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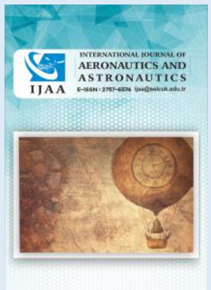

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Research Article / Araştırma Makalesi

Analysis of a UAV propeller produced by various materials / Çeşitli malzemelerle üretilen bir İHA pervanesinin analizi

Süreyya Sevinç Varol[1*], Mehmet Emin Çetin[2], Mesut Uyaner[2], Bilge Albayrak Çeper[1]

[1]*Department of Astronautical Engineering, Faculty of Aeronautics and Astronautics, Erciyes University, Kayseri, Türkiye*
[2]*Department of Aeronautical Engineering, Faculty of Aeronautics and Astronautics, Necmettin Erbakan University, Konya, Türkiye*

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ABSTRACT

Recently, Unmanned Aerial Vehicle (UAV) systems have started to attract great interest worldwide. With the orientation of the technology sector to this field, studies on UAV systems have gained momentum. Propellers, which are an important part of UAV systems, are of great importance to the propulsion system of the aircraft. Deformations that may occur, especially in propellers that are expected to have high strength, greatly affect flight safety. In this study, a two-bladed propeller model measuring 12 inches was created. The deformations caused by applying force to the created propeller model were examined. In this study, CFRP (Carbon Fiber Reinforced Polymer) and PLA (Polylactide Acid) materials were preferred. The mechanical properties of materials are defined in the ANSYS program. As a result of the force applied to the propeller model, the amounts of deformation occurring in CFRP and PLA materials have been obtained. At the end of the study, the difference between the properties of the two materials was discussed.

ÖZET

Son zamanlarda insansız Hava Aracı (İHA) sistemleri dünya çapında büyük ilgi görmeye başlamıştır. Teknoloji sektörünün bu alana yönelmesiyle İHA sistemleri üzerine çalışmalar hız kazanmıştır. İHA sistemlerinin önemli bir parçası olan pervaneler, uçağın tahrik sistemi için büyük önem taşımaktadır. Özellikle yüksek mukavemete sahip olması beklenen pervanelerde oluşabilecek deformasyonlar uçuş güvenliğini büyük ölçüde etkiler. Bu çalışmada 12 inç ölçülerinde iki kanatlı pervane modeli oluşturulmuştur. Oluşturulan pervane modeline kuvvet uygulanmasıyla oluşan deformasyonlar incelenmiştir. Bu çalışmada CFRP (Karbon Fiber Takviyeli Polimer) ve PLA (Polilaktik Asit) malzemeler tercih edilmiştir. Malzemelerin mekanik özellikleri ANSYS programında tanımlanmıştır. Pervane modeline uygulanan kuvvet sonucunda CFRP ve PLA malzemelerinde meydana gelen deformasyon miktarları belirlenmiştir. Çalışmanın sonunda iki malzemenin özellikleri arasındaki fark tartışılmıştır.

* Corresponding author, e-mail: sureyyavarol@erciyes.edu.tr

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1. Introduction

Propeller propulsion system in aircraft is of great importance as it affects parameters such as flight range, duration and power consumption [1]. These subsystems, which provide acceleration of aircraft, can be subjected to high stress instantaneously. Due to the shape of the propeller blades, accurate calculation of the stresses is very difficult [2]. Determining where and how much stress under a certain force at the propeller is important for propeller performance. In addition, propellers must be manufactured in such a way that they can withstand these loads to be used safely. Different materials are used to produce high-strength propellers depending on the area of use.

