

Assessment of composite materials in construction and automobile industries

By

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Abstract

Composite sandwich plates are gaining increasing popularity in engineering practice, due to their – strength, high – stiffness – to – light – weight ratio. Durable materials are always desired by structure engineer. Composite materials of thermoplastics origin are blended with fiber glass or carbon fiber to produce a sandwich type composite, used in sandwich panels is now becoming the structural material in civil engineering and automobile parts in recent years also due to its light – weight and anti – corrosion properties. Although carbon fiber reinforced-polymer meets the demands, but its anisotropy makes the connection of structural elements considerably weak which is the main cause that make its high strength not be utilized fully. However, the lower face lamina, the top face are made of polypropylene with (30%) fiber glass or (1%)carbon fiber composite, sandwich laminates are made of thin outer skin of fiber reinforced polymer adhesively bonded to a thicker core of foam. Composite materials in sandwich panels require knowledge of the mechanical behavior of the materials used for the facings and the core. In this work, different mathematical models will be used to evaluate structural analysis of the sandwich panels. The results of the experimental study have showed that reinforced thermoplastics composite will have potential benefits for the structures in future.

Sandwich structures represent a special form of a layered structure that consists of two thin stiff and strong face sheets separated with a relatively and thick, lightweight core material. In modern sandwich structures the faces are usually made of namely laminated composite materials, and typically a compliant compressible core made of a low-strength honeycomb type material or polymeric foam. The faces and the core are joined by adhesive bonding, which ensures the load transfer between the sandwich constituent parts. The end result is a special structure with extremely high bending stiffness and strength to weight ratios with a low-strength compressible core. Sandwich structures are used in aircraft, train and being used successfully for a variety of applications such as spacecraft car structures, wind turbine blades, boat/ship superstructures, boat/ship hulls. The application of modern sandwich structures is expanding steadily, and all forecasts predict that such sandwich structures will take over from traditional metallic and even rib- stiffened such structures require advanced method for analysis and design. The expanding use of structural composite and sandwich structure has been accompanied by increasing research effort, and a vast amount of experience in the manufacturing and exploitation of sandwich construction has been accumulated over the last two to three decades. Moreover, vast improvements of the understanding of the fundamental physical behavior of sandwich structures have been achieved. Stress strain behavior are experimentally investigated for sandwich panels manufactured in laboratory for reinforced PP with FG and CF. CO₂ emissions will be reduced by 30% for automobile by reducing the quantity of fuels used.

INTRODUCTION

Sandwich panels are composite structural elements, consisting of two thin, stiff, strong faces separated by a relatively thick layer of low-density and stiff material. The faces are commonly made of steel, aluminium, hardboard or gypsum and the core material may be polyurethane, polyisocyanate, expanded polystyrene, extruded polystyrene, phenolic resin, or mineral wool. In Australia, sandwich panels are commonly made of expanded polystyrene. Sandwich construction has been widely used in aircraft and many structural applications for a long time. In recent years, sandwich panels are increasingly used in building structures particularly as roof. They are also being used as internal walls and ceilings. However, research and development of sandwich panels with profiled faces began only in late 1960s. Due to the increasing interest in the use of structural sandwich panels, a good deal of research has continued in recent years.

In this study, a procedure for polypropylene based sandwich panels is presented. PP/glass laminates as the skins and PP foam as the core material are used, the increasing use of composite materials in many industrial sectors is accompanied by the concern for recycling scrap materials and composite waste parts. Particularly, in the automotive field, the substantial increased use of composites resulted from their higher weight/mechanical performance ratio, and from the possibility of being formed into complex shapes, with respect to metals.

Depending on the type of matrix resin used, there are a variety of methods available for recycling polymer composite materials. Because of their crosslinked nature, the thermoset composites can typically be recycled by three methods: chemical recycling, mechanical recycling, or energy recovery. The mechanical recycling of thermoset-based composites is obtained by milling them into fine particles, which can subsequently be used as a filler in new plastic or composite applications as a replacement, for example, of calcium carbonate.

In general, the thermoplastic polymers are considered more suitable for recycling than thermosets because they can be heated above their melting temperature and reformed into a new shape. In analogy with thermosetting composites, thermoplastic composites can also be recycled by chemical processes or for energy recovery but, in addition, they can also be recycled as a molding compound obtained simply by grinding for injection- or compression-molding. Grinding/reprocessing can be considered a 'secondary' recycling technique as the performance of the thermoplastic composite is degraded by both the grinding and the reprocessing steps, due to fiber length decrease, polymer degradation, and fiber/matrix interface degradation. Nonetheless, grinding/reprocessing appears to be the most viable technique for recycling thermoplastic composite materials today because it is potentially cost-effective and leads to a valuable molding compound.

In this study, a mechanical properties for PP-based sandwich panels made of continuous (glass fibers and carbon fiber)/PP matrix laminates as skins, and PP foam as the core material, is presented. It can be considered as process in which the sandwich panel with long fiber composite skins is converted into a short glass fiber composite material with a reinforcement volume fraction depending on the ratio between the skin, and the core thicknesses in the original sandwich structure.

The Origins of Sandwich Technology

The first successful landing of a space ship on the moon on 20 July 1969 was the result of the successful application of a number of new technologies including rocketry, computers and sandwich construction. Although public interest centered on rocketry and computer technology, it was only with the help of sandwich technology that a shell of the spacecraft could be

constructed that was light in weight and yet strong enough to sustain the stresses of acceleration and landing.

Figure1 shows the wall construction of the Apollo capsule which consisted of two interconnected sandwich shells. Figure 2 shows details of the outer shell, which comprised two thin steel facings and a honeycomb core. The inherent advantage of sandwich construction is immediately apparent, namely, high strength and rigidity at low weight.

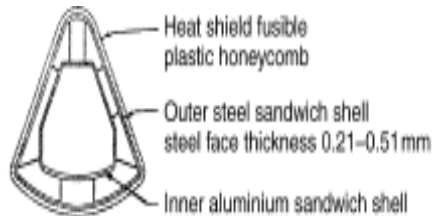


Figure1 Sandwich construction of the Apollo capsule.

