

# The growing competition and innovation engineering essay

[Engineering](#)



**ASSIGN  
BUSTER**

## **Abstract**

This paper addresses the suitability of composite leaf springs on vehicles and their advantages. In early years, efforts have been made to reduce the cost of composite leaf spring to that of steel leaf spring. From the research, it has shown that the composite can be a very replacement material for conventional steel due to the achievement of their weight reduction with acceptable improvement of mechanical properties. Also, the materials and manufacturing processes are selected based on their strength factor. A suitable design method is selected and optimised. From the study, it can be seen that composite leaf springs are superior and more economical than conventional leaf springs. It is evident that after an extended use of conventional steel springs, its strength gradually reduces, and eventually the vehicle starts moving back side down, hitting on the chassis. This problem can be completely removed by this special purpose composite leaf springs.

## **CHAPTER 1**

### **INTRODUCTION**

#### **General Background**

The growing competition and innovation in the automobile industry aims at modifying existing products or replacing old products by the introduction of new and advanced material products. In the present scenario, weight reduction has been the main focus for the automobile manufactures. The suspension leaf spring is one of the dormant parts for weight reduction in automobiles as it accounts for ten to twenty percent of the unsprung weight, which is considered to be mass not supported by the leaf spring. The

innovations have been regularly implemented on the suspension system of a vehicle and efforts have been taken to ensure the comfort of the user. The manufacturing of leaf springs should aim to provide for certain necessities such as appropriate balance of comfort riding and economy. They should also absorb the vertical vibrations and collisions that can happen due to the unevenness of the road by means of vibrations in the spring. This energy is absorbed, stored in spring as strain energy and then released slowly. Hence, strain energy of material becomes an important property to be considered. The relationship of the specific strain energy is discussed further in the paper. The introduction of composite materials for the leaf springs have resulted in the weight reduction without reducing any load carrying capacity. Thus steel leaf springs are being replaced by composite leaf springs and discussed in this paper. A composite material is a mixture of two or more materials that produces a combined effect so that they produce cumulative properties that are different from any of its constituents achieving independently. The resultant has superior structural properties to either of constituent alone and mainly result from the load sharing mechanism. This is being specifically done to accomplish different design, manufacturing and other service advantages of products. Composites are not only used for structural properties but also for their thermal, electrical, tribological and environmental applications. Thus they usually have a fibre or a particle phase that is stiffer and stronger than continuous matrix phase. Fatigue failure is the most important failure mode of many automobile components. These components can be subjected to various fatigue loads such as shocks due to uneven roads traced by road wheels or the sudden loads due to

wheels over the bumps etc. The leaf springs are the most affected by these fatigue loads and the fatigue behaviour of the composites have been studied and selected suitably. From those products, leaf spring is the primary focus of this research, for which researchers are trying to get the best composite material meeting the specific requirement of strength and weight reduction to replace the existing steel leaf spring. Researches has been done and reviewed depicting the background of this paper. FIGURE NEEDED NOT THIS ONEC: UsersASWINDesktopleaf spring. gif

## **Motivation For Current Research**

There has been innovations and increasing interest in replacement of steel leaf springs with fibre glass reinforced polymers in the automobile sector. By the introduction of composite materials for the leaf springs, the weight of the steel leaf springs can be reduced. The fatigue life of the spring can also be increased. The stiffness of the leaf spring can be increased.

## **Past Work**

The Inland Division of General Motors (GM), which had become part of the supplier Delphi Corp., first investigated into composite leaf spring development in 1963. This company had developed over 150 quarter and semi elliptical springs running over four years. This research had displayed the material's advantages but the inability to strengthen the suitable market had eventually ceased the development. In 1977, the company re-investigated the programme due to industry's interest in fuel economy and mass production. From the series of experimentation with a variety of reinforcement and resins, a material combining epoxy resin and

unidirectional fibreglass had been found meeting market requirements and Delphi Corp. named the material as Liteflex™. The important characteristic of the material is their high elastic strain properties that made them ideal for use as a spring. Fig: A first rear transverse composite spring on 1988 Corvette. The process involved filament winding resin-impregnated fibreglass rovings over an open mould and curing was done by compression moulding at high temperatures. After moulding, machining has been done to attach the brackets/cushions to the spring to a suspension system. Delphi Corp. introduced Liteflex as a rear suspension composite spring for the 1981 Corvette. This mono leaf transverse spring weighing 3.6 kg replaced ten-leaf steel spring (19kg) thereby reducing the mass to about 80%. Eventually by 1984, the new Corvette models were introduced with Liteflex composite springs on both front and rear suspensions. Their applications progressively grew on trucks with GM's Astro Van in the following year using longitudinal configuration. Finally, these composite springs were put on rear suspensions of front-wheel drive luxury passenger cars in a constant width, transverse mounted configuration. The annual production rate of these composite springs had surpassed 1 million parts by 1989. C: UsersASWINDesktoppastw2. jpg

