

## **An impact of fiberglass fabric reinforcement on shelves made from particleboard**

ANNA SZYMSKA, PIOTR BEER

Department of Technology and Entrepreneurship in Wood Industry, Institute of Wood Sciences and Furniture,  
Warsaw University of Life Sciences - SGGW, Poland

**Abstract:** *An impact of fiberglass fabric reinforcement on shelves made from particleboard.* The research used two variants of shelves reinforcement: reinforcement by gluing fibreglass cloth on particleboard and reinforcement by gluing pre-tensioned fibreglass cloth. The results obtained for reinforced shelves were compared to the results obtained for non-reinforced shelves. The characteristics of particleboard and existing on the global market ways to reinforce furniture shelves are presented in the initial chapters. Further chapters contain the methodology and the results of fatigue tests, shelf stiffness tests and modulus of elasticity tests. Based on the test results, it was found that the cloth reinforcement of particleboard furniture shelves using fiberglass with and without pre-tension results in the strength of the shelves by 15–40%. Also, reinforced shelves deflect less than the shelves made of unreinforced chipboard.

*Keywords:* particleboard, fibreglass, shelf, reinforcement

### **INTRODUCTION**

The most commonly used wood-based material in furniture production is the chipboard, which is made from cheap raw materials (Thoemen, Irle, Sernek 2010). Despite the fact that in furniture industry chipboards have replaced solid or glued wood do not have the same strength parameters. To make stronger chipboard that has got adequate strength, manufacturers use various methods to improve it. The ways to improve, generally speaking, mechanical properties of chipboards for example are:

- improving density,
- improving thickness,
- increasing degree of particles gluing.

Furniture shelves are often under heavy loads, even if the manufacturer does not recommend it. Therefore, it will bend to varying degrees. This is associated not only with the loss of aesthetic value, but in extreme cases also with the risk of cracking of the material from which the shelf was made. To prevent this, different solutions are used. The most popular ones include (Caspar 2019):

- adding a strip (e.g. wooden) which is thicker than shelf on the long edge,
- increasing the thickness,
- adding a vertical support in the middle of the shelf length,
- making the shelf from a material with high static bending strength,
- adding a strip of material with higher static bending strength on the long edge of the plate (without increasing its thickness),
- edge banding,
- gluing or tightening (joining with screws, nails, staples,...) the short side of the plate to the wall and/or back of the furniture.

In an attempt to increase the strength of composites, tests of sandwich panels made from wood-based phenolic impregnated laminated paper assembled with an interlocking tri-axial ribbed core were carried out (Li *at al.* 2014). Panels with fiber glass exhibited significantly increased strength and apparent MOE in edgewise compression and bending.

The aim of the study is to investigate the effect of reinforcement in the tension zone of chipboard shelves with fibreglass fabric on the amount of deflection under fatigue load. The work also aims to study the modulus of elasticity of reinforced shelves.

## MATERIALS

A raw three-layer chipboard with the following parameters was used for the investigation: thickness 18 mm, plate type P2 (PN-EN 312), emission class E1 formaldehyde, density on the product card  $650 \text{ kg/m}^3$  (<https://www.swisskrono.pl/>).

15 samples in two dimensions were used for the tests:  $800 \times 300 \times 18 \text{ mm}$  and  $1200 \times 300 \times 18 \text{ mm}$ . Plates intended for testing were divided into 3 variants:

1. raw board,
2. board reinforced with fibreglass fabric,
3. board reinforced with pre-tensioned fibreglass fabric – for the length of 1200 mm.

The density profile of the boards investigated was examined. The density profile test was performed on a GreCon device which uses x-rays for testing. Thanks to this, precise results of the density distribution for a given material can be obtained (Kozakiewicz, Kurowska, Borysiuk 2010). The density of the samples was tested every 0.02 mm. The results of the density profile tests are shown in Table 1.

Table 1. Density of samples

Type	Mean density of the board	The highest density of the board surface
	$\text{kg/m}^3$	$\text{kg/m}^3$
Raw	630	1008
Reinforced	644	2323
Reinforced pre-tensioned	642	2131

The results of the raw board density presented in the table are similar to the density value provided by the panel manufacturer (<https://www.swisskrono.pl/>). Fabric reinforced panels have a slightly higher density than the raw panel, which due to the increase in density on the reinforced surface.

