clamping pressure and the resin's open time and viscosity.
- ***Breather material:*** A breather (or bleeder) cloth allows air from all parts of the envelope to be drawn to a port or manifold by providing a slight air space between the bag and the laminate. It is a wide lightweight polyester blanket that provides air passage within the vacuum envelope and absorbs excess epoxy. A variety of other materials can be used such as mosquito screen, burlap, fiberglass cloth or a bubble type swimming pool cover.
- ***Vacuum bag****:* The vacuum bag, in most cases, forms half of the airtight envelope around the laminate. If vacuum pressure of less than 5 psi is used at room temperatures, polyethylene plastic can be used for the bag. Clear plastic is preferable to an opaque material to allow easy inspection of the laminate as it cures. For higher pressure and temperature applications, specially manufactured vacuum bag material should be used. A wrinkled type film is available from Film Technology, Inc. Its special texture is designed to channel air and eliminate the need for breather fabric the vacuum bag should always be larger than the mold and allow for the depth of the mold. When a bag wider than the standard width is needed, a larger bag can be created by splicing two or more pieces together with mastic sealant. Vacuum bag mold prepared in the experiment has been shown in Fig.3.3

Fig. 3.3: Vacuum bag mold used to develop the composite material.

- ***Mastic sealant:*** Mastic is used to provide a continuous airtight seal between the bag and the mold around the perimeter of the mold. The mastic may also be used to seal the point where the manifold enters the bag and to repair leaks in the bag or plumbing. Generally, better the airtight seal between the mold and bag material, smaller is the pump needed. Poor seals, or material which allows air leaks, will require a larger capacity pump to maintain satisfactory vacuum pressure.
- ***Plumbing system:*** The plumbing system provides an airtight passage from the vacuum envelope to the vacuum pump, allowing the pump to remove air from and reduce air pressure in the envelope. A basic system consists of flexible hose or rigid pipe, a trap, and a port that connects the pipe to the envelope. A more versatile system includes a control valve and a vacuum throttle valve that allow you to control the envelope vacuum pressure at the envelope. A system is often split to provide several ports on large laminations, or may include some type of manifold within the envelope to help channel air to a single port. A variety of pipe or tubing can be used for plumbing as long as it is airtight and resists collapsing under vacuum.
- ***Mold release:*** Mold release is essential for preventing the epoxy from sticking to the mold when laminating a part. There are generally three types of mold release used depending on the mold material and desired characteristics of the finished part.

Figures 3.4 and 3.5 show the vacuum bagging equipment required for fabrication of composite material by vacuum bagging method in the present work.

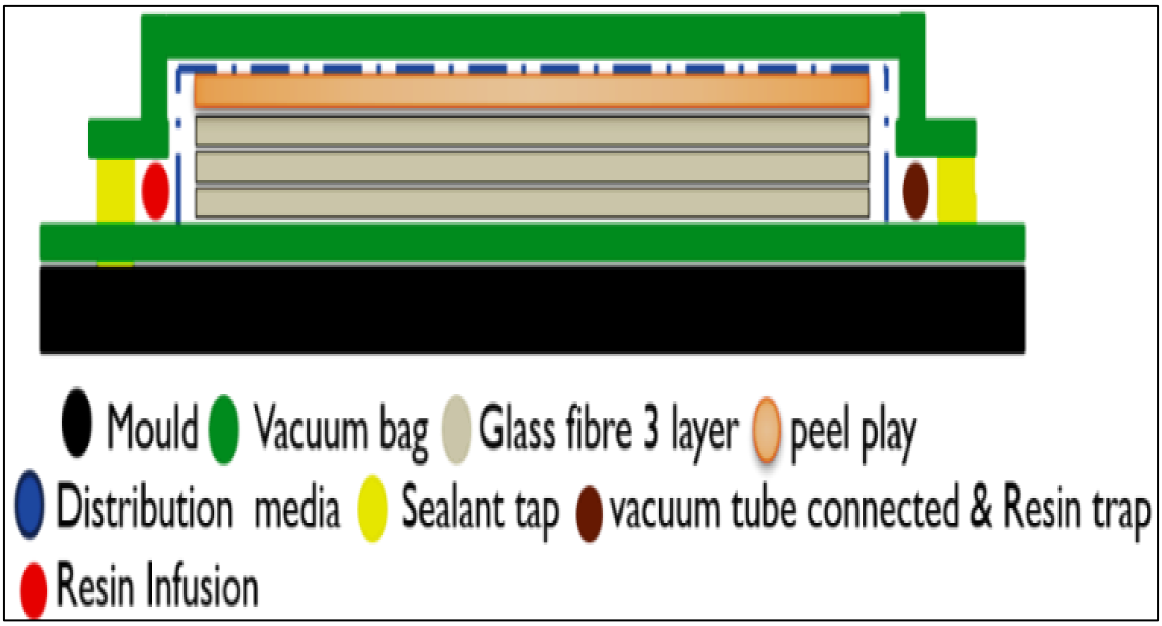


Fig. 3.4: Schematic of vacuum bag with vacuum bagging materials.

