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Nano and Micro Developments in Polymer Materials-application in CFRP Car

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Abstract — Low weight, high tensile strength and rigidity as well as low thermal expansion—with these properties, carbon fibre reinforced plastics (CFRP) are being applied in more and more industries. Effective new processes for simulation and production have also made an economic series production of CFRP components possible.However; the factors that prevent it from being prominently used are expensive fabrication, repair and recycling process. While materials like steel and aluminium have desirable performance when subjected to forces in certain ways or from certain directions, in the next 10 – 15 years, these metals may not be in a position to meet the legislative requirements, thereby mandating the use of carbon fibre composites.

Keywords— carbon fibre, CFRP, tensile strength, thermal expansion.

1. INTRODUCTION

Carbon fibre reinforced plastics (CFRP) are up to 70 percent lighter than steel; compared to aluminium, a weight saving of up to 40 percent is possible. But, lightweight is only one forth of this compound material; its other benefits are its very high tensile strength and rigidity, resistance to corrosion, as well as its low thermal expansion. With these properties, CFRP has picked up points in the aerospace industry for about two decades already. The share of components made from this lightweight material is increasing steadily—in the Airbus A380, more than 20 percent is made from this material and in the new Boeing 787 Dreamliner, it is 50 percent [11].While struggling global economies have put enormous pressure on automakers over the last two years, rising fuel prices and consumer awareness of climate change are turning out to be the new challenges for automakers in this decade. To address the these new challenges, automakers are working hard to improve the fuel efficiency of their vehicles by using and testing new lightweight materials such as carbon fibre composites and bio – based materials. Carbon fibre is a composite material made from embedding fibres of carbon in epoxy resin[2].

This paper frames as follows, section two depicts about properties of CFRP , section three informs about manufacturing methods of CFRP, section four gives idea regarding importance of CFRP fibre direction, section five gives detail about economical production methods of CFRP, section six explains various applications of CFRP in automotive. Civil engineering and other typical applications of CFRP with examples, at last section seven concludes the paper with new ideas for developing material and challenges and requirement of more advance research and development work for newer materials like photo mobile polymer materials for future.

2. Properties of CFRP:

Carbon Fibre Reinforced Polymer (CFRP) is a Polymer Matrix Composite material reinforced by carbon fibres. The reinforcing dispersed phase may be in form of either continuous or discontinuous carbon fibres of diameter about 0.0004" commonly woven into cloth.Carbon fibers are very expensive but they possess the highest specific (divided by weight) mechanical properties: modulus of elasticity and strength. Carbon fibres are used for reinforcing polymer matrix due to the following their properties: Very high modulus of elasticity exceeding that of steel; High tensile strength, which may reach 1000 ksi (7 GPA); Low density: 114 lb/ft³ (1800 kg/m³); High chemical inertness. The main disadvantage of carbon (Graphite) fibres is catastrophic mode of failure (carbon fibres are brittle). [3] [4]

The types of carbon fibres are as follows:

UHM (ultra high modulus). Modulus of elasticity > 65400 ksi (450GPa).HM (high modulus). Modulus of elasticity is in the range 51000-65400 ksi (350-450GPa).IM (intermediate modulus). Modulus of elasticity is in the range 29000-51000 ksi (200-350GPa).HT (high tensile, low modulus). Tensile strength > 436 ksi (3 GPA), modulus of elasticity < 14500 ksi (100 GPA).SHT (super high tensile). Tensile strength > 650 ksi (4.5GPa). [6][7]

3. Manufacturing methods of Carbon fibres:

Carbon fibres are also classified according to the manufacturing method:

3.1. PAN-based carbon fibres (the most popular type of carbon fibres):

In this method carbon fibres are produced by conversion of polyacrylonitrile (PAN) precursor through the following stages: Stretching filaments from polyacrylonitrile precursor and their thermal oxidation at 400°F (200°C). The filaments are held in tension. Carbonization in Nitrogen atmosphere at a temperature about 2200 °F (1200°C) for several hours. During this stage non-carbon elements (O, N, and H) volatilize resulting in enrichment of the fibres with carbon. Graphitization at about 4500 °F (2500°C). [8]

3.2. Pitch-based carbon fibres:

Carbon fibres of this type are manufactured from pitch: Filaments are spun from coal tar or petroleum asphalt (pitch).

