Fibrous Orientation Effects on the Deformation and Stress of an Insect-like Flapping-wing Micro Aerial Vehicle Based on ACP

Akther Shema, Chunjin Yu*, Fang Wang
Institute of Aircraft Engineering, Nanchang Hangkong University, Nanchang 330063, China
Email: 34005@nchu.edu.cn

Abstract. This paper examines the effect of different orientation of composite material on the deformation and stress of dragonfly-like flapping-wing micro aerial vehicles (FWMAVs). After billions of years of evolution, insects employing flapping-wing tend to have excellent flight capabilities. In order to understand the bionic wings will be helpful to design high performance aircrafts. FEM analysis of flapping wing structure simulating dragonfly wings having three layers Epoxy carbon composite material and resin epoxy is glue for adhesive two layers. In the process, the flapping wing model was created in ANSYS Workbench ACP (pre), ACP (post) and then the loading of the flapping wing in each phase will be calculated. Finally, the graphs showing the changes of the maximum deformation displacement and maximum stress can be worked out. It can be known that for the first principle stress, -35° is the best performance because -35° stresses is lowest stress and +35° is the worst performance because this angle is the highest stress. For the second principle stress the -25° is the best performance because -25° have the lowest stress. For the third principle stress, -45° is the worst performance because -45° is the highest stress, +45° is the best performance because here stress is the lowest and 0° is the worst because here stress is the highest. The findings are helpful in answering why insect wings are so impeccable, thus providing possibility of improving the design of flapping wing aerial vehicles. This paper will found why insect wings are impeccable.

1. Introduction
After billions of years of evolution, many insects use flapping-wing flight mode. Over the past few years, we have witnessed the rapid development of flapping wing micro-air vehicles (FWMAVs) with sizes approximating the dimensions of insects or small birds. We inspired by insects we think in the future (FWMAVs) will be very useful for defense and civilian technology. Compare to flapping wings, conventional fixed wing airplane are relatively simple [1-4]. Inspired by insect flight in the wild, this type of FWMAVs offers promising future applications in both defense and civilian technology. Compared to conventional types of aircraft, such as rotorcraft and fixed-wing vehicles, FWMAVs are believed more efficient when scaled down to the insect size range [5]. How insect wings function structurally under dynamic wing loading is not yet fully understood, although existing studies have generated novel insight in how the venation pattern of insects is critical for their load baring capacity and aero elastic function. Wing membranes are highly flexible with large deformations during the stroke [6].

A major potential advantage claimed for fibrous composite materials in structural applications is that the material can be tailored by proper orientation of the fibers in various layers so as to optimize...
the desired structural behavior [7]. Yet the very nature of fibrous composites with their anisotropic elastic behavior has kept such optimal tailoring beyond the reach of most design engineers.

FWMAVs is an imitation of birds or insects [8-10] flying new aircraft concepts in the application of its technology beyond the traditional scope of the study aircraft design and aerodynamics [11-13], while creating micro-electromechanical systems (MEMS) technology applications in the field of aviation. Bionic efficient wing design and manufacture with good dynamic characteristics [14-15], is bionic FMAV study of a key, but also the currently very challenging research problems.

2. Method of Calculation
In general, fiber composite materials are heterosexual, if the selected coordinate system is consistent with the material, it can be simplified as orthogonal anisotropy. For the analysis of anisotropic or orthotropic materials, the basic assumptions of elastic mechanics can be continued and the basic equations can be derived from the following, taking into account the minor deformations.

