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Research Article / Araştırma Makalesi

Low velocity impact response of CFRP and Al2024-T3 helicopter blade / CFRP ve Al2024-T3 helikopter kanadının düşük hızlı darbe cevabı

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Low-velocity impact

ABSTRACT

A high level of safety is demanded in response to the foreign object damage (FOD) problem frequently encountered in aviation. For this reason, in this study, the effect of stone impact on a helicopter blade performed within the scope of FOD is investigated. Considering the actual size of the propeller, a stone impact is applied to a certain section and the mechanical behavior of the propeller is examined according to the material type. In this direction, the Bo-105 helicopter blade with the NACA-23012 profile is taken as a reference, and a 3D drawing of the blade is made in the SolidWorks program. The behavioral properties of metal and composite materials frequently preferred in aviation against stone impact are compared. For this purpose, Al2024-T3 and carbon fiber reinforced polymer (CFRP) are selected. These materials are frequently preferred in aviation. To observe the difference between the materials, low-velocity impact analysis is performed on two blade sections with span dimensions of 140 mm and chord dimensions of 310 mm under the same geometry and conditions. The analysis of the simulated action is obtained using the LS-DYNA program. Because it is a mechanical action, the Arbitrary Lagrangian (ALE) method was used accordingly. Within the scope of this method, the stone to be hit by the blade was modeled as a 5 mm solid structure and hit the blade surface with a speed of 3500 mm/s. While the blade with Al2024-T3 material was modeled as a shell, the CFRP blade was modeled as a composite part consisting of six layers at [0-90-0-90-0-90] degrees. Material properties were defined on the blade using 018 Law Plasticity and 54/55 Enhanced Composite Damage material cards for Al2024-T3 and CFRP, respectively. As a result of this analysis, the time-dependent changes in displacement, kinetic energy, and force parameters were acquired. Then, the low-velocity impact responses of the CFRP and the Al2024-T3 blades were compared.

ÖZET

Havacılık sektöründe sıklıkla karşılaşılan yabancı madde hasarı (YAMAHA) sorununa karşılık yüksek emniyet seviyesi talep edilmektedir. Bu nedenle çalışmada, YAMAHA kapsamında gerçekleştirilen helikopter pali üzerine taş çarpması etkisi araştırılmaktadır. Palin gerçek boyutu göz önüne alınarak taş çarpması belirli bir kesit üzerine uygulanmaktadır ve palin sahip olduğu malzemeye göre göstermiş olduğu mekanik davranış incelenmektedir. Bu doğrultuda NACA-23012 profiline sahip olan Bo-105 helikopter pali referans alınmış olup palin 3B çizimi Solidworks programında yapılmıştır. Çalışmada havacılıkta sıklıkla tercih edilen metal ve

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kompozit malzemelerin taş çarpmasına karşı davranış özellikleri karşılaştırılmıştır. Bu amaçla çalışmada Al2024-T3 ve Karbon fiber takviyeli polimer (CFRP) tercih edilmiştir. İki malzemenin farkını gözlemlemek üzere aynı geometri ve koşullarda spanı 140 mm ve veteri 310 mm boyutlarına sahip iki pal kesiti üzerine düşük hızlı darbe analizi gerçekleştirilmiştir. Simüle edilen eylemin analizi LS-DYNA programı kullanılarak elde edilmiştir. Mekanik bir eylem olması gerekçesiyle buna uygun olarak Keyfi Lagrange (ALE) metodu kullanılmıştır. Bu metod kapsamında pale çarptırılacak olan taş, 5 mm boyutunda katı bir yapıda modellenmiş olup 3500 mm/s hızıyla pal yüzeyine çarptırılmıştır. Al2024-T3 malzemeye sahip pal kabuk olarak modellenirken CFRP malzemeli pal [0-90-0-90-0-90] açılarında altı katmandan oluşan kompozit part olarak modellenmiştir. Malzeme özellikleri Al2024-T3 ve CFRP için sırasıyla 018 Law Plasticity ve 54/55 Enchanced Composite Damage materyal kartları kullanılarak pal üzerine tanımlanmıştır. Gerçekleştirilen bu analiz sonucunda her iki malzemenin yer değiştirme, kinetik enerji ve kuvvet parametrelerinin zamana bağlı değişimleri incelenmiştir. Böylece havacılık teknolojisinde sıklıkla tercih edilen CFRP ve Al2024-T3 malzemelerinin düşük hızlı darbe karşısındaki mekanik özellikleri karşılaştırılmıştır.