The fibres are cured at 600°F (315°C).Carbonization in nitrogen atmosphere at a temperature about 2200 °F (1200°C).The most popular matrix materials for manufacturing Carbon Fibre Reinforced Polymers (CFRP) are thermosets such as epoxy, polyester and thermoplastics such as nylon (polyamide).Carbon Fibre Reinforced Polymers (CFRP) materials usually have laminate structure, providing reinforcing in two perpendicular directions. Carbon Fibre Reinforced Polymers (CFRP) is manufactured by open mold processes, closed mold processes and Pultrusion method [8].Carbon Fibre Reinforced Polymers (CFRP) is characterized by the following properties:

Light weight; High strength-to-weight ratio; Very High modulus elasticity-to-weight ratio; High Fatigue strength; Good corrosion resistance; Very low coefficient of thermal expansion; Low impact resistance; High electric conductivity; High cost[2].

4. Importance of CFRP Fibre Direction:

Carbon fibre reinforced plastics are available for the construction of CFRP components in different variations, such as short or long fibres, continuous fibres, fibre hoses as well as batts, fabrics and mesh. In the so-called uni-directional batts, for example, the fibres are arranged in parallel, whereas fabrics consist of warp and weft, which cross and sling around each other. Multi-axial batts consist of several randomly arranged batt layers which are connected to each other. The versatility of material permits the precise setup of the components for the load to be expected or present. The significant characteristic feature is that the high tensile strength and rigidity is achieved only in longitudinal direction of the fibres— comparable to the human bone structure which is designed according to the direction of load. The design of a CFRP component, in which the material can demonstrate its material properties in an ideal way, is thus always characterized by a certain organic flow, which means there are soft radii and nuclear- cut dividing lines. The material is not suited for sharp edges and corners as they will lead to enormous peak stress. In order to influence certain properties, such as the crash behaviour of CFRP structures, the material can be combined with glass-fibre reinforced plastics. The fibre orientation for components and structures can be optimized by means of the Finite Element Method (FEM) [11].

5. Economical Production Methods of CFRP:

Up to now, the most frequent manufacturing process for lightweight components has been the prepreg method. Fabric pre-impregnated with resin is placed into a mold, which is covered up air-tight and evacuated. The curing of the semi-finished fibre product is effected in an autoclave at a pressure of up to 10 bar and a temperature of up to 356°F. This process takes between three and six hours. Apart from long cycle times, extensive manual work and the accruing costs stand in the way of economical series production For this reason, the last few years have seen the development of new processing technologies which permit a more cost-effective production, including, for example, the RTM (resin transfer molding) and the VARI (vacuum assisted resin infusion) process. These two processes use so-called preforms (dry fibre structures), into which the resin is injected. This permits the manufacture of component parts with complex contours as well as the use of different types of fibre, such as fabric, multi-axial butts and mesh for a component. This also permits a reinforced functional integration, through which components can be produced without screwing or welding individual components.

Another advantage of the preforms is their improved drapability.In the RTM process, the resin is injected under pressure into a closed mold. In the VARI method, the fibres in the mold are covered with a special distribution medium. The mold is then evacuated, through which the resin is drawn into the mold under atmospheric pressure. On the one hand, the medium permits equal distribution of the resin across the entire surface of the component, and on the other hand it has a distinctly higher permeability than semi-finished fibre products. By applying injection methods, CFRP components can be produced in shorter cycle times. In addition, compared to prepregs, they have a distinctly better surface quality. In order to further reduce process times, a further progressing automation of production as well as a faster and more efficient curing of the plastic resins by microwave radiation, for example, will contribute to the development of innovative manufacturing technologies [12].

6. Applications of CFRP:

6.1 Automotives:

Carbon fibre-reinforced polymer is used extensively in high-end automobile racing. The high cost of carbon fibre is mitigated by the material's unsurpassed strength-to-weight ratio, and low weight is essential for high-performance automobile racing. Race car manufacturers have also developed methods to give carbon fibre pieces strength in a certain direction, making it strong in a load-bearing direction, but weak in directions where little or no load would be placed on the member. Conversely, manufacturers developed unidirectional carbon fibre weaves that apply strength in all directions. This type of carbon fibre assembly is most widely used in the "safety cell" monocoque chassis assembly of high-performance race cars [1]. Many supercars over the past few decades have incorporated CFRP extensively in their manufacture, using it for their monocoque chassis as well as other components. Cast vinyl has also been used in automotive applications for aesthetics, as well as heat and abrasion resistance. Most top of the line cast vinyl materials such as 3M's DiNoc (interior use) and SI's Si-1000 3D (exterior use) have life spans of 10+ years when installed correctly. Until recently, the material has had limited use in mass-produced cars because of the expense involved in terms of materials, equipment, and the relatively limited pool of individuals with expertise in working with it. Recently, several mainstream vehicle manufacturers have started to use CFRP in everyday road cars. [3] [5]

