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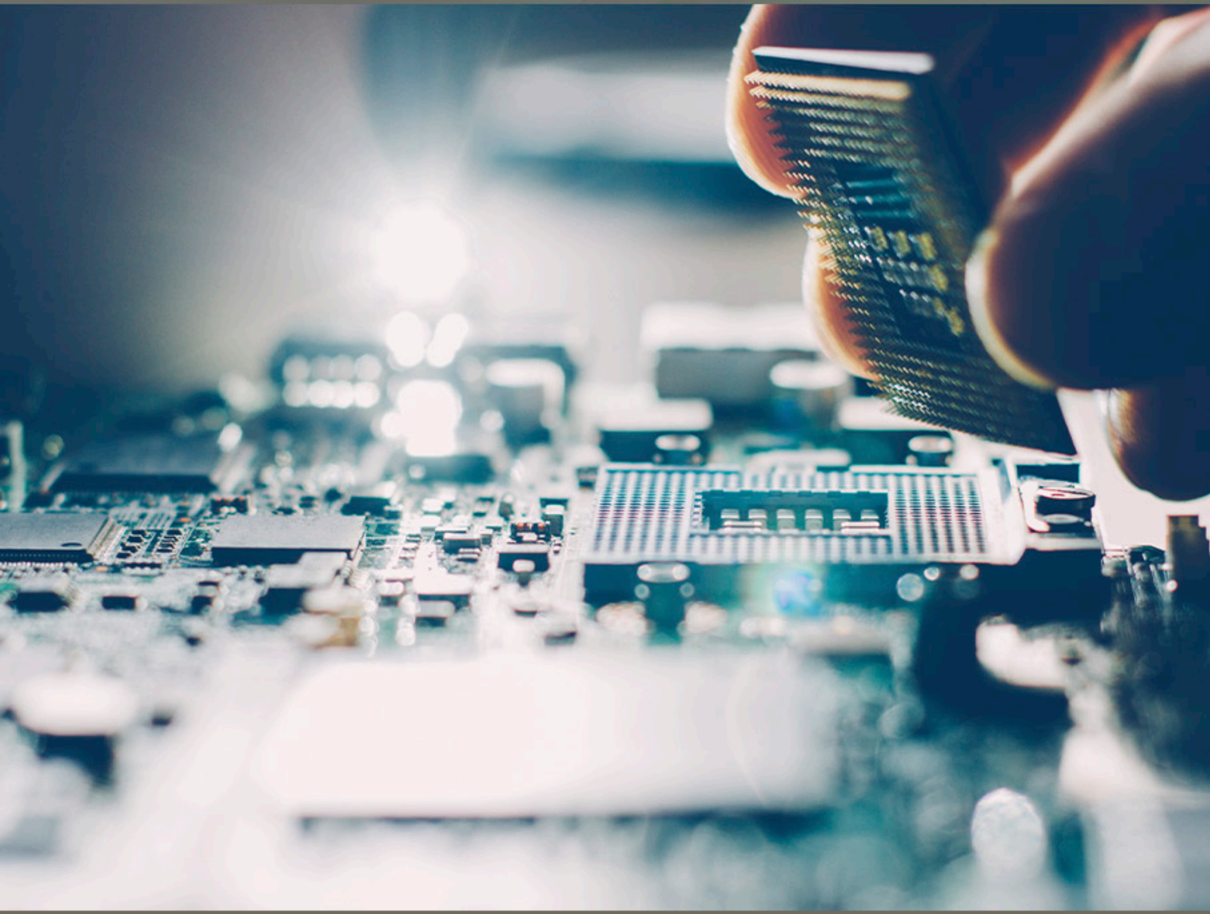

LILIAN COELHO DE FREITAS
(ORGANIZADORA)

