EFFECTS OF CORE GEOMETRY ON THE VIBRO-ACOUSTIC BEHAVIOUR OF FIBRE REINFORCED CORRUGATED CORE SANDWICH PANELS

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Abstract

In this study, the vibro-acoustic behaviour of sandwich bio-panels is investigated. An arc-and-tangent core profile geometry is adopted for ease of manufacturing. Effects of core geometry radius and orientation on the overall transmission loss are studied. Experimental modal analyses are carried out on flat samples to determine the material dynamic properties and to update the numerical models. A fully coupled Finite Element-Indirect Boundary Element model is developed to evaluate the acoustic transmission characteristics of the panels. It is found that by appropriate design of the corrugated core geometry it is possible to substantially attenuate the travelling bending waves in the sandwich structure (predominant path of the acoustic transmission), which may significantly reduce the total transmitted sound level.

1 Introduction

In this study, the vibro-acoustic behaviour of bio-panels consisting of natural fibres reinforced thermoplastic cores and face sheets is investigated. Due to their inherent high stiffness-to-weight ratio, it is often challenging to design them for both structural and acoustical applications simultaneously. However, for applications in residential, commercial or industrial environments, the transmitted noise levels must be reduced to acceptable levels. It is typical for such structures that the critical bending frequency is found within or below the band of the intelligible speech, in effect favouring the transmission of noise in that band. Therefore, to prevent the effects of coincidence phenomena, corrugated cores, manufactured from natural fibre reinforced thermoplastics, can be properly designed. For simplicity and ease of manufacturing, an arc-and-tangent geometry is adopted in this case. The effects of core geometry such as, the arc radius and the orientation of the core on overall transmission loss (TL) are studied. Experimental modal analyses are carried out on flat samples to determine the material dynamic properties. A fully coupled Finite Element-Indirect Boundary Element model is developed to evaluate the acoustic transmission characteristics of the panels. It is found that by appropriate design of the corrugated core geometry it is possible to substantially attenuate the travelling bending waves in the sandwich structure (the predominant path of acoustic transmission), which may significantly reduce the total transmitted sound level.

The paper starts with a comprehensive review on the state of the art of corrugated core sandwich structures design and analysis and bio-based alternative materials application. In the second section a structural optimisation is illustrated with respect to some geometrical parameters of the corrugated core component. Vibro-acoustic properties of the optimised design are later on numerically evaluated.

2 Corrugated core composite sandwich panels

Not many studies about manufacturability and formability of corrugated polymeric sheets reinforced with short natural fibres are present in literature. The use of natural fibres reinforcements in resin matrix (as polypropylene, PP) has been studied for different core geometries in [1]. Among others, corrugated core sandwich structures are highly attractive for ease of manufacture and the great design freedom offered. They can be in fact designed in order to have core walls perpendicular to the face sheets (Figure 1 - left side) or parallel (Figure 1 - right side). Furthermore, the latter can be arranged with several layers, parallel or crossed oriented.

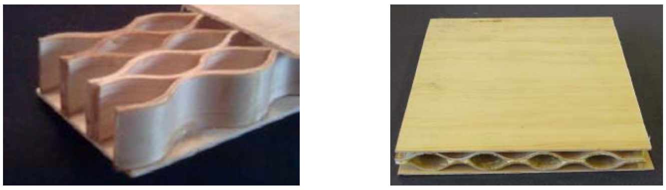

Figure 1. Out-of-plane cell (on the left) and in-plane (on the right) corrugated core sandwich

