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The Effect of Reinforcing Fibres and Resin Types on Composite Materials Used in the Automotive Industry

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Abstract
This paper focuses on the fabrication of composite materials tailored for automotive applications. The manufacturing technologies of composites with carbon and Kevlar pulp are reported. Carbon fiber composites are highlighted for their high strength-to-weight ratio, rigidity, and corrosion resistance, while Kevlar pulp composites are noted for their exceptional wear and abrasion resistance, as well as their ability to enhance reinforcement and viscosity control under stress. Both materials contribute to significant weight reduction in automotive components, enabling lighter vehicles that improve fuel efficiency and reduce emissions, aligning with the industry's focus on sustainability and performance optimization. The materials were subjected to tensile testing to evaluate their mechanical properties, with the best-performing sample undergoing additional bending tests. The study highlights the critical role of composites in reducing material weight, contributing to lighter vehicle designs. This weight reduction enhances fuel efficiency and reduces emissions, aligning with the industry's push towards sustainability and improved performance.

Keywords
composites, automotive applications, manufacturing technologies

1. Introduction

Over the past few decades, many new materials have been designed, with improved quality, reliability, durability, that contributed to the miniaturization of products and the decrease in the consumption of classic materials. Among these materials one can distinguish new metallic alloys, metals coated with thin films, plastics with elastomers, laminated glass, amorphous metals or alloys (metallic glasses), fibre-reinforced ceramic materials, and so on [1, 2].

Due to these improvements in properties, new materials, such as polymers or aluminium alloys, are rapidly replacing steel in various industrial sectors. This substitution influences the manufacturing processes, in addition to the characteristics of the final product, (reduced weight, resistance to high temperatures, fatigue, corrosion, and so on). Powder metallurgy and composite production processes allow the production of parts that have an almost definitive shape, with reduced post-processing needs [1, 3].

The main materials used for the manufacture of automotive components are steel, aluminium alloys, magnesium alloys, Kevlar and carbon fibre-reinforced composites, and polymers. Recent research has shown that up to 50% of the body/chassis can be made by replacing steel with aluminium alloys. Magnesium alloys are increasingly used in automotive engineering, due to their reduced weight. Several advantages for the automotive industry are also generated by fibre-reinforced composites, however they can be used only for certain components (side fenders, bumper, etc.) [4].

Weight reduction is an important strategy for energy efficiency related to transportation [5]. As a result of regulations to reduce emissions and develop energy-efficient strategies, interest in reduced weight materials for cars is growing. Automobiles are manufactured over 63% from heavy materials. A 10% reduction in the weight of conventional vehicles could decrease fuel consumption by 6-8% for internal combustion engines and 10% for electric vehicles [6].

The main factors for material selection, especially for the car body, are numerous, including thermal, chemical or mechanical resistance, ease of manufacturing and durability [7].

Composite materials are widely used in the automotive sector due to their unique combination of mechanical properties, lightweight characteristics, and design versatility. These materials are mixtures of two or more materials that together offer superior advantages compared to traditional materials, generally exhibiting improved properties compared to those shown by each component. For instance, carbon fibre offers high tensile strength while having a much lower density than steel. In the base material of the composite, known as the matrix, the reinforcing materials (particles, fibres, meshes, whiskers, etc.) can be introduced uniformly dispersed or controlled, aiming to achieve improved properties such as: improved wear resistance and tensile strength, density, high temperature resistance, surface hardness, vibration damping capacity and dimensional stability [8, 9]. Carbon fibres (figure 1a) are chemically inert, a high temperature stability and resistance to corrosion. They have low thermal conductivity and density, they are good electrical conductors, have good mechanical characteristics and temperature dependant characteristics [10]. Kevlar fibre has the following characteristics: light weight, low elongation at break point, high tensile strength and modulus of elasticity, high chemical resistance, low electrical conductivity, fire resistance, self-quenching and high toughness [11]. Moreover, Kevlar pulp (shown in figure 1b) is a highly fibrillated, short staple fibre characterized by exceptional toughness, which enhances wear and abrasion resistance. It serves as a specialized performance additive, offering superior reinforcement and effective viscosity regulation under shear stress conditions.