Atena Editora
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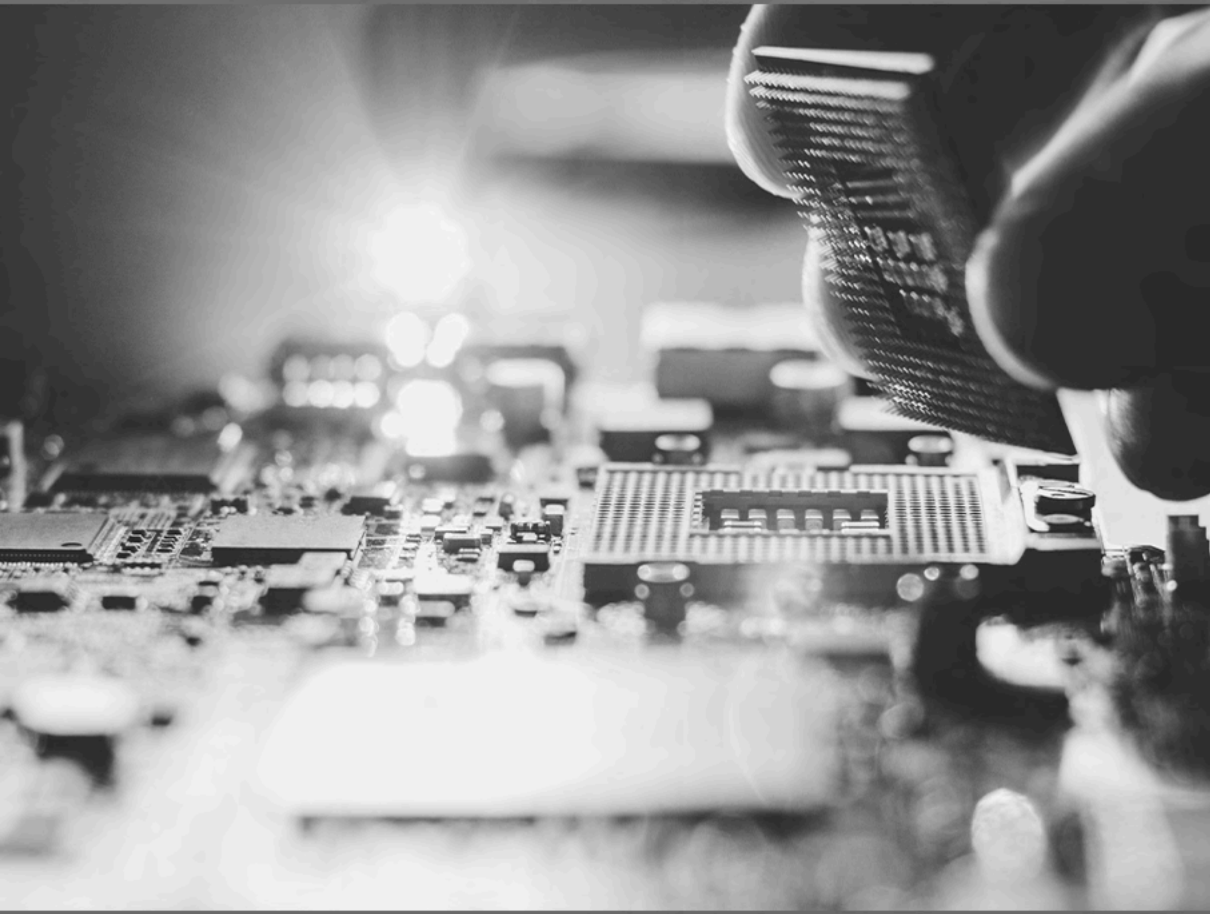

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APRESENTAÇÃO

A Atena Editora tem a honra de presentear o público em geral com a série de *e-books* intitulada "*Coleção desafios das engenharias: Engenharia de computação*". Em seu terceiro volume, esta obra tem o objetivo de divulgar aplicações tecnológicas da Engenharia de Computação na resolução de problemas atuais, com o intuito de facilitar a difusão do conhecimento científico produzido em várias instituições de ensino e pesquisa do país.

Organizado em 20 capítulos, este volume apresenta temas como utilização de aprendizagem de máquina na avaliação de riscos de infeção por COVID-19; dispositivos automatizados para administração de remédios; comunicação científica apoiada por realidade aumentada; métodos de elementos finitos aplicados na análise de materiais para indústria aeronáutica; aplicações de processamento digital de imagens e de algoritmos genéticos; entre diversas outras aplicações da automação e do desenvolvimento de *software,* combinados para melhorar as atividades do nosso dia-a-dia.

Dessa forma, esta obra contribuirá para aprimoramento do conhecimento de seus leitores e servirá de base referencial para futuras investigações.

Os organizadores da Atena Editora, agradecem especialmente os autores dos diversos capítulos apresentados, parabenizam a dedicação e esforço de cada um, os quais viabilizaram a construção deste trabalho.

Boa leitura.

