CHAPTER 2

LITERATURE REVIEW

2.1 NEED OF BIO POLYMERS IN AUTOMOBILE STRUCTURAL COMPONENTS

The automotive industry is the largest manufacturing sector in the world. However, along with the automotive production, non-recyclable and non-biodegradable materials are generated and there often end up in landfills. The synthetic fibers and petroleum-based thermoplastics are contributors to these wastes as well as green-house gas emissions (Ken et al 1990).

Biopolymers and biocomposites present many environmental advantages and functional benefits, including reduction of fossil fuel use and lower green-house gas emissions. Due to the importance of the automotive industry to the safe environment, Toyota has recently developed Eco Plastic made from sugar cane or corn. Eco Plastic combines PLA, a plastic derived from plants, with composites from kenaf (Toyota Motor Corporation 2006). Four key factors have driven Toyota’s research into bio-based materials: 1. Environment-friendly technologies, 2. increasing speed of dismantling, 3. reduction of use of materials toxic to humans or the environment, and 4. reduction of PVC use. DaimlerChrysler is using biofibers from flax, coconut and abaca in their Vehicle (Juska et al 2000)
Chu and Sullivan (1996) analysed the recyclability of the natural fibers and glass fibers. Life cycle analysis on natural fiber-reinforced polypropylene proved these advantages compared to an equivalent glass fiber-reinforced material. The development of compounds based entirely on renewable resources will further enhance this benefit. This is the main ecological argument besides saving limited non-renewable resources such as crude oil. Finally, plant fibers are more flexible than glass fibers. The implication is less fiber shortening during recycling processes and consequently superior properties of the recycled materials. The Figure 2.1 shows the environmental problems related to automobile and its importance for green environment.
Sanadi et al (1994) discussed the other constituent of FRP composites namely the fiber reinforcement, and this can be divided into two categories, like natural and synthetic. Natural or plant fibers are fibers that are obtained from nature. These fibers undergo a pre-processing technique that allows them to be used in composite structures. A remarkable weight reduction of about 20% was achieved, and the mechanical properties, important for passenger protection in the event of an accident, were improved. Furthermore, the flax/sisal material can be molded in complicated 3-dimensional shapes, thus making it more suitable for door trim panels than the previously used materials.

Suhara et al (2006) stated that the main motivation of using natural/bio- fibers like Kenaf and Hemp to replace glass fibers is the low cost, low density (½ of glass), acceptable specific strength properties, enhanced energy recovery, CO₂ reduction, and biodegradability. Figure 2.2 shows the use of natural fibers in automobile industries.

![Graph showing comparison between synthetic and natural fibers](image)

**Figure 2.2 Use of natural fibers in automobile(Suhara et al 2006)**

Auto companies are seeking materials with sound abatement capability as well as reduced weight for fuel efficiency. It is estimated that 75% of a vehicle’s energy consumption is directly related to factors
associated with vehicle’s weight, and it is identified as critical the need to produce safe and cost-effective light-weight vehicles. Natural fibers possess excellent sound absorbing efficiency and more shatter resistant and have better energy management characteristics than glass fiber based composites. In automotive parts, compared to glass composites, the composites made from natural fibers reduce the mass of the component; lower the energy needed for production by 80%. To reduce vehicle weight; a shift away from steel alloys towards aluminium, plastics and composites has been predicted and that in the near future polymer and polymer composites will comprise 15% of a car weight.

Shin and Lee (2002) discussed the Fiber reinforced composite materials that have been widely used in various transportation vehicle structures because of their high specific strength, modulus and high damping capability. If composite materials are applied to vehicles, it is expected that not only the weight of the vehicle is decreased but also that noise and vibration are reduced. In addition to that, composites have a very high resistance to fatigue and corrosion.

Mohanty et al (2000) had done excellent study and reported that synthetic fibers are commonly used to reinforce thermoplastics due to their good impact strength of the natural fibers and they can replace the glass fibers. The fibers reinforce the composite structure by giving strength and stiffness. Traditionally, these fibers have included glass, aramid and carbon. General characteristics of these fibers include high Biocomposites in Automotive Manufacturing. The properties of E-glass can be found low cost, high production rates, high stiffness, relatively low density, high thermal resistance and high moisture resistance. Disadvantages include low modulus, abrasive and high density in comparison to carbon and organic fibers. Although it is more difficult to process, S-glass has a higher stiffness in
comparison to E-glass. These can be replace by properly treated natural fibers.

Mohanty et al (2002) analysed again over the advantages of biofibers. They are low cost, low density, strength properties, carbon dioxide sequestration and recyclability. However, biofibers are hydrophilic and do not bind readily to the hydrophobic polymeric matrix. They are also degraded at low processing temperatures required during processing. There are also concerns relating to the poor moisture resistance and dimensional stability, which can lead to de bonding and micro cracking. Nevertheless, green composites are considered important alternatives to synthetic polymers.

2.2 APPLICATION OF FIBERS IN VARIOUS FIELDS

Table 2.1 shows the details of natural fibers and their applications for various industries.

<table>
<thead>
<tr>
<th>Name of the fiber</th>
<th>Applications</th>
</tr>
</thead>
</table>
| Jute              | 1. It is used as packaging material (bags) like sacks.  
2. It is used as carpet backing, ropes, mat and yarns.  
3. It is used for wall decoration |
| Coir              | 1. It is used for the production of yarn.  
2. It is used for the manufacture of rope and fishing nets.  
3. It can be used for the production of brushes and mattresses.  
4. Coir has also been tested as filler or reinforcement in different composite materials. |
| Sisal             | 1. It is mainly used for ropes, mats, carpets, and cement reinforcement.  
2. It is also used in cement reinforcement.  
3. In developing countries, sisal fibers are used as reinforcement in houses. |
| Kenaf             | 1. Automotive interior parts.  
2. Car body panel works.  
3. Structural beams |
2.3 ADVANTAGES OF NATURAL FIBERS OVER SYNTHETIC FIBERS

The use of natural fibers only recently became popular once again, especially in the automotive and aerospace industries, because of the drive for more environmentally friendly products and because of a number of advantages natural fibers hold over synthetic ones.

These include, among others, the facts that

- It costs less to produce; since the fibers are often obtained as a by-product during the manufacturing of textiles, they are usually more readily available and can be sourced cheaply from local sources.

- It has a low density, which means it is light-weight and would, for instance, reduce the overall weight of a vehicle in which it is used and therefore better its fuel consumption.

- It has specific mechanical properties such as flexibility, thermal insulation, and acoustic insulation.

- It is a sustainable resource of which the production requires little energy; carbon dioxide (CO2) is used while oxygen is given back to the environment.

- It is easy to recycle natural fibers, as they are biodegradable and will not pollute the earth.

- Thermal recycling is possible, where glass fibers cause problems in combustion furnaces.
When used in textiles for clothing, natural fibers are known to be more comfortable (i.e. more sweat absorbent, no skin irritation, cooler in summer and warmer in winter, softer and less scratchy).

On the other hand, natural fibers have their shortcomings, and these have to be solved in order to be competitive with synthetic fibers such as glass fibers. Natural fibers have lower durability and lower strength than glass fibers. However, recently developed fiber treatments have improved these properties considerably.

## 2.4 INTRODUCTION TO COMPOSITE MATERIALS

Composite materials have come to be known as the emerging materials of this century. Although it is not clear, man understood the fact that mud bricks made sturdier houses if lined with straw and used them to make buildings that lasted long. Ancient Pharaohs made their slaves use bricks with the straw to enhance the structural integrity of their buildings, some of which testify to the wisdom of the dead civilization even today.

Contemporary composites result from research and innovation from the past few decades and have progressed from glass fiber for automobile bodies to particulate composites for aerospace and a range other applications.

Ironically, despite the growing familiarity of composite materials and their ever-increasing range of applications, the term defies a clear definition. Loose terms like “materials composed of two or more distinctly identifiable constituents” are used to describe natural composites like timber, organic materials, like tissue surrounding the skeletal system, soil aggregates, minerals and rock. As they are biodegradable and their strength is more and equal to that of the plastics many applications like in transportation industry composites are preferred and used.
Composite materials, often shortened to “Composites” or called composition materials, are engineered or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct at the macroscopic or microscopic scale within the finished structure. They are solids that are composed of two or more materials.

