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Composite Material for Morphing Wing Skin Application – A Numerical Analysis

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Abstract: Aircraft design tends to overall performance and weight reduction in order to withstand the aerodynamic loads in different flight conditions. The new technology of morphing wing is to alter the wing geometry to adapt the desirable flight conditions. This study is to conduct a structural analysis for the morphing wing model by using the carbon fiber reinforced polymer (CFRP) on the flexible skin and compare the mechanical properties with Al 2014-T6 for the morphing wing model. The NACA 4415 airfoil is selected for morphing wing model. Hence, the design of morphing wing model is done by the SolidWorks software and the simulation is completed by using the ABAQUS software. The Abaqus/Explicit is used in this finite element analysis. The materials selected in the simulation are Al 2014-T6, T300/QY8911, T800/M21 and M55J/epoxy. The Al 2014-T6 is adopted for the inner structure and the CFRP composite laminates is adopted for the flexible skin. The body force is applied on the model from 1000N to 100kN with different CFRP laminates for flexible skin. From the stress-strain diagram obtained, the result shown that M55J/epoxy has the highest stiffness among the CFRP composite laminates. When comparing with the Al 2014-T6 that applied on the flexible skin, the M55J/epoxy shown the high stiffness-to-weight ratio compared to the mechanical properties of Al 2014-T6 in the stress-strain diagram. The most suitable material for the morphing wing model in this study is the high strength CFRP of M55J/epoxy for the flexible skin in order to reduce the overall weight of an aircraft with high performance during flight.

Keywords: Morphing Wing Model, Carbon Fiber Reinforced Polymer (CFRP), Al 2014-T6, M55J/Epoxy

1. Introduction

In aeronautics industry, aircraft design is satisfied to meet the requirement on flying performance, reliability, safety factor and service life [1]. Hence, the aircraft structure is one of the most important design parts to support the applied load during flight. Structural analysis for an aircraft is primarily to avoid the structural failure during flight. In order to improve the overall performance and efficiency of an aircraft, it is possible to reduce the overall weight by using the composite material in the aircraft

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structure. Based on the manufacturing of Boeing 787 airliner, there have been replaced 50% of carbon fiber reinforced polymer (CFRP) composites as the highest use of composite material for the aircraft construction [2]. Among all the aircraft components, structural analysis mainly studies the wings since their performance is critical for the overall safety of aircraft [3]. The aircraft wings with aerodynamic shape that used composite materials will increase the lift-to-drag ratio. Due to the high stiffness-to-weight ratio of the composite structure, the development composite materials are mainly used in the aircraft manufacturing process. The structural skins for an aircraft wing must withstand high loads, inhospitable environments and provide superior mechanical properties such as high local out-of-plane stiffness and high flexural strength in combination with a smooth and closed aerodynamic surface. Therefore, the aircraft wing applied the new technologies such as the morphing wing to optimize the aerodynamic performance of an aircraft with the implementation of composite material.

This study mainly focuses on the structural analysis for the morphing wing model with the carbon fiber reinforced polymer (CFRP) composite laminate for the flexible skin of morphing wing model. After that, the CFRP composite laminate is compared with the mechanical properties of Al 2014-T6 in the stress-strain diagram. The Abaqus/Explicit is used to conduct the structural analysis for the geometrical nonlinear morphing wing model.

2. Methodology

In this study, the numerical analysis is used for simulation of morphing wing model for the finite element analysis. The Abaqus/Explicit is used to perform the static structural analysis of morphing wing model in term of stress, logarithmic strain and displacement.

2.1 Morphing Wing Model

The morphing wing model is designed by using the SolidWorks software which consists of 15 ribs, 2 spars and the wing flexible skin. The NACA 4415 airfoil is selected from airfoil plotter available online and the provided coordinates of the airfoil profile is imported into the SolidWorks software imported to the SolidWorks software. Table 1 shows the morphing wing design parameters. The morphing wing model is shown in Figure 1.

