COMPARATIVE STATIC BUCKLING STUDY OF FML THIN-WALLED PROFILES

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Abstract

The paper deals with linear (eigen-buckling) and nonlinear buckling and post buckling analysis of thin-walled profiles made of FML type layered material. Considered profiles of open cross-section are subjected to axial compression. The analysis is performed with application of analytical and numerical method which results are compared with laboratory experiment. This multi-way approach gives the opportunity to improve both analytical and numerical models and solution methods which have been applied in our research team, with respect to current experiment results.

1. Introduction

The fibre reinforced metal laminates have been present in the aircraft industry during only past few decades but have achieved a recognized position in aerospace engineering application [3]. Instead of just only aluminium alloys, the fuselage panels, stiffeners and stringers made of FMLs obtained an important and still increasing position in aircraft design [1]. A fibre reinforced metal laminate is a hybrid composite consisting of thin aluminium layers alternating with thin layers of fibre reinforced epoxy. As reinforcing fibres Aramid fibres, glass fibres, carbon fibres or boron fibres one can apply [9]. As improved design the aluminium is replaced by titanium layers [4]. This mixture of isotropic metals and anisotropic composite gives high bearing strength and impact resistance, excellent fatigue characteristics, with improved damage tolerance to count only the most important benefits. On these utility properties most of analytical, numerical and experimental investigations are focused. There are comparatively few papers devoted to static buckling and post-buckling analysis of thin-walled FML profiles. Buckling phenomenon is however of great importance in structural behaviour of thin-walled load-carrying members or stiffener parts in the lightweight design. Therefore, in this papers the buckling comparative study of some profiles made of fibre reinforced metal laminate is presented. The additional aim of the study is to prepare the buckling experimental tests of FML profiles under axial compression load. The results of both analysis will be finally compared as well.

2. Methods of analysis

Under analysis were short thin-walled columns made of FML multi-layered materials. These elements are complex plate profiles of open cross-section. The shape of channel section, Z-section and hat-section were taken into consideration as those met in aircraft design. The cross-section area of Z and C profiles is assumed equal for comparative reason. The 2-1 and 3-2 versions of FML lay-ups were investigated, whereas for assumed number of aluminium layer different stacking sequences of composite layers are considered. It is assumed that all layers of FML profile walls have been perfectly adhesively bonded what in practice is the main technology challenge.

In this study the analytical approach is based on the general Koiter's asymptotic theory in the Byskov and Hutchinson formulation [2], it is on asymptotic expansions of the post-buckling path [6]. For analysed short FML column/profiles the local buckling dominates therefore a determination of post-buckling equilibrium path requires the second order approximation. The assumed displacement field follows the first order shear deformation theory description.

The numerical analysis was performed with application of the finite element method and ANSYS software package. The study concerns thin-walled structure therefore shell finite element was chosen to discretisation the column walls and to formulate the finite element model [8]. It was the SHELL181 finite quadrilateral shell element. This element is suitable to nonlinear applications (strain and material) and is governed by the first order shear deformation theory. However this element is sufficient for buckling analysis another effect which occur in loaded FML structure requires different finite element application [7]. The restrictions for this multilayered element assume no slippage between the layers. To achieve an acceptable level of accuracy for FML plate profile behaviour the geometric nonlinearity in numerical modelling was assumed. The initial imperfections were modelled according to first buckling mode with its magnitude referred to profile total wall thickness (i.e. 0.01t – 0.1t).

Material	E [GPa]	ν	G [GPa]
Al 2024 T3	72	0,33	12,88
TVR 380 M12/R	E_L - 46,43 E_T - 14,92	ν_L - 0,269 ν_T - 0,089	G_{LT} - 5,23

Table 1. Material properties of FML components.

The computations were preceded by very detailed material tests of all FML constituents. Determined then material moduli are given in Table 1. Owing to this data the finite element analysis and analytical-numerical analysis could be validated to achieve better mutual correspondence between applied methods and models [5]. The thickness of aluminium layer was 0.3 mm whereas GFR composite layers were of 0.26 mm each. The width of flanges was assumed as equal to a = 40 mm, web to b = 80 and in case of hat-section the lips were of c = 10 mm width. The length of profiles/columns was changed in the range 100 - 500 mm.

