APPLICABILITY OF LATTICE REINFORCED CFRP PANELS IN AIRCRAFT FUSELAGE DESIGN

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Abstract

Nonlinear FEM calculations are used to analyze the applicability of lattice reinforced CFRP panels in aircraft fuselage design. The results are compared to an orthogonally stiffened reference panel with omega-frames and T-Stringers. The comparison of the performance of those panels is made by applying global buckling-, maximum strain- and stress-criteria. Those calculations are made for different shear/compression ratios. A high shear/compression ratio slightly favors the lattice reinforced CFRP panel. Whereas a low shear/compression ratio significantly favors the orthogonal reference structure. The shear/compression ratio and panel design influences the critical failure criterion.

1. Introduction

1.1 CFRP Fuselages in civil aviation today

The concept of CFRP panel design in civil aircraft today is directly derived from metallic fuselage structures. A common stringer/frame setup with small alterations regarding the shape of the used stiffeners and their distance. This approach reduces the possible advantages the CFRP usage can offer significantly. The full potential of fiber reinforced structures can only be reached if the design is chosen without restricting it to the conventional construction methods. An example of a conventional CFRP panel design is the reference structure used in this paper as illustrated in **figure 1**.

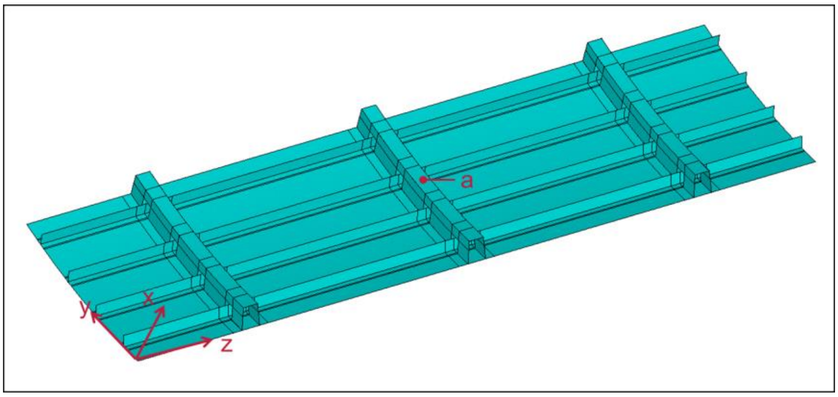

Figure 1. CFRP reference panel with omega-frames and T-stringers; “a” gives an example for a relevant node position regarding global buckling

1.2 The lattice reinforced CFRP concept

This paper investigates possible applications of unidirectional CFRP stripes placed in a lattice alignment as a stiffener concept for a CFRP aircraft fuselage. A typical layup is shown in **figure 2**.

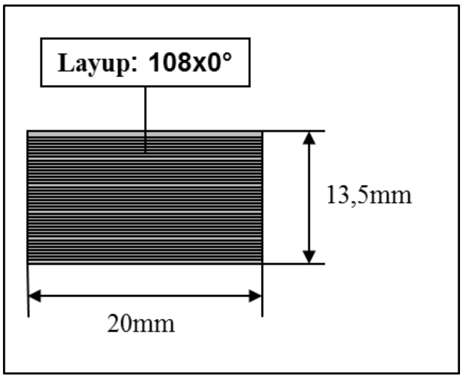

Figure 2. Stripe layup of a lattice reinforced CFRP panel, the number of stripes is chosen to reach weight equivalence with the reference structure

The concept of lattice shell CFRP structures, especially isogrid and anisogrid structures can lead to a highly efficient design for cylindrical and conical structures experiencing high compressive or bending loads [3]. The concept analyzed in this paper is arranged without the circumferential stiffeners. Different angles of stripe placement are investigated. The stripes have a predefined width and distance. The height is adjusted to reach desired weight equivalent to the reference structure. The concept is illustrated in **figure 3**.

