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GLASS FIBER COMPOSITE MATERIALS: STUDIES AND EXPERIMENTAL TESTS

Munteanu M.V. *[1], Scutaru M.L.[1], Istrate S.[1]

1.Transilvania University of Brașov, Romania, v.munteanu@unitbv.ro, lscutaru@unitbv.ro

Abstract: *Glass-based composite materials have become increasingly important due to their exceptional mechanical and chemical properties. This article reviews the current state of research, describes the experimental methodology for testing the mechanical properties of glass fiber reinforced composites, and presents the results of tensile, compressive, and bending tests. The findings highlight the high potential of these materials in various industries, from construction to aviation*.

Keywords*: composite materials, glass fibers, mechanical tests, mechanical properties, reinforced materials.*

1. INTRODUCTION

Glass fibers are obtained by drawing molten glass at high temperatures and can be integrated into various types of matrices such as polymers, metals or ceramics to create versatile composite materials. These fibers are particularly valued for their high tensile strength and for the fact that they do not degrade in corrosive environments, making them ideal for applications in harsh industrial environments [1-7].

Another major advantage of fiberglass is its excellent weight-to-strength ratio. This makes glass fiber reinforced composite materials preferred in fields such as aeronautics, shipbuilding, civil infrastructure and the automotive industry. Glass fibers, as a reinforcing element, give composite materials increased tensile strength, corrosion resistance and high thermal stability [3, 7-10].

Although there are other reinforcing materials such as carbon and aramid fibers, fiberglass remains one of the most popular choices due to its cost-performance ratio. Despite the superior performance of carbon fibers, they are much more expensive to produce and their processing is more complicated, making fiberglass a more affordable and cost-effective alternative [10-16].

The objective of this study is to present a synthesis of the current state of glass-based composite materials, also presenting their experimental testing methodology and the results obtained, especially in tensile tests, bending tests and compression tests, thus providing a basis for future research and applications in modern engineering.

2. THE CURRENT STATE OF GLASS-BASED COMPOSITE MATERIALS

Glass-based composite materials occupy an important place in the field of advanced materials, being widely used due to their outstanding properties, such as high mechanical strength, light weight, and durability under thermal and chemical stress conditions [6-8]. Glass fibers, as a reinforcing material, are the most used in the production of composites due to their relatively low cost, excellent mechanical properties and the ease with which they can be produced on an industrial scale [17-20].

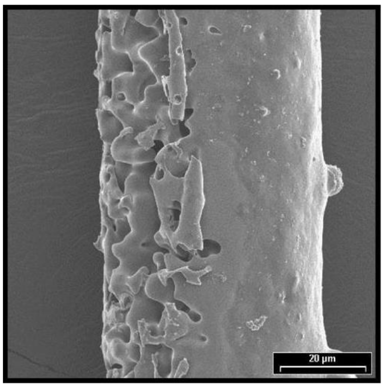


Figure 1: Fiberglass [8]

The industrial process of obtaining the fibers involves melting the glass at high temperatures and drawing the fibers through specially designed nozzles, which allow the formation of extremely fine filaments, usually between 5 and 20 μm in diameter [21-23]. After forming, these filaments are chemically treated to increase adhesion with the polymer matrix, especially in composites used in construction and the automotive industry [14, 24]. Figure 1 illustrates the structure of the glass fiber obtained by this process.

The properties of glass fibers make them ideal for use in aggressive environments, such as infrastructure exposed to corrosion or structures subject to high thermal stresses. These fibers are known for their chemical and thermal stability, as well as the fact that they do not absorb moisture, which makes them ideal in applications where water and moisture resistance is essential [25-26].

In the automotive industry, glass fiber reinforced composites are used for body parts, panels and internal components due to their ability to reduce the overall weight of the vehicle, resulting in lower fuel consumption. In construction, these composites are preferred for reinforcing concrete structures or for facade elements due to their resistance to corrosion [18, 21].

Another field with a significant increase in the use of glass-based composites is that of the wind turbine [19, 20]. Wind turbine blades are frequently made of glass fiber reinforced composites due to their excellent weight-to-strength ratio, which allows them to rotate efficiently at high speeds while ensuring high durability against external factors.