Table 1: Morphing Wing Design Parameters

Parameters	Dimension	Unit
Wing Span	27.05	m
Half Wing Span	13.525	m
Wing Area	61	m^2
Aspect Ratio	12	-
Wing Chord	2.26	m
Airfoil Type	NACA 4415	-
Front Spar	20% of chord	-
Rear Spar	65% of chord	-
Rib Thickness	20	mm
Spar Thickness	6	mm
Distance between Each Ribs	150.67	mm

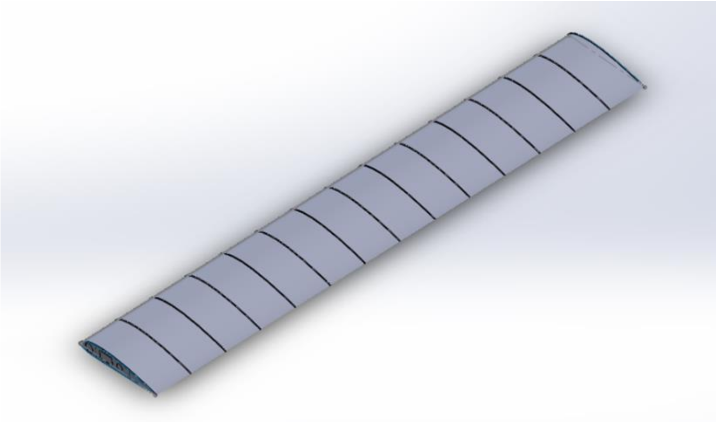


Figure 1: Morphing Wing Model

2.2 Material Selection

The materials used in this study is Al 2014-T6 and carbon fiber reinforced polymer (CFRP) composite laminates. The CFRP gives the benefit of lightweight and high stiffness-to-weight-ratio. For the inner structure (ribs and spars), the material used is Al 2014-T6 while the flexible skin used CFRP such as T300/QY8911, T800/M21 and M55J/epoxy. For the CFRP composite laminate used in the flexible skin, there are 10 plies of fiber with 0.15mm thickness each and the fiber oriented in a balance and symmetric ply sequence at the angle of 0˚, 90˚, 45˚, -45˚, 90˚. Table 2 shows the mechanical properties of Al 2014-T6 and Table 3 shows the material properties of the CFRP composite laminate.

Table 2: Mechanical Properties of Al 2014-T6 [4]

Mechanical Properties	Value	Unit
Elastic Modulus, E	73.1	GPa
Shear Modulus, G	27	GPa
Poisson's Ratio, ν	0.35	-
Density, ρ	2790	kg/m^3

Table 3: Material Properties of the CFRP composite laminate [5-7]

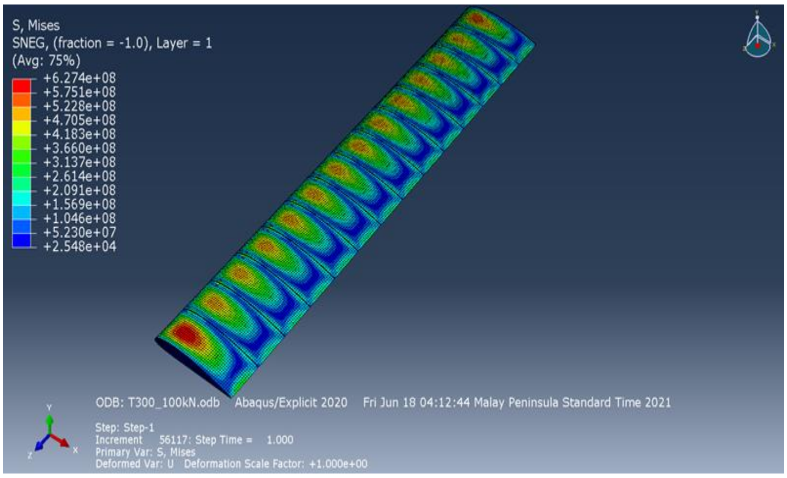
Material Properties	T300/QY8911	T800/M21	M55J/epoxy	Unit
Longitudinal Modulus, E_1	135	172	300	GPa
Transverse modulus, E_2	8.8	8.9	12	GPa
In-plane shear modulus, G_{12}	4.47	4.2	3.87	GPa
Out-of-plane shear modulus, G_{13}	4.47	4.2	3.87	GPa
Out-of-plane shear modulus, G_{23}	4.47	4.2	3.87	GPa
Poisson's Ratio, ν	0.2	0.35	0.365	-
Density, ρ	1570	1600	1760	kg/m^3