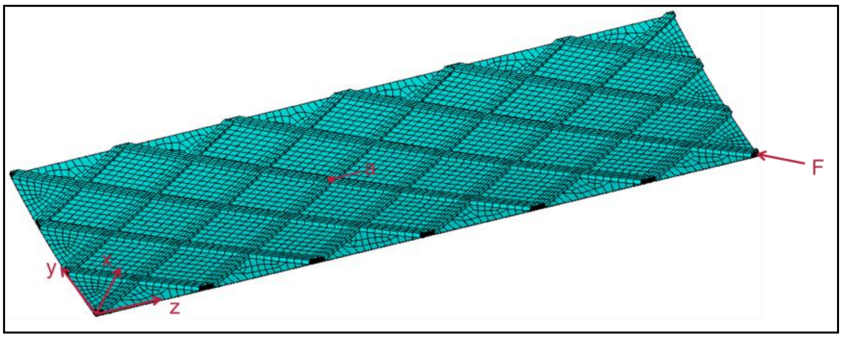

Figure 3. Lattice reinforced CFRP panel with coarse elementation, “a” gives an example for a relevant node position regarding global buckling

2. Analysis

2.1 Load Cases

Nonlinear FE computations are made to analyze buckling behavior and strain and stress failure under different load combinations. The load combinations analyzed vary from pure compression to pure shear in steps of 15 degrees of the load vector. An exemplary load vector and the point of load application can be seen in **figure 3**. Both structures are weight equivalent and the applied loads are given as load per unit length to ensure comparability. The panels are supported by periodic boundary conditions to indicate a circular barrel design.

2.2 Global Buckling

2.2.1 Reference Panel

To analyze the global buckling behavior of the reference panel at a given load combination the out of plane displacement of a relevant node for the frame and stringer is recorded and a load/displacement curve is plotted. The first load at which one of these nodal displacements shows a nonlinear behavior defines the global buckling failure load. An example for the global buckling failure of a frame is given in **figure 4**. The position of the investigated node can be seen in **figure 1**.

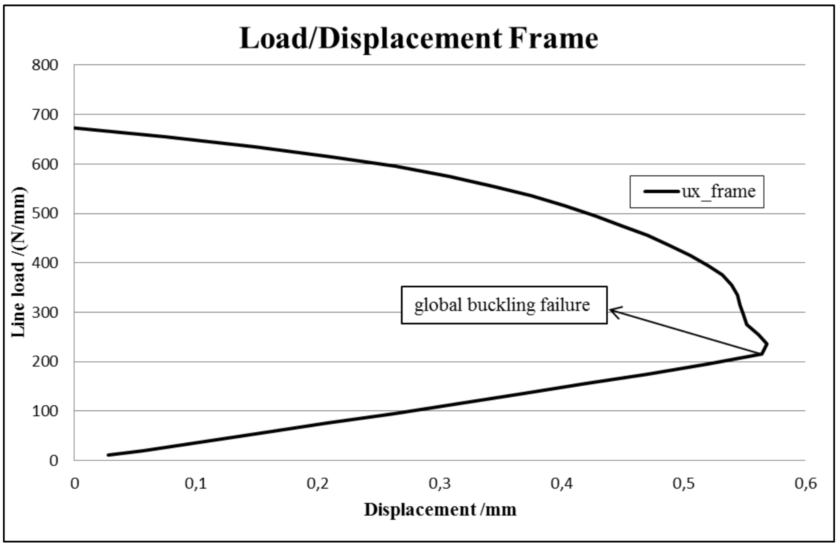

Figure 4. Load/displacement curve of the out of plane displacement of a relevant frame node of the reference panel at pure compression load

The initial out of plane displacement is due to the non-symmetric build-up and initially shows a linear behavior until the global buckling load is reached.

2.2.2 Lattice Reinforced Panel

The definition of the point of global buckling for the lattice reinforced panels is more complex. The load displacement curves for the nodes of the lattice structure immediately show a nonlinear behavior. This is due to the stiffening stripes placed at an opposing angle which supports the out of plane movement of the stiffener intersections. Therefore a different approach is needed. The point of global buckling failure is defined as the lowest load at which one of the curves of the nodal out of plane displacement of the stripe crossings shows a kink as shown in **figure 5**. An example for a crossing position is given in **figure 3**.