In the same study an algorithm for selecting the best manufacturing parameters is proposed on the base of the results of a defined full factorial design of experiments (Taguchi method). Production techniques, reported in [1] and [2], have been applied in the case of a multi-ply wood veneer composite sheet and of a natural fibres reinforced PP sheet in order to obtain a cost-effective and recyclable structural product and to check the effect of the natural fibres reinforcement on final mechanical properties. After the composites are produced through an optimised continuous extrusion process [1], roll forming technique is proved to be suitable for a continuous or semi-continuous manufacturing of this kind of core and material. Moreover, the corrugation solution allows broad design flexibility. Depending on the material chosen it is possible to structurally optimise the geometry of the corrugated profile and the core pattern for both panel configurations. A first attempt has been successfully conducted for the case of a three ply wood veneer hollow cores sandwich panel [3], where the final design is the result of a structural optimisation, with respect to some failure criteria, in order to get the minimum panel weight when the structure undergoes a bending load. The approach developed is general and so applicable for similar cores made of other materials. The corrugated core profile is the one shown in Figure 1 (on the left) and schematically sketched in Figure 2, where the geometric parameters used for the design optimisation are also indicated. The cross section illustrated in Figure 2 consists of circle-arcs of length $2R_c\Theta_c$ (where R_c is the circle radius and $2\Theta_c$ the subtended angle), tangent to each other. In order to uniquely identify the presented geometry four independent geometric parameters can be defined: t_c/R_c; h_c; H_c (cell core depth); Θ_c. Similar geometries are already common in various structural applications, like bridge decks or packaging solutions. In these cases the corrugated profile usually has a sinusoidal shape rather than circle-arcs and often longitudinal flat reinforcements are added to the core structure. Davalos et al [4] have studied modelling and experimental characterisation of fibre-reinforced plastic honeycomb sandwich panels for highway bridge applications in the case of sandwich structures.

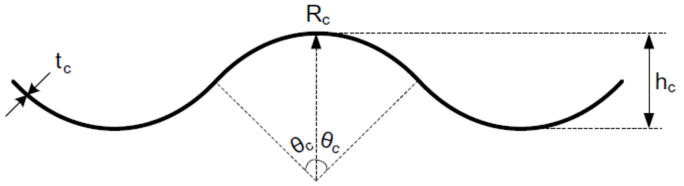

Figure 2. Characteristic geometric parameters of the corrugated profile optimised in [3]

A homogenization process is used to obtain the equivalent core material properties for the honeycomb geometry with sinusoidal waves. A Representative Volume Element method, assuming periodic conditions, can be applied, being the core produced from chopped strand mat (ChSM) with random fibres orientation, and hence considered as isotropic. In the case of the TorHex core panel a fast and continuous production process has been developed and patented [5] and also functional properties have been numerically and experimentally studied [6]. In some cases sandwich panels may in fact not be used exclusively for their structural properties but satisfactory functional properties might be required. As already widely documented, due to their high stiffness-to-weight ratio, it is often challenging to design lightweight components for both structural and acoustical applications simultaneously. Xin and Lu [7] studied the effect of core topology on sound insulation performance of lightweight all-metallic sandwich panels for in-plane core geometry of a different profile section than what considered so far. Still applicable to any kind of periodic sandwich structure with corrugated in-plane core, the space-harmonic method is used to define an equivalent concentrated element model (translational and rotational springs are implemented in place of unit core cells). This way a simplified analytical analysis of the vibro-acoustic problem is developed. As in the case tackled by Davalos, the core walls are again made out of isotropic material (all-metallic).

Given the complexity related to the use of composite non-isotropic materials implemented for both face sheets and core structure, numerical tools are exploited herein, to analyse the vibro-acoustic behaviour of composite corrugated core sandwich panels. Analytical solutions are instead used to describe the mechanical failure mechanisms and to identify an optimised structural design.

3 Optimisation of a corrugated core composite sandwich panel

The aim of the present work is to design a fully composite sandwich panel (composites materials are used for both face sheets and core components), made out of eco-friendly materials and fully recyclable, not only structurally performing but also able to show satisfactory Noise, Vibration and Harshness (NVH) properties. From a vibro-acoustic point of view it is typical for sandwich structures of any kind (with isotropic or not materials) that the critical bending frequency is found within or below the band of the intelligible speech, in effect favouring the transmission of noise in that band. Different approaches to achieve high TL of composite panels are found in literature. The “shear wall” by Watters and Kurtze, [8] and the “coincidence wall” by Warnaka and Holmer [9] are two examples. Both are based on a full understanding of the coincidence effects in the interaction of the incident field with the structural vibration response. Coincidence phenomena occur when the wave speed of the incident field equals that of the vibration in the panel, resulting in a strong and more or less abrupt reduction in TL, dependent on the damping loss factor. The first approach aims to avoid coincidence in the frequency range of interest, while the latter operates in the way of controlling the structural response via damping. It is shown how the damping of bending waves particularly reduces the transmission through the panel, contrasting the propagation of sound-radiating waves.