3. Results and Discussion

The 1000N, 5000N, 10kN, 50kN and 100kN of body force is applied on flexible skin with different CFRP composite laminate such as T300/QY8911, T800/M21 and M55J/epoxy. The contour plot of the morphing wing model with different CFRP composite laminate of flexible skin is displayed in term of Von Mises Stress, logarithmic strain and displacement. The body force of 100kN is shown for the contour plot for the T300/QY8911, T800/M21 and M55J/epoxy respectively. Figure 2, Figure 3 and Figure 4 shows the contour plot of T300/QY8911, T800/M21 and M55J/epoxy at 100kN respectively.

3.1 T300/QY8911

Figure 2 shows the contour plot of structural analysis for T300/QY891 of morphing wing skin.



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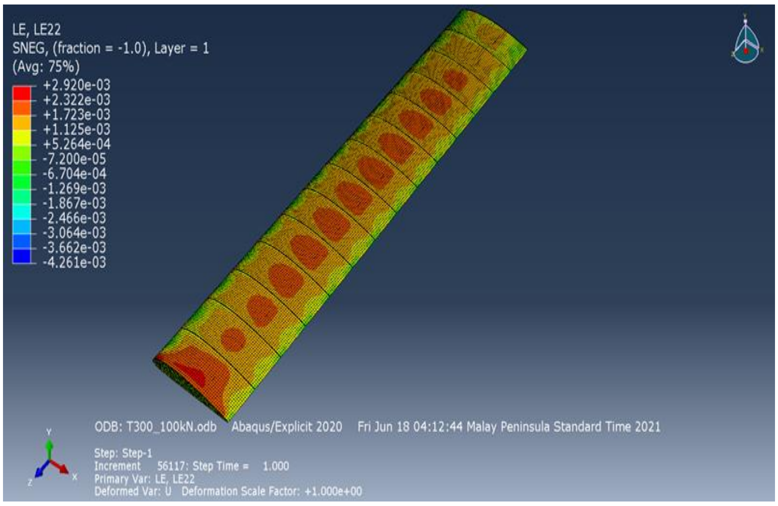

