Polish Society of Composite Materials
Polskie Towarzystwo Materiałów Kompozytowych

17: 3 (2017) 126-130

COMPOSITES THEORY AND PRACTICE

Rico Blei[1], Rafal Stanik[1]*, Maik Gude[1], Andrzej Czulak[2]

[1] Institute of Lightweight Engineering and Polymer Technology, Technische Universität Dresden, Holbeinstr. 3, 01307 Dresden, Germany
[2] New Era Materials Sp. z o.o., ul. Komandosów 1/7, 32-085 Modlniczka, Poland
**Corresponding author. E-mail: rafal.stanik@tu-dresden.de*

Received (Otrzymano) 14.06.2017

CHARACTERIZATION OF BALSA SANDWICH STRUCTURES WITH FIBER REINFORCED EPOXY FACE SHEETS

The aim of this study was to examine the effect of different material combinations and process parameters on the material characteristics of sandwich structures. Therefore, the material properties of sandwich structures made from woven fabrics (glass/ flax fibers) and powder epoxy resin as well as balsa cores were investigated. These material combinations are highly interesting for customized lightweight constructions as they bear the potential to construct three-dimensional free shape structures. The structural set-up observed during this study consists of balsa wood which is covered with two outer layers of fiber reinforced epoxy resin. In order to compare the effects of these outer layers on the material behavior, specimens with woven fabrics made out of glass and flax fibers were manufactured. During a hot pressing process, the fiber bed was infiltrated with powder epoxy resin while being pressed to the balsa core. To determine the material characteristics of the manufactured composite, mechanical tests such as 4-point-bending (DIN 51227) and peel tests (DIN EN 1464) were executed. Further investigations consisted of microscopic analyses to ensure quality control of the specimens. Additionally, the degree of wood penetration was examined during this screening process. It was revealed that the specimens with glass face sheets yielded a higher flexural strength (average: 19.54 MPa) and modulus (1815.12 MPa) than the flax specimens (strength: 16.14 MPa; modulus: 1353.83 MPa). Furthermore, the average peel resistance of the glass specimens (1.54 N/mm) was slightly higher than the average value of the flax fabric specimens (1.38 N/mm). Concerning the infiltration behavior, greater penetration of the balsa core was noted when using glass face sheets.

Keywords: **glass epoxy composite, flax epoxy composite, woven fabrics, powder processing, balsa sandwich structure, material characterization**

CHARAKTERYSTYKA STRUKTUR TYPU SANDWICH Z RDZENIEM Z BALSY ORAZ OKŁADZINAMI Z KOMPOZYTU WŁÓKNISTO-EPOKSYDOWEGO

Celem pracy było zbadanie wpływu różnych kombinacji materiałów i parametrów procesu wytwarzania na własności wytrzymałościowe struktur warstwowych. W związku z tym zbadano właściwości struktur warstwowych wykonanych z tkanin (włókien szklanych/ lnianych), sproszkowanej żywicy epoksydowej oraz drewnianego rdzenia z balsy. Dzięki możliwości trójwymiarowego kształtowania kombinacja tych materiałów posiada bardzo duży potencjał w indywidualnych, lekkich konstrukcjach. Badany kompozyt wielowarstwowy składa się z rdzenia z balsy, pokrytego dwiema okładzinami zewnętrznymi, składającymi sie z żywicy epoksydowej wzmocnionej włóknami. W celu porównania wpływu tych zewnętrznych warstw na zachowanie materiału wytworzono próbki z wzmocnieniami z tkaniny z włókna szklanego oraz lnianego. W procesie prasowania tkanina została przesycona żywicą podczas jednoczesnego dociskania i połączenia z rdzeniem z balsy. W celu wyznaczenia własności materiałowych wytworzonego kompozytu wykonano testy mechaniczne, takie jak czteropunktowe zginanie (DIN 51227) i próby odrywania (DIN EN 1464). Dalsze badania obejmowały analizę mikroskopową w celu kontroli jakości próbek. Ponadto przeprowadzono analizę wpływu rodzaju materiału wzmocnienia na stopień penetracji drewna. Przeprowadzone badania wykazały, że próbki z okładzinami szklano-epoksydowymi posiadają wyższą wytrzymałość na zginanie (średnio 19.54 MPa) i moduł (1815.12 MPa) niż próbki zawierające wzmocnienie w włókna lnianego (wytrzymałość: 16.14 MPa, moduł: 1353.83 MPa). Ponadto średnia odporność na odrywanie okładzin zawierających wzmocnienie szklane (1.54 N/mm) była nieco większa niż średnia wartość próbek z wzmocnieniem lnianym (1.38 N/mm). Analiza mikroskopowa wykazała, iż zastosowanie wzmocnienia z włókna szklanego umożliwia uzyskanie wyższych głębokości penetracji rdzenia z balsy.