Usually, the result of embedding fibers, particles, or layers of one material in a matrix of another material, composites are designed to exploit the best properties of both components to produce a material that surpasses the performance of the individual parts.

A composite material consists of two or more physically and/or chemically distinct, suitably arranged or distributed phases, with an interface separating them. It has characteristics that are not depicted by any of the components in isolation. Most commonly, composite materials have a bulk phase, which is continuous, called the matrix, and one dispersed, non-continuous, phase called the reinforcement, which is usually harder and stronger. The function of individual components has been described as:

### 2.4.1 Matrix Phase

The primary phase, having a continuous character, is called matrix. Matrix is usually more ductile and less hard phase. It holds the dispersed phase and shares a load with it.

### 2.4.2 Dispersed (Reinforcing) Phase

The second phase (or phases) is embedded in the matrix in a discontinuous form. This secondary phase is called ‘dispersed phase’. Dispersed phase is usually stronger than the matrix, therefore it is sometimes called reinforcing phase.
Many of common materials (metal alloys, doped Ceramics and Polymers mixed with additives) also have a small amount of dispersed phases in their structures; however, they are not considered as composite materials since their properties are similar to those of their base constituents (physical properties of steel are similar to those of pure iron). There are two classification systems of composite materials. One of them is based on the matrix material (metal, ceramic, and polymer) and the second is based on the material structure:

2.5 CLASSIFICATION OF THERMOPLASTIC COMPOSITES

From the figure 2.3 a clear subdivision of the composite is discussed based on particulate, fiber reinforced and structural thermoplastic composites.

THE FAMILIES OF AUTOMOTIVE THERMOPLASTIC COMPOSITES

![Figure 2.3 Classification of thermoplastic composites](image)

2.6 CLASSIFICATION BASED ON REINFORCING MATERIAL STRUCTURE

There are three main categories:
2.6.1 Particulate Composites

Particulate Composites consist of a matrix reinforced by a dispersed phase in the form of particles. These are the cheapest and most widely used. They fall in two categories depending on the size of the particles:

- Composites with random orientation of particles.
- Composites with preferred orientation of particles.

2.6.2 Fibrous Composites

Short fiber reinforced composites

Short-fiber reinforced composites consist of a matrix reinforced by a dispersed phase in the form of discontinuous fibers (length < 100*diameter). They are classified as

- Composites with random orientation of fibers.
- Composites with preferred orientation of fibers.

Long-fiber reinforced composites

Long-fiber reinforced composites consist of a matrix reinforced by a dispersed phase in the form of continuous fibers.

- Unidirectional orientation of fibers.
- Bidirectional orientation of fibers (woven).

2.6.3 Laminate Composites

When a fiber reinforced composite consists of several layers with different fiber orientations, it is called multilayer composite.
2.7 NEED FOR THE PRESENT STUDY

Automakers now see strong promise in natural fiber composites. Natural fibers have higher strength to weight ratio than steel and is also considerably cheaper to produce. Natural fiber composites are emerging as a realistic alternative to glass-reinforced composites. While they can deliver the same performance for lower weight, they can also be 25-30 percent stronger for the same weight. The main motivation of using natural/bio-fibers like Kenaf and Hemp to replace glass fibers is the low cost, low density (½ of glass), acceptable specific strength properties, enhanced energy recovery, CO₂ sequesterization, and biodegradability.

Auto companies are seeking materials with sound abatement capability as well as reduced weight for fuel efficiency. It is estimated that 75% of a vehicle’s energy consumption is directly related to factors associated with vehicle’s weight, and it is identified as the critical need to produce safe and cost-effective light-weight vehicles. Natural fibers possess excellent sound absorbing efficiency and more shatter resistant and have better energy management characteristics than glass fiber based composites. In automotive parts, compared to glass composites, the composites made from natural fibers reduce the mass of the component; lowers the energy needed for production by 80%.

The need for continual improvement in material performance is a common feature of many modern engineering endeavors. Engineering structures now encompass a wide range of technologies from materials development, analysis, design, testing, production, and maintenance. Advances in materials technologies have been largely responsible for major performance improvements in many engineering structures and continue to be key in determining the reliability, performance and cost effectiveness of such
systems. The use of natural fiber in composite plastics is gaining popularity in many areas, particularly the automotive industry. The use of natural fiber in polymers can provide many advantages over other filler technologies. And Areas of applications appear limitless. The automotive industry is now currently shifting to “green” outlook, as consumers are looking for environmentally friendly vehicles.

2.8 IMPORTANCE OF THERMOPLASTICS IN AUTOMOBILES

The ever-growing use of reinforced thermoplastics in various industrial applications has led to a demand of always-higher mechanical performances for injection-moulded parts. However, because of the low residual fiber length after processing, mechanical properties are often limited when short fiber reinforced thermoplastic pellets are used. In order to overcome this limitation, Long Fiber Thermoplastic (LFT) pellets have been developed so as to answer these new market requirements through a higher fiber aspect ratio (length/diameter ratio) theoretically leading to higher mechanical properties.

The improvement of mechanical properties, however, also depends on the homogeneity and isotropy of the injection-moulded plastic parts, which are governed by the fiber distribution and orientation mechanisms, and on the capacity of the processing technologies to limit fiber breakage. The thermoplastic biopolymers lignin, starch, PLA (polylactic acid) was established as engineering composites for parts used in many commodities for various industrial branches. Their properties lie well in the range of PP/talcum, which is a widely utilized plastic in these fields. Impact modified materials developed with innovative methods of Long Fiber Direct Processing (LFT-D) could surpass the challenging target of the project, an impact
strength of 50 kJ/m². Cellulose regenerated fibers increase impact strength without reduction of tensile properties of pp composites. Figure 2.4 shows the impact properties of the thermoplastics in brief. These materials can compete with ABS (AcrylonitrileButadieneStyrene) and HIPS (high impact polystyrene) often used for the housing of equipment of electronics and automotive interior panels. Fire resistance could achieve highest classifications.

![Figure 2.4 Overview of mechanical properties of thermoplastic](image)

**Figure 2.4 Overview of mechanical properties of thermoplastic**

### 2.9 TYPES OF NATURAL FIBERS

The classification of the natural fibers is explained below in the Figure 2.5. In this research the natural fibers like kenaf, jute, and sisal were taken due to easy availability in plenty, in India, also due to the good mechanical and thermal properties. These two properties are very important when selecting the fiber for automotive structure.
2.9.1 Kenaf

Kenaf (*Hibiscus cannabin’s*) is a fiber plant native to east-central Africa where it has been grown for several thousand years for food and fiber. Kenaf is a promising source of raw material fiber for pulp, paper and other fiber products, and has been in use since World War II in India, China, USSR, Thailand, South Africa, Egypt, Mexico and Cuba.
Kenaf is a herbaceous annual plant that can be grown under a wide range of weather conditions, for example, it grows more than 3m within 3 months even in moderate ambient condition. It exhibits low density, non-abrasiveness during processing, high specific mechanical properties and biodegradability. It can be used as a domestic supply of cordage fiber in the manufacture of rope, twine carpet backing and burlap. In automotive industry it works as a substitute for fiber glass or other synthetic fibers, and can be found in automobile dashboards, carpet padding and corrugated medium. The main processes by which the fiber and matrix can turn into final product are injection moulding and extrusion. It is shown in Figure 2.6. Okuda et al (2008), Kenaf fiber finds use in the following:

- Automobile dashboards
- Carpet padding
- Substitute for fiber glass in automobile industry.
- Products as rope, twine, bagging and rugs.

### 2.9.2 Jute

Jute is a natural fiber with golden and silky shine and hence called the Golden Fiber. It is the cheapest vegetable fiber procured from the bast or skin of the plant's stem and the second most important vegetable fiber after cotton, in terms of usage, global consumption, production, and availability. It is shown in Figure 2.7. It is being characterized by a long, soft and shiny fiber which can be spun into coarse strong threads (Boyd et al 1987).
Environment friendly being 100% bio-degradable, the jute fiber is affordable and can be blended with other fibers, either synthetic or natural. Jute fiber presents a high tensile strength, low extensibility, low thermal conductivity and acoustic insulating properties. Compared to other fibers jute having high insulation properties.