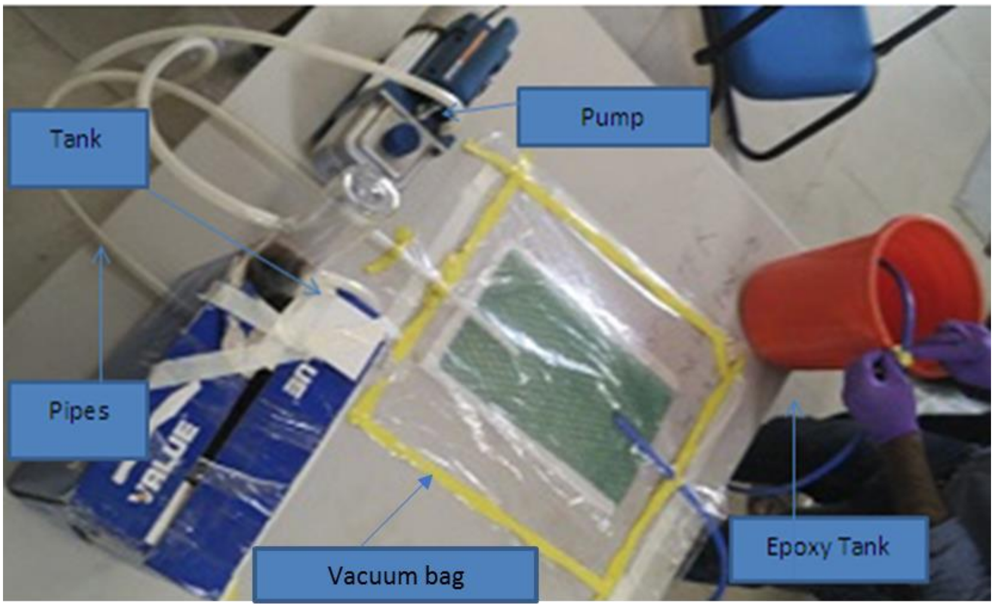
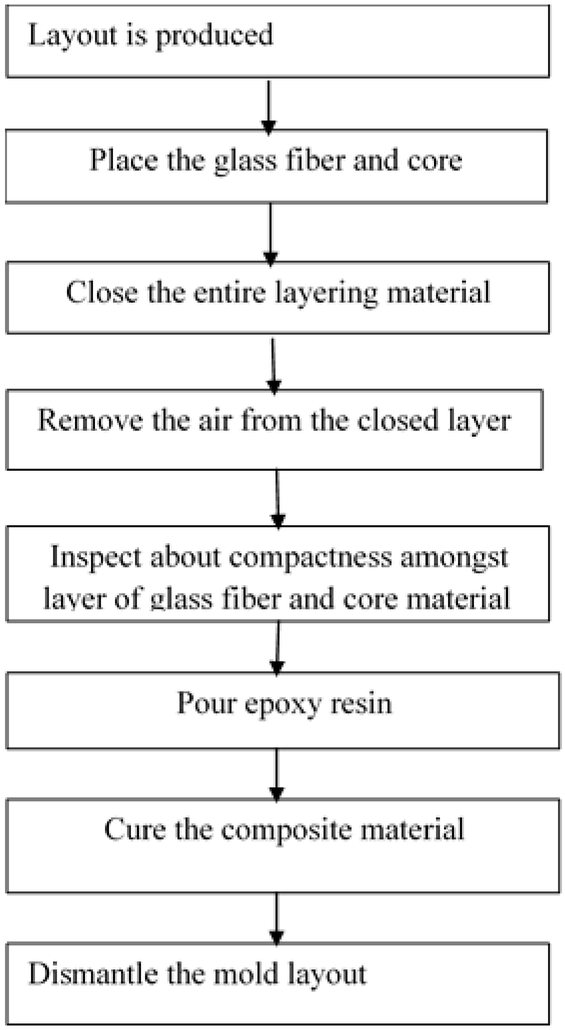


Fig. 3.5: Setup of the vacuum bagging setup.

3.4.4 Procedure of Fabrication of the Composite

The flow chart of fabrication of composite material is shown below:



3.5 Calculation of Weight of the Developed Composite

Density of existing material in VECV Ltd. Bus flooring =0.65 g/cc

- D_1=density of balsa wood (0.163 g/cc)
- D_2=density of epoxy resin (1.25 g/cc)
- D_3=density of glass fibre (2.11 g/cc)
- D_4=density of SAN foam (0.12 g/cc)
- D = density of composite material
- W_1 = weight fraction of balsa wood
- W_2 = weight fraction of epoxy resin
- W_3 = weight fraction of glass fibre
- W_4 = weight fraction of SAN foam

3.5.1 For Single Layer Fibre on Balsa Wood as Core Material

$$D = \frac{1}{\frac{W1}{D1} + \frac{W2}{D2} + \frac{W3}{D3}}$$

$$D = \frac{1}{\frac{0.6}{0.16} + \frac{0.16}{2.1} + \frac{0.24}{1.15}}$$

D = 0.24 g/cc

Change in density = (0.65 - 0.24) = 0.41g/cc

Percentage reduction in density $= \frac{(0.65 - 0.24)}{0.65} X\ 100 = 63\%$

3.5.2 For Double Layer Fibre on Balsa Wood as Core Material

$$D = \frac{1}{\frac{W1}{D1} + \frac{W2}{D2} + \frac{W3}{D3}}$$

$$D = \frac{1}{\frac{0.36}{0.16} + \frac{0.28}{2.1} + \frac{0.36}{1.15}}$$

D = 0.3709 g/cc

Change in density = (0.65 - 0.3709) = 0.2791g/cc

Percentage reduction in density $= \frac{(0.65 - 0.2791)}{0.65} X\ 100 = 42.93\%$

3.5.3 For Single Layer Fibre on SAN foam as Core Material

$$D = \frac{1}{\frac{W4}{D4} + \frac{W2}{D2} + \frac{W3}{D3}}$$

$$D = \frac{1}{\frac{0.318}{0.12} + \frac{0.36}{2.1} + \frac{0.318}{1.15}}$$

D = 0.323 g/cc

Change in density = (0.65 - 0.323) = 0.327g/cc

Percentage reduction in density $= \frac{(0.65 - 0.323)}{0.65} X\ 100 = 49.6\%$

3.5.4 For Double Layer Fibre on SAN foam as Core Material

$$D = \frac{1}{\frac{W4}{D4} + \frac{W2}{D2} + \frac{W3}{D3}}$$

$$D = \frac{1}{\frac{0.218}{0.12} + \frac{0.5}{2.1} + \frac{0.281}{1.15}}$$

D = 0.436 g/cc

Change in density = (0.65 - 0.436) = 0.2133g/cc

$$\text{Percentage reduction in density} = \frac{(0.65 - 0.436)}{0.65} X\ 100 = 32.92\%$$

