Contemporary Engineering Sciences, Vol. 12, 2019, no. 4, 267 - 274
HIKARI Ltd, www.m-hikari.com
https://doi.org/10.12988/ces.2019.91134

Comparative Study between Plastic Composites and Steel in Structural Parts of Automobile

A. Elbazze

Université Hassan 1er, FST de Settat, Km 3
B.P. : 577 Route de Casablanca, Maroc
Laboratoire d'Ingénierie
Management Industriel et Innovation (IM2I) FSTS, Maroc

B. Radi

Université Hassan 1er, FST de Settat, Km 3
B.P. : 577 Route de Casablanca, Maroc
Laboratoire d'Ingénierie
Management Industriel et Innovation (IM2I) FSTS, Maroc

Abstract

This paper shows that composite materials based on plastic reinforced with mineral fibers (glass or carbon, etc.) used in structural parts of the automobile, assembled with their environment via bolted connections, are able to replace some steel parts. While keeping these materials have industrial and economic advantages; as they permit on the one hand to lighten the automotive structure for less consumption of fuels and on the other hand to lower the cost of manufacture for more competitiveness in the automotive market. The tasks that have been done in this study is to submit these composite parts to the same stresses as steel, by using new concepts, so that they adapt to their environment and reply to the criteria of reliability and validation's car approval. The numerical results show the ability of these materials to replace steel in some structural parts of the automobile and they represent a strategic choice in the automotive industry of the future.

Keywords: Composite materials, bolted assembly, numerical modeling, crash

1. Introduction

Composite materials are increasingly used in the automotive, rail and aerospace industries. In the automotive sector, the race for energy savings and the limitation of emissions of polluting gases are clearly a rising interest from manufacturers and equipment manufacturers in the use of low-density materials and good mechanical strength. In parallel, the concern to protect the motorists but also the pedestrians during a shock, are at the origin of standards of security more and more severe. Comprising materials with complementary characteristics; composites appear as good candidates to meet all these requirements. They have in fact a low density, high mechanical properties and, moreover, have interesting properties in terms of energy absorption. In general, in the automotive industry, these materials are intended to be used in structural parts such as front shock absorbers, or on parts intended to work in fatigue such as suspension blades. However, the use of these materials in parts of the body car is very limited in the automotive industry. The objective of this study is to show that thermoplastic composite materials represent a strategic choice to replace steel, based on our study on the numerical simulation of certification tests to strengthen the choice of composites.

2. Thermoplastic composite materials

The thermoplastic composite materials consist mainly of a fibrous reinforcement embedded in a polymer matrix. The role of the fibers is to significantly improve the thermo-mechanical and dynamic properties of the plastic matrix. Composite materials combine the strength and rigidity as well as the lightness, flexibility and corrosion resistance of plastics. They are particularly adapted to the constraints of the automobile. Today glass fibers are the most used in the automotive industry thanks to these physical properties and its adaptation with plastic.

2.1. Glass fibers

Glass belongs to the group of non-metallic inorganic materials, so it does not have a linear macromolecular structure like most other fibers but rather a crystalline structure that gives it a high rigidity. Glass fibers are the elements of the composite material which generally provide interesting mechanical properties.

Mechanical characteristics of virgin filaments						
	Type of glass					
	E	D	A	C	R	S
Tensile strength (MPa)	3200 à 3400	2500	3100	3300	4400	4600
Tensile modulus of elasticity (GPa)	72 à 73	55	71	70,3	86	87
Tensile elongation (break) (%)	4,6 à 4,8	4,5	4,4	4,8	5,2	5,4

Table 1: Mechanical characteristics measured on virgin filaments

2.2. Thermoplastic matrix

The composites that we are going to compare with steel, the mechanical properties of the matrix are generally very weak compared to those of the reinforcements. The curves below show clearly this difference between the matrix and the fibers.

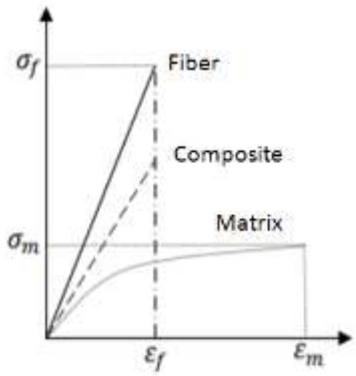

Figure 1: Schematic curves stress / strain

Thermoplastic resins generally appear as powders or granules which must be heated to form. Thermoplastics have an entangled linear (or slightly branched) structure that does not result from polymerization. When shaping by heating, the macromolecules fold back and then lock during cooling. For the material obtained after implementation, the bonds between macromolecules are weak physical bonds of Van Der Waals type: this transformation is reversible.

