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EXPERIMENTAL ANALYSES OF SHOCK PROTECTION AVAILABILITY FOR LOW DENSITY CELLULOSE COMPOSITES

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Abstract: *The paper presents a set of experimental analyses regarding the behaviour of the low density cellulose (LDC) composites subjected to the shocking loads. Three types of LDC were considered, and one type of reference polymeric material as expanded polyethylene (EPE) was supposed in order to compare the final results. The experimental tests were developed based on laboratory stand for impulsive loads generating, providing the force and the acceleration signals both at the input, and at the output of the probe. The evaluation of availability of these composites to supply shock protective capacity, in order to embed them within such protection devices, fill the goal of this study. The experimental results denote a very good capability to reduce the shock effects, providing some minimal differences depending by the base materials and mixing percentages.*
Keywords: *shock protection, low density cellulose, composites, experimental analysis, impulsive loads*

1. INTRODUCTION

This study is included into the area of new materials intended for enabling higher protection levels against the effects of the various and intensive shocking charges. Composites based on recycled materials, or from renewable sources, gain much concerning in actual research within various science and engineering fields. As a direct consequence of this reality, the research regarding the protective solution against impulsive/shocking loads based on recycled materials acquires leading positions.

Balea et al. [1] had investigated the cellulose nanofibers from bleached eucalyptus and pine pulps as potential strength additives and the effects on the mechanical properties of recycled old corrugated containers were analyzed through bursting, tensile and short span compressive strength tests. Haghdan et al. [2] had analyzed composites of thin wood veneer and a polyester matrix and the impact properties were evaluated based on drop-weight impact tester. In paper [3] the authors had studied the performance of green (white) coconut fiber as a cushioning material for use in packaging systems and the mechanical performance were evaluated by shock absorption tests. Composite panels made from randomly oriented bamboo fibers reinforced polyester matrix were evaluated in paper [4] and the results reveal that the bamboo fibre composites can be regarded as valid alternatives to replace some conventional fibres as reinforcement in polyester matrix in areas of low strength structural applications. Ogah et al. [5] had investigated the rheology of composites made by *high density polyethylene* (HDPE) and different agro fiber by-products, and in particular, the effect of particle size distribution of the agro fibers by-products on the rheological behavior of these composites was examined. Hellen et al. [6] had made a comparison between HDPE and blends of HDPE /coconut husks, HDPE/cassava and HDPE/oak tree, and discussed the exact difference between their mechanical properties. Boran et al. [7] had produced and analyzed HDPE/*ultrafine cellulose* (UFC) composites using different compounding methods and characterized them to evaluate mechanical, thermal and rheological properties. Composites of polypropylene polymers as a matrix, filled with the fibers of wheat straw and paper mill sludge, were considered by Khademieslam & Kalagar [8], and the results reveal that using of paper mill sludge had a higher contribution than wheat straw fiber, in terms of impact strength. The work [9] provides contributions to basic research on nanocelluloses, while yielding concrete benefits for the industrial context, and suggests novel value-added applications of cellulose nanofibers beyond the classic cellulose applications.

This study presents a set of assessments based on experimental analyses regarding the dynamic behaviour of *low density cellulose* (LDC) composites subjected to the impulsive/shocking loads. Three types of LDC were considered in order to produce the basic composites, and one type of reference polymeric material as *expanded polyethylene* (EPE) was supposed enabling comparison within the final results.

2. EXPERIMENTAL ANALYSIS

For this experimental analysis, the authors had supposed composites based on LDC, produced in foam laid media, air dried freely at the room temperature for a time period between 24 and 48 hours [10]. No pressing procedure was used. According with the notations within Figure 1, the probe codes have the meanings as follows: (1) denotes the *air dried foam fibre* (ADFF) composite from 100% cellulose fibres with high purity, (4) denotes ADFF composite with 50% cellulose fibres and 50% fibres from recycled paper, (3S) means the ADFF composite based on 100% fibres from recycled paper, and (EPE) denotes the reference material – expanded polyethylene.

(a)


(b)

Figure 1: Samples of LDC composites (a) and reference sample EPE-based

The experimental tests was developed using a laboratory tester (as a stand-alone equipment) intended for impulsive loads generating, based on a controlled heavy pendulum, with a vertical impact direction upon a static probe, and enabling the continuous synchronized acquisition of forces and accelerations that acts on both sides of the probe. Some additional technical aspects regarding the use of an impact pendulum in order to capture the material responses induced by instantaneous loads were presented in the paper [11]. Within proposed experimental setup, the digital acquisition was performed by using National Instruments – 9233/9162® and HBM – Spider8® devices, with HBM – S9® force transducers and PCB – triaxial ICP® accelerometers, and computational processing was developed based on the Matlab® software. A high sampling rate of 9600 Hz was used in order to provide highest accuracy of acquired signals. One general view of experimental setup was presented in Figure 2.