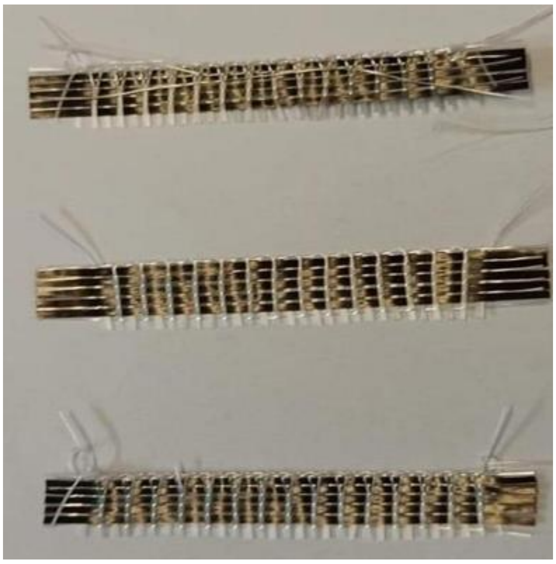


Fig. 1a. Carbon fibres

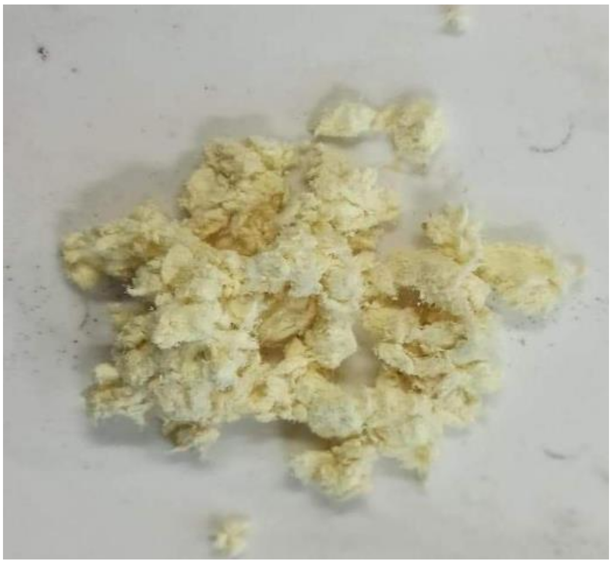


Fig. 1b. Kevlar pulp

The objective of this paper is to demonstrate the growing integration of composite materials within the automotive industry and to emphasize that their application in manufacturing components must be strategically designed to optimize performance while maintaining cost efficiency.

2. Materials and Methods

2.1. Sample preparation

Two types of epoxy resin were used: epilox A 19-00 and epilox T 19-38/700, in conjunction with the same hardener (H 10-30).

Before use, the Kevlar pulp was dried in the oven at a temperature of 110 °C for 11 minutes to remove moisture and ensure stability and high performance, followed by oven cooling.

For samples 1.1 and 1.2: Each type of resin was mixed with the hardener (40 grams of resin and 20 grams of hardener). A certain amount of mixture was added to the mould (15 grams of resin + hardener). After that, the Kevlar pulp (25 grams) was mixed with the resin + hardener (15 grams). The prepared mixture was pressed into the mould and then covered with a thin layer of resin + hardener. Finally, then put the carbon fiber (a strip at 250 mm) on top of it and covered with resin.

For samples 2.1 and 2.2: Mix the resin (10 grams) with the hardener H 10-30 (10 grams), add a few grams (6.6 grams) to the mold, the kevlar pulp (5 grams) is then added, which is also mixed with a few grams of resin + hardener (6.6 grams), the pulp is pressed into the mold and then coated with a thin layer of resin + hardener (6.6 grams).

The samples were kept in the moulds for 24 to 48 hours, for curing. After this time, the samples were removed and cut with the help of a mechanical grinder, followed by the measurement of the samples, with the help of a digital calliper.

