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Composite Material Testing for UAV Development

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Abstract: *Since the invention of the first UAV's, different industries realized it's capabilities and potential uses. Drones and UAV's are part of our everyday life and their development has seen an unprecedented speed due to their multiple applications, from scientific research to military applications. When we talk about UAV's we also talk about composite materials. Today's drones and UAV's are using almost exclusively carbon fiber, glass fiber and 3D printed materials. This paper presents the development and testing of fiber carbon materials along with a future concept of an UAV. In the end of this paperthe results of testing the materials are presented.*

Keywords*: carbon fiber, UAV, 3D printer, matrix*

1. Introduction

The XXI century is characterized by great changes in the aerospace industry, the emphasis falling on fuel economy, on the use of lightweight materials and recyclability. Thus, the performance of the aircraft has improved more and more. At the same time, so-called drones, or unmanned aircraft vehicles, change both everyday life and the field of defense and military applications. In the aerospace field, additive manufacturing (AM) plays an important role in manufacturing technology [1]. The development of new composite materials facilitates the research and development of new types of fuselages, engines and wings with high performance compared to the classic ones [2,3]. This topic is relevant due to the very rapid change in aviation technologies that must be highlighted and considered when designing future aircraft with or without a pilot [4, 5].

Unmanned aerial vehicle (UAV), also popularly known as a drone, is an aircraft that does not have a human pilot on board, its control being carried out by a digital autopilot on board, either from a ground control center or which is in another aircraft or by remote control. UAV performance is limited by short flight time. Sensor accuracy, harsh atmospheric conditions, fixed-wing size and battery endurance are main UAVs vulnerabilities [6]. These issues can be overcome by using high-quality materials [7,8] and the latest generation devices [9, 10].

Drones can generally be divided into two categories depending on the field in which they are used: military drones or civilian drones [11]. Military drones are generally used for espionage, surveillance, reconnaissance, or combative purposes. Depending on the purpose for which they are used, they may have useful task weapons or surveillance and reconnaissance tools. Civilian drones can also be divided into two other general categories: recreational drones or commercial drones. Chord drones are generally used in sports competitions or for FPV (first-person view) flights. Commercial drones are usually used for filming and measuring large areas, scientific research, product deliveries.

Composites generally refer to multiple materials or certain components that are combined in such a way that they behave as a single material. A sandwich structure is a composite material structure that is usually created to be made of whole metal or composite materials, so metal materials can also be considered composite materials [12].

The first composite materials use fiberglass and have become known since the 1930s. They were used in the manufacture of radars and military aircraft of World War II. In the 1960s fiberglass is significantly improved and begins to be used on the control surfaces of the aircraft such as: ailerons, spoilers, elevator [13].

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Carbon fiber. Carbon fiber is usually the main choice for the construction of large contemporary airliners. Carbon fiber (93-95% carbon) is similar to graphite fiber (>95% carbon). Carbon fiber has very good properties: high tensile strength, increased rigidity, and very good resistance to fatigue. Carbon fiber is used in the construction of the primary structures of the plane [14].

In general, carbon fiber can be classified into 5 categories of fiber depending on the modulus of elasticity:

- small modulus of elasticity;
- standard modulus of elasticity;
- intermediate elasticity mode;
- high elasticity mode;
- very high elasticity mode.

Carbon fibers of standard and intermediate mode are high-performance materials due to their rigidity and resistance to increased stress. This type of fiber is generally used for both civilian and military aircraft. Some classic examples of carbon fibers with high elasticity mode are: IM7, IM8, T800, T1000 and IMS. Other examples of carbon fibers with standard elasticity mode are: AS4, T300, T700 and T650 [15].

Composite materials are increasingly used as structural components. A reliable design is possible if material properties are correctly identified [16].

Fiberglass. There are several types of fiberglass: E-glass (electrical grade), S-glass, S2glass (structural grade) as well as other types. When compared to carbon fiber, fiberglass supports a longer elongation until it fails and usually has a high ability to absorb impact. Fiberglass is cheaper than carbon fiber, but its rigidity is lower. The tensile strength of the glass fiber is also lower than in a standard and intermediate mode carbon fiber. Also, the resistance to fatigue is lower than in the case of carbon fiber. Because of these causes fiberglass is not commonly used on the primary structures and coatings of the aircraft, but small planes use this fiber routinely on primary structures [12].