Fig: Filament winding resin-impregnated fibreglass rovings over an open mould

## Recent Work

Recently, Henkel AG & Co. KGaA (Dusseldorf, Germany), a specialist expertise in polyurethane chemistry has made it possible to mass produce the lightweight, fibre reinforced composite springs by collaborating with Benteler SGL Composite Technology GmbH (Ried im Innkreis, Austria), one of

the leading manufacturers of composite components for automotive applications based on polyurethane matrix resin using a specially developed resin transfer molding (RTM) process. These composite leaf springs are expected to be 65 percent lighter than the conventional steel leaf springs. With Loctite MAX 2, Henkel offers a polyurethane based composite matrix resin, which is said to cure considerably faster than any epoxy products, used for the RTM process. This polyurethane resin has a lower viscosity that makes them to penetrate and impregnate the fibre material more easily and with less displacement, thereby enabling shorter injection times. It also has a high stress intensity factor and this measure of toughness has a superior effect on fatigue loads. The use of such flexible material with higher fatigue tolerance can prolong the component life as these leaf springs are subjected to dynamic loading while the automobile is running. Resin transfer molding process have succeeded in the manufacture of such composites for mass production of automobiles as the curing reaction can be controlled more reliably by either temperature adjustment or addition of an accelerometer. During curing process, overheating and the resulting shrinkage is also reduced as the polyurethane generates only less overall heat as compared to other epoxy resins. This process also enables fast curing of the matrix resin as it permits shorter cycle times thus making it attractive for volume production of automobiles. Fig: 1. 2. Fibre-Reinforced Leaf springs Based on Polyurethane matrix resin

## **Research Hypothesis and Objectives**

The principal objective of the project is to design and optimize the mono composite leaf spring for the same load carrying capacity and stiffness like

<https://assignbuster.com/the-growing-competition-and-innovation-engineering-essay/>

that of a multi leaf steel spring. This will explore a number of developments like: Reduction of weight of the leaf spring without reducing any load carrying capacity and stiffness. Increase in fatigue life of the spring. Composite leaf spring is lighter and more economical than conventional leaf spring with similar design specifications. Composite leaf springs has lower stresses compared to steel spring. All of the above will result in fuel savings which will eventually make the country energy independent as fuel saved is fuel produced. The overall idea of the research is to carry out fabrication and testing of a mono composite leaf spring with actual design considerations and loading conditions and compare it with the existing conventional steel leaf springs.

## **Dissertation Outline**

The layout of the dissertation is as follows: Chapter 1 gives an introductory explanation on Composites and existing leaf springs, Motivation for doing this dissertation, works done on it and its aims and objectives. Chapter 2 contains literature data on the innovation and methodology used. Chapter 3 contains Fabrication and Test AnalysisChapter 4 contains Results and Discussions

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2. 1. Summary**

In view of the objectives outlined in the Chapter 1, background literature relevant to this study can be classified into topics as follows: Suspension SystemMaterialsManufacturing ProcessesProgramme Methodology

## 2. 2. Preliminaries

To achieve the (for the design, analysis, what are the constants, constraints)??????

## 2. 3. Suspension System

The ability to absorb and store more amount of energy facilitates the comfortable operation of a suspension system. While using steel leaf springs, there is a problem with its heavy weight and this can be rectified by introducing a composite material instead of steel which is normally used in the conventional leaf springs. The springs are designed to absorb and store energy and then release it. Therefore, the strain energy of the materials becomes a prominent factor for the design of springs. The relationship of the specific strain energy can be expressed as follows: Where,

,

It can be observed that the specific strain energy is inversely proportional to density and Young's modulus. This means that lower the density and the modulus, greater the specific strain energy capacity. Hence, this makes the composite material a suitable choice for leaf spring applications. C:

UsersASWINDesktopspecific strain enrgy. gifFig: Specific strain energies of the spring materialsThe objectives of the suspension system are to prevent the road shocks/vibrations from being transmitted to the automobile components and to maintain the stability of the automobile in pitting/rolling while in motion.



