Annals of Warsaw University of Life Sciences - SGGW
Forestry and Wood Technology № 87, 2014: 55-59
(Ann. WULS - SGGW, For. and Wood Technol. 87, 2014)

Study of furniture constructions made of postconsumer cardboard

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Abstract: *Study of furniture constructions made of postconsumer cardboard.* The aim of the study was to determine the possibility of using postconsumer cardboard as a material for manufacturing furniture. To make a piece of furniture waste cardboard boxes and tubes for plastic wrap were used. The furniture elements cut out of cardboard were joined together with glue. The strength of horizontal elements and the stiffness of the piece of furniture for the three variants of the load were studied. It was found out that postconsumer cardboard can be efficiently used for manufacturing furniture. The significant impact on the deformation and stiffness of the piece of furniture was to load applied to horizontal elements.

Key words: furniture constructions, stiffness of the furniture, postconsumer cardboard

INTRODUCTION

Eco-design becomes a necessity nowadays, which is especially stressed by Woźniak *et al.* (2008). They stress that this refers to both large and small companies and each of us. Therefore, also in the European Union the idea of eco-innovation is increasingly being implemented. It is defined as the implementation of a new or significantly improved product, good, service or process substantially reducing the negative environmental impacts. Also Lau (2007) pays special attention to the need to apply the principles of sustainable development and ecological industry as well as to the necessity to include these principles in the education of future engineers.

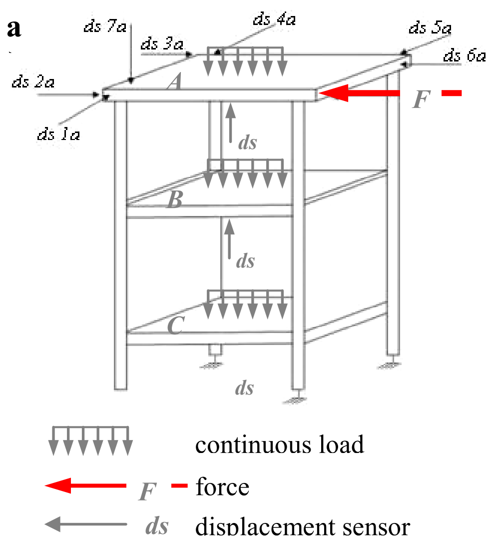
Although the raw materials used in the manufacture of furniture are mostly organic materials, the principles of eco-design and eco-innovation should also apply to furniture industry. But one should remember that furniture must meet a number requirements, including strength, regardless of the material used for its production.

The impact of various factors on the strength and stiffness of furniture was studied among others by Albin *et al*. (1987), Chai and Wang (1993), Tankut (2009), İmirzi and Efe (2013). In solving problems related furniture and joints various methods were used, including the FEM (Eckelman *et al.* 1985, Smardzewski 1998, Nicholls and Crisan 2002, Gawroński 2006, Kociszewski *et al.* 2009, Wilczyński *et al*. 2010). Also the fatigue life of the materials used for manufacturing furniture was analysed (Bao and Eckelman 1995). Although the examples of using cardboard for the production of furniture are known, there are a few of them (Lau 2007). First of all there is a need for studies reporting extensively on the stiffness and strength of the furniture made of cardboard, especially of postconsumer cardboard. Therefore, the aim of this study was to determine the possibility of using postconsumer cardboard as a material for producing furniture. In particular, to examine the strength of horizontal elements and the stiffness of the piece of furniture made of postconsumer cardboard.

MATERIALS AND METHODS

To make a piece of furniture, waste cardboard boxes and tubes for plastic wrap were used, that were obtained from shops. Cardboard boxes were made of corrugated cardboard. There were mostly the large sheets of cardboard with sizes from 450 × 400 mm to 550 × 600 mm. In order to provide the greater strength of tubular parts (legs of the piece of furniture), special cardboard reinforcements were made. The furniture elements cut out of cardboard were joined together with glue. Next the piece of furniture was kept under laboratory conditions (at a temperature of 20 °C and humidity of 50 %) for 7 days. Afterwards, the piece of furniture was painted with paint not containing water, and then was again kept under laboratory conditions for 7 days.

