Performances of an architectured composite plate with nonlinear stick-slip interactions for vibration reduction

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Abstract

Metamaterials are architectured structures that have recently shown convincing performances for vibration reduction. Two main phenomena are commonly coupled to achieve these performances, local resonances and Bragg scattering that allow to develop interesting frequency bandgaps where waves cannot propagate. The performances for vibration reduction of a lattice metamaterial introduced as a core in a composite structure are here experimentally and numerically studied. This structure is composed of a series of slits with rotational symmetries and is placed between two aluminium plates : the planar configuration with periodic resonant patterns is propitious to generate bandgaps. Different parameters are adjusted to achieve good performances as the number of patterns, the width of the slots, or the length of the internal beams. Nonlinear effects consisting in stick-slip interactions inside patterns are evaluated as favorable aspects to increase the obtained global damping.

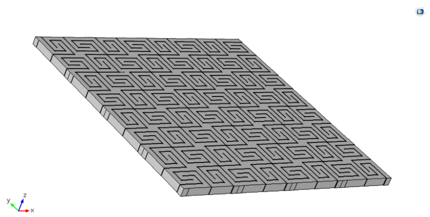
Keywords : metamaterial, absorption, vibroacoustics, nonlinear, resonance

1 Introduction

Metamaterials are emerging lighweight strategies developed to reduce noise or vibrations. They are born from the extension of phononic crystals [5] that consist in periodic composite media acting as a Bragg mirror, and exhibiting specific band frequencies where destructive interferences occur and wave do not propagate. The lowest frequency at which Bragg effects occur corresponds to twice the medium periodicity length, and it leads to solutions that are too large to be applicable at low frequencies. To overcome this limitation, local resonators have been introduced in the unit cells of the periodic media giving birth to the metamaterials [4]. Stopbands are here linked to the resonance properties and not to the periodicity length, and it allows to reduce vibrations at smaller wavelength. Such a configuration has shown to be efficient for vibroacoustic applications for instance [2,3]. A specific metamaterial is studied in this paper : its specificity it consists in an architectured structure introduced as a core between two aluminium plate.

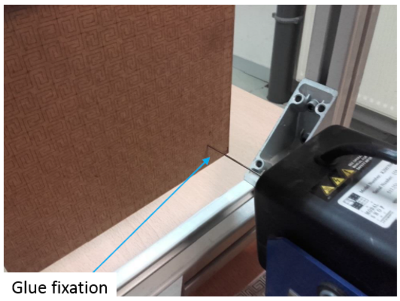
2 Architectured mematerial with rotating beam elements

The designed metamaterial is intended to be used as a core between two aluminium plates. Tt consists in an architectured structure presenting resonators that are rotating beam elements with flexural behavior (**Fig.1a**). One same unit geometry is repeated along two directions to create a 2D configuration that can be realized using a laser cutting facility (**Fig.1b**). For sake of easy machining the material of the studied specimen is medium, and one interesting observed point is a consequent loss of rigidity after structure machining : it becomes a super flexible double curvature surface [1]. Thus the architectured plate presents a very lower static stiffness compared to the full medium plate, what is interesting for conformability in industrial applications. A numerical modal analysis has been performed on the metamaterial with material parameters $E =$ 4.113 MPa and $\nu = 0.339$ considering the medium as an isotropic homogeneous media. These date have been determined by correlation with experimental measurements of the three first modes by laser velocimetry (**Fig.1c**). The plate is a square plate whose dimensions are 190x190x3 mm in which we insert the periodical pattern. The cutting diameter, which is the space between the beams, is 3 mm. When considering only one pattern in the two plate directions, the first local mode appears at around 145 Hz, which is less than the frequency of the the first global mode appearing around 231 Hz (**Fig.2a**). A parametric study (**Fig.2b**) changing the number of patterns has shown that the eigenfrequency of the first global mode tends to decrease, in agreement with the drop in stiffness observed, unlike the eigenfrequency of the first local mode that