Although glass fiber composites perform well in many applications, there are also certain limitations. Disadvantages include low strength at very high temperatures compared to other types of fibers, such as carbon, and some brittleness [21]. In addition, the recycling of these materials remains a challenge because thermoset composites cannot be reused in the same form [22, 23].

3. EXPERIMENTAL METHODOLOGY FOR TESTING COMPOSITE MATERIALS BASED ON GLASS FIBERS BENDING STRESS

The testing methodology of composite materials includes mechanical tensile testing, bending and compression tests of glass fiber reinforced composite samples [24, 25]. The samples are processed according to international standards, involve the use of samples specially processed for each type of test and subjected to mechanical stress to determine the resistance of the materials to various types of stress (Figure 2). The samples of composite materials were made using the Romanian standard SR EN ISO 14125 from 1998, Fiber-reinforced plastic composites, Determination of bending properties. This part of ISO 14125 is based on ISO 178 and deals with fiber-reinforced plastics. The testing process includes measuring the maximum force sustained and microscopic analysis of the fracture surface. The method is used to determine the bending behavior of the samples but also to determine the bending resistance, the bending modulus and other aspects related to the stress/deformation relationship under the given conditions. It applies to a simply supported lever, loaded at three or four bending points. The method of placing and testing the specimen is chosen in such a way as to limit shear deformation and avoid interlaminar shear breakage.

Figure 2. Composite material sample after bending stress

The equipment used is a constant speed testing machine. The testing machine for the three-point bending test used is the LR5K Plus, produced by Lloyd's Instruments, which provides a maximum force of Fmax = 5 kN. Two supports and a hemispherical load punch are arranged according to the scheme in Figure 3. The bending test machine allows the experimental results to be downloaded in electronic format, through the NEXYGEN Plus software.

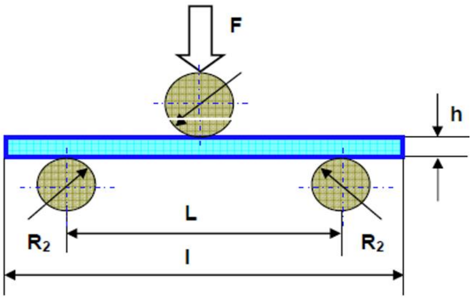


Figure 3: Schematic of the 3-point bending test

3.1 Testing the samples

The experimental research considered the study of the influence of Al2O3 inserts in glass-based composite materials. The specimens were tested in the mechanical testing laboratory of the Department of Mechanical Engineering. The tests were performed on three types of composites:

- 5 samples of composite material based on matte glass
- 5 glass-based composite material samples with 5% Al2O3 inserts
- respectively 5 glass-based composite material samples with 10% Al2O3 inserts.

All 3 sets of specimens were cut on a numerical control machine, to the dimensions indicated according to STAS. Each set of specimens was tested to see how the Al_2O_3 inserts influence the mechanical behavior. The specimens were subjected to a bending test and the results were analyzed to identify variations in strength and stiffness.

4. RESULTS AND DISCUSSION

4. 1. Bending test and the influence of Al_2O_3 inserts on the mechanical properties

The plain frosted glass specimens showed basic flexural strength with moderate breaking strength and elongation values. The insertion of 5% Al_2O_3 caused an increase in the fracture strength and stiffness of the specimens, with a general improvement in the mechanical properties being observed. However, when the proportion of Al_2O_3 was increased to 10%, the results indicated a slight decrease in the mechanical properties, which suggests that an excessive content of inserts may lead to an alteration of the structural homogeneity of the composite.

Due to some errors in testing the samples, the values for only 4 samples were considered in the case of the matte glass-based composite material.

The data generated by the test machine software were centralized in tables 1, 2 and 3, below, so that they can be interpreted through graphical representations.