Słowa kluczowe: **laminaty szklano-epoksydowe, laminaty lniano-epoksydowe, tkanina, struktura typu sandwich, charakterystyka materiału**

INTRODUCTION

Lightweight constructions are exceedingly appreciated because of their reduced material weight and lower moments of inertia, especially in such fields as transportation technology, the sports equipment industry, wind power plant technology and special purpose machines industry. In this context, fiber reinforced composites are increasingly used to build highly stressed components and structures [1].

By using fiber reinforced composites, the high specific stiffness and strength of structures can be realized. Not only the geometry of the design, but also the variables of the material itself influence the performance of the lightweight structure. Therefore, these materials offer the possibility to design load-adapted constructions [2-4].

Especially sandwich structures offer the opportunity to achieve high specific stiffness and strength while maintaining low mass of constructions [5]. Usually two thin surface layers made of high performance materials (e.g. fiber reinforced thermosets) are applied to a thicker core (e.g. balsa) characterized by a low density and sufficient shear strength. Hence, by using sandwich constructions, high bending stiffnesses and low grammage can be combined. By using balsa as the core material and two translucent surface layers, manufactured sandwich structures are well appreciated in the furniture industry in the field of transport. Thus, they can be found as components of interior design in caravans, yachts, rail vehicles and aircraft. Balsa wood and flax fibers are natural materials and are therefore renewable. This is especially important in times of dwindling resources and increasing ecological awareness [6, 7].

With the introduction of the new material system A.S.SET POWDER, it is possible to process thermosetting matrices similar to those with thermoplastic characteristics. A great benefit of this epoxy-based material is that relatively short processing times are feasible. Thus, the benefits of both material groups are combined and can be made use of during manufacturing processes. By using the powder as matrix material for face sheets, these material based advantages can be combined with well-developed lightweight construction methods such as balsa sandwich structures. Therefore the main criteria for applications in the fields of interest (as stated above) can be fulfilled:

- low density of composite yields lightweight structure,
- natural character (balsa core),
- robust surfaces (fiber reinforced A.S.SET POWDER),
- possibility to apply 3D-shaping,
- feasibility of small- and middle-scale production [8].

The main goal of this study was to investigate the effects of processing parameters on the material behavior of sandwich structures and thus, to be able to make recommendations for the manufacturing process. By analyzing the gathered data, the whole process can be predicted. Thus, the main goal, to automate composite manufacturing processes and hereby allow the production of large quantities in an economical way, can be achieved [9, 10].

MATERIALS AND MANUFACTURING

To manufacture different specimens of sandwich plates, the following components were used in this study:

- epoxy powder resin A.S.SET POWDER 1010 (New Era Materials Ltd.),
- woven fabrics, glass (twill 2/2; 280 g/m^2; Panda^{TM}, R&G Faserverbundwerkstoffe GmbH),
- woven fabrics, flax (twill; 2/2; 315 g/m^2; Sicomin Epoxy Systems),
- balsa wood (adhesive-bonded, compressed elements, 125 kg/m^3).