2.2. Sample characterization

Tensile strength is used to determine the behaviour and tensile strength of the samples. The specimen is elongated along its axis until it breaks or until the tension or the elongation reaches a predetermined value [8]. The tensile testing was carried out on a Universal Testing Machine, model WDW 150S. The equipment is capable of tests on standardized or non-standard samples, in a very wide temperature range (from -1500 °C to 1250 °C), with a maximum force of 150 KN. The samples presented herein (parallelepipedal shape, shown in figures 2 and 3, and Table 1) were tested at RT (room temperature).

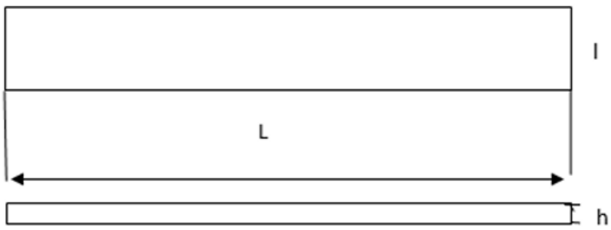


Fig. 2. Shape of the specimen

The 3-point bending strength was determined on the same WDW-150S test machine from Transilvania University of Brasov. This type of test can provide the energy at break and the modulus of elasticity at bending. In figure 2, L represents the length of the specimen, l is the width of the specimen and h is the thickness (values provided in Table 1). These working parameters are entered into the machine software from which the test diagrams are obtained. The tensile test diagrams for the specimens from table 2 are shown in figure 4.

Table 1. Samples used for tensile strength

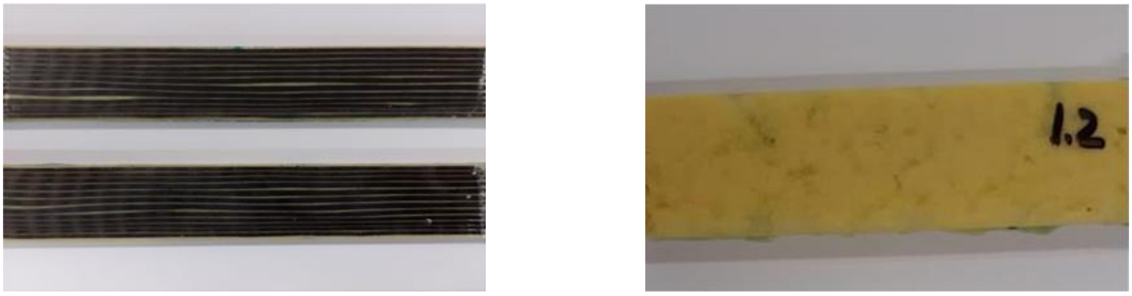
Sample number	Sample description	L – length (mm)	l – Width (mm)	h – Thickness (mm)
1.1	Epilox A19-00 + carbon fibre	123.77	24.8	5.55
1.2	Epilox T19-38/700 + carbon fibre	108.48	24.5	5.78
2.1	Epilox A19-00 + Kevlar pulp	124.52	24.36	5.19
2.2	Epilox T19-38/700 + Kevlar pulp	106.34	24.18	5.41

3. Results and Discussions

Figure 3 presents the specimens derived from the preparation of the composite materials previously mentioned. These specimens were carefully machined and shaped to meet the specific dimensions and requirements necessary for the mechanical tests. The fabrication process was aimed at ensuring the specimens were suitable for the various testing protocols, ensuring accurate and reliable results for the subsequent analyses.

Figure 4 provides a detailed overview of the measurements for the specimens used in the mechanical tests (see Table 1), more specific to tensile strength.

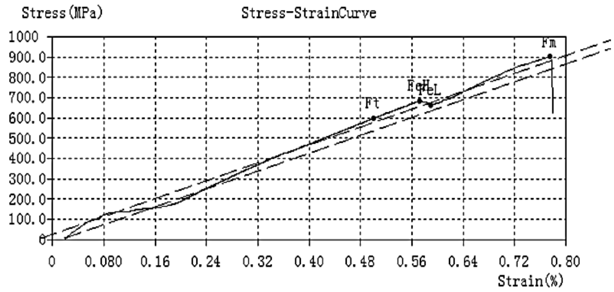
The composite material based on epilox resin A 19-00 reinforced with Kevlar pulp and carbon fiber bears the highest load, but is very rigid. Meanwhile, the composite material based on epilox resin T 19-38/700 reinforced with Kevlar pulp has the highest tensile strength (figure 4). This material has been shown to be the most resistant to bending astabe well.



