LOCAL BUCKLING OF SANDWICH MATERIALS WITH NON-ORTHOGONAL PLAIN WOVEN COMPOSITE FACESHEETS

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Summary Fabric was often attached on lightweight core to form a sandwich plate. When complex sandwich structure was manufactured, the fabric facesheets were in a state of in-plane tension or shear deformation, and the angle between the warp and weft yarns was altered. Analytical model to calculate the local buckling load of sandwich plates with non-orthogonal plain woven composite facesheets was established, and the effects of various parameters were demonstrated. Analysis results indicate that the yarn orientation of facesheets has significant influence on the local facesheets buckling behavior of sandwich plate.

INTRODUCTION

Woven composite materials have been widly used as facesheets of sandwich structures in aerospace and defence industry. The yarn orientation was assumed as orthogonal relationship in usual mechanical models for plain woven composite facesheets. But generally the angle between the warp and weft yarns is not right-angle [1-6]. For example, the yarns orientation of facesheets may be changed when the sandwich is curing by Resin Transfer Molding Method. In addition, when the dry fabric is shaped around a core with complex shape, it is in a state of in-plane tension and shear deformation, and the orientation of yarn will be altered. In order to accurately characterize the local buckling of sandwich plate with non-orthogonal woven composite facesheets, a theoretical approach is developed in this paper, and then numerical examples are presented to demonstrate the influences of fabric configuration on the local facesheets buckling behavior of sandwich.

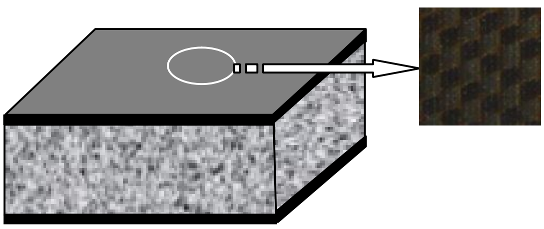

Figure 1 Sandwich plate with non-orthogonal plain woven composite facesheets

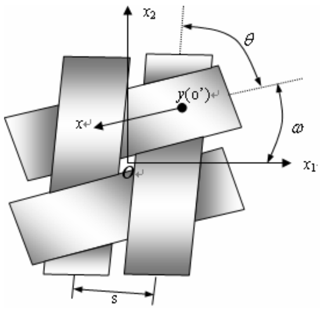

Figure 2 Representative element of non-orthogonal plain woven composite facesheets

ANALYTICAL MODEL

The representative element of non-orthogonal balanced plain woven composite facesheets is shown in Fig.2. For a yarn with arbitrary orientation, the spatial location of yarn slice can be discribed by angles α and β, shown as Fig.3.

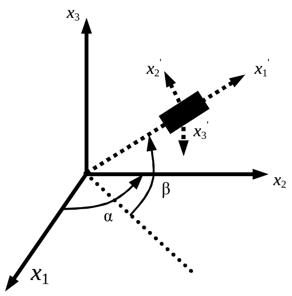

Figure 3 Yarn slice in the local coordinates

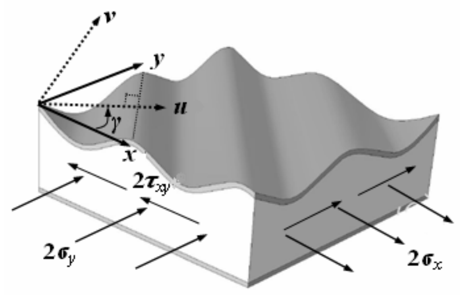

Figure 4 A sketch of the local facesheets buckling of sandwich plate

The compliance matrix which is defined as the integral along the length of the yran in representative element:

$$\boldsymbol{S}_{Li} = (1/L)\int \boldsymbol{T}_{\varepsilon}(\alpha_i,\ \beta_i)\,\boldsymbol{S}_i'\,\boldsymbol{T}_{\varepsilon}(\alpha_i,\ \beta_i)^T\, dL \tag{1}$$

where the subscript i refers to the ith yarn, L denotes the length of yarn in representative element, $\boldsymbol{T}_{\varepsilon}$ is strain transformation matrix, and $\boldsymbol{S}'$ is the compliance matrix of yarn slice.