Balsa wood

The core consists of adhesive-bonded compressed balsa wood elements which have been cut into a 20 mm thick plate with an angle of 90° to the longitudinal axis and thus 90° to the fiber direction. In this context, wood deformation is the main prerequisite to generate moldable end grain boards [11]. Non-cutting deformation of solid wood is almost impossible due to its low plasticity. The necessary material characteristics with a fracture strain of up to 50% were realized by thermomechanic densification. Subsequently, wood can be integrated as a visco-elastic polymer into a controllable deformation process. Here, several conditions of the process such as deformation degree, stress distribution, load application, shape geometry, size of the specimen and material characteristics have an immense impact on the deformation result. Compression was realized during a hot pressing process in an open mold system under temperatures from 90 to 140°C and moisture contents in the wood from 6 to 14%. During the densification process in a conventional hot press, the subsequent three process steps were carried out:

1. heating of the wood
2. application of pressure
3. conditioning and re-cooling

Usually, conventional hot presses with force and path control are used, with the help of which the final product characteristics can be influenced depending on the material and process parameters. According to the initial material, desired degree of densification, applied compression process and chosen process parameters, densification was carried out biaxially using a pressure of 3 MPa. Biaxial densification transverse to the fiber starts with buckling of the cell walls until the cell lumen are partly or entirely closed in the earlywood and latewood [12]. During load removal, time-dependent springback of the densified material occurs. Further descriptions as well as the suitability of softwood for densification have been documented by Liu et al., Haller et al., Navi et al., Sandberg et al. [13-16].

After the specimens were densified, they were planed, glued and cut into plates using a blocking procedure (Fig. 1). Here one-component PUR-resin was used and the pressure of 0.5 MPa was applied to the structure. Thus, specimens with moisture contents of approximately 8% and degree of densification of 60% were prepared.

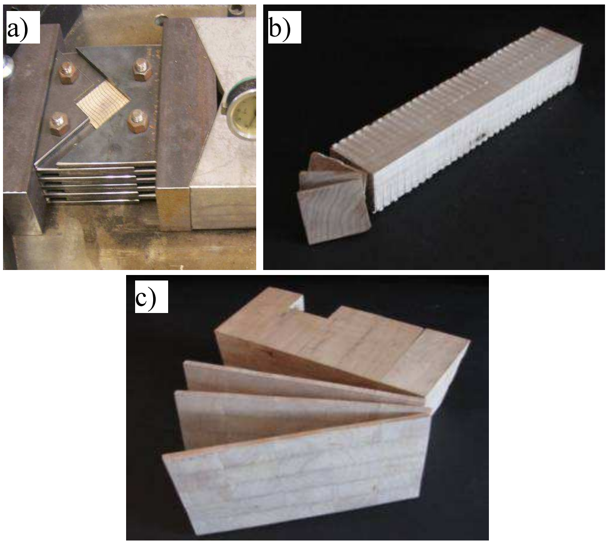

Fig. 1. Production process for end grain boards: a) densification device, b) densified squared timber, c) glued block and sliced end grain board

Rys. 1. Proces zagęszczania płyt drewnianych o prostopadłym kierunku włókien: a) urządzenie do zagęszczania; b) zagęszczony pojedynczy segment drewna; c) sklejony z pojedynczych segmentów blok oraz pocięte płyty

Sandwich structure

Together with the matrix material (A.S.SET POWDER 1010) and woven fabrics (glass, flax), the prepared balsa specimens were used to manufacture sandwich structures (Fig. 2).