Benefits of jute fiber

- Having good insulating and antistatic properties.
- Having low thermal conductivity and a moderate moisture regain.

2.9.3 Sisal

Figure 2.8 shows the Sisal fiber, it is one of the most widely used natural fibers and is very easily cultivated. Almost 4.5 million tonnes are produced every year, all over the world. Tanzania and Brazil are the two most important producers.
The fiber is extracted from the leaf either by retting, by scraping or by retting followed by scraping or by mechanical means using decorticators. Generally the sisal fibers are defined by their source, age and cellulose content, giving them the strength and stiffness. The tensile properties of the sisal fiber are not uniform along its length. The root or lower part has low tensile strength and modulus but high fracture strain. The fiber becomes stronger and stiffer at mid-span and the tip has moderate properties. The price of sisal fiber comes to about one-ninth of the glass fiber. For specific price (modulus per unit cost) it is very close to the jute amongst all the synthetic and cellulosic fibers.

**Benefits of sisal fiber**

- Environmental friendly parts
- Potential weight reduction
- CO2 emissions reduction (agricultural based raw material)
- Surface appearance improvement (warm touch/feeling)
- Total process cost reduction (temperature and cycle time > production rate increase)

### 2.10 NATURAL FIBERS Vs GLASS FIBERS IN TERMS OF COST

To select the natural fibers as the alternate to the glass fibers, it is essential to study the mechanical properties of the natural fibers along with those of the glass fibers. Table 2.2 shows the properties of the natural fibers. Since the 1990s, natural fiber composites are emerging as realistic alternatives to glass-reinforced composites in many applications. Natural fiber composites such as hemp fiber-epoxy, flax fiber-polypropylene (PP), and China reed fiber-PP are particularly attractive in automotive applications because of lower cost and lower density. Glass fibers used for composites have density of 2.6 g/cm³ and cost between $1.30 and $2.00/kg. In comparison, flax fibers have a density of 1.5 g/cm³ and cost between $0.22 and $1.10/kg (Foulk et al. 2000). While, natural fibers traditionally have been used to fill and reinforce thermosets, natural fiber reinforced thermoplastics, especially polypropylene composites, have attracted greater attention due to their added advantage of recyclability (Mohanty et al.).

Natural fiber composites are also claimed to offer environmental advantages such as reduced dependence on non-renewable energy/material sources, lower pollutant emissions, lower greenhouse gas emissions, enhanced energy recovery, and end of life biodegradation of components. Since, such superior environmental performance is an important driver of increased future use of natural fiber composites, a thorough comprehensive analysis of the relative environmental impacts of natural fiber composites and conventional composites, covering the entire life cycle, is warranted. In this article, we review select Life Cycle Assessment (LCA) studies comparing
natural fiber composites and glass fiber composites. We identify the major drivers of the relative environmental performance of natural fiber composites, and draw conclusions about whether the specific findings of these studies can be generalized. Rising prices of petroleum based products, strong government support to eco-friendly products, higher acceptance and positive growth of end use industries will drive natural fiber composites growth to new horizon. From the Figure 2.9 it is clear that the price of the natural fibers are very less in terms of $ compared to the conventional materials.

**Table 2.2 Mechanical properties of the natural fibers (Mohanty 2000)**

<table>
<thead>
<tr>
<th>Fiber</th>
<th>Density (g/cm$^3$)</th>
<th>Diameter (μm)</th>
<th>Tensile strength (MPa)</th>
<th>Young's modulus (GPa)</th>
<th>Elongation at break (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>1.5-1.6</td>
<td>-</td>
<td>287-800</td>
<td>5.5-12.6</td>
<td>7.0-8.0</td>
</tr>
<tr>
<td>Jute</td>
<td>1.3-1.45</td>
<td>25-200</td>
<td>393-773</td>
<td>13-26.5</td>
<td>1.16-1.5</td>
</tr>
<tr>
<td>Flax</td>
<td>1.50</td>
<td>-</td>
<td>345-1100</td>
<td>27.6</td>
<td>2.7-3.2</td>
</tr>
<tr>
<td>Hemp</td>
<td>-</td>
<td>-</td>
<td>690</td>
<td>-</td>
<td>1.6</td>
</tr>
<tr>
<td>Kenaf</td>
<td>1.50</td>
<td>20-150</td>
<td>500-1000</td>
<td>61.4-128</td>
<td>2-3.8</td>
</tr>
<tr>
<td>Sisal</td>
<td>1.45</td>
<td>50-200</td>
<td>468-640</td>
<td>9.4-22.0</td>
<td>3-7</td>
</tr>
<tr>
<td>PALF</td>
<td>-</td>
<td>20-80</td>
<td>413-1627</td>
<td>34.5-82.51</td>
<td>1.6</td>
</tr>
<tr>
<td>Coir</td>
<td>1.15</td>
<td>100-450</td>
<td>131-175</td>
<td>4-6</td>
<td>15-40</td>
</tr>
<tr>
<td>E-glass</td>
<td>2.5</td>
<td>-</td>
<td>2000-3500</td>
<td>70</td>
<td>2.5</td>
</tr>
<tr>
<td>S-glass</td>
<td>2.5</td>
<td>-</td>
<td>4570</td>
<td>60</td>
<td>2.8</td>
</tr>
<tr>
<td>Aramid</td>
<td>1.4</td>
<td></td>
<td>3000-3150</td>
<td>63-67</td>
<td>3.3-3.7</td>
</tr>
<tr>
<td>Carbon</td>
<td>1.7</td>
<td>-</td>
<td>4000</td>
<td>230-240</td>
<td>1.4-1.8</td>
</tr>
</tbody>
</table>
2.11 BIO-COMPOSITE PLASTICS USED BY GLOBAL AUTOMOTIVE MANUFACTURERS

In the early 1930’s, Henry Ford examined a variety of natural materials including cantaloupes, carrots, cornstalks, cabbages and onions in a search for potential candidate materials from which he could build an organic car body. He developed a prototype based on Hemp but due to economic limitations at that time the vehicle was not mass produced. Interest in natural materials diminished with the advent of other more durable materials, such as metals, and it was not until the 1940’s that natural fibers began to make a comeback. Ford scientists discovered that soybean oil could be used to make high quality paint enamel and could also be moulded into a fiber based plastic. The company claimed that the material had 10 times the shock-resistance of steel. Henry Ford Proceedings of the Symposium on Natural Fibers delighted in demonstrating the strength of the material by pounding the soybean boot lid with an axe. If it was not for the fact that the material required a long cure time, and did not suffer from moulding problems, we
might well be driving cars made from this material today. Composites, particularly natural fiber reinforced plastics, have been receiving increased attention since 1941 in other industries such as the aerospace and marine industries (Suddell et al. 2005).

In the 1950’s the body of the East German Trabant car was the first production vehicle to be built from natural fibers. Cotton was used embedded within a polyester matrix. These cars were still in production up until 1990, and can still be seen on the roads of Eastern European cities today. Later, in the 1980’s the first use of natural fiber and bio resin was used in combination to create the first all bio-composite automotive door panel.