The volume of the unit body is set force \( \varphi (f_x, f_y, f_z) \). OAED surface stress component of \( \sigma_{xx}, \tau_{xy}, \tau_{xz} \), stress OCGD surface is \( \sigma_{yx}, \tau_{yx}, \tau_{yz} \), OABC surface stress component \( \sigma_{zz}, \tau_{zx}, \tau_{zy} \), as shown in Figure 1. Let u, v, w is the Cartesian coordinate system displacement component \( \varepsilon_x, \varepsilon_y, \varepsilon_z, \gamma_{xy}, \gamma_{yz}, \gamma_{zx} \), as the dependent variable, then in small deformation conditions, the relationship between them is;

\[
\begin{align*}
\varepsilon_x &= \frac{\partial u}{\partial x}, \quad \varepsilon_y = \frac{\partial v}{\partial y}, \quad \varepsilon_z = \frac{\partial w}{\partial z} \\
\gamma_{yz} &= \frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}, \quad \gamma_{zx} = \frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}, \quad \gamma_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}
\end{align*}
\]

Figure 1. Unit body stress

After elimination of the above formula u, v, w obtained:

\[
\begin{align*}
\frac{\partial^2 \gamma_{xy}}{\partial x \partial y} &= \frac{\partial^2 \varepsilon_x}{\partial x^2} + \frac{\partial^2 \varepsilon_y}{\partial y^2} \\
\frac{\partial^2 \gamma_{zx}}{\partial x \partial z} &= \frac{\partial^2 \varepsilon_x}{\partial x^2} + \frac{\partial^2 \varepsilon_z}{\partial z^2} \\
\frac{\partial^2 \gamma_{yz}}{\partial y \partial z} &= \frac{\partial^2 \varepsilon_y}{\partial z^2} + \frac{\partial^2 \varepsilon_z}{\partial y^2}
\end{align*}
\]
More than six equations by displacement - strain relation derived directly called the continuity equation, also called the deformation compatibility condition.

If the object is zero in the absence of stress, or when the stress is zero when the stress is zero, in the Cartesian coordinate system, said the general relationship between stress and stress is:

\[
\begin{bmatrix}
\varepsilon_x \\
\varepsilon_y \\
\varepsilon_z \\
\gamma_{yz} \\
\gamma_{zx} \\
\gamma_{xy}
\end{bmatrix}
= \begin{bmatrix}
\bar{S}_{11} & \bar{S}_{12} & \bar{S}_{13} & \bar{S}_{14} & \bar{S}_{15} & \bar{S}_{16} \\
\bar{S}_{21} & \bar{S}_{22} & \bar{S}_{23} & \bar{S}_{24} & \bar{S}_{25} & \bar{S}_{26} \\
\bar{S}_{31} & \bar{S}_{32} & \bar{S}_{33} & \bar{S}_{34} & \bar{S}_{35} & \bar{S}_{36} \\
\bar{S}_{41} & \bar{S}_{42} & \bar{S}_{43} & \bar{S}_{44} & \bar{S}_{45} & \bar{S}_{46} \\
\bar{S}_{51} & \bar{S}_{52} & \bar{S}_{53} & \bar{S}_{54} & \bar{S}_{55} & \bar{S}_{56} \\
\bar{S}_{61} & \bar{S}_{62} & \bar{S}_{63} & \bar{S}_{64} & \bar{S}_{65} & \bar{S}_{66}
\end{bmatrix}
\begin{bmatrix}
\sigma_x \\
\sigma_y \\
\sigma_z \\
\tau_{yz} \\
\tau_{zx} \\
\tau_{xy}
\end{bmatrix}
\] (4)

If the inverse of the above formula, there are:

\[
\begin{bmatrix}
\sigma_x \\
\sigma_y \\
\sigma_z \\
\tau_{yz} \\
\tau_{zx} \\
\tau_{xy}
\end{bmatrix}
= \begin{bmatrix}
\bar{C}_{11} & \bar{C}_{12} & \bar{C}_{13} & \bar{C}_{14} & \bar{C}_{15} & \bar{C}_{16} \\
\bar{C}_{21} & \bar{C}_{22} & \bar{C}_{23} & \bar{C}_{24} & \bar{C}_{25} & \bar{C}_{26} \\
\bar{C}_{31} & \bar{C}_{32} & \bar{C}_{33} & \bar{C}_{34} & \bar{C}_{35} & \bar{C}_{36} \\
\bar{C}_{41} & \bar{C}_{42} & \bar{C}_{43} & \bar{C}_{44} & \bar{C}_{45} & \bar{C}_{46} \\
\bar{C}_{51} & \bar{C}_{52} & \bar{C}_{53} & \bar{C}_{54} & \bar{C}_{55} & \bar{C}_{56} \\
\bar{C}_{61} & \bar{C}_{62} & \bar{C}_{63} & \bar{C}_{64} & \bar{C}_{65} & \bar{C}_{66}
\end{bmatrix}
\begin{bmatrix}
\varepsilon_x \\
\varepsilon_y \\
\varepsilon_z \\
\gamma_{yz} \\
\gamma_{zx} \\
\gamma_{xy}
\end{bmatrix}
\] (5)