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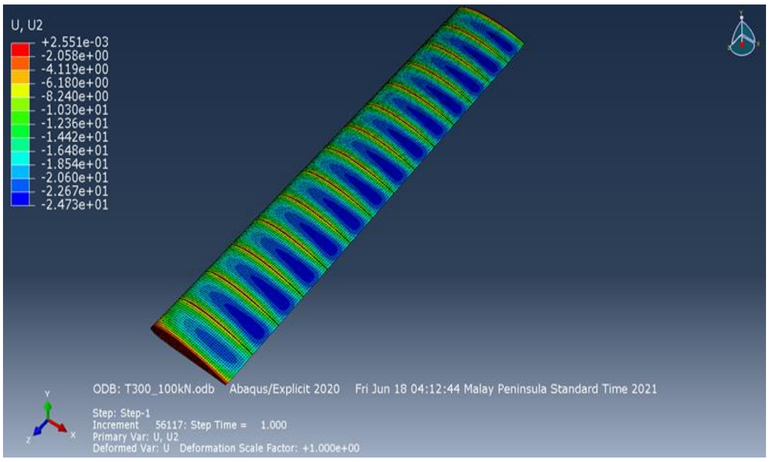
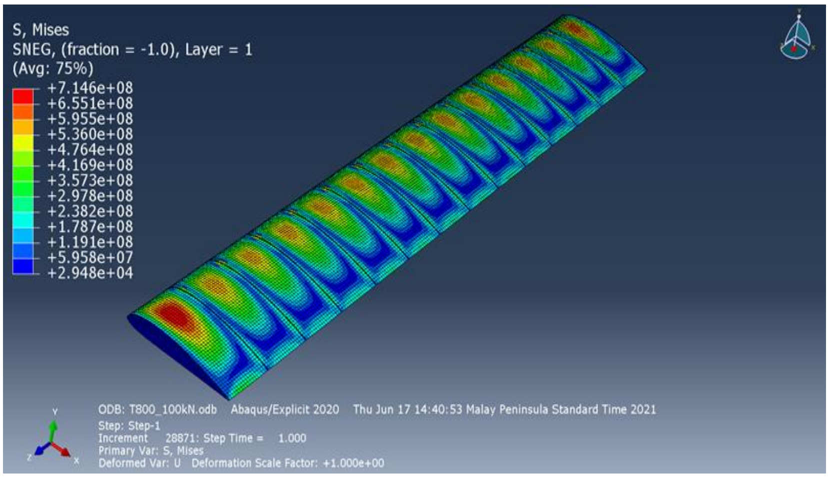


(c)

Figure 2: Structural Analysis of T300/QY8911 (a) Von Mises Stress, (b) Logarithmic Strain, (c) Displacement

3.2 T800/M21

Figure 3 shows the contour plot of structural analysis for T800/M21 of morphing wing skin.



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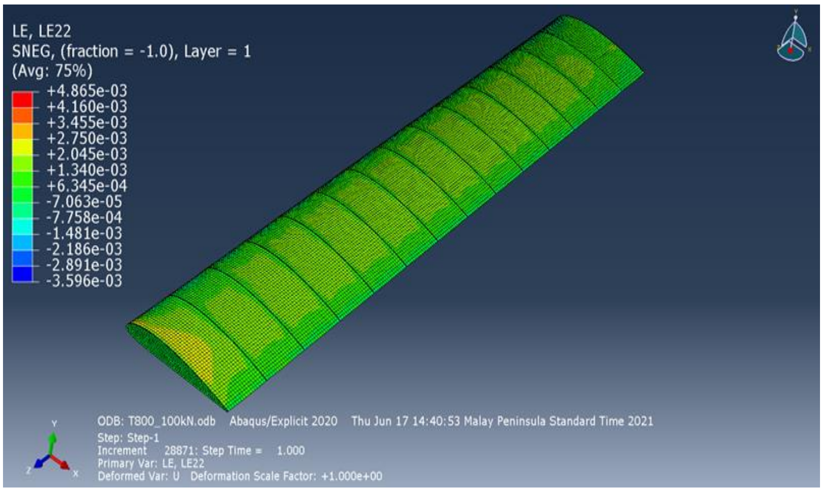