There were analysed few typical lay-ups summarized in Table 2.

No	Lay-up
1	Al/0/90/Al/90/0/Al
2	Al/90/0/Al/0/90/Al
3	Al/45/0/Al/0/45/Al
4	Al/0/45/Al/45/0/Al
5	Al/0/0/Al/0/0/Al
6	Al/25/0/Al/0/25/Al
7	Al/0/25/Al/25/0/Al

Table 2. Analyzed FML layers sequences.

3. Some exemplary results

Some results of the buckling analysis are presented in the next few figures. They show structural behaviour of the FMLs profiles according to varied basic parameters: stacking sequence of composite layers and orientation angle of GFR layers. Similar analysis but for different materials – both metal and composite layers is planed during further research.

In all cases of performed analysis it was assumed that the loaded edges of studied columns/profiles were simply supported. The volumetric composite content of both constituent was constant in all computed profiles, i.e. with 0.46 metal volume for 3/2 FMLs and 0.54 for 2/1 version.

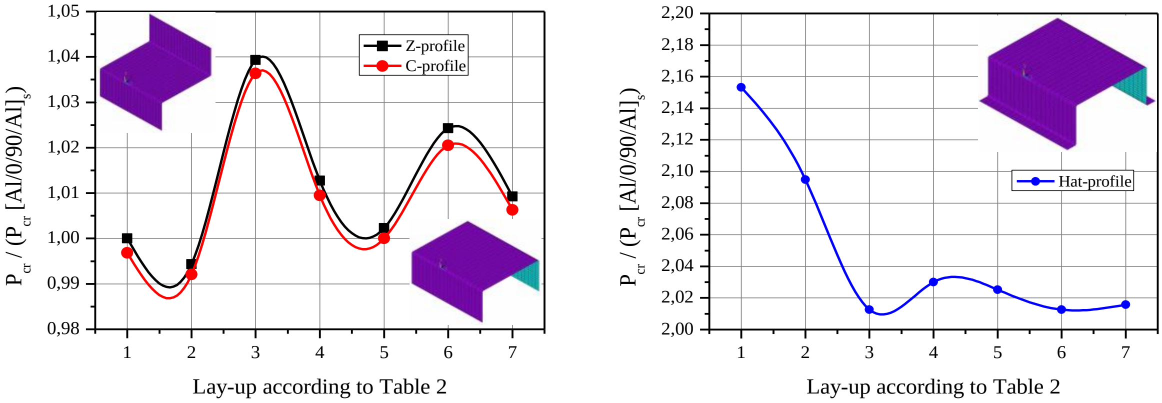

Figure 1. Influence of composite layers orientation on buckling mode of 320 mm 3/2 FML hat profile: a) lay-up 1; b) 2; c) 4.

In Fig. 1 the dependence of critical normalized stress on the stacking sequence for three profile cross-section shapes is presented. On the abscissa one can find designation from Table 2. For Z and channel profiles of equal cross-section area there are very small differences between their buckling loads when the highest are for Al/45/0/Al/0/45/Al stacking in both cases. It is worth to be mentioned that for hat section two narrow lips of 10 mm each doubled the buckling load where the area increased in 12.5% only. However the buckling load for the hat section depends less on lay-ups than in Z and channel profile case.

The hat section is sensitive yet to composite layers orientation giving - despite alternating buckling load, different buckling shapes according to GFR layers angles (Fig. 2). Additionally even for short profile/column an interaction in buckling modes could be observed (Fig.2a) and global mode of small amplitude was detected. This is not the case for Z and channel profiles where the buckling mode depends mainly on profile length not the lay-up and is of local type.

