DESIGN, ANALYSIS AND SIMULATION OF AN AUTOMOTIVE CARBON FIBER MONOCOQUE

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Abstract

Honeycomb sandwich materials are used in many aerospace applications. However, in this study, these were used in the automotive application. Materials used for the monocoque chassis of Formula SAE were investigated. These materials were designed. Design of the chassis is very important because the weight and stiffness properties are directly related with the performance of the car and the safety of the driver. Based on the results of researches, Nomex was chosen the core of the honeycomb sandwich structure and carbon fiber orientations were determined. The strength and stiffness of a composite material depend on the orientation layout of layers. Therefore the layout of the layers was chosen as [F/03/F/core/F/03/F] and [F4/core/F4]. The use of the honeycomb sandwich construction in a monocoque chassis results in a chassis that is lighter than the steel.
Keywords: Honeycomb sandwich construction, Monocoque chassis, Nomex, Carbon fiber.

1 Introduction

Every year hundreds of university teams from around the world participate in the Formula Student competition that is organized by SAE International. Formula SAE or FSAE is a contest in which students design and produce small formula-style race cars. The FSAE competition involves a strict of rules. Also, the FSAE competition tests the limits of student imagination, practical engineering and to some extent, driving skills. The most critical point of success in the FSAE is that it is light-weight while maintaining the rigidity of the Formula racing car. For this reason, it has always been in search of new materials to achieve success. Formula cars are made up of approximately 80% composites by volume, especially in the most critically stressed components of the vehicle structure such as chassis, suspension arms, brake disks, aerodynamic devices, crash structures, and gearbox housings (Hamilton, Joyce, Forero, Mc Donald , 2013).

The development of technology has made it necessary to produce light-weight and strength materials that people need. Composite materials were developed along with the needs. Composite materials are becoming more important in the aerospace, defense industry, automotive and transportation. Especially fiber reinforced layered composite materials are used in requiring high technology such as aerospace and defense industries. Composite materials have been observed to have a large place in the field of advanced materials in the world. Composite materials have advantages such as lightness, high strength and strength, corrosion resistance and easy forming, high temperature resistance.

A composite is a structural material that consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called the ***reinforcing phase*** and the one in which it is embedded is called the ***matrix*.** The reinforcing phase material may be in the form of fibers, particles, or flakes. The matrix phase materials are generally continuous. Examples of composite systems include concrete reinforced with steel and epoxy reinforced with graphite fibers, etc. (Kaw, 2006). The manufacturers can produce a new material that matches the properties desired by selecting a suitable combination of reinforcement and matrix material.

In automobile production, composite materials can be used more than steel in the future. Because composites are 5 times lighter and 10 times stronger than steel. For this reason, the composites will take the place of the steel. The disadvantage of composites is usually the cost. Although manufacturing processes are often more efficient when composites are used, the raw materials are expensive. And no doubt new materials will be found as the technology evolves.

2 Literature review on Monocoque Chassis and Composite Materials

2.1 Monocoque Chassis

The two most important points in the design of a race car chassis are that it be lightweight and rigid. Two forms of chassis design are commonly used in race cars; space frame and monocoque design as shown in Fig.1.

The Space Frame chassis consists of a large number of shaped structural metal pipes (usually steel) to form a strong frame. A monocoque chassis is a structure which integrates body and chassis together to form a composite structure which has better stiffness as well as weight advantage. The stress generated by the vehicle during the movement is distributed among the structure in a monocoque chassis. Monocoques were first widely used in aircraft in the 1930s. The 1960s race cars, which used monocoque chassis, had a cylindrically formed construction to improve the torsional rigidity (Eurenius, Danielsson, Khokar, Krane, Olofsson, Wass, 2013).

