9th International Congress of the
Serbian Society of Mechanics
July 5-7, 2023, Vrnjacka Banja, Serbia

# Book of Proceedings

The Ninth International Congress
of the Serbian Society of Mechanics
July 5-7, 2023,  Vrnjačka Banja, Serbia

# The Ninth International Congress of the Serbian Society of Mechanics, July 5-7, 2023, Vrnjačka Banja, Serbia – Book of Proceedings

**Editor**
Professor Nenad Filipović
Professor Miloš Kojić

**Technical Editor**
Đorđe Dimitrijević

**Proofreaders**
Neda Vidanović Miletić
Milena Đorđević
Marijana Dimović

**Year of publication**
2023

**ISBN-978-86-909973-9-8**

9th International Congress of the Serbian Society of Mechanics
July 5-7, 2023, Vrnjačka Banja, Serbia

# EXPERIMENTAL AND NUMERICAL ANALYSIS OF THE STRENGTH OF A DRONE ARM MADE OF COMPOSITE MATERIAL

**Petar R. Ćosić[1], Miloš D. Petrašinović[1], Aleksandar Grbović[1], Danilo Petrašinović[1], Mihailo Petrović[1], Veljko Petrović[1], Nikola Raičević[1] and Boško Rašuo[1]**

[1] Faculty of Mechanical Engineering, University of Belgrade, Kraljice Marije 16, 11120 Belgrade 35, Serbia
e-mail: cpetar112@gmail.com, mpetrasinovic@mas.bg.ac.rs, agrbovic@mas.bg.ac.rs, dpetrasinovic@mas.bg.ac.rs, petrovicmiha@gmail.com, vpetrovic@mas.bg.ac.rs, nraicevic@mas.bg.ac.rs, brasuo@mas.bg.ac.rs

## Abstract

Aerospace engineering, as a field in which the reduction of mass has always been one of the primary tasks of its engineers, has made significant progress as a result of numerous developments and advancements in the field of composite materials in the sense of gaining large benefits from the relatively low density that characterizes composites. In the spirit of the increasing use of composite materials on aerospace structures, in this paper we will conduct an experimental and numerical analysis of the strength of a drone arm made of a composite material. Every method of analysis, whether it is analytical, numerical, or experimental, has some advantages and disadvantages. Experimental results are easily affected by random and instrumental errors and numerical methods are highly affected by the chosen physical model. In order to obtain the most reliable analysis solution, a mixture of numerical analysis backed up by experimental data is required. In the hope of bypassing the expensive and time-consuming experiments in the future, in this paper we will conduct a numerical analysis on a drone arm made of composite materials which will then be replicated by an experiment verifying its validity.

**Keywords**: composites, composite materials, drones, UAV, structural analysis, numerical analysis, experimental analysis.

## 1. Introduction

Due to their high specific strength ratio, relatively low density, and many other advantages, composite materials have found application in various fields of engineering and applied sciences and continue to be used more and more intensively as production processes develop and enable the production of composite parts without (or with less) manual labor. As mentioned before, aerospace engineering, in particular, has had significant benefits from the properties that characterize composite materials. In the case of drones and UAVs, composite materials play an even greater role in the task of improving their performance. Since UAVs are unmanned vehicles, they rely on sensors, cameras, and other electronics that are powered by batteries which have a large drawback in the form of large relative mass, which along with the mass of sensors, cameras, and electronics drastically affect the overall performance of UAVs. With this in mind, it is easy to understand why composites are so heavily used on drones and UAVs today [1].

The specific composite drone arm that we are going to be analyzing in this paper can be seen in Fig. 1 (a) along with its CAD model (b). As far as materials are concerned, the arm is made out of woven epoxy-carbon fabrics whose thickness is 0.21 mm.

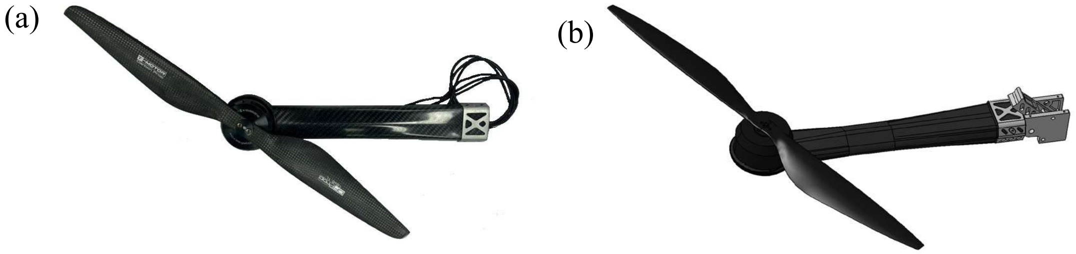

**Fig. 1.** Drone arm assembly.

## 2. Experimental analysis

Before presenting the plan of the experiment, it is necessary to give a more detailed breakdown of the scaffolding and the elements on which the experiment is going to be carried out. Figure 2 shows the CAD model of the scaffolding and the main elements connected to it.