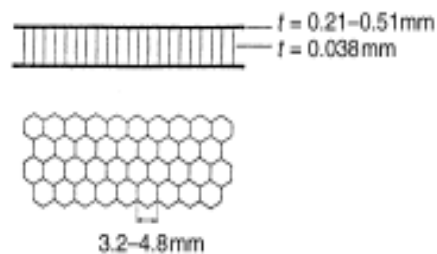


Figure. 2 Cellular sandwich forming the outer shell of the Apollo capsule.

Prior to about 1960, sandwich technology had been confined almost entirely to aerospace applications. The World War II Mosquito aircraft is often quoted as being the first major application of sandwich panels but there were numerous earlier, though less spectacular, uses of the sandwich principle. By about 1960, increasing numbers of alternative uses were being discovered, such as in the building, refrigerated storage, automobile and shipbuilding industries. This period was also the beginning of a worldwide boom in prefabricated building elements for diverse applications⁽¹⁾.

Principles of Sandwich Construction

The structure of sandwich panels always follows the same basic pattern. Two facings, which are relatively thin and of high strength, enclose a core which is relatively thick and light and which has adequate stiffness in a direction normal to the faces of the panel. A great many alternative forms of sandwich construction may be obtained by combining different facing and core materials. The facings may be steel, aluminium, wood, fibre-reinforced plastic or even concrete. The core may be made of cork, balsa wood, rubber, solid plastic material (polyethylene), rigid foam material (polyurethane, polystyrene, phenolic foam), mineral wool slabs or from honeycombs of metal or even paper.

Figure 3 shows three examples of structural sandwich elements, namely :

- panel with a polyurethane or polystyrene core
- panel with a metal or paper honeycomb core
- panel with a mineral wool core

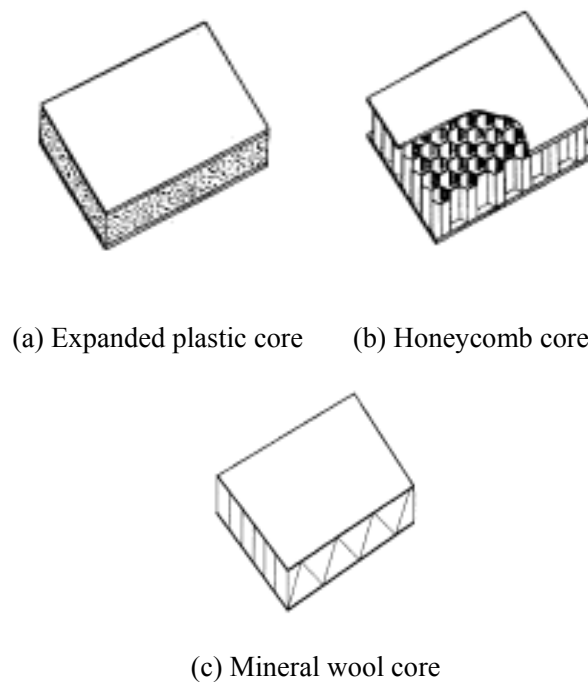


Figure 3 Examples of structural sandwich elements.

In each case, the faces may be colour coated steel, or aluminium, or they may be non-metallic, such as plywood particle board or glass reinforced plastic.

This possibility of combining materials to form composite panels enables optimum designs to be produced for particular applications. In composite panels, the positive properties of the individual materials can be combined and the negative properties eliminated. For example, the good thermal insulating properties of plastic foam materials or mineral wool may only be used if they are protected against moisture by raintight and diffusion-proof facings; whereas the strength and stiffness of thin-walled metal cladding can only be fully utilized if it is stiffened against buckling under compressive force by the presence of the core material.

Sandwich panels with thin steel or aluminium facings with low density plastic or mineral wool cores have a particular combination of properties that make them ideal for use as walls and roofs. They combine the positive properties of metal facings, namely their load-bearing capacity, protection of the insulation against mechanical damage, weather protection and vapour barrier with the complementary positive core properties, namely thermal and acoustic insulation and corrosion protection on the inside.

The resulting composite panel owes its success to the following favorable properties:

- high load-bearing capacity at low weight.
- excellent and durable thermal insulation.
- absolute water and vapour barrier.
- excellent airtightness.
- surface finished facings providing resistance to weather and aggressive environments.
- capacity for rapid erection without lifting equipment; easier installation in hostile weather conditions.
- easy repair or replacement in case of damage.
- economical mass production to pre-cut lengths of components of uniform high quality.
- long life at low maintenance cost.

- behavior in fire of panels with mineral wool cores.

Naturally, sandwich elements have some less favorable properties and the following may also be identified:

- behavior in fire of elements with rigid plastic foam cores
- deformation when one side is exposed to heat, e.g. strong sunlight
- creep under sustained load of elements with rigid foam cores
- low thermal capacity
- although sandwich elements give good sound insulation compared with alternative wall and roof construction of similar weight, the insulation level achieved is characteristic of light weight construction.

The components of this sandwich must be bonded together in such a way that they act as a composite load-bearing unit for the expected working life. This bonding may be achieved by a line foaming process, by use of separate adhesives or by mechanical fastenings.

Facing Materials

Relatively thin, high-strength sheets are generally used as facing materials. Facing must satisfy the manufacturing requirements with regard to roll-forming and bending, the functional requirements with regard to wind, water and vapor tightness, the structural requirements in their capacity as components of a composite panel and their ability to resist local loads and, furthermore, they must have adequate resistance to corrosion and fire. Not all of these requirements are of equal importance in any given application but it is clear that they are economically satisfied by metal sheets, especially steel or aluminium sheeting. The metal faces are produced from coils and can be easily profiled by roll-forming and incorporated in a continuous manufacturing process using a laminating line.