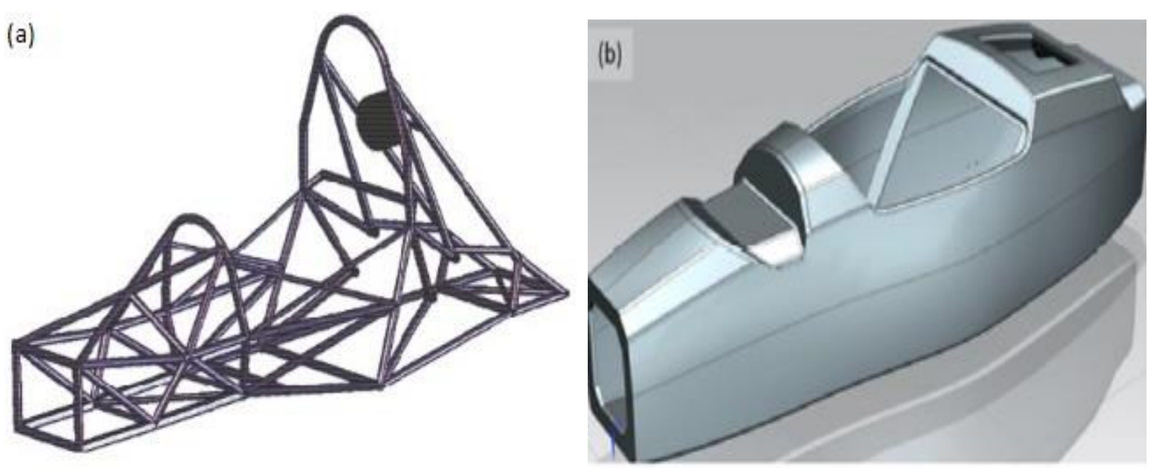

Fig.1. a) Space Frame b) Monocoque Chassis

2.2 A Honeycomb Sandwich Structure

Honeycomb sandwich constructions are especially used where high mechanical strength is required in which absorptive energy is generated. Honeycomb Sandwich constructions are more expensive than other sandwich materials. Converting it into a sandwich structure is more difficult to process. For this reason, it is used to provide high mechanical strength in marine, racing cars, aviation and space industries.

A honeycomb sandwich structure consists of two high strength face-sheets which are separated by the light-weight core as shown in Fig.2. The adhesives are used to bind the core and face-sheets (Petras, Sutcliffe, 1999).

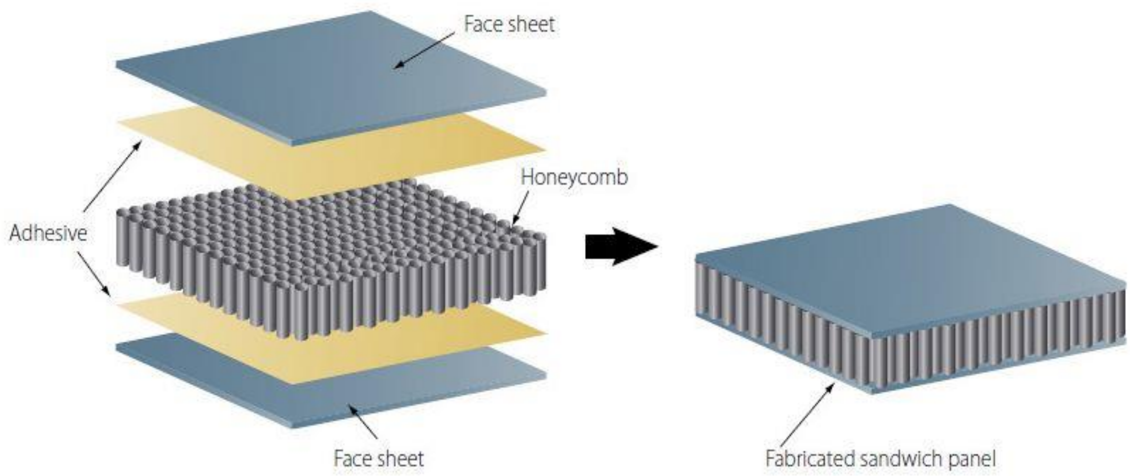

Fig.2. A Honeycomb Sandwich Structure

Honeycomb sandwich structure provides low density and ease of fabrication. Placing the honeycomb sandwich structure between the plates increases the bending strength. The honeycomb sandwich structure is similar to honeycombs made by honey bees.