## 2. 4. Materials

M. N. Rittner, " Metal Matrix Composites in the 21st Century: Markets and Opportunities," Report GB-108R, Business Communications Co., Inc., Norwalk, CT, 2000J. R. Davis, Ed., Metals Handbook Desk Edition, 2nd ed., ASM International, 1998, p 674-680High Performance Composites Source Book 2001, Ray Publishing, www. hpcomposites. comT. Saito, A Cost-Effective P/M Titanium Matrix Composite for Automobile Use, Adv. Perform. Mater. Vol 2, 1995, p 121-144Composites are commonly classified into two categories. The first category is based with respect to the matrix constituent. These include organic-matrix composites (OMCs), metal-matrix composites (MMCs) and ceramic-matrix composites (CMCs). The organic-matrix composites are further sub-divided into polymer-matrix composites (PMCs) and carbon-matrix composites (CMCs). These carbon-matrix composites are generally formed by carbonizing and densifying the original polymer matrix. In each of these categories, the matrix is a continuous phase throughout the component. The second classification is based on the reinforcement form such as particulate reinforcements, whisker reinforcements, continuous fibre laminated composites and woven composites including braided and knitted fibres which are depicted in the Fig 1. 1 below. There must be a considerable volume fraction of 10 % or more of reinforcement in order to provide for a useful increase in the properties. This reinforcement refers to a particle if all the dimensions are roughly equal. C: UsersASWINDesktopi0020910. pngFig 1. 1: Common forms of fibre reinforcement Source [1][1] Carl Zweben, Composite Materials and Mechanical Design, Mechanical Engineer's Handbook, 2nd ed., Myer Kutz, Ed., John Wiley & Sons, Inc., New York, 1998.

## **2. 4. 1. General Characteristics**

The composites are the engineered materials that is designed to provide high specific stiffness, specific strength and higher structural efficiency in overall. This strength and stiffness are provided by the high strength and high modulus reinforcements in composite materials. Their magnitude can be controlled by changing either the fraction of volume of the reinforcements or by selecting them with greater levels of strength and stiffness. In fibre-reinforced composites, these above factors are controlled by the fibre orientation. The superior levels can be achieved when all the fibres are placed along the primary loading direction within the composite, but at the same time produces a material of lower properties for the loads perpendicular to the fibre direction. These are the very anisotropic properties that should be considered in the use of material.

## **2. 5. Material Selection**

Being engineered materials, these composites in actual applications merge the specification of materials and component design. With some exceptions, only " high performance" composites are considered in this research paper as these have superior performance than conventional metals. As organic-matrix composites (OMCs) has been discussed earlier in the paper, the focus for OMCs is on continuous fibre- reinforced composites. These are generally referred to as simply fibre-reinforced composites and consists of fibres of high strength and modulus embedded in or bonded to a matrix with distinct interfaces between them. In this arrangement, both the fibres and the matrix maintain their physical and chemical properties by combining their properties that cannot be achieved by either of the constituents alone. So

these fibres are the principal load carrying members while the surrounding matrix keeps them in desired location and orientation. CHAPTER????

## REINFORCEMENT AND MATRICES

### 2. 6. Reinforcements

The main aim of the reinforcement is provide excellent levels of strength and stiffness to a composite. In continuous fibre-reinforced composites, the fibres basically provide all of the strength and stiffness. The typical reinforcing materials are glass, graphite, SiC and alumina. For example, the addition of 20 % SiC to 6061 aluminium provides an increase in over 50 % of strength and 40 % of stiffness. In addition to these structural properties, they also provide electrical and thermal conductivity, wear resistance and controlled thermal expansion. The most widely used reinforcement in OMCs is a fibre tow and these are thousands of filaments arranged in a single bundle.