2.3. Technologies for shaping thermoplastic composites

In the automobile market, two types of process are distinguished: compression and injection:

Long Fiber Technology (LFT): The LFT granules are made by extrusion. The molten polymer and the reinforcement in the form of cut son are mixed at temperatures of the order of 250 °C. The mixture is extruded in the form of rods which are cooled and then cut. The glass levels can range from 10 to 60% by weight. The granules are molded on injection or injection-compression presses where they are preheated to over 250 °C. They are injected under very high pressure (> 200bar) into a cooled closed mold. The cycle times vary according to the parts to be made from 30 seconds to 2 minutes 30.

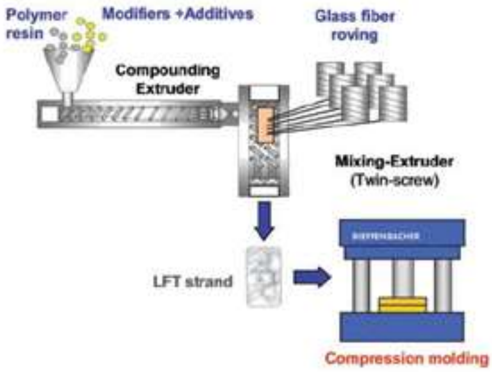

Figure 2: Descriptive diagram of the LFT method

Glass Mat Reinforced Thermoplastic (GMT): is essentially dedicated to the automobile. The sheet materials, generally made by extrusion / calendering are preheated in the form of pre-cut blanks at over 250 °C (Infra-Red oven) and then transferred to a cooled mold mounted on a vertical press. They are then molded by compression / stamping. Cycle times are less than a minute but the high material cost penalizes them. They are more and more competing with the emergence of new material / technology pairs of the LFT type.

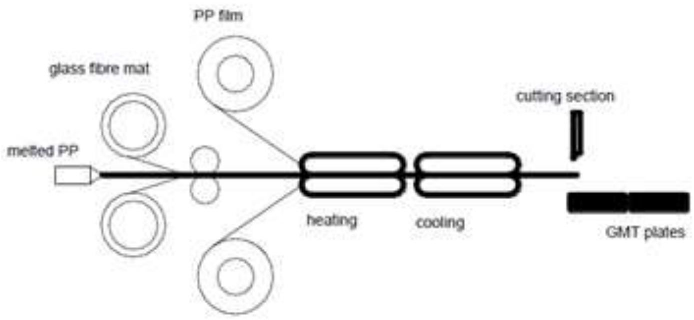

Figure 3: Descriptive diagram of the GMT method

2.4.Mechanical and thermal characteristics of composite materials studied

In general, the mechanical or static characteristics of the composite materials used in the automobile depend greatly on the percentage and the nature of the fibers used in the material. In our study we are interested in composite materials with continuous glass fibers and a very high percentage in the matrix, it is made from LFT technology. The mechanical and thermal characteristics of the studied material are identified from the physical tests:

criteria	value
Tensile modulus	33900 MPa
Poisson coefficient	0,29 / 0,35
Density	1,66 g/cm3
Tensile strength	931 MPa
Tensile Elongation before break	10%
Flexural modulus	33200 MPa
Flexural strength	606 MPa
Flexural Elongation before break	3%

Table 2: Mechanical characteristics of the studied material

The test results shown in the table above and the stress-strain curves below were used to identify the parameters of the JOHNSON-COOK law, in order to model the composite material numerically before using it in the simulation of the certification test. The law represents a model of multiplicative behavior. It takes into account the effects of the rate of strain, but also those of the temperature.

$$\sigma(\varepsilon, \dot{\varepsilon}) = \left(\sigma_0 + K_0 \varepsilon_p^n\right)\left(1 + K_1 \ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon_0}}\right)\right)(1 - T^{*m})(1)$$

where T^* is a function of the melting temperature T_m and the reference temperature T_0

$$T^{*m} = \frac{T - T_0}{T_m - T_0}(2)$$

K_0 and n define the work hardening, K_1 and $\dot{\varepsilon_0}$ define the sensitivity to the rate strain, m coefficient of sensitivity to temperature.

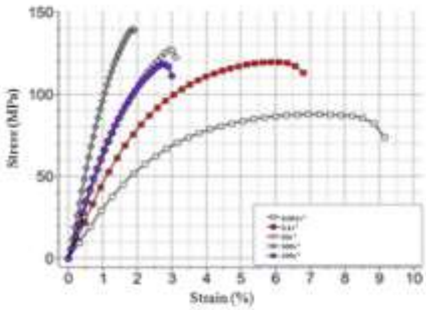

Figure 4: Stress Curves as a Function of strain

3. Application of composites in the automobile

The application of long fiber composites concerns three major areas in vehicles: front block, rear block, and basement:

Front block: The evolution of composite materials used in giant parts shows the progress made on the materials and on the know-how of the manufacturers and the equipment manufacturers.

Figure 5: Image of front facade made from composite

Rear block: In this example of the rear door the Mercedes shows all the parts being made of composite, whose objective is to lighten the structure of the vehicle.