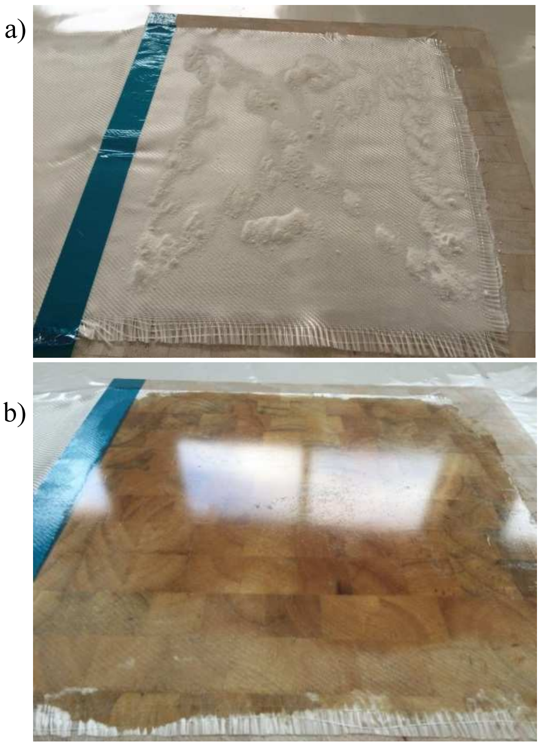

Fig. 2. Balsa core with glass fabric and powder resin (a) and finished composite structure (b)

Rys. 2. Proces wytwarzania laminatów warstwowych: a) warstwa wzmocnienia wraz z rozprowadzoną sproszkowaną żywicą epoksydową, b) gotowy kompozyt po procesie prasowania

Resin Powder Molding, which is a technology based on A.S.SET 1010, was used to join the outer layers and core components. Firstly, a layer stack was prepared. For this purpose, the balsa wood core and the fabrics were cut to a size of 500 mm × 500 mm. The sandwich structure consisted of one layer of fabric per core side surrounded by two layers of A.S.SET 1010 resin. The powder was applied by using a screen and a scraper. Thus, the fiber content of the cover layers was about 50 wt.%.

Afterwards, the sandwich structures were consolidated in a mold under pressure and temperature using a hydraulic press Rucks KV284. The Resin Powder Molding parameters were chosen on the basis of previous works (T = 120°C, t = 8 min, P = 0.25 MPa) [5]. Further details of the samples are listed in Table 1.

TABLE 1. **Sandwich samples**
TABELA 1. **Badane próbki**

Sample [01…03]	Type of fiber	Thickness [mm]	Amount of resin [g]	4-point-bending test	Peel test
G_A_b_...	glass	21.2	400	X	
G_A_p_...	glass	21.2	400		X
F_A_b_...	flax	21.9	600	X	
F_A_p_...	flax	21.9	600		X

MICROSCOPIC ANALYSIS TO INVESTIGATE CORE PENETRATION

In order to determine the material parameters of the manufactured specimens, several tests were performed. The microstructure of the sandwich structures was examined with a light microscope AxioTech 100HD. Samples were cut from the manufactured plates, which were polished afterwards. By inspecting the microstructure of the composite, information about bonding of the outer layers to the core material as well as the influence of the pressing parameters on the microstructure of the composite and the balsa core were obtained.

In order to determine the quality of fiber infiltration with the matrix material, microscopic images as depicted in Figures 3 and 4, had to be analyzed.