There are many studies in the literature on the strength of different materials. Yeh (2020) printed PLA and Carbon Fiber Composite materials with Fused Deposition Modeling (FDM) method. Standard tests were applied on the models created. As a result of the tests, Carbon Fiber Composite material was found to be six times more durable than PLA [3]. Ramesh et al. (2020) compared the strength of propellers modeled with Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) materials. In addition, material optimization was performed using two advanced numerical methodologies (Fluid-Structure Interaction (FSI) and Moving Reference Frame (MRF)). At the end of the study, it was found that the strength of GFRP material was higher [4]. Jayakumar et al. (2024) designed a drone with a coaxial propeller in their study. The propeller designed in the study was modeled with CFRP, GFRP and titanium materials. Numerical analysis of the modeled propellers was performed and material strengths were compared. As a result of the comparison, titanium material has lower total deformation, normal and equivalent stress. In the light of the data obtained, titanium material was found to have the best performance [5]. Uddin et al. (2021) compared Nickel Aluminum Bronze (NAB) and composite (CFRP and GFRP) materials on a ship propeller. Maximum principal stress, maximum principal strain, equivalent stress, equivalent strain values were calculated with structural analysis. As a result of the study, it was observed that the deformation amount of CFRP material was lower compared to other materials [6]. Siddarth et al. (2023) compared CFRP and GFRP materials. As a result of the study, it was observed that GFRP material deformed more than CFRP material. Considering the strength and thermal properties, it was concluded that CFRP material is more preferable than GFRP [7]. Arivalagan et al. (2023) performed structural analysis on turbine blades produced by 3D printing method. In the study, the structural properties of PLA and ABS (Acrylonitrile Butadiene Styrene) materials were compared. As a result of the study, PLA material was found to have better structural properties compared to ABS [8].

In this study, the stresses on a two-blade UAV propeller made from CFRP and PLA materials were investigated and the material strengths were compared. The new propeller model was designed and the materials were defined as anisotropic materials. By defining the materials as anisotropic, the results are aimed to be close to reality. During this investigation, SolidWorks software was used for propeller design and ANSYS software was preferred for mechanical analysis.

2. Material and Methods

2.1. Materials

Composite materials are lightweight and durable materials obtained by combining different materials and used in various sectors. These materials consist of matrices and fibers in matrices. Matrices are used to maintain geometric order and transfer the load acting on the material to the fibers [9]. Composites have many advantages which are high impact resistance, high thermal resistance and high wear resistance [10]. For these reasons, composite materials are widely used in many industries such as aerospace, automotive, construction and sporting goods. For the CFRP material properties given in Table 1, Ref. [11] was utilized.

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Table 1. Material properties of CFRP

Properties	Values
Density (ρ)(kg/m^3)	1600
Young's Modulus E_X (GPa)	120
Young's Modulus E_Y (GPa)	10
Young's Modulus E_Z (GPa)	10
Poisson's Ratio NU_{XY}	0.16
Poisson's Ratio NU_{YZ}	0.2
Poisson's Ratio NU_{ZX}	0.16
Rigidity Modulus G_{XY} (GPa)	5.2
Rigidity Modulus G_{YZ} (GPa)	3.8
Rigidity Modulus G_{ZX} (GPa)	6

PLA is a thermoplastic polymer derived from biodegradable and renewable resources. It is usually obtained by polymerization of lactic acid produced from plant sources such as corn starch or sugar cane [12]. This way, PLA is considered an environmentally friendly material and is seen as a potential alternative to replace traditional petroleum-derived plastics. PLA has the advantages of light weight, biocompatibility and good mechanical properties [13]. For the PLA material properties given in Table 2, Ref. [14] was utilized.

Table 2. Material properties of PLA

Properties	Values
Density (ρ)(km/m^3)	1.24
Please check Young's Modulus E_X (MPa)	2444
Young's Modulus E_Y (MPa)	2864
Young's Modulus E_Z (MPa)	2864
Poisson's Ratio NU_{XY}	0.35
Poisson's Ratio NU_{YZ}	0.35
Poisson's Ratio NU_{ZX}	0.35
Rigidity Modulus G_{XY} (MPa)	1040
Rigidity Modulus G_{YZ} (MPa)	1040
Rigidity Modulus G_{ZX} (MPa)	1040

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2.2. Methods

2.2.1. Propeller design

In this study, the behavior of a UAV propeller with different materials defined under a certain force is investigated. Within the scope of the study, an original design was used in the propeller model. NACA 2412 was used as the airfoil structure in the propeller. The airfoil structure is given in Figure 1. The propeller is modeled as a 12 inch long UAV propeller in SolidWorks program. The model consists of 5 stations. The airfoil angle at each station is 14, 37, 34, 20 and 5 degrees from root to tip, respectively. The propeller model is given in Figure 2.