Table 3.4: Densities of fabricated composite materials:

Weight	**Balsa wood**		**SAN foam**		**Plywood material**
	Single layer	**Double layer**	**Single layer**	**Double layer**	
Density (g/cc)	0.24	0.3709	0.323	0.436	0.65
Change in density	0.41	0.2791	0.327	0.2133	
Percentage reduction in density	63%	42.93%	49.6%	32.92%	

Chapter 4

Results and Discussions

4.1Tensile Test

Tensile test is conducted for several reasons. The results of tensile tests are used in selecting materials for engineering applications. Tensile properties frequently are included in material specifications to ensure quality. Tensile properties often are measured during development of new materials and processes, so that different materials and processes can be compared. Finally, tensile properties often are used to predict the behavior of a material under forms of loading other than uniaxial tension. The strength of a material often is the primary concern. The strength of interest may be measured in terms of either the stress necessary to cause appreciable plastic deformation or the maximum stress that the material can withstand.

Tensile Specimens and Testing Machines: Tensile testing procedure has unique method of sample preparation. All samples preparation and testing is performed in accordance with requirements adopting the most appropriate specification such as ASTM, AMS, ASME. In the present work, flat tensile test samples were prepared. The standard tensile test sample for flat specimen as defines by ASTM International is depicted in Fig.4.1 and Fig.4.2 represents tensile test machine

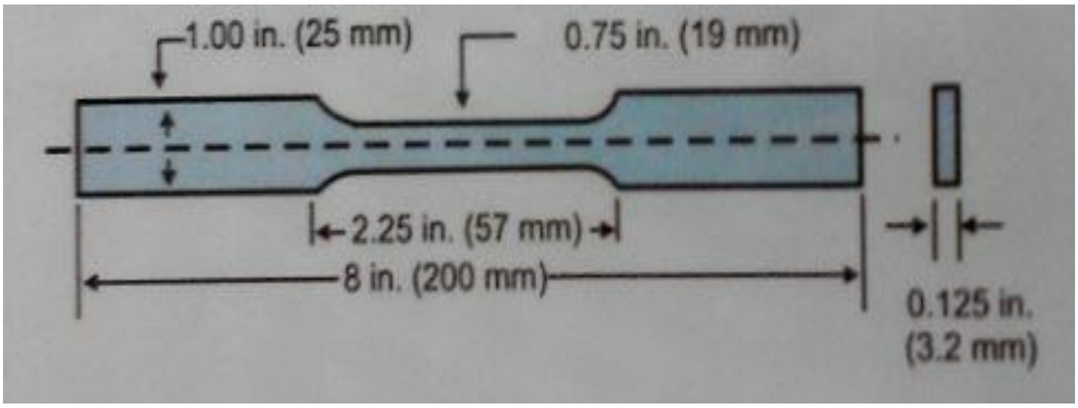


Fig.4.1: Tensile specimen of the developed composite material.

Fig. 4.2: Tensile testing machine of **Tinius Olsen**.

4.1.1 Tensile Test Results of Single Layer SAN Foam as Core Material

Prepared sample and strength obtained in tensile test of single layer SAN foam as core material are depicted in Fig. 4.3 and Fig. 4.4 respectively

Fig. 4.3: Prepared specimen for single layer SAN foam composite material.

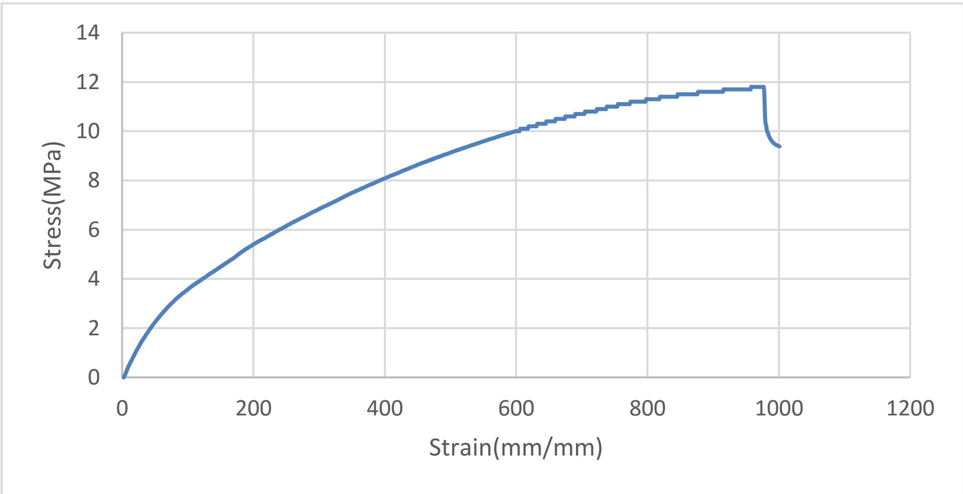


Fig. 4.4: Graph between stress and strain for single layer SAN foam composite in tensile loading.

4.1.2 Tensile Test Results of Double Layer SAN Foam as Core Material

Prepared sample and strength obtained in tensile test of double layer SAN foam as core material are depicted in Fig.4.5 and Fig.4.6 respectively

Fig. 4.5: Prepared specimen for double layer SAN foam composite material.