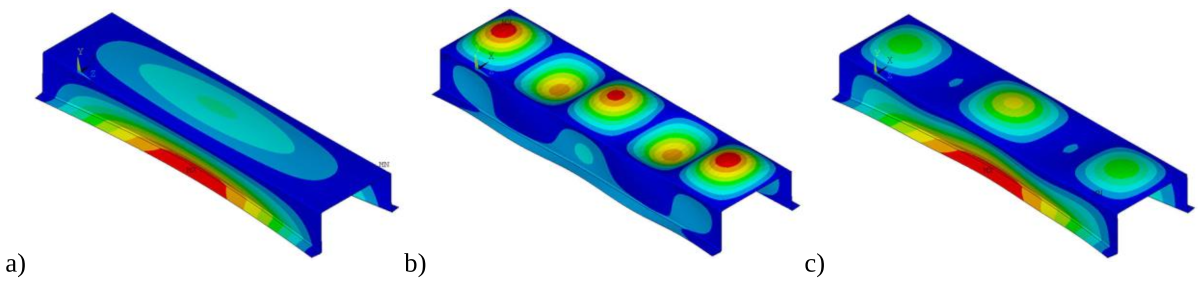

Figure 2. Influence of composite layers orientation on buckling mode of 320 mm 3/2 FML hat profile: a) lay-up 1; b) 2; c) 4.

4. Conclusions

In the paper some initial results of buckling analysis of FML column/profiles are included. The applied procedures and methods are briefly introduced and discussed. The results of numerical computations are presented in figures where the static buckling loads for chosen cases of profile shapes and lay-ups are illustrated.
The aim of the study is to improve the modelling and computation methods for buckling analysis of thin-walled open cross-section profiles made of FML materials. In the presented preliminary considerations some analysis were conducted to verify the range of experiments and input data for analytical and numerical approach. Among them the material properties were carefully determined, the numerical finite element model was established and all employed methods mutually verified. The further planned laboratory tests will allow to improve the tools of computations also on the constitutive level.

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References

[1] Alderliesten R., On the Development of Hybrid Material Concepts for Aircraft Structures, *Recent Patents on Engineering*, Vol. 3, pp. 25-38, 2009.
[2] Byskov E, Hutchinson J.W., Mode interaction in axially stiffened cylindrical shells, *AIAA J.*, 15(7), 941-948, 1977.
[3] van Hengel C., Kortbeek P., ARALL and GLARE FML's: three decades of bridging the gap between theory and operational practice, in Bos M. (ed.), *ICAF 2009, Bridging the gap between theory and operational practice*, pp. 601–615, Springer, 2009.
[4] Hundley J.M., H. Thomas Hahn H.T., Yang J-M., Facciano A.B., Multi-Scale Modeling of Metal-Composite Interfaces in Titanium-Graphite Fiber Metal Laminates Part I: Molecular Scale, *Open Journal of Composite Materials*, Vol. 1, pp. 19-37, 2011.
[5] Iaccarino P., Langella A., Caprino G., A simplified model to predict the tensile and shear stress–strain behaviour of fibreglass/aluminium laminates, *Composite Science & Technology*, Vol. 67, pp. 1784-1793, 2007.
[6] Kołakowski Z., Teter A., Interactive buckling of thin-walled beam-columns with intermediate stiffeners or/and variable thickness, *Int. J. Solids Structures*, 37, 24, pp. 3323-3344, 2000.
[7] Linde P., Schulz A., Rust W., Influence of modelling and solution methods on the FE-simulation of the post-buckling behaviour of stiffened aircraft fuselage panels, *Composite Structure*, 73, pp. 229-236, 2006.
[8] Mania R., Kowal-Michalska K., Parametric analysis of dynamic buckling of thin-walled structures with FEM application, in Niezgoda T. (ed.), *Numerical analysis of chosen mechanical problems*, pp. 229-245, WAT, Warsaw, 2007 (in Polish).
[9] Sinmazçelik T., Avcu E., Özgür Bora M., Çoban O., A review: Fibre metal laminates, background, bonding types and applied test methods, *Materials and Design*, 32, pp. 3671-3685, 2011.