TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 61, Issue I, March, 2018

COMPARATIVE ANALYSIS OF DIFFERENT RIBS USED TO RIGIDIZE THE RESISTANCE STRUCTURE OF A SOFA SIDE MADE OF COMPOSITE MATERIALS BASED ON VEGETABLE FIBERS

Cornel CIUPAN, Mihai STEOPAN, Emanuela POP, Emilia CAMPEAN, Ioan FILIP, Emilia CIUPAN

Abstract: *The paper presents a comparative analysis of four stiffening models by ribbing for a sofa side made of composite materials based on vegetable fibers. The purpose of the paper is to provide the date for optimizing the amount of material used for the resistance structure of a sofa side. For each model, simulations were made for different wall thicknesses, and the results were used to obtain polynomial regression functions.*
Key words: *Comparative analysis, rib, sofa side, composite material*

1. INTRODUCTION

Most of the tapestried products contain a resistance structure in the form of a frame timber. Wood is an excellent, functional, ecological and aesthetic material, but excessive exploitation places its mark on the environment, determing most of the countries to adopt forestry legislation. For these reasons, manufacturers of large series of wooden articles, including furniture manufacturers, are looking for solutions to replace wood with other recyclable products, which offer benefits in terms of productivity and of the overall cost of the product [4].

S.C. TAPARO SA company from Târgu-Lăpuş is one of the big manufacturers of upholstered furniture at national level. It consumes a large quantity of wood every year, such as about 25,000 cubic meters of timber and 50,000 cubic meters of plank. A significant part of this wood, after processing, becomes waste. In order to reduce the pressure of legal regulations, pricing and taking into account reuse and recycling issues, the company has developed its own composite material, using a patented process and technology.

The composite material made by S.C. TAPARO S.A. and used for the analyzed parts in this paper consists of a thermoplastic fibrous component (polypropylene fibers) and a plant fiber component (hemp, jute, sisal, coconut, etc.) or a mixture of natural fibers. Polypropylene fibers with a length of 4-60 mm and a linear mass density of 7-16 DEN are combined in a proportion of 50% -60% of the total weight of the mixture with vegetable fibers having a defibration degree of about 70-80 Tden and a fiber length of 5-100 mm.

2. STATE OF THE ART

The study entitled "The Influence of Reinforced Materials and Manufacturing Procedures on the Mechanical Characteristics of Polymeric Composite Materials" is highlighting the influence of manufacturing processes and of the glass fiber and carbon fiber structures on the mechanical properties of composite materials [1]. Experimental research in this study has led to the conclusion that the structure of reinforcement material will influence the mechanical characteristics.

The authors of the present paper have researched the replacement of wood from the resistance structure of upholstered products with composite materials. Several products (armchair, sofa, chairs, etc.) made at TAPARO were presented in paper [2]. The way in which the layout of the layers influences the mechanical properties of the thermoformed material was studied in the paper [4]. From the composite material developed by TAPARO, were cut a set of samples from the thermoformed plates of 2, 3 and 4 layers. For some plates, the layers of reinforced nonwoven material were superimposed either in the feed direction of the interlacing machines or combined. Samples were tested on the Zwick Roell Z150 traction test machine. Samples and test method were adopted in accordance with D3039 standard, „Test Method for Tensile Properties of Polymer Matrix Composite Materials". The obtained results [4] were used in this paper for the simulations. Problems related to redesigning parts of the resistance structure of upholstered products for the manufacture of composite materials based on natural fibers have been trated within the paper [3].

The paper [5] proposes an integrated optimization methodology that takes into account reducing the weight, improving structural performance and reducing the cost of the composite structures.

A two-phase optimization method for designing the shape and thickness of shell structures made of orthotropic materials is presented in the paper „Multi-objective free-form optimization for shape and thickness of shell structures with composite materials" [6].

An optimization of honeycomb core sandwich beams having arbitrary density is treated by Annette Meidell in the paper Minimum weight design of sandwich beams with honeycomb core of arbitrary density [7]. The authors of the paper determine a simple algorithm for estimating the distance between face centers, face thickness, and cell wall volume was deduced. The algorithm minimizes the mass of the beam for a given rigidity.

An unconventional approach to the manufacture of biocomposite sandwich structures made from natural fibers (jute, flax, hemp and cellulose) is treated within the paper [8]. A number of three different structures were tested, resulting that the least thickness structure, having 21.9 mm, which can withstand the test, is the flax one.

