DESIGN OF FLEXIBLE COMPOSITE BELLOWS COUPLING

Frantisek Sedlacek^a, Vaclava Lasova^b, Radek Kottner^c

^{a,b}*University of West Bohemia, Faculty of Mechanical Engineering, Regional Technological Institute,
Univerzitni 8, 306 14 Pilsen, Czech Republic*

^c*University of West Bohemia, Faculty of Applied Sciences, New Technologies for the Information Society,
Univerzitni 8, 306 14 Pilsen, Czech Republic*

Abstract

This paper deals with the design of a bellows coupling from composite material. This type of clutch-shaped bellows can be used as an alternative to a conventional universal joint. A numerical strength and stiffness analysis were performed. This analysis included design optimization in terms of the required rigidity and uniformity of stress distribution. The strength was evaluated by using maximum stress strength criterion. This numerical model respects overlays of layers of prepregs and distortion of fibres.

Keyword: composite material; bellows coupling; numerical simulation; finite element model

This Publication has to be referred as: Sedlacek, F[rantisek]; Lasova, V[aclava] & Kottner, R[adek] (2016). Design of Flexible Composite Bellows Coupling, Proceedings of the 26th DAAAM International Symposium, pp.0930-0935, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-07-5, ISSN 1726-9679, Vienna, Austria DOI:10.2507/26th.daaam.proceedings.130

1. Introduction

Composite materials are being used more often in the industrial sector and in certain applications are even pushing out conventional homogeneous materials. Their positive features such as high strength with low weight, high fatigue life, low friction, high resistance to weathering, and many others, are highly advantageous when used as a flexible connecting element [1, 3, 7]. However, the use of composite materials has many negative aspects, which include complicated design and manufacturing, which are mainly caused by the orthotropic properties of the material [8].

Flexible elements from composite materials exist for many years, but especially in the form of leaf or torsion springs, which transmit compressive or tensile force components. This paper deals with the design of a bellows coupling from composite material which can be used as an alternative to a universal steel joint. More precisely, the main task of this coupling is a torque transmission with a certain angular deflection but which also allows axial deformation.

2. The basic design of the bellows coupling from composite material

First, the most appropriate basic shape of a bellows coupling was found. The maximum possible mounting dimensions of a bellows coupling were taken into account; the width of the bellows coupling was a major limiting factor. Furthermore, a suitable method for mounting or dismounting the coupling was taken into consideration. In order to ensure easy replacement of the coupling conventional screw joint fastenings were selected that are positioned around the perimeter of the flanges of the bellows coupling.

Further, the possible loading conditions (torsion loading, centrifugal force, angular and axial deformation or their combination) were taken into account, including the desired stiffness and strength of the coupling. However, ensuring the possible production was the main factor. A "W" cross-section of the bellows coupling was selected from the individual designs, see Fig. 1, type (a).

Fig. 1. Variants of compared cross-sections of the bellows couplings

3. Choice of material

The material was chosen during the design and selection of the geometrical parameters. The choice was very limited and depended on the choice of the method of production. Two methods for manufacturing can be used. Production methods include winding, or manual placing of layers of prepreg, or woven.

However, for winding it would be necessary to use a multi-axial three-dimensional winding centre, which is not available. Therefore we selected the method of production of laying layers of prepreg into molds, with subsequent hardening in an autoclave. The fabric was carbon prepreg (fabrics with orientation of fibres $0^\circ/90^\circ$). [2]

E1 [MPa]	E2 [MPa]	E3 [MPa]	G12 [MPa]	G23 [MPa]	G13 [MPa]	ν_{12} [-]
85000	80000	9000	5500	4400	4400	0.048

Table 1. Mechanical properties of the carbon prepreg

4. Numerical analysis of composite bellow coupling

A parametric two dimensional model was then created, on which was applied a 2D mesh (CQUAD8; 8-node quadrilateral element). "Laminate" type physical properties with associated orthotropic materials were assigned to the elements of the 2D mesh.

Subsequently, the corresponding material orientation was assigned to each element. For this purpose the special 'draping' function, which is directly intended for designing laminates, was used. The material orientation of individual layers including checks and calculation of wrinkling of fibers and distortion of their main directions was determined using this function.

Fig. 2. 2D FE model of the composite bellows couplings and check of wrinkling and distortion of the fibers.

4.1. Load conditions of composite bellows couplings

Structural analysis was created as a multi-subcase with several formulations of load conditions. More specifically torsional loading, axial deformation, angular deformation, centrifugal force caused by rotation and finally a combination of all of these conditions was done, see Fig. 2.