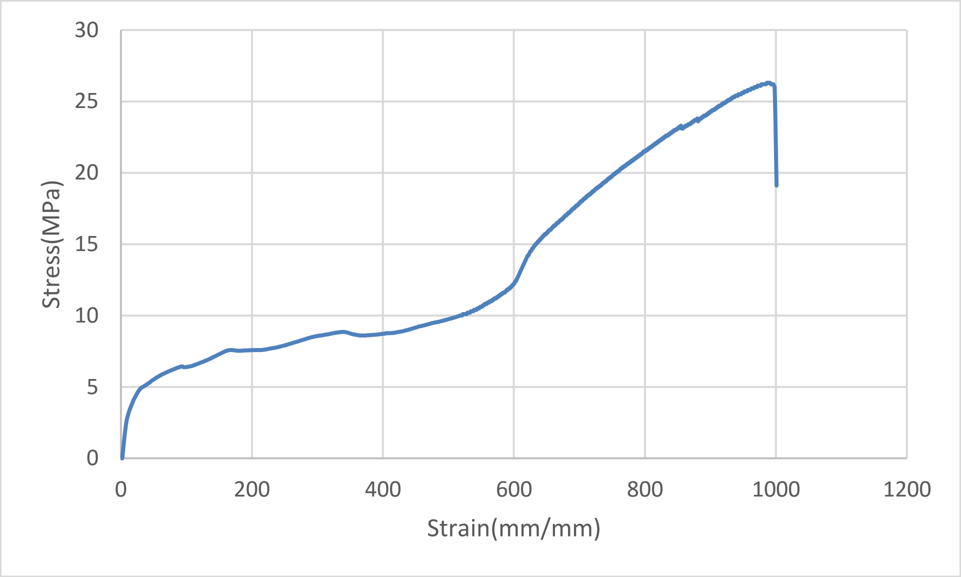


Fig. 4.6: Graph between stress and strain for double layer SAN foam composite in tensile loading.

4.1.3 Tensile Test of Composite Material having Balsa wood as Double Layer Core Material

Prepared sample and strength obtained in tensile test of double layer balsa wood as core material are depicted in Fig.4.7 and Fig.4.8 respectively

Fig. 4.7: Prepared specimen for double layer balsa wood composite material.

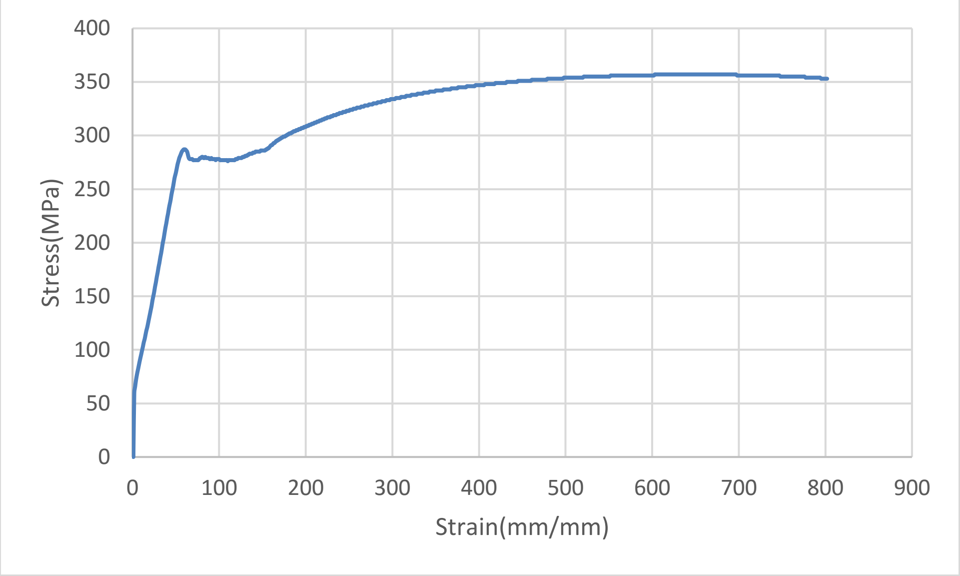


Fig. 4.8: Graph between stress and strain for double layer balsa wood composite in tensile loading.

4.1.4 Tensile Test of Composite Material having Balsa wood as Single Layer Core Material

Prepared sample and strength obtained in tensile test of single layer balsa wood as core material are depicted in Fig. 4.9 and Fig. 4.10 respectively

Fig. 4.9: Prepared specimen for single layer balsa wood composite material.

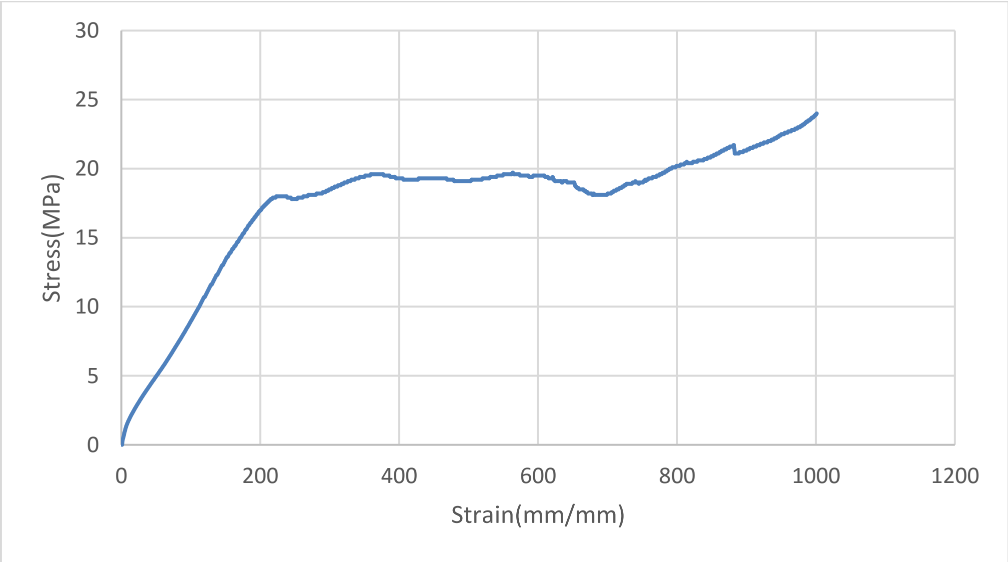


Fig.4.10: Graph between stress and strain for single layer balsa wood composite in tensile loading.