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1. Introduction

Helicopters are important air vehicle frequently used in the defense industry for emergencies such as medical and natural disasters, applications such as reconnaissance and passenger transportation, and military operations without the need for long runways thanks to their vertical takeoff and landing features [1]. Therefore, it is aimed at helicopters to provide a safe flight. This situation requires various analyses and examinations of vehicle components. The impact of foreign objects, one of the important problems of the aviation industry, is also seen as a subject that needs to be examined in this regard. Foreign object impacts cover a wide range of scenarios. This study focuses on low-velocity impacts, which are those where the velocity of the impacting mass is 10 m/s or less and typically occur during production or service [2-3]. For this reason, the impact of foreign objects on different aircraft components is the subject of many studies in the literature. The study aims to examine the effect of stone impact on helicopter blades. The main rotor blade, which is one of the most important components of the helicopter, is the component that produces thrust force to balance the inertia of the helicopter and perform translational motion. When the main rotor blade is damaged by a foreign object such as a stone, an imbalance occurs in the rotor. Thus, the helicopter develops unwanted vibrations during flight. Vibration occurring in the blades can lead to a decrease in the performance of the helicopter due to the negative effect on the thrust force produced, as well as blade fatigue and exceeding the endurance limit [4-5]. Considering the internal structure and number, the selection of the material to be used in the production of the blades, which have a great effect on the total weight of the helicopter, is very important [6]. Metal alloys and composite materials are generally used in the production of helicopter blades. Titanium, which is resistant to high temperatures, and aluminum, which has high corrosion resistance, are the preferred metal materials in helicopter blades. Commonly used composite materials are carbon fiber, fiberglass, and Kevlar fiber [7]. Composite materials provide the rotor with the strength it needs due to their high strength/weight ratio, while also providing weight savings, which is a critical parameter for the flight performance of an aircraft [8].

This study focuses on modeling low-velocity impact simulations of CFRP and Al2024-T3 materials defined on a helicopter blade using the LS-DYNA software. The primary objective of this research is to contribute to the literature by investigating and documenting the behavior of these two materials under low-velocity impact conditions, which are frequently encountered in the aerospace industry. The simulations aim to provide insights into the impact response of these materials, facilitating a better understanding of their applicability and performance in aviation-related scenarios.

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2. Method

Within the scope of the study, a low-speed impact test on the helicopter blade was performed in the LS-DYNA program using two different materials to see the effect of the material on the blade behavior. A stone impactor was modeled as a solid with a diameter of 5 mm. For the blade, two separate models were applied as a shell in Al2024-T3 material and a composite part in CFRP material for the purpose of the study. The material was given a thickness of 12 mm for both models. For CFRP, this thickness was provided with 6 plies at [0-90-0-90-0-90] degrees, each layer being 2 mm. The stone hits the surface of the blade at a speed of 3500 mm/s and the entire action is completed in 0.03 seconds [9].

Automatic Nodes to Surface connection was established between the stone and the blade to perform the impact action. The data to be obtained at the end of the analysis were determined as MATSUM and RCFORCE under the ASCII heading. With MATSUM, the energy, speed, momentum, and displacement values of the blade and the stone along the x, y, and z axes were obtained. With RCFORCE, the change in the net force on the part over time is observed. The obtained data is graphed with the D3PLOT command.

2.1. Material selection

Composite material is a type of multiphase material formed by combining two or more component materials with significantly different chemical or physical properties. It usually consists of a reinforcement phase with high rigidity and strength, and a matrix phase that holds the fibers together by forming the majority of the volume around it and has higher ductility. Composite materials are classified in various ways. According to the matrix materials, they are classified as metal matrix, ceramic matrix, and polymer matrix composites. According to the type of reinforcement, they are classified as particle-reinforced, fiber-reinforced, and structural composites [10].

In the scope of the study, carbon fiber reinforced polymer (CFRP), which has very good resistance to tensile force and high fatigue life, was used as a composite material [11]. While the polymer in the structure of CFRP forms the matrix phase, carbon fiber forms the reinforcement phase [12].

CFRP, whose properties are given in Table 1, is modeled as a composite part. The material properties are defined with the 054/055-Enhanced Composite Damage material card.

Table 1. CFRP Material Properties [13]

Material	CFRP Laminate
ρ [g/cm^3]	1.6
E_{11} [GPa]	153
E_{22} [GPa]	10.3
G_{12} [GPa]	5.2
ν_{12} [-]	0.3
XT [MPa]	2540
XC [MPa]	1500
YT [MPa]	82
YC [MPa]	236
SC [MPa]	90
DFAILT	0.017
DFAILC	–0.0135
DFAILM	0.1
DFAILS	0.03
G_{IC} [J/m^2]	225
G_{IIC} [J/m^2]	640

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The properties of the Al2024-T3 material used are given in Table 2. The shell method was used when modeling the Al blade. The material properties were defined with the 018-Power Law Plasticity material card.