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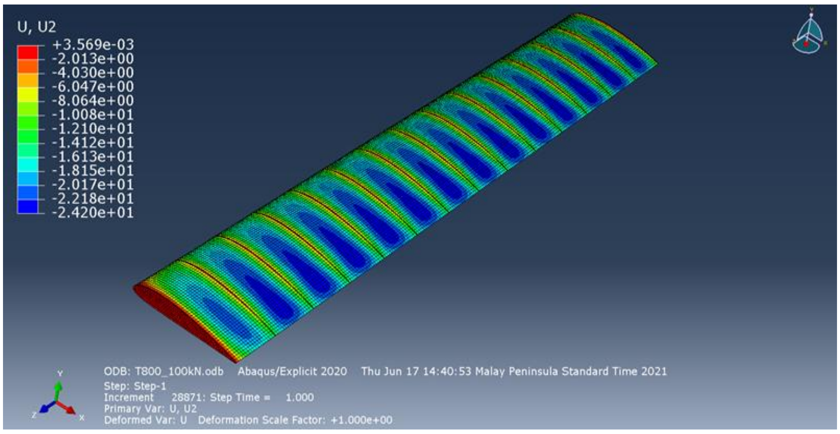
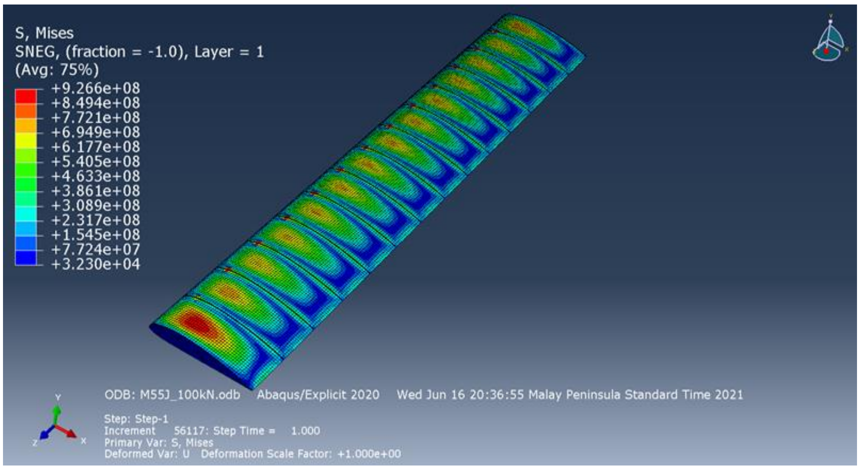


(c)

Figure 3: Structural Analysis of T800/M21 (a) Von Mises Stress, (b) Logarithmic Strain, (c) Displacement

3.3 M55J/epoxy

Figure 4 shows the contour plot of structural analysis for M55J/epoxy of morphing wing skin.



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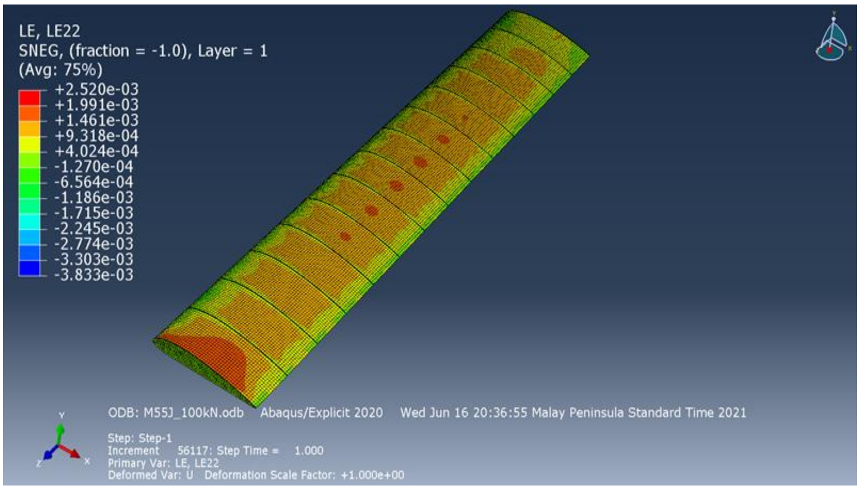