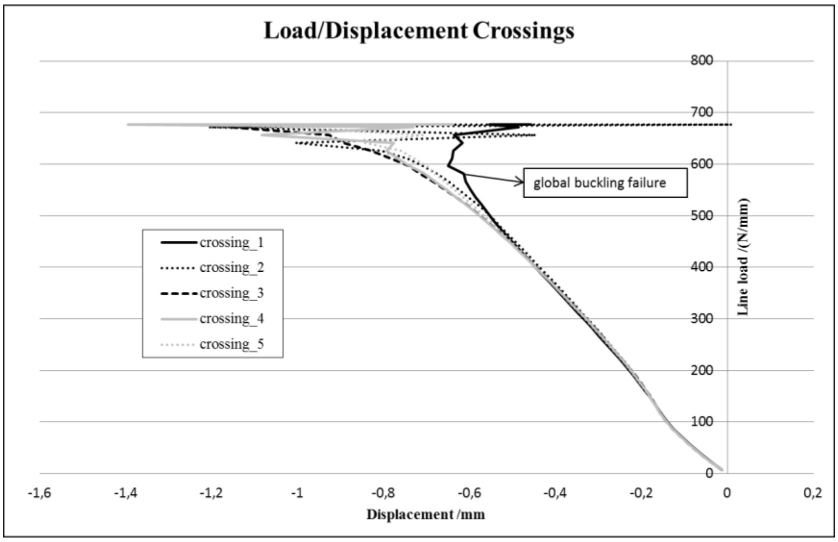

Figure 5. Load/Displacement curves of the out of plane displacement of stripe crossings for the lattice reinforced CFRP panel with 30° stripe alignment

2.3 Strain failure

To analyze both panel concepts regarding strain failure a factor of exertion $f_{E,strain}$ is defined as given in equation (1).

$$f_{E,strain} = \sqrt{\left(\frac{\varepsilon_x}{\varepsilon_{all}}\right)^2 + \left(\frac{\gamma_{xy}}{\gamma_{all}}\right)^2} \tag{1}$$

With the shear strain allowable γ_{all} and the direction dependent strain allowable ε_{all}.

$$\text{If } \varepsilon_x < 0 \qquad \varepsilon_{all} = \varepsilon_{all,c} \tag{2}$$

$$\text{If } \varepsilon_x > 0 \qquad \varepsilon_{all} = \varepsilon_{all,t} \tag{3}$$

With the strain allowable for compression $\varepsilon_{all,c}$ and the strain allowable for tension $\varepsilon_{all,t}$. The calculations are based on common material data given in **table 1**. The factor of exertion is calculated for all elements at each load step. If the calculated factor of an element at a given load step is greater than 1, strain failure occurs at the associated load. The maximal allowable load is the associated load of the highest load step without strain failure.

2.4 Stress failure

The stress failure is analyzed plywise for each element with a similar approach to the strain failure following a simple approach from [2]. A factor of exertion $f_{E,stress}$ is calculated as shown in equation (4).

$$f_{E,stress} = +\sqrt{\left(\frac{\sigma_i}{R_\sigma}\right)^2 + \left(\frac{\tau_i}{R_\tau}\right)^2} \tag{4}$$

With i indicating the ply number, R_σ the compression/tension strength and R_τ the shear strength of the used material. The maximal allowable load regarding stress failure is evaluated analogical to *2.3*.

$\varepsilon_{all,c}$	$\varepsilon_{all,t}$	γ_{all}	$\frac{R_{\parallel,t}}{E_{\parallel,t}}$	$\frac{R_{\parallel,c}}{E_{\parallel,c}}$	$\frac{R_{\perp,t}}{E_{\perp,t}}$	$\frac{R_{\perp,c}}{E_{\perp,c}}$	$\frac{R_\tau}{G}$
0,35	0,4	0,7	0,017	0,011	0,009	0,029	0,028

Table 1. Relevant material data for the stress and strain calculations

2.5 Shear/compression interaction curves

To compare the results of the different panels shear/compression interaction curves are used. For each panel the interaction curves for global buckling, maximal allowable strain and stress are plotted in the same diagram. The minimal values create the final shear/compression interaction curve for the regarding panel. This procedure is shown in **figure 6** using the example of the lattice reinforced panel with 30° stripe placement.