Table 2. Al2024-T3 Mechanical Properties [14]

Material	Al2024-T3
ρ [g/cm^3]	2.78
E [GPa]	73.1
ν	0.330
k	1.4

Finally, the material properties of the stone impactor determined are given in Table 3. The material information of the stone modeled as solid was integrated using the 020-Rigid material card.

Table 3. Material Properties of the Impactor Mass

Material	Impact Mass (Solid)
ρ [g/cm^3]	1.680
E [GPa]	207
ν	0.3

2.2. Blade design

The blade design is based on the Bo-105 model scale rotor blade in the literature [15]. Using the dimensions of the Bo-105 helicopter rotor, 3D modeling of the blade was performed with the SolidWorks program and it is shown in Figure 1.

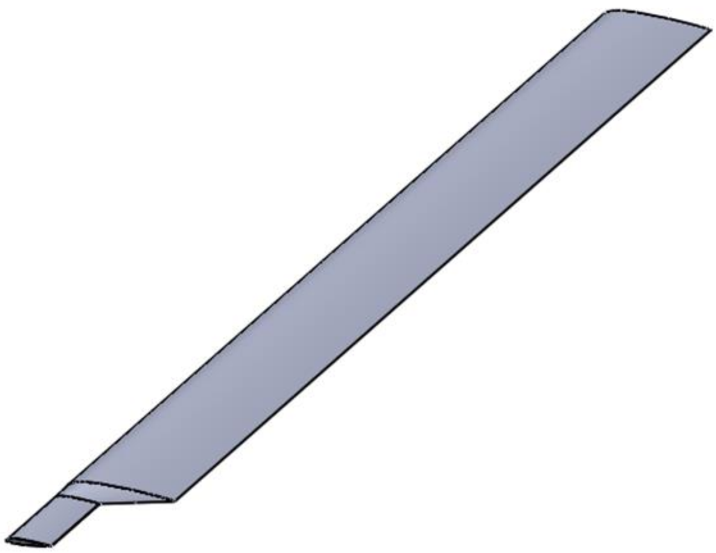

Figure 1. 3D Model of the Bo-105 Helicopter Blade

The Bo-105 helicopter uses the aerodynamically efficient NACA23012 profile. Figure 2 gives the NACA23012 profile.

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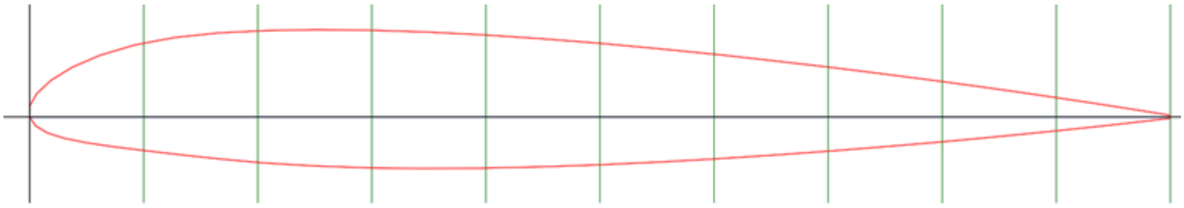

Figure 2. NACA23012 profile-[16]

For the analysis, the solid modeling of the functional area of the blade used in the Bo-105 helicopter was carried out using the SolidWorks program at a scale of approximately 1/30. Figure 3 and Figure 4 give the 3D modeling of the drawing and the main parts of the helicopter blade and their dimensioning on the technical drawing, respectively.