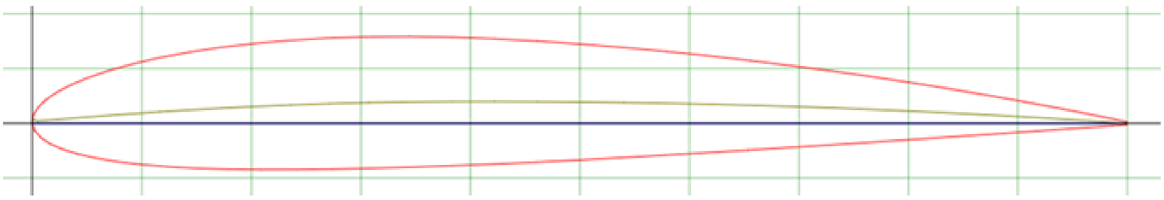

Figure 1. The appearance of the NACA 2412 airfoil used

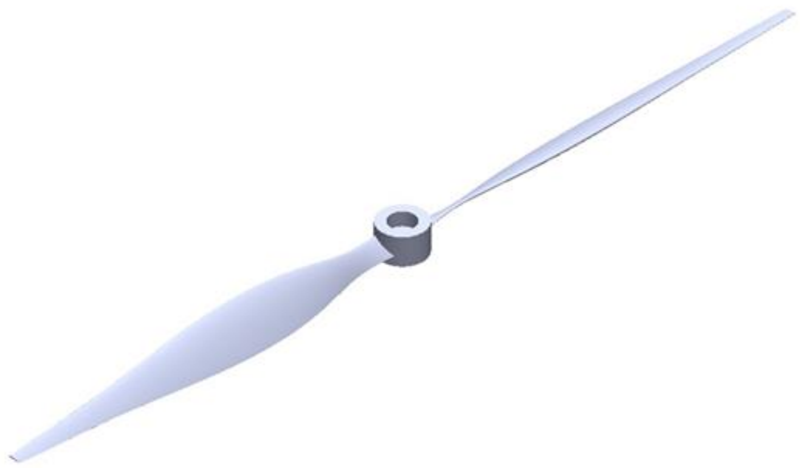

Figure 2. The designed propeller model

2.2.2. Structural analysis

ANSYS software was used for numerical analysis. The mechanical properties of CFRP and PLA materials were defined in the program. A 10 mm mesh was placed on the propeller model. In order to determine the optimum element size, analyses were performed with mesh models of 5 mm, 8 mm, 10 mm, 12 mm, 15 mm and 18 mm using CFRP material. The results obtained are given in Table 3. When the results were examined, it was seen that the values were close to each other and it was decided to use 10 mm mesh size for the analysis. The mesh model is shown in Figure 3.

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Table 3. Analysis results according to mesh sizes

Properties	5 mm	8 mm	10 mm	12 mm	15 mm	18 mm
Total Deformation (mm)	160.54	160.55	**160.33**	160.52	160.49	160.49
Directional Deformation (mm)	83.811	83.763	**83.737**	83.806	83.803	83.803
Equivalent Elastic Strain (mm/mm)	0.040063	0.040068	**0.040076**	0.04005	0.04008	0.04008
Maximum Shear Elastic Strain (mm/mm)	0.043479	0.043484	**0.043498**	0.043502	0.04351	0.04351
Equivalent Stress (MPa)	362.13	362.23	**362.24**	361.91	32.29	362.29
Maximum Shear Stress (MPa)	182.06	182.06	**182.09**	182.03	182.1	182.1