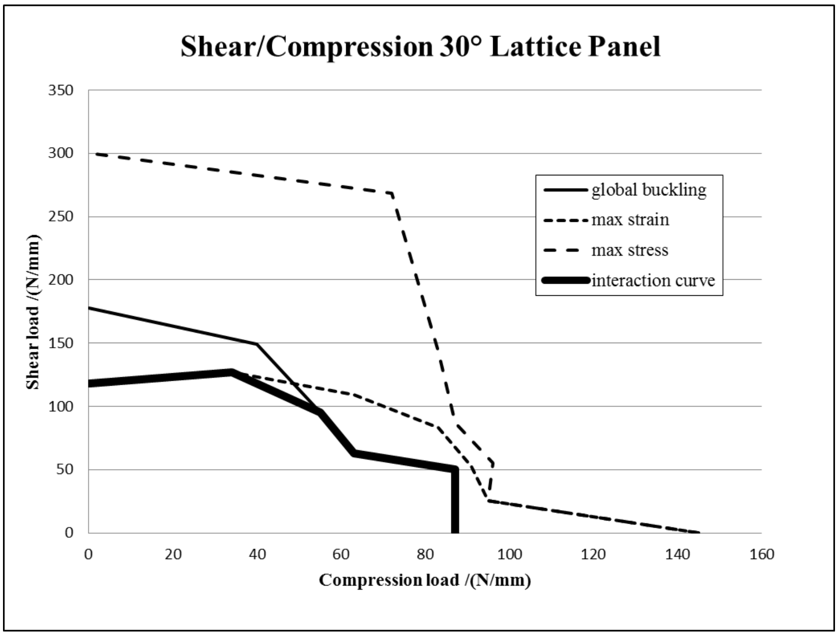

Figure 6. Creating the shear/compression interaction curve of the lattice reinforced CFRP panel with 30° stripes

3. Results

Due to the angular placement of the stripes it is clear that an advantage over the reference structure can be achieved at a high shear/compression ratio. This can easily be shown by comparing the according shear/compression interaction curves in **figure 7**.

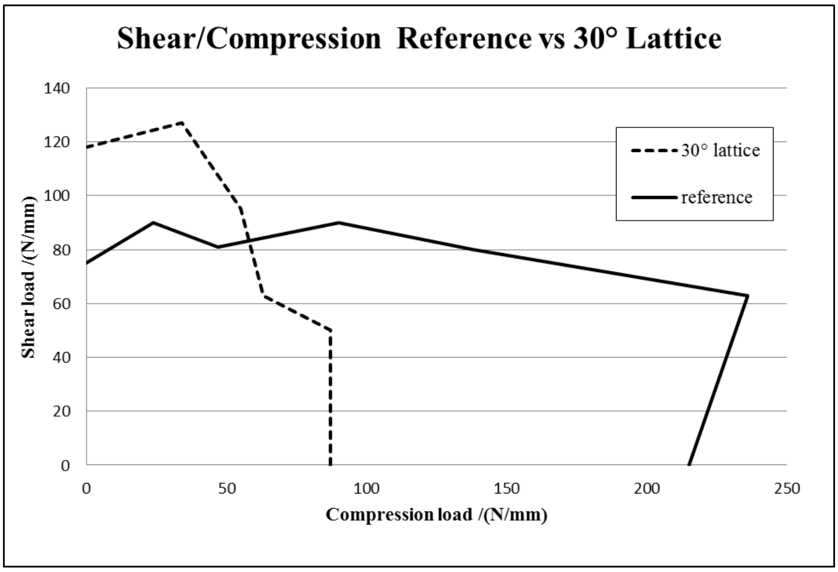

Figure 7. Shear/compression interaction curves of the lattice reinforced CFRP panel with 30° stripes and of the reference sturcture

It can also be seen that in areas with high compression loading the stripe-stiffened concept is considerably inferior to the reference structure. This is due to the buckling failure of the lattice structure. This disadvantage can be reduced by changing the stripe angle to 15° as shown in **figure 8**.