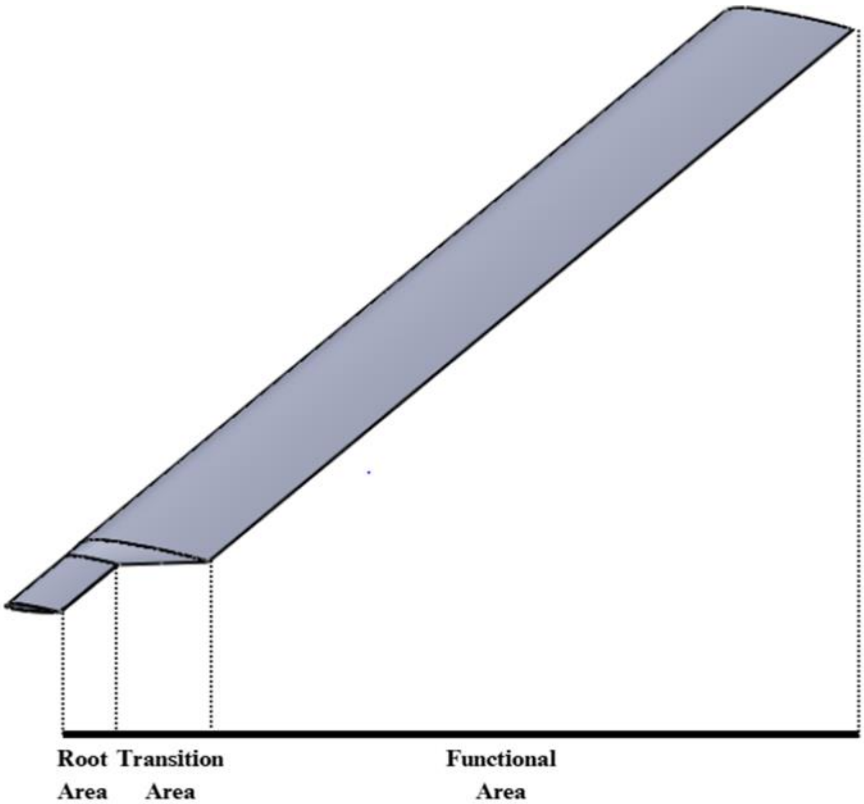

Figure 3. Main Parts of the Helicopter Blade.

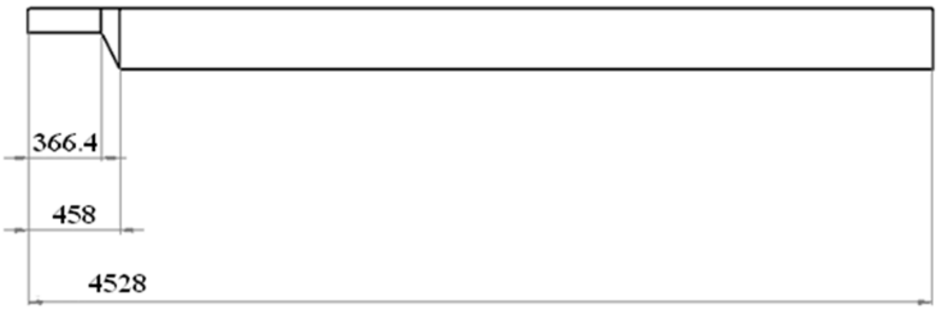

Figure4. Technical Drawing of the Bo-105 Helicopter Blade (Dimensions are in mm).

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2.3. Finite Element Method

The subject of the study is the helicopter blade impact test, which was carried out using virtual experiments. In virtual experiments, algorithms such as Lagrangian, Euler (EM), Arbitrary Lagrangian Euler (ALE), and Smoothed Particle Hydrodynamics (SPH), which are nonlinear finite element (FE) codes, are used [17]. The distortions that occur in the mesh during the virtual experiment are a factor that negatively affects the security of the results. Therefore, the improvement in the mesh provides more accurate analysis results. ALE can fix the mesh with Euler elements or model the movement of the mesh by using Lagrangian elements and adapting them to the material [18]. In this way, the quite complex collision scenario, which depends on many parameters such as geometry, material, and contact can be simulated. In addition, the deformation and loading on the impacting and crashed surfaces can be estimated at an acceptable level of accuracy [17]. Due to these advantages, the ALE algorithm of the finite element method was preferred within the scope of the study. Due to the torque created by the rapidly rotating rotor, foreign objects such as stones on the ground fly up and can damage the blade. In this study, the effect of stone hitting the tip of the blade was examined. Analysis was carried out on the region that was predicted to be heavily affected by the collision. The cross-sectional surfaces in the examined region were accepted as boundary conditions and their movements were limited in all directions. The representation of the boundary conditions on the model is given in Figure 5.