Table 1. Characteristics of the test samples based on mat glass

NO. SAMPLES	BREAKING STRENGTH	ELONGATION	ADMISSIBLE TENSION	MODULE OF ELASTICITY	STIFFNESS

(MATT GLASS)	F [N]	ΔL [mm]	σ [Mpa]	E [Mpa]	k [N/mm]
SAMPLES 1	499	10.31	199	3365	49278
SAMPLES 2	711	8.25	285	975	14275
SAMPLES 3	541	9.83	217	4564	66849
SAMPLES 4	611	7.84	244	5759	84375

Table 2. Characteristics of the test samples based on mat glass with 5% Al2O3 inserts

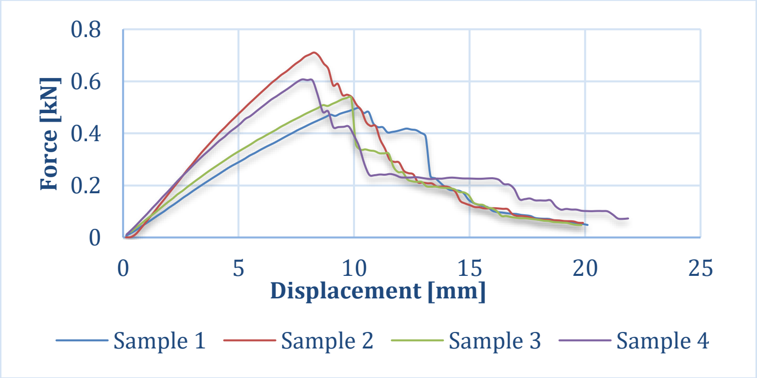
NO. SAMPLES (GLASS WITH 5% AL2O3 INSERTS)	BREAKING STRENGTH	ELONGATION	ADMISSIBLE TENSION	MODULE OF ELASTICITY	STIFFNESS
	F [N]	ΔL [mm]	σ [Mpa]	E [Mpa]	k [N/mm]
SAMPLES 1	684	8.42	274	6519	95499
SAMPLES 2	754	8.74	302	7448	109102
SAMPLES 3	719	8.25	288	7302	106954
SAMPLES 4	660	8.90	265	6058	88746
SAMPLES 5	606	9.37	2422	5584	81788

Table 3. Characteristics of the test samples based on mat glass with 10% Al2O3 inserts

NO. SAMPLES (GLASS WITH 10% AL2O3 INSERTS)	BREAKING STRENGTH	ELONGATION	ADMISSIBLE TENSION	MODULE OF ELASTICITY	STIFFNESS
	F [N]	ΔL [mm]	σ [Mpa]	E [Mpa]	k [N/mm]
SAMPLES 1	826	7.51	199	4882	148983
SAMPLES 2	885	8.20	212	3543	108116
SAMPLES 3	703	9.05	169	2524	77006
SAMPLES 4	757	9.69	182	2307	70399
SAMPLES 5	783	7.82	188	4104	125243

4.2. Comparative analysis of flexural strength between specimens

Figures 4, 5 and 6 show the load (F-displacement) graphs made for each set of specimens showing a different stress and stiffness distribution depending on the material composition.



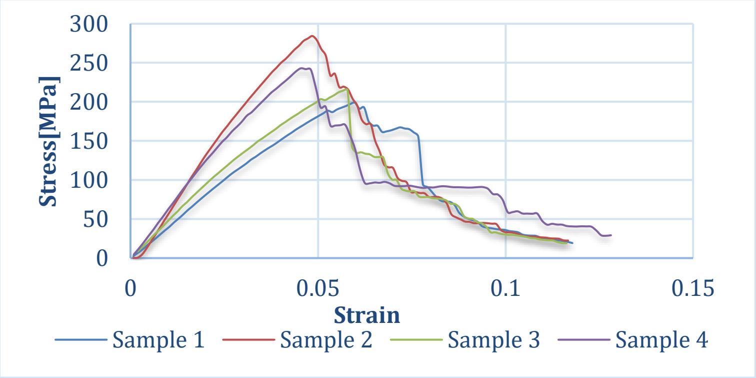


Figura 4. Load curves for the samples made of composite material based on mat glass