Fig. 3. Load conditions of the composite bellow coupling

4.2. Geometric optimization of shape

Siemens NX 10 software with a NX Nastran 10 nonlinear solver and NX Laminates Composites module for analysis and pre/post-processing of data was used. To find the most appropriate geometric parameters a geometric optimization with NX Nastran Optimizer was done. Finding the geometry with minimal stress for all six directions with respect to the minimum required stiffness was chosen as the objective function. Several iterations of the analysis (including the initial and final iteration) are shown in Fig. 3.

Fig. 4. Progress of geometrical optimization of composite bellows coupling

4.3. FE model of the final design of composite bellows coupling

Subsequently the placement of individual layers and their overlaps was carried out. The laying of plies on the periphery of the bellows coupling in the direction of the longitudinal axis of rotation of the coupling was carried out. Finally two undivided plies in the shape of an annulus were laid on the side walls of the coupling.

A functional cross section of the composite bellows coupling is composed of six-layers of carbon prepreg with a layer thickness 0.199 mm and with alternating overlapping layers. The individual layers are placed in the direction $\pm 45^\circ$ relative to the axis of rotation. A total of 106 of the flat patterns of the prepreg plies were used. This 2D model was subsequently converted into 3D, including the generation of Resin Wedge Elements, see Fig. 5.

Fig. 5. The layout of the individual layers of carbon prepreg; (a) 3D finite element model of composite bellows coupling, (b) layers used and their orientation, (c) resin wedge element

4.4. Results of numerical analysis

Again the analysis was done by the NX Nastran non-linear solver. The figure below shows the results of the most loaded variants of the bellows coupling (combination of 1st to 3rd & 5th loading; see Fig. 2). And as expected, the highest stress was in the first two directions and in the fourth shear direction.

Fig. 6. Stress results for the most loaded condition - combined load status

Furthermore, evaluation of the strength of the composite bellows couplings was performed. Individual components of stress were evaluated by using 3D strength criterion maximum stress with regard to possible delamination of the individual layers. According to this theory, failure occurs if any component of stress has reached the ultimate strength of the material [3, 6, 9]. The most exposed areas were detected at the inner periphery and in the area of the holes for screw connections, see Fig. 7.

Fig. 7. Failure index for the most loaded condition - combined load status (Maximum stress strength criterion)

5. Conclusion

This paper deals with the possibility of replacing a conventional steel universal joint with a composite bellows coupling. The aim is to create a flexible joint from composite materials with low weight and high fatigue life.

The geometric optimization was used for finding the most suitable shape of cross-section for the composite bellows couplings. High Strength Carbon prepreg was used as the material. The layout of the individual layers of carbon prepreg was used in a direction $\pm 45^\circ$ relative to the axis of rotation of the coupling. Subsequently, evaluation of the strength of the coupling was carried out by using the maximum stress failure criterion for composites. This type of composite coupling compared with a conventional steel universal joint is more than 72% lighter and also has a whole range of positive properties, such as high fatigue life, corrosion resistance, etc.

On the basis of this proposal, we are working on creating physical samples for experimental testing followed by validation using numerical analyses.

6. Acknowledgements

This paper is based upon work sponsored by project RTI - Regional Technological Institute reg. no. CZ.1.05/2.1.00/03.0093 and TAČR TA project TE01020075.

7. References

- [1] Krishan K. Chawla: Composite materials; Science and Engineering, 3rd Edition. Springer, New York, 2012.
- [2] Sedlacek F.: Flexible joints from composite materials. SVOČ – FST 2015, University of West Bohemia, Pilsen, 2015. ISBN 978-80-261-0509-1.
- [3] Vasiliev Valery V., Morozov Evgeny V.: Advanced Mechanics of Composite Materials and Structural elements, 3rd Edition. ISBN: 978-0-08-098231-1, Elsevier, Oxford, 2013.
- [4] Talreja Ramesh, Singh V. Chandra: Damage and Failure of Composite Materials. ISBN 978-0-521-81942-8, Cambridge University Press, Cambridge, 2012.
- [5] Laš, V.: Mechanika kompozitních materiálů. University of West Bohemia, Pilsen, second edition, 2008.
- [6] Krystek J.: Pevnostní kritéria pro kompozitní materiály. University of West Bohemia, Pilsen, 2012.
- [7] Krystek, J., Kottner, R., Load capacity prediction of carbon or glass fibre reinforced plastic part of wrapped pin joint. *Materiali in Tehnologije*, 2015, roč. 49, č. 6. ISSN: 1580-2949
- [8] D.-H. Kim, D.-H. Choi, S.-H. Kim. Design optimization of a carbon fiber reinforced composite automotive lower arm. *Composites Part B*, 58 (2014), pp. 400–407. ISSN: 13598368.
- [9] R.H. Lopez, M.A. Luersen, E.S. Cursi. Optimization of laminated composites considering different failure criteria. *Composites Part B: Engineering*, Elsevier, 2009.