Composite materials have been purposefully created to improve mechanical qualities. The mechanical properties of fiber-reinforced composites are heavily influenced by the volume fraction, fiber orientation, layer sequence, and fiber distribution in the matrix [17, 18].

This paper aims to showcase the manufacturing and testing of carbon fiber and show some results.

2. Materials and methods

Within the Department of Materials and Structures, the Department of Advanced Materials and Tribology, composite materials are analyzed and made, using cold manufacturing processes without autoclave. We proceeded to the realization of structural elements made of composite materials for a UAV-INCAS drone. The elaborate structural elements were the outer shells for the wings, empennage etc. A cold manufacturing technique with resin infusion was used in order to manufacture the plate.

2.1. Preparation of samples for testing

The extraction of carbon fiber test-pieces for carrying out the various tests must not in any way affect its properties, so the material must not undergo pronounced heating.

The following process steps were followed to create the panel:

a. After cleaning the molds with alcohol, a 50 μm and 150 μm polish paste was used to remove defects from the surface where the carbon fiber fabric will be inserted.

b. Wax was used to coat the molds. Five coats were applied at 30 min intervals. The release wax acts as a non-adherent barrier between the surface of the mould and the final parts, which are formed of epoxy resin-impregnated composite materials.

c. The carbon fiber was carefully stretched and aligned, with a 45° orientation. We used the heatgun to dry the fiber after applying a coat of fixing spray. The cutout shape was laid over the carbon fiber, and the carbon fiber was cut to the contour.

d. The cut carbon fiber was applied to the molds in a double layer.

e. The glass fiber and peel-ply were stretched to cut them according to the cut out shape.

The removal of the carbon fiber specimens for the various testing must have no effect on their qualities, and the material must not be overheated. Standardized mechanical test conditions are developed for all polymers, and thermoplastic specimens are obtained through injection moulding.

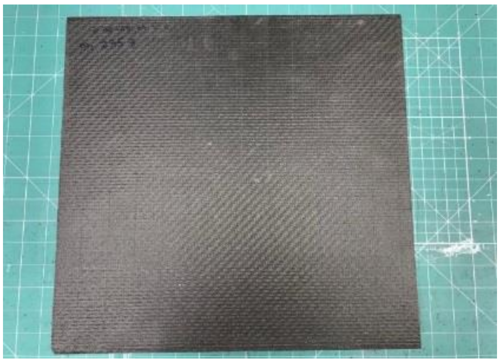

Figure 1. Carbon fiber panel used to analyse the mechanical properties of carbon fiber

For all polymers, standardized mechanical test conditions are established, and in the case of thermoplastic materials, the test-pieces are obtained by injection into the mold.

For the testing of carbon fiber test specimens, ASTM D3039/D3039M – 14 is used [19].

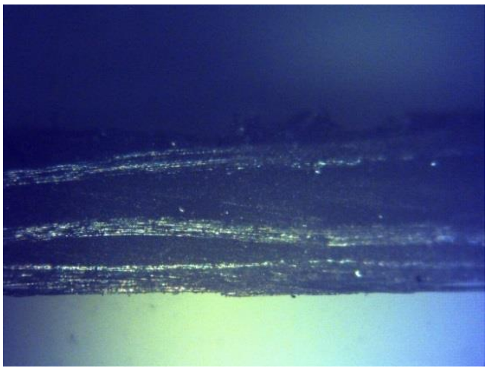

Figure 2. Carbon fiber layers

2.2. Microscopic observations

For the analysis of the tested samples, they will be subjected to imaging investigation using an optical microscope. After the test pieces were tested for bending, an analysis of it in the breakage zones was performed to identify manufacturing defects, as well as the analysis of carbon fiber layers.