Steel facings

Thin steel sheets are the most frequently used facing material. In general, only sheets with both metallic and organic (plastic) coatings should be used. Organic coated sheets without a metallic corrosion protection layer should not be used. Figure 2.6 shows two possible coating variations. The steel itself is usually cold rolled after pre-coating with a metallic corrosion protection layer, the most common being hot-dipped pure zinc but zinc $\pm$ aluminium or aluminium $\pm$ zinc alloys are also applied to steel sheeting. The zinc layers alone do not generally provide sufficient corrosion protection and their aesthetic appearance is poor. At the same time, a reliable bond between the core and the metallic surface of the face is hard to obtain so that additional organic coatings are usually added. These protect the metallic layer from mechanical and chemical wear.

Both sides of the steel sheet are usually coated first with a primer (thickness 5 ± 10 mm) that provides a good bond with the metallic layers). Further organic coatings will adhere easily to this primer layer and are usually applied immediately after the primer.

The organic coatings are then applied. Usually, the thickness of the coating applied to the reverse side backing coat is 7 ± 15 mm and rather more than this on the top surface. There may also be additional primer or other layers. Figure 2.5(b) shows the alternative case when the metallic corrosion layer alone is considered to be sufficient for the top side. The primer layer and backing Coat are still needed on the reverse side in order to ensure a reliable bond between the core and the face.

Aluminium sheeting

Sandwich panels with facings made of bare aluminium sheet are sometimes used in applications where there are special requirements for corrosion resistance or hygiene; for example, in the production or storing of foodstuffs. The material thickness is usually in the range 0.7 ± 1.2 mm. A thickness of 0.7mm is often considered to be the minimum in order to avoid local damage during handling but 0.5mm is sometimes used.

The recommended alloys are AlMn (manganese alloyed in aluminium), AlMg (magnesium alloyed) and AlMgMn (both manganese and magnesium alloyed). A typical alloy may have a tensile strength in the range $200\pm 250\text{N/mm}^2$ and a 0.2% yield strength below 200N/mm^2 .

Other facing materials

Timber-based and other types of building boards can also be employed as faces in sandwich construction. The general problem with these boards is that they are produced in fixed lengths that rarely exceed 3.5m and are therefore not very suitable for use in a continuous foaming line. They may be used with mould foaming and glueing methods but, when producing long panels, special joints must be used. Wood-based chipboard and plywood can be used in environments where no great variations of air humidity exist but, under long-term loading, creep of the face must be considered as well as creep of the core material. Other building boards that may be utilised are gypsum boards, gypsum boards reinforced with fibres, cement-based boards and plastic boards.

Gypsum boards may be reinforced with paper or pulp fibres (amount of the fibres $15\pm 20\%$ by weight) or glass fibres. The mechanical and other properties are similar to gypsum boards with cardboard faces.

An extra facing layer of gypsum board or of chipboard can be added between the thin metal sheeting and the rigid plastic foam core in order to protect the core in the case of fire. When using this technique, the board must be glued to skin before the manufacturing of the panel ⁽¹⁾.

Introduction to Composite Materials

Composite materials consist of two or more materials combined in such a way that the individual materials are easily distinguishable. The individual materials that make up a composite are called constituents. Most composites have two constituent materials: a binder or matrix, and reinforcement. The reinforcement is usually much stronger and stiffer than the matrix, and gives the composite its good properties. When the same properties are desired in every direction on the plane of the lamina, randomly oriented fibers are used. Composite materials are available as plies or lamina. A single ply consists of fibers oriented in a single direction (unidirectional) or in two directions (bidirectional; for example a woven fabric). Composite properties are best in the direction of the fibers. In the direction perpendicular, or transverse, to the fibers, the matrix properties dominate because load must be transferred by the matrix every fiber diameter. Because most structures are not loaded in a single direction, even though one direction may dominate, it is necessary to orient fibers in multiple directions. This is accomplished by stacking multiple plies together. Such a stack is called a laminate ⁽⁶⁾.

Constituents of Composite Materials.

The Composite materials are made up of constituent materials which are grouped as: (matrix - reinforcement - fibre matrix interphase-fillers).

Matrix

Definition –The phase that receive the inserts in phase composition is continuous phase & is called as matrix. It is also called as binders .Ex- Polymer, Ceramics, Metals.

The matrix material employed for fabrication of composites material are usually polymer & commonly called as Resin.

Functions –The function of matrix or binders are as follows.

- a) It gives mould ability or shape to composite.
- b) It makes the composite materials generally resistance to adverse environment.
- c) It also protect the reinforcement from adverse environment.

Types – The materials used for the matrix are plastic , rubbers , ceramic & metals .

Plastic matrix based composite materials now constitute more than 95% of all composite materials in use today . Both Thermoplastic & Thermosetting materials are used as matrix materials . Among these plastic material we are interested in the matrix made up of Thermo-plastic composite with their inherent properties which can contribute to composite materials⁽⁷⁾.

Polymers

Polymers used for autobody applications may be split into thermoplastics and thermosets. Thermoplastics are high molecular weight materials that soften or melt on the application of heat. Thermoset processing requires the non-reversible conversion of a low molecular weight base resin to a polymerized structure. The resultant material cannot be remelted or reformed. Composites consist of two or more distinct materials that when combined together produce properties that are not achievable by the individual components of that composite. In autobody applications, reinforced plastics are the major composite material. For example, the term fibreglass consists of a plastic resin reinforced with a fibrous glass component. The resin acts to define the shape of the part, hold the fibres in place and protects them from the damage. The major basic advantages of composites are their relatively high strength and low weight, excellent corrosion resistance, thermal properties and dimensional stability. The strength of a polymer composite will increase with the percentage of fibrous material and is affected by fibre orientation. Tailoring the fibre orientation and concentration can therefore allow for strength increase in the particular region of a component⁽⁹⁾.