#### 2. 6. 1. Glass Fibres

The initial experimentation and engineering understanding of fibre-reinforced organic matrix composites was based on glass fibre reinforced composites. The both continuous and discontinuous glass fibre reinforced composites have a broad range of applications extending from non-structural and low performance uses such as panels in aircraft and appliances to high performance uses such as pressure vessels and rocket motor cases. The glass fibres have been used in the composites both in the past and present due to following characteristics:

Competitive price	Good
Handleability	Availability
Ease of processing	High strength-to-weight ratio
Good	dimensional stability
Resistance to heat, cold, moisture and corrosion	Good

Electrical insulationEase of fabricationIn addition, these glass fibres are compatible with highly efficient coupling agents like polyester or epoxy matrices that provides a boost of strength in their properties and in environmental durability. The most commonly used glass fibre is E-glass (electrical) which provides a balance of mechanical, chemical and electrical properties at a moderate cost. Their typical strength is about 3450 MPa (500 ksi) and stiffness is about 75.8 GPa ( $11 \times 10^6$  psi). The other types are C-glass (corrosion) and S-glass where C glass has a higher resistance to chemical corrosion than E glass but is more expensive and has lower strength. S glass has a higher Young's modulus and is more resistant to temperature. S glass is more expensive than E glass and specially used in the aircraft industry.

## **2. 6. 2. Boron Fibres**

These were the first high performance monofilament reinforcement used in advanced composites. These fibres are used in structural components on the U. S Air Force F-15 and U. S. Navy F-14 aircraft. Due to their excellent mechanical properties, thermal stability and lesser reactivity with the matrix, they have been used in MMCs. The boron-epoxy composites are used in the sports goods industry. These fibres are produced as a large monofilament fibre or wire by chemical vapour deposition (CVD) of boron onto a tungsten or pyrolyzed carbon substrate. The resultant has a superior strength of 3450 MPa (500 ksi) and stiffness of 400 GPa ( $58 \times 10^6$  psi). They can form composites with greatly higher compressive strengths due to their large fibre diameters. These fibres are hardly used as their manufacturing processes

are really expensive but lately they have been used in the composite patch repairs of damage of cracks in aluminium aircraft structures.

### **2. 6. 3. Carbon Fibres**

Carbon fibres are the well-known and most widely used reinforcing fibres in the advanced applications of composites. The most predominant factors associated are the manufacturing technology and that of their engineering properties. Although their manufacturing process is complex but susceptible to large scale production as compared to other advanced fibres. Their engineering properties can be easily interpreted into usable composite physical and chemical properties. The carbon fibres were earlier produced by thermal decomposition of rayon precursor materials and subsequently rayon has been replaced by polyacrylonitrile (PAN). The Pan material produce more economical fibres as the yield of carbon is higher and they do not primarily require a high temperature graphitization step. These PAN based carbon fibres have strengths of range between 3515 and 6380 MPa (510 to 925 ksi) combined with modulus from 240 to 310 GPa (35 to 45 \* 10<sup>6</sup> psi) and are commercially available. Due to their linear stress-strain behaviour to failure, the increase in strength also leads to increase in elongation to failure. They provide elongations up to 2. 2% exceeding the strain capabilities of other organic matrices. These PAN based fibres are available in tow sizes i. e. number of carbon fibres per bundle. These sizes range from 1000 fibres per tow at high cost (£ 26 to £ 45 per pound) to a very high counts (hundreds of thousands of fibres per tow) for less than £ 6 per pound. Carbon fibers are also manufactured from pitch precursor for specialty applications. Pitch- fiber properties typically include high modulus and thermal conductivity, as might

be required on satellite structures. Modulus values in commercially available fibers range up to 825 GPa ( $120 \times 10^6$  psi).

## **2. 6. 4. Aramid Fibres**

Aramid is a general name for a class of aromatic polyamide fibres which had been popularized in the early 1960s. These fibres are all types of poly para-phenyleneterephthalamide and available in a wide range of properties. The most commonly used is Kevlar 49 (DuPont) and has a tensile modulus of 131 GPa ( $19 \times 10^6$  psi) and strength of 3620 MPa (525 ksi). Technically, these fibres are thermoplastic polymers like nylon but does not melt when heater, rather it decomposes before reaching its required melting temperature. The major drawback is that their manufacturing processes are extremely complex involving many aggressive chemical categories. These fibres were earlier used in filament wound rocket motor cases, gas pressure vessels and lightly loaded secondary structures on fixed-wing commercial aircrafts and helicopters. As compared to carbon and other inorganic fibres, these aramid fibres provides far lesser strength in compression and poor bonding to matrix resins.

## **2. 6. 5. Other Organic fibres**

Among other fibres are the polyethylene fibres which have ultra-high molecular weight such as Spectra from AlliedSignal Inc. Spectra provide tensile strengths up to 3250 MPa (470 ksi) and modulus of about 113 GPa ( $16 \times 10^6$  psi). Their properties include high chemical impact, moisture resistance, good vibration damping, low density and low dielectric constant. They have been used in applications such as ballistic armor, boats and other

recreational products. Depending on the design requirements, an appropriate composite reinforcing fibre has been selected for the fabrication of the automotive leaf springs even though the cost of the fibres are high.