(a) Architectured plate with chiral hinge lattice

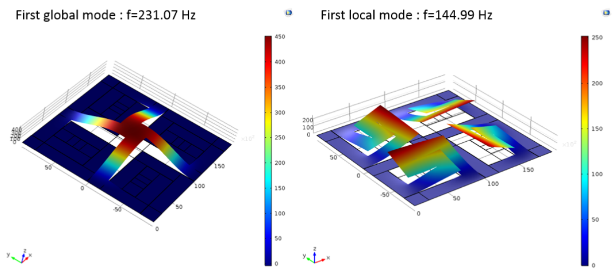
(b) Picture of one laser-cutted plate



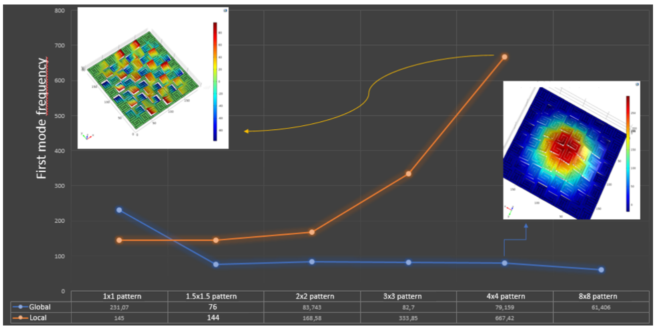
(c) Experimental characterisation on the free-free plate with shaker excitation

Figure 1: Architectured metamaterial with chiral hinge lattices

tends to increase with the number of patterns. Above the 8×8 patterns configuration, the local modes become impossible to identify.



(a) First global mode and first local mode of the embedded plate with a 1×1 pattern



(b) Evolution of the first global and local modes with the number of patterns

Figure 2: Modal behavior of the metamaterial

3 Vibratory study of a "sandwich" plate integrating the architectured metamaterial

The purpose of the proposed work is to study if this material whose flexibility properties are not common also presents an interesting behavior in terms of vibratory absorption. Indeed, the structure network consists in a periodic series of patterns exhibiting resonance effects to to the flexion of the ribs. Thus, when associated to a plate with tuned frequency, this metamaterial is assumed to absorb vibrations, leading to a reduction of the vibrations for the main plate. To check this point, the metamaterial is introduced as a core between two aluminium plates to compose a sandwich structure (**Fig.3**). The aluminium skins are not in contact with the medium architectured plate. Overthicknesses are added to keep the space needed for the travel of the internal beams. The edges of the structure are all embedded. An harmonic force of 1 Newton in a range of frequencies going from 20 to 400 Hz with a step of 2 Hz is applied around a corner of the structure, and the displacement at the center of the plate is studied.This work is currently in the making but the first results with comparison to a configuration without metamaterial tend to show that the main plate displacement is decreased (**Fig.4**). Ongoing study tends to tune with precision the frequency of the local material modes with those on the main skin plates. It also appears that the resonance effects are associated with non-linear stick-slip nonlinear effects that act in favor of reducing vibrations.

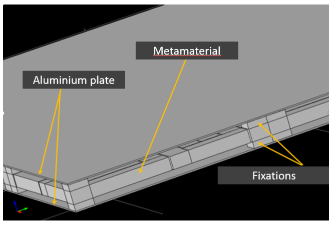
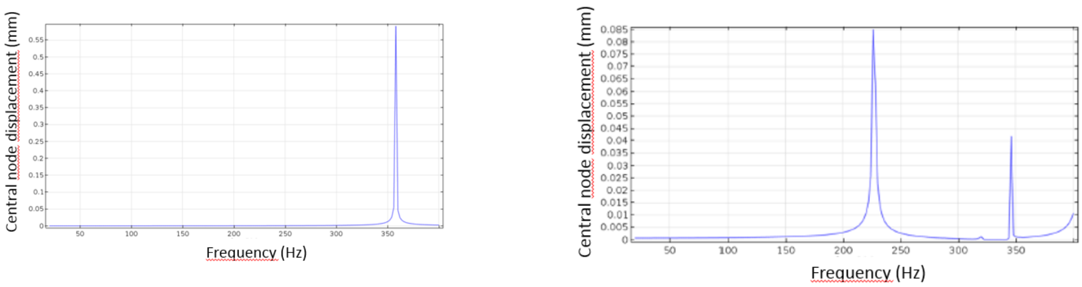


Figure 3: Sandwich structure integrating the architectured metamaterial



(a) Without metamaterial

(b) With metamaterial

Figure 4: Central point displacement of a sandwich structure with and without the metamaterial

4 Conclusion

A specific metamaterial exhibiting a super flexible double curvature surface behavior has been studied to evaluate its performances in terms of vibration mitigation. Indeed, this structure consists in a periodic repetition of cutted patterns with flexural resonances able to generate an absorption effect when tunably designed. The first numerical simulations have shown that the use of this material as a sandwich core can lead to a vibration reduction. Besides, non-linear stick-slip effects occuring between ribs motions seem to act in favor of this absorption. Ongoing work aims at evaluating the contribution of these nonlinearities.

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