So, we can obtain the compliance matrix of representative element by:

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$$\bar{\boldsymbol{S}} = \left(1/V\right)\int \boldsymbol{S}_L dV = \sum_{i=1}^{n} V_i \boldsymbol{S}_{Li} \tag{2}$$

where n denotes the number of yarns with different orientation in the representative element.

Then, the stiffness matrices $\boldsymbol{A}$, $\boldsymbol{B}$ and $\boldsymbol{D}$ of facesheets can be calculated by the classical laminated plate theory.

Considering the sandwich plate is subjected to in-plane normal stresses $2\sigma_x$, $2\sigma_y$, and shear stress $2\tau_{xy}$, shown as Fig.4. The stresses that contribute to the local buckling of facesheets are the in-plane stress perpendicular to the weave σ_u and the through-thickness stress in the core σ_c. The equilibrium equation of the facesheets is:

$$D_{uv-11}\frac{\partial^4 w}{\partial u^4} + \sigma_u h_f \frac{\partial^2 w}{\partial u^2} = \sigma_c \tag{3}$$

Through a series of deduction, finally we can obtain the buckling strength:

$$\sigma_{uc} = \frac{2}{h_f}\sqrt{2D_{uv-11}\frac{E_c}{h_c}} \tag{4}$$

where h_f is the thickness of facesheets; E_c and h_c denotes the modulus and thickness of core, respectively; D_{uv-11} is the element of bending stiffness matrix of facesheets $\boldsymbol{D}_{u\text{-}v}$ under the *u-v* coordinate system (Fig.4).

NUMERICAL EXAMPLES AND DISCUSSION

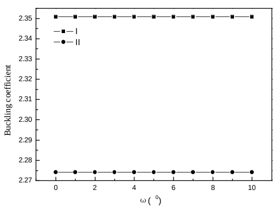

Figure 8 Buckling coefficient vs. the off-axis angle *ω*.

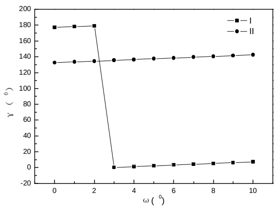

Figure 9 Buckling direction *γ* (Fig.4) vs. the off-axis angle *ω*.

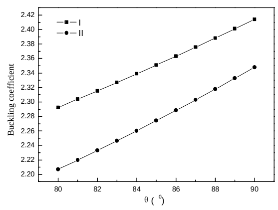

Figure 10 Buckling coefficient vs. the angle between the warp and weft yarns *θ*.

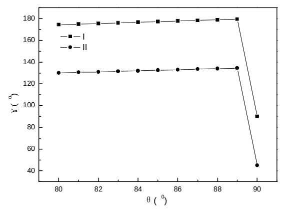

Figure 11 Buckling direction *γ* vs. the angle between the warp and weft yarns *θ*.

Suppose a sandwich plate is subjected to in-plane biaxal compression load (-100 N/mm, -100 N/mm). The buckling coefficient is defined as the ratio of buckling load to subjected load. The layups of balanced plain woven composite facesheets I and II are $[0/45]_s$ and $[0_4]$, respectively.

Figs.8-9 depict the small change of off-axis angle ω have no distinct influence on the buckling coefficient when the angle between the warp and weft yarns θ is fixed at 85^0, but it has obviously influence on buckling direction γ of facesheets, and the degree of influence is depended on the layup of facesheets. Figs.10-11 present the change of θ has significant influence on the buckling coefficient when the angle ω is fixed at 5^0. The abrupt change of γ occurs when the angle θ is close to 90^0. These figures also show that the buckling coefficient of sandwich plate with facesheets I is higher than that of sandwich plate with facesheets II. It is argued that reducing the anisotropy of facesheets can increase the local facesheets buckling load of sandwich plate.

CONCLUSIONS

An analytical model to predict the local buckling behavior of sandwich structure with non-orthogonal plain woven composite facesheets is developed. Various factors that affect the buckling load and wave direction of facesheets is demonstrated based on this model. It is shown that the geometrical parameters of non-orthogonal plain woven composite facesheets, including the orientation of warp and weft yarns, have significant influences on the local facesheets buckling behavior of sandwich structure.

References

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