The evaluation of the flexural strength of the horizontal elements consisted in applying a load being bags with steel balls to the horizontal elements of the piece of furniture and noting the value of deflection. The load was determined on the basis of the ISO 7170: 1977 standard. The determined value of the load for one horizontal element was 6 kg. The deflection of elements was noted 60 s after applying the load. The load application and the sensor location are shown in Fig. 1.



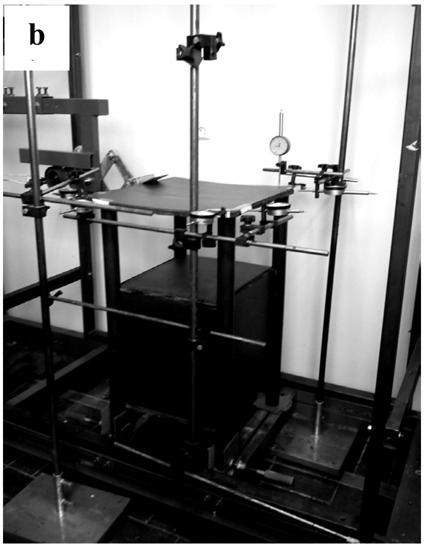


Fig. 1. Diagram of load application and location of displacement sensor (a), test stand (b)

The examination of the stiffness of the piece of furniture was carried out according to the BN-82/7140-12.02 standard, but the lateral force was applied at the corner of the upper horizontal element. Force was applied in increments of 5 N form 5 N and 35 N, and displacements of furniture elements were determined using displacement sensors shown in Fig. 1. This examination was conducted in three variants: variant *I* for furniture with no load applied, variant *II* for furniture with a partial load applied (elements *B* and *C*) and variant *III* for the piece of furniture with a full load applied (elements A, *B* and *C*). The value of the load for one horizontal component was 6 kg.

RESULTS

When analysing the results of examinations of the strength of the horizontal elements (Table 1), one can notice that when the 6 kg load is applied, their maximum deflection does not exceed 2.5 mm in any case. The deflection of the upper element *A* registered by the sensor ds1b is on average two and a half times higher than that of two remaining elements *B* and *C* (ds2b i ds3b). It was noted that the deformation of the element A had been due to the poorer quality of the material used for its production.

Table 1. Values of deflections of horizontal elements subjected to 6 kg loads

	Displacement sensors		
	ds1b	ds2b	ds3b
Displacement (mm)	2.42	0.53	0.88

It was noted that the deformation of the examined piece of furniture was similar to that occurred in examining traditional cabinet furniture. For all three variants (*I*, *II* and *III*) of loads used in the study, the largest displacement was registered by the sensor ds2a (Fig. 2). These average displacements are more than three times higher than the average displacement recorded by the sensor ds7a, for which the smallest displacement was registered. The comparable mean values, as for the sensor ds7a, were noted in the case of the sensors ds1, ds4a and ds5a. The displacement higher on average by 70% was recorded for the sensors ds3a and ds6a in comparison with the sensor ds7a.

The analysis of the results shows that generally with an increase in the load applied to the piece of furniture from 0 kg to 18 kg its deformation reduces. The greatest difference in displacement between the variant *I* and *III* of load was observed in the case of sensors ds1a, ds4a and ds7a. The displacement recorded for the variant *I* by the sensor ds1a was about twenty times higher, by the sensor ds4a about nine times, and by the sensor ds7a about seven times higher than for the variant *III* of load. There was no such trend, however, in the case of the sensor ds3a, in which the differences between deformations for the variants *I* and *III* did not exceed 1 %.