One of the crucial elements of the experimental setup is the force loading joint which has the task of applying the load on the drone arm in such a way that it mimics the actual surface loading produced by the thrust force of the propeller. The actual value of the force being applied on the drone arm can be measured using a load cell, while the displacement can be measured using a displacement transducer.

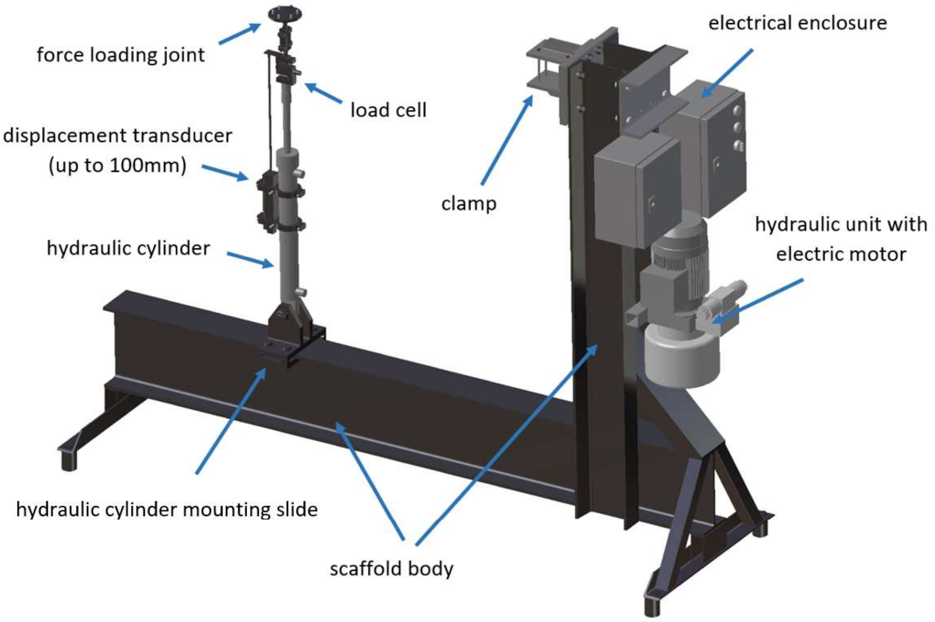

**Fig. 2.** Scaffolding and main elements.

To simulate the arm-body connection, we can fix one end of the arm in a way that can be seen in Fig. 3. The other end of the arm will be connected to the force loading joint that is, as mentioned, going to attempt to simulate the effect of the propeller's thrust force.

Once we have the drone arm set up, we can connect all the necessary equipment needed for data acquisition (Fig. 4).

The data we are aiming to extract from this experiment is the change in intensity of force in time acquired by the load cell and the change of displacement in time collected from the displacement transducer.