Use of the material has been more readily adopted by low-volume manufacturers who used it primarily for creating body-panels for some of their high-end cars due to its increased strength and decreased weight compared with the glass-reinforced polymer they used for the majority of their products. Use of carbon fibre in a vehicle can appreciably reduces the weight and hence the size of its frame. This will also facilitate designers/ engineers more creativity and more in-cabin space for commuters. [6]

6.2 CFRP IN LIGHTWEIGHT ELECTRIC CARS:

To target large – scale volumes at competitive costs ,German luxury car maker BMW and Seattle – based SGL Automotive announced the formation of a joint venture (in late 2009) SGL Automotive Carbon fibres LLC.The manufacturing facility at Moses Lake,Washington,will manufacture CFRP for applications in its future Megacity series of vehicles i3 and i8.BMW is particularly interested in using carbon fibre for its electric cars in order to counterbalance the extra weight of the batteries and improve range.i3 is expected to be ready for global launch by 2013.[3]

6.3 Civil engineering applications:

Carbon fibre reinforced polymer-[CFRP] has over the past two decades become an increasingly notable material used in structural engineering applications. Studied in an academic context as to its potential benefits in construction, it has also proved itself cost-effective in a number of field applications strengthening concrete, masonry, steel, cast iron, and timber structures. Its use in industry can be either for retrofitting to strengthen an existing structure or as an alternative reinforcing (or prestressing material) instead of steel from the outset of a project. Retrofitting has become the increasingly dominant use of the material in civil engineering, and applications include increasing the load capacity of old structures (such as bridges) that were designed to tolerate far lower service loads than they are experiencing today, seismic retrofitting, and repair of damaged structures. Retrofitting is popular in many instances as the cost of replacing the deficient structure can greatly exceed its strengthening using CFRP [10]. Applied to reinforced concrete structures for flexure, CFRP typically has a large impact on strength (doubling or more the strength of the section is not uncommon), but only a moderate increase in stiffness (perhaps a 10% increase). This is because the material used in this application is typically very strong (e.g., 3000 MPa ultimate tensile strength, more than 10 times mild steel) but not particularly stiff (150 to 250 GPa, a little less than steel, is typical). As a consequence, only small cross-sectional areas of the material are used. Small areas of very high strength but moderate stiffness material will significantly increase strength, but not stiffness.CFRP can also be applied to enhance shear strength of reinforced concrete by wrapping fabrics or fibres around the section to be strengthened. Wrapping around sections (such as bridge or building columns) can also enhance the ductility of the section, greatly increasing the resistance to collapse under earthquake loading. Such 'seismic retrofit' is the major application in earthquake-prone areas; since it is much more economic than alternative methods. If a column is circular (or nearly so) an increase in axial capacity is also achieved by wrapping. In this application, the confinement of the CFRP wrap enhances the compressive strength of the concrete. However, although large increases are achieved in the ultimate collapse load, the concrete will crack at only slightly enhanced load, meaning that this application is only occasionally used. Specialist ultra-high modulus CFRP (with tensile modulus of 420 GPA or more) is one of the few practical methods of strengthening cast-iron beams. In typical use, it is bonded to the tensile flange of the section, both increasing the stiffness of the section and lowering the neutral axis, thus greatly reducing the maximum tensile stress in the cast iron. When used as a replacement for steel, CFRP bars could be used to reinforce concrete structures, however the applications are not common.CFRP could be used as prestressing materials due to their high strength. The advantages of CFRP over steel as a prestressing material, namely its light weight and corrosion resistance, should enable the material to be used for niche applications such as in offshore environments. However, there are practical difficulties in anchorage of carbon fibre strands and applications of this are rare. In the United States, prestressed concrete cylinder pipes (PCCP) account for a vast majority of water transmission mains. Due to their large diameters, failures of PCCP are usually catastrophic and affect large populations. Approximately 19,000 miles of PCCP have been installed between 1940 and 2006. Corrosion in the form of hydrogen embrittlement has been blamed for the gradual deterioration of the prestressing wires in many PCCP lines. Over the past decade, CFRPs have been utilized to internally line PCCP, resulting in a fully structural strengthening system. Inside a PCCP line, the CFRP liner acts as a barrier that controls the level of strain experienced by the steel cylinder in the host pipe. The composite liner enables the steel cylinder to perform within its elastic range, to ensure the pipeline's long-term performance is maintained. CFRP liner designs are based on strain compatibility between the liner and host pipe. [3].CFRP is a more costly material than its counterparts in the construction industry, glass fibre-reinforced polymer (GFRP) and aramid fibre-reinforced polymer (AFRP), though CFRP is, in general, regarded as having superior properties. Much research continues to be done on using CFRP both for retrofitting and as an alternative to steel as a reinforcing or prestressing material. Cost remains an issue and long-term durability questions still remain. Some are concerned about the brittle nature of CFRP, in contrast to the ductility of steel. Though design codes have been drawn up by institutions such as the American Concrete Institute, there remains some hesitation among the engineering community about implementing these alternative materials. In part, this is due to a lack of standardization and the proprietary nature of the fibre and resin combinations on the market [8].