4.2 Compression Test

A compression test is any test in which a material experiences opposing forces that push inward upon the specimen from opposite sides or is otherwise compressed, “squashed”, crushed, or flattened. The test sample is generally placed in between two plates that distribute the applied load across the entire surface area of two opposite faces of the test sample and then the plates are pushed together by a universal test machine causing the sample to flatten. A compressed sample is usually shortened in the direction of the applied forces and expands in the direction perpendicular to the force.

Compression Specimens: The standard compression test sample for compression test of composite material is of cubical in dimension.

4.2.1 Compression Test of Composite having Balsa Wood as Single Layer Core Material

Prepared sample of (8X8X8) dimension and strength obtained in compression test of single layer balsa wood as core material are depicted in Figs. 4.11 and 4.12 respectively

Fig. 4.11: Prepared compression specimen for single layer balsa wood composite material.

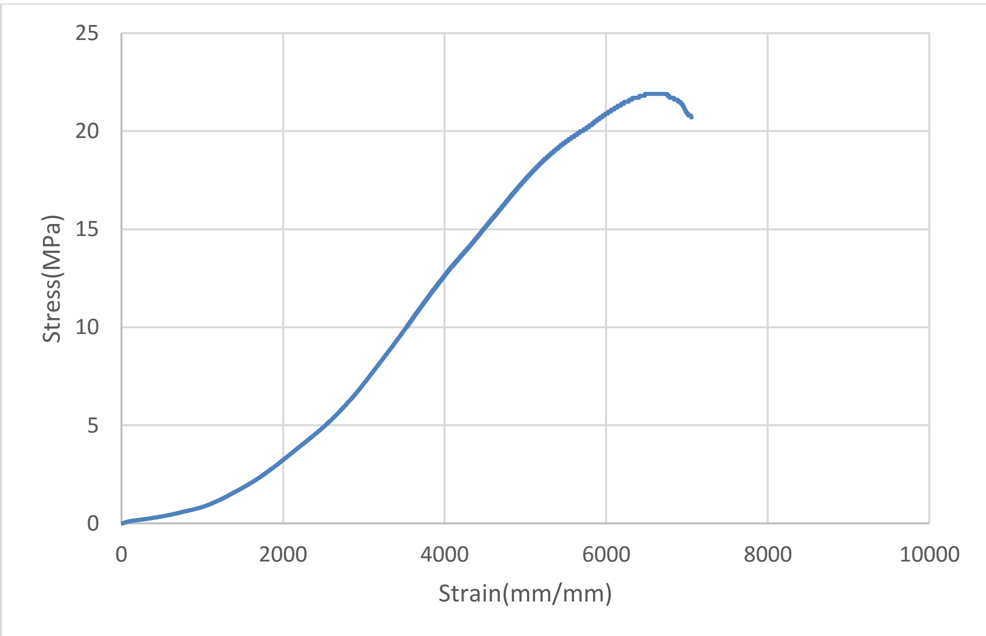


Fig. 4.12: Graph between stress and strain for balsa wood single layer in compression loading.

4.2.2 Compression Test of Composite Material having Balsa wood as Double Layer Core Material

Strength obtained in compression test of double layer balsa wood as core material is depicted in Fig.4.13

Tensile Strength: 160 MPa

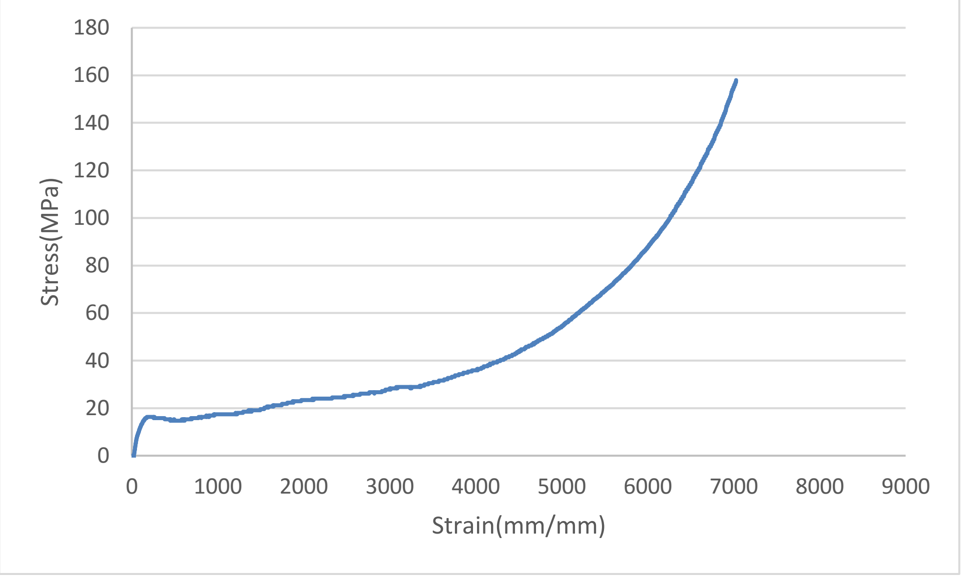


Fig. 4.13: Graph between stress and strain for balsa wood double layer in compression loading.