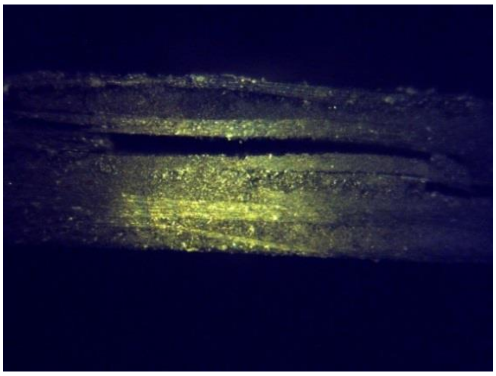

Figure 3. Carbon test piese analysed in the breakage zone after bending test

2.3. Traction test procedure

In the case of a traction test, a test-piece is generally fixed at one end while the second end is displaced with constant speed while measuring the force required producing the deformation and elongation of the sample. Under these conditions, the two quantities, the monitoring of which allows the analysis of the behavior of the material can be determined.

- effort:

$$\sigma = \frac{F}{A} \tag{1}$$

where: F: required force
A: cross-sectional area, if the area is that of the undeformed test-piece

- theoretical deformation:

$$\varepsilon = \frac{L-L_0}{L_0} \tag{2}$$

where:
L_0: length of the test tube before the start of the test
L: the length of the test tube at a time

$$\varepsilon_{real} = \ln(1+\varepsilon) \tag{3}$$

where:
ε_{real} is the real deformation.

when the test-piece is subjected to traction in the z-direction it undergoes contractions along the other two directions, given by relationships of the type:

$$\varepsilon_x = -\nu\varepsilon_z \tag{4}$$

where υ is the Poisson coefficient of the material and the minus sign indicates shrinkage

2.4. Bending test procedure

Bending tests (ISO 1425 standard or ASTM D (790-03) are usually used to determine: bending resistance, bending module or other sizes that derive from effort analysis - deformation when the test-forming is supported on two supports and the loading is carried out in the middle of the distance between the two supports [20].

These tests are applied to test-pieces of loaded or reinforced thermoplastics and thermosetting materials.

- The test piece endures when the bending has a value of 1.5h (MPa);
- Deformation at bending where:

$$-\varepsilon_f = \frac{6sh}{L^2} \quad \varepsilon_{real} = \ln(1+\varepsilon) \tag{5}$$

where:
s - is bending;
h - thickness of the test tube;
L - the distance between the supports

The bend elasticity modulus - is the slope of the linear region of the stress curve - bending deformation can be assessed using the coordinates of two points in this region, with the help of the relation:

$$E_f = \frac{\sigma_{f2} - \sigma_{f1}}{\varepsilon_{f2} - \varepsilon_{f1}} \tag{6}$$

The standard test piece used for bending tests can be formed by molding, extrusion, or casting.

Bending tests are aimed at determining the following parameters:

- Bending effort (MPa), where:

$$\sigma_f = \frac{3FL}{2bh^2} \quad (7)$$

where:

F - the value of the load force module;
L - the distance between the supports;
b - the width of the test tube;
h - thickness of the test tube.

- Bending effort at breakage - the value of the effort at the time of breaking the test-piece (MPa);
- Bending resistance - the maximum value of the bending effort that in the central third of the test-piece.

2.5. Density of carbon fiber

The realizations of various components in aircraft from composite materials are the result of the properties of these materials (wear resistance, fatigue resistance, mechanical strength) and especially of the fact that many of these properties are associated with a small debility.

A representative example is that of polyethylene where knowledge of density leads almost immediately to the correct identification of the mechanical properties of the material.