a b

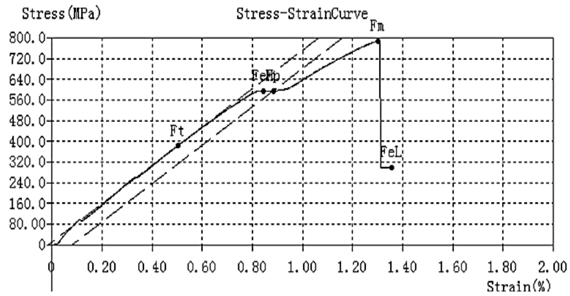
Fig. 3. Epoxy Resin Matrix Composites
a) Carbon fiber reinforced; b) Kevlar pulp reinforced

Coil No/Packet No	proba 1.1	Type	Flat
Size(mm)	24.8	So(mm²)	5.55
Lo(mm)	85	ParallelLength(mm)	70
Le	123.77	Lu(mm)	
A(%)	/	Z(%)	/
Fm(kN)	5.006	Rm(MPa)	902
FeH(kN)	3.800	ReH(MPa)	685
FeL(kN)	3.675	ReL(MPa)	662
Fp(kN)	/	Rp(MPa)	/
Ft(kN)	3.316	Rt(MPa)	597
E(GPa)	122	End_Ex	0.96
At(%)	1.1		



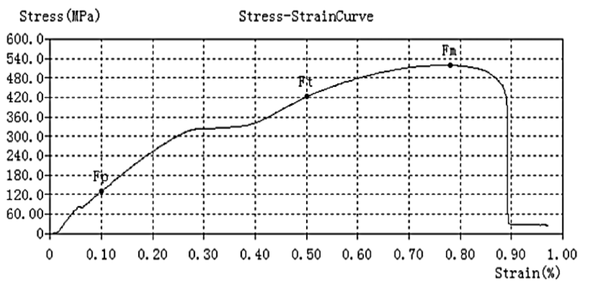
Stress-strain curve of sample 1.1

Coil No/Packet No	proba 1.2	Type	Flat
Size(mm)	24.5	So(mm²)	5.78
Lo(mm)	85	ParallelLength(mm)	70
Le	108.48	Lu(mm)	
A(%)	/	Z(%)	/
Fm(kN)	4.549	Rm(MPa)	787
FeH(kN)	3.447	ReH(MPa)	596
FeL(kN)	1.726	ReL(MPa)	299
Fp(kN)	3.447	Rp(MPa)	596
Ft(kN)	2.215	Rt(MPa)	383
E(GPa)	76	End_Ex	1.48
At(%)	1.7		

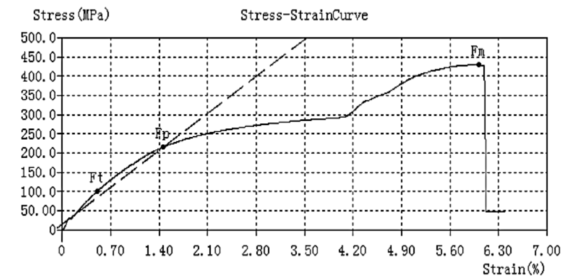


Stress-strain curve of sample 1.2

Coil No/Packet No	proba 2.1	Type	Flat
Size(mm)	24.36	So(mm²)	5.19
Lo(mm)	85	ParallelLength(mm)	70
Le	124.52	Lu(mm)	
A(%)	/	Z(%)	/
Fm(kN)	2.695	Rm(MPa)	519
FeH(kN)	/	ReH(MPa)	/
FeL(kN)	/	ReL(MPa)	/
Fp(kN)	0.678	Rp(MPa)	131
Ft(kN)	2.196	Rt(MPa)	423
E(GPa)	/	End_Ex	1.21
At(%)	1.4		