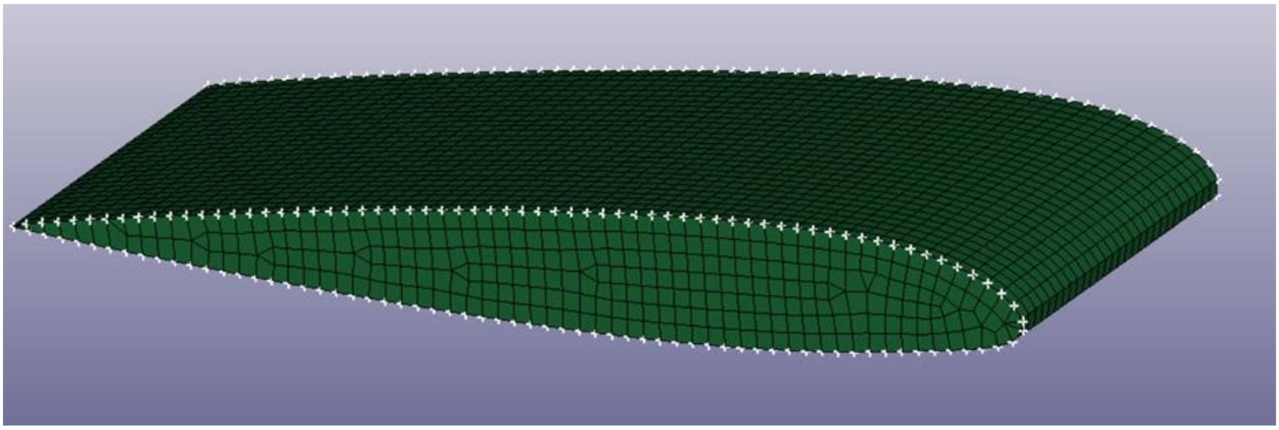

Figure 5. Boundary Layer Conditions.

3. Results

Low-speed impact analysis of helicopter blades designed from Al2024-T3 and CFRP materials was performed using the LS-DYNA program. The data obtained as a result of the analysis are given in the form of graphics. The Kinetic Energy-Time Graphs of CFRP and Al2024-T3 blades are given in Figure 6 and Figure 7.

Since the impactor has an initial velocity, the kinetic energy of the impactor is at its highest value at the first moment, while the kinetic energy of the blade is zero because it is stationary. During the collision, the impactor transfers most of its kinetic energy to the blade. The CFRP blade was able to absorb more kinetic energy of the impactor and distribute the impact to the structure. The Al2024-T3 blade, on the other hand, was harder and therefore absorbed less energy and could not distribute the impact.

Figure 8 and Figure 9 present the deformed shapes of CFRP and Al blades, respectively.

The magnitude of the resultant force generated on the blades due to impact varies depending on the type of material. Figure 10 shows that the resultant force on the CFRP blade is lower compared to that on the Al2024-T3 blade shown in Figure 11.

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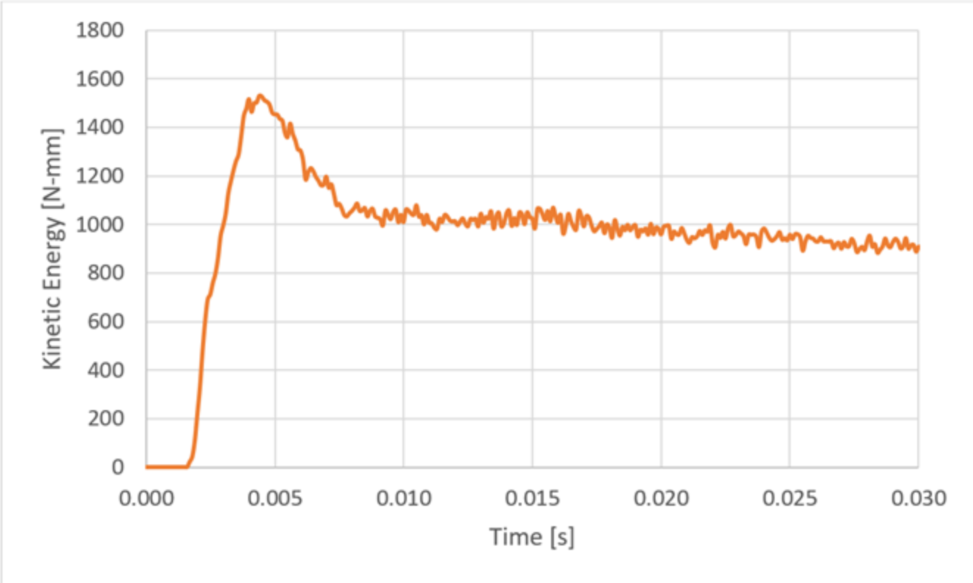

Figure 6. The CFRP Helicopter Blade’s Kinetic Energy-Time Graph.