For gluing fibreglass fabric on the particleboards Epidian 6011 epoxy resin was used together with IDA hardener in a ratio of 2 to 1 (by mass). Glue application was  $163 \text{ g/m}^2$ . The fibreglass fabric used for the research was in the form of plain canvas weave. The surface density of the material was  $163 \text{ g/m}^2$ .

## METHODS

A vacuum bag was used during gluing of the fibreglass with particleboards, so in order to avoid the resin being completely absorbed by the chipboard, a thin resin undercoat was previously applied to the raw board. The boards prepared in this way were covered with a 0.5 mm thick PET G layer to obtain a smooth surface and separate the laminate from the mat protecting the vacuum bag against tearing. The elements were placed in a bag in which a hose connected to the vacuum pump was inserted. After extracting air out of the bag samples were left for 24 hours to completely harden the resin (Fig. 1a). In the case of plates with tensioned fibreglass fabric profiles, the procedure of gluing glass fibre was similar to reinforced plates. The fabric was pre-tensioned (Fig. 1b) by turning a nut on a tension screw. The stretch over the length was 2.8%. After 24 hours, the samples were removed from the bag. Excess fibreglass fabric was cut off and the tape protecting narrow surfaces was torn off.

The finished boards were signed and laid down with the laminated surface down on the shelves matched to the dimensions of the boards right before loading.

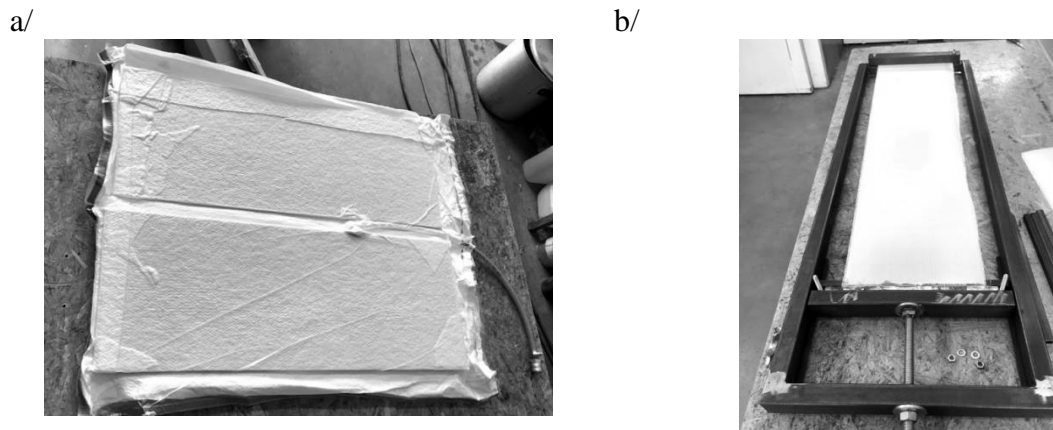


Figure 1. A – reinforced boards in a vacuum bag, B – reinforced pre-tensioned boards before gluing

To test IB for raw boards and adhesion for reinforced boards 18 samples of 50×50 mm were used, 6 samples from each type of board. The main assumption of this test was to check the weld strength between the raw board and the fibreglass fabric. The pull-off test was conducted on a DeFelsko device called PosiTest AT-A (automatic adhesion tester), in accordance with the EN ISO 4624: 2003 standard.

Strength is calculated from the formula:

$$\sigma = \frac{F}{A} \left[ \frac{N}{mm^2} \right] \quad (1)$$

were:

- $\sigma$  – strength [N/mm<sup>2</sup>],
- F – maximum pull-off force [N],
- A – surface of the contact [mm<sup>2</sup>].

The average tensile strength of the raw board was 1.41 N/mm<sup>2</sup>, the reinforced board 1.53 N/mm<sup>2</sup>, and the reinforced board under tension 1.45 N/mm<sup>2</sup>.