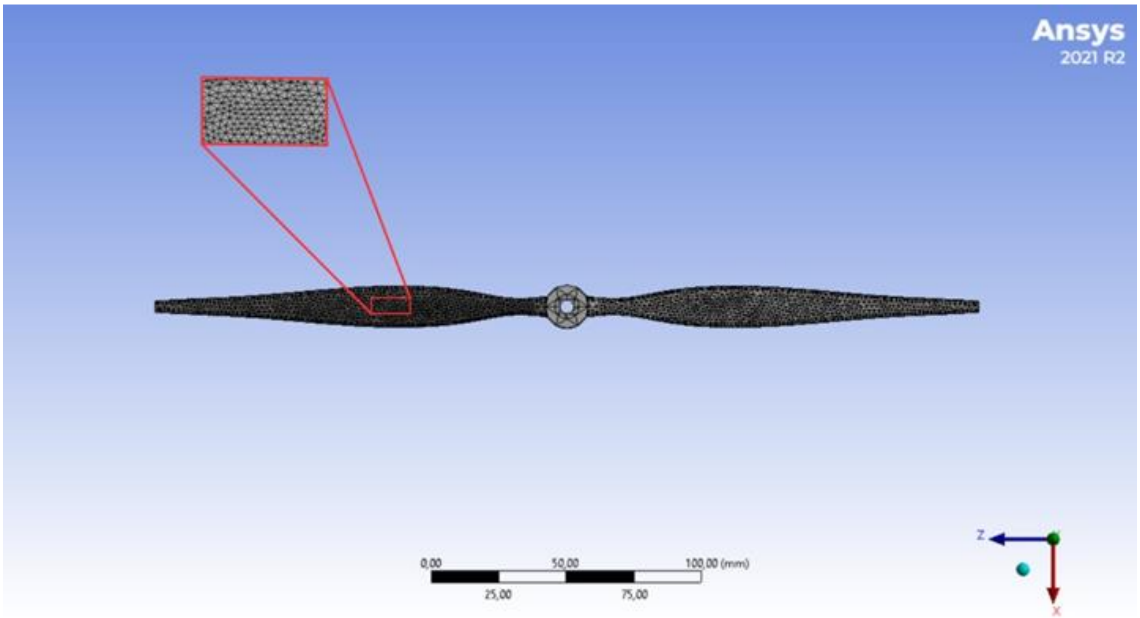

Figure 3. The mesh model on the propeller

On the model, the fixed part is defined as the propeller hub and the parts to be applied force are defined as the propeller blades. After the necessary definitions were made, force was applied on the blades. The forces are applied to the midpoints of the propeller blades. The fixed part on the propeller and the applied forces are shown in Figure 4 and Figure 5. The amount of force to be applied to the propeller blades was defined as appropriate for an airplane requiring 0.3 kgf (2.941995 N) thrust.

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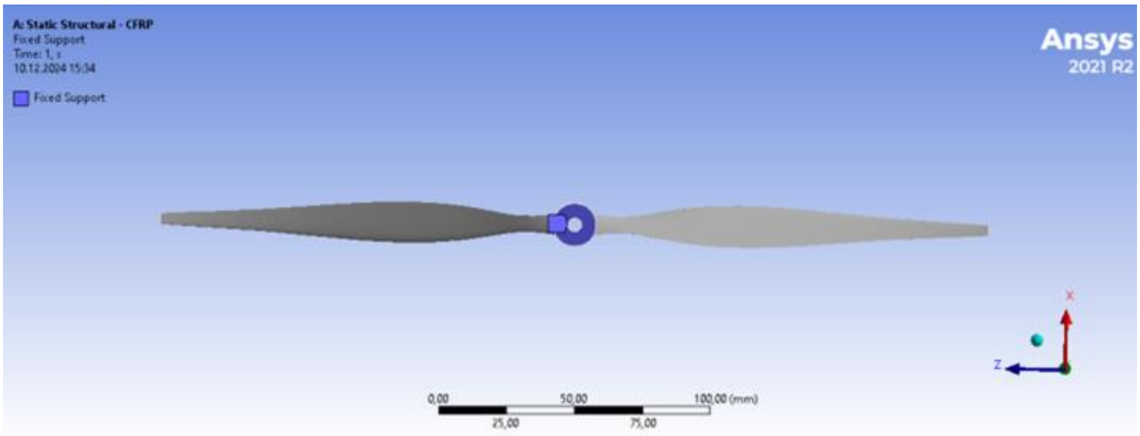