Density is a physical quantity derived in the International System of Quantities and Units (SI) represents the mass of the unit of volume or, in terms of physical properties, the level of manifestation of the inertia of the place in the space occupied by the body:

$$\rho = \frac{m}{V} \quad (8)$$

$$[\rho]_{si} = \frac{1kg}{m^3} \quad (9)$$

3. Results and discussions

3.1. Tensile analysis

During the test, the following parameters are tracked:

- Test speed - the speed of separation of the test machine's grips (mm/min);
- Theoretical effort - force per unit area of the area of employment, at any moment of time (MPa);
- Flow effort - the first value of the effort for which an elongation occurs without increasing the effort (MPa);
- Tearing effort - the effort when the sample σ_R (MPa) fractures;
- The effort at x % deformation - the value of the effort at which the deformation reaches a value specified in percentage (MPa);
- Tensile deformation - increase in length per unit of initial engagement length, dimensionless size, ε;
- Belt deformation - deformation of the material corresponding to the flow effort, dimensionless size ε_C;
- Deformation at breakage - deformation corresponding to the breaking effort, dimensionless size, ε_R;
- Elasticity module - Young module (MPa);
- Poisson coefficient.

Table 1. Table of sample sizes used for tensile testing

Proof	Length [mm]	Width [mm]	Thickness 1 [mm]	Thickness 2 [mm]	Thickness 3 [mm]	Thickness Medium, [mm]
T1	199	25	1.19	1.19	1.19	1.19
T2	199	25	1.17	1.21	1.17	1.183
T3	199	25	1.22	1.16	1.14	1.173
T4	199	25	1.16	1.13	1.15	1.146
T5	199	25	1.14	1.17	1.19	1.154
T6	199	25	1.22	1.182	1.21	1.204

All tests were carried out using the INSTRON 5982 mechanical testing machine, according to the standards specified in each type of test in the ASTM D3039/D3039M-14 standard. The tests were carried out at room temperature. The test-pieces were fixed in the jaws of the INSTRON 5982 mechanical testing machine and subjected to the request of traction until the maximum total failure force of the test-piece was reached [20].

Tensile performance tests were performed according to ISO-527 or ASTM 3039-93 standards on test-pieces of the following dimensions [20]:

- Length L = 2001 mm, ±
- Width w = 251 mm, ±
- Thickness h = 1.50.4 mm, ±

Axial thrust and deformation were recorded using a digital procurement system from the equipment. The specific voltage-deformation characteristic curves were plotted for a loading speed of 2 mm/min for the first 2 test pieces, then 5 mm/min for the other 2 test pieces at a constant speed throughout the test.

Two sets of test-pieces were compared. The first series of tests contains 3 test pieces and was tested at ambient temperature at a speed of elongation of the test-piece of 5 mm/min.

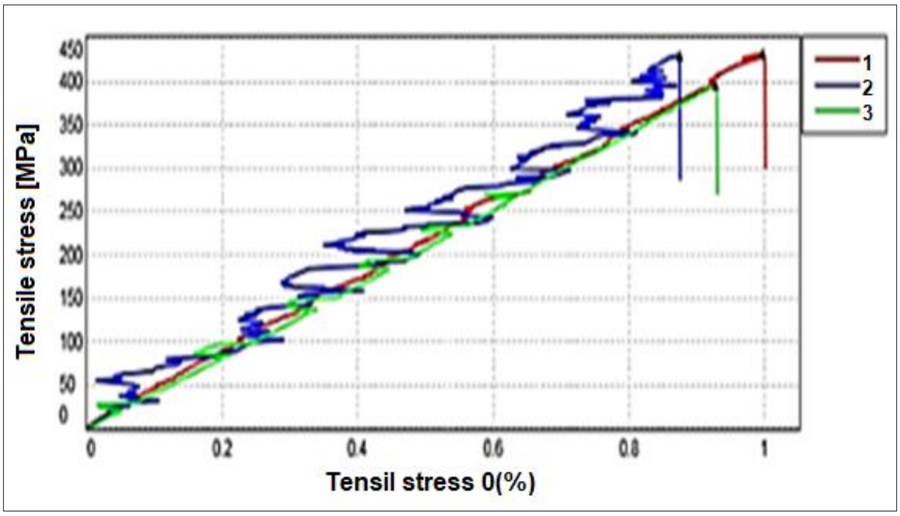

Figure 4. Elongation diagram of samples

Table 2. Properties obtained by 5mm/min testing

Proof	Applied force [kN]	Breaking energy[J]	Young Module[GPa]	Tensile stress [MPa]	Tensile elongation[%]	Poisson coefficient
T1	12.841	3.16	45.314	431.647	0.997	0.018
T2	12.720	2.73	42.275	430.105	0.874	0.316
T3	12.383	2.66	44.361	395.114	0.927	0.213
Standard deviation	0.69	0.27	1.55	20.66	0.06	0.015
Average	12.383	2.85	43.983	418.955	0.933	0.182