Fig.3. Honeycomb

2.2.1 Core Materials

There are different honeycomb core materials. Each honeycomb core has certain properties. These core materials are made of aluminum, steel, fiberglass, thermoplastics, aramid paper, carbon, ceramics. The most common core material used for racing car honeycomb structures is aramid paper (Nomex). In this study, a composite material, a honeycomb sandwich construction was chosen. Nomex was chosen the core of the honeycomb sandwich structure and carbon fiber orientations were determined. Honeycomb is also the ideal material for energy absorption. The honeycomb core was selected 6 mm thickness.

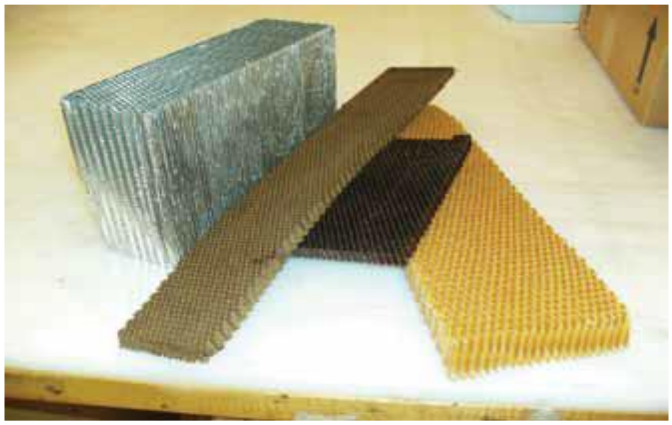

Fig.4. Honeycomb Core Materials

Nomex is a form of paper based on Kevlar. Nomex honeycomb is increasingly used in high performance places due to its high mechanical properties and low density. However, it is much more expensive than other core materials.
Properties of Nomex honeycomb core;

- Flame resistant,
- Fire retardant,
- Good insulating properties,
- Low dielectric properties,
- Good formability.

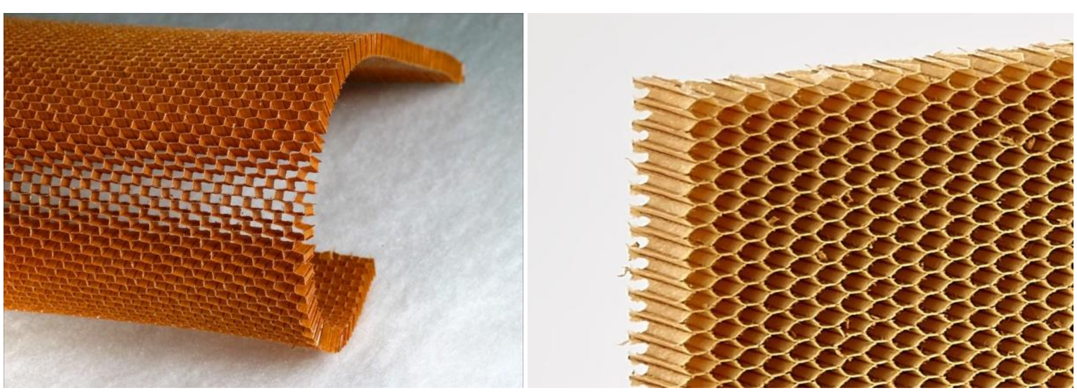

Fig. 5. Nomex Honeycomb Core

2.2.2 Honeycomb Geometry

The geometry of the honeycomb consist of hexagons. The honeycomb core structure has three different geometries. These are hexagonal honeycomb core, overexpanded core, flex core as shown in Fig.6.