Figure 4. The part that is considered fixed on the propeller

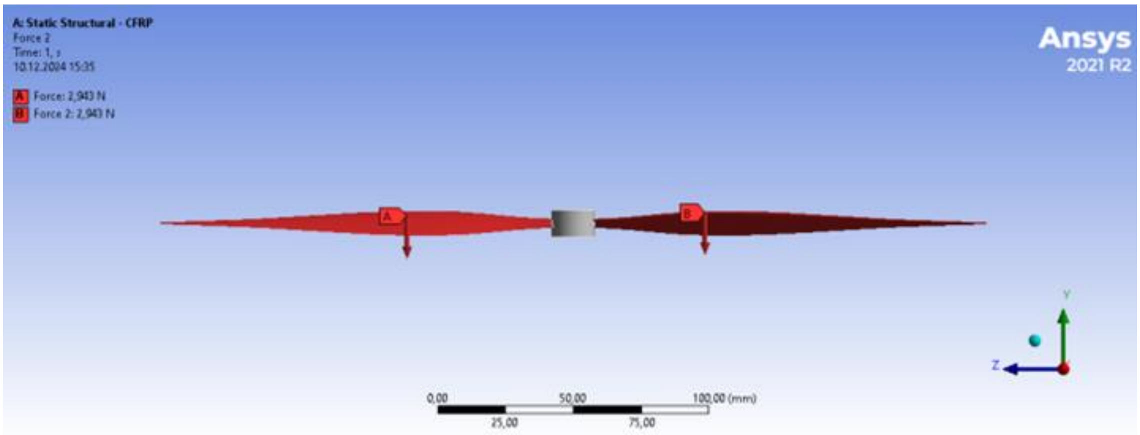

Figure 5. Forces applied to the propeller blades

3. Results

In this study, a propeller with NACA 2412 airfoil structure is designed. Structural analysis of the propeller with CFRP and PLA materials was performed with ANSYS program. The analysis results are given separately for CFRP and PLA materials.

3.1. Structural analysis – CFRP

The deformation of the propeller in the direction of the applied force is shown in Figure 6 and Figure 7. Figure 6 shows the total deformation of the CFRP material and Figure 7 shows the maximum shear stress. Total deformation, directional deformation, equivalent elastic strain, maximum shear elastic strain, equivalent stress and maximum shear stress values obtained from the analysis are given in Table 3.

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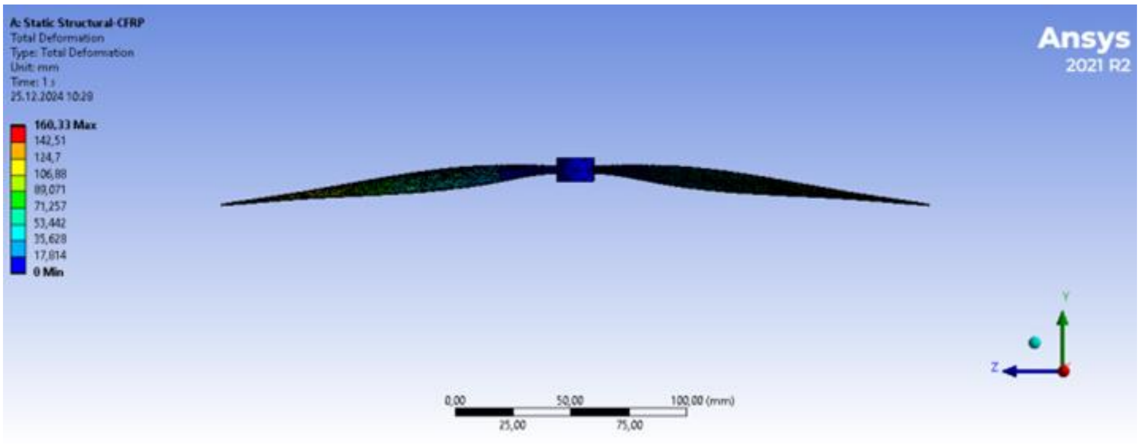