Thermoplastic Polymers

Thermoplastics can be divided into amorphous and crystalline varieties. In amorphous forms the molecules are orientated randomly. Typical amorphous thermoplastics include polyphenylene oxide, polycarbonate and acrylonitrile butadiene styrene. Advantages of amorphous thermoplastics include:

- Relatively dimensionally stable
- Lower mould shrinkage than crystalline thermoplastics
- Potential for application for structural foams

Disadvantages include:

- Poor wear abrasion and repeated impact
- Poor fatigue resistance
- Increased process times compared to crystalline thermoplastics

In a crystalline variety there will be regions of regularly orientated molecules depending on factors such as the processing techniques used, cooling rate, etc. Examples include nylon , polypropylene (PP) and polyethylene (PE). Advantages of crystalline thermoplastics include:

- Good solvent, fatigue and wear resistance
- Higher design strain than amorphous grades

- High temperature properties improved by fibre reinforcement

Disadvantages include:

- Potentially high and variable shrinkage
- Difficult to adhesive bond
- Higher creep than amorphous thermoplastics

Thermosetting Polymers

Thermosets are generally more brittle than thermoplastics so they are often used with fibre reinforcement of some type. Advantages of thermosets include:

- Lower sensitivity to temperature than thermoplastics
- Good dimensional stability
- Harder and more scratch resistant than thermoplastics

Disadvantages of thermosets include:

- Low toughness and strain at fracture
- Difficulties in recycling
- Difficult to obtain 'A' class finish

There is a wide range of different processing techniques that can be used to produce components from the above raw materials ⁽⁹⁾.

Reinforcement

Fibers are the principle constituents in fiber reinforcement composite materials. These are materials which basically gives strength , stiffness & other mechanical properties to composite materials . Ex – Glass, Boron, Jute fibers.

Definions :-It is materials which gives strength , stiffness & other mechanical properties to composite materials .

Function: - The reinforcement are used to improve the structural characteristics of materials. They can be continuous in form of fiber, filament or discontinuous in forms of (whiskers, flake or particular). The reinforcement increases the ratio of strength to density & stiffness to density. Improve formability & electrical prop. It also increase resistance to corrosion fatigue, creep & repturs stress & reduce cost ⁽⁷⁾.

Glass Fibre.

Glass fiber are the oldest form of strength fiber used in composite structure materials. Continuous fiber are made by a growth extension process. In air craft aerospace & military application in which strength to wt. Ratio are critical constitute the fastest growing market for glass fiber reinforced materials.

The glass fiber for reinforcement is available in several forms like fibers ravings, chopped, strands, yarns & mate. The principle ingredients in all glass fibers is silica and other oxide.

The Na₂O & K₂O content in glass fiber is quite low which give them a better corrosion resistance to water as well as higher surface resistively. The glass fibers are available in no. of grades for reinforcement purpose.

A particular form is choose depending on the molding methods, properly to be improved & cost of final products.

A glass – cost effective, for general purpose. Easily attacked by moisture & alkaline.

E glass –these has high level electrical resistivity, surface resistivity & forming.

C glass – impact, high acid resistance

D glass – highest structural resistance properly when stiffness is more important than strength.

Application : These found application in pressure bottles, automobile bodies, for tubing & pipes & in sports goods.

CARBON FIBRE

Now a days carbon fibers finds its own place in the composite materials where weight reduction are valuable. Many techniques have been tried for producing carbon fiber. All of them involve the heat treatment of carbon containing raw material usually in form of polymer fiber & carbonizing them. Three raw materials generally employed for production of commercial products these are rayon, acrylic, & PAN fiber & fiber span pitch. Carbon filled composite has electrical conductivities coupled with good mechanical prop.

Advantages

1. High tensile strength – wt. Ratio.
2. High tensile modulus – wt. Ratio.
3. Very low co-efficient of linear thermal expansion which provides dimensional stability.
4. High fatigue strength.

Disadvantage – low impact resistance, high electrical conductivity.

Applications – High temperature property of carbon fiber are being put to use in pump packing, bearing & breaks or breaks disc materials.

2.9.2.4 BORON FIBRE

Boron fiber is also emerging as the principle constituents or high characteristic properties contain fiber. This are prepared by reduction of boron tri-chloride in chemical vapor deposition process on hot tungsten or graphite filament.

Advantages .

1. these are of low density, high tensile strength, high modulus fibers.
2. these are extremely hard.

Disadvantages – The amorphous boron fiber has excellent properties but process is very costly.

Applications –These are highly suitable for aerospace industries, Automobile industries. Boron fiber have been used in some sporting good equipments.

EXPERIMENTAL WORK

The extruder is a part of injection molding machine manufacturing by the Japanese steel work, Ltd, The plant is installed in Rabta Libya. The machine is designed to handle high temperature resin and composite material. It consists of clamping unit having heavy clamping force, high speed moving unit, high tension unit and high temperature unit with three typical zones.

1- Feed zone: this is designed to preheat the composite material and convey it to the other zones. The constant screw depth supplies sufficient material to the metering zone so as not starve it, however composite material should not exceed the limit such that the metering zone will be over run. The optimum design in this work has been achieved by trial and error of several experimental runs where the geometry of the screw and the frictional. Properties of the screw and barrel have a close link to the composite material mechanical and physical properties.

2-Compression zone: the screw depth is gradually decreased in order to compact the composite material. This compaction has the role of squeezing any trapped air pockets back in to the feed zone and improving the heat transfer through the composite material.

3- Metering zone: the screw depth is constant but much less than the feed zone. In the metering zone the melt is homogenized so as to supply at constant rate, composite material at uniform temperature and pressure to the die, this zone involves a viscous melt flowing along the uniform channel. The pressure build up which occurs along the screw is essential in the design calculations of the composite material involved.

Hazards are involved in the operating of the unit. Precautions have followed to reduce the risk of injury where manual steps have been followed in the operations. ^[21]

The plant is a horizontal type injection-molding machine equipped with in line screw type injection unit and high speed, energy saving type toggle operated clamp unit. It can be operated manually, semi-automatic and fully automatic modes in tune with work conditions and capacity needed. In this paper the experimental is run manually where operating temperature is obtained at 200 °C.

The adjustment of the screw revolution and backpressure is very important in the experimental run of the plant. The cylinder has to be heated to the set temperature and the composite material has to be ready and well mixed. Since the screw is rotated at high speed. Running the plant with a delay of adding the melt resin films on the bore surface of the cylinder will result to a possible damage of the screw and the cylinder.