In the 90’s, Daimler-Benz pioneered the use of natural fibers in commercial vehicles as part of the ‘Belem’ project based in the Amazon delta in South America. In this application, coconut fibers were used with latex in trucks for around a nine year period, with backrests, head restraints, bunk cushions and sun visors being produced, demonstrating the potential that indigenous fibers can have for a country and how they can be used in a commercial application in the automotive industry. This not only improved the quality of life for the individuals involved in this new application but it also became a commercial success and ensured its continuation. Coconut fibers have been used in cars for more than 60 years in such applications as interior trim and seat cushioning. Estimated service life for these products is around 90 years – well exceeding the lifespan of the intended application. Unlike plastic foam, the coconut fibers have good ‘breathing’ properties which are a distinct advantage for vehicle seats being used in countries where the climate is hot, as is the case in Brazil. Coconut fibers are also naturally resistant to fungi and mites and the remains of the fibers also make an effective natural fertilizer at the end of their lifetime (Daimler 2001).
In 1994, Daimler Chrysler started using flax and sisal fibers in the interior trim components of its vehicles. They continued investing in their application of natural fibers and in 1996 Jute was being utilised in the door panels of the Mercedes Benz E-Class vehicles. Daimler Chrysler as a company investing in environmental initiatives is a good example to cite here. In 2000, they spent around $1.5bn on environmental initiatives of which $870m was spent on environmentally friendly products and production processes resulting in a plethora of natural based components for their entire range of vehicles. German Car manufacturers are aimed to make every component of their vehicles either recyclable or biodegradable.

Nowadays, there is an increasing trend for the use of natural fibers as a result of government legislation on environmental issues. This is particularly important in those countries where products from agricultural sources offer an attractive and cheap alternative for developing degradable materials. However, their potential use as a reinforcement is greatly reduced because of their hydrophilic (water absorbing) nature, and the lack of sufficient adhesion between untreated fibers and the polymer matrix resulting in poor impact resistance of the products. The issue of poor interfacial adhesion between fibers and matrix material is due to a mismatch in surface polarities – cellulose (polar) and polyolefins (non polar). These issues have been addressed by the development of effective surface treatments for the fibers in both physical (Cold plasma and Corona) and chemical treatments (maleic anhydride and organosilanes etc.). If a composite exhibits poor adhesion then it is going to be more susceptible to environmental attack and ultimately a reduced life span. As a result, considerable effort is currently being directed towards optimising the mechanical performance of fiber reinforced composites, and in particular their durability, through optimisation of the interfacial bond between the fibers and the polymer matrix (Motovalli et al 1999).
Another issue in relation to poor impact properties is due to the high concentration of fiber defects imparted to the fibers in many cases during the mechanically intensive harvesting and processing stages which must also be addressed for improved product performance.

The nature of the car industry (manufacturers, suppliers and legislation etc.) means it is necessary to look at the issue of these novel materials from a global perspective. However, this review covers developments of the global automotive industry predominantly. One of the most important sectors to have adopted natural fibers in recent years has been the European automotive.

A study conducted by Suddell et al (2003), states that in 1999 indicated that up to 20 kg of natural fibers could be used in each of the 53 million vehicles being produced globally each year. This means that for each new model of car there would be a requirement of between 1,000 and 3,000 tonnes of natural fibers per annum, with some 15,000 tonnes of flax being used in 1999 in the European automotive industry alone. To the natural fiber producer, the automotive market is attractive as a vehicle models platform life is for a minimum of 5 years but more realistically 7-8 years. This ensures a sustained period of demand for the natural fibers and helps to establish a period of credibility for the natural materials.

A study by Joseph et al (2000) projected the market possibilities for the use of short hemp and flax fibers in Europe. In this study, a survey of German flax and hemp producers showed that 45% of hemp fiber production went into automotive composites in 1999. One of the attractions of hemp, as compared with flax, is the ability to grow the crop without pesticide application. The potential for fiber yield is also higher with hemp. The type of natural fiber selected for manufacture is influenced by the proximity to the source of fiber, thus panels from India and Asia contain jute, ramie and kenaf,
panels produced in Europe tend to use flax or hemp fibers, panels from South America tend to use sisal, curaua, and ramie.

Ford uses from 5 to 13 kg (these weights include wool and cotton). The car manufacturer, BMW, has been using natural materials since the early 1990’s in the 3, 5 and 7 series models with up to 24kg of renewable materials being utilised. In 2001, BMW used 4,000 tonnes of Natural fibers in the 3 series alone. Here the combination is a 80% flax with 20% sisal blend for increased strength and impact resistance. The main application is in interior door linings and panelling. Wood fibers are also used to enclose the rear side of seat backrests and cotton fibers are utilised as a sound proofing material (Lewin et al 2000).

In 2000, Audi launched the A2 mid-range car which was the first mass-produced vehicle with an all-aluminium body. To supplement the weight reduction afforded by the all-aluminium body, door trim panels were made of polyurethane reinforced with a mixed flax/sisal mat. This resulted in extremely low mass per unit volume and the panels also exhibited high dimensional stability.

Recently, in the last few years, Volvo has started to use Soya based foam fillings in their seats along with natural fibers. They have also produced a cellulose based cargo floor tray – replacing the traditional flax and polyester combination used previously which resulted in improved noise reduction.

Toyota has been using increasingly more natural fibers in their components since 1999 in the range of their vehicles such as in the Celsior, Brevis and Harrier. Kenaf fibers used in board production along with Polypropylene are the composite of choice for door trims, manufactured at Toyota’s Indonesian production facility. The interesting note in this case is that the three vehicle models mentioned above adopted the natural fiber
components within a relatively short time frame of 4 years for the three models. Toyota also claim to have manufactured the first mass produced 100% natural automotive product in the world back in May 2003 namely the RAUM spare tyre cover which is comprised of Kenaf fiber and Polylactic acid or PLA as it is commonly known. Lactic acid-based polymers (polylactides) are polyesters made from lactic acid, a compound found in both plants and animals.

German automotive manufacturers continue to lead the way, with Daimler-Chrysler for example, having a global natural bre initiative program that benefits third world nations by developing products made from indigenous agricultural materials.

The Mercedes-Benz Travego travel coach, is equipped with flax reinforced engine and transmission covers. This was the first use of natural fibers for standard exterior components in a production vehicle and represents a milestone in the application of natural fibers. Exterior components pose interesting issues for the manufacturers, as in these applications the components must function as a protective cover for the vehicle and as a result the component must be able to resist a more aggressive environment (as compared to the interior applications) being exposed to both weathering effects and also chipping caused by debris making contact with the external surface (Bledzki et al 2002).

Daimler-Chrysler made considerable investment in Research and Development in flax reinforced polyester composite for exterior or semi-exterior applications in recent years. A truck with flax-based, rather than glass-based, exterior skirting panels is now in production. Tests carried out by the Daimler-Chrysler Research Centre in Ulm, Germany, showed that these composite components stood up to impact without shattering into splinters, which is an important consideration in crash behaviour tests. They were also
dimensionally stable and weather-resistant (Piggot et al 1980). Daimler-Chrysler suppliers found that switching from using glass fibers to natural fibers resulted in no problems in terms of the production equipment being able to use the same tools and machines and importantly at no additional cost to the manufacturer. Daimler-Chrysler committed to producing a spare wheel well cover for the A-class vehicle in January 2002, this came into being in January 2005. The cover incorporates Abaca fibers in the exterior application of an under floor cover. It won the JEC award for innovation in May 2005 and also the Daimler Chrysler Environmental leadership award in November of the same year. The goals of the project were to create a functional safeguard component with equal characteristics to those of glass fiber products. The component also had to meet stringent test procedures which included – water crossing, kerbstone contact, shaking routes, heat, rock slides, and acoustic tests.

The benefits realised in the Travego coach include a weight reduction in the engine transmission cover of 10% and a cost reduction of 5% over traditional materials. Fibers were typically purchased in 2002 for about 0.5-0.6 Euros/kg. This compares with approximately 1.5 Euros/kg for glass fiber rovings used in standard composite reinforcements. Natural fibers also exhibit numerous other advantages which have been reported widely in the literature over synthetic fibers (Hill et al 1997).