3. Result Analysis

FEM analysis of flapping wing structure simulating dragonfly wings having three layers, the top and bottom layers are Epoxy carbon (230) composite material, the middle layer is resin epoxy. In the process, the flapping wing model was created in ANSYS Workbench ACP (pre), ACP (post) and then the loading of the flapping wing in each phase will be calculated.

Pressure calculation is assumed as ref.7, the gravity of dragonfly wing is

\[G=754mg=0.754g\] (reference)

Area of dragonfly wing

\[S=222.63\times 2=445\text{mm}^2\] (area has got from design of this paper dragonfly wing)

\[P=\frac{G}{S} = \frac{0.754g}{445\text{mm}^2} = \frac{0.754\times 10^{-2}N}{445\text{mm}^2} = 0.1694 \times 10^{-5} N/\text{mm}^2\]

In this paper a wing like dragonfly was analyzed in ANSYS workbench ACP. In this graph, the middle layer of composites is fixed, and only the orientation angle of top layer and bottom layer were changed. Fig.2 is the structure’s failure analysis profile; it shows that the structure is safe.
Figure 2. Failure analysis profile

Fig. 3 is the total deformation graph, the middle layer is fixed and the top layer and bottom layer is kept same orientation.

Figure 3. Deformation graph analysis

Here -45° angle is best performance for dragonfly wing in my design, because -45° angle is the lowest deformation. In addition, +45° is worst performance because +45° have highest deformation.
Fig. 4 is the principle stress of three layers.

a. First layer principle stress of the wing

b. Second layer principle stress
c. Third layer principle stress

**Figure 4. Principle stress of three layers**

From figure 4 it can be known that for the first principle stress, \(-35^\circ\) is the best performance because \(-35^\circ\) stresses is lowest stress and \(+35^\circ\) is the worst performance because this angle is the highest stress. For the second principle stress the \(-25^\circ\) is the best performance because \(-25^\circ\) have the lowest stress. For the third principle stress, \(-45^\circ\) is the worst performance because \(-45^\circ\) is the highest stress, \(+45^\circ\) is the best performance because here stress is the lowest and \(0^\circ\) is the worst because here stress is the highest.

4. Conclusion

In this thesis paper the representative of the nature the dragonfly as the research object, establish a precise geometric model of dragonfly wing. Reference to the previous research results, the selection of material were taken named as epoxy carbon. This material using for three layers epoxy carbon used for top and bottom layers and resin epoxy used in the middle layer resin epoxy is glue it is for adhesive top and bottom layers.

This paper analysis total maximum deformation, maximum stress for three layers for single orientation angle. In addition, for singe orientation \(-35^\circ\) is the best orientation angle and \(+35^\circ\) is the worst orientation angle. Moreover, here also analysis maximum stress for two-layer different orientation.

After analysis, the results can be concluded as follows:

1. The deformation of the structure is obviously reduced; the maximum deformation of the structure is about 5% of the whole wing length.
2. The stress on the membrane is also reduced, the maximum stress of the membrane is also less comparing with the original one, and the stress on the membrane is also distributed in the distribution of the concentration.
3. For the dragonfly-like composite wing, single orientation \(-35^\circ\) is the best orientation and \(+35^\circ\) is the worst orientation.

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