Lilian Coelho de Freitas

SUMÁRIO

CAPÍTULO 17

FINITE ELEMENT METHOD APPLIED TO MECHANICAL ANALYSIS OF AERONAUTICAL RIBS IN CARBON FIBER AND 7075 ALUMINUM ALLOY

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ABSTRACT: The aeronautical industry is increasingly demanding lightweight materials with good mechanical properties in order to improve aircraft performance. The carbon fiber associated with the epoxy resin generates a composite with high structural performance and lower mass values when compared to aluminum alloys. This work aimed to compare the mechanical performance of a carbon fiber rib and a rib made of 7075 aluminum alloy (AA7075). The analyzes were made using the finite element technique. The results show that the carbon fiber has higher stress values, indicating a higher resistance, also presenting less mass when compared to the metal rib. However, the rib made of AA7075 has greater deformation, this being a fundamental factor since it allows greater flexibility during flight, while carbon fiber can present critical flaws.
KEYWORDS: Carbon fiber; Aluminum alloys; Mechanical resistance; Finite element methods.

MÉTODO DE ELEMENTOS FINITOS APLICADO À ANÁLISE MECÂNICA DE NERVURAS AERONÁUTICOS EM FIBRA DE CARBONO E LIGA DE ALUMÍNIO 7075

RESUMO: A indústria aeronáutica exige cada vez mais materiais leves e com boas propriedades mecânicas para melhorar o desempenho das aeronaves. A fibra de carbono associada à resina epóxi gera um compósito com alto desempenho estrutural e menores valores de massa quando comparado às ligas de alumínio, ambos utilizados em estruturas aeronáuticas. Este trabalho teve como objetivo comparar o desempenho mecânico de uma nervura de fibra de carbono e uma nervura de liga de alumínio 7075 (AA7075). As análises foram feitas pelo método de elementos finitos. Os principais resultados mostram que a fibra de carbono possui maiores valores de tensões, indicando maior resistência, apresentando também menor massa quando comparada à nervura em liga metálica. Contudo, a nervura simulada em AA7075 apresenta maior deformação, sendo este um fator fundamental, pois permite maior flexibilidade durante o voo, enquanto a fibra de carbono pode apresentar falhas críticas.
PALAVRAS-CHAVE: Fibra de carbono; Ligas de alumínio; Resistência mecânica; Elementos finitos

1 I INTRODUCTION

The aeronautical industry, due to its need, develops studies that look for lighter and mechanically resistant materials (BOUVET, 2017). The development of composites based on carbon fiber with epoxy resin is interesting because the final product has high mechanical characteristics, excellent performance under fatigue and low weight (YI; DU; ZHANG, 2018). This material appears as an alternative to the use of metallic materials, such as 7075 aluminum alloys, for example, aiming at weight reduction and optimization of mechanical performance (VILCHES *et al.*, 2017).

In this context, the ribs used in aircraft have the function of shaping the wing profile and transmitting the coating efforts to the side members, leading this component to strong load requests (Zhang, Yu, & He, 2019). The aluminum alloy 7075, widely used in the manufacture of ribs, has zinc alloy as its main element and has an elasticity module of 70 GPa, being a mechanically efficient alloy, however, it presents problems such as corrosion and limited life under fatigue (HERNANDEZ; RAMÍREZ; MACKAY, 2017).

One of the ways to verify the behavior of a part is to carry out a Finite Element Method (FEM) analysis, which consists of submitting the simulated part to a certain load, checking where the greatest effort requests occur (VISCARDI *et al.*, 2018). The FEM's power lies in its ability to be implemented in computer codes, allowing us to solve extensive structural analysis problems (CIANETTI *et al.*, 2019). For the analysis of structures of composite materials, the Inventor software from the Autodesk company was selected, as it characterizes the stacking according to the defined mathematical model.

Thus, this work aims to compare the mechanical performance, through an analysis by the finite element method, of a rib in carbon fiber and a rib in aluminum alloy 7075, under the effect of a load of 10000 N applied in the center of mass of the part, enabling the identification of points with higher Von Mises stress values, which is admitted as a failure criterion, and finally showing the advantages and disadvantages of making a rib and carbon fiber in substitution of the 7075 alloy.

2 | LITERATURE REVIEW

A literature review is needed to understand the characteristics of 7075 aluminum alloy and carbon fiber with epoxy resin. This knowledge allows an analysis and correct interpretation of the data provided by the finite element analysis.