4.2.3 Compression Test of Composite Material having SAN foam as Double Layer Core Material

Prepared sample of (6X6X6) dimension and strength obtained in compression test of double layer SAN foam as core material are depicted in Fig.4.14 and Fig.4.15 respectively

Fig. 4.14: Prepared compression specimen for double layer SAN foam composite material.

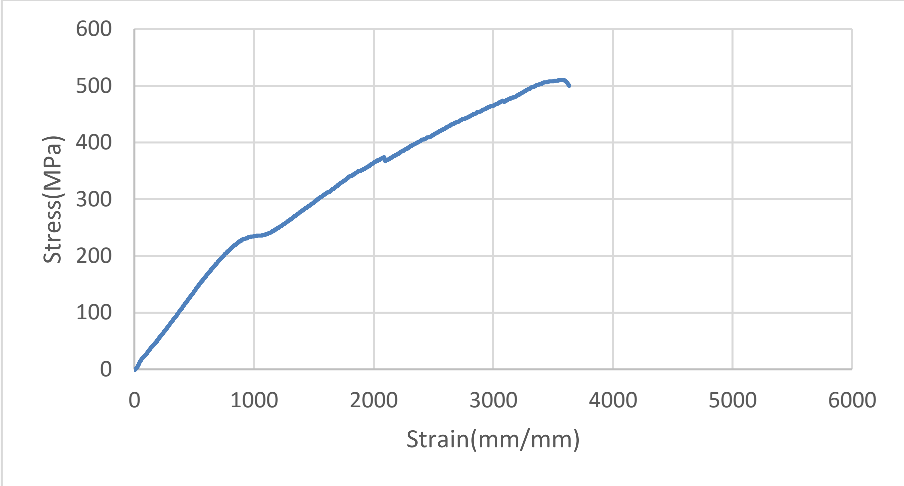


Fig. 4.15: Graph between stress and strain for SAN foam double layer composite material in compression loading.

4.2.4 Compression Test of Composite Material having SAN foam as Single Layer Core Material

Strength obtained in compression test of single layer SAN foam as core material is depicted in Fig.4.16

Compressive Strength: 275 MPa

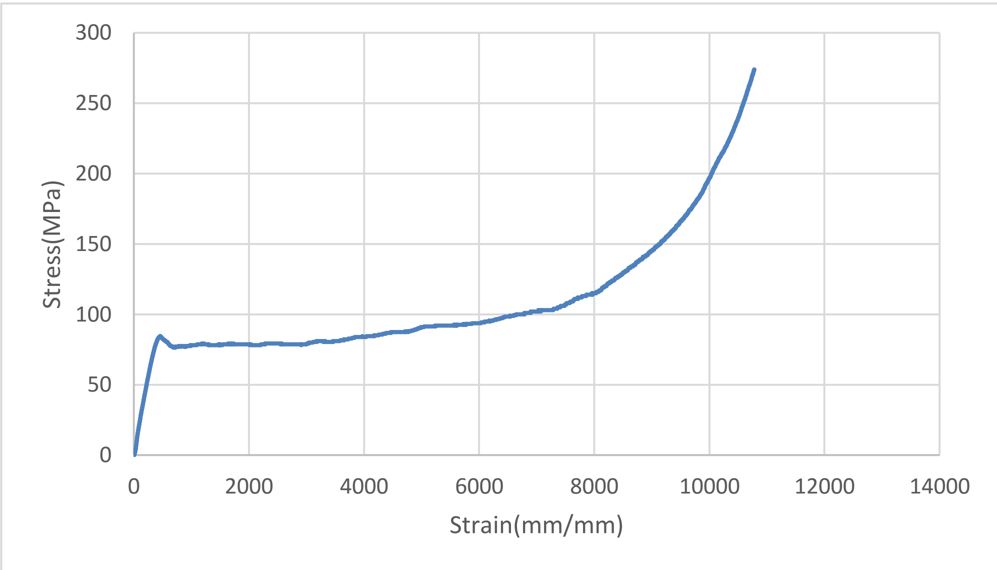
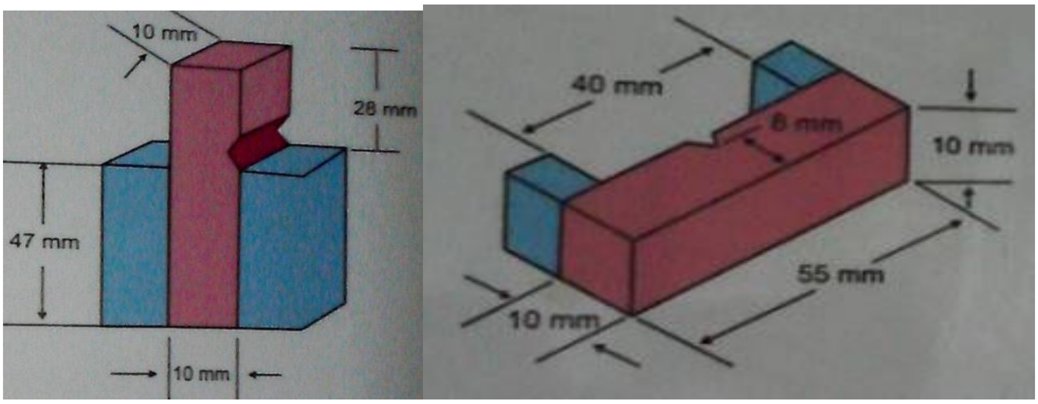


Fig. 4.16: Graph between stress and strain for SAN foam single layer composite material in compression loading.

4.3 Impact Test

The purpose of impact testing is to measure an object's ability to resist high-rate loading. It is usually thought of in terms of two objects striking each other at high relative speeds. A part or material's ability to resist impact often is one of the determining factors in the service life of a part, or in the suitability of a designated material for a particular application. Impact resistance can be one of the most difficult properties to quantify. The ability to quantify this property is a great advantage in product liability and safety.