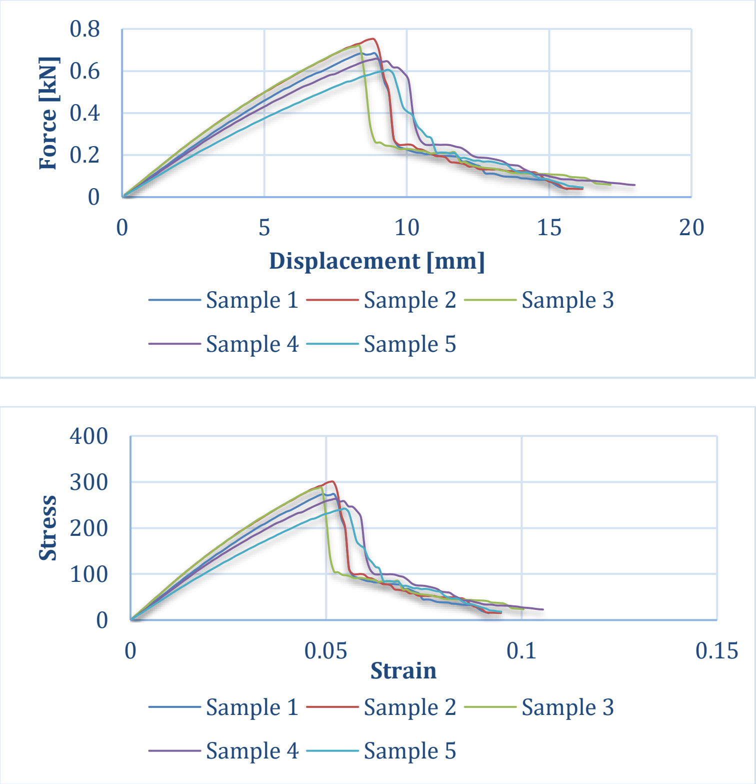
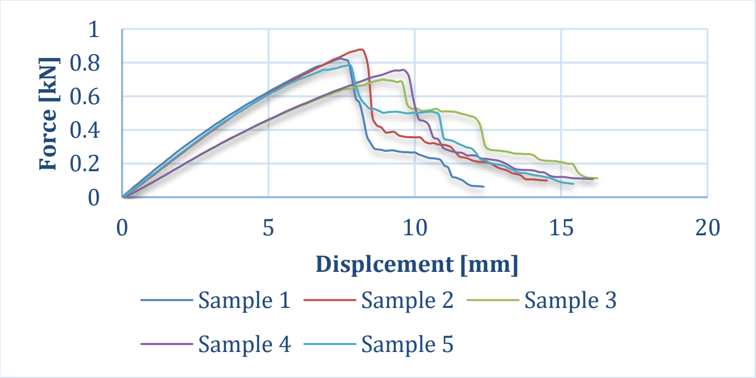


Figure 5. Load curves for the samples made of composite material based on mat glass with 5% Al_2O_3 inserts



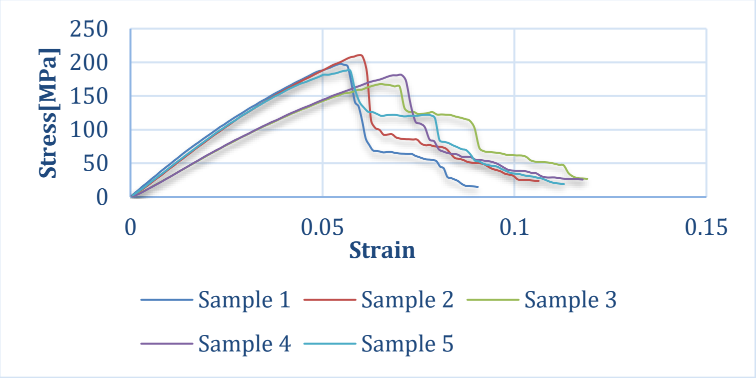


Figure 6. Load curves for the samples made of composite material based on mat glass with 10% Al_2O_3 inserts

Specimens with 5% Al_2O_3 showed an improvement in flexural strength, while specimens with 10% Al_2O_3 showed a slight decrease in strength, probably due to the formation of interlaminar defects or a non-uniform distribution of Al_2O_3 particles.