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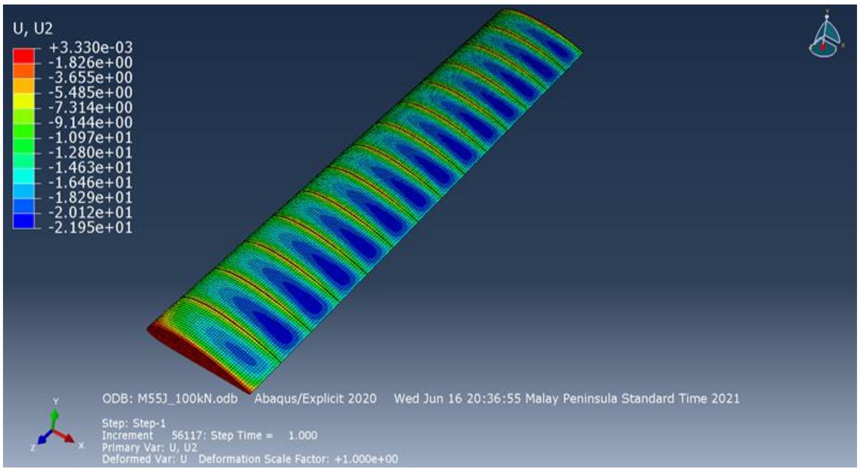

(c)

Figure 4: Structural Analysis of M55J/epoxy (a) Von Mises Stress, (b) Logarithmic Strain, (c) Displacement

3.3 Stress-strain Diagram

The stress-strain diagram is used to measure the mechanical behavior of a material when subjected to a load. The strength and elasticity of a material can be performed in this stress-strain diagram. As the stress increases proportional with the strain, the slope of stress-strain is represented the modulus of elasticity or Young's Modulus, E. Hence, the mechanical behavior of CFRP laminates for flexible skin is shown when the body force is applied. Figure 5 shows the stress-strain diagram of morphing wing model at 100kN body force.

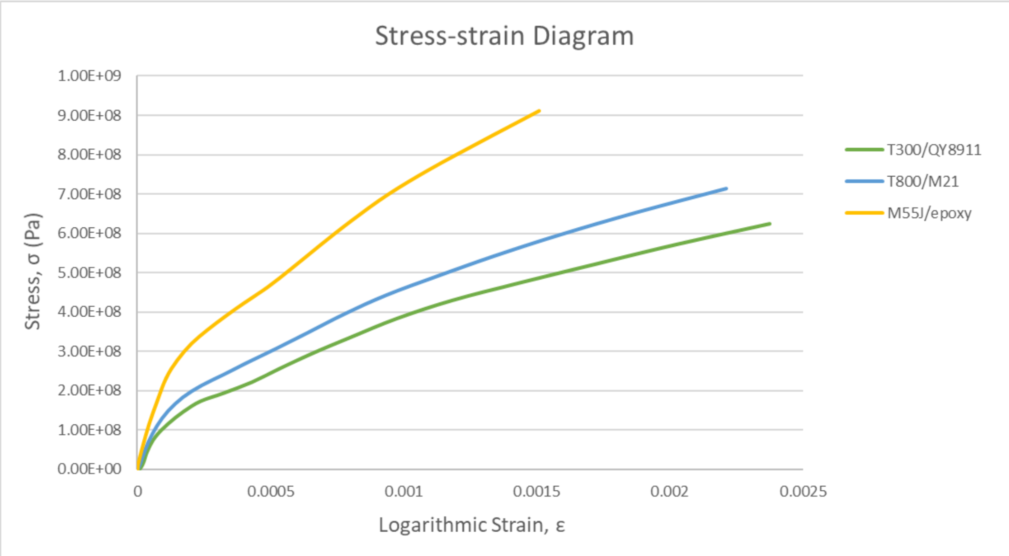

Figure 5: Stress-strain Diagram of Morphing Wing Model at 100kN Body Force

Based on the Figure 5, the stress increases proportional with the strain until the proportional limit, which the modulus of elasticity indicates the stiffness of the material and the ability to withstand deformation under the applied load [8]. Hence, the high stiff material will have the high modulus of elasticity with less deformation under the strain. Therefore, from Figure 5, the M55J/epoxy shows the highest stiffness significantly among the three CFRP laminates. In fact, the M55J/epoxy has the highest value of E which is 300GPa while the value of E for the T300/QY8911 and T800/M21 is 135GPa and 172GPa. As the CFRP composite laminates is the anisotropic material, the properties will change with different directions. Hence, it provides stronger resistance due to the applied in different directions [8]. The fiber orientation angle for stacked ply also considered as the important for CFRP. As the fiber oriented at 0˚, 90˚, 45˚, -45˚, 90˚ with its symmetry ply laminate to the applied load, thus it helps to enhance the in-plane shear strength of the laminates [8].