Renewable materials such as Hemp, kenaf, Eco wool and Sisal have been utilised providing natural, biodegradable engineering materials. With the use of locally farmed Hemp (from East Anglia), the carbon miles to produce the Eco Elise are therefore reduced. Sustainable hemp technical fabrics have been used as the primary constituent in the high quality ‘A’ class composite body panels and spoiler. The hemp fiber has also been used in the manufacture of the lightweight lotus designed seats. The hemp material is
Sisal, a renewable crop, has been used for the carpets in the Eco Elise, as it is a tough, abrasion resistant material. The manufacturer stated that 30% of the car’s interior components were made from biobased materials. Brake pads interestingly are one of the key components in the race to develop greener transport, with 80 million sets used in the UK every year. Since the use of asbestos was phased out in the 1980s, most have been formulated using man-made aramid fibers. They also incorporate significant amounts of heavy metal compounds. Around 20,000 tonnes of dust containing these materials are discharged into the environment as the pads wear each year. Now research into eco-friendly brake pads, backed by the Sustainable Technologies Initiative, has shown how a switch to natural fibers such as hemp, which can be grown in the UK, could offer a more sustainable solution. Researchers demonstrated how renewable fibers could reduce the reliance on synthetic materials and allow heavy metal constituents to be replaced with safer alternatives. The outcome is expected to provide up-to-date solutions to the global transport industry and its friction material supply base. Commercial development is going ahead, initially for the railway industry. The main end users, EFI, are particularly interested in exploiting the use of hemp in train brakes.

Manufacturers wanted to remove the use of sintered metal brakes that result in heavy metals getting into the environment. Interest is also expected from operators of underground and metro lines because of health concerns over airborne brake dust particles in enclosed spaces. The natural materials could cut production costs by a significant margin. Aramid fiber costs 20-30 times more than hemp fiber and it stands out as by far the most expensive ingredient that goes to make up a brake pad.
The two most important factors now driving the use of natural fibers by the automotive industry are cost and weight, but ease of vehicle component recycling is also an ever-increasing consideration to meet the requirements of the end of life vehicle directive. When you consider that 10 million cars are scrapped in Europe each year (11 m in the US), and of those 96% are processed by shredder facilities, leaving 25% of the vehicles weight remaining as waste products in the form of plastics, fibers, foams, glass and rubber. The directive aims to ‘depollute’ all scrapped vehicles, avoid hazardous waste and reduce the amount of materials going to landfill sites to a maximum of 5% per car by 2015.

Figure 2.10 Application of natural fibers in automobiles, source Juska et al (2006)

The applications of the natural fibers in the automobile are clearly shown in Figure 2.10. The possibility of the use of natural fibers in
New environmental regulations and societal concern have triggered the search for new products and processes that are compatible to the environment. The incorporation of bio-resources in to composite materials can reduce further dependency of petroleum reserves. Limitations of present biopolymers are their high cost. Again renewable resource based bio-plastics are currently being developed and need to be researched more to overcome the performance limitations. Bio-composites can supplement and eventually replace petroleum based composite materials in several applications thus offering new agricultural, environmental, manufacturing and consumer benefits.

2.12 INFLUENCE OF NATURAL FIBERS AS REINFORCEMENT FOR AUTOMOTIVE THERMOPLASTIC COMPONENTS

Sannadi et al (1994) had discussed, particularly with respect to the thermal stability, the properties of glass fibers and natural fibers differing significantly. By reason of their natural origin, plant fibers respond to thermal impact by far more labile than synthetic fibers. For natural fibers thermal degradation processes commence at temperatures as low as 120°C, resulting in a decomposition of waxes. Temperatures around 180°C lead to a decomposition of pectin, temperatures of approximately 230°C have the consequence of a decomposition of cellulose.

This obviously leads to the consumption that even transient thermal impact must result in a non-reversible reduction of fiber strength, inevitably affecting the mechanical properties of the later composite. However, to ensure sufficient flow capabilities of the binder component throughout the molding process, temperatures of at least the stated magnitude are required. As
mentioned previously, polypropylene as the most commonly used thermoplastic binder component for natural fiber composites requires processing temperatures of 200 to 250°C to achieve a sufficient low viscosity. Determining the parameters for a new production process, therefore, requires a consideration of both ensuring the general process ability on one hand and avoiding thermal damage of the fiber component on the other. Results suggest that agro based fibers are viable alternative to inorganic/material based reinforcing fibers in commodity fiber thermoplastic composite materials. Among other natural fibers, kenaf–pp provides excellent tensile and flexural properties.

Milewski et al (1992) have done an excellent review on short and long fiber composites covering a variety of reasons associated with long and short fibers influence in composite preparations. The long fibers, influence in fiber orientation, fiber length distribution and fiber matrix adhesion. The efficiency of the composite also depends on the amount of stress transferred from matrix to fibers.

The studies carried out by Mamalis et al (1997) tend to relate the energy absorption capability of an FRP to the individual properties of its constituent fibers and matrix. It was proposed that energy absorption is substantially dependent on the relative (rather than the absolute) properties of the fibers and matrix. In particular, the relative values of fiber and matrix strain significantly affect energy absorption. It is suggested that the maximum energy absorption from an FRP, a matrix material with a higher failure strain than the fiber reinforcement should be used to achieve maximum energy. The orientation of the fibers in a given layer and the relative orientation of successive layers within a laminate, can significantly affect a component’s mechanical properties.
Farag et al (1997) presented two quantitative methods of materials substitution. The first method (performance/cost) allows the designer to either look for a substitute material of similar performance at a lower cost or for a material with better performance but at a higher cost. The second method (compound objective function) allows the designer to develop different substitution scenarios based on the relative weights allocated to the different performance requirements. Using the two methods to be examined the case of material substitution for interior motorcar panels yielded consistent results. Composites of polypropylene reinforced with 40% hemp or flax fibers rank highest when cost is important, while wood and cork rank highest when aesthetics and comfort are emphasized. These results are consistent with the current trends in industry.

Sujit et al (2001) conducted a study with regard to the assessment of the current viability of composites in automotive applications which is based on the very limited cost information currently available. The specific cost estimate provided for a given manufacturing technology should not be generalized for that technology. Each cost estimate is based on many underlying assumptions, both technical and economic; the degree of overall cost sensitivity to these assumptions will vary across different technologies. The use of different sources of information also poses a problem in the consistency of input assumptions made for the cost estimation. The information drawn from various sources in the literature and used in this assessment does not allow one-to-one comparison among various manufacturing technologies for a part application; it does, however, allow one to assess general, qualitative trends and to identify major barriers to the economic viability of composite technology.

Mamalis et al (1997) tend to relate the energy absorption capability of an FRP to the individual properties of its constituent fibers and matrix. It
was proposed that energy absorption is substantially dependent on the relative (rather than the absolute) properties of the fibers and matrix. In particularly, the relative values of fiber and matrix strain significantly affect energy absorption. It is suggested that the maximum energy absorption from an FRP, a matrix material with a higher failure strain than the fiber reinforcement should be used to achieve maximum energy. The orientation of the fibers in a given layer, and the relative orientation of successive layers within a laminate, can significantly affect a component’s mechanical properties.

Tests conducted by Farely et al (1983) showed that on comparable specimens, natural fiber reinforced tubes absorb higher energy than those of glass or aramid fibers. The reasons for this related to the physical properties of fiber, overall failure mechanisms, and fiber-matrix bond strengths. He concluded that the static crushing tests were conducted on graphite reinforced composite tubes to study the effects of fiber and matrix strain failure on energy absorption. To obtain the maximum energy absorption from a particular fiber could be obtained when the matrix material in the composite must have a greater strain at failure than the fiber.

Malkapuram et al (2008), have published their work on deformation and failure of polypropylene composites reinforced with lingo cellulosic fibers. In their work they found that polypropylene /wood composites were prepared from two lingo cellulosic fibers with different particle size and aspect ratio in order to determine the effect these factors on the deformation and failure mechanism. Wood content was changed from to 0 to 80 wt% alienated polypropylene was added to improve interfacial adhesion. The map/wood ratio was kept contrast at 0.1. Mechanical properties were determined by tensile testing. Micro mechanical deformations process was followed by acoustic emission and volume strain measurements. The
results proved that micromechanical deformations change drastically both with decreasing particle size and changing interfacial adhesion.

Nabi Saheb et al (1999) studied the mechanical properties of the fibers extracted from the kenaf and compared the results with those of the other known natural fiber coir. Further these Areca fibers were chemically treated and the effect of this treatment on fiber strength was studied. Areca fiber composite laminates were prepared with randomly distributed fibers in Maize stalk fine fiber and Phenol Formaldehyde. Composite laminates were prepared with different proportions of phenol formaldehyde and fibers. Tensile test, moisture absorption test, and biodegradable tests on these laminates were carried out. Properties of these areca-reinforced phenol formaldehyde composite laminates were analyzed and reported.