This can also be highlighted in the graphs in Figures 7 and 8, when on 2 representative specimens from each sample (frosted glass, frosted glass with 5% Al2O3, frosted glass with 10% Al2O3) the representative graphs were represented

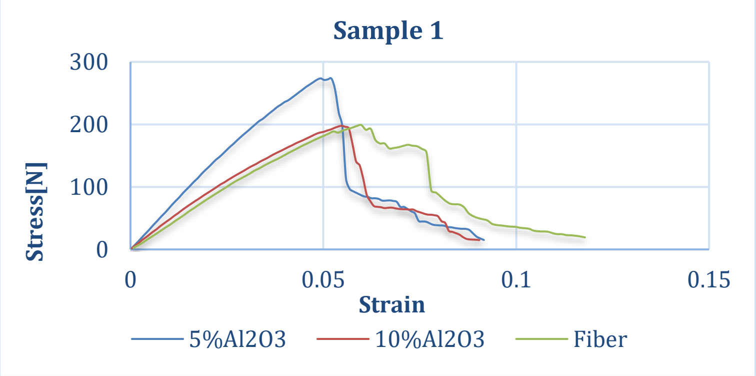


Figure 7. Comparative analysis on the influence of Al_2O_3 powders in glass fiber composites (sample 1 of 3 sets of samples)

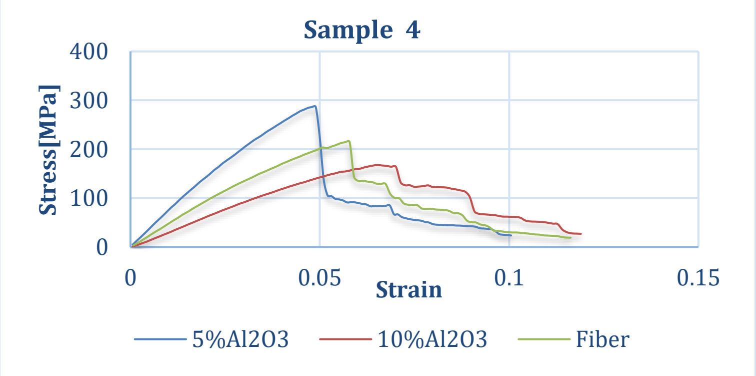


Figura 8. Comparative analysis on the influence of Al_2O_3 powders in glass fiber composites (sample 4 of 3 sets of samples)

4.3. Microscopic analysis of composites

The detailed visualization was made with a high-performance microscope, located within the ICDT-UNITBv. This microscope can magnify the studied surface 500 times, up to 2000 times, and the images were made as clearly as possible and even down to the depth of the material. The results obtained with the microscope were both 2D and 3D, observing at the same time how the entire structure of these materials changed.

