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CROSS-LONGITUDINAL REINFORCEMENT DESIGN FOR THIN STRUCTURES IN AEROSPACE INSPIRED BY DRAGONFLY WING

Abstract

The aim of this study is to establish a novel design approach for aerospace structures, especially thin structures such as pressurized vehicle skin and propellant tank, by utilizing biomimetics. This design approach particularly focused on the dragonfly wing, whose skin is reinforced by cross-veins and longitudinal veins.

The preliminary study on an aircraft wing cover emulated only cross-veins reinforcing the skin along a mathematical layout of Centroidal Voronoi Tessellation (CVT), which achieved an innovative structure effective in buckling and significantly contributed to the weight reduction of the entire reinforced skin.

The optimized structures indicated the necessity of emulating the longitudinal veins as well as the cross-veins to reduce the structural weight furthermore. Consequently, the longitudinal veins have been emulated by reinforcing the skin along an additional layout of a centerline extracted from the topology optimization result on the skin to be reinforced, through image analysis of binarization and skeletonization. This longitudinal layout increased the stiffness of the reinforced skin without increasing the mass, distributing the inner load only with essential reinforcements.

In this design approach (called cross-longitudinal reinforcement design), the CTV layout was also improved to reinforce the skin more efficiently by weighting the CVT density on the out-of-plane displacement on the skin. This weighted CVT layout improved the effectiveness of the reinforced skin against buckling drastically.

As a result, the skin reinforced along the cross-longitudinal layout by the topology optimization and weighted CVT increased buckling load 2.7 times higher even with less mass than the conventional layout. In addition, the utilizing only the skeleton from the density distribution of topology optimization result has overcome the conventional dependency on designers especially in the post-process and the difficulties in numerical description and handling the buckling.

Furthermore, a prototyping and an X-ray inspection has revealed the structure achieved by the cross-longitudinal reinforcement design can be manufactured by the state-of-the-art additive manufacturing technology, although the manufacturing parameters has to be modified to achieve the quality conforming to the design.

Thus, the cross-longitudinal reinforcement design has been confirmed to be effective in thin structures in aerospace through the evaluation of feasibility on the pressurized vehicle skin. This design approach is expected to be effective in the other aerospace applications with thin structure where the lightness, stiffness and effectiveness against buckling are required.