Investigations about the vibro-acoustic behaviour of corrugated natural fibres reinforced thermoplastic core sandwich panels are carried out in the present study in the frequency range up to 2 kHz. Future works will be extended up to higher frequencies. Experimental Modal Analysis (EMA) tests are firstly run in order to evaluate the magnitude of damping loss factor of sisal-PP. Recycled short sisal fibres reinforced PP flat samples have also been tested in order to study the effect of the recycling process on the dynamic properties.

Several core configurations are numerically analysed, keeping unvaried material properties and overall dimensions. Different directions of the corrugated wall are taken into account (Figure 3). The numerical models are updated through the results of the EMA and the acoustic TL is calculated for these first attempts. The acoustically best performing configuration is selected and an optimisation study is carried out. Structural requirements are first met defining the expressions for the failure mechanisms within the sandwich structure components (composite core and face sheets). A combined loading case, consisting of in-plane compression and shear forces, is taken. The optimisation algorithm seeks for the optimal radius of the corrugated core geometry, giving the minimum weight with the maximum failure load index.

3.1 EMA of natural fibres reinforced PP composite: material properties identification

EMA tests are firstly carried out in order to evaluate the magnitude of the damping loss factor exhibited by natural fibres reinforced PP composites. Compared with other biodegradable thermoplastic polymers showing higher structural stiffness (as it is the case of polylactic acid, PLA), PP matrix is chosen in this study for the higher damping exhibited. PP plates with short sisal fibres and recycled samples have been tested. Wolcott and co-workers [10] had shown an increase in the mechanical properties of wood fibre plastic composites due to a 10% addition of talc. The same is considered in the present study, given the similar choice of natural fibres and thermoplastic matrix. On the base of a previous work developed by Rao [2], a fibre volume fraction of 30% is selected. As extensively reported in literature, he has shown how the production process (continuous extrusion) affects the natural fibres length and their alignment inside the matrix. The fibres are in fact shortened during the process and most of them (more than 60% in the case of sisal-PP) get aligned along the extrusion direction, resulting in a final composite lamina with orthotropic behaviour. The process parameters have been optimised in order to achieve the highest mechanical properties. Furthermore, in the same work analyses on recycled sisal-PP composites have been carried out and they show the influence on the mechanical properties of the recycled product. The latter exhibits a slight stiffness decrease along the direction of extrusion and a slight increase in the transverse direction. A similar trend is also observed in the strength properties. When not specifically mentioned, the material properties reported in [2] are implemented in the upcoming numerical models.

With the use of a laser vibrometer (Polytec Laser Doppler Vibrometer), velocities of the samples surfaces are recorded during impact hammer free-free EMA tests. The extracted modal parameters (experimental data are post processed in LMS Testlab10B) are used to update the numerical FE models (built and solved using MSC Patran 2008r1 and MD Nastran 3rB). Two samples for each material are tested. Sisal-PP composite shows a damping ratio of 2.4% (averaged over [0-200] Hz band). The recycled sisal-PP sample appears to be more damped (2.56% averaged over the same frequency band) but less stiff (as confirmed in [2]). Further researches might be carried out in order to understand the influence of the fibres length on the damping factor (as mentioned before, it is noticed that fibres are shortened during the recycling process). For both the original and the recycled sisal-PP materials the experimental data yielded an updated shear modulus. Frequencies of the experimental modal shapes involving twisting component happen to be shifted towards lower values than what predicted using properties reported in [2] (measured in the static case). The 35% of the initial shear modulus is used to correlate numerical and experimental results with satisfactory accuracy (numerical and experimental natural frequencies within 5% up to 200 Hz and a Modal Assurance Criterion value higher than 70%).

3.2 Effect of corrugation direction on the acoustic TL

FE numerical models are built and updated through the results of the EMA, in order to predict the system dynamic behaviour and the acoustic TL. Several core configurations are analysed numerically, keeping unvaried material properties and overall dimensions (complying the manufacturability requirements). A three layers sisal-PP composite (layout [0-90-0]) is used for both top and bottom face sheets, while a single layer of the same material is used for the corrugated core. The fibres in the core wall layer are considered oriented along the corrugation direction (the alignment of about the 60% of the fibres within the matrix gives a slight orthotropic characteristic to this composite, with $E_2 \sim 2E_1$). The initial parameters taken to define the core geometry are based on the results reported in [11], where 3 plywood veneer corrugated core sandwich panels have been produced and numerically and experimentally tested (static and dynamic mechanical properties identification). The total thickness of the panel is then 19 mm, with a core radius R_c of 17.45mm and a corrugation angle Θ_c of 46°. A4 standard size global dimensions are considered in order to meet the manufacturability requirements. Different directions of the corrugated wall are taken into account (Figure 3): in-plane corrugation parallel to the longest panel side (configuration A); in-plane corrugation parallel to the shortest panel side (configuration B); out-of-plane corrugation, i.e. along the thickness direction (configuration C).