## **2. 7. Matrices**

The main purpose of the matrix is to bind the reinforcements together because of its cohesive and adhesive properties, to transfer the load to and between the reinforcements and to protect the reinforcements from handling and environments. (Citation required). It also provides a solid form to the composite that is normally required in the finished part as it supports handleability during manufacture as the reinforcements are not of sufficient length in discontinuously reinforced composites. From the structural context, the matrices are generally the weaker link in the composite because of reinforcements being stronger and stiffer. These matrices, in the continuous phase, manages the transverse properties, interlaminar strength and the composite strength with respect to elevated temperature. On the other hand, it provides the transfer of load effectively from the external forces to the reinforcements by making use of their strength to the full potential. It is the matrix which holds the fibre reinforcements in the proper orientation and position so that the intended loads can be carried and evenly distributed among them. Furthermore, they provide inelastic response which results in the reduction of stress concentrations and redistribution of internal stresses from broken reinforcements. The organic matrices such as polyester and vinyl ester resins are used for commercial applications and the epoxy resins have been used for some advanced high end applications.

### **2. 7. 1. Polyester and vinyl ester resins**

These resins are the most extensively used matrix materials. They are used in various industrial, commercial and transportation uses such as piping, reactors, trucks, bathtubs, showers, automobile hoods and doors. They provide a broad range of physical properties with addition of number of resin formulations, curing agents and other components. Silanes have been used as coupling agents for the adhesion of glass and carbon fibres to develop a polymer matrix thereby stabilising the composite material. This development have been used to fabricate the glass fibre reinforced polyester and vinyl ester composites which in turn provides the superior mechanical properties and environmental durability. For these reasons, they have been widely used in the composites today. Due to their failure of adhesion to carbon and aramid fibres, there has been no development of applications of polyester or vinyl resins using these fibres. These poor properties of resins when used with other fibres has restricted them to lower performance applications.

### **2. 7. 2. Epoxy resins**

Nowadays, the epoxy resins have been used more than any matrices in the advanced applications of composite materials. These epoxies are far more superior to polyester in resisting moisture and provides less cure shrinkage even though they are sensitive to moisture in both cured and uncured states. They also provide better mechanical properties and resistant to other environmental factors. Despite having nearly low elongation-to-failure for most cured epoxies, they provide a blend of handling characteristics, processing flexibility, mechanical properties and an acceptable cost. By the addition of thermoplastic or rubber additives, these modified toughened



resins formulations provide improved elongation capabilities. These epoxies have been used on the structural components of U. S Air Force and U. S. Navy since 1972 and their experience with these components have been suitable. These resins have a maximum service temperature of about 1200C (250 0F) for high loads and long term applications and minimum temperatures from 80 to 105 0C (180 to 220 0F). There has been continuous effort to extend the performance of epoxy resins at higher temperatures when wet and however the progress in increasing this temperature limit has been very slow. Moisture absorption decreases the glass transition temperature ( $T_g$ ) of an epoxy resin. Because a significant loss of epoxy properties occurs at the  $T_g$ , the  $T_g$  in most cases describes the upper-use temperature limit of the composite. To avoid subjecting the resins to temperatures equal to or higher than this so-called wet  $T_g$  (the wet  $T_g$  is the  $T_{g\text{measured}}$  after the polymer matrix has been exposed to a specified humid environment and allowed to absorb moisture until it reaches equilibrium)

### **2. 7. 3. Bismaleimide resins (BMI)**

These resins share most of the characteristics as epoxies such as ease of processing, better handleability and great composite properties. They are also better than epoxies in the maximum hot or wet use temperatures which are from 177 to 230 0 C (350 to 450 0F). They also have an even lower elongation to failure and considerably brittle. The tolerance of damage is comparable to that of commercial epoxy resins in aerospace applications and these are being formulated for improvement of its toughness properties. These are readily available from number of suppliers.

## **2. 7. 4. Polyimide resins**

These are the resins with maximum hot or wet in-service temperature of 232 0 C (450 0F) and can go up to 3700 C (700 0 F) for single short periods.

Unlike the resins mentioned above, these resins are cured by a condensation reaction producing volatiles which in turn leads to voids in the resulting composite. There are also other polyimide resins in which final curing is done by an addition reaction which does not produce the volatiles which has good quality composite parts. Like BMIs, they are also brittle.