During the run of the plant, the screw backpressure improves ease in kneading the resin but prolonging the metering time. Decreasing the screw backpressure in our experimental work is adjusted at 15 Kg/cm². The extruder used in the paper is represented in fig (4).

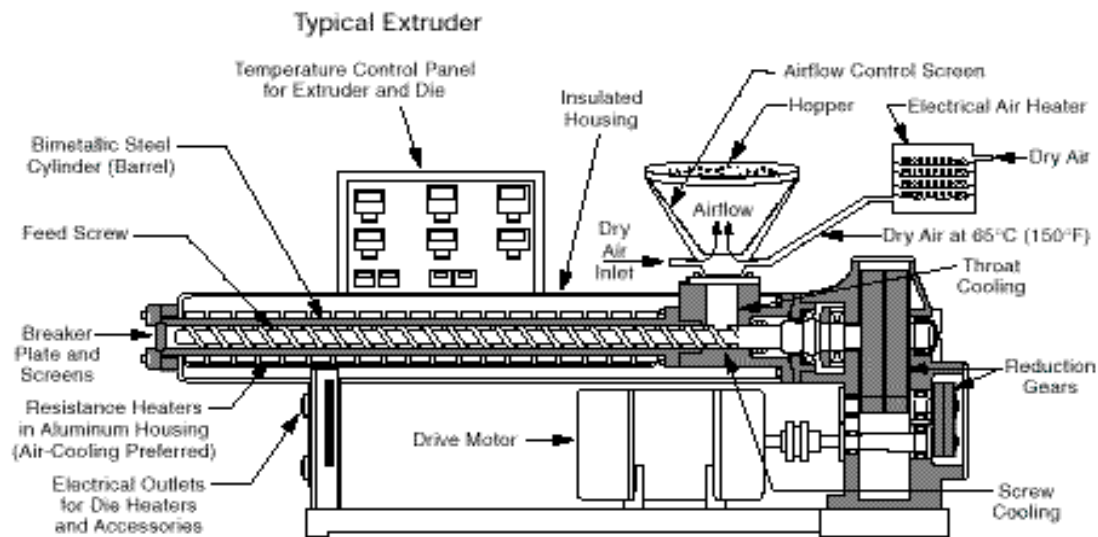


Fig 4 : Rabta Extruder

INJECTION MOULDING PROCESS

In making fiber glass reinforcements thermoplastic pellets materials, continuous glass ravings is first sized to increase inter facial adhesion between glass & resin.

The glass fiber are impregnated & coated with thermoplastic resin & finally chopped into pellets containing 20 to 30% wt fiber glass. The fiber glass in the pellets can be obtained 1/8 in length to 3/8 in length, injection moulding thermoplastic composite material are shown in figure 5.

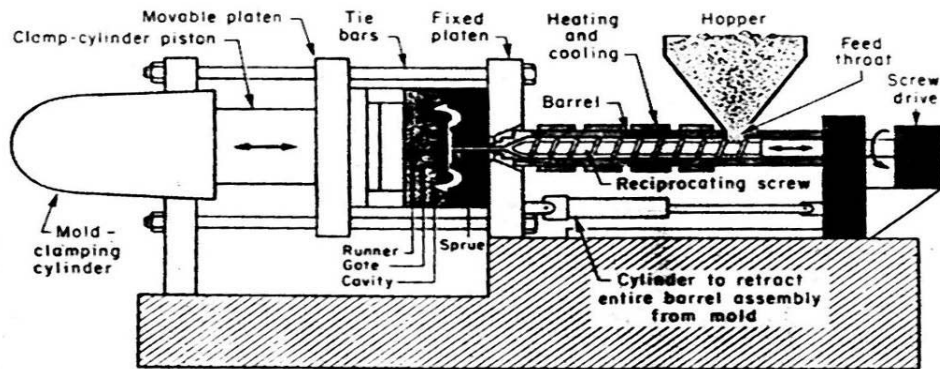


Fig. 5 Extruder coupled with injection moulding

Advantages –

1. Complicated shape is possible.
2. Surface finish is good.

Disadvantage –

It is difficult to predict the orientation of fibers.

- RESULT AND DISCUSSION:

Characteristics of the Reinforcement–Matrix Mixture

We denote as ply the semi-product “reinforcement + resin” in a quasi bidimensional form. This can be

- A tape of unidirectional fiber + matrix,
- A fabric + matrix, or
- A mat + matrix.
-

Fiber Mass Fraction

Fiber mass fraction is defined as:

$$M_f = \text{Mass of fibers} / \text{Total mass} \quad (1)$$

In consequence, the mass of matrix is:

$$M_m = \text{Mass of matrix} / \text{Total mass} \quad (2)$$

With $M_m = 1 - M_f$

Fiber Volume Fraction

Fiber volume fraction is defined as:

$$V_f = \text{Volume of fiber} / \text{Total volume} \quad (3)$$

As a result, the volume of matrix is given as:

$$V_m = \text{Volume of matrix} / \text{Total volume} \quad (4)$$

With

$$V_m = 1 - V_f$$

Mass Density of a Ply

The mass density of a ply can be calculated as

$$\rho = \text{total mass} / \text{Total volume} \quad (5)$$

The above equation can also be expanded as:

$$\rho = \frac{\text{mass of fiber}}{\text{total volume}} + \frac{\text{mass of matrix}}{\text{total volume}} \quad (6)$$

Theoretical calculation:
$$= \frac{\text{volume of fiber}}{\text{total volume}} \rho_f + \frac{\text{volume of matrix}}{\text{total volume}} \rho_m$$
 fiber reinforced composite are based on the fiber volume fraction in the material.

Experimentally, it is easier to determine the fiber weight fraction M_f , from which the fiber volume fraction v_f and composite density ρ_c can be calculated⁽¹³⁾:

$$\rho_c = v_f \times \rho_f + v_m \times \rho_m \quad (7)$$

Mechanics of fiber-reinforced composites

The mechanics of materials deal with stresses, strains, and deformations in engineering structures subjected to mechanical and thermal loads. A common assumption in the mechanics of conventional materials, such as steel and aluminum, is that they are homogeneous and isotropic continua. For a homogeneous material, properties do not depend on the location, and for an isotropic material, properties do not depend on the orientation. Unless severely cold-worked, grains in metallic materials are randomly oriented so that, on a statistical basis, the assumption of isotropy can be justified. Fiber-reinforced composites, on the other hand, are microscopically inhomogeneous and not isotropic.