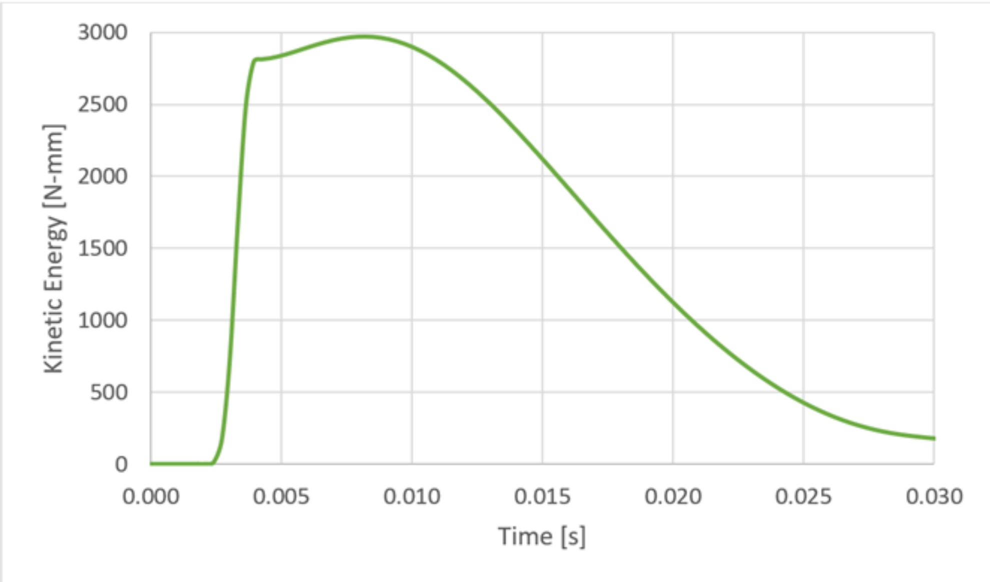

Figure 7. The Al2024-T3 Helicopter Blade’s Kinetic Energy-Time Graph.

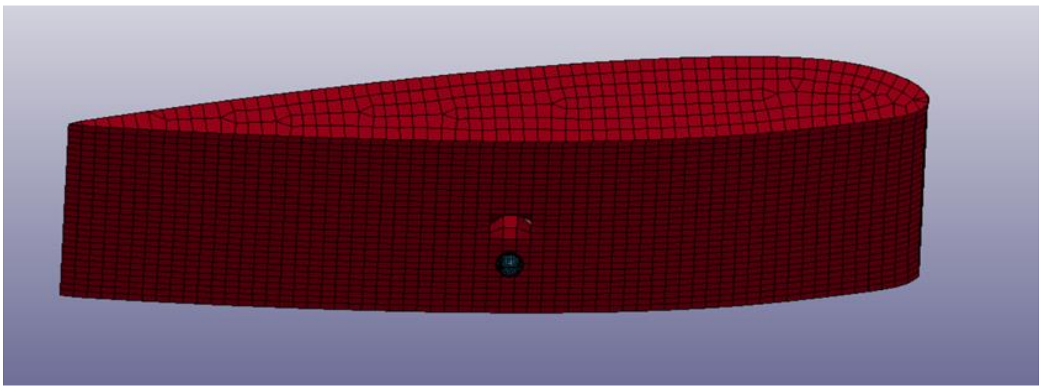

Figure 8. Impacted Al2024-T3 Helicopter Blade.

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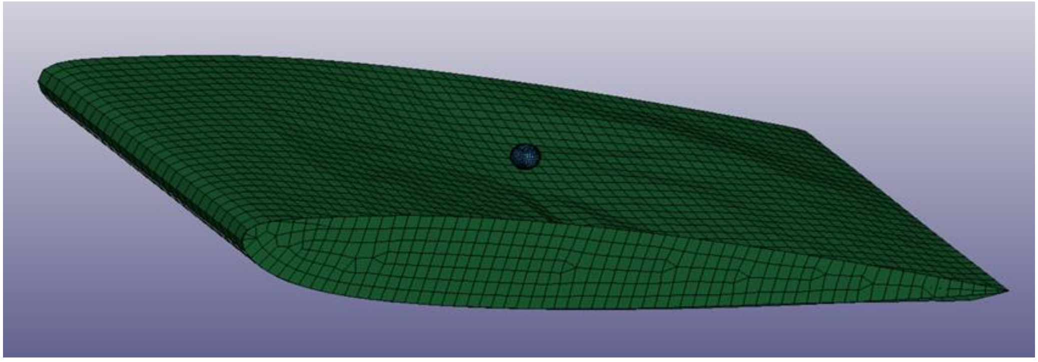

Figure 9. Impacted CFRP Helicopter Blade.