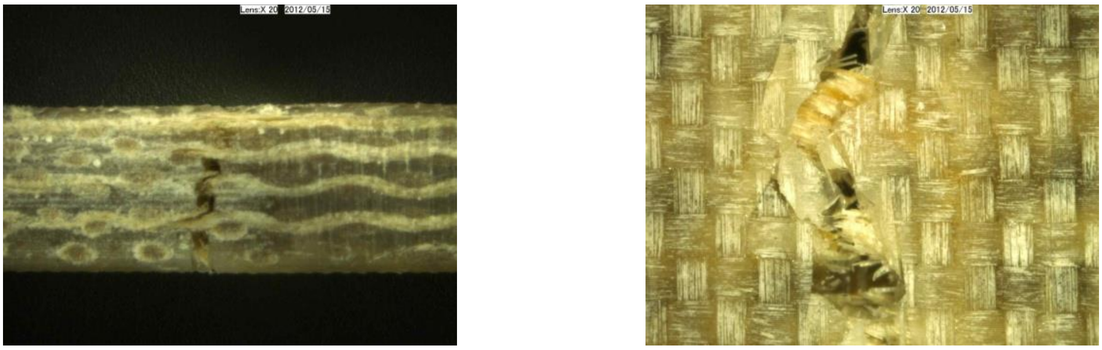


Figure 9. Side and front view of mat glass sample

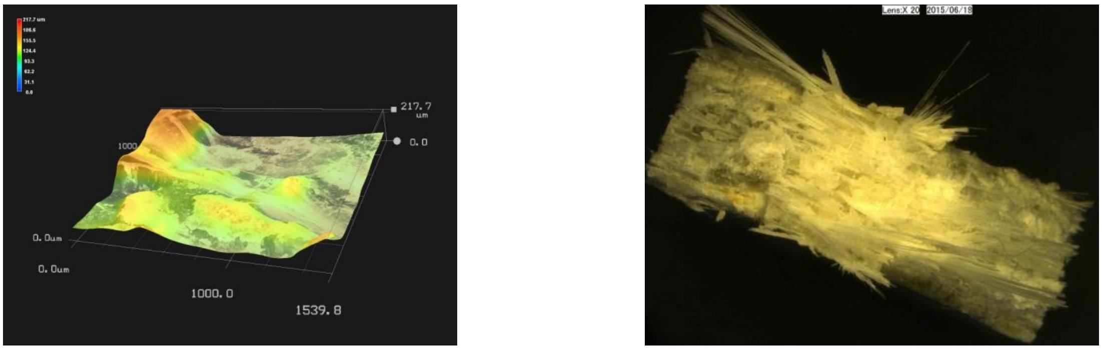


Figure 10. Sectional view for mat glass with 5% Al_2O_3 inserts

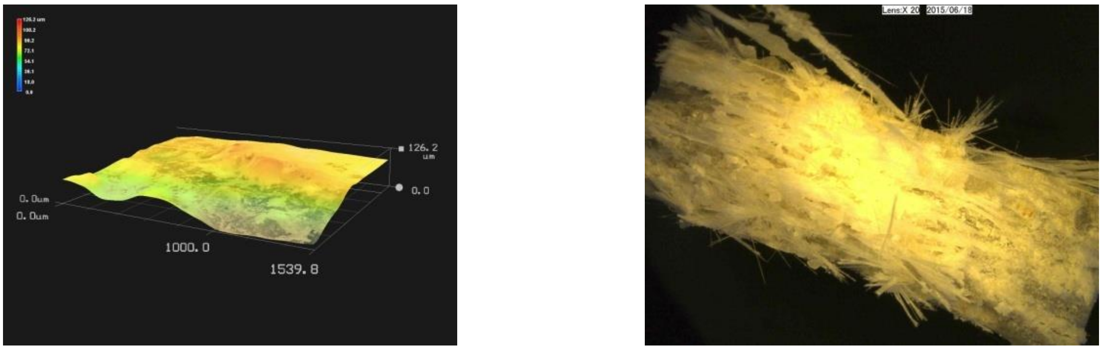


Figure 11. Sectional view for mat glass with 10% Al_2O_3 inserts

Microscopic images taken on the tested specimens revealed the layered structure and distribution of glass fibers and Al_2O_3 inserts. In the case of specimens with 5% Al_2O_3 inserts, the structure showed a relatively homogeneous distribution without major defects, which explains the improved mechanical performance. In the 10% Al_2O_3 specimens, microscopic analysis revealed small inclusions and defects in the composite matrix, which may contribute to a slight decrease in stiffness and flexural strength.

5. CONCLUSIONS

The study of glass-based composites with and without Al_2O_3 inserts showed that the addition of Al_2O_3 particles can have a significant impact on the mechanical properties of the material. Experimental results indicate that:

1. Insertions of 5% Al_2O_3 significantly improved the stiffness and flexural strength of the composites, demonstrating that an optimal concentration of Al_2O_3 can contribute positively to the mechanical performance of the material.

2. Increasing the proportion of Al_2O_3 to 10% did not generate a proportional improvement in mechanical properties, but even led to a slight decrease in bending strength, suggesting a limit to the optimal concentration of inserts to avoid structural inhomogeneities.

3. Microscopic analysis highlighted the impact of the composite structure on the mechanical performance, indicating that a uniform distribution of Al_2O_3 inserts can contribute to more durable and resistant materials.

In conclusion, glass-based composites with a low percentage of Al_2O_3 show potential for applications in fields such as aeronautics, construction and the automotive industry, which require materials with improved mechanical strength. The results of this study provide a basis for future research in optimizing the proportion of inserts in glass-based composites to maximize their mechanical performance and durability in industrial applications.

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