2.1 PROPERTIES OF 7075 ALUMINUM ALLOY

Pure aluminum, as such, is a soft material with little mechanical resistance. By adding small amounts of other elements, aluminum alloys improve their properties, such as mechanical strength and hardness. Among the elements most used to form alloys with aluminum are Fe, Mg, Zn, Si, Cu, Ti, Cr, Li, B, W, Ni, Zr, S (Pandey, Singh, Chattopadhyay, Srinivas, & Singh, 2017). The final properties depend mainly on the specific purpose of the alloy and therefore, be able to modify them according to your requirements (NAVASER; ATAPOUR, 2017).

These alloys are commonly known as light alloys, as they have a lower density compared to steel. This lightness has led the industry to use them mainly for transportation, since they provide less weight in vehicles, providing additional advantages such as reduced fuel consumption and a notable decrease in polluting gases that cause serious and irreparable damage to the atmosphere (CHOI *et al.*, 2020). Different types of aluminum alloys offer a wide range of capacities and are therefore considered the material of choice for many products and markets. Aluminum alloys are classified using a four-digit system. The classification of alloys is established by the American National Standard Institute (ANSI) (AOBA, KOBAYASHI; MIURA, 2017).

In this way, the 7xxx series alloys include aluminum alloys with zinc, in average amounts from 1% to 8%, and can be heat treated to achieve a high level of resistance. They are widely used in aircraft fuselage structures, mobile equipment and parts subject to high working stresses in the aerospace industry (WANG *et al.*, 2017). These alloys have low corrosion resistance and are often used slightly aged to provide better combinations of strength, corrosion resistance and fracture resistance, which makes their use interesting in rib construction (LEI *et al.*, 2017).

2.2 CARBON FIBER AND ITS APPLICATION IN AERONAUTICS

Before talking about carbon fiber it is necessary to talk about composite materials. A composite material is a material that differs from macroscopically homogeneous materials such as metals and polymers. It comprises continuous or cut fibers of resistant material (reinforcement) that is incorporated in a matrix whose mechanical resistance is much lower (AAMIR *et al.,* 2019). There are several types of fiber arrangements. The role of the matrix is twofold (LEFEUVRE *et al.*, 2017):

- Preserves fiber layout;
- Transmits the stresses to the part is subjected.

Carbon fiber consists of extremely thin fibers, about five to ten micrometers in diameter, and is composed mainly of carbon atoms. These are clustered in microscopic crystals that are aligned more or less parallel along the fiber. The alignment of the crystals makes the fiber extremely resistant to its size. Several thousand carbon fibers are wound together to form a yarn, which can be used as such or woven (BARILE; CASAVOLA, 2019). This material is characterized by its low density, high tensile and compression resistance, flexibility, good electrical and thermal conductivity, temperature resistance and chemical oxidation inertia. Its main use is to serve as reinforcement in composite materials, which makes it possible to obtain parts with good mechanical properties, being lighter than metallic parts (LI; ENGLUND, 2017).

Carbon fibers are obtained by depositing chemical vapor from a carbon precursor, such as benzene, have different properties and applications and are generally referred to as carbon nano fibers. A carbon fiber is a material with a high carbon content (more than 90%

by weight). At the atomic level, a fiber is composed of poly aromatic carbon sheets stacked in a structure that can be very close to graphite, but which can also be more disordered than graphite (LI *et al*., 2019). The level of graphitization of the fibers depends on the precursor used, but also on the method of elaboration used. The arrangement of the carbon leaf stacks constitutes the microstructure of the carbon fibers, it also depends on the carbon precursor and the synthesis process (CHOWDHURY; SEHITOGLU; RATEICK, 2018).

A fiber is a monodimensional material, it is available to the fibers in two or three dimensions that will allow to obtain a composite part of C / C with good mechanical properties. The wear properties of a carbon fiber are therefore characterized in the longitudinal direction of the fiber. The diameter of carbon fibers is today between 5 and 10 µm. The density of carbon fibers is about 1.7 g / cm^3 (LI; ZHANG; JIANG, 2019). This makes it possible to design composite materials with similar density, which represents a very significant reduction compared to metallic materials. The main use of carbon fibers is the development of composite materials with improved mechanical properties with reduced weight. The mechanical properties are, therefore, the essential characteristics of a fiber. Two parameters are used mainly (BARILE, CASAVOLA; DE CILLIS, 2019):

- The modulus of elasticity that corresponds to the relationship between an applied stress and the deformation of the fiber;
- The stress corresponding to the rupture of the fiber called “rupture force”.