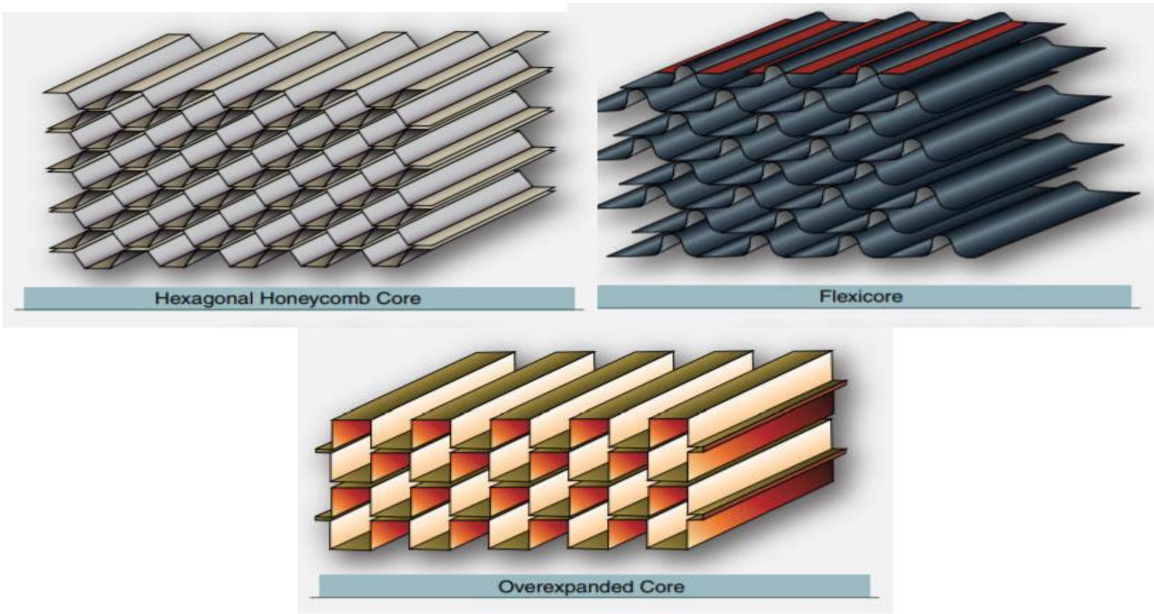

Fig.6. Honeycomb Core Types

The surface is made up of hexagons, the smallest surface ensures that we get the widest coverage on the surface. With this hexagonal structure, we are able to use the least amount of material.

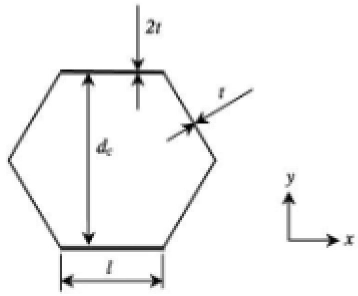

Fig.7. Hexagonal Honeycomb cell

- l: Length of the side of hexagonal core
- t: Face sheet thickness
- dc: Cell size

2.2.3 Form of Fibres

An advanced composite material is made of a fibrous material embedded in a resin matrix, generally laminated with fibers oriented in alternating directions to give the material strength and stiffness. In general, the fibers are placed in the load direction for optimum use of the composite. Fibers are load carrying elements of composite materials (Federal Aviation Administration, 2008). Thus the geometry and sequence of the fibers is very important. There are two fiber forms that are used most frequently. These are unidirectional (tape) and bidirectional (fabric) as shown in Fig.8.

