Composite Structures 132 (2015) 215–225

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Composite chiral shear vibration damper

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ARTICLE INFO

Article history:
Available online 22 May 2015

Keywords:
Wind turbine blade
Edgewise mode
Chiral
Auxetic
Damper

ABSTRACT

The work describes a structural composite damper concept based on a chiral auxetic configuration. Chiral structures couple uniaxial and rotational deformations to provide a negative Poisson's ratio behaviour and high dissipation through shear strain energy, and this feature is exploited by up-scaling the deformation mechanism of the chiral cell to design a damper that dissipates energy in the edgewise/shear modes, like the ones occurring in wind turbine blades. The damper concept and its configuration are evaluated through a series of Finite Element parametric and probabilistic models. A small-scale demonstrator is manufactured and subjected to compressive cyclic loading at increasing maximum displacements. Good agreement between the numerical and experimental force–displacement and energy dissipated-displacement curves is observed, showing the feasibility of the chiral composite damper concept for vibration damping-related applications at low frequencies.

1. Introduction

The increase importance of wind turbine technology in the provision of renewable energy during the last two decades has generated a significant amount of research and development initiatives to improve the dynamics of wind turbine/soil systems [1,2], as well as enhancing the design of the wind turbine blades from a structural dynamics [3,4] and performance/aeroelastic perspective [5–8]. The two fundamental bending-related modes of vibration in a wind turbine blade are of flapwise and edgewise type. Designers relay on the structural damping of the material to alleviate the peak amplitudes close at resonance, and this type of damping affects the two modes in a similar way. However, the aerodynamic damping contributes significantly to the overall modal damping ratio of the flapwise mode, whereas for the edgewise mode shape the only damping mechanism present is the structural one. As a consequence, lower damping is associated to the edgewise direction. Edgewise bending moments are mainly caused by gravity loads, and therefore they change cyclically in terms of direction due to the rotation of the blade. Attempts have been made to increase the structural damping of a blade by using different materials with high loss factors (polyester resins and aramid fibres) [9]. Macro-composites inserts with inclusions made from non-classical shapes have been also investigated by some of the Authors to increase the dissipation of the strain energy at low frequencies [10].

The present work is concerned with exploring a novel solution to increase the modal damping ratio of edgewise-type modes – the chiral composite damper. Chiral structures are a subset of auxetics (negative Poisson's ratio materials and structures) [11–14]. Chiral structures provide non-affine deformations coupling in-plane rotations with uniaxial loading, and therefore generate the negative Poisson's ratio behaviour [15,16]. A characteristic of auxetic materials and structures is the observed enhancement of energy dissipation and vibration damping performance under dynamic loading due to their micro-mechanical deformation [17,18], a feature that has also been used to design larger-scale cellular structures with dissipative properties [19–22,18,23]. Chiral structures with six, four or three-ligaments tessellations are produced by using cylindrical units connected by tangential segments, and the rotation of these units under uniaxial loading leads to the bending and unwinding of the ligaments, with a consequent global volumetric increase of the solid when the loading is tensile.[1] Chiral structures configurations have shown a significant potential for morphing wing and deployable applications [26–28], platforms for phononics, wave propagation and smart sensing [29–31] and truss-core with increased shear stiffness and strength [32]. The peculiar shear deformation characteristics of the chiral configuration is exploited here to increase the equivalent loss factor associated to modes dominated by shear deformation, like edgewise modal shapes

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[1] It is worth mentioning that when chiral solids with 4-ligaments are considered under a micro-polar theory framework they result in having a zero in-plane Poisson's ratio [24], similarly to what observed in cross-chiral structures [25].

http://dx.doi.org/10.1016/j.compstruct.2015.05.048

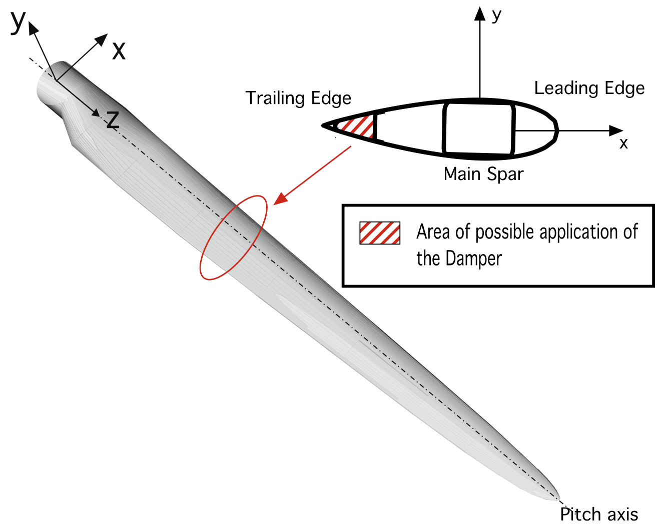

Fig. 1. Location of the possible application of the damper in the trailing edge.