As a result, the mechanics of fiber-reinforced composites are far more complex than that of conventional materials. The mechanics of fiber-reinforced composite materials are studied at two levels:

1. The micromechanics level, in which the interaction of the constituent materials is examined on a microscopic scale. Equations describing the elastic and thermal characteristics of a lamina are, in general, based on micromechanics formulations. An understanding of the interaction between various constituents is also useful in delineating the failure modes in a fiber-reinforced composite material.
2. The macro mechanics level, in which the response of a fiber-reinforced composite material to mechanical and thermal loads is examined on a macroscopic scale. The material is assumed to be homogeneous. Equations of orthotropic elasticity are used to calculate stresses, strains, and deflections⁽¹⁴⁾.
- 3.

COMPLIANCE AND STIFFNESS MATRICES

Specially Orthotropic Lamina ($\theta = 0^\circ$ or 90°)

Arranging Equations 4 through 7 in matrix form , we can write the strain– stress relation for a specially orthotropic lamina as

$$\begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & 0 \\ S_{21}(=S_{12}) & S_{22} & 0 \\ 0 & 0 & S_{66} \end{bmatrix} \begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \tau_{xy} \end{bmatrix} = [S] \begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \tau_{xy} \end{bmatrix}, \quad (8)$$

where:

$$\begin{aligned} S_{11} &= \frac{1}{E_{11}} \\ S_{12} = S_{21} &= -\frac{\nu_{12}}{E_{11}} = -\frac{\nu_{21}}{E_{22}} \\ S_{22} &= \frac{1}{E_{22}} \\ S_{66} &= \frac{1}{G_{12}} \end{aligned} \quad (9)$$

The [S] matrix is the compliance matrix for the specially orthotropic lamina.

Inverting Equation 9, we can write the stress–strain relations for a specially orthotropic lamina as :

$$\begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \tau_{xy} \end{bmatrix} = \begin{bmatrix} Q_{11} & Q_{12} & 0 \\ Q_{21}(=Q_{12}) & Q_{22} & 0 \\ 0 & 0 & Q_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{bmatrix} = [Q] \begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{bmatrix}, \quad (10)$$

where [Q] represents the stiffness matrix for the specially orthotropic lamina. Various elements in the [Q] matrix are

$$\begin{aligned} Q_{11} &= \frac{E_{11}}{1 - \nu_{12}\nu_{21}}, \\ Q_{22} &= \frac{E_{22}}{1 - \nu_{12}\nu_{21}}, \\ Q_{12} = Q_{21} &= \frac{\nu_{12}E_{22}}{1 - \nu_{12}\nu_{21}} = \frac{\nu_{21}E_{11}}{1 - \nu_{12}\nu_{21}}, \\ Q_{66} &= G_{12}. \end{aligned} \quad (11)$$

General Orthotropic Lamina ($\theta \neq 0^\circ$ or 90°)

The strain–stress relations for a general orthotropic lamina, can be expressed in matrix notation as⁽¹⁶⁾

$$\begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{bmatrix} = \begin{bmatrix} \bar{S}_{11} & \bar{S}_{12} & \bar{S}_{16} \\ \bar{S}_{12} & \bar{S}_{22} & \bar{S}_{26} \\ \bar{S}_{16} & \bar{S}_{26} & \bar{S}_{66} \end{bmatrix} \begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \tau_{xy} \end{bmatrix} = [\bar{S}] \begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \tau_{xy} \end{bmatrix}, \quad (12)$$

where $[\hat{S}]$ represents the compliance matrix for the lamina. Various elements in the $[\hat{S}]$ matrix are expressed in terms of the elements in the [S] matrix for a specially orthotropic lamina.

When a unidirectional reinforced orthotropic lamina is loaded only in the principal material directions the deformation is independent of any shearing effects and there is no coupling between in-plane and shear strain. This is not the case when the loading is applied at some arbitrary angle θ to the principal axis (Figure 6).

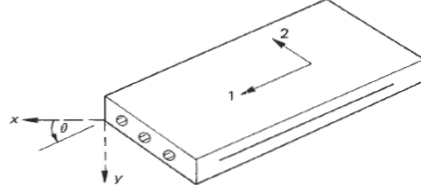


Figure 6 Orientated⁽¹⁴⁾

Expressing stress in the x,y coordinate system in terms of stresses in the 1,2 coordinate system in the following way , shear strain must be used in the transformation:

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_{xy} \end{Bmatrix} = \begin{bmatrix} m^2 & n^2 & -2mn \\ n^2 & m^2 & 2mn \\ mn & -mn & m^2 - n^2 \end{bmatrix} \begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{Bmatrix} \quad (13)$$

where : $m = \cos(\theta)$, and $n = \sin(\theta)$.

$$\begin{aligned} \{\sigma_{xy}\} &= [T] \{\sigma_{12}\} \\ \{\sigma_{xy}\} &= [T]Q\{\epsilon_{12}\} = [T][Q][T]^{-1}\{\epsilon_{xy}\} = [\bar{Q}]\{\epsilon_{xy}\} \\ \begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \tau_{xy} \end{Bmatrix} &= \begin{bmatrix} \bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{16} \\ \bar{Q}_{12} & \bar{Q}_{22} & \bar{Q}_{26} \\ \bar{Q}_{16} & \bar{Q}_{26} & \bar{Q}_{66} \end{bmatrix} \begin{Bmatrix} \epsilon_{xx} \\ \epsilon_{yy} \\ \gamma_{xy} \end{Bmatrix} \end{aligned} \quad (14)$$

where $[\bar{Q}]$ represents the stiffness matrix for the lamina. Various elements in the $[Q]$ matrix are expressed in terms of the elements in the $[Q]$ matrix as