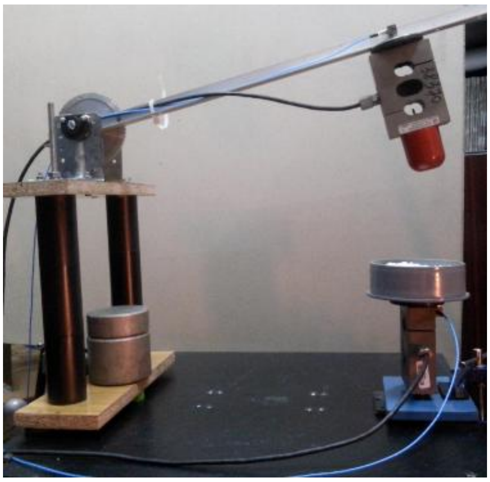

Figure 2: Experimental setup for impact testing

Based on the acquired signals, it was evaluated a set of parameters (accelerations, velocities, displacements, timed variation of acceleration, impact energy, dissipated energy, forces, deformations, etc.), which are able providing a global characterization of the probe capability to dissipate the impact energy [12,13]. In this paper, the following characteristics were considered for presentation: raw acquired signals – both forces and accelerations, dissipated energy – per impact cycle and cumulative, transfer function estimate via Welch.

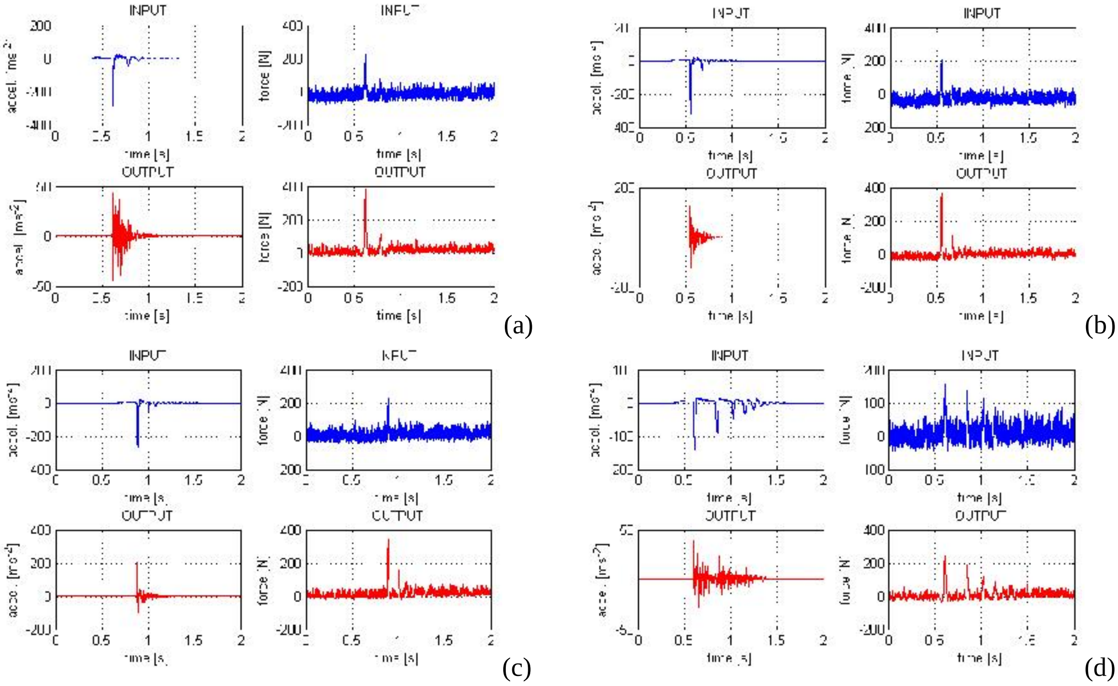

Figure 3: Raw signals of acceleration and force respectively, acquired from experiments: (a) composite code 1, (b) composite code 4, (c) composite code 3S and (d) EPE reference probe.