The vibro-acoustic analyses are run using LMS Virtual.Lab Rev10. A diffuse field is used as excitation source, while a free-field is considered at the other side of the partitioning sample. The acoustic power radiated by the structural component is evaluated over the surface of a semi-sphere including the vibrating structure. The effect of the panel modal behaviour is represented by dips and peaks in the predicted TL, separating the low frequency region (mainly controlled by stiffness) from the TL mass law region. The three composite sandwich panels are characterised by same global dimensions (A4 standard size and same thickness) and similar mass (the heaviest configuration, B, is less than 7% heavier than the lightest configuration, C). A detailed investigation on the modal behaviour shows interesting aspects. Only global modal behaviours are observed in the frequency range up to 2 kHz (in other words the structural wavelength is always larger than the unity cell size). Any coincidence phenomenon is observed in this frequency window. The three systems are characterised by a similar number of natural frequencies in the range up to 2 kHz (about 10 modes). Because of the corrugation direction and reinforcing fibres orientation, configuration B is such that the stiffnesses in the width and length directions are both enhanced, making this system performing better from the acoustic transmission point of view (both for undamped and damped cases, as shown in Figure 3, in which no damping and 2% modal damping are applied, in the two graphs on the top and bottom respectively). Odd-odd modes (with uneven number of half wavelengths in both width and length directions) are in fact shifted towards higher frequencies. From this point on the study is further developed considering a panel configuration of kind B. Panel B is shown to have an acoustic TL 10 dB higher than the mass law prediction of a homogeneous aluminium panel with the same weight.

3.3 Optimal structural design of a sisal-PP corrugated core sandwich panel

Corrugated core structures like the one considered here can be preferred to solid-foam or honeycomb sandwich, for the fact that they can resist higher loads compared to the first, since the core also resists a portion of in-plane compressive load. This construction can also be used as heat exchanger or liquid storage (in-plane configuration).

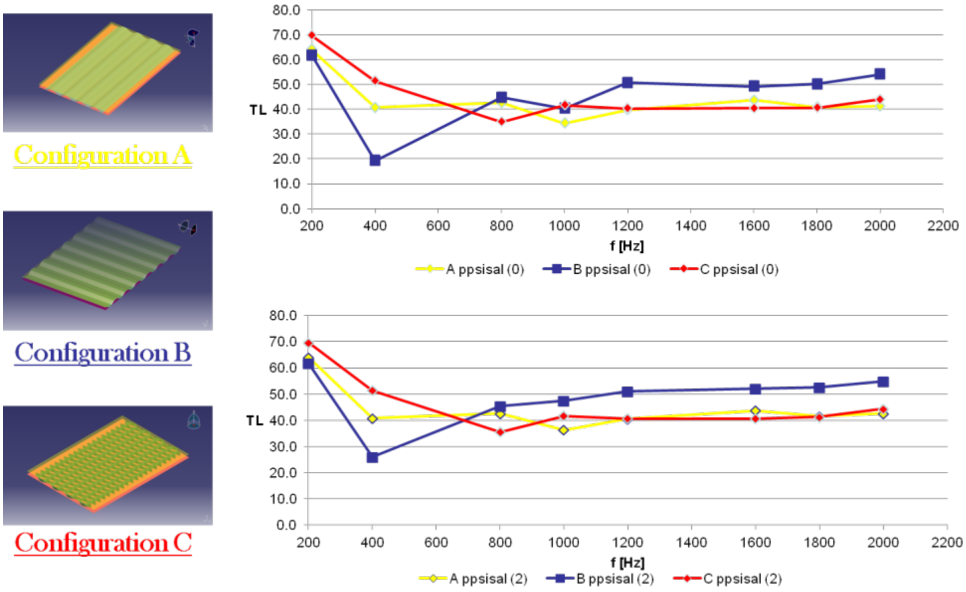

Figure 3. TL for three different configurations of the corrugated core sisal-PP honeycomb panels