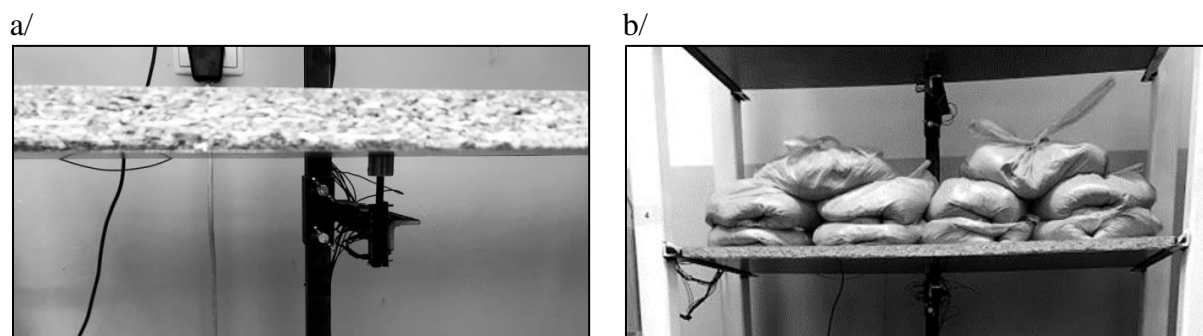


Figure 2. A – a sensor placed in the middle of the length of a plate, B – stand during test

The fatigue tests were carried out on three boards 800 and 1200 mm long, raw, reinforced and reinforced under tension. The main assumption of this study was to examine the deflection in the middle of shelves length. Sensors from Variohm EuroSensor (Fig. 2) were used for this purpose, that tested the deflection with an accuracy of 0.5 mm. They were mounted in specially prepared places under the shelves. Special metal discs were attached to

the shelves, which prevented the sensors from bending sideways, which could cause erroneous measurements. The first reading was made just after the load was placed. Then the results of the measurements were register automatically every 6 hours.

To reflect the natural load on furniture shelves, such as those found in bookcases, a uniform load has been applied over the entire length of the board. For this purpose, bags made of strong foil were filled with 3 kg of sand and securely tied in order to prevent any moisture from evaporating, which could cause weight loss. 10 bags were placed on each shelf, giving a total load of 30 kg per sample (for 800 mm - 0,24 kg/m<sup>2</sup> and for 1200 mm – 0,36 kg/m<sup>2</sup>). This value was assumed based on the data available in the technical card (maximum load for the shelves 800 mm long) of one of the furniture concerns. In tests, both 800 mm long and 1200 mm long shelves were loaded in the same way. Samples were left for 80 days. During this time, deflection measurements were taken 4 times a day.

The stiffness coefficient of single shelf was calculated using the following formula (Swaczyna, Świetliczny 1983):

$$k = \frac{P}{\Delta l} \left[ \frac{N}{mm} \right] \quad (2)$$

were:

k – stiffness coefficient [N/mm],

P – load [N],

Δl – deflection [mm].

The same samples were used for the testing of the modulus of elasticity as for the fatigue test. Each sample was cut in half lengthwise. 30 samples were prepared this way, 6 of each type. The main assumption of this study was to compare the modulus of elasticity of the raw plate to the modulus of elasticity of the plate glued with fibreglass fabric and the plate glued with pre-stressed fibreglass fabric. The test was carried out in accordance with the EN 408: 2003 standard. the tests were carried out on a testing machine TIRATEST 2300. Diagrams of placing shelves are presented in Figure 3a and Figure 3b.

The modulus of elasticity was calculated using the formula below:

$$E = \frac{l^3(F_2 - F_1)}{bh^3(w_2 - w_1)} \left[ \left( \frac{3a}{4l} \right) - \left( \frac{a}{l} \right)^3 \right] \left[ \frac{N}{mm^2} \right] \quad (3)$$

were:

E – modulus of elasticity [N/mm<sup>2</sup>],

L – distance between support centres [mm],

F<sub>1</sub>, F<sub>2</sub> – increase in load on the straight-line section of the load-deformation curve; F<sub>1</sub> – 10% of the load, F<sub>2</sub> – of the load [N],