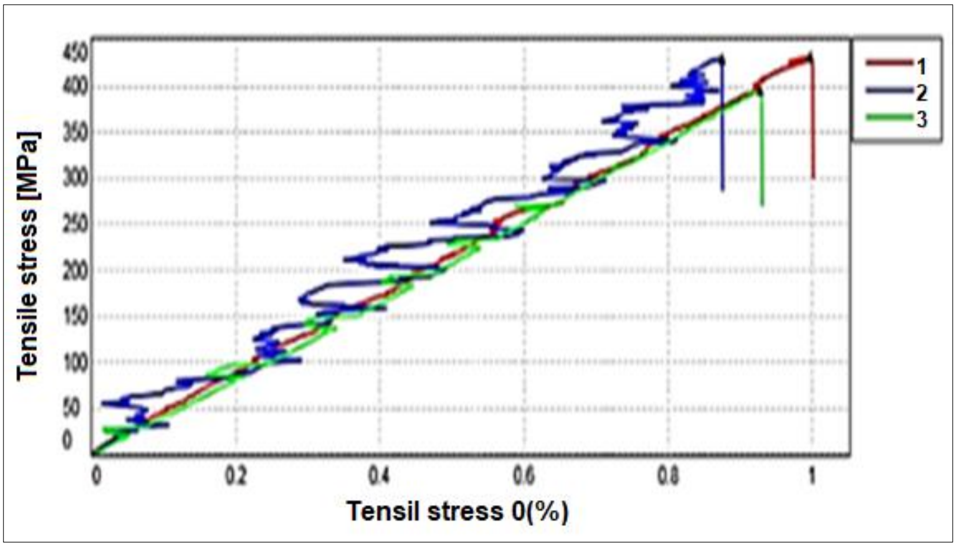

Figure 5. Elongation diagram of samples 2

Table 3. Properties obtained by testing at 2mm/min

Proof	Force applied [kN]	Breaking energy [J]	Young Module [GPa]	Tensile effort [MPa]	Tensile elongation [%]	Poisson coefficient
T4	11.714	2.66	58.375	408.855	0.896	0.397
T5	11.811	2.37	52.150	409.391	0.825	0,071
T6	11.670	2.51	50.860	387.719	0.874	0.430
Standard deviation	0.69	0.27	4.02	12.36	0.04	0.20
Average	11.670	2.37	50.862	401.989	0.865	0.299

Compared to the first test, in the case of a lower elongation speed, the values improve. Compared to the materials that are in the trade, the samples assessed in this case are inferior. This fact is due to the way of manufacture, the choice of material, as well as subsequent defects.

3.2. Bending test

For bending tests, test-pieces with the dimensions from Table 4 were used. The tests were carried out using the mechanical testing machine INSTRON 5982.As in the case of tensile stress, two sets of test-pieces were compared. The first series of tests contains 3 test pieces and was tested at ambient temperature at a speed of elongation of the test-piece of 2 mm/min. For the second test, the speed of elongation of the test pieces was increased to 5mm/min.

Table 4. Table of dimensions of test specimens used for bending testing

Proof	Length	Width	Thickness 1	Thickness 2	Thickness 3	Thickness Medium
I.1	133	15	1.18	1.18	1.19	1.183
I.2	133	15	1.17	1.17	1.18	1.173
I.3	133	15	1.25	1.20	1.22	1.223
I.4	133	15	1.17	1.14	1.17	1.160
I.5	133	15	1.22	1.19	1.21	1.206