In the paper [9] the authors examined the possibility of reducing the mass of composite material by designing vertical and/or horizontal ribs placed on each of the two components of a sofa side. This work resulted in the important role of the ribs, which offers the possibility to reduce the deformations more than 3 times.

3. SOFA SIDE MADE FROM COMPOSITE MATERIALS BASED ON ORGANIC FIBERS

TAPARO's R & D department has designed and built a series of components for furniture made of composite materials based on organic fibers and intends to continue research to replace wood from the structure of the upholstered products. Replacing wood with composite material raises a number of problems with redesigning components that have to meet both product and economic functional requirements. Besides the resistance to the stresses imposed by the tests of the upholstered furniture (static stress, dynamic and fatigue stress tests), the component should be analyzed also in terms of costs and thermoforming technology. The cost of the product is proportional to the amount of composite required for manufacture. Another cost component is the complexity of the mold and the press. To this is added the quality of the thermoformed product. Therefore, in this paper the authors intend to study how the application of ribs influences the mechanical characteristics of the component and the possibility of reducing the mass by reducing the thickness of the wall. To carry out the research was considered the side of a sofa with different ribbed patterns (Table 1).

In the component redesign process, engineers took into account, in addition to technical constraints, the simplification of molds design and the improvement of the thermoforming process.This paper seeks the optimization of the resistance structure of a composite sofa side by adding ribs of different shapes, in order to stiffen it.

The sofa side used for the study was redesigned from a wooden sofa side (figure 1), made out of 21 different wooden, chipboard and cardboard parts.

Fig. 1. Wooden sofa side

The redesigned sofa side, to be made of composite material, is made in the form of a box, two semi-sides (figure 2), one outer (figure 2.a) and one inner (figure 2.b) side and a rib in between the two sides (figure 2.c). The two semi-sides are assembled by stapling on the contour or by gluing.

The optimization aims to reduce the overall mass while increasing the stiffness by using two types of ribs: in the circular arc pattern (C) and the zigzag pattern (Z). The ribs are made through thermoforming, independent of the two semi-sides and later assembled by gluing or stapling.

For each of the two rib patterns, two sub-models were created: a model (C1) or (Z1) where the rib is contained in the inner half and another model, (C2), respectively (Z2) that is placed in between both semi-sides (table 1).

4. FINITE ELEMENT ANALYSES OF SOFA SIDE MODELS

The models presented in Table 1 were analyzed using the Finite Element Analysis (FEA) method. According to the tests requested by the manufacturer, linear simulation tests were performed.

After 3D modeling of the four variants, fixing surfaces and test surfaces were established. The fixing surfaces correspond to the floor contact area. The size and position of the test surfaces were determined in accordance with the customer's standards.

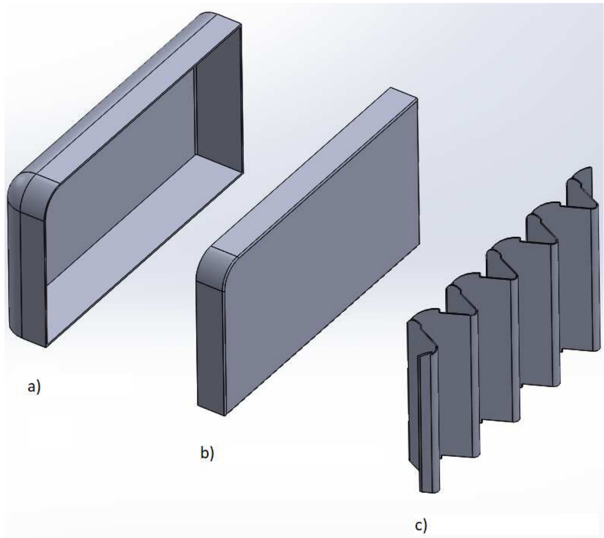


Fig. 2. Composite sofa side: a) outer side, b) inner side, c) rib model Z2

In order to determine the way in which the ribs influence the rigidity of the sofa side, static loading tests were simulated for a model without ribs and the four models presented in table 1. The parameters used in the simulation are:

- variation of wall thickness: g = 2 ... 4 mm, with a pitch of 0.5 mm;
- statically applied horizontal load of 350 N;
- statically applied vertical load of 750 N

Figures 3 and 4 present the simulation results for the non-ribbed-side model. For the non-ribbed model, the thickness of the outer walls in the 2-4mm range was considered. For wall thicknesses of 2 mm, the following values were obtained: the equivalent load 32.2 MPa, deformation 21.5 mm with a product mass being 1.269 Kg and for 4 mm wall thickness 16 MPa, 9.1 mm deformation and the product mass of 3.502 Kg.