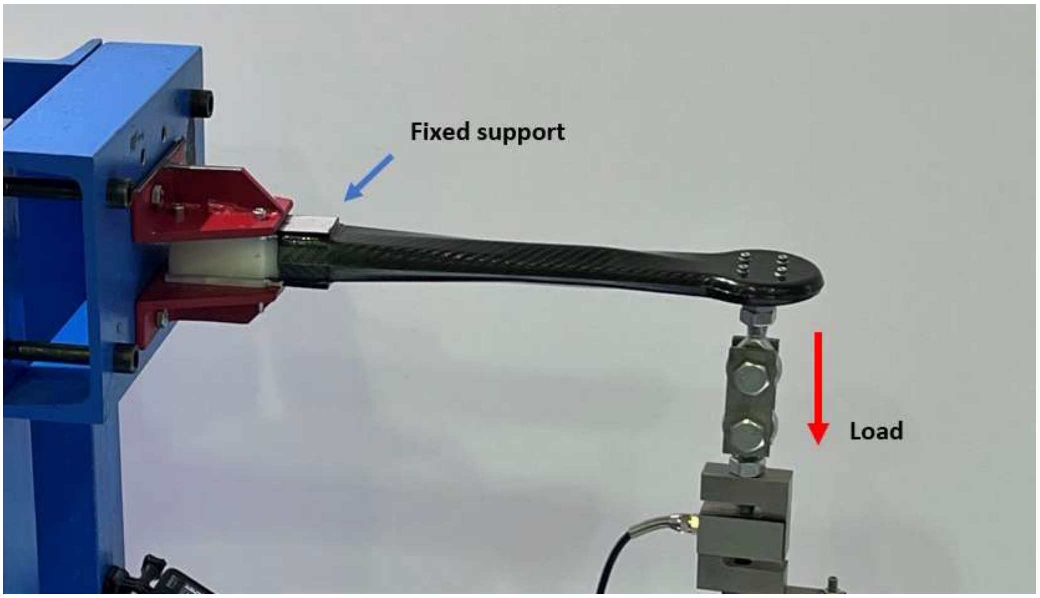

**Fig. 3.** Loads and constraints.

Once we have the data collected, we can form the connection between the force applied and the displacement produced by removing time from consideration. This connection is what is of crucial value as we are going to try to verify the numerical results that give us the mentioned force-displacement connection.

**Fig. 4.** Experiment setup.

*2.1 First experiment – applying the force on the arm until failure*

The first experiment will consist of applying force on the drone arm until failure. We can then repeat this four times while monitoring the force-displacement correlation.

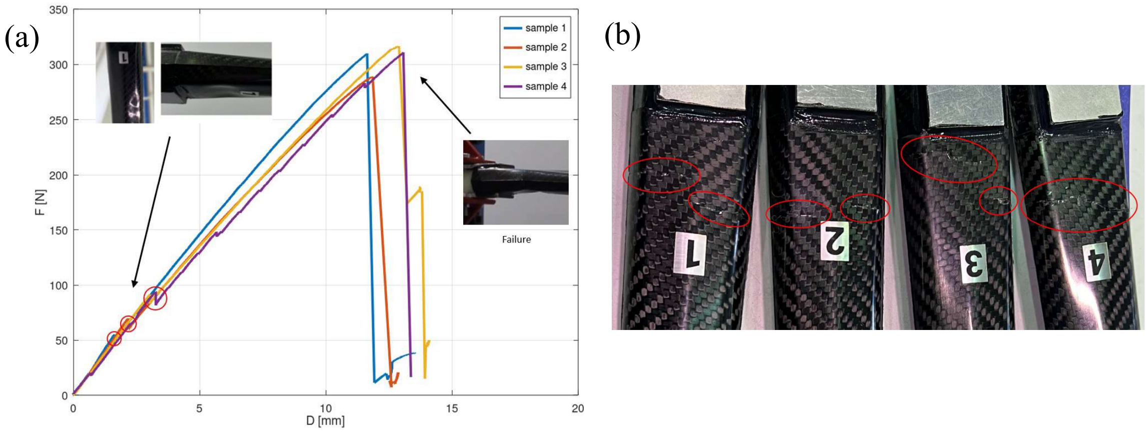

**Fig. 5.** First experiment results (a) Force-displacement graph and (b) failure location.

On the graph shown in Fig. 5 (a), we can see that failure occurs at roughly 320 N of force. Another interesting thing to notice in this experiment is that for all four samples, failure occurs on the lower part at the base of the arm Fig. 5 (b).

### *2.2 Second experiment – periodically loading and unloading the arm*

Now that we roughly know the force at which our drone arm breaks, we can reduce the applied force (approximately 1/1.5 of its maximum intensity) and periodically load and unload the arm so we can produce a clear force-displacement correlation.

Once we execute this, the data acquired from the sensors will give us the results of the experiment in the form of a set of data that can be represented in the form of three graphs. The first graph shows us the force-time correlation (Fig. 5 (a)), the second one displacement-time correlation (Fig. 5 (b)), and the last graph gives us the key force-displacement correlation (Fig. 6).