Impact Test Specimens: Impact testing most commonly consists of Charpy and Izod specimen configurations. The standard test sample for Izod and Charpy Impact test as defines by ASTM International and Impact Testing Machine have been shown in Fig.4.16 and Fig.4.17.



(a) **(b)**

Fig. 4.17: Standard test samples to determine its toughness (using **ASTM International**): (a) Izod test sample; and (b) Charpy test sample.

Fig. 4.18: Impact testing machine (**Model:** Impact 104 from **Tinius Olsen**)

4.3.1 Charpy Test for Single Layer Fibre with SAN foam as core Material

Toughness Strength obtained in Charpy impact test of single layer SAN foam as core material is: **71.302 kJ/m²**

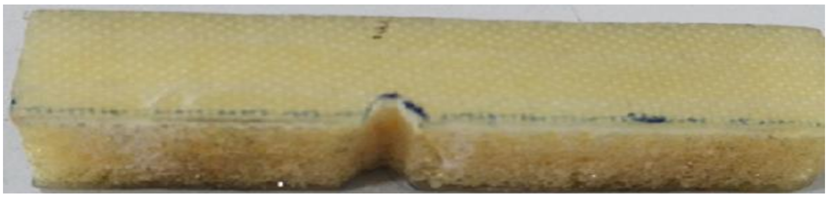


Fig. 4.19: Izod test samples for SAN foam composite material.

4.3.2 Charpy Test for Double Layer Fibre with SAN foam as core Material

Toughness Strength obtained in Charpy impact test of double layer SAN foam as core material is: **120.602 kJ/m²**

Fig. 4.20: Charpy test samples for SAN foam composite material.

4.3.3. Charpy Test for Double Layer Fibre with Balsa Wood as core Material

Toughness Strength obtained in Charpy impact test of single layer balsa wood as core material is: **101.213 kJ/m²**

Fig. 4.21: Charpy test samples for balsa wood composite material.

4.3.4 Charpy Test for Single Layer Fibre with Balsa Wood as core Material

Toughness Strength obtained in Charpy impact test of single layer balsa wood as core material is: **39.824 kJ/m²**

Fig. 4.22: Charpy test samples for balsa wood composite material.

4.4 Analysis of the Results

Results obtained through different mechanical tests on developed composite material have been summarized below in the table 4.1:

Table 4.1: Results obtained after conducting mechanical tests

Mechanical testing	**Balsa wood**		**SAN foam**	
	Single layer	**Double layer**	**Single layer**	**Double layer**
Tensile strength (MPa)	24	350	12	28
Compressive strength (MPa)	22	160	275	500
Impact (kJ/m^2)	39.824	101.213	71.3072	120.602

Following inferences can be made by studying the results obtained by experiments:

Mechanical Properties: Mechanical Properties of developed composite material is better than existing material (Plywood) in bus flooring of VECV Ltd.

Tensile Strength: Tensile strength of plywood material is in Between 25-31 MPa. And tensile strength of developed composite material of balsa wood double layer and SAN foam double layer composite material are 350 MPa and 28 MPa respectively. It means that tensile strength of these materials is better than plywood material.

Compressive Strength: Compressive strength of plywood material is about 40MPa. And compressive strength of developed composite material of balsa wood double layer and SAN foam double layer composite material are 160 MPa and 500 MPa respectively which is better than plywood material. Compressive strength obtained in both of double layer composite material is even better than steel. And compressive strength of SAN foam single layer composite material is also better than plywood material. Hence single layer of SAN foam composite material can be used for lower flooring of buses.

Impact Strength: Impact strength of plywood material is about 18 kJ/m^2 in Charpy test. And impact strength of all the developed composite material is better than plywood material as it can be seen from the table 4.1.

Chemical Properties: Chemical properties of developed composite are better than plywood material. Some chemical properties are given below:

1 fire resistance of developed composite material is better than plywood material. Flash point of epoxy resin is about 120°C. Whereas plywood material can sustain only up to 90°C.

2 Epoxy resin used in fabrication of composite material is not hazardous to health.

3 Chemically stable structure.

4 Good whether ability

Weight Reduction: Weight reduction in case of single layer SAN foam is 49.06%. and compressive strength obtained is also better than plywood material, so it can be used as alternative material for lower bus flooring because lower bus flooring are subjected to compressive loading. Therefore it can be concluded that for lower flooring of buses, single layer SAN foam composite is best option. And for roof of buses double layer of either SAN foam or double layer of balsa wood composite material can be used with weight reduction of 32.92% and 42.93% respectively.

Chapter 5

Conclusions and Scope for Future Work

This chapter presents the conclusions of the present work along with mentioning directions for the future work.

6.1 Conclusions

Following conclusions can be made from the present work:

- Weight reduction in case of double layer composite material with SAN foam as core material is about 32.92% and the mechanical test results are meeting the expectations as desired.
- Weight reduction in case of double layer composite material with Balsa wood as core material is about 42.93% and the mechanical test results are meeting the expectations as desired.
- Weight reduction in case of single layer composite material with SAN foam as core material and weight reduction in case of single layer composite material with Balsa wood as core material are satisfactorily about 63% and 49.9% respectively. But the mechanical results obtained are not much well enough to go for this as an alternate material for bus flooring.
- Generally, cost of composite structure is more compared to single one but considering that the weight reduction is significant in composite material, it can be economically feasible to replace the plywood structure by composite material.
- The cost of Balsa wood specimen (having dimensions 1000 mm X 100 mm X 1.5 mm) is approximately ₹130 and cost of plywood specimen (having dimensions 1000 mm X 100 mm X 1.5mm) is ₹80. It can be concluded that cost of Balsa wood is more than plywood but as weight reduction is considered more significant, it will be feasible to replace plywood with Balsa wood composite material. The cost of Balsa wood may further be reduced if Balsa wood is purchased in bulk instead of piecemeal basis.
- Weight can further be reduced by replacing polypropylene and ABS materials by polycarbonate and ASA respectively in bus hatrack assembly. Because major part of hatrack assembly is made of polypropylene and ABS materials.