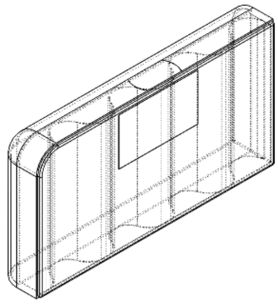
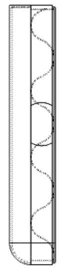
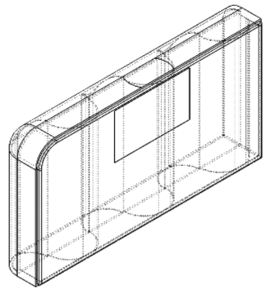
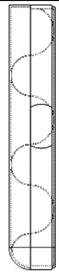
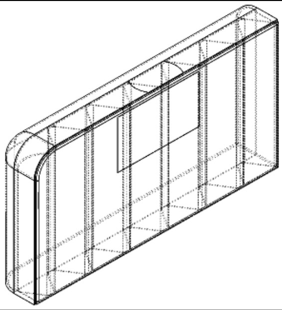
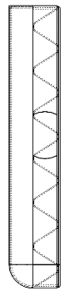
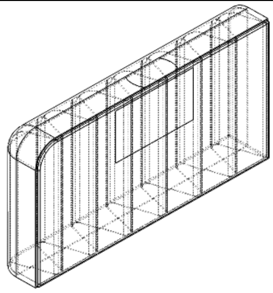
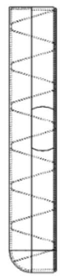
The characteristics of the material used in the simulation were:

- modulus of elasticity: 15 MPa;
- breaking strength: 32 MPa;
- Poison's ratio: 0.39.

For the models in Table 1, the same simulations as for the non-ribbed model were performed. The only variable considered was the thickness of the wall: from 2 mm to 4 mm, considering a 0.5 mm increase increment. A set of 5 tests for each model were done, resulting in a total of 25 tests for all the models considered.

Table 1.

Rib patterns used for testing

Model name	Model sketch		Model name	Model sketch	
Rib type C_1			**Rib type C_2**		
Rib type Z_1			**Rib type Z_2**		

Considering that in the worst-case scenario (the non-ribbed model) the test results were within acceptable limits, only the deformation and the weight of the product were followed parameters, considering that they provide the best information on stiffness and cost. Thus, for each of the models the following data sets were collected (figure 5):

- on the vertical axis, the deformation in mm
- on the horizontal axis, the mass of the product in grams.

Based on the simulation results, a set of 2nd order polynomial regression functions were determined with respect to the weight of the product. The determined R^2 parameter was between 0.98 and 0.99.

Figure 5 shows the results of the analyzes centralized. On the vertical axis is the deformation in mm, and on the horizontal axis the mass calculated in grams. For graphical reasons, for the non-ribbed model we considered deformation values for a mass of product ranging from 1.75-3.5 kg.