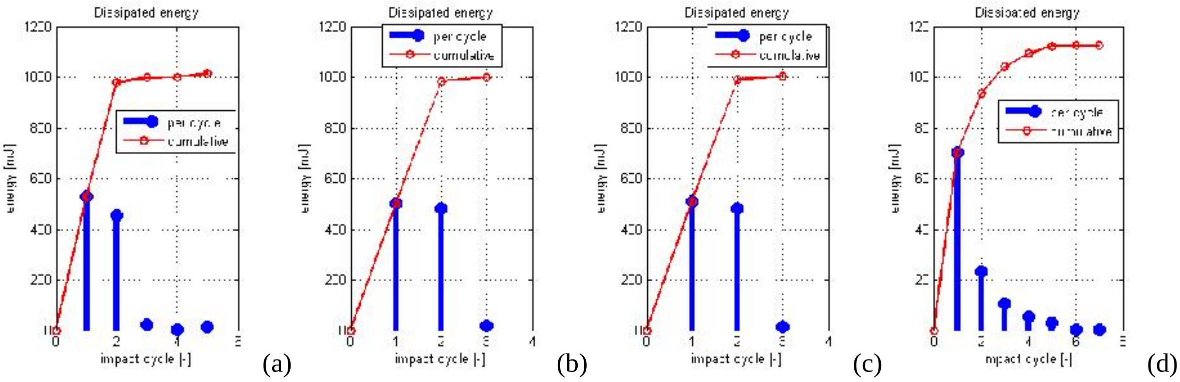

Figure 4: The evolution of dissipated energy per each significant impact cycle and cumulative respectively: (a) composite code 1, (b) composite code 4, (c) composite code 3S and (d) EPE reference probe.

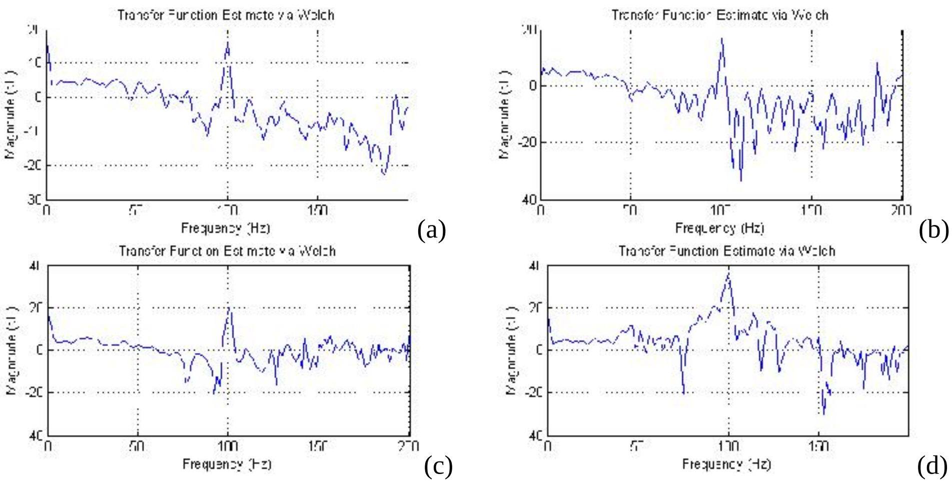

Figure 5: Estimated transfer function: (a) composite code 1, (b) composite code 4, (c) composite code 3S and (d) EPE reference probe.

Diagrams in Figure 3 depict the raw acquired signals for each probe (including the reference material) as follows: (a) composite code 1, (b) composite code 4, (c) composite code 3S and (d) EPE reference probe.

In Figure 4 was presented the diagrams of cumulative dissipated energy and the stem diagram corresponding to dissipated energy within each impact cycle – supposed to be complete and evaluated until velocity decay to full-negative values per cycle. Diagrams regarding the transfer function estimate via Welch theory were depicted in Figure 5. Both sets of graphs in Fig. 4 and Fig. 5 respect the probe code sequence such as Fig. 3.

In Figure 6 was presented the comparative analysis between the behaviour of all probes (including the reference material) taking into account the maximum force and acceleration respectively – see Fig.6(a), deformation within the first impact cycle – see Fig.6(b), maximum value of acceleration variation in respect with time – see Fig.6(c), cumulative (total) dissipated energy – see Fig.6(d).