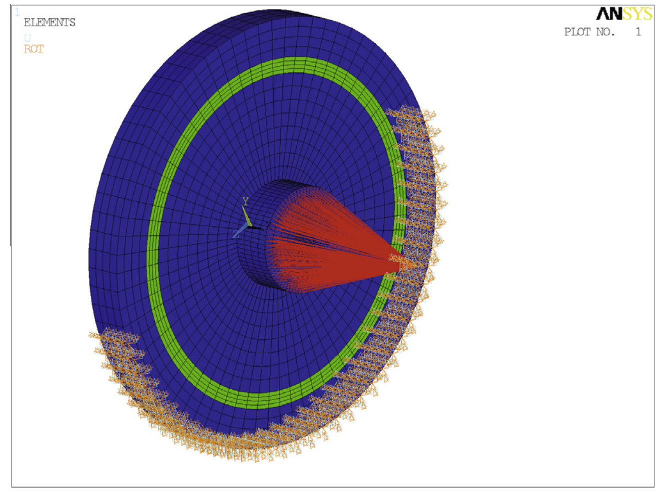

Fig. 4. Boundary conditions applied to the damper to simulate the ideal behaviour.

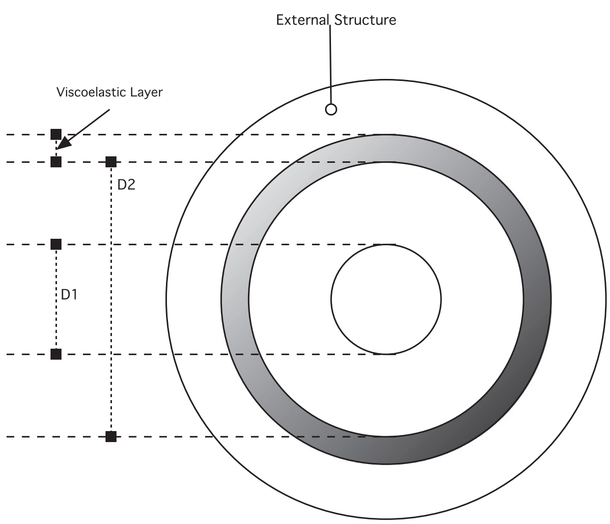

Fig. 2. Characteristic dimensions of the chiral damper concept.

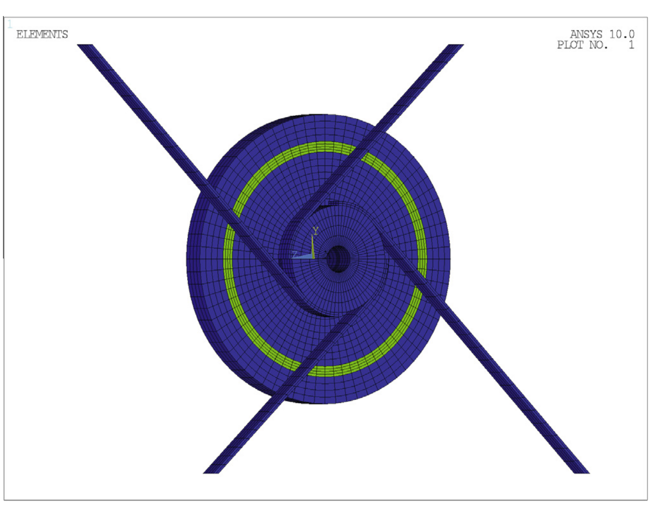

Fig. 3. Example of the chiral damper configuration. The green areas represent the sections where the viscoelastic layer is confined. (For interpretation of the references to colour in this figure caption, the reader is referred to the web version of this article.)

of wind turbine blades with high tensile/compressive stresses at the trailing edge. Within the blade trailing edge, this damper can be placed to take advantage of its particular deformation mechanism and dissipate energy using a viscoelastic constrained layer included in the chiral structure (Fig. 1).

A strain energy-based method [33–36] has been used in this work to evaluate the loss factor of this chiral damper. According to the strain energy approach any component of the damper contributes to the total damping (total loss factor) of the structure in a measure proportional to the individual loss factor and the amount of strain energy stored. A baseline assumption is that only the viscoelastic region contributes to the overall damping and that the material loss factor does not change with frequency [10]. Loss factors of typical viscoelastic materials used in potential damping treatments of wind turbine blades are observed to remain nearly constant in the frequency range of interest [0–20 Hz] for the fundamental blade dynamics [37].

The paper is organised as follows. The composite chiral damper concept is first illustrated with its design parameters and deformation mechanisms, and its design space is then explored by using a combination of Finite Element (FE) analysis and parametric surface response methods (SRM). A prototype of chiral damper is then manufactured using 3D printing components and viscoelastic layers, and then subjected to cyclic loading. The experimental results are then compared with the FE simulations carried out for the parametric design analysis of the chiral damper. It will be shown that the experimental and numerical results provide a good agreement and demonstrate the validity of using a composite chiral structure as a platform for vibration damping applications.

2. Chiral damper concept – design, modelling and parametric analysis

The chiral damper concept consists in coupling a fixed and a moving structure through a viscoelastic intermediate layer. The moving part is represented by a disc with two sections having different radius (Fig. 2). The internal radius is connected to four beams (or slender shells) that are attached to the structure to be damped. The disc with the external radius is in contact with a viscoelastic layer, which in turns is connected to the external fixed structure, therefore creating the equivalent of a viscoelastic constrained layer. The presence of the connected ligaments creates the equivalent of a chiral (tetrachiral) structure that transfers the deformation of the component to be damped to the moving disc,