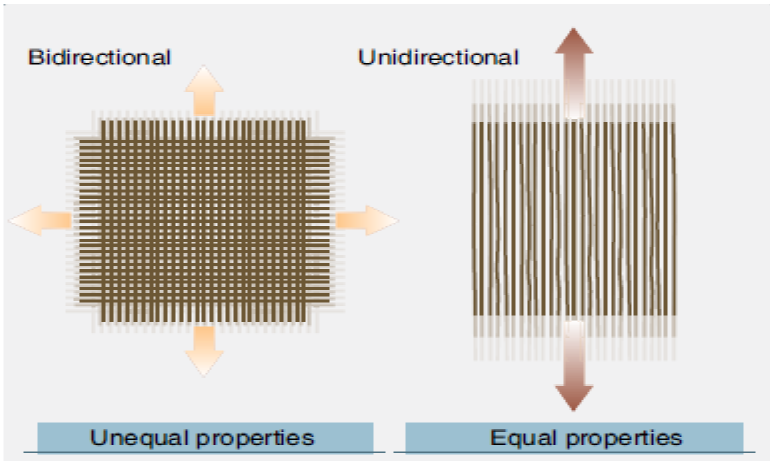

Fig.8. Bidirectional and Unidirectional Material Properties

Unidirectional prepreg tapes have been used the aerospace industry for many years. And the fiber is typically impregnated with thermosetting resins. Tape products have high strength in the fiber direction and virtually no strength across the fibers. Tapes have a higher strength than woven fabrics. Unidirectional layers provide longitudinal stiffness.

Most bidirectional constructions offer more flexibility for layup than straight unidirectional tapes offer. Fabrics offer the option for resin impregnation either by solution or the hot melt process. Bi-directional layers provide torsional stiffness. Tightly woven fabrics are usually the prefer to decrease weight. Reinforcement tows, strands, or yarns construct woven structural fabrics which interlock themselves with over/under placement during the weaving process. The more common fabric styles are plain or satin weaves as shown in Fig.9 (Federal Aviation Administration, 2008).

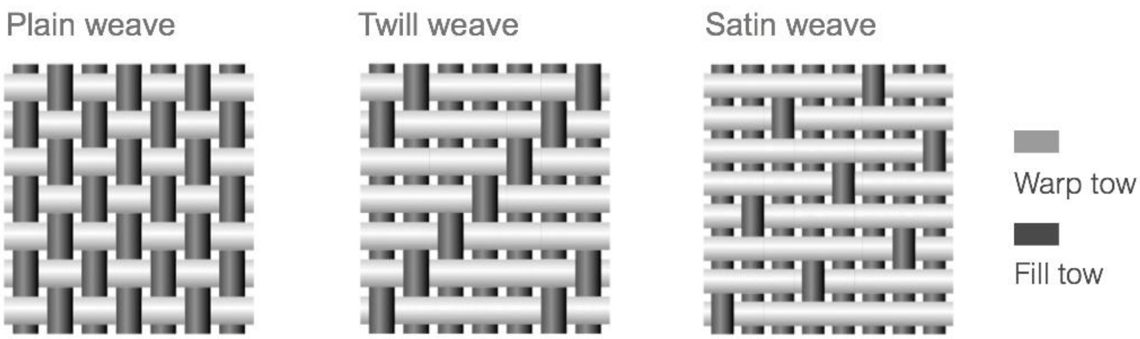

Fig.9. Plain Weave, Twill Weave and Satin Weave

2.2.4 Orientation of Fibres

The strength and stiffness of a composite material depends on the orientation sequence of the layers. And the fibers provide strength in terms of orientation. The layer orientation must be selected properly to provide an efficient design in composite materials. The part might require 0° plies to react to axial loads, ±45° plies to react to shear loads, and 90° plies to react to side loads. Layer orientation and layer sequence must be done correctly to obtain a strength design. For example, the pre-impregnated (prepreg) tape is a unidirectional layer orientation.