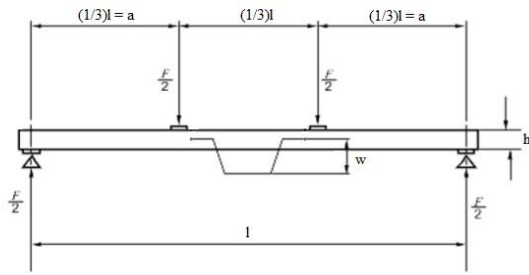
w<sub>1</sub>, w<sub>2</sub> – increase of the deflection arrow measured in the middle of the sample length [mm], (w<sub>1</sub>, w<sub>2</sub> correspond to F<sub>1</sub> and F<sub>2</sub>),

b – plate width [mm],

h – board thickness [mm],

a – distance between the point of application of force and the nearest support [mm].

a/



b/

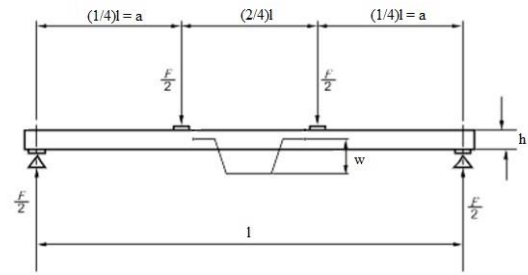


Figure 3. A diagram of shelf setting (a – 800 mm plate and b – 1200 mm plate) for testing of the modulus of elasticity

## RESULTS

Figure 4 summarizes the results of fatigue tests. Reinforcing the bottom surface of raw particleboards with fibreglass fabric contributed to a reduction in deflection of the 800 mm reinforced shelves by an average of 5 mm compared to the non-reinforced shelves. Pre-tensioning of the fibreglass fabric resulted in a 13 mm reduction in shelf deflection compared to that in the unreinforced shelves. Reinforced with pre-tensioned fibreglass fabric reduced the deflection by 6mm compared to the non-pre-tensioned fabric.