6.4. Lightweight Components for Vehicle Production:

The reduction of carbon dioxide emissions, saving of resources and increase in the economic performance are all driving forces in the automotive industry for the development of new processes for the series production of CFRP components. The latest example in this field is the CFRP roof of the new BMW M3 coupé, which is produced in a highly automated production line at the BMW plant in Landshut (Germany) [1]. The roof consists of several layers of a CFRP batt, which are first pre-shaped in dry condition, and then saturated in resin in the so-called RTM process. For standardized and economical series production in significantly higher numbers, the motor-vehicle manufacturer developed innovative tools and process techniques. Apart from a reduction in weight of about 11 pounds, the light material originating from the aerospace industry permitted the centre of gravity of the new sports car to be lowered even further, thus positively influencing the vehicle dynamics. At present, all motor-vehicle manufacturers are dealing with the subject of lightweight construction. Thus, the producers are in the process of developing structural and cassis components made of CFRP, such as the B pillar and the crash box, shock absorbers and axles. Significantly larger components are required for the development of a 40-ton towing vehicle made of a carbon fibre reinforced compound construction which started in autumn of last year. Primarily, the articulated lorry consists of the lightweight material in the area of the chassis, the driver's cab as well as a number of mounting parts, and thus, will weigh between 5.6 and 6 tons less (towing vehicle and three-axle semi-trailer). On one hand, this reduction in weight permits a considerable saving of CO2 emissions, and on the other hand it is available for additional payload and thus contributes to the payback of the costs which will increase by about 20 percent [11].

6.5. Use in Machine and Device Construction:

Aerospace, vehicle construction as well as racing and sports equipment belong to the "accustomed" fields of application for CFRPs, but the application possibilities of this lightweight material have not been exhausted by a long way yet. By reducing the mass of the components to be accelerated, such as skids or spindles in tool machines and handling devices, for example, the dynamics and productivity can be increased, and at the same time, the wear is reduced as well. This also applies for all oscillating moving machine parts, such as levers and skids in printing, textile and packaging machines. For fast running rollers, CFRP components permit higher speeds through the reduction of the centrifugal forces. Axles and shafts made of carbon fibre reinforced plastics reduce the load on bearing, reduce thermally induced deformations, and thus increase the service life of machines and devices. In robot construction and automation, CFRP components are beneficial for movement and positioning structures. Apart from excellent damping behaviour, they ensure faster and more precise movement, and consume less energy in the process due to the low weight. [11]

6.6 Other applications:

The large majority of NHL ice hockey players use carbon-fibre sticks. Carbon-fibre-reinforced polymer has found a lot of use in high-end sports equipment such as racing bicycles. For the same strength, a carbon-fibre frame weighs less than a bicycle tubing of aluminium steel. The choice of weave can be carefully selected to maximize stiffness. The variety of shapes it can be built into has further increased stiffness and also allowed aerodynamic considerations into tube profiles. Carbon fibre-reinforced polymer frames, forks, handlebars, seat posts, and crank arms are becoming more common on medium- and higher-priced bicycles. Carbon fibre-reinforced polymer forks are used on most new racing bicycles. Other sporting goods applications include rackets, fishing rods, long boards, and rowing shells. Much of the fuselage of the new Boeing 787 Dreamliner and Airbus A350 XWB will be composed of CFRP, making the aircraft lighter than a comparable aluminium fuselage, with the added benefit of less maintenance thanks to CFRP's superior fatigue resistance. Due to its high ratio of strength to weight, CFRP is widely used in micro air vehicles (MAVs). In MAVSTAR Project, the CFRP structures reduce the weight of the MAV significantly. In addition, the high stiffness of the CFRP blades overcomes the problem of collision between blades under strong wind. [12]