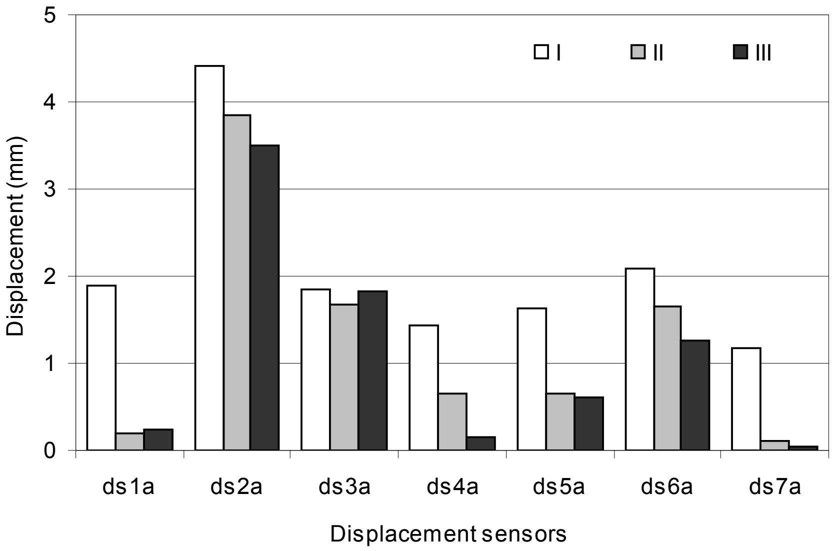


Fig.2 Displacement of furniture corners caused by the force 35 N, for the variants *I*, *II* and *III* of load

The Table 2 shows the equations of trend lines and the coefficient of determination R^2 that characterise the deformations of the furniture corners, registered by displacement sensors and caused by loads from 5 N to 35 N for the variants *I, II*, and *III* of the load.

Table 2. Equations of trend lines and values of the coefficient of determination R^2 that characterise the way of deforming the furniture corners caused by loads from 5 N to 35 N

Displ. sensors	Variant I		Variant II		Variant III	
	R^2	equations of trend lines	R^2	equations of trend lines	R^2	equations of trend lines
ds1a	0.994	$y = 5E\text{-}05x^3 + 0.0004x^2 - 0.0174x + 0.0321$	0.958	$y = 3E\text{-}05x^3 - 0.0011x^2 + 0.011x - 0.0086$	0.984	$y = 3E\text{-}05x^3 - 0.0011x^2 + 0.0092x - 0.0085$
ds2a	0.982	$y = -0.0001x^3 + 0.0113x^2 - 0.129x + 0.1489$	0.982	$y = -0.0001x^3 + 0.0107x^2 - 0.1027x + 0.0765$	0.892	$y = 6E\text{-}05x^3 + 0.0018x^2 - 0.0333x + 0.0432$
ds3a	0.887	$y = -0.0001x^3 + 0.0083x^2 - 0.0939x + 0.115$	0.875	$y = -0.0001x^3 + 0.0076x^2 - 0.0858x + 0.1048$	0.898	$y = 1E\text{-}05x^3 + 0.0018x^2 - 0.0213x + 0.0312$
ds4a	0.915	$y = -4E\text{-}06x^3 + 0.0016x^2 - 0.0118x - 0.0032$	0.990	$y = 2E\text{-}05x^3 - 1E\text{-}04x^2 + 0.0024x - 0.0062$	0.965	$y = -8E\text{-}05x^3 + 0.0041x^2 - 0.0426x + 0.0524$
ds5a	0.938	$y = -0.0001x^3 + 0.0085x^2 - 0.074x + 0.0459$	0.987	$y = 7E\text{-}05x^3 - 0.0027x^2 + 0.0235x - 0.0218$	0.957	$y = -0.0002x^3 + 0.012x^2 - 0.1303x + 0.1547$
ds6a	0.917	$y = -0.0002x^3 + 0.011x^2 - 0.0953x + 0.0736$	0.991	$y = -3E\text{-}05x^3 + 0.0033x^2 - 0.0337x + 0.0306$	0.959	$y = -0.0001x^3 + 0.0081x^2 - 0.0833x + 0.0864$
ds7a	0.963	$y = -0.0002x^3 + 0.0096x^2 - 0.1119x + 0.138$	0.959	$y = 1E\text{-}06x^3 - 6E\text{-}05x^2 + 0.0006x - 0.0006$	0.893	$y = -6E\text{-}06x^3 + 0.0003x^2 - 0.0004x - 0.003$

It should be stressed that regardless of the variant of load and the place of applying the displacement sensor the changes of displacements that were registered are in the form of a third-degree polynomial with a high value of $R^2 > 0.887$, which indicates a good degree of fit of the function.