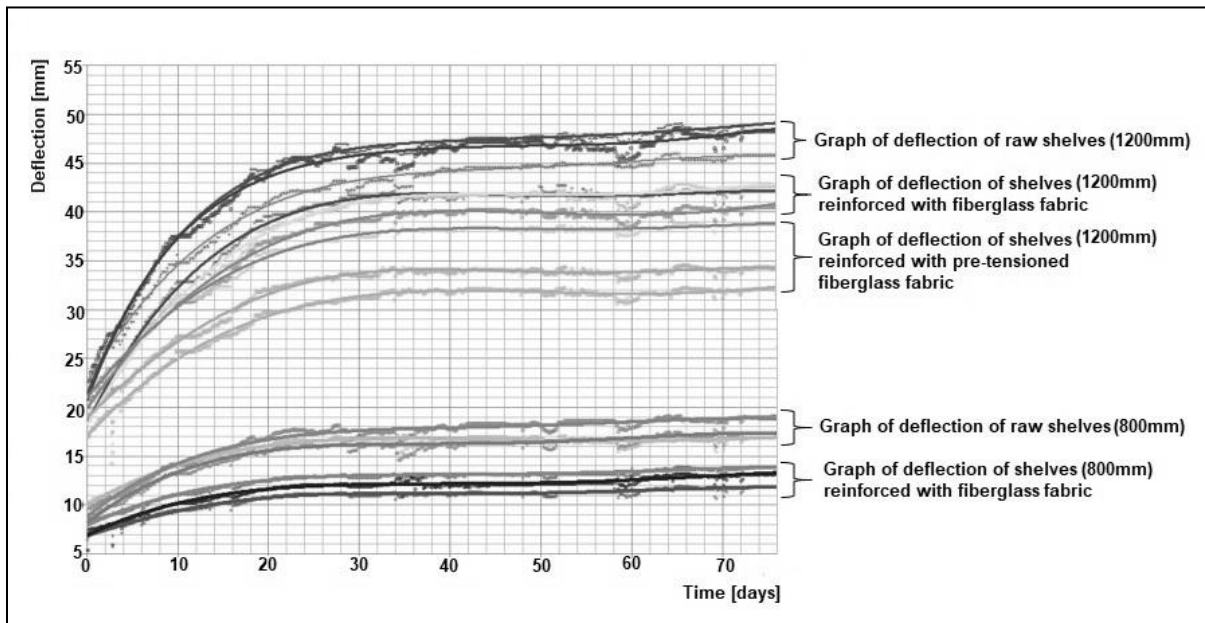


Figure 4. Deflection over time of 800 and 1200 mm shelves

Reinforcing the 800 mm long shelves with fibreglass fabric reduced the shelf deflection by approximately 30%. Reinforcing the 1200 mm long shelves with fibreglass fabric resulted in a reduction of shelf deflection by approximately 10%. Reinforcing the 1200 mm long shelves with fibreglass fabric with pre-tension reduced the shelf deflection by approximately 25%.

The increase in shelf length resulted in the stiffness of the shelves is presented in the Figure 5.

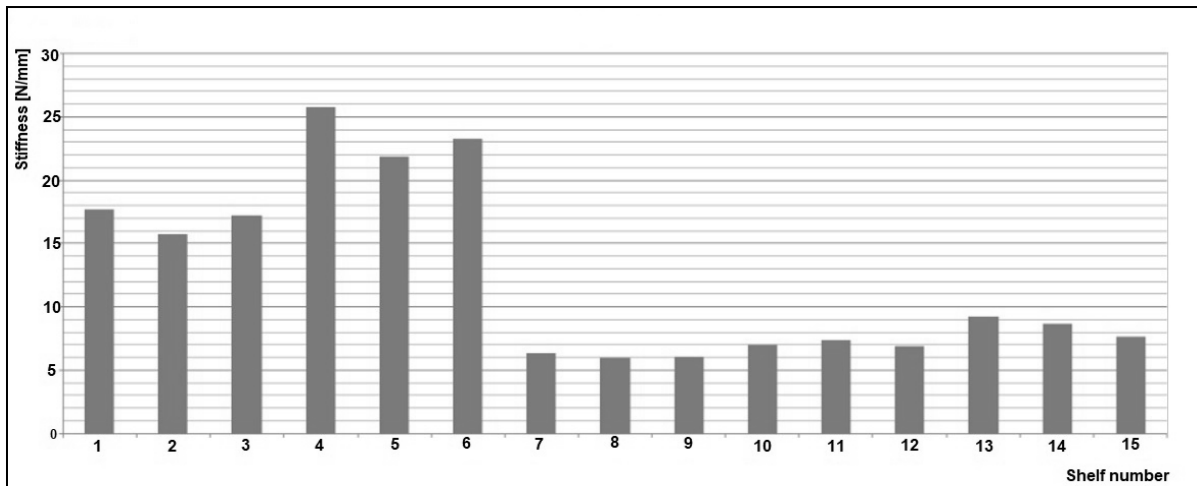


Figure 5. Boards stiffness. 800 mm: 1 – 3 raw and 4 – 6 reinforced; 1200 mm: 7 – 9 raw, 10 – 12 reinforced and 13–15 reinforced with pre-tension

The average rigidity of raw shelves with a length of 1200 mm (7.3 N/mm) is almost three times lower than the average rigidity of shelves with a length of 800 mm (20.3 N/mm). The highest stiffness was achieved with 800 mm long shelves reinforced with fibreglass fabric, and the smallest with 1200 mm long shelves made of raw chipboard. Pre-loading of fibreglass slightly increases the stiffness of the shelves compared to non-pre-load fibreglass fabric.

Reinforcing the 800 mm shelves with fibreglass fabric increased their stiffness by 40%. Reinforcing the 1200 mm shelves with fibreglass fabric increased their stiffness by 15%, while the stiffness of the shelves with pre-tensioned fabric reinforcement increased by 40%, compared to the raw particleboard of the same length.

Figure 6 presents the average test results of the modulus of elasticity of shelves made of raw chipboard and boards reinforced with fibreglass fabric and pre-tensioned fibreglass fabric.