## **2. 7. 5. Thermosetting Resins**

There has been numerous ongoing attempts for the production of improved thermosetting resins based on the hot or wet performance and impact resistance of epoxies, BMIs and polyimides. There are some resins which are commercially used for specialised applications. One of them are Phenolic resins which provides high heat resistance, superior char and performance. They also have good dielectric property with blend of dimensional and thermal stability. Like polyimide resin, they can also be cured by condensation reaction giving out water as by-product resulting in a voidy laminate. They are generally used in aircraft interior panels as they produce low smoke and less toxic by-products upon combustion and these requirements justify the lower properties. The other matrix material used is cyanate ester which has lower moisture absorption and excellent electrical properties. They are used in satellite structures, antennas and electronic components.

## **2. 7. 6. Thermoplastic Resins**

The high temperature thermoplastic resins have been developed by the attempts for the improvement of both hot/wet properties and impact resistance of the composite matrices as discussed earlier. These are different from the normal thermoplastics such as polyethylene, polyvinyl chloride and polystyrene that are used as plastic bags, plastic piping and tableware. These display very little resistance to elevated temperatures whereas the high performance thermoplastics show superior resistance compared to that of an epoxy. These thermoplastics are tougher and provide improved hot/wet resistance and long term room temperature storage. Due to their high strain-to-failure behaviour, they theoretically provide full strain potential along with high strength carbon fibres. These are designed to be semicrystalline i. e. polymer atoms arrange themselves in regular arrays to a degree or amorphous i. e. molecular chains has no local order. These include resins such as polyether etherketone, polyphenylene sulphide and polyetherimide which maintains their thermoplastic character in the final composite and other resins such as polyamideimide which is originally molded as a thermoplastic but postcured in the final composite producing partial thermosetting characteristics thereby improving temperature resistance.

## **2. 8. Manufacturing Processes**

B. T. Åström, Manufacturing of Polymer Composites, Chapman & Hall, 1997 Manufacturing is generally a mixture of machining, molding and/or joining material that is in forms such as solid, block, rod, plank, sheet etc. In case of the fibre reinforced composites, the manufacturing is entirely different as the materials and the components are manufactured

<https://assignbuster.com/the-growing-competition-and-innovation-engineering-essay/>

simultaneously. The main aim in manufacturing composites is to obtain ideally a net-shape manufacturing with no post manufacturing machining or trimming required thereby improving process economy and the properties of the components. Also, these methods must avoid the entrapment of air or vapour in the form of bubbles or voids.

## **2. 8. 1. Outlook**

The composite manufacturing areas are still developing and some of them have been discussed in the paper: The traditional open-mold techniques such as wet hand lay-up and spray-up have been progressively replaced with closed-mold techniques such as Resin Transfer Molding (RTM), structural reaction injection molding (SRIM) and vacuum infusion. The main advantage is to reduce the volatile emissions thus improving work environment and minimizing factory emissions (air treatment costs). These processes also improve consistent component properties and reduce the use of matrix. In the advanced aerospace applications, hand lay-up of preimpregnated reinforcement is still used in the industry while automated lay-up techniques and RTM are progressing around to enhance repeatability and reduce cost. The traditional processes are still used in manufacturing competitive yachts similar to those in aerospace applications such as use of preimpregnated reinforcement with high performance polymer foam or honeycomb cores and the composite matrix is crosslinked under vacuum and at high temperatures or even in an autoclave. The performance is enhanced. The trial and error method has still been the approach in optimizing the technique to a great extent and the process modelling has become a common manufacturing process in the industry. The overall benefit is cost reduction through

automation and enhancements in cycle time and component properties. For expensive components with high requirements (e. g., aircraft components) it may be financially beneficial to embed, within the component, sensors that monitor factors like degree of mold filling or crosslinking; this allows processing conditions to be tailored in order to optimize properties. Such tailoring depends on real-time process modeling to interpret sensory output and determine the most appropriate course of action. Also, in this case, the driver is cost reduction through improvements in process robustness and component properties. The high performance manufacturing processes have been discussed by focussing on the leaf springs. The best fabrication process must be selected for the leaf spring to provide an acceptable quality at a lower cost.