Coil No/Packet No	proba 2.2	Type	Flat
Size(mm)	24.18	So(mm²)	5.41
Lo(mm)	85	ParallelLength(mm)	70
Le	106.34	Lu(mm)	
A(%)	/	Z(%)	/
Fm(kN)	2.323	Rm(MPa)	429
FeH(kN)	/	ReH(MPa)	/
FeL(kN)	/	ReL(MPa)	/
Fp(kN)	1.165	Rp(MPa)	215
Ft(kN)	0.541	Rt(MPa)	100
E(GPa)	14	End_Ex	6.80
At(%)	8.0		



Stress-strain curve of sample 2.1

Stress-strain curve of sample 2.2

Fig. 4. Force-strain curves

Table 2. Sample used for bending test

Sample number	L - length(mm)	l -Width (mm)	h – Thickness (mm)
2.1	123.26	24.43	5.37

Bending tests were conducted on only one of the four sample configurations, specifically the one that exhibited the best results in the prior tensile test (see figure 5). This approach was adopted to focus on the sample with the highest mechanical performance, ensuring the evaluation of its bending properties under optimal conditions. By selecting the best-performing sample, the study aimed to maximize the reliability and relevance of the bending test results, while also conserving resources and maintaining a streamlined testing methodology.

Size(mm)	24.43	So(mm²)	5.37
Ls(mm)	90	Fbb(kN)	0.64
Rbb(MPa)		Fpb(kN)	0.57
Rpb(MPa)		Eb(GPa)	
U(J)	7.342		

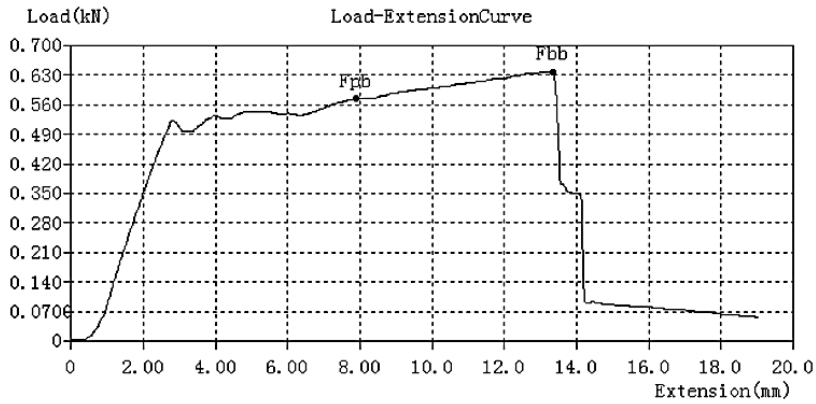


Fig. 5. Bending test for sample 2.1

Using the data from the bending diagrams and the parameters determined before the test, the bending stress is calculated with equation (1):

$$\sigma f = \frac{3FL}{2bh^2} \quad (1)$$

where *h* represents the thickness of the specimen, [mm]; *b* represents the width of the specimen, [mm]; σf represents the bending stress, [MPa]; *F* represents the force, [N]; *L* represents the distance between the supports, [mm] [11].

Analysing the results obtained from the bending rupture tests, it is found that composite materials have different properties depending on the constituents that compose them, depending on the proportion they occupy in the composition of the material. The performance of the material is conditioned by the environmental conditions in which they are forced to work.

4. Conclusions

The automotive industry requires new materials and alloys to design components to achieve ever higher quality standards, optimize weight and reduce emissions.

For automotive design, the first and most important factor is the choice of materials, and a systematic approach to material selection would be an increasingly important foundation for the automotive industry. Composites are increasingly making their way into the automotive industry, and their use to produce parts for this industry must be done in an informed manner in order to be able to achieve maximum performance without raising production prices.

The composite material based on Epilox A 19-00 resin, reinforced with Kevlar pulp and carbon fiber, withstands the highest load but is very rigid.

The composite material based on Epilox T 19-38/700 resin, reinforced with Kevlar pulp, exhibits the highest tensile strength and has also proven to be the most resistant to bending.

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