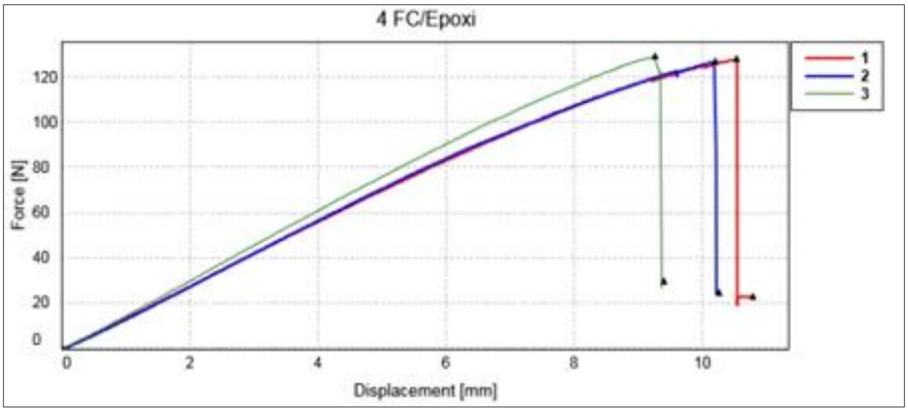

Figure 6. Force-elongation diagram for test specimens tested at 2 mm/min

Table 5. Results of bending testing for a speed of 2 mm/min

Proof	Force applied [N]	Bending resistance [MPa]	Kerning relative to bending [%]	Young Module [GPa]
I1	128.064	585.650	1.825	38.239
I2	126.959	590.536	1.754	40.006
I3	129.268	553.117	1.661	37.803
Standard deviation	1.15	20.34	0.08	1.17
Average	128.097	576.435	1.747	38.683

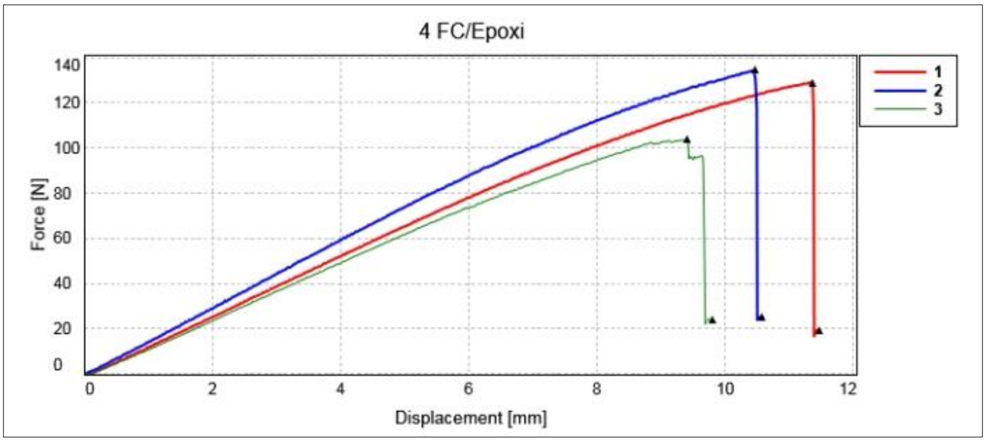

Figure 7. Elongation-force diagram for test specimens tested at 5 mm/min

Table 6. Elongation-force diagram for test specimens tested at 5mm/min

Proof	Force applied, [N]	Bending resistance [MPa]	Kerning relative to bending [%]	Young Module, [GPa]
I4	129.117	614.114	1.933	37.934
I5	134.519	591.927	1.850	37.714
I6	103.768	505.676	1.581	37.875
Standard deviation	16.42	57.29	0.18	0.11
Media	122.468	570.572	1.788	37.841