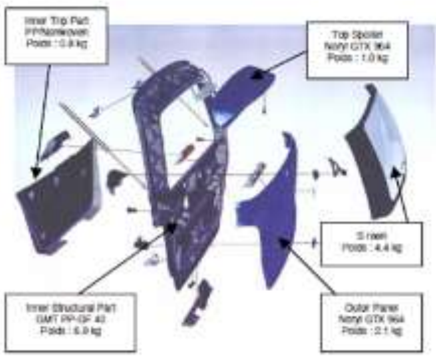

Figure 6: Image of a rear openning made from composite

Basement: Another example of a part made of composite, used in the base of Mercedes:

Figure 7: Image of a composite load floor

Body car: The rate of use of composite materials in automobile body parts remains to this day still marginal and we can observe a strong disparity between manufacturers and markets.

4. Evaluation of composites in structural parts

In this study, we have injected these materials in structural parts automobile that are heavily requested in homologation tests, with the aim to use simulation in order to validate these materials and know its behavior and reliability. The test that we used in numerical study is the ECE R14 or FMVSS210; it is a test used to check the fastening zones of safety belts at the body car and the seats. The figure below shows an illustration of the means used to perform this test.

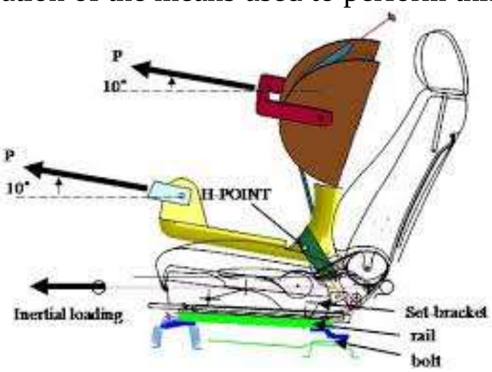

Figure 8: Belt anchor strength test

4.1.Comparison Results with Steel

The numerical study was done on a structural part of the body car where we fixed the rear seats via bolted connections.

The numerical simulation results using the belt anchor strength test show that the composite materials respond favorably to the demands imposed during the simulation.

4.1.1. Validation on the displacement

The displacement results comparing steel and composites show that the latter sufficiently comply with the critical values of the approval test.

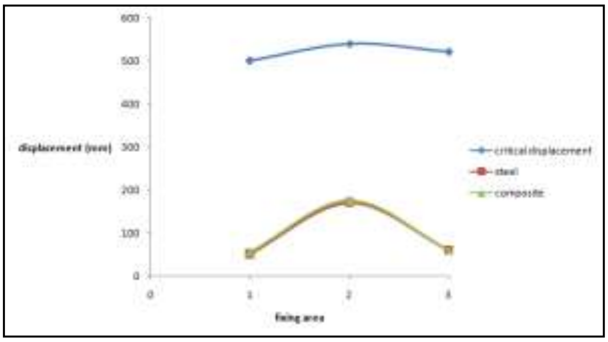

Figure 10: curves of displacement

4.1.2. Mechanical strength of composites

Generally in a quasi-static calculation automotive, the mechanical strength validation of the parts always pass by the measure of the plastic strain by comparing with the limits of elongation of the materials. In this study the plasticity results of our material is favorable (9.3%) compared to the allowed elongation of the latter (10%), while keeping only the modification of the design of the target part compared to the one used in steel. as well as the parts that surround it greatly improve the behavior of the part in the numeric simulation.

5. Conclusion

The results of the numerical simulation of the homologation test (resistance of belt anchors) show that thermoplastic composite materials reinforced with continuous glass fibers are able to reply the validation criteria for parts that are strongly requested during the numerical test. Today, these materials represent an innovative solution to replace steel in some of important parts of the body car with the ultimate goal of lowering the cost of manufacturing and the consumption of fuel.

References

[1] J. Aucher, *Etude comparative du comportement composite à matrice thermoplastique ou thermodurcissable*, INSA of Rouen, 2009.

[2] *Ecology and safety as a driving force in the development of vehicles*, Radom, 2008.

[3] J. Carpenter & Al, *Research needs in predictive engineering of advanced composite materials,* 2004.

[4] M. Jeanne Dupont, A. Bentolila, B. Baroin, P. Bréard, *The French industry of composite materials: priority challenges for sustainable development, DiGITIP Study,* 2001.

[5] Erica R. H, *Strategic material selection in the automobile body: Economic opportunities for polymer composite design,* Massachusetts Institute of Technology, 2006.

[6]*Channel prime alliance, Celstran® CFR-TP PP GF70-13. Celanese Corporation-polypropylene.* https://www.ulprospector.com , 2019.

[7] T. Renault, *Les matériaux composites dans l'automobile*, Faurecia Automotive Seating, 2001.

Received: December 2, 2019; Published: December 31, 2019