Shinji Ochi et al (2008) identified the various fiber volume fractions of kenaf fiber composites and compared with samples containing an equivalent fiber volume fraction of chopped strand mat E-glass fiber reinforcement. Post-impact damage was assessed using Scanning Electron Microscopy (SEM). The experiment results showed a significant improvement in load bearing capability and impact energy absorption was found in the hemp fiber as reinforcement.

The study by Lee et al (2009) on MAPP deals with the composites with Polypropylene (PP) and 2 wt% NaOH treated jute fibers were prepared by the injection molding technique. In order to improve the affinity and adhesion between the reinforced jute fiber and the polymer matrix (polypropylene) during manufacturing, Maleic Anhydride Grafted Polypropylene (MAPP) as a coupling agent was employed. Tensile tests were carried out to evaluate the composite mechanical properties. The tensile test results showed the composite to have higher strength and modulus than pure Polypropylene (PP). In addition; strength and modulus were found to be
influenced by the variation of MAPP contents (1%, 2%, and 3%). The tensile strengths were improved by 19.3%, 21.7%, and 23.8%, respectively, compared with the raw PP. The tensile moduli were improved by 110.7%, 122.7%, and 148%, respectively, compared with the raw PP.

A great deal of work has been reported in the literature of Holbery et al (2006) which discusses the mechanical behaviour of fiber reinforced polymer composites. From the above literature we can learn that the natural fiber reinforced polymer composites have better mechanical strength compared to virgin polymer and glass fibers reinforced polymer composites. The compatibilizer MAPP acts as a good coupling agent for increasing the strength and gives a better result at 5%.

Li and Tabil (2009) determined the appropriate value of injection temperature and pressure for natural fiber thermoplastic bio composites. These results showed that higher fiber content in composite led to higher mechanical strength and also the fibers could withstand the temperature up to 200°C during injection molding.

The study by Saheb et al (1999) revealed that the proper alkali treatment of the fiber led to reduce the water absorption of the natural fibers and could be used in automobile components. Similarly the fiber lengths present in the composite depended on the type of compounding and moulding equipment used.

Broge et al (2000) discussed that the Semi structural components could be manufactured by natural fiber reinforced thermoplastics since the mass of the composites were less in weight compared to glass fiber composites and could lower the energy needed for production by 80%.
Matsuda et al (2006) developed a hybrid natural fiber reinforced thermoplastic composite for bumper beam and discussed the mechanical, thermal and recycling properties with LFRT and concluded that the natural fibers could be used in structural components.

Davoodi et al(2008) focused their attention on the mechanical properties of the hybrid kenaf epoxy composite for utilisation in passenger car bumper beam. The comparison charts shows some mechanical properties having more advantage with common bumper beam material GMT.

Xinto Cui et al (2008) reported a new method for designing lightweight automotive body assemblies using multi-material construction with low cost penalty. Current constructions of automotive structures are based on single type of materials, e.g., steel or aluminum. The principle of the multi-material construction concept is that proper materials are selected for their intended functions. The design problem is formulated as a multi-objective nonlinear mathematical programming problem involving both discrete and continuous variables. The discrete variables in this study explained the material types and continuous variables such as the thicknesses of the panels. This problem was then solved using a multi-objective genetic algorithm. An artificial neural network was employed to approximate the constraint functions and reduce the number of finite element runs.

Ramakrishna and Hamada (1998) concluded that the composites absorb more energy than steel or aluminum. Steel has higher Young’s modulus, yet fails to absorb higher energy. In composites, there are different kinds of fibers having different stiffness. For instance, carbon fibers are stronger than glass, yet glass withstand load for a longer time than carbon fibers. The energy absorption capability and crashworthiness of the composites in the above study were found to be good or even better than those of steel and aluminium of the vehicle structures.
2.13 EFFECT OF PP MATRIX WITH NATURAL FIBERS

PP, also known as poly-propane, is a thermoplastic polymer used in a wide variety of applications including packaging and labeling, textiles (e.g., ropes, thermal underwear and carpets), stationery, plastic parts and reusable containers of various types, laboratory equipment, loudspeakers, automotive components, and polymer banknotes. An addition polymer made from the monomer propylene, it is rugged and unusually resistant to many chemical solvents, bases and acids.

In 2008, the global market for polypropylene had a volume of 55.1 million metric tons, which led to a turnover of about $65 billion (Isamu Terasawa et al. 2007).

- Most commercial polypropylene is isotactic and has an intermediate level of crystalline between that of Low-Density Polyethylene (LDPE) and High-Density Polyethylene (HDPE). Polypropylene is normally tough and flexible, especially when copolymerized with ethylene. This allows polypropylene to be used as an engineering plastic, competing with materials such as ABS.

- Polypropylene is reasonably economical, and can be made translucent when uncolored but is not as readily made transparent as polystyrene, acrylic, or certain other plastics.

- It is often opaque or colored using pigments.
- Polypropylene has good resistance to fatigue.

- The melting point of polypropylene occurs at a range, so a melting point is determined by finding the highest temperature of a differential scanning calorimetry chart. Perfectly isotactic PP has a melting point of 171 °C (550 °F). Commercial isotactic PP has a melting point that ranges from 160 to 166 °C (520 to 551 °F), depending on atactic material and crystallinity. Syndiotactic PP with a crystallinity of 50% has a melting point of 150 °C (266 °F).

- The Melt Flow Rate (MFR) or melt Flow Index (MFI) is a measure of molecular weight of polypropylene. The measure helps to determine how easily the molten raw material will flow during processing. Polypropylene with higher MFR will fill the plastic mould more easily during the injection or blow-moulding production process. As the melt flow increases, however, some physical properties, like impact strength, will decrease (Riedel et al 1990).

For external applications, UV-absorbing additives must be used. Carbon black also provides some protection from UV attack. The polymer can also be oxidized at high temperatures, a common problem during moulding operations. Anti-oxidants are normally added to prevent polymer degradation.

Most polypropylene used is highly crystalline and geometrically regular (i.e. Isotactic) opposite to amorphous thermoplastics, such as polystyrene, PVC, polyamide, etc., which radicals are placed randomly (i.e. atactic). It is said that PP has an intermediate level of crystallinity between
LDPE and HDPE; On the other hand PP has higher working temperatures and tensile strength than polyethylene. Because PP is low in cost but has outstanding mechanical properties and moldability, it accounts for more than half of all the plastic materials used in automobiles. PP compounds are used for a variety of parts, including bumper facias, instrumental panels and door trims. Several grades of PP compounds, with their diverse performance characteristics, have been developed by compounding PP with various other materials according to the performance requirements of the intended parts. The impact strength of the “impact PP,” which is composed of homo PP and Ethylene Propylene copolymer (EP), is improved by adding an ethylene-based elastomer such as ethylene-butene or ethylene-octene copolymer, to which inorganic filler such as talcum is added for enhanced rigidity (Yokoi et al 2008).

Polypropylene is an economical material that offers a combination of outstanding physical, chemical, mechanical, thermal and electrical properties not found in any other thermoplastic. Compared to low or high density polyethylene, it has a lower impact strength, but superior working temperature and tensile strength. Polypropylene possesses excellent resistance to organic solvents, degreasing agents and electrolytic attack. It has a lower impact strength, but its working temperatures and tensile strength are superior to low or high density polyethylene. It is light in weight, resistant to staining, and has a low moisture absorption rate. This is a tough, heat-resistant, semi-rigid material, ideal for the transfer of hot liquids or gases. It is recommended for vacuum systems and where higher heats and pressures are encountered. It has excellent resistance to acids and alkalis, but poor aromatic, aliphatic and chlorinated solvent resistance. Table 2.3 shows the filler materials
recommended for pp compounds. Its clear that the natural fibers also used as a filler for pp (Lau et al 2006).