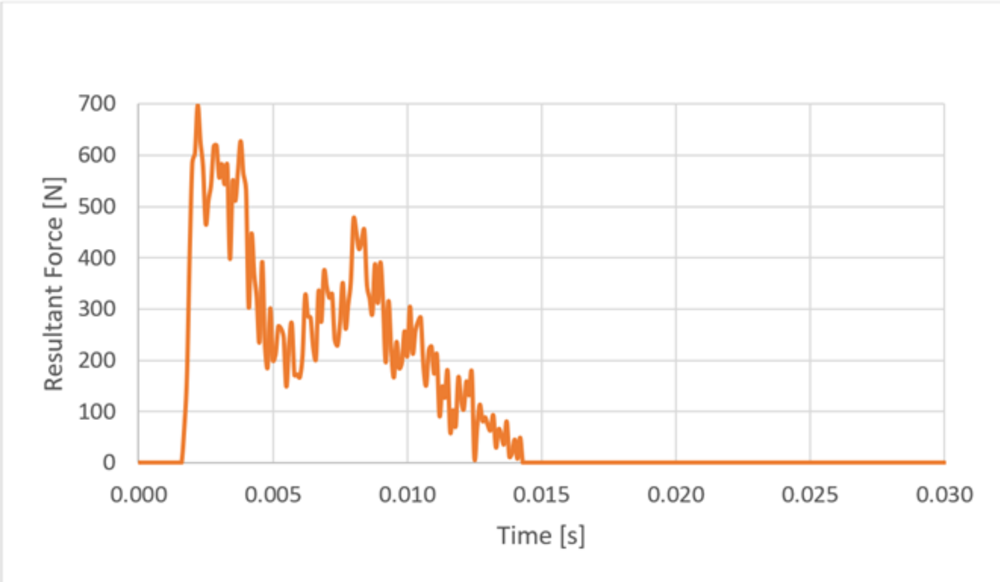

Figure 10. Resultant Force-Time Graph for the CFRP Blade.

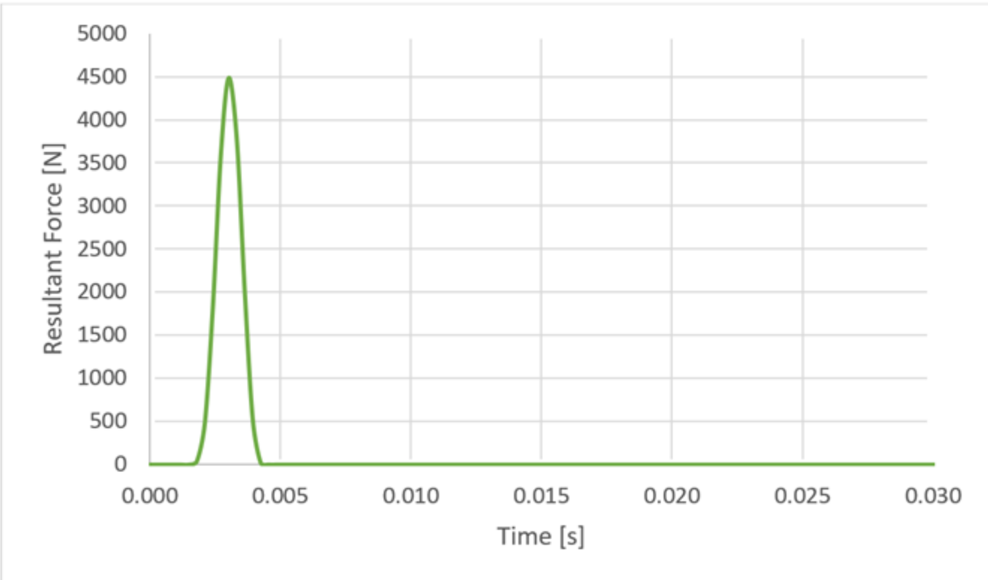

Figure 11. Resultant Force-Time Graph for the Al2024-T3 Blade.