A fiber with a high modulus of elasticity will deform very little, but it can break for moderate stresses. Used as a reinforcement it can lead to a material with a fragile character. This type of fiber is called a high modulus fiber. A fiber with a more moderate modulus of elasticity will have greater resistance to breaking, providing the composite material with a better breaking strength, but with greater deformability. If a carbon fiber has a very graphical character and a very ordered structure, it will have a high modulus of elasticity, on the other hand, it will have a fragile character (ARENA *et al*., 2019).

The control of this structure is obtained by choosing the precursor, but also by using a high temperature heat treatment. The fibers obtained from polyacrylonitrile represent most of the reinforcements used in composites. This is related to the fact that they can have good mechanical properties and have a moderate manufacturing cost. PAN is a polymer with the formula [-CH2-CH (CN) -] n (VISCARDI *et al.,* 2018).

The first step is to obtain monofilaments by centrifuging and elongating the polymer. These monofilaments are then mounted on wicks containing several thousand threads. This step already allows obtaining a preferential orientation of the polymer chains in the direction of the wire; the blocks are stabilized by oxidation between 200 ° C and 300 ° C for one to two hours (Yadav *et al*., 2020). During this step, the wires are kept energized to maintain the orientation of the PAN chains. During this treatment, a dehydrogenation of the polymer is observed, leading to a first cyclization phase. Oxidation makes it possible to create chemical functions containing oxygen in the carbon chains (-CO2H, -C = O, -OH, etc.) (MOSKVITIN; MAKAROV; LEONOVICH, 2019).

These functions will later allow the chains to cross-link with each other; carbonization under an inert atmosphere between 1000 ° C and 1500 ° C leads to a large part of the elements H, N and O. The polymerization of the polymer continues and a fiber with a disordered structure is obtained; to improve the fiber structure, a second heat treatment can be carried out at an elevated temperature (above 2000 ° C) (VERA-CÁRDENAS et al., 2019). This makes it possible to eliminate the elements H, N and O almost completely and increase the graphical character of the fiber and, therefore, its mechanical properties. Understanding how to obtain carbon fiber parts is vital to understanding their mechanical behavior (GONG *et al*, 2020).

The epoxy resin used with carbon fiber is also known as polyepoxides or epoxy polymers. They are produced by polymerizing epoxide monomers with a hardener (crosslinking agent) that can be based on acid anhydride, phenol or generally amine (poly amine, amino amide): these are three-dimensional polymers. The most well-known representative of epoxy polymers is Araldite glue. Epoxy (or epoxy) resins harden (irreversible reaction) in the presence of a hardener, under the effect of heat (thermosetting materials) (SANGA, GARNIER, PANTALÉ, 2018):

Epoxy resin + hardener → polyepoxide.

In the formulation, they are incorporated with various hardeners, reactive or non-reactive diluents, plasticizers, fillers, solvents, additives (dyes, stabilizers, etc.). Polyepoxides are commonly used as glues or paints. Their chemical properties make them useful in food and construction. In fact, once “dry” (after complete cross-linking), a polyepoxide film practically no longer reacts with other products (GRANGE *et al*., 2018). Once “dry”, it becomes rigid and maintains its shape, allowing it to be used to reinforce the components they use. In addition, when the mixture polymerizes, it reacts chemically with many organic or inorganic materials (PANTELAKIS, 2020). This reaction forms an adhesive with good tensile strength in the presence of many materials (wood, glass, porcelain, metal, etc.) (ARAI *et al*., 2019).

3 I MATERIALS AND METHODS

The rib was developed in the Autodesk Inventor Professional 2021 software with a rope length of 1 m and height of 0.2 m, considering it as close as possible to a real aircraft. Then, separate files were generated in order to establish the materials used. The data regarding the mechanical properties of each material were entered manually into the software. Table 1 shows the data for the 7075 aluminum alloy and carbon fiber.

