Design and Analysis in Carbon Fiber Composites

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Abstract - *The need for lighter vehicles is becoming more and more important for the heavy-duty industry. This can be achieved by using composite materials. One of the most promising materials is carbon fiber reinforced plastics, a composite material with carbon fibers bonded together by a polymer. Carbon fiber reinforced plastics are in many ways different from conventional materials, such as steel that is commonly used in the structural parts today. This project has investigated issues with using carbon fiber reinforced plastics, with a focus on fatigue and how to design in composite materials. In the early phases of the project, a literature review was done, where delamination, galvanic corrosion, fatigue and joining were seen as the most critical problems. This was followed by further investigation of fatigue. Fatigue is weakening of the material due to cyclic loading and is difficult to predict and to validate because of the inhomogeneous structure of composite materials, and because failure often is sudden and without prior notice. If fatigue is critical is very much dependent on the type of loading and the design of the structure. It is therefore important to have fatigue in mind when designing in composite materials, to minimize its impact and the risk it occurs. Many factors affect the material behavior and that have to be considered when designing in composite materials, such as the material properties and the material design, e.g. the lay-up of the fibers, the manufacturing process, and the design of the structure. The behavior can also be affected by environmental conditions and the type of load applied to the composite. Due to all those parameters and the complexity of composites it is difficult to give clear directions of how to design in composite materials. There is however general guidelines that have to be followed for most composites, for example the fiber orientation are strongly affecting the strength of the composite. The result of this project is guidelines for designing in composite materials, the guidelines states important parameters to have in mind when designing.*

Key Words*: *Composite materials, design constrains, material property, and static analysis.

1. INTRODUCTION

More and more requirements are affecting the heavy-duty vehicles. India has set the aim to decrease the emissions with 20 per cent compared to today. One way to do this is by reducing the weight of the vehicle. The payloads of the trucks can be increased and the fuel consumption and the associated CO_2 emissions could be reduced by using lightweight materials. Reduced fuel consumption is an important factor for mass production vehicles, and it is estimated that 75 per cent of the fuel consumption is directly related to the weight of the vehicle. The weight of mass transit transportation vehicles and trucks could be reduced with 40 to 60 per cent using composite materials instead of metal. Mass transit vehicles with lower weight have become of interest to the customers. One of the most promising composite materials is carbon fiber reinforced plastics, CFRP, a composite material with carbon fibers bond together by a polymer. This type of material is not used for structural parts within heavy-duty vehicles today, but is used within the aerospace industry. The specific modulus and strength of polymer matrix composites are superior to many other materials, which are the main reasons for polymer matrix composites being used extensively in aerospace and transportation Carbon fiber composites are becoming more and more important and the market is expected to grow believe that the material have a large future in the automotive sector. Carbon fiber composites are already used in vehicles, mainly in high performance cars where they often are the primary structural material. To meet the environmental obligations from the automotive industry it is expected that the implementation of lightweight materials and design must be included. To develop structures of lightweight material is therefore important for companies within the heavy-duty vehicle industry, in order to keep their position on the market.

1.1 Literature review: **-** It is possible to reduce the weight for mass transit transport vehicles and heavy trucks with 40 to 60 per cent by changing from metal to composite material. The market is heavily under-utilized in terms of composites, because metal is the most used material today. Composite materials are used in other applications, one example is the airplane Boeing 747, where 50 per cent of the frame consists of CFRP and carbon fiber reinforced plastic. It is possible to save up to 30 per cent of the weight of conventional model by using CFRP instead of aluminum in the airplane structure .Other examples of the use of CFRP are the roof of the BMW M6 and the front and fenders of the Chevrolet Corvette Z06. The front fenders in the Dodge Viper are also in CFRP, as well as the rear deck lid inner structure of the Ford GT. Lamborghini has produced the body of one of their cars, with exception for door and roof structure, entirely in carbon fibers reinforced epoxy. The weight has been reduced with 34 kg, approximately 40 per cent compared to its predecessor that had a body in aluminum. Carbon fiber composites are also used within military.