CFRP has also found application in the construction of high-end audio components such as turntables and loudspeakers, again due to its stiffness. It is used for parts in a variety of musical instruments, including violin bows, guitar pick guards, and a durable ebony replacement for bagpipe chanters. It is also used to create entire musical instruments such as Blackbird Guitars carbon fibre rider models, Luis and Clark carbon fibre cellos, and Mix carbon fibre mandolins.In firearms it can substitute for metal, wood, and fibreglass in many areas of a firearm in order to reduce overall weight. However, while it is possible to make the receiver out of synthetic material such as carbon fibre, many of the internal parts are still limited to metal alloys as current reinforced plastics are unsuitable replacements. Shoe manufacturers use carbon fibre as a shank plate in their basketball sneakers to keep the foot stable. It usually runs the length of the sneaker just above the sole and is left exposed in some areas, usually in the arch of the foot.CFRP is used, either as standard equipment or in aftermarket parts, in high-performance radio-controlled vehicles and aircraft, i.e. for the main rotor blades of radio controlled helicopters—which should be light and stiff to perform 3D maneuvers. Fire resistance of polymers or thermoset composites is significantly improved if a thin layer of carbon fibres is molded near the surface—dense, compact layer of carbon fibres efficiently reflects heat.[4]IBM/Lenovo's ThinkPad laptops and several Sony laptop models use this technology. Carbon fibre is a popular material to form the handles of high-end knives. This material is used when manufacturing squash, tennis and badminton racquets. Carbon-Graphite spars are used on the frames of high-end Sport kites[10].In 2006 a company introduced cricket bats with a thin carbon fibre layer on the back which were used in competitive matches by high-profile players (e.g. Ricky Ponting and Michael Hussey). The carbon fibre was claimed to increase the durability of the bats, however they were banned from all first-class matches by the ICC in 2007[12].Carbon-fibre is used in the manufacture of high quality arrows for Archery.

7. Conclusion:

Carbon fibre composites were never considered mainstream technology for automotive applications in the past, but the attitude of designers towards these technologies is changing. While steel and aluminium will continue to hold a significant position in car manufacturing for the next 10 – 15 years, these metals may not be in a position to meet the legislative requirements at that point of time. By 2025, automakers may have little choice but to make greater use of Carbon fibre composites and natural fibre composites. Despite the significant production costs, carbon fibre is an extremely appealing material for high-performance applications where cost restrictions are not so tight. It is commonly stated that carbon fibre can offer the same tensile strength as steel for just 25% of the weight. This is subject to careful design and fabrication to ensure the best possible performance across a component. Carbon fibre-reinforced polymers (CFRPs) have a long service lifetime when protected from the sun. When it is time to decommission CFRPs, they cannot be melted down in air like many metals. When free of vinyl (PVC or polyvinyl chloride) and other halogenated polymers, CFRPs can be thermally decomposed via thermal depolymerisation in an oxygen-free environment. This can be accomplished in a refinery in a one-step process. Capture and reuse of the carbon and monomers is then possible. CFRPs can also be milled or shredded at low temperature to reclaim the carbon fibre; however this process shortens the fibres dramatically. Just as with downcycled paper, the shortened fibres cause the recycled material to be weaker than the original material. There are still many industrial applications that do not need the strength of full-length carbon fibre reinforcement. For example, chopped reclaimed carbon fibre can be used in consumer electronics, such as laptops. It provides excellent reinforcement of the polymers used even if it lacks the strength-to-weight ratio of an aerospace component. Despite its high initial strength-to-weight ratio, one structural limitation of CFRP is its lack of a fatigue endurance limit. As such, failure cannot be theoretically ruled out from a high enough number of stress cycles. By contrast, steel and certain other structural metals and alloys do have an estimable fatigue endurance limit. Because of the complex failure modes of such composites, the fatigue failure properties of CFRP are difficult to predict. As a result, when utilizing CFRP for critical cyclic-loading applications, engineers may need to employ considerable strength safety margins to provide suitable component reliability over a sufficiently long service life.

Future scope

A new class of polymer materials has been developed that can convert light energy directly into mechanical work, and show a variety of three-dimensional movements simply from exposure to light. These polymer materials can be fabricated into any shape and size using photolithographic methods and it is expected they will be developed for various applications.Such materials are also useful in future in carbon fiber cars for energy saving purpose.Already research in this regard is in process in japan by Tomiki Ikeda and Toru Ube Research & Development Initiative, Chuo University, Tokyo 112-8551, Japan.[1]

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