Properties	7075 Aluminum Alloy	Carbon fiber
Density	2,8 g/cm³	1,76 g/cm³
Flow resistance	390 MPa	661 MPa
Maximum tensile strength	480 MPa	16 MPa
Young's Module	71 GPa	170 GPa
Poisson's ratio	0,33	0,27
Shear module	26,6917 GP	66,9291 GPa

Table 1 - Mechanical properties of 7075 aluminum alloy and carbon fiber with epoxy resin

It is noteworthy that the data referring to the carbon fiber were obtained through studies carried out in the laboratory, since these values may change according to the manufacturing process developed. For finite element simulation, a load applied to the center of mass of the rib was determined as shown in Figure 1.

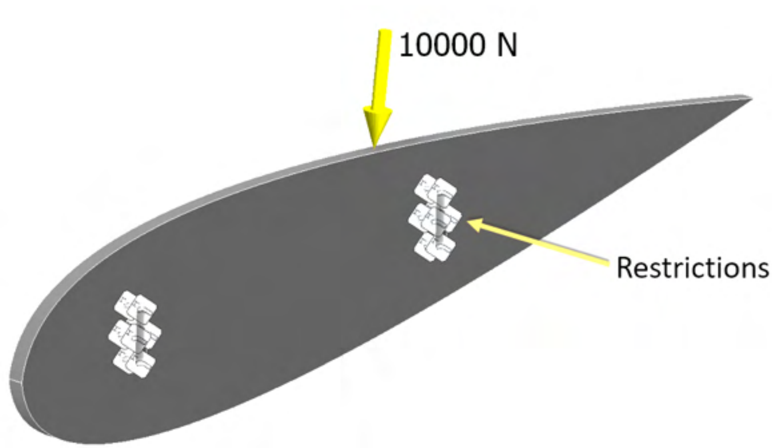

Figure 1 - Load application and attachment points (Restrictions) on the rib.

The restrictions shown in Figure 1 include the points where the stringers will be in contact with the ribs, with load transfer at these points. However, in this study only the behavior of the rib with an applied load of 10000 N was investigated, disregarding the transfer of this force to the stringers.

4 I RESULTS AND DISCUSSIONS

The main data to be identified in the two simulations are the Von Mises stresses, Main stresses and maximum displacement of the element. Figure 2 shows the Von Mises Tension values indicated by the software used in this study.

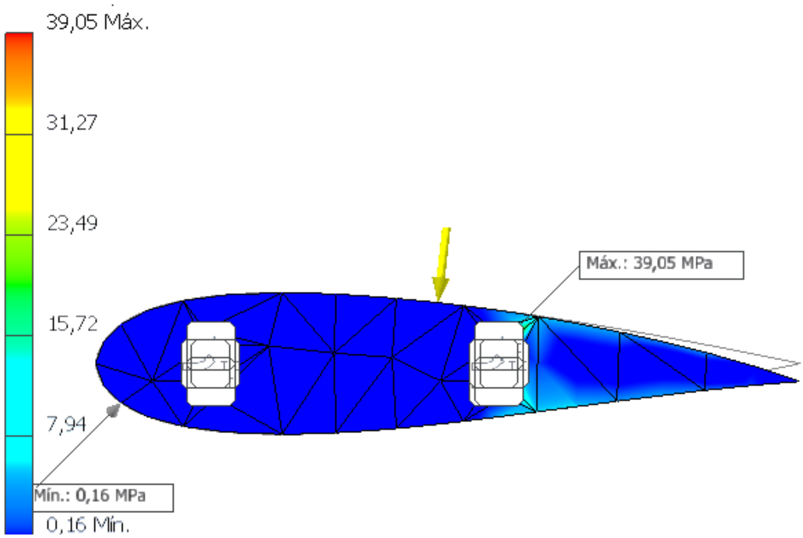

Figure 2 - Von Mises tension for the simulated rib with AA7075.

The main data to be identified in the two simulations are the Von Mises stresses, main stresses and maximum displacement of the element. Figure 2 shows the Von Mises stress values for the element made with AA7075 used in this study. Figure 2 indicates that the maximum stress is at the point of contact where the thickness of the rib is less, increasing the possibility of material failure at this point. The minimum tension is identified on the front of the rib. This is one of the most important results in the analysis of metallic and plastic components. The von Mises tension, as its name implies is a tension, it has the property of being a number (a scalar) that is obtained by combining the “beam” of all the stresses in space (stresses in the x, y, z directions) expressed by Equation 1:

$$\sigma_{VM} = \sqrt{\sigma_{xx}^2 + \sigma_{yy}^2 + \sigma_{zz}^2 - (\sigma_{xx}\sigma_{yy} + \sigma_{yy}\sigma_{zz} + \sigma_{zz}\sigma_{xx}) + 3(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)} \quad (1)$$

It should also be noted that the stress calculations are done automatically by the software and it is not necessary to enter parameters. Following with the Von Mises stress analysis, Figure 3 presents the data obtained for the simulation of the carbon fiber rib.