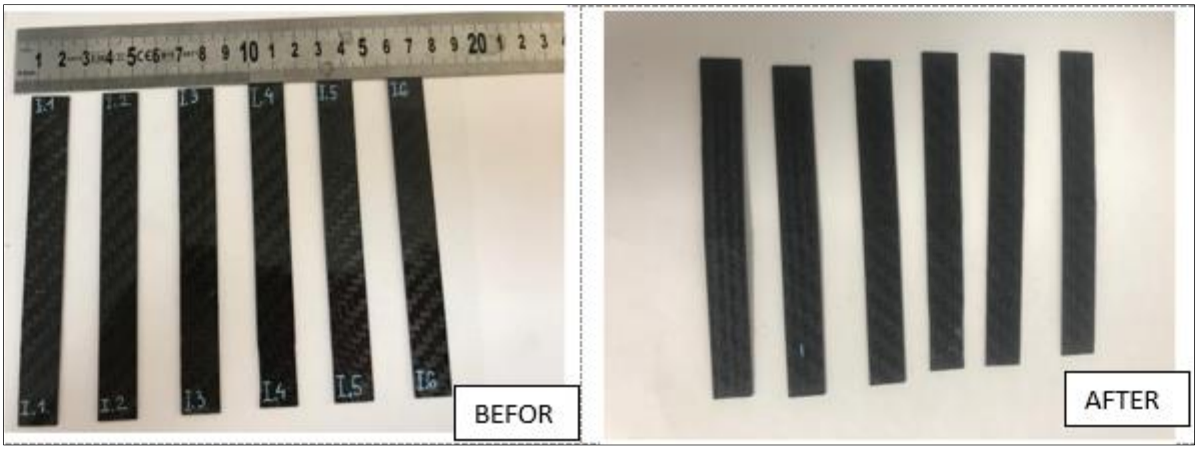

Figure 8. Fiber carbon test samples before and after the bending test

3.3. Carbon fiber density determination

Carbon fiber is a material that is known for its high strength-to-weight ratio and its low density. The typical density of carbon fiber is around 1.75 g/cm^3. A fiber carbon with a density of 1.26 g/cm^3 would be a low-density carbon fiber. This could potentially make it a more lightweight option for applications in aerospace engineering such as the UAV. However, it is important to note that the density of a material is not the only factor that determines its strength and suitability for this application.

Additionally, it's worth noting that the density of fiber is also related to its cost, a lower density fiber is less expensive than a higher density one.

Table 7. Fiber carbon samples density

Thickness [mm]	Volume[V] [mm^3]	Density[ρ] [g/cm^3]
1.183	2360	1271
1.173	2340	1281
1.223	2439	1230
1.160	2314	1296
1.206	2405	1247
ρ= 1.26 g/cm^3		1265

4. Conclusions

This paper aims to demonstrate the process of testing carbon fiber material that used a cold manufacturing process without autoclave for development of materials suitable for UAV's. The results of the bending and the traction test demonstrate that the manufactured carbon fiber is suitable for the construction of a small VTOL. Additionally, we determined the density of the manufactured carbon fiber samples.

Another important aspect worth mentioning is the process of manufacturing cold carbon fiber without an autoclave is that is cheaper and shorter in time duration being useful in the construction of the drone.

Further studies will proceed in the development and designing a VTOL that can use this kind of materials along with 3D printed materials such as PLA or TPU etc. Also, these results will be useful for the FEM analysis that the UAV will undergo in future development.

References

1.KLIPPSTEIN, H., DIAZ DE CERIO SANCHEZ, A., HASSANIN, H., ZWEIRI, Y., SENEVIRATNE, L., Fused Deposition Modeling for Unmanned Aerial Vehicles (UAVs): A Review, *Adv. Eng. Mater*, **20**, 2018, 1700552. https://doi.org/10.1002/adem.201700552.
2.VICTOR GIURGIUTIU, *Structural Health Monitoring of Aerospace Composites*, Elsevier, 2016.