$$\begin{aligned} \bar{Q}_{11} &= Q_{11} \cos^4 \theta + 2(Q_{12} + 2Q_{66}) \sin^2 \theta \cos^2 \theta + Q_{22} \sin^4 \theta, \\ \bar{Q}_{12} &= Q_{12}(\sin^4 \theta + \cos^4 \theta) + (Q_{11} + Q_{22} - 4Q_{66}) \sin^2 \theta \cos^2 \theta, \\ \bar{Q}_{22} &= Q_{11} \sin^4 \theta + 2(Q_{12} + 2Q_{66}) \sin^2 \theta \cos^2 \theta + Q_{22} \cos^4 \theta, \\ \bar{Q}_{16} &= (Q_{11} - Q_{12} - 2Q_{66}) \sin \theta \cos^3 \theta + (Q_{12} - Q_{22} + 2Q_{66}) \sin^3 \theta \cos \theta, \\ \bar{Q}_{26} &= (Q_{11} - Q_{12} - 2Q_{66}) \sin^3 \theta \cos \theta + (Q_{12} - Q_{22} + 2Q_{66}) \sin \theta \cos^3 \theta, \\ \bar{Q}_{66} &= (Q_{11} + Q_{22} - 2Q_{12} - 2Q_{66}) \sin^2 \theta \cos^2 \theta + Q_{66}(\sin^4 \theta + \cos^4 \theta). \end{aligned}$$

and $[T]$ is called the transformation matrix., Using the same matrix manipulation, the reduced

compliance matrix can be generated as follows⁽¹⁷⁾

$$[\hat{S}] = [Q]^{-T}$$

$$\begin{Bmatrix} \epsilon_x \\ \epsilon_y \\ \epsilon_{xy} \end{Bmatrix} = \begin{bmatrix} \bar{S}_{11} & \bar{S}_{12} & \bar{S}_{16} \\ \bar{S}_{12} & \bar{S}_{22} & \bar{S}_{26} \\ \bar{S}_{16} & \bar{S}_{26} & \bar{S}_{66} \end{bmatrix} \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_{xy} \end{Bmatrix}$$

These expressions are⁽¹⁴⁾

$$\begin{aligned} \bar{S}_{11} &= \frac{1}{E_{xx}} = S_{11} \cos^4 \theta + (2S_{12} + S_{66}) \sin^2 \theta \cos^2 \theta + S_{22} \sin^4 \theta, \\ \bar{S}_{12} &= -\frac{\nu_{xy}}{E_{xx}} = S_{12}(\sin^4 \theta + \cos^4 \theta) + (S_{11} + S_{22} - S_{66}) \sin^2 \theta \cos^2 \theta, \\ \bar{S}_{22} &= \frac{1}{E_{yy}} = S_{11} \sin^4 \theta + (2S_{12} + S_{66}) \sin^2 \theta \cos^2 \theta + S_{22} \cos^4 \theta, \\ \bar{S}_{16} &= -m_x = (2S_{11} - 2S_{12} - S_{66}) \sin \theta \cos^3 \theta - (2S_{22} - 2S_{12} - S_{66}) \sin^3 \theta \cos \theta, \\ \bar{S}_{26} &= -m_y = (2S_{11} - 2S_{12} - S_{66}) \sin^3 \theta \cos \theta - (2S_{22} - 2S_{12} - S_{66}) \sin \theta \cos^3 \theta, \\ \bar{S}_{66} &= \frac{1}{G_{xy}} = 2(2S_{11} + 2S_{22} - 4S_{12} - S_{66}) \sin^2 \theta \cos^2 \theta + S_{66}(\sin^4 \theta + \cos^4 \theta). \end{aligned}$$

Fig 7 and fig 8 indicate the superiority of using fiberglass and carbon fiber on the mechanical properties of the composite materials to be used in producing light weight cars. Fuel consumption will be drastically reduced leading to minimization of carbon dioxide emissions.