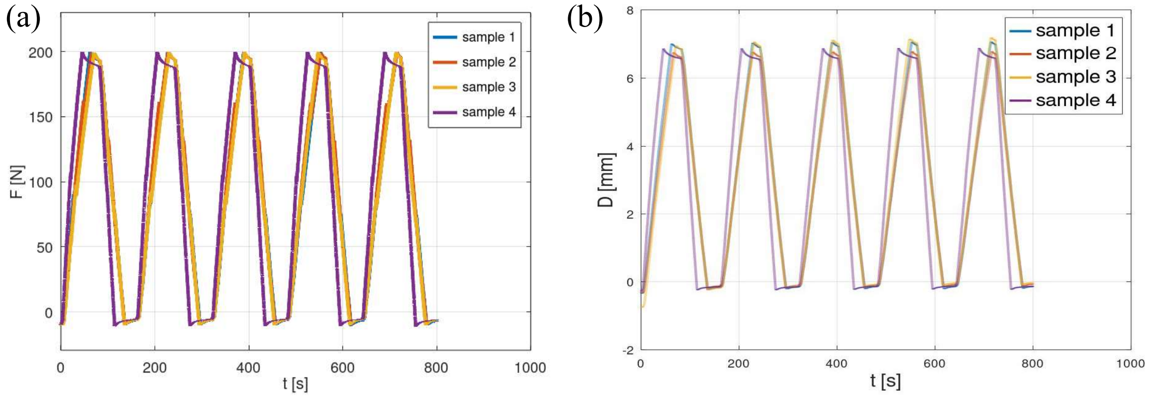

**Fig. 6.** (a) Force-time graph and (b) displacement-time graph.

Given that we periodically loaded and unloaded the drone arm, on the graph shown in Fig. 6 (a) we can see the occurrence of a slight hysteresis that is the consequence of the dependence of the behavior of the arm on the history of its state.

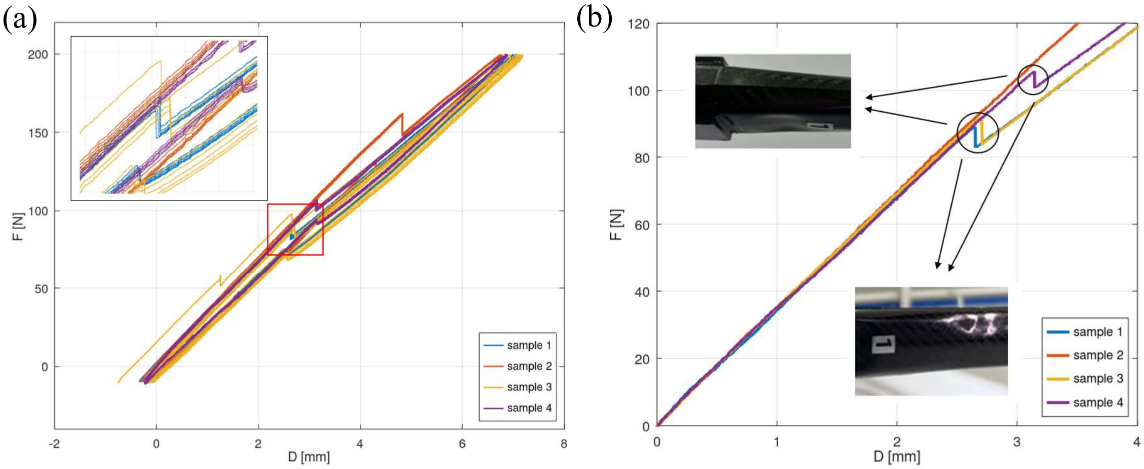

**Fig. 7.** Force-displacement graph (a) original and (b) filtered.

We are currently not interested in the unloading behavior of the arm so we can filter the results and only show the loading part in the domain that is of interest to us (Fig. 6 (b)).

As we can see in Fig. 6 (b), another anomaly occurs in our analysis in the form of a discontinuity of the linear part as a consequence of slight buckling of the structure of the arm.

Although this is an interesting occurrence, it is not a serious obstacle in our analysis as we are only interested in the linear part from 0 up to 75 N (50 N with a safety factor of 1.5) as that is the domain in which our drone arm is going to be exploited in.

## 3. Determining the mechanical characteristics of the material

Given that we are going to be conducting a numerical analysis with FEM software, we will need the information on the mechanical characteristics of said material which forces us to conduct an experiment using a tensile test machine in the hope of determining their value.

The first part of the analysis will consist of determining the needed mechanical characteristics of the material using a tensile test machine and the appropriate test samples composed of the same epoxy-carbon woven composite material that the drone arm is made of (Fig. 8).