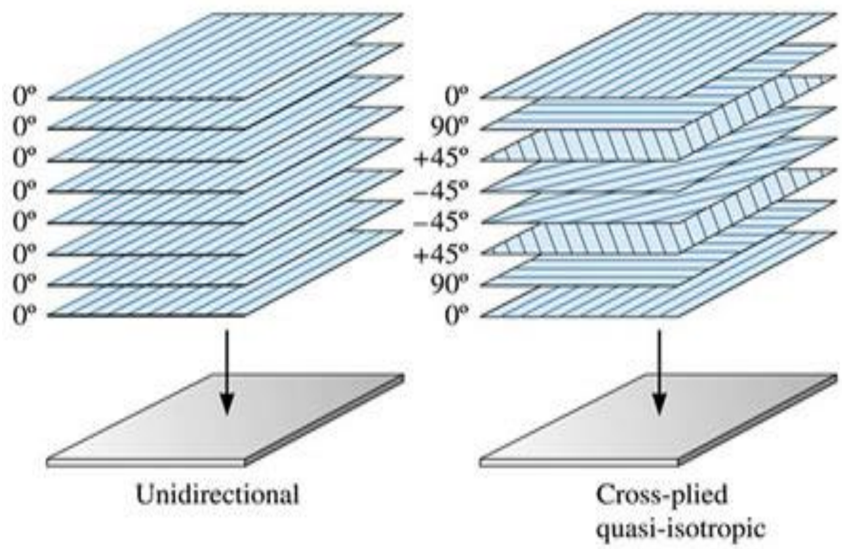

Fig.10. Orientation of Fibers

Bi-directional layers provide torsional stiffness and unidirectional layers provide longitudinal stiffness. For this reason, orientations have been chosen as both bi-directional and unidirectional carbon/epoxy. Two different sandwich configurations were ultimately chosen. In the final configurations, [F/03/F/core/F/03/F] has been used for the front bulkhead support region and [F_4/core/F_4] has been used for the side impact zones. In these layup descriptions, the 'F' refers to the bi-directional fabric and the '0' refers to the unidirectional tape and the subscript numeral refers to the number of layers (Hamilton, et all., 2013).

The following fiber orientations were chosen for this study.

For the front bulkhead support region;

- [F/03/F/core/F/03/F]: F/0°/45°/90°/F/Honeycomb core/F/90°/45°/0°/F

For the side impact zones;

- [F_4/core/F_4]: 0°/45°/90°/0°/ Honeycomb Core /0°/90°/45°/0°/

2.3 Tests that can be applied

2.3.1 Three Point Bending Testing

The three-point bending flexural test provides values for the modulus of elasticity in bending, flexural stress, flexural strain and the flexural stress–strain response of the material. The three-point bending test has the ease of specimen preparation and testing. However, this method has some disadvantages. In this test a specimen is placed on two parallel supporting pins. The loading force is applied in the middle. The test method usually includes a test fixture specified in a universal test machine as shown in Fig.11 (Three-point flexural test, wikipedia).

Fig.11. Three Point Bending Test Machine

2.3.2 Perimeter Shear Testing

The perimeter shear test is one of the tests that must be applied for the Formula SAE competition. Thus, the purpose is to find out the maximum force (F_{max}) that can penetrate the upper (outer) fiber of the laminate. In particular, perimeter shear test is an important test required for the side impact laminate in order to protect the driver from possible penetration of objects in case of a collision (Olsen, Lemu, 2016).

Fig.12. Perimeter Shear Testing

3 Conclusion and Future Work

Firstly, I worked on the design of the monocoque chassis of the Formula Student racing cars with composite material. I have explored the advantages and disadvantages of designing the chassis in monocoque and its differences from other designs. I was informed about the structure of the honeycomb sandwich which is popular in aviation and automotive applications. I searched about the core and face-sheet of honeycomb sandwich structure. I did research on the sequence and orientation of the fibers and I developed new orientations by taking advantage of the data I found.

In the future, they can work on fiber orientations and sequence that I have found. Test can be done that above mentioned. And the results of the tests can be compared to the articles in references.

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