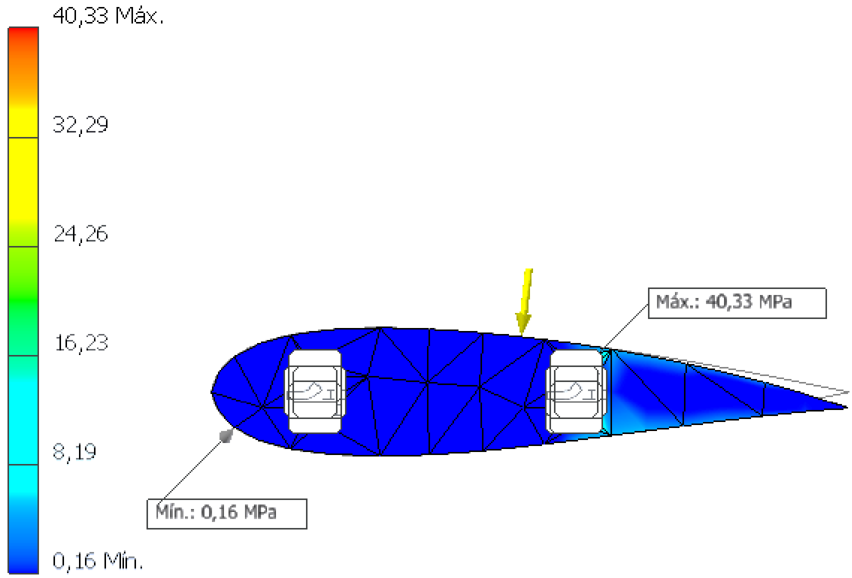

Figure 3 - Von Mises tension for the rib made with carbon fiber.

In the carbon fiber part, the maximum and minimum stress locations are the same as shown in Figure 2. However, in the carbon fiber part the maximum allowable stress is greater when compared to the 7075 aluminum alloy rib, being about 1.20 MPa higher, indicating that for these conditions the rib made of carbon fiber has a more satisfactory behavior

The main stress values, which are also important in the analysis of finite elements for setting tension and compression values are shown in Figure 4.

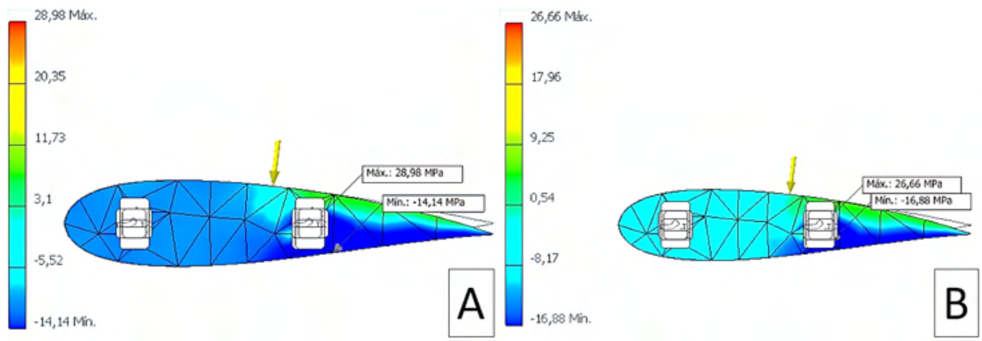

Figure 4 - Main tension in the 7075 Aluminum rib (A), and in the Carbon Fiber rib (B).

From the data presented in Figure 4, it can be noted that the 7075 aluminum rib has a maximum main stress of 28.98 MPa, while the carbon fiber rib has a maximum stress value equal to 26.66 MPa. These data show that, in this analysis, the metal alloy performs better when compared to the composite.

Regarding the minimum stress presented, being that it refers to the traction, the 7075 aluminum rib has the value of -14.14 MPa, while the carbon fiber fiber rib has the value of -16.88 MPa. This analysis indicates that the carbon fiber rib undergoes greater traction when purchased with the aluminum rib. These data show that the fiber rib is more efficient when considering maximum stress related to compression, but when considering the minimum stresses, related to traction, the aluminum rib 7075 has a better behavior, requiring studies best suited to determine which meets the required conditions of use.