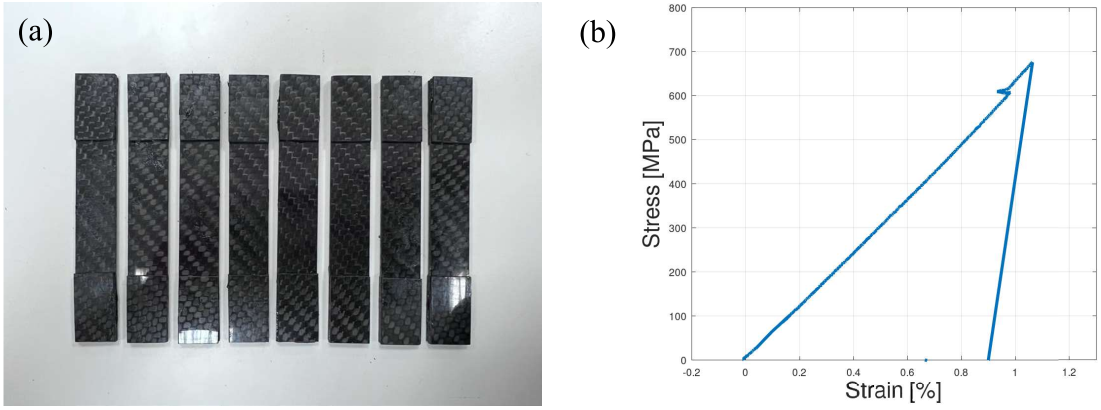

**Fig. 8.** Test samples (a) and the representative Stress-Strain graph (b).

Out of all the test samples shown in Fig. 8 (a), the behavior of the most representative one can be seen in Fig. 8 (b). Given that we are going to be conducting a numerical analysis in the ANSYS environment, we will need a value of Young's modulus which for the given material based on the experiment conducted on the tensile test machine is 61 GPa, more specifically, given that we are working with woven fabrics, both modulus E1 and E2 are going to have a value of 61 GPa. Even though, as some of the authors have already shown in [2], elastic properties of carbon fiber reinforced composites vary with temperature changes, in this analysis these properties will have a constant value.

## 4. Numerical analysis

Now that we have gathered the results from the experimental analysis, we can try to recreate the analysis but this time in a numerical way. In this chapter we will briefly show the process of conducting the numerical analysis. The end goal of this analysis is to gather the data that will allow us to verify the numerical analysis which should produce the same results as the experimental one.

The numerical analysis that is presented was carried out in the ANSYS environment according to the following plan. Firstly, we can analyze the constraints and the loads that the drone arm is subjected to. Then we can extract the adequate geometry from the CAD model of the entire drone arm assembly in accordance with the considered physicality of the problem (Fig. 9).

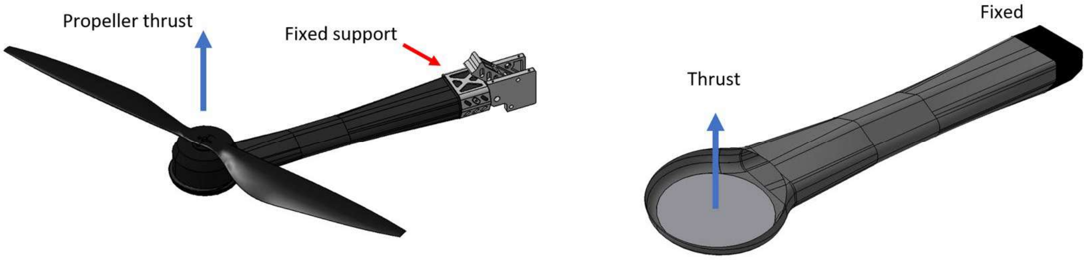

**Fig. 9.** Loads and constraints.

As can be seen in Fig. 9, we can approximate the fixed support of the arm by restricting all translations and rotations on part of the drone arm that the support is applied on [3].

In the case of loads, the only force acting on the arm is the thrust force of the propeller [4]. Given that we are trying to replicate the conducted experiment, we need to model the entire assembly so we can apply the appropriate contacts while conducting the numerical analysis (Fig. 10).