Based on the design configuration above indicated with B, the unity structural cell is identified and shown in Figure 4. h_c is the core thickness, R_c and Θ_c are defined as above, while l represents the length of the face sheet strips spanning from one contact line (between face sheet and core element) to the next. It is easy to show how l and h_c are directly determined once R_c and Θ_c are given. Preliminary studies on the normal modal behaviour of such structure showed that the hypothesis of taking an ideal contact line to simulate the connection between core and face elements is valid with satisfactory approximation.

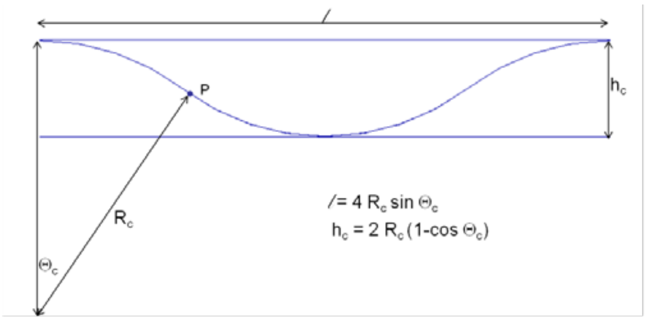

Figure 4. Unity cell geometry for a panel of kind B. Cross-section view.

Keeping a constant corrugation angle, $\Theta_c=46°$, core wall material properties, viz. composite layout (single layer sisal-PP, with fibres orientation parallel to the corrugation direction) and wall thickness (1.72mm), and unvaried face sheets properties (sisal-PP, layout [0-90-0]), the core corrugation radius, R_c, is optimised with respect to the following structural failure criteria: buckling of the face sheet under combined in-plane compression loads; buckling of the face sheet under in-plane shear load; face debonding; buckling of the corrugated core wall under combined in-plane compression and shear loads. Each loading case (in-plane compressions and shear) is considered acting with the same amplitude, although the procedure is generally valid for any load combination. Considering the unity cell shown in Figure 4, the unity face sheet element consists of a flat strip of width l and length a (equal to the global panel width). A core section like the one depicted in Figure 4 is made out of four circle-arcs, each of them connected on one side to one of the face sheets and on the other side to the next arc. The latter connection point (indicated with P in the same picture) is a point of contra flexure. Radial displacements and bending moment are forced to vanish in those points. The edges of both skin layers and core unity elements are hence all considered simply supported, leading to a conservative final design (real boundary conditions will be something in between simply supported and clamped). Mathematical formulations used to express the failure loads are based on the following assumptions: elastic behaviour; thin shell; small deflections; classical laminate theory (through thickness shear deformation and forces are neglected); specially orthotropic laminates (no bending-stretching/bending-twisting coupling).

A specially orthotropic laminate has either a single layer of specially orthotropic material or multiple specially orthotropic layers symmetrically arranged about the middle surface. As noted by Vinson [12], aiming at the design of a structure expected to carry compression loads, one should better design the structure to be mid-plane symmetric (like it is the case of the present specially orthotropic laminate), so that bending-stretching couplings are negligible and overstressing is not occurring before buckling. Obviously discarding the effect of transverse shear makes the methodology not conservative. Although the evaluated buckling load results only approximated, it is considered still good for preliminary design stage.

3.3.1 Buckling of the face sheets

The face sheet element has dimensions a x l , where $l = a\ R_c \cos \Theta_c$. It is considered as a simply supported plate. This element can experience different kind of failures, among others: face sheet fracture; buckling; delamination; debonding. Unlike honeycomb and solid or foam-core sandwich constructions, an in-plane corrugated core sandwich is such that the core itself will carry a portion of the in-plane compressive load. It can be shown that face wrinkling (buckling instability) and core shear crimping (shear instability) occur at higher values for corrugated core structures. According to Reddy [13], holding the hypotheses listed above and considering combined compression loads in both x and y directions (N_{xx} and N_{yy} respectively), the critical buckling load in terms of N_0 is