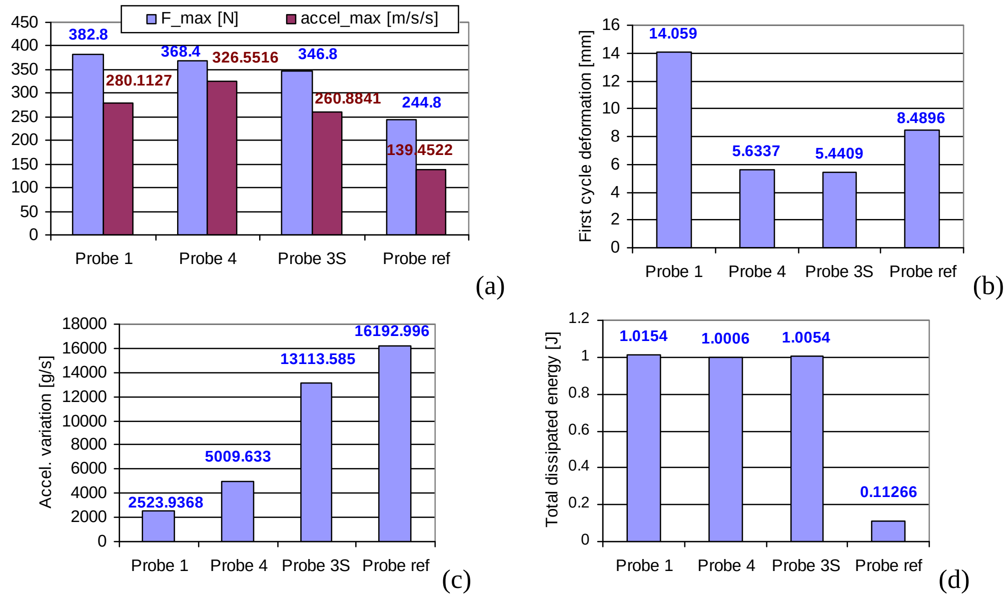

Figure 6: Comparative results (in terms of maximum values) regarding: impact force and acceleration (a), deformation within first impact cycle (b), normalized acceleration in respect with time (c), total dissipated energy (d).

3. RESULTS AND DISCUSSIONS

Histograms within Fig. 6 reveal the shock protection availability of proposed composites LDC–based. Hence, each of the three materials provides good capacity of impact energy damping, even if it can observed relative small differences between them. Maximum values of force and acceleration respectively, during the first impact cycle (Fig.6.a) denote that proposed composites present an approximate constant evolution. In the same time, the first cycle deformation (Fig.6.b), in terms of total value containing both conservative and dissipative components, reveals strong deformation of code (1) material comparative with the others two; it can be explained by the strong dissipative characteristic of this material. Last judgment has been also sustained by the maximum value recorded for acceleration variation, which, for code (1) composite, present the smaller value even if the peak acceleration signal acquires the higher value (see comparative diagrams in Fig.6.a,c). The histograms depicted in Fig 6(c) highlight the fact that in the same time with recycled paper percentage grows up, the performance in terms of specific deceleration slow down. From analysis of the peak values presented in Fig 6(d) results that proposed composites provide a constant capacity of damping energy, but in addition with the specific deceleration (Fig.6.c) and deformation (Fig.6.b), it can be denote that balancing between cellulose fibres and recycled paper percentages within composite material assure suitable capability of shock reduction in terms of dynamical effects. The numbers of impact cycles until stopping motion, and the distribution of dissipated energy within each cycle also present a great significance for a comparative analysis of shock mitigation availability of such materials – see stem diagrams in Fig. 4. The reference material was adopted thus that will be able to provide a considerable conservative characteristic, comparative, at least, with estimated mainly dissipative characteristics of proposed composites. This fact was justified through correspondent values in Fig. 6.

In addition, analyzing the diagrams within Fig. 4 and 5, the previous conclusions were also underlined. Taking into account the evolution of the dissipative energy per each impact cycle – see Fig.4 – results that composite code (1) provides the best performances, follows by composite code (4) and composite code (3S). The “*performance hierarchy sequence*” corresponds with the maximum values of the acceleration variation in respect with time, which is a major parameter that can prove the shock isolation level. Comparative analysis of the estimated transfer functions – see Fig. 5 – indicates a group of relative identical diagrams for proposed composites, and certain differences, in the low-medium range of frequency (50...100Hz), for the reference elastomeric material.

4. CONCLUSION

The main conclusion of this study, according the previously mentioned results and discussions, dignify the availability level of the composites based on LDC, to supply a suitable solution for shock isolation devices. Authors' future researches in this area will be focused on increasing the recycled paper percentage and optimization of the composites solutions, in order to supply higher isolation levels with constancy in providing final characteristics. The experiments within this study were performed for low level impact energy, taking into account one of the main area of usability that is small weight package protection. Hence, in the future, the authors will develop the tests also for big volume and/or high weight packaging impact protective solutions.

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