Figure 6. Total deformation of CFRP

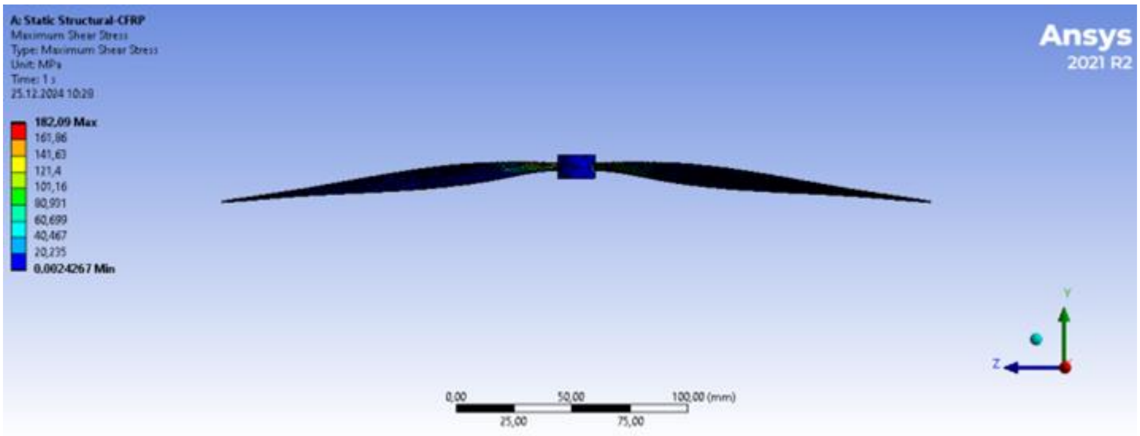

Figure 7. Maximum shear stress of CFRP

3.2. Structural analysis – PLA

The deformation of the propeller with PLA material is shown in Figure 8 and Figure 9. Figure 8 shows the total deformation of the PLA material and Figure 9 shows the maximum shear stress. Total deformation, directional deformation, equivalent elastic strain, maximum shear elastic strain, equivalent stress and maximum shear stress values obtained from the structural analysis are given in Table 4.