$$N_0 = -\pi^2 \frac{\left[D_{11}\left(\frac{m}{a}\right)^2 + 2(D_{12} + 2D_{66})\left(\frac{n}{l}\right)^2 + D_{22}\left(\frac{n}{l}\right)^4\left(\frac{a}{m}\right)^2 \right]}{1 + k\left(\frac{a}{l}\frac{n}{m}\right)^2}, \tag{1}$$

where

$$N_{xx} = k_1 N_0; N_{yy} = k_2 N_0; k = N_{yy} / N_{xx} \tag{2}$$

The plate buckling load depends on all four bending stiffness terms (D_{11}, D_{12}, D_{22}, D_{66}). In the same hypotheses made so far, the Rayleigh-Ritz approximated method (reported by Vinson [12] and Ahston and Whitney [14]) is used to formulate the critical buckling load expression for simply-supported laminated plates under shear load. Considering the following displacement field approximation (with p and q integers)

$$w_0(x, y) \approx W_{MN} = \sum_{m=1}^{M}\sum_{n=1}^{N} c_{mn} \sin\left(\frac{m\pi}{a} x\right) \sin\left(\frac{n\pi}{l} y\right), \tag{3}$$

$$\frac{al}{4}\left[D_{11}\left(\frac{p\pi}{a}\right)^4+(D_{12}+2D_{66})\left(\frac{p\pi}{a}\right)^2\left(\frac{q\pi}{l}\right)^2+D_{22}\left(\frac{q\pi}{l}\right)^4\right]c_{pq}-2N_{0xy}\sum_{m=1}^{M}\sum_{n=1}^{N}\frac{m\pi}{a}\frac{n\pi}{l}S_{mnpq}c_{mn}=0, with$$
$$S_{mnpq}=\begin{cases}\frac{4al}{\pi^2}\frac{pq}{(p^2-m^2)(q^2-n^2)}, if\left[p^2\neq m^2, q^2\neq n^2\right]\\ 0, if\left[p=m, q=n, with\left(p\pm m=even; q\pm n=even\right)\right]\end{cases} \tag{4}$$

With a reasonable number of terms (*M = N = 10* for the actual case) convergence is reached. It seemed convenient to express also the shear load N_{xy} in function of the reference value N_o

$$N_{xy}=k_3N_0 \tag{5}$$

The results shown below are referred to the case where $k_1=k_2=k_3=1$, for sake of generality.

3.3.2 Face sheet debonding

Two different bonding techniques are investigated by Rao in [2] for application on bio-based materials: adhesive and ultrasonic bonding. Following the ASTM D-1002-01 standard, tests carried out on both cases bring to a maximum shear stress of about 5-6MPa, when Loctite® 401 from Henkel Corporation is used as gluing substance and at least a weld time of 1sec is taken for the adhesive and ultrasonic solution respectively. The authors chose a maximum delamination limit of 5.5MPa.

3.3.3 Buckling of composite corrugated core

Stability of simply-supported laminated cylindrical plates under combined loads has been extensively studied, [15]. The proposed formulation leads in the current case to the following expression

$$\left(F_{mn}-k_1N_0m^2-k_2N_0n^2R_c^2\right)c_{mn}-32\frac{mnR_c}{a^2}\sum_{i=1}^{\infty}\sum_{j=1}^{\infty}\left\{M_{ij}\left[\left(m^2+i^2\right)D_{16}+\left(n^2+j^2\right)D_{26}-k_3N_0\frac{a^2}{\pi^2}\right]c_{ij}\right\}=0$$
$$M_{ij}=\begin{cases}\frac{ij}{\left(m^2-i^2\right)\left(n^2-j^2\right)}, if\left(m\pm i=odd/n\pm j=odd\right)\\ 0, if\left(i=m/j=n\right), with\left(m\pm i=even/n\pm j=even\right)\end{cases} \tag{6}$$

where N_{xx}, N_{ss} (along the curvilinear abscissa of the corrugated profile) and N_{xs} are expressed in terms of the reference load N_0 in the same way as described above (considering $N_{ss} = N_{yy}$ and $N_{xs} = N_{xy}$). A limited number of terms used in the series expansion (*i = 1..10; j = 1..10*) leads the solution to convergence. Fundamental difference with the case of flat laminated plates is represented by the non vanishing bending-twisting coupling stiffness terms D_{16} and D_{26}, whose effect increases with increasing curvature and also leads to different critical buckling loads for positive and negative shear load.