As the M55J/epoxy laminates shown the best performance among the three CFRP laminates in stress-strain diagram, hence the M55J/epoxy laminates is compared with Al 2014-T6 for the morphing wing flexible skin. Figure 6 shows the stress-strain diagram for the comparison of M55J/epoxy and Al 2014-T6 for the morphing wing model at 100kN body force.

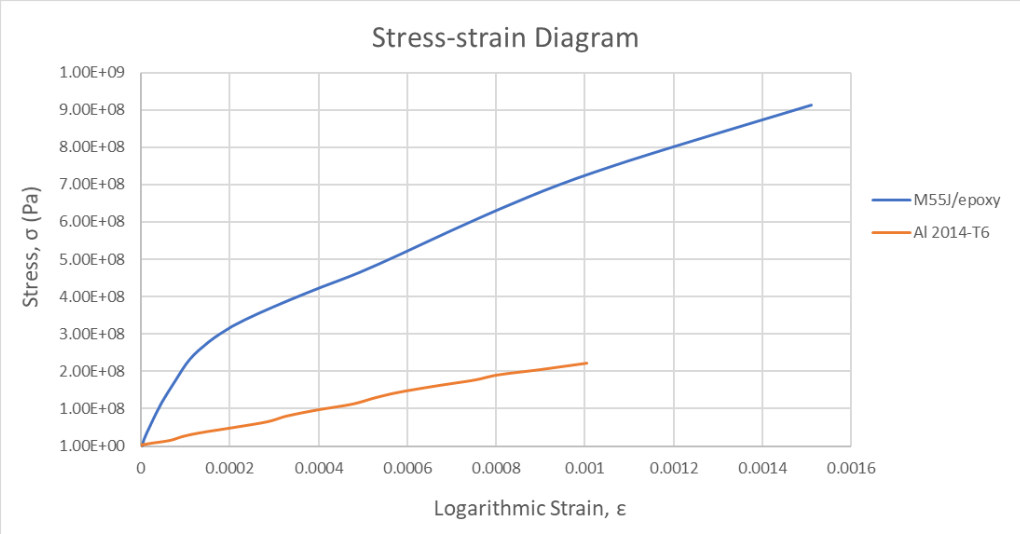

Figure 6: Comparison of M55J/epoxy and Al 2014-T6 in Stress-strain Diagram

As a comparison, in the Figure 6, the M55J/epoxy shows the high stiffness significantly compared to Al 2014-T6. The Al 2014-T6 has low modulus of elasticity with high value of strain under the 100kN body force applied on the flexible skin. In fact, the Al 2014-T6 has modulus of elasticity of 73.1GPa while M55J/epoxy shows 300GPa which means that M55J/epoxy has higher strength than Al 2014-T6. When compared with the density, Al 2014-T6 has the value of 2790 kg/m3 and M55J/epoxy shows 1760 kg/m3. This means that the use of M55J/epoxy in flexible skin can reduce its weight about 37% compared to Al 2014-T6. As a conclusion, CFRP has the benefit of high strength and high stiffness-to-weight ratio compared to Al 2014-T6 when consider for the design of morphing wing flexible skin.

4. Conclusion

In conclusion, the objectives for this study have been achieved successfully. The structural analysis is conducted for model wing model by simulation method. The carbon fiber reinforced polymer (CFRP) composite laminate is used for the morphing wing flexible skin and compare with the mechanical properties of Al 2014-T6. The Abaqus/Explicit is used for this numerical analysis of morphing wing model. As a result, the M55J/epoxy is the most suitable composite laminate for the morphing wing flexible skin due to the high strength and high stiffness-to-ratio performance in this study.

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