1.2 Carbon fibers: **-** The properties of carbon fibers are equal to steel, but with lower density. Carbon fibers high stiffness and strength, and the fibers have also good thermal stability and when combined into a matrix is the fatigue resistance excellent. The combination of properties is superior, but the material is much more expensive than both glass and aramid. Carbon fibers have poor abrasion resistance, and are attacked from some acids, and undergo galvanic corrosion when the material have contact with certain metals and allows .Carbon fibers are commonly combined with a polymer matrix, and are then often called CFRP or carbon fiber reinforced plastics. It is possible to receive a high performance material with a weight reduction of more than 50 per cent compared to high strength steel by using CFRP. The strength of CFRP is as high as for high strength steel, the stiffness high and the density is 40 per cent lower than aluminum. The material's fatigue and creep resistance are good, and by using laminate orientation can the material be designed to be tougher and more damage tolerant than metals. The chemical and corrosion resistance are also good as well as the dimensional stability, and compared to metals the vibration damping is ability excellent. The electrical resistivity is low, and the thermal conductivity is high. Composites based on carbon fibers have low energy-absorbing capacity, poor resistance to transverse impact loading and the plies have a tendency to separate from each other in the laminate.

It is possible to get carbon fibers with a wide range of different strength and stiffness. Classifies them in three categories due to strength and stiffness; high strength, intermediate- modulus or high modulus fibers. Classifies carbon fibers a slightly different way, also in three categories: general-purpose (GP), high-performance (HP), activated carbon fibers (ACF). General-purpose fibers have low tensile strength, low tensile modulus and low cost, and high-performance have relatively high strength and modulus. Activated carbon fibers have a large number of open microspores, which acts as adsorption sites, the material has therefore a good adsorption capacity, comparable to activated carbon but the shape of the fibers allows the adsorbate to get to the adsorption site faster. The fibers have also specific names depending on properties; AS4, T300 and C6000 are some .Carbon fibers and graphite is both names used to describe carbon fibers. The main difference between them is the content of carbon. Carbon fibers consists of typically 95 per cent carbon, and are carbonized at circa 1000 to 1500°C, while graphite fibers contain about 99 per cent carbon, and are first carbonized and then graphitized at temperatures between 2000°C and 3000°C. The graphite-isation process generally results in a fiber with higher modulus .Carbon fibers can be made from rayon, polyacrylonitrile (PAN) or petroleum-based pitch. The best combination of properties is produced of PAN-based fibers, which is a form of acrylic fibers. Rayon is rarely used today, because of higher cost and lower yield compared to carbon fibers. Petroleum-based pitch fibers are mainly used to produce high- and ultrahigh-modulus graphite fibers, but were developed as a lower cost alternative to PAN. Carbon fibers are produced as untwisted bundles, so-called tows, with thousands of fibers, common is one, three, six, 12 or 24 thousand fibers. In order to improve the adhesion of carbon fibers to the polymer matrix are they normally surface treated immediately after manufacturing? Sizing is also often applied in form of thin film, to improve handle ability and protect the fibers during weaving and other handling operations. Depending on the processing temperature it is possible to receive carbon fibers with different stiffness and strengths. To get high strength and high stiffness carbon fibers it is necessary to process the material between 1200° and 1500°C. Ultrahigh stiffness graphite fibers are processed at temperatures between 2000° and 3000°C. The increase of stiffness is achieved at the expense of the strength. The majority of all carbon fibers are made from PAN precursor.

Polymer matrix composites are today used for lightweight structures, and carbon fiber composites are for example used within the aerospace, automobile (e.g. formula 1 cars), and offshore industry but also in sporting equipment .

1.3 Matrices:-The matrix is both maintaining the position and orientation of the fibers as well as protects them from possible degrading environments. In polymer and metal composites is the matrix transiting load from the matrix to the fibers through shear loading at the interface. The most commonly used matrices are polymer matrices, and are reinforced with glass, carbon, aramid or boron fibers. These composites are used at relatively low temperatures .Other matrices are metal and ceramic matrices and carbon/carbon composites. The metal matrices composites consist of metals or alloys and are reinforced with boron, carbon or ceramic fibers. The softening or melting temperature for the matrix limits the maximum temperature for metal composites. The matrix in ceramic matrix composites is ceramics as well as the fibers. This composite is well suited for very high temperature applications. The last one, carbon/carbon composites, is carbon or graphite matrix reinforced with graphite yarn or fabric. The properties are unique with relatively high strength at high temperatures in combination with low thermal expansion and density.

1.4 Composites: - Combining two creates a composite or more materials into one and a material with better properties than the individual materials can be achieved. The composite consists typically of one or more fillers, reinforcement, in a certain matrix. The reinforcement is usually fibers, e.g. carbon. It is the reinforcement that provides strength and stiffness, and is in most cases harder, stronger and stiffer than the matrix. The reinforcement can be in layers, but also as yarn or woven or as short fibers without specific organization. The matrix, in a polymer or metal composite, transmits loads from the matrix to the fibers through shear loading at the interface. By using different materials as fibers and matrix it is possible to receive a composite with different properties, in order to get a material well suitable for the specific purpose. The most common way to classify fiber-reinforced composites is according to the matrix used: polymer, metal, ceramic, or carbon.