**Table 2.3 Recommended filler for PP (source Lau et al 2006)**

<table>
<thead>
<tr>
<th>Inorganic Compound</th>
<th>Oxide</th>
<th>Hydroxide</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Silica, Titanium oxide, Magnesium oxide, antimony oxide</td>
<td>Aluminun hydroxide, Magnesium hydroxide, Calcium hydroxide</td>
</tr>
<tr>
<td>Carbonate</td>
<td>Calcium carbonate, Dolomite</td>
<td>Talcum, Clay, Mica, Glass filler.</td>
</tr>
<tr>
<td>Sulfate</td>
<td>Basic magnesium sulfate</td>
<td>Glass balloon, Glass beads, Calcium silicate, Montmorillonite, Bentonite</td>
</tr>
<tr>
<td>Silicate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carton</td>
<td>Carton black, Graphite, Carbon fiber</td>
<td>Wood poseer, jute, kenaf fiber, Hemp fiber, Nyron Fier, Aromatic polymide fiber</td>
</tr>
</tbody>
</table>

2.14 **PROPERTIES OF POLYPROPYLENE**

- Has excellent resistance to stress and high resistant to cracking (i.e. it has high tensile and compressive strength)
- Withstands High operational temperatures with a melting point of 160°C
- Has excellent dielectric properties
- It is highly resistant to most alkalis and acid, organic solvents, degreasing agents and electrolytic attack. On the contrary is less resistant to aromatic, aliphatic and chlorinated solvents and UV.
- Is Non-toxic
2.15 COMPATIBILIZER USED FOR IMPROVING IMPACT STRENGTH IN THERMOPLASTICS

Sanadi et al (2000) reports that maleic anhydride polypropylene copolymer (MA-g-PP) was used as a compatibilizer to increase the compatibility between the PP matrix. In order to improve the affinity and adhesion between the reinforced jute fiber and the polymer matrix (polypropylene) during manufacturing, maleic anhydride grafted polypropylene (MAPP) as a coupling agent was employed.

The maleated coupler acts as an intermediate to chemically connect the polar nature of the fiber and non-polar nature of the polyolefin polymer resin. Furthermore, the decrease in viscosity of the resin which results from the melting point reduction by the MAPP, leads to an increase of contact area with the fiber interface. The improvement of the PP composite blend of the maleated coupler with the long fibers mat in conjunction with the change of physical parameters in the thermoplastic resin has been discussed. MAPP mixture has a very strong relationship with the tensile and flexural strength and modulus. The molecular formula for MAPP is C₄H₂O₃ and its appearances are like white crystals, and it is soluble in water.

Klason and Kubat (1986) in general dispersing agents and/or coupling agents, are necessary for property enhancement when fibers are
incorporated in thermoplastics. Grafting chemical species on the fiber surface has also been reported to improve the interaction between the fibers and matrix. Although grafting can improve the properties of the composite to a significant extent, this process increases the material cost of system. The use of dispersing agents and/or coupling agents is a cheaper route to improve properties and makes more practical sense for high volume, low cost composite systems. In general, cellulosic fillers or fibers have a higher Young's modulus as compared to commodity thermoplastics thereby contributing to the higher stiffness of the composites. The increase in the Young's modulus with the addition of cellulosics depends on many factors such as the amount of fibers used, the orientation of the fibers, the interaction and adhesion between the matrix, the ratio of the fiber to matrix Young's modulus, etc. The Young's modulus of the composite can be crudely estimated through the simple rule of mixtures and other simple models.

Hull et al (1981) discussed the use of dispersing or coupling agents that can change the molecular morphology of the polymer chains both at the fiber-polymer interphase and also in the bulk matrix phase. Crystallites have much higher moduli as compared to the amorphous regions and can increase the modulus contribution of the polymer matrix to the composite modulus. A good understanding of the effect of dispersing and coupling agents on trans crystallinity at the fiber-matrix interphase and the corresponding effect on the composite Young's modulus is non-existent.

2.16 FINITE ELEMENT ANALYSIS OF BUMPER BEAM TESTING

In fact, the automotive industry deals with a large variety of crash situations. The wide variety of accidents makes it desirable to consider them in groups with basic similarities. However, in practice exactly similar accidents might rarely occur. Figure 2.11 shows that the largest proportion of
accidents, about 60%, occurs at the front of the vehicle and of these frontal impacts are the most commonly seen accidental situations on roads, and they also give rise to the highest portion of deaths (Frank and Gruber 1992).

Oblique or side collisions are less frequent and serious in their effects, and rear impacts and “roll-overs” are relatively rare. Research has therefore concentrated mainly on front and side impacts, the former of which can be considered as the “typical” serious accident (Reid et al 1996).

In a frontal or rear crash, the bumper beam is the primary component which undergoes damage and transfers the forces to the rest of the structure. Thus, the modern bumper beam systems should play a key part in the safety concept of an automobile, ensuring that minimal accelerations are transferred to the passenger. Further the automotive producers are demanding for robust bumper beam systems showing good and reproducible impact behaviour.

Figure 2.11  Distribution of real-world severe passenger car accidents by type of collision (Frank and Gruber 1992)
Manufacturing of bumper beams from aluminium extrusions often involve series of forming operations performed in the soft W-temper condition, and then artificial age-hardening of the components to the material’s peak hardness condition. Thus it is clear that for proper crash performance of the systems the FE-model must rely upon the geometry obtained from a simulation of the process route, i.e. including simulation of all major forming operations. Moreover, the forming operations also results in an inhomogeneous evolution of some internal variable (among others the effective plastic strain) within the shaped components.

Reyes et al (2004) showed that plastic straining in W-temper results in significant change of the T6 work hardening curves. However, in industrial product development process effects on material are not included. Instead the homogeneous material properties of the final temper in its virgin/unformed state would be used even though the process effects may play a prominent role for the system’s performance in a crash. Traditional industrial modelling procedures for the numerical analyses of bumper beam systems include the most widely used material models, i.e. MAT-24 and MAT-103, in LS-DYNA (Hallquist 1998 and 2003), but these models does not support any attempt at including process effects on the material. For the accuracy and robustness of the analyses in general it is, however, possible to include process effects in to the numerical analyses and to perform “process-based” crash simulation.

The industrially offered solutions are required to behave in a strictly controlled and robust manner in low to high velocity impacts and often the systems also include a crash box situated in between the bumper beam and the longitudinal. The idea with this system design is that the bumper beam system should yield a specific function within different velocity regimes. The legislation for requiring the use of bumpers to prevent damage
and ensure safety of passengers and auto parts such as the headlights, engine, fuel tank etc., is essential for the vehicle manufacturers.

Present laws dictate that a vehicle’s bumper withstands two types of impacts:

- Five miles per hour collision of a vehicle to which the test bumper is affixed, into a stationary barrier.

- Impact by a pendulum device moving at five miles per hour into a vehicle upon which the test bumper is affixed. (The pendulum shall have a mass equal to that of the vehicle upon which the bumper is mounted.)

- In this research the FEA simulation of the frontal impact is analyzed by LS DYNA as per FMVSS and IIHS Standards.

Automotive impact is a highly complex phenomenon involving large and unstable elastic-plastic deformations. In a crash, the crash energy is dissipated by extensive plastification of the structural elements that are used as energy absorbers. Usually crash events occur at higher strain-rates, thus consideration of viscous effects might also be crucial in the analyses. The aim of this chapter is to present the basics of elasto-plastic/visco-plastic constitutive modelling, including the effect of strain-rate and plastic instability mechanisms. Hence it is suitable to analyse the impact testing using LS DYNA.

Javad Marzbanrad et al (2009) studied the most important parameters including material, thickness, shape and impact condition for the design and analysis of an automotive front bumper beam to improve the crashworthiness design in low-velocity impact. The simulation of original bumper under condition impact was according to the low-speed standard of
automotives stated in E.C.E. United Nations Agreement, Regulation no. 42, 1994. The bumper beam analysis was accomplished for composite and aluminium material to compare the weight and impact behaviour. The strength in elastic mode was investigated with energy absorption and impact force in maximum deflection situation. Figure 2.12 shows the real picture of the impactor and bumper during testing.