3.MANGALGIRI, P. D., *Composite materials for aerospace applications,* Bulletin of Materials Science, **22**(3), 1999, 657 – 664, https://doi.org/10.1007/BF02749982.
4. PALIK, M., NAGY, M., *Brief history of UAV development*, Repüléstudományi Közlemények, **31**, 2019, 155-166. doi: 10.32560/rk.2019.1.13.
5.NONAMI, K., *Prospect and Recent Research & Development for Civil Use Autonomous Unmanned Aircraft as UAV and MAV,* Journal of System Design and Dynamics, **1**(2), 2007, https://doi.org/10.1299/jsdd.1.120.
6. MOHSAN, S.A.H., KHAN, M.A., NOOR, F., ULLAH, I., ALSHARIF, M.H, *Towards the Unmanned Aerial Vehicles (UAVs): A Comprehensive Review*, Drones, **6**, 2022, 147. https://doi.org/10.3390/drones6060147
7.GARCÍA-GASCÓN, C., CASTELLÓ-PEDRERO, P., GARCÍA-MANRIQUE, J.A, *Minimal Surfaces as an Innovative Solution for the Design of an Additive Manufactured Solar-Powered Unmanned Aerial Vehicle (UAV).* Drones, 6, 2022, 285. https://doi.org/10.3390/drones6100285
8.LIU, J., HUANG, J., ZHANG, C., YU, H., *Topology Optimization and Additive Manufacturing of Fiber-Reinforced UAV Components,* Proceedings of 2021 International Conference on Autonomous Unmanned Systems (ICAUS 2021. ICAUS 2021. Lecture Notes in Electrical Engineering, **861**. Springer, Singapore, 2022. https://doi.org/10.1007/978-981-16-9492-9_268
9.J. KIM, S. KIM, J. JEONG, H. KIM, J. PARK, T. KIM, *CBDN: Cloud-Based Drone Navigation for Efficient Battery Charging in Drone Networks*, IEEE Transactions on Intelligent Transportation Systems, **20** (11), 2019, 4174-4191, doi: 10.1109/TITS.2018.2883058.
10.S. ZHANG, H. ZHANG, B. DI, L. SONG, *Resource allocation and trajectory design for cellular UAV-to-X communication networks in 5G*, Proc. IEEE GLOBECOM, 2018, 1-6.
11.ABRO, G.E.M., ZULKIFLI, S.A.B.M., MASOOD, R.J., ASIRVADAM, V.S., LAOUTI, *A. Comprehensive Review of UAV Detection, Security, and Communication Advancements to Prevent Threats*.Drones, **6**, 2022, 284. https://doi.org/10.3390/drones6100284
12.BRIAN Esp, *Practical Analysis of Aircraft Composites,* Grand Oak Publishing, 2017, ISBN-0983245398
13.MRÁZOVÁ, MÁRIA, Advanced composite materials of the future in aerospace industry, INCAS Bulletin, 5, 2013, 139-150.
14.C. SOUTIS, *Carbon fiber reinforced plastics in aircraft construction*, Materials Science and Engineering: A, **412 (**1–2), 2005, 171-176, https://doi.org/10.1016/j.msea.2005.08.064.
15.SHUGO D., YOSHIAKI A., TOMONAGA O., *Effects of fiber properties on aerodynamic performance and structural sizing of composite aircraft wings*, Aerospace Science and Technology,**124**, 2022, https://doi.org/10.1016/j.ast.2022.107565.
16.GHOLIZADEH, S, *Impact behaviours and Non-Destructive Testing (NDT) methods in Carbon Fiber Composites in Aerospace Industry: A Review*, 2022, DOI: 10.22541/au.164502808.88072147/v1
17. IVICA KOŽAR, NEIRA TORIĆ MALIĆ, DANIJEL SIMONETTI, ŽELJKO BOŽIĆ, *Stochastic properties of bond-slip parameters at fibre pull-out*, Engineering Failure Analysis, Volume 111, 2020, 104478, ISSN 1350-6307, https://doi.org/10.1016/j.engfailanal.2020.104478.
18.SPYRIDON KILIMTZIDIS, ATHANASIOS KOTZAKOLIOS, VASSILIS KOSTOPOULOS, *Efficient structural optimisation of composite materials aircraft wings*, Composite Structures, Volume 303, 2023, 116268, ISSN 0263-8223, https://doi.org/10.1016/j.compstruct.2022.116268.
19. ***ASTM, *ASTM D3039/D3039M*, Annu. B. ASTM Stand., 1–13, 2014, doi: 10.1520/D3039
20. ***ASM Material Data Sheet http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=MA6061T6 (accessed on 01.02.2023)

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