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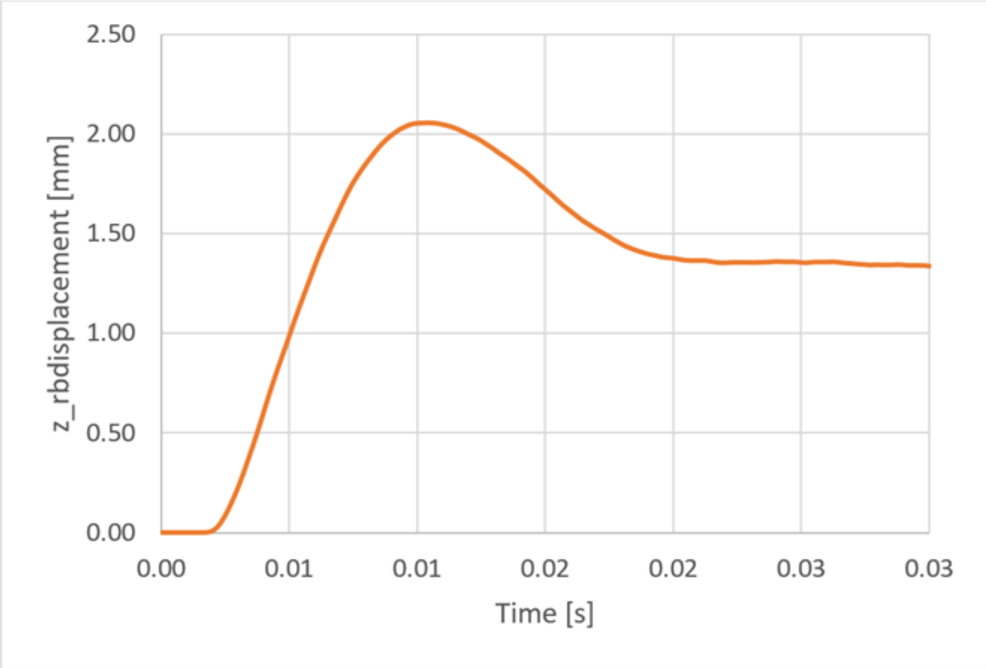

Figure 12. Displacement history for the CFRP Blade.

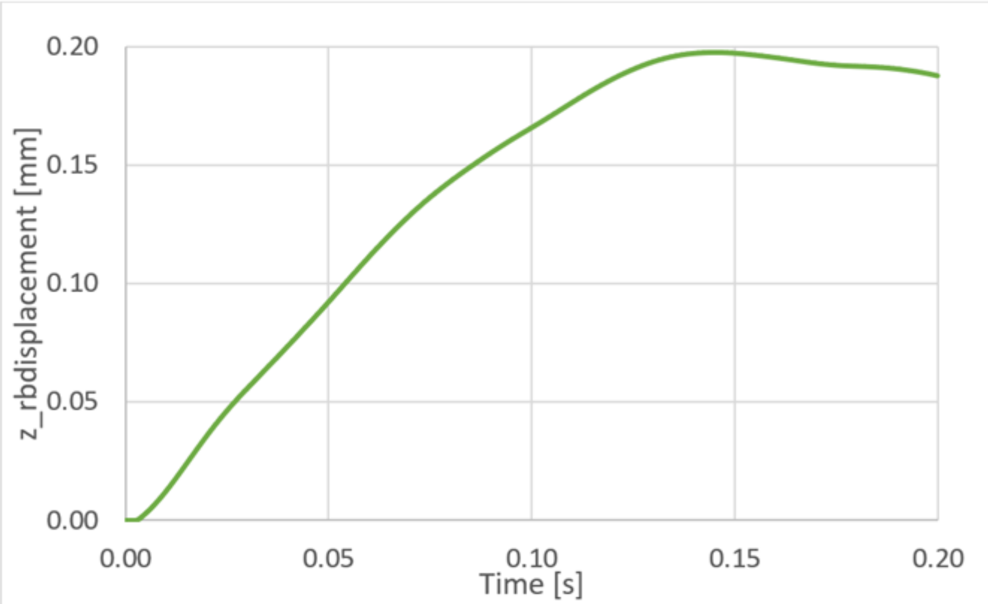

Figure 13. Displacement history for the Al2024-T3 Blade.

Figure 12 and Figure 13 provide the displacement versus time graphs. In the CFRP blade, it is seen that the displacement increases rapidly and reaches a maximum point at approximately 0.01 seconds. After this point, the displacement decreases slightly and becomes stable. The Al2024-T3 material shows a slower increase in terms of displacement. It is seen that it reaches a maximum displacement amount at the end of approximately 0.2 seconds. It was concluded that the amount of permanent deformation in the Al2024-T3 blade is greater than in the CFRP blade and the amount of elastic deformation is less.

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4. Conclusion

In this study, a low-speed impact test was applied to two different blades consisting of Al2024-T3 and CFRP materials. With the analysis results, the behavioral properties of the two different materials used were examined with a focus on displacement, kinetic energy, and force parameters. As a result, it was observed that the CFRP material blade provided a larger area of impact distribution in the structure compared to the Al2024-T3 blade, while the Al2024-T3 blade created a greater force against the impact. Finally, when the displacement amounts were examined, it was seen that the blade with the CFRP material performed a larger displacement. As a result of this research, the Al2024-T3 and CFRP structural materials were compared in the mentioned aspects and their impact behaviors were examined, and added to the literature.

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