![Figure 2.12 Impactor and bumper layout](image)

Figure 2.12 Impactor and bumper layout

Front bumper beam made of three materials aluminium, GMT, SMC was studied by impact modelling to determine the deflection, impact force, stress distribution and energy absorption behaviour. The mentioned characteristics were compared to each other to find the best one. The result showed that a modified SMC bumper beam could minimize the bumper beam deflection, impact force and stress distribution and also maximize the elastic strain energy.
Ramin Hosseinzadeh et al (2005) discussed the possibility of using a commercial front bumper beam made of Glass Mat Thermoplastic (GMT) during frontal collision. It is studied and characterized by impact modelling using LS-DYNA ANSYS 5.7 according to the E.C.E. United Nations Agreement, Regulation no. 42, 1994. Three main design factors for this structure: shape, material and impact conditions are studied and the results are compared with conventional metals like steel and aluminium. Finally the aforementioned factors are characterized by proposing a high strength SMC (sheet moulding compound) bumper instead of the current GMT.

Rimy et al (2006) in their paper have presented a study of the structure and material employed for car bumper in one of the national car manufacturer’s products. In this study, the most important variables like material and impact conditions were studied for analysis of the bumper beam in order to improve the crashworthiness during collision. The simulation of a bumper was characterized by impact modelling using Abaqus 6.9 according to the speed that is (48kmph) given in order to analyze the results. This speed was according to regulations of Federal Motor Safety Standards, FMVS 208-Occupants Crash Production where by the purpose and scope of these standard specified requirements to afford impact protection for passengers.

In this research, the three type of materials that are relevant to be applied to the front bumper beam were selected. The material consisted of Expanded Polypropylene (EPP), GMT and Sheet Metal Compound (SMC). These materials were studied by impact modelling to determine the displacement, velocity, impact force and stress. The selected materials were compared to each other to find the best material with highest material strength and structure.

Simulation using Finite Element Analysis software, which is ABAQUS, was conducted. These results showed that a SMC bumper could
reduce the impact of collision with higher performance and was suggested to replace other material. The duration taken for SMC to deflect the impact was the shortest compared to other material.

Cheon et al (1995) discussed in their paper steps to meet the safety requirements and to reduce the component weight. It was necessary that destructive tests for new bumper system were to be performed. It is very expensive and time consuming. Therefore the economical design and analysis of the bumper system using finite element method using computer simulation is used. The analysis has been performed for center-center pendulum and barrier impact of bumper system of thermoplastic material under process of injection molding. Also, the results are compared with test results to evaluate the property of analysis procedure.

Glance et al (1984) presented a design and analysis procedure for thermoplastic automotive bumper program. The procedure was built around a general purpose finite element program. The design procedure used a simplified dynamic model of the bumper system and a detailed non-linear static model of the thermoplastic bumper beam. Design improvements determined by the procedure for center-center hits were evaluated on a pendulum test stand.

Sapuan et al (1999) have applied a conceptual design approach to the development of polymeric based composite automotive bumper system. Various methods of creativity such as mind mapping, product design specifications, brainstorming, morphology chart, analogy, and weighted objective methods were employed for the development of composite bumper fascia and for the selection of materials for bumper system. The evaluation of conceptual design for bumper fascia is carried out using weighted objective method and highest utility value appeared to be the best design concept. Polymer-based composites are the best materials for bumper fascia, which
are aesthetically pleasant, lighter weight and offer many more advantages that are substantial.

Nimmer et al (1987) in their paper “Beamless bumper system” proposed for small passenger cars to answer today’s important issue that automotive society is facing with: Cost reduction, fuel economy, and recyclability. The innovative aspect of the system is to utilize the Expanded Polypropylene (EPP) as an energy absorber and eliminate the entire metal beam from the bumper system. The system is a semi-module one that consists of a fascia, an EPP energy absorber, and brackets for assembly to the body. This semi-module system reduces the number of parts used for the bumper system, which helps cost reduction and improves productivity. The elimination of main beam results in weight reduction and better fuel efficiency, while maintain the key performance criteria. The use of EPP improves the recyclability of the system.

Hosseinzadeh et al (2004) have designed different types of the bumpers for reducing the weight of passenger cars by using composite structures. Bumpers have three main parts that include fascia, beam and absorber. Bumper beams have been designed using different materials such as aluminum, steel, different types of fibers, thermoplastic and thermoset resins, Plastic Engineered Products (PEP) etc., and manufacturing methods such as SMC, press for metal shaping, GMT and was characterized by FEM modelling in accordance with the low velocity impact standards. Conventional materials (steel and aluminum) showed inappropriate characteristics such as structural failure and weight increase at the time their specifications were assigned to the model.

GMT as the original material of the bumper was studied and the basic shape factors such as strengthening ribs, showed their effects in stabilization and rigidity of the structure. To offer a more suitable material at
lower cost and easier production, high strength SMC composite was proposed to replace GMT and the ribs of the structure were all removed. The structure showed very good impact behavior compared with other structures, which all failed and showed manufacturing difficulties due to strengthening ribs or weight increase due to use of more dense materials.

Ping et al (2002) have developed a preliminary version of an Evolutionary Modelling Approach (EMA), which targeted at reducing the cost of surrogate model construction process, for the applications that involve highly non-linear underlying mapping relationship over a large design space. Surrogate modelling method was optimized by orthogonal arrays that are used to simulate system behavior in Taguchi’s parameter and robust design. The EMA generated surrogate models for an automotive bumper system validated by the FEA and physical test data, demonstrated better prediction accuracy than the existing simplified simulation while they entailed much lower computational cost compared to FEA. Ford Taurus bumper was a roll-formed beam and foam system with a “B” beam cross-section. After a list of important design and performance parameters for a steel bumper system was generated.

Design of Experiments (DOE) was performed; it is a feasible method for an initial data selection in overall design space, particularly where a large number of design and performance parameters are involved and their value ranges are relatively bigger. Several application cases have been conducted in order to study the interplay between various DOE strategies and aims. They believe that Applications to various engineering domains beyond automotive bumper system will have been needed for testing and adapting EMA as an integrated part of industrial design decision support system.

Yan Zhang et al (2006) have investigated the shallow shell theory, the expression of dent resistance stiffness of double curvatures shallow shell
was obtained under the concentrated load condition. Lightweight and crashworthiness are two important aspects of auto-body design. The critical loads resulting in the local trivial dent in the center of the shallow shell were regarded as the important index for the lightweight of the automobile parts. The crashworthiness simulation of the lightweight part proved the validity of the light weighting process.

The deformation history of bumper using new material was achieved after the car crash is re-simulated with updated part thickness. By simulation, the deformations of bumper made of two different kinds of material were similar in that plastic hinge and tensional plastic deformation appear in the middle part of bumper. This rule was applied to the lightweight design of the bumper system by using high strength steel instead of mild steel. From the small difference in the energy absorption between two materials is i.e., about 4.1% for beam of the bumper, from the conclusion that can be drawn is that it is feasible to reduce the thickness of the bumper panel based on the dent resistance evaluation index.

2.17 SUMMARY

This chapter has presented an introduction to LFRT, a fiber reinforced polypropylene matrix composite material, summarising current applications and material property information available in the public domain. Hot impregnation process technique has been introduced and a processing window has been defined based on the work by Lafranche et al(2007). General testing of composites for characterisation and specifically the mechanical performance of natural fibers used for reinforcements has also been discussed. Furthermore, a range of tests has been identified as suitable for acquisition of the material properties required in this study. A review of current structural applications of composite materials in the automotive industry has also been performed. Areas where composites
potentially offer an alternative to metallic structures have been discussed. Frontal impact protection has been identified as a suitable application for the candidate material in this study.

The following three areas have therefore been identified for detailed review:

1. The application of damage modelling techniques to long glass fiber reinforced polypropylene matrix composites.

2. The use of the natural fiber materials in automotive composites and the development of bio composites, which provide an alternative to the glass fibers to improve the mechanical and recycling properties.

3. The application of finite element modelling for the bumper beam for the frontal impact test as per FMVSS. The tests were performed for various parameters like shape, material, and design for obtaining better results. The analysis was done using the LS DYNA software techniques to the design of such components.