Assuming that the furniture stiffness is the relation between the loading force F and the displacement of the furniture corner measured in the direction of its action (ds2a) (note – displacement is measured), the piece of furniture obtained the highest stiffness when the variant *III* of load was used. With $F = 35$ N and the variant *III* of the load the stiffness of the piece of furniture was by about 10 % greater than that with the variant *II* and by about 26 % with the variant *I*.

CONCLUSIONS

The research results allow to conclude that postconsumer cardboard can be efficiently used for manufacturing furniture. The significant impact on the deformation and stiffness of the piece of furniture was due to load applied to horizontal elements. Adding the load contributed to the growth of its stiffness. The research showed that with its low weight the piece of furniture is sufficiently strong to perform the assigned role of a nightstand.

REFERENCES

Albin, R., Müler, M., Scholze, H., (1987): Investigations on the strength of corner joints in casetype furniture, Holz als Roh- und Werkstoff 45 (5): 171-178.

Bao Z., Eckelman C. A. (1995): Fatigue life and design stresses for wood composites used in furniture. Forest Prod. J. 45 (7/8):59-63

Chai L., Wang F. (1993): Influence of the Stiffness of Corner Joint on Case Furniture Deflection. Holz als Roh-und Werkstoff 51: 406-408.
Eckelman, C., A., Rabiej, R., (1985): A Comprehensive Method of Analysis of Case Furniture, Forest Product Journal 35(4):62-68.
Gawroński, T., (2006): Rigidity-Strength Models And Stress Distribution In Housed Tenon Joints Subjected To Torsion. Electronic Journal of Polish Agricultural Universities, Wood Technology, 9,(4).
İmirzi Ö. H., Efe H.,(2013): Strength properties of case type furniture produced with different construction techniques and panel thicknesses. Proceedings of the XXVIth International Conference Research for Furniture Industry 2013
Kociszewski M., Gozdecki C., Wilczyński A., (2009): Effect of back wall attachment on rigidity of bookcase with joints of the confirmat type. Annals of Warsaw University of Life Science – SGGW. Forestry and Wood Technology. No 68, s. 375-379.
Lau A. S.,(2007): Green design in first-year engineering, Penn State School of Engineering Design, Technology, and Professional Programs. Int. J. Engng. Ed. 00, (0):1-11
Nicholls, T., Crisan, R., (2002): Study of the Stress-Strain State in Corner Joints and Box Type Furniture Using Finite Element Analysis (FEA). Holz als Roh-und Werkstoff, 60:66-71.
Smardzewski, J. (1998): Numerical Analysis of Furniture Constructions, Wood Science and Technology, 32 (4) : 273-286.
Tankut N. (2009): Effect of various factors on the rigidity of furniture cases. African Journal of Biotechnology, 8(20): 5265-5270.
Wilczyński A., Kociszewski M., Gozdecki C., (2010): Effect of locating pins on the rigidity of demountable bookcase with joints of the confirmat type. Annals of Warsaw University of Life Science – SGGW. Forestry and Wood Technology. No 70, s. 312-317.
Woźniak L., Ziółkowski B., Warmińska A., Dziedzic S. (2008): Przewodnik ekoinnowacji, diagnoza trendów i dobre praktyki. Politechnika Rzeszowska Rzeszów Opracowano na zlecenie Ministerstwa Gospodarki.

Streszczenie: *Badania konstrukcji mebli wykonanych z poużytkowego kartonu*. Celem badania było określenie możliwości wykorzystania poużytkowego kartonu jako materiału do wytwarzania mebli. Do wykonania mebla użyto odpadowe kartony oraz rolki po folia spożywczej. Wycięte z kartonu elementy mebla zostały połączone ze sobą za pomocą kleju. Badano wytrzymałość elementów poziomych i sztywności mebla w trzech wariantach obciążenia. Stwierdzono, że poużytkowe kartony mogą zostać efektywnie wykorzystane do wytwarzania mebli a istotny wpływ na odkształcenie i sztywność takich mebli ma obciążenie użytkowe elementów poziomych.

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