3.3.4 Construction of failure mode maps

The solutions to the sets of equations presented above give the critical value of N_0 for the elements undergoing a combined load of in-plane compressions and shear, in function of the corrugated geometry profile radius, R_c.

The face sheet component appears to be the most critical (lower N_0). For sake of generalisation, one can define a non-dimensional load index. Correspondent stresses in the face and core elements are defined as below

$$\sigma_{xx\_f}=k_1\frac{N_{0compression\_face}}{t_f\cdot l};\sigma_{yy\_f}=k_2\frac{N_{0compression\_face}}{t_f\cdot a};\tau_{xy\_f}=k_3\frac{N_{0shear\_face}}{a\cdot l};\tau_{xy_{debonding\_face}}=5.5MPa;$$
$$\sigma_{xx\_c}=k_1\frac{N_{0core}}{t_c\cdot c};\sigma_{yy\_c}=k_2\frac{N_{0core}}{t_c\cdot a};\tau_{xy\_c}=k_3\frac{N_{0core}}{a\cdot c};k=\frac{t_c\cdot a\cdot l}{\sqrt{D_{11\_core}\cdot D_{22\_core}}} \tag{7}$$

with t_f the face thickness, t_c the core thickness and c the length of the single circle-arc. The non-dimensional load index k is used to non-dimensionalise the above defined stresses. Non-dimensional stresses indexes for the face sheets elements, considering buckling and debonding failures, are plotted in Figure 5, in function of the radius R_c on the left. At the optimum point failure of the face sheet occurs for achievement of critical load for debonding and buckling due to compression in y direction. Considering the core material density ρ_c and the corrugated core sandwich panel density ρ^*, a non-dimensional density index Φ is defined as

$$\Phi = \frac{\rho^*}{\rho_c} = \frac{\Theta_c \cdot t_c}{180^\circ R_c \sin\Theta_c (1-\cos\Theta_c)} \tag{10}$$

Non-dimensional load indexes are plotted in function of Φ (Figure 5, on the right). The optimum corresponds to a corrugated core geometry with a radius $R_c = 0.05m$. The final design is developed with respect to these optimal geometrical parameters and vibro-acoustic analysis is carried out to study the non-structural performance.

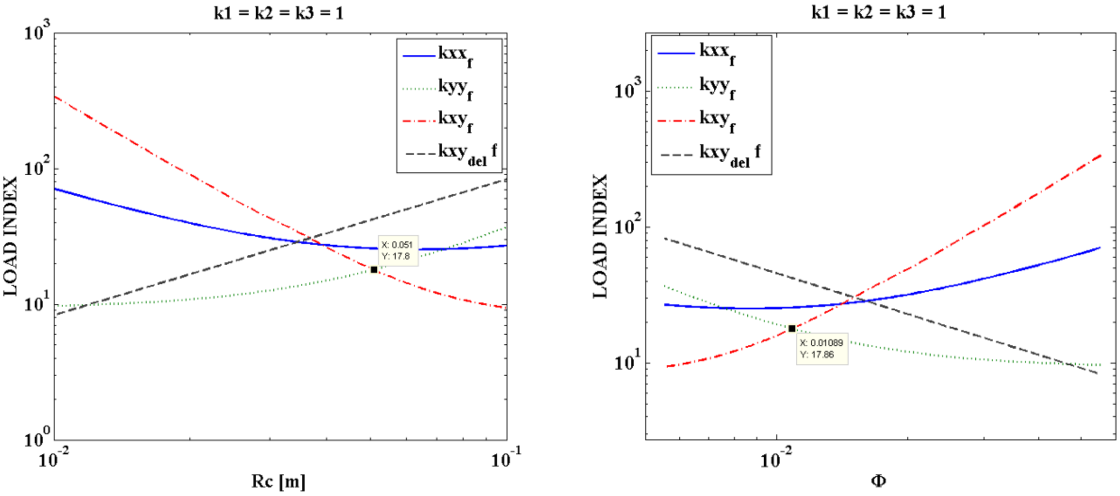

Figure 5. Non-dimensional load indexes for face sheet failure, function of Rc (on the left) and Φ (on the right)

4 Vibro-acoustic analysis of the optimised panel

Vibro-acoustic properties of the optimised design (Figure 6) are numerically evaluated in terms of acoustic TL.