Another important aspect in relation to the analysis of finite elements is the vibration of the element that can directly interfere in its operation. As the comparative analysis is performed here it is a metal and a composite material, the vibration values are extremely different, as shown in Figure 5.

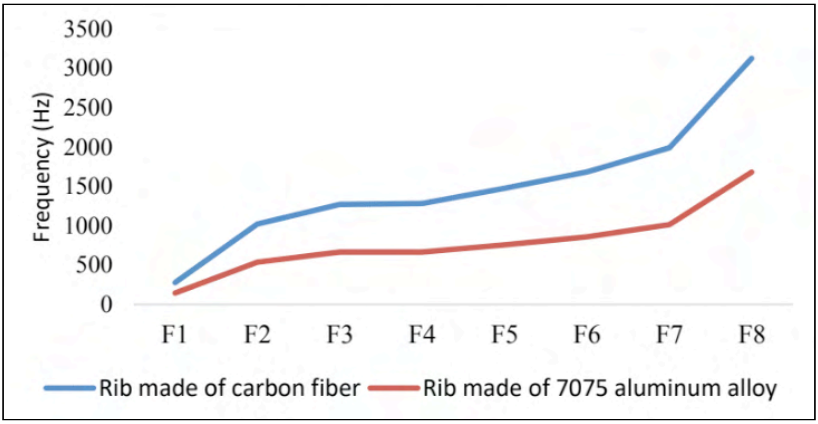

Figure 5 - Frequency (F) for the carbon fiber ribs and the 7075 aluminum alloy rib.

The data in Figure 5 show values of frequencies 8 points of the ribs studied in this work. It is noted that the carbon fiber has higher values of higher frequencies than the aluminum alloy 7075. High values of frequency mean that objects vibrate more during their operation, which may lead, for example, to the occurrence of resonance, causing that extra care is taken when using carbon fiber.

The next analysis refers to the displacement on the x-axis referring to the deformation suffered by the rib from the application of the force of 1000 N. Figure 6 shows the comparisons for the two materials.

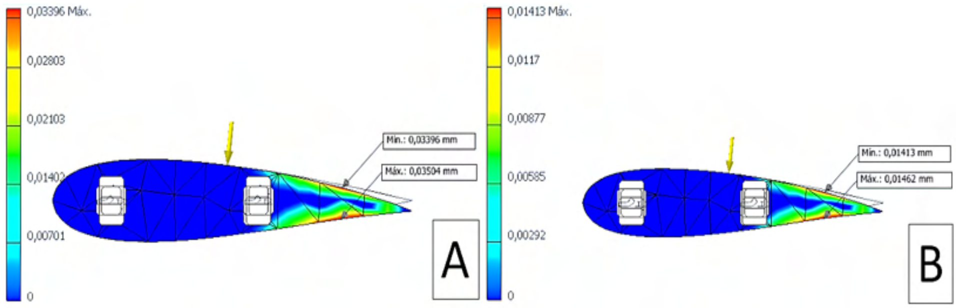

Figure 6 - Main tension in the 7075 Aluminum rib (A), and in the Carbon Fiber rib (B).

From the data presented, it is noted that the aluminum alloy has a greater displacement in relation to carbon fiber. In the aeronautical segment, this shift is extremely relevant, since it allows greater flexibility during the operation. When considering the choice of material, it is also necessary to consider the weight of the components, which in this case is carbon fiber with a mass of 3.49842 kg, while the aluminum rib has a mass of 5.56567 kg.

5 I CONCLUSION

Based on the presented study, it can be said that the use of carbon fiber for the production of aeronautical ribs is more advantageous than the aluminum alloy 7075, since it has mechanical properties superior to metal and less mass. However, the metal alloy presents deformations superior to the composite material, which makes carbon fiber more prone to critical failures.

It is also worth noting that the quality of a rib made of carbon fiber or other composite material is directly related to its production process, so that in the end it is necessary to carry out tests to determine the mechanical properties. Finally, the selection of the type of material must take into account the aircraft's characteristics, such as its load capacity, mass, among others, seeking to obtain the most suitable material.

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ÍNDICE REMISSIVO

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