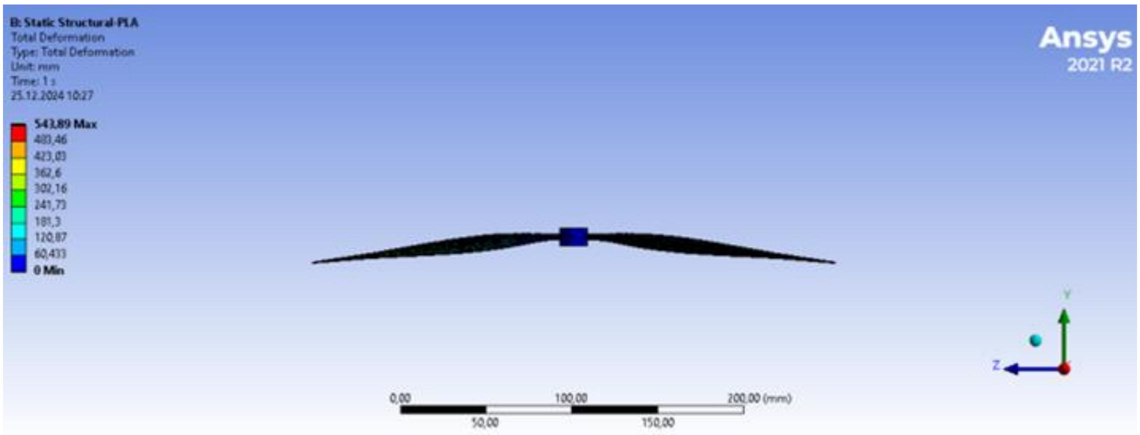

Figure 8. Total deformation of PLA

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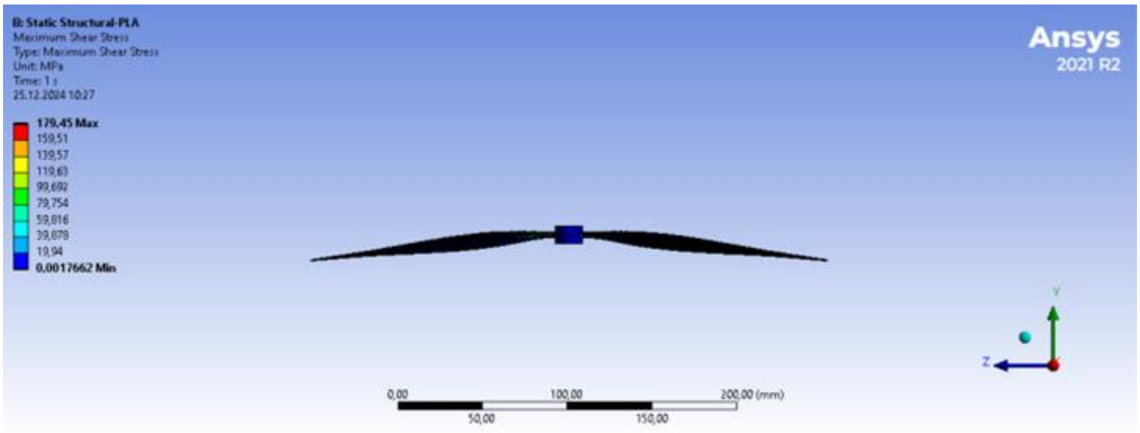

Figure 9. Maximum shear stress of PLA

Table 4. Analysis results for CFRP and PLA

Material	CFRP	PLA
Total Deformation (mm)	160.33	543.89
Directional Deformation (mm)	83.737	285.62
Equivalent Elastic Strain (mm/mm)	0.040076	0.1193
Maximum Shear Elastic Strain (mm/mm)	0.043498	0.17168
Equivalent Stress (MPa)	362.24	350.11
Maximum Shear Stress (MPa)	182.09	179.45

Table 4 shows that the total deformation of PLA is 3.39 times the total deformation of CFRP. PLA's directional deformation is 3.41 times, equivalent elastic strain is 2.98 times and maximum shear elastic strain is 3.95 times that of CFRP. For equivalent stress and maximum shear stress, the values are close to each other.

4. Conclusion

In this study, a 0.3 kgf (2.941995 N) thrust force was applied to a propeller model with different materials and the amount of deformation on the propeller was investigated. As a result of the structural analysis, Total Deformation, Directional Deformation, Equivalent Elastic Strain, Maximum Shear Elastic Strain, Equivalent Stress and Maximum Shear Stress values were obtained. When the values obtained were analyzed, it was seen that PLA material was deformed more than CFRP material. In addition, when the stress on both materials was compared, it was found that the CFRP material was subjected to more stress. As a result of the study, CFRP material was found to be approximately 3.4 times more durable than PLA material and this result was found to be compatible with the studies in literature. It is also concluded that the deformation amounts of the materials have large values compared to the applied force. The reason for this is thought to be that the propeller model design does not have sufficient thickness for the materials used. As a suggestion to this, an optimization study using a different airfoil structure is aimed to be carried out in future studies.

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Süreyya Sevinç Varol, *Research, Visualization, Conceptualization, Methodology, Software, Formal Analysis.* **Mehmet Emin Çetin,** *Investigation, Supervision, Examination.* **Mesut Uyaner,** *Examination, Visualization, Supervision, Editing.* **Bilge Albayrak Çeper,** *Investigation, Supervision, Examination.*

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