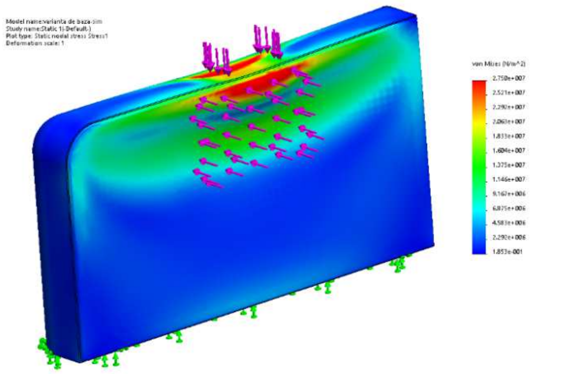


Fig. 3. First simulation no rib model - von Mises test

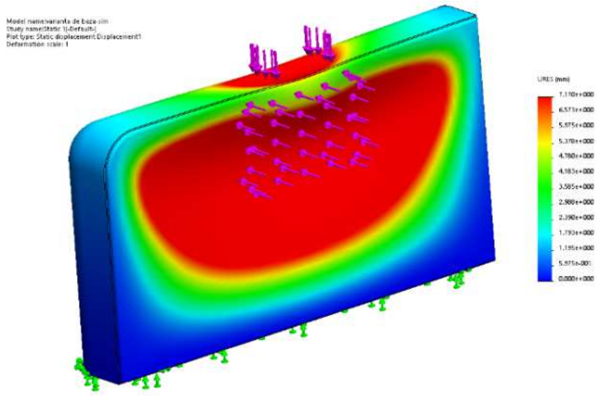


Fig. 4. First simulation no rib model - Deflection

Table 2

Regression functions for each of the studied models

Model	y(x) – 2^{nd} degree polynomial regression function	Wall thickness	Weight [kg]	Deflection [mm]
No rib	$y(x) = 2E\text{-}06x^2 - 0.0188x + 41.424$	2 mm	1.269	21.5
		4 mm	2.502	9.10
Rib type C_1	$y(x) = 1E\text{-}06x^2 - 0.009x + 17.321$	2 mm	1.772	5.62
		4 mm	2.924	1.93
Rib type C_2	$y(x) = 3E\text{-}07x^2 - 0.005x + 15.437$	2 mm	1.799	6.94
		4 mm	2.970	2.62
Rib type Z_1	$y(x) = 2E\text{-}06x^2 – 0.0116x + 18.085$	2 mm	1.846	2.90
		4 mm	3.058	1.03
Rib type Z_2	$y(x) = 2E\text{-}06x^2 - 0.011x + 17.517$	2 mm	2.179	1.62
		4 mm	3.370	0.40

5. CONCLUSION

Based on the results of the simulation, all four ribbed models are consistent with static loading tests. The model without ribs, with a wall thickness of 2 mm, slightly exceeds the breaking strength limit with the largest deformation and the lowest material consumption.

From the simulations performed for the analyzed models, the following qualitative evaluations were carried out in relation to the model without roibs, considering the mass of the product in relation to the deformation:

1. Rib type (C1) reduces the deformation by 66% compared to the simple version at the same weight of the 1.775 kg
2. Rib type (C2) leads to a 47% deformation, compared to the version without ribs, at the same weight of the 1.775 kg
3. The zig zag ribs, type (Z1), reduces the deformation by 78% compared to the simple version at the same weight of the 1.815 kg
4. The zig zag ribs, type (Z2) reduces the deformation by 72% compared to the simple version at a 1.775 kg side weight.

Also the beneficiary can choose the most appropriate ribbed pattern, considering the sofa side deformation and weight. A major advantage for using the ribbed patterns is that they leads to an increased stiffness, with a reduced mass increase, compared to reducing the deformations only by thickening the walls.

For example, for an acceptable deformation, between 3 and 6 mm and a weight of 1.815 kg, the beneficiary may select from several variants, based on its own considerations:

1. The Z1 model has the smallest deformation, 3.05 mm, at the selected weight;
2. The Z2 model has a deformation of 3.66 mm;
3. The C1 model has a 4.65 mm deformation;

Due to the fact that the material consists of several interwoven layers, some phenomena can not be simulated, which is why it is recommended to conduct experimental researches on a set of prototypes in the laboratory, both in static, dynamic loading, but also in fatigue tests.

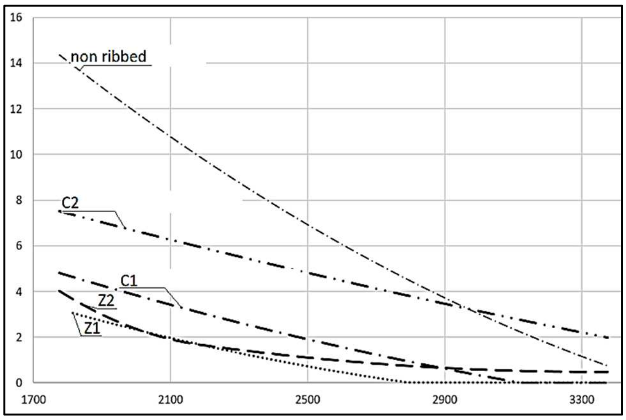


Fig. 5. The deflection for each of the studied models

6. ACKNOWLEDGEMENTS

This work was supported by a grant of the Romanian National Authority for Scientific Research and Innovation, CNCS/CCCDI – UEFISCDI, project number PN-III-P2-2.1-PTE-2016-0179, within PNCDI III.