## **2. 8. 2. Hand and spray placement**

## **2. 8. 3. Press Molding**

## **2. 8. 4. Vacuum Molding**

## **2. 8. 5. Autoclave Molding**

## **2. 8. 6. Resin Transfer Molding**

## **2. 8. 7. Reaction Injection Molding**

## **2. 8. 8. Pultrusion**

## **2. 8. 9. Filament winding**

## **Fig: Composite Processing Technologies**

## **2. 9. Recyclability of composite materials**

There has been rise in environmental and economic awareness for need of recycling carbon fibre reinforced polymer waste due to increase in use of CFRPs. The latest UK governmental strategy for composites recognises "Increasing Sustainability and Recycling" as one of the three main goals for composite industry (BIS, 2011). The recycling processes for CFRP and challenges for the introduction of these recyclates are outlined in this research. In addition to all advantages associated with CFRPs, their increasing use leads to an increasing amount of CFRP waste. The typical waste sources include out-of-date pre-pregs, manufacturing cut-offs, testing materials, production tools and end-of-life (EoL) components as shown in the fig below???. The manufacturing waste contributes about 40% while woven trimmings around 60 % of all the CFRP waste generated (Pickering et al., 2006). Fig : Out-of-date pre-preg rolls Fig: Manufacturing cut offsThe recycling of composites is crucial due to the following: Complex composition

(fibres, matrix and fillers) Cross-linked nature of thermoset resins which cannot be remoulded Combination with other materials such as metal fixings, honeycombs, hybrid composites etc. Most of the CFRP waste is landfilled (Pickering, 2006) and the end-of-life components are also landfilled or generally dumped in desert graveyards (Carberry, 2008 and PAMELA, 2005). These solutions are, however, inadequate for the following reasons:

Environmental impact: increasing production of CFRP has raised concerns on waste disposal and consumption of non-renewable resources. Legislation: Recently, European legislation invoked a strict control on composite disposal; the component's manufacturer has full responsibility on disposing EoL composites, legal landfilling of CFRP is limited and for instance it is required that automotive vehicles disposed after 2015 are 85 % recyclable (EU 1999/31/EC, 1999 and EU 2000/53/EC, 2000). Cost of Production: Carbon fibres are expensive in terms of energy consumption up to 165 kWh/kg during manufacturing and material price up to 40 £/kg. (Carberry, 2008) Management of resources: The demand for carbon fibres has exceeded the supply capacity (Roberts, 2007) and therefore these recycled carbon fibres could be reintroduced for non-critical applications in the market (Carberry, 2009). Economic opportunity: Landfilling of CFRP can approximately cost 0.2 £/kg (Meyer et al., 2007) and the recycling would lead from an expensive disposal to a profitable reusable material. It can be concluded that the recycling of CFRP waste into a valuable resource is vital for continuous use in automotive industry applications (Pickering, 2006). There are some papers available that have been reviewed on carbon-fibre recycling. DeRosa et al., 2005 and Pickering, 2006 aimed at setting up

recycling processes, while McConnel, 2010 and Wood, 2010 reviewed their implementation at commercial applications. Pimenta et al., 2010 discussed about a strong connection between recycling, re-manufacturing processes and the performance of the recyclates and Line, 2009 explained the markets where recycled CFCs can be introduced which has a great impact for any commercial recycling operation.

### **2. 9. 1. Carbon fibre recycling processes**

The main technologies proposed for CFRP recycling are Mechanical recycling and Fibre reclamation as shown in the figure?? below: Fig: Mechanical recycling Fig: Fibre reclamation

#### **Mechanical recycling**

Mechanical recycling refers to breaking down the composite by shredding, crushing, milling or other similar mechanical process. Then, the resulting scrap pieces can be separated by sieving into powdered products rich in resin and fibrous products rich in fibres (Pickering, 2006 and Palmer et al., 2009). These mechanically-recycled composites can be re-incorporated in new composites as a filler or reinforcement and can be used in automotive or construction industry for artificial woods or asphalt or as mineral sources for cement (Conroy et al., 2006). Generally, these represent low-end applications and so mechanical recycling can only be used for glass fibre reinforced polymers although utilized for thermoset and thermoplastic CFRP applications (ECRC, 2003 and Takahashi et al., 2007). The mechanical performance of the recyclates can only be assessed at the composite level as this process does not recover individual fibres.