6.2 Scope for the Future Work

There is a sufficient scope for future work. Some of the directions for the future work are as follows:

- More efficient and more compact composite material can be fabricated by using advanced vacuum bagging method in sophisticated laboratory so that strength obtained is more than what is achieved by this experiment.
- Further strength and compatibility can be improved by incorporating more than one core material in sandwich structure with sole effect of reduction in weight.
- This research will bolster researcher to encounter new research in development of advanced composite material.
- This research enables the way for replacing the metallic parts by composite material from the automotive industry including buses, trains, aero planes etc. to reduce the weight without compromising strength.
- This research work also facilitates development of metallic and composite combined structure for automotive industry.
- Future work can be focus on changing to new orientation of glass fiber and by changing the type of epoxy resin to fabricate more compatible composite structure.

References

Agarwal, B.D.; Broutman, L.J.; Sekahara, K.C. (2017), Analysis and Performance of Fiber Composites (4th Edition), John Wiley & Sons, Inc. New Jersey. (ISBN: 978-81-265-3636-8)

Aparna, M.L.; Chaitanya, G.; Srinivas, K.; Rao, J.A. (2016) Fabrication of continuous GFRP composites using vacuum bag molding process, **International Journal of Advanced Science and Technology,** 87, 37-46. (DOI:10.14257/ijast.2016.87.05)

Chung, D.D.L. (2017), Processing structure property relationships of continuous carbon fiber polymer matrix composites, **Material Science and Engineering: R: Reports,** 113, 1-29. (DOI: 10.1016/j.mser.2017.01.002)

Fan, J.; Njuguna, J. (2016), An introduction to Lightweight Composite Materials and their Use in Transport Structures, In: **Lightweight Composite Structures in Transport: Design, Manufacturing, Analysis and Performance** (Editor: Njuguna, J.), Woodhead Publishing, Duxford (UK), pp 3-34. (DOI: 10.1016/B978-1-78242-325-6.00001-3)

Gubencu, D.V.; Gabrielm M. (2010), Use of composite materials in railway industry, **Nonconventional Technologies Review,** 4, 29-34.

Hota, G.R. (2017), Infrastructure Applications of Fiber Reinforced Polymer Composites, In: **Applied Plastics Engineering Handbook** (2nd Edition), William Andrew, Oxford (UK), pp: 675-695. (DOI:10.1016/B978-0-323-39040-8.00032-8)

Karthigeyan, P.; Raja, M.S.; Hariharan, R.; Karthikeyan, R.; Prakash, S. (2017), Performance evaluation of composite material for aircraft industries, **Materials Today Proceedings,** 4(2), 3263–3269. (DOI: 10.1016/j.matpr.2017.02.212)

Khalil, Y.F. (2017), Eco-efficient lightweight carbon-fiber reinforced polymer for environmentally greener commercial aviation industry, **Sustainable Production and Consumption,** 12, 16–26. (DOI: 10.1016/j.spc.2017.05.004)

Kong, C.; Lee, H.; Park, H. (2016), Design and manufacturing of automobile hood using natural composite structure, **Composite Part B: Engineering**, 91; 18-26. (DOI: 10.1016/j.compositesb.2015.12.033)

Kong, C.; Park, H.; Lee, J. (2014), Study on structural design and analysis of flax natural fiber composite tank manufactured by vacuum assisted resin transfer molding, **Materials Letters,** 130; 21-25. (DOI: 10.1016/j.matlet.2014.05.042)

Larsson, S. (2009), Weight and Dimensions of Heavy Commercial Vehicles, (Directive 96/53/EC for European Modular System) (https://ec.europa.eu/transport/sites/transport/files/modes/road/events/doc/2009_06_24/2009_gigaliners_workshop_acea.pdf

Martinez, M.; Yanishevsky, M.; Rocha, B.; Groves, R.M.; Bellinger, N. (2015), Maintenance and Monitoring of Composite Helicopter Structures and Materials, In: **Structural Integrity and Durability of Advanced Composites: Innovative Modelling Methods and Intelligent Design** (Editor: Beaumont, P.W.R), Woodhead Publishing Cambridge (UK), pp. 539-578. (DOI:10.1016/B978-0-08-100137-0.00021-3).

Nam, S.; Lee, D.; Kim, J.; Lee, D.G. (2015), Development of the light weight carbon composite tie bar, **Composite Structures,** 134, 124-131. (DOI: 10.1016/j.compstruct.2015.08.024)

Panthapulakkal, S.; Raghunanan, L.; Sain, M.; KC, B.; Tjong, J. (2017), Natural fiber and hybrid fiber thermoplastic composites: Advancements in light weighting applications, In: **Green Composites:** Natural and Waste based Composites for a Sustainable Future (2nd Edition; Editors: Baillie, C.; Jayasinghe, R.), Woodhead Publishing, Duxford (UK), pp: 39-72. (DOI:10.1016/b978-0-08-100783-9.00003-4).

Patil, A.; Patel, A.; Purohit, R. (2017), An overview of polymeric materials for automotive applications, **Materials Today Proceedings,** 4(2); 3807-3815. (DOI:10.1016/j.matpr.2017.02.278)

Patill, S.B.; Joshi, D.G. (2015), Structural analysis of chassis: a review, **International Journal of Research in Engineering and Technology,** 4(4), 293-296. (DOI: 10.15623/ijret.2015.0404050)