7. REFERENCES

[1] Iancau H., Bere P., Borzan M., Hancu L., Crai A., *The Influence of Reinforced Materials and Manufacturing Procedures on the Mechanical Characteristics of Polymeric Composite Materials*, Materiale Plastice, Vol.45, Nr.3, 2008

[2] Filip I., Ciupan E., Cionca I., Ciupan M., Pop E., Câmpean E., Hereş V, Rat F. *Furniture parts made of composite materials based on vegetable fibers*. The 21th International Conference of Inventics, Iasi, pg. 38 – 45, 2017.

[3] Ciupan C., Pop E., Filip I., Ciupan E., Câmpean E.,Cionca I., Hereş V. *A new approach of the design process for replacing wooden parts of furniture.* The 13th Modern Technologies in Manufacturing, Cluj-Napoca, 2017.

[4] Ciupan E., Lăzărescu L., Filip I., Ciupan C., Câmpean E., Cionac I., Pop E. *Characterization of a thermoforming composite material made from hemp fibers and polypropylene.* The 13th Modern Technologies in Manufacturing, Cluj-Napoca, 2017.

[5] Chung H. P., Saouab A., Bréard J., Han W. S., Vautrin A., Lee W. I., *An integrated optimisation for the weight, the structural performance and the cost of composite structures*, Composites Science and Technology, vol. 69, pag. 1101–1107, 2009.

[6] Ikeya K., Shimoda M., Shi J.-X., *Multi-objective free-form optimization for shape and thickness of shell structures with composite materials*, Composite Structures, Volume 135, Pages 262-275, 2016.

[7] Meidell A., *Minimum weight design of sandwich beams with honeycomb core of arbitrary density*, Composites: Part B, vol. 40, pag. 284–291, 2009.

[8] Jiang L., Walczyk D., McIntyre G., Bucinell R., Tudryn G., *Manufacturing of biocomposite sandwich structures using mycelium-bound cores and preforms*, Journal of Manufacturing Processes vol. 28 pag. 50–59, 2009.

[9] Steopan M., Ciupan C., Campean E., Pop E., Filip I., Stelea L., *Optimizing a sofa side made of composite materials based on vegetable fibre*, Proceedings of the XXIth International Scientific Conference "INVENTICA 2017", Iasi, June 29-30, pp. 95-103, 2017.

ANALIZA COMPARATIVĂ A UNOR SOLUŢII DE NERVURARE A STRUCTURII DE REZISTENŢĂ A UNEI LATERALE DE CANAPEA REALIZATĂ DIN MATERIAL COMPOZIT PE BAZA DE FIBRE VEGETALE

Rezumat: Lucrarea prezintă o analiză comparativă a patru modele de rigidizare prin nervurare a unei laterale de canapea realizată din materiale compozite pe bază de fibre vegetale. Scopul lucrării este de oferii date pentru optimizarea cantităţii de material compozit utilizat pentru structura de rezistenţă a lateralei. Pentru fiecare model s-au făcut simulări pentru diferite grosimi ale peretelui, iar rezultate au fost utilizate pentru obţinerea unor funcţii de regresie polinomială.

Cornel CIUPAN, Professor, Ph.D. Eng., Technical University of Cluj-Napoca, Department of Industrial Design and Robotics, cornel.ciupan@muri.utcluj.ro, 103-105 No., Muncii Blvd.

Mihai STEOPAN, Lecturer, Ph.D. Eng, Technical University of Cluj-Napoca, Department of Industrial Design and Robotics, mihai.steopan@muri.utcluj.ro, 103-105 No., Muncii Blvd.

Emanuela Sorina POP, Lecturer, Ph.D. Eng, Technical University of Cluj-Napoca, Department of Industrial Design and Robotics, emanuela.pop@muri.utcluj.ro, 103-105 No., Muncii Blvd.

Emilia CAMPEAN, Lecturer, Ph.D. Eng, Technical University of Cluj-Napoca, Department of Industrial Design and Robotics, emilia.campean@muri.utcluj.ro, 103-105 No., Muncii Blvd.

Ioan FILIP, Chairman of the Board of Directors, TAPARO SA, 43562 Village Borcut, No. 98, Maramures County, Romania.

Emilia CIUPAN, Associate professor, Ph.D., Technical University of Cluj-Napoca, Department of Management and Economic Engineering, emilia.ciupan@mis.utcluj.ro, 103-105 No., Muncii Blvd. Cluj-Napoca, Romania.