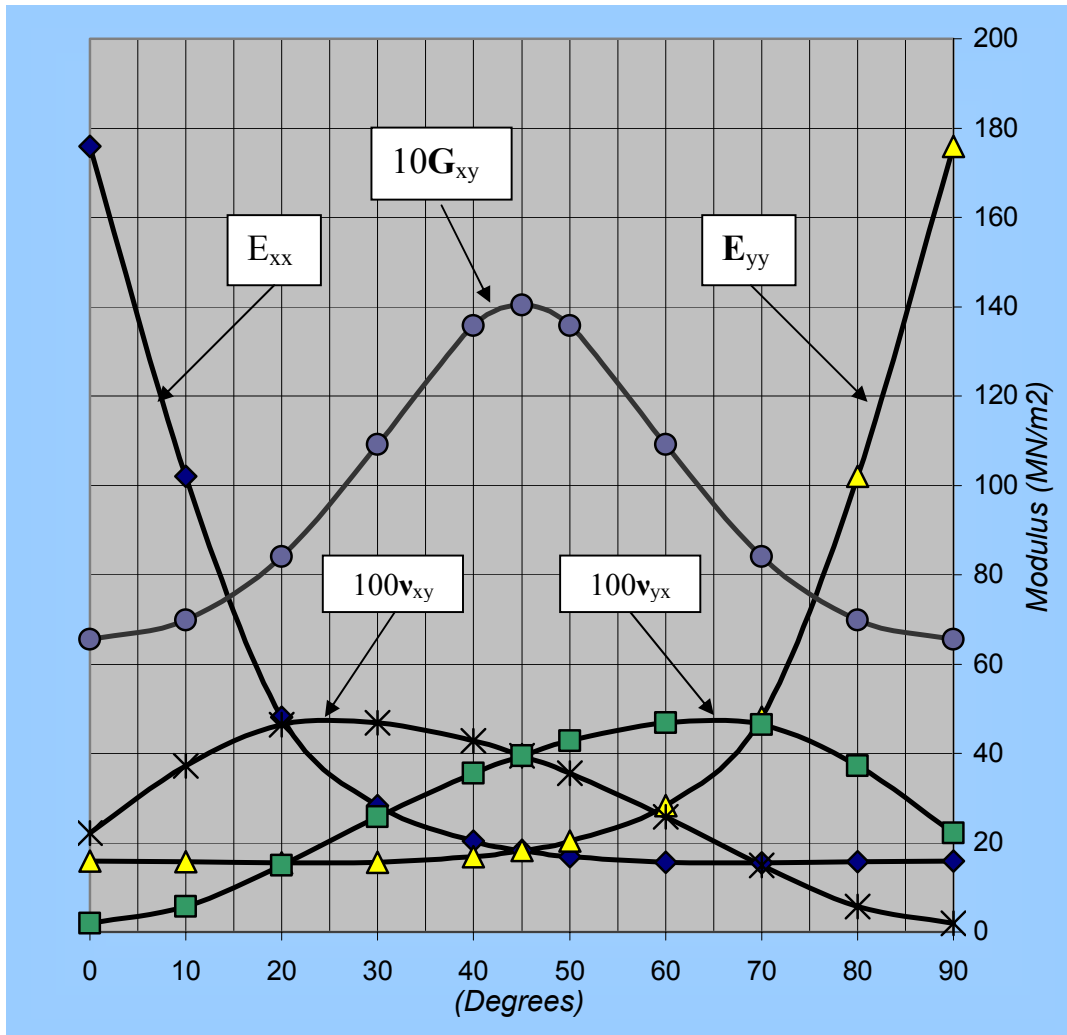


Figure 7 Variation of elastic properties for a single ply of Polypropylene with (30%) Fiber glass composite

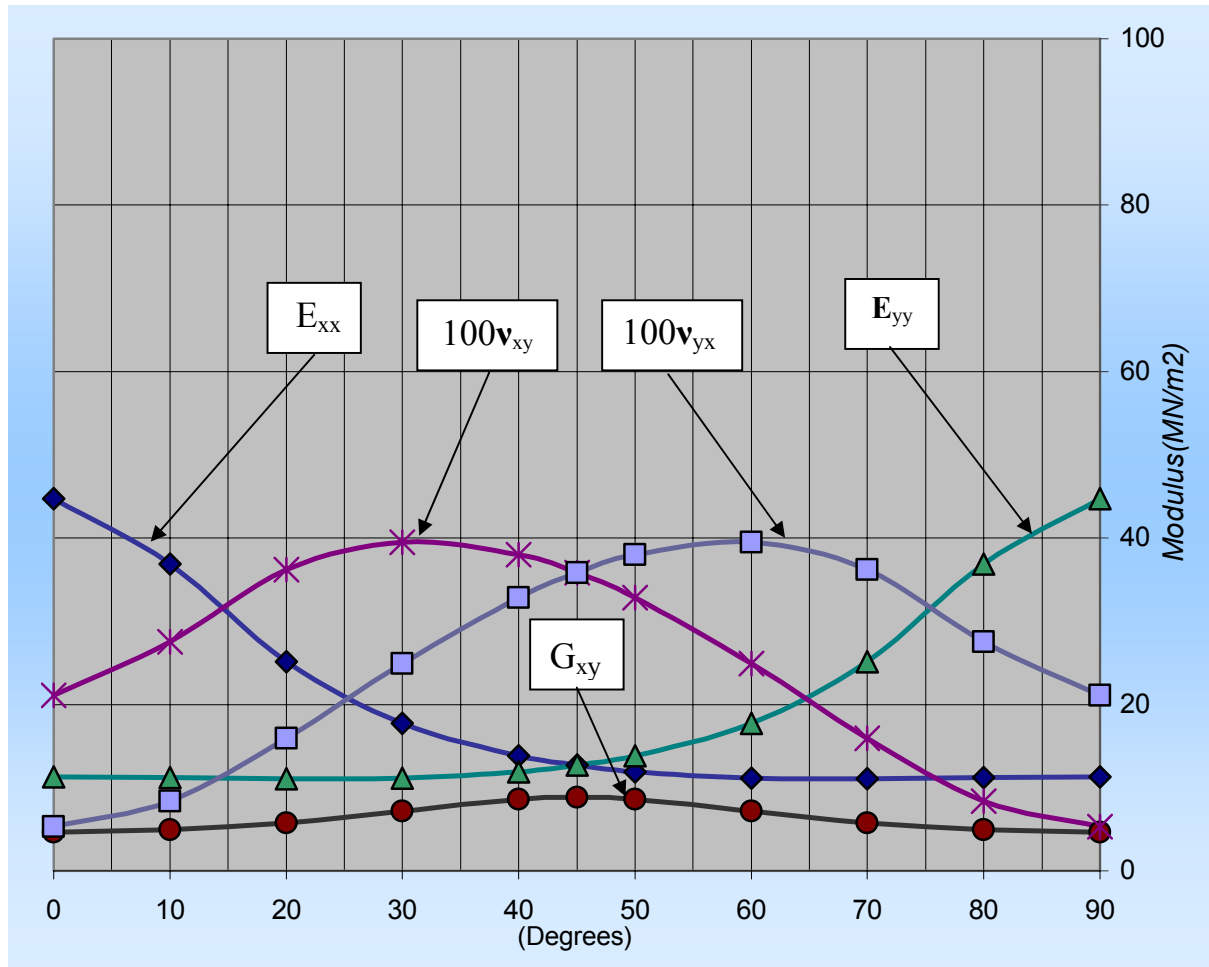


Figure 8 Variation of elastic properties for a single ply of Polypropylene with (1%) Carbon Fiber composite

CONCLUSION

Sandwich panels has future to replace conventional metals in airspace, automobile and building industries due to their light weight and energy saving and carbon dioxide low emissions. Most structures are not loaded in a single directions. The orientation of sandwich panels are in multiple directions stacking the multiple phase together and enhancing the major mechanical properties.

Stress strain correlations of composite materials made from polypropylene reinforced by fiberglass or carbon fiber are shown superiority and are in the range of applications in the field of airspace, automobile and building industries.

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