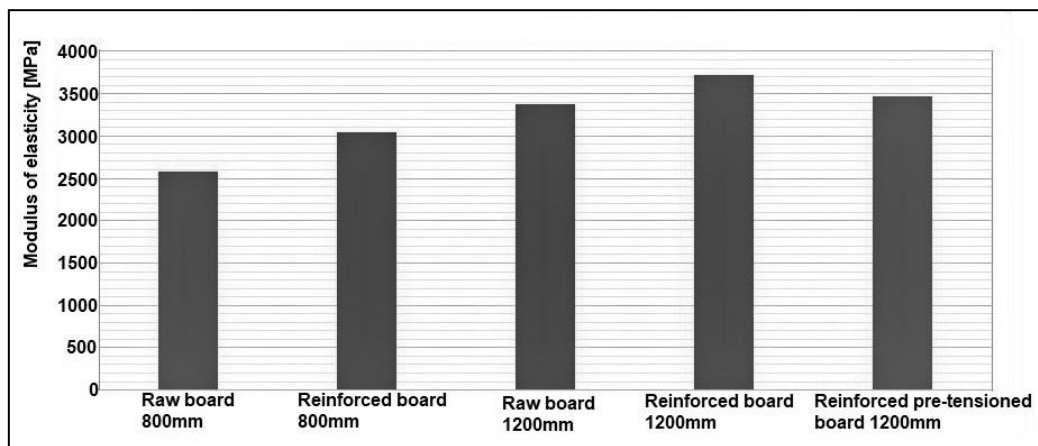


Figure 6. Average values of modulus of elasticity

The greatest modulus of elasticity for the tested samples was achieved by a 1200 mm long board reinforced with fibreglass fabric – 3719 N/mm<sup>2</sup>. Slightly lower results were obtained for the other boards of the same length: for the raw board – 3378 N/mm<sup>2</sup>, and for panel reinforced with pre-tensioned fabric – 3475 N/mm<sup>2</sup>. A board of this length reinforced with fibreglass fabric achieved a score of 3048 N/mm<sup>2</sup>, and a raw board of 2582 N/mm<sup>2</sup>. The general difference of values of the modulus of elasticity for 800 mm long boards is almost 700 N/mm<sup>2</sup>, compared to those of 1200 mm.

The modulus of elasticity of the fibreglass fabric-reinforced shelves is higher than of the raw shelves: 18% for 800 mm and 11% for 1200 mm boards.

## CONCLUSIONS

1. Both 800 mm and 1200 mm shelves reinforced with fibreglass fabric showed less deflection than the unreinforced shelves.
2. Reinforcing the 800 and 1200 mm shelves with fibreglass fabric increased their stiffness.
3. The modulus of elasticity of the fibreglass fabric-reinforced shelves is higher than of the raw shelves.
4. Due to obtaining positive results, further research on the reinforcing of furniture shelves should be focused on optimizing the degree of tension of fibreglass fabric for a given thickness and length of the board.

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**Streszczenie:** *Wpływ wzmocnienia tkaniną z włókna szklanego na półki z płyty wiórowej.* W badaniach wykorzystano dwa warianty wzmocnienia półek: wzmocnienie poprzez podklejenie płyty wiórowej tkaniną z włókna szklanego oraz wzmocnienie poprzez podklejenie płyty wstępnie naprężoną tkaniną z włókna szklanego. Wyniki uzyskane dla półek wzmocnionych zostały porównane do wyników uzyskanych dla półek niewzmocnionych. W początkowych rozdziałach pracy przybliżono charakterystykę płyt wiórowych oraz istniejących na rynku sposobów na wzmacnianie półek meblowych. Dalsze rozdziały zawierają metodykę oraz wyniki badań takich jak badania zmęczeniowe, sztywność półek oraz badanie modułu sprężystości. Na podstawie przeprowadzonych badań stwierdzono, że wzmocnienie półek meblarskich wykonanych z płyty wiórowej tkaniną z włókna szklanego, bez i ze wstępnym naprężeniem, skutkuje wzmocnieniem płyt w granicach 15-40%. Również półki wzmocnione ulegają ugięciu w mniejszym stopniu niż półki z płyty wiórowej niewzmocnionej.

Corresponding author:

Piotr Beer  
Institute of Wood Sciences and Furniture  
Warsaw University of Life Sciences - SGGW  
Nowoursynowska Str. 159  
02-787 Warszawa, Poland  
w-mail: piotr\_beer@sggw.edu.pl  
phone: +48 22 59 38 526