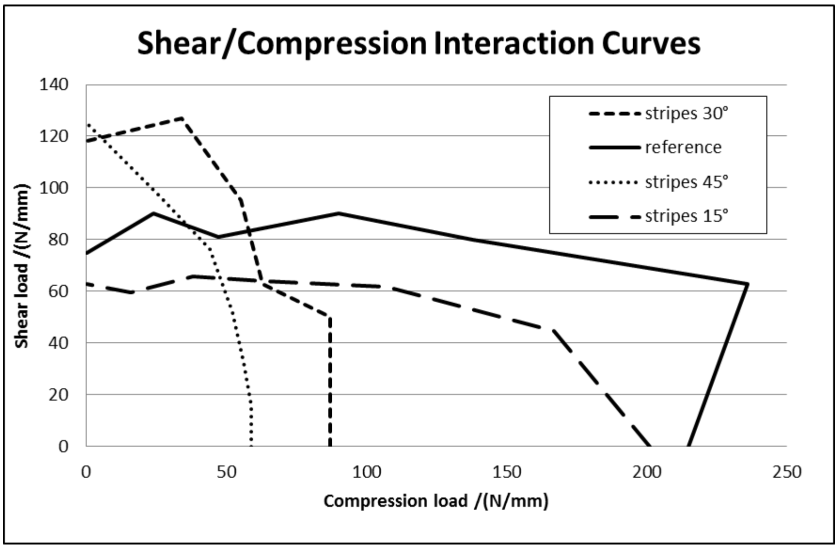

Figure 8. Shear/compression interaction curves of the lattice reinforced CFRP panels and the reference sturcture

However the lattice reinforced CFRP panel with 15° stripe placement offers no advantages over the reference structure at a high shear/compression ratio. Increasing the stripe angle to 45° only offers advantages over the 30° stripe panel at pure shear loading. With a rising shear/compression ratio the failure of the lattice panels switches from buckling failure to strain failure (see **figure 6**). The strain failure first takes place at the intersection points of the stripes. In those crossings the plies are stacked in alternate order and the shearing leads to high strains normal to the fiber direction. Contrary to the lattice reinforced CFRP panel design the limiting design parameter for the reference panel is always the stress failure as seen in **figure 9**.

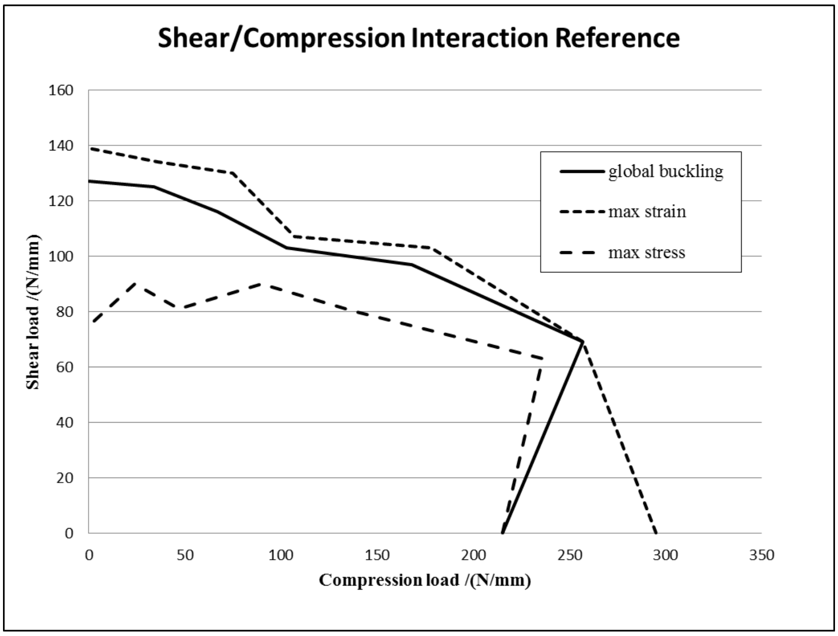

Figure 9. Shear/compression interaction curves of the reference sturcture

This is due to the fact that the reference structure is stiffer that the lattice reinforced CFRP panels. Allowable strain is not relevant for the reference panel design. It is clear that with the given material data in **table 1**, stiff structures will not succumb to strain failure.

4. Conclusion

In this paper it was shown that the usage of lattice reinforced CFRP panels in aircraft design can offer an advantage over conventional panel structures in areas with high shear loading. This has already been observed for metallic fuselage structures [1]. The advantage in the acceptance of shear loads makes the lattice concept interesting for the sides of aircraft fuselages. The disadvantage at compression loads can be reduced by applying circumferential reinforcements. Those reinforcements increase the weight of the lattice structures and it has to be determined if the advantage at high shear/compression ratios can be sustained. The integration of load application points also has to be investigated. It is thinkable to include frames with a high pitch to serve as circumferential reinforcements and to supply possible positions for load application points.

References

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