There are many advantages with using composites instead of conventional materials. The weight can be reduced, the tooling costs lower, the number of parts could be reduced and fewer assembly operations could reduce the costs for acquisition and/or life cycle costs for composite materials. These advantages are sometimes diluted as the costs for raw material, fibers, prepreg and auxiliary material used in fabrication in combination with composite material his high. Conventional structural materials have usually a lower cost for raw material but the cost for tooling, machining and assembly is on the other hand high. Corrosion is a common problem within the marine industry and those problems can be avoided by using composite materials. This thanks to the material properties and their good corrosion resistance. The life length is longer for composite materials and they require less maintenance than many other materials with less corrosion resistance. Other advantages with composites compared to conventional materials are:

- Lower weight
- Possible to tailor the lay up for optimum strength and stiffness
- Improved fatigue life
- Corrosion resistance
- With good design practice it is possible to reduce cost due to fewer detail parts and fasteners

And some disadvantages:

- High costs for raw material
- Usually high costs for fabrication and assembly
- Adverse effects of both temperature and moisture
- Poor strength in the out of plane direction where the matrix carries the primary load
- Susceptibility to impact damage and delamination or plyseparations
- More difficult to repair composites compared to metallic structures

A composite with a metal matrix is not relevant as the purpose of changing to composite material is to reduce the vehicles weight, and with a metal matrix is such a high reduction not possible. Ceramic matrices are only used for very specific purposes, and are very well suited for high temperature applications. Another kind of composite materials are sandwich-structured composite, where two sheets of material are joined together by another material, e.g. carbon fibers in the sheets and some kind of foam between the sheets, to receive different properties.

2. Tensile Testing Of Composites Material.

The tensile tests were carried out to determine the tensile in-plane properties of high performance composites according to the standard ASTM D3039/D3039M-08 (ASTM International, 2008). From the test the ultimate tensile strength, ultimate tensile strain, tensile chord modulus of elasticity, Poisson's ratio and transition strain can be obtained. The material was designed according to the standard, with a length (L) of 250 mm, width (b) of 20 mm and a thickness (d) of 2.5 mm (ASTM International, 2008). The specimen should according to the standard be mounted in the grips of the mechanical testing machine and monotonically loaded in tension until failure, while the force is recorded. The ultimate strength can be determined from the maximum force carried out before failure. The ultimate tensile strain, tensile modulus of elasticity, Poisson's ratio and transition strain can be derived from the stress-strain response of the material. The tensile tests were performed until failure, and Fig.1and Fig.2 show what one specimen looked like after the test. The layers have delaminated from each other and as can be seen the fibers in the loading direction have failed, but the specimen is still hold together by fibers in the other directions. Those fibers can however not take any loads in the tensile direction and the composite has therefore failed.

Fig-1: Specimen after tensile test, from above

Fig-2: Specimen after tensile test, side view

Fig.3: Weight of Carbon Fibers Composite specimen.

Fig.4: Weight of Aluminum specimen.

2.1 Observation Table For Carbon fibers Composites

Name of Lab: - S. N. Metallurgical Services.

Lab Ref.No. : - L-00280 Date: - 09/04/2018

Specimen Size: - 250 X 20 X 2.5 mm

Weight: - 21.3 gm.

Sr.No.	Test Conducted	Observations
01	Tensile Strength N/mm^2	281.50
02	% of Elongation	7.52
03	Yield Strength N/mm^2	281.50
04	Strength to Weight Ratio $N/gm.\ cm^2$	1321.6

2.2 Observation Table for Aluminum

Name of Lab: - S. N. Metallurgical Services.

Lab Ref.No. : - L-00281 Date: - 09/04/2018

Specimen Size: - 250 X 20 X 2.5 mm

Weight: - 32.4 gm.

Sr.No.	Test Conducted	Observations
01	Tensile Strength N/mm^2	175.81
02	% of Elongation	23.10
03	Yield Strength N/mm^2	102.36
04	Strength to Weight Ratio $N/gm.\ cm^2$	542.62

3. CONCLUSIONS

Hence we can finally conclude that:

a) Carbon Fiber Composites materials have high strength to weight ratio.

b) So they are best suited for various heavy-duty vehicles applications.

c) Carbon Fiber Composites materials offer high fatigue and corrosion resistance.

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