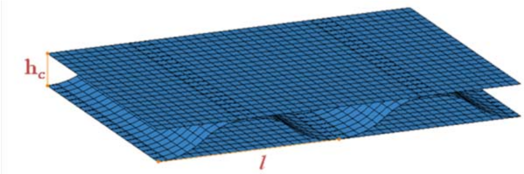

Figure 6. FE model of the optimised design (A4 size)

The calculated TL is shown in Figure 7 (2% modal damping factor) and compared with the TL mass law of an aluminium panel with the same mass (homogeneous panel, 8.2mm thick, same surface and global dimensions). An overall improved TL is clearly visible in the case of the sandwich construction. Above the first frequency region, mainly controlled by the panel stiffness, two abrupt dips in the TL curve occur. They correspond to the first two natural modes of the clamped structure at about 370Hz and 470Hz, difficult to damp out. In the following frequency region the modal behaviour is still well. Coincidence phenomena do not occur in this range (the expected critical coincidence frequency of the face sheet is at about 5.1 kHz).

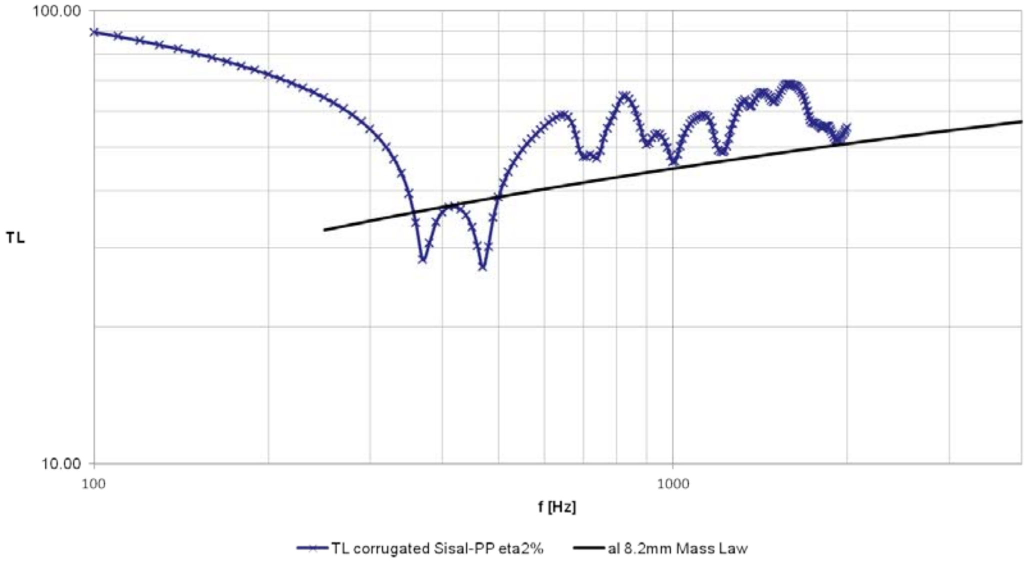

Figure 7. Numerical TL of the optimised panel compared to TL mass law of a homogeneous aluminium panel with the same mass

Conclusions

A procedure is given for designing a composite sandwich panel, made out of eco-friendly materials and fully recyclable. The face sheets and core materials implemented in the present application are made out of layers of short natural sisal fibres in polypropylene resin. The sandwich core has a corrugated geometry, which is optimised in terms of its arc radius in order to get the lightest design able to show the less critical failure limitations. The vibro-acoustic behaviour is numerically predicted up to 2 kHz. The frequency range will be further extended up to 6 kHz, in order to cover the region up to the critical frequency (coincidence of the face sheets, expected to be around 5.1 kHz). An A4 sized sample is going to be manufactured and will be tested and used to validate the design specifications and update the numerical models. Other vibro-acoustic constraints will be included in the optimisation loop (exclusively structural at this stage). The study offers inspiration for many further investigations, as the effect of boundary conditions on the formulation of critical loads of flat and curved composite components, that of natural fibres length on the structural damping of reinforced thermoplastic materials or the effect of different load combinations. At the same time other design parameters can be included as well in the optimisation algorithm, as thickness and layout of face sheets and core, global panel dimensions and core corrugation angle.

These first analyses have revealed a good potential in the use of short natural fibres reinforced composites for noise reduction applications.

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