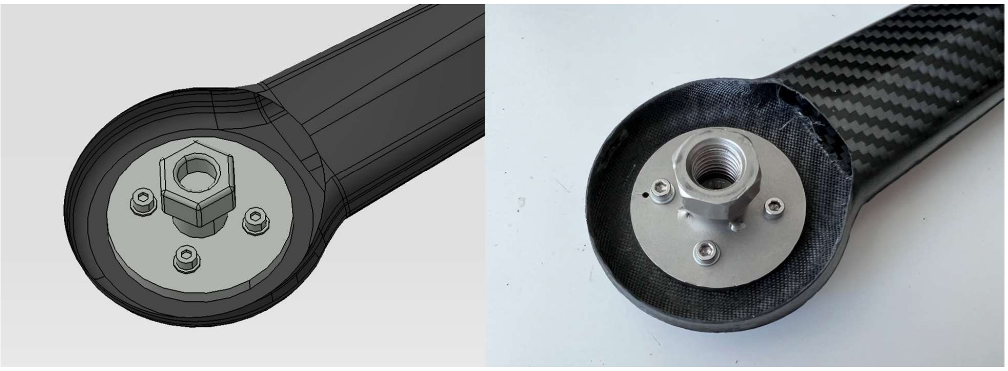

**Fig. 10.** Model of the attachment part used for creating appropriate contacts.

The next step is to form the fabrics and the laminate stackups by following the number of layers that are, for the specific drone arm that we are going to be observing, placed in the way that can be seen in Fig. 11.

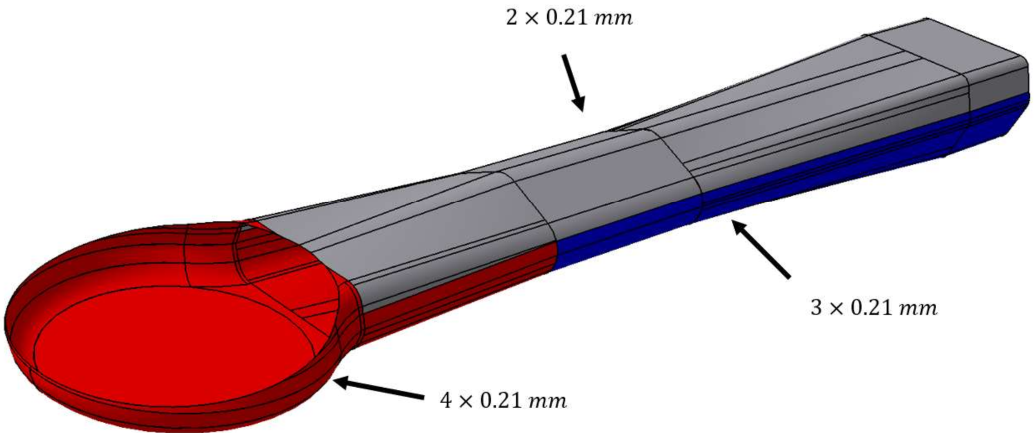

**Fig. 11.** Number of layers on a given section.

In order to be able to assess the accuracy of the fiber orientation, we can simultaneously display the actual sample arm and the simulation model (Fig. 12) and compare the fiber orientation in both cases. In Fig. 12, we can notice that the fibers are, in both cases, oriented along and perpendicular to the arm's length.