## **Fibre Reclamation**

Fibre reclamation involves breaking down the matrix (usually a thermoset) by utilizing an aggressive thermal or chemical process thus recovering the fibres from CFRP. In this process, the fibres are released and collected and then energy/molecules can be recovered from the matrix followed by preliminary operations such as cleaning and mechanical reduction in size of the waste. Since these carbon fibres have high thermal and chemical stability, their superior mechanical properties especially stiffness are not considerably weakened by this process. Therefore, the fibre reclamation process is exceptionally suitable to CFRPs. The recycled carbon fibres commonly has a clean surface and similar mechanical properties compared to virgin carbon fibres as shown in the figure below?? and however some exhibit surface defects which includes pitting, residual matrix and char as shown in the figure and also strength degradation have also been noted(Heil et al., 2009). Fig: Clean recycled fibres Fig: Recycled fibres with char residueAfter reclamation process, these recycled fibres are then re-impregnated with new resin to manufacture recycled CFRPs.

### **2. 9. 2. Pyrolysis**

Pyrolysis is the thermal decomposition of organic molecules in an inert atmosphere (Nitrogen) and is one of the most widespread recycling processes for CFRP. During the process, CFRP is heated around 450 0C and 700 0C in the absence of oxygen (nearly) and the polymer matrix is evaporated into molecules with lower weight although the carbon fibres continue to be inert and are eventually recovered. (Meyer et al., 2009). Their advantages include (i) High retention of mechanical properties (ii) No use of

chemical solvents and potential to recover chemical feedstock from resin. However this process delivers a few drawbacks such as possible deposition of char on fibre surface and environmentally hazardous off-gases. In UK, the Milled Carbon Group developed a pyrolysis process for CFRP in a pilot plant and has been recognised as the world's first continuous recycled carbon fibre operation in commercial scale and formed Recycled Carbon Fibre Ltd (RCFL, 2009). Their process is performed on a semi-open continuous-belt furnace with controlled atmosphere thereby preventing formation of char. It conform to all legislation on the combustion of off-gases and the resin's calorific value is recovered and fed back in the process as the recovery of material from the polymer is not economically applicable (Alsop, 2009). This company has been successfully recovered fibres from all types of waste as shown in the figure above?? and the furnace belt with large dimensions permits the recycling of out-of-date prepreg rolls while maintaining the reinforcement structure. They have recently introduced Green Carbon Fibre Ltd. (GCF, 2010) for commercialisation of recycled products such as milled and chopped fibres/pellets.

### **2. 9. 3. Oxidation in fluidised bed**

Oxidation is also a thermal process which consists of combustion of polymer matrix in a hot and flow rich in oxygen i. e. air at 450 0C to 550 0C. The fluidised bed process (FBD) is the most widely used by few researchers and this has been developed and implemented by Pickering et al. at University of Nottingham (2000). This process is advantageous as there is (i) high tolerance to contamination, (ii) no presence of residual char on fibre surface and it is a well-established and documented process. The recycled fibres will

have degradation of strength between 25 % and 50 % and also an unstructured fibre architecture. This process has some difficulties in recovering material from resin. During process, CFRP scrap, which is reduced to fragments at approximately 25 mm large, is delivered into a bed of silica on a metallic mesh. The hot air stream is passed through the bed to decompose the resin while both the fibre filaments and the oxidised molecules are being driven within the air stream. Also, heavier metallic components sink in the bed and this natural separation makes this recycling process especially applicable for contaminated end-of-life components. These fibres are then separated in cyclone, from the air stream, and finally resin is fully oxidised in an afterburner (Pickering, 2006).

## **2. 9. 4. Chemical Recycling**

This CFRP recycling process is based on a reactive medium such as catalytic solutions, benzyl alcohol and supercritical fluids under low temperature less than 350 °C. In this process, the polymer resin is decomposed into very large oligomers, while the carbon fibres remain inert and finally collected (Marsh, 2009). They provide a very high confinement of mechanical properties and fibre length and high potential for recovering materials from resin. As compared with other processes, this recycling process provide less contamination tolerance, reduced adhesion to polymeric resins and impact on environment if hazardous solvents are used. Supercritical fluids (SCFs) are those fluids at temperature and pressure just above the critical point in which these have combined characteristics such as liquid-like density and its dissolving capability, gas-like viscosity and diffusivity (Eckert et al., 2008).

These SCF fluids, mixed with alkali catalysts, such as water, methanol,

ethanol, acetone and propanol, have been used for recycling process.

Nowadays, this chemical recycling with SCFs has been used for producing recycled carbon fibres with nearly no mechanical degradation and also allows to recover useful chemicals from the matrix (Pickering, 2009).