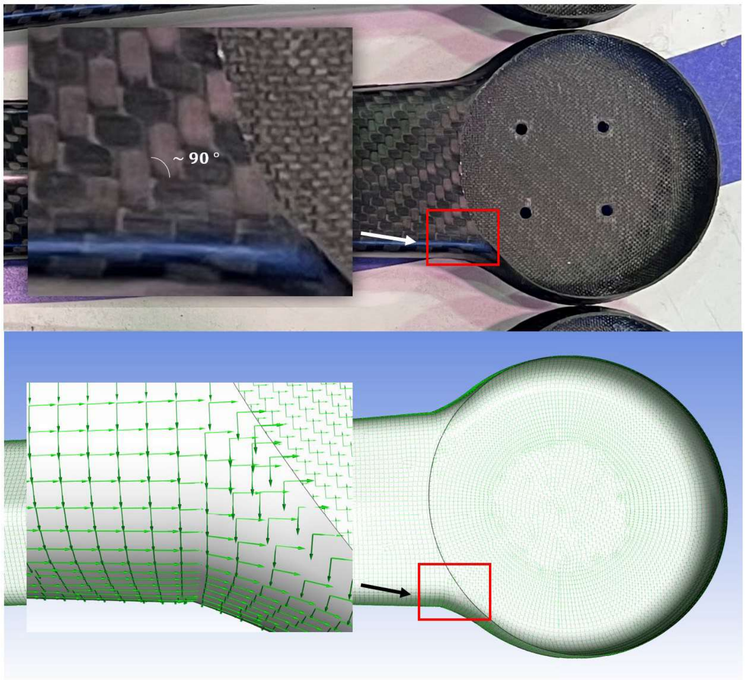

**Fig. 12.** Fiber orientation validation.

## 5. Results verification

The crucial part of this paper is the verification of the results of the numerical analysis with the experimental data. The best way to do this is to form the linear part of the force-displacement curve using the numerical model that we previously formed. We can do this by forming two points and drawing a line through them. We can acquire these points [displacement, force] by loading our drone arm with a force of an arbitrary intensity and reading the displacement value of the appropriate node (Fig. 13 (a)). Once this is done twice, there are two points in a plane from which a numerically produced linear part can be formed (Fig. 13 (b)).

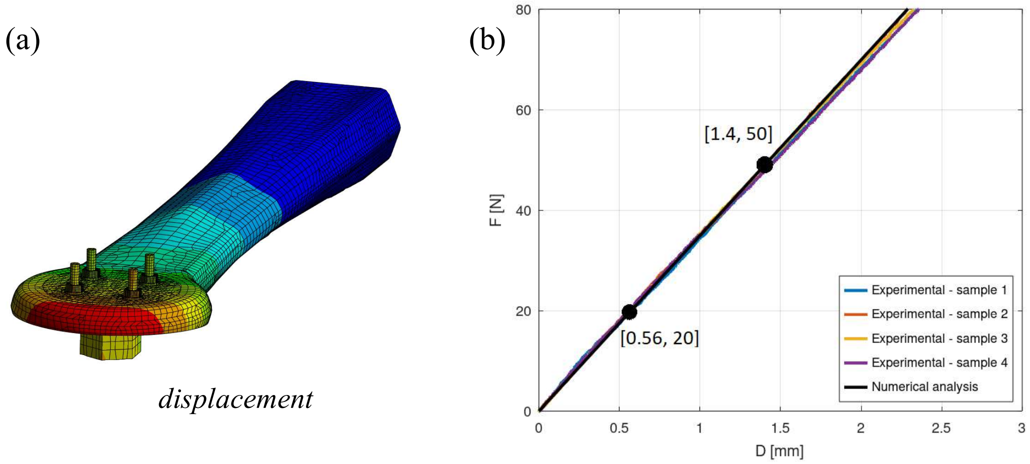

**Fig. 13.** Results verification (a) ANSYS simulation and (b) Force-displacement comparison.

## 6. Conclusions

As we can see in Fig. 13 (b), the slope of the numerical curve is roughly the same as the slope of the experimental one which tells us that the numerical model is correctly formed and is valid for further use. The validity of this analysis allows us to bypass the entire expensive and risky experimental process, and it allows us to safely conduct the numerical analysis for any given geometry without worrying about the validity of the results. Another important thing that we concluded in this paper is the load at which the arm will break. This data on the maximum load is important both for practical reasons of drone exploitation and for future failure analyses.

## References:

[1] Sönmez M., Pelin C.E, Georgescu M., Pelin G., Stelescu M.D., Niruica M., Stoian G., Alexandrescu L., Gurau. D., *Unmanned Aerial Vehicles – Classification, Types of Composite Materials Used in Their Structure and Applications,* ICAMS 2022 – 9th International Conference on Advanced Materials and Systems, https://doi.org/10.24264/icams-2022.I.11

[2] Taha S. A., Petrović V., Grbović A., Lozanović-Šaljić J., Balać I., *Numerical Evaluation of the Elastic Properties of Carbon Fiber Reinforced Composite Material at Elevated and Lowered Temperatures,* Science of Sintering, Vol 53, 127-136, 2021.

[3] Brischetto S., Torre R., *Preliminary Finite Element Analysis and Flight Simulations of a Modular Drone Built through Fused Filament Fabrication,* J. Compos. Sci. 2021, 5, 293. https://doi.org/10.3390/jcs5110293

[4] Bahrom M. Z., Manshoor B., Zain B.A.M., Zaman I., Didane D.H., Haq R.H.A., Ibrahim M.N., *Thrust Force for Drone Propeller with Normal and Serrated Trailing Edge,* Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 101, Issue 1 (2023) 160-173.