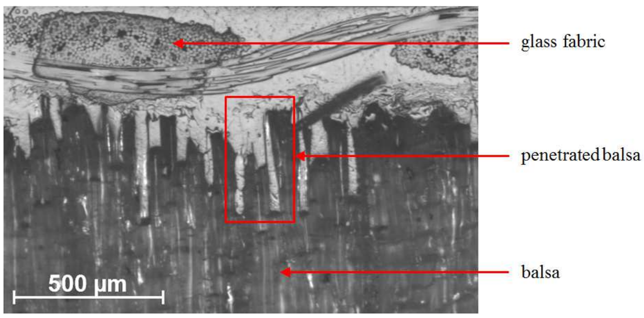

Fig. 3. Microscopic image of glass-balsa sandwich

Rys. 3. Mikrostruktura kompozytu typu sandwich z okładzinami z włókna szklanego

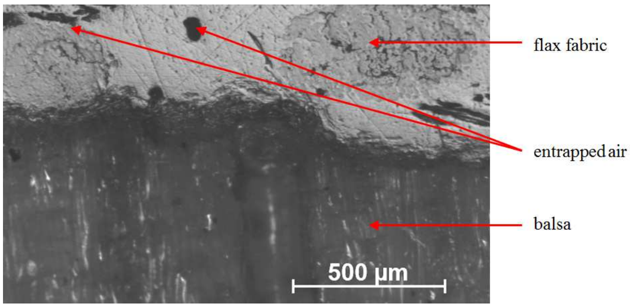

Fig. 4. Microscopic image of flax-balsa sandwich

Rys. 4. Mikrostruktura kompozytu typu sandwich z okładzinami z włókna lnianego

During the microscopic analysis, satisfactory infiltration of the fiber face sheets was determined. However, some areas of entrapped air were detected during investigation of the flax specimens. Furthermore, penetration of the balsa cores by the resin is much deeper in the samples with glass fiber face sheets. It can be seen that the penetration depth is very small and varies throughout the whole structure. Both phenomena can be explained by the irregular structure of natural materials [17]. Natural fibers, such as flax, are characterized by their ability to absorb a high level of moisture. Therefore a certain amount of resin is necessary not only to infiltrate the fiber bed, but also to penetrate the filament bundles. This is the reason why more resin was used during the manufacturing of the flax sandwich structures than when processing the glass specimens. However, the fast curing resin system was still not able to reach each non-infiltrated area, which resulted in the mentioned air entrapments.

MECHANICAL CHARACTERIZATION

4-point-bending tests

4-point-bending tests were carried out according to DIN 51227 on a Zwick 1465. Samples (54 mm x 500 mm) were cut, then placed on two bending table supports 420 mm apart and with 210 mm between the bending punch rolls. The bending tests were performed at room temperature (23°C) with a traverse velocity of 10 mm/min. Deflection of the samples was measured by the optical system ARAMIS.

In Figure 5, two samples after these bending tests are depicted. In Table 2, the compiled results of the bending tests are listed.

The obtained results confirm the significant influence of the face sheet material on the mechanical properties of the sandwich structure. In this context, glass fibers with higher bending stiffnesses than flax fibers, have a direct effect on the bending behavior of the corresponding sandwich structures. Considering the fact that in the case of natural materials there is no guarantee of 100% homogeneity of the mechanical properties in the entire material, very low scattering of the results of individual sample types can be seen. The distribution of the flexural strength of the samples with the glass fiber covering layer is about 0.38 %. In comparison, the scattering of the flexural strength of the structures with the flax fiber covering layer is only 0.27%. A significant difference can be seen in the failure behavior of the structures. Upon examining the samples with glass fibers, failure of the upper cover layer can be seen. Since the top layer is basically subjected to compression, the glass fiber layer is fractured in the middle of the sample at one point. In the structure with flax fibers on the other hand, the bottom cover layer failed. In this case, the flax fiber layer was subjected to tensile stress and cracked in two places (Fig. 5).

Fig. 5. Sandwich structure samples after 4-point bending test with flax (top) and glass face sheets (bottom)

Fig. 5. Próbki kompozytów typu sandwich z wzmocnieniem z włókna szklanego oraz lnianego po zginaniu czteropunktowym

TABLE 2. **Results of 4-point-bending tests**

TABELA 2. **Wytrzymałość na zginanie wyznaczona w systemie czteropunktowym**

Sample	Flexural strength [MPa]	Flexural modulus [MPa]	Maximum force [kN]	Maximum deflection [mm]
G_A_b_01	19.35	1796.79	1497.08	17.99
G_A_b_02	20.60	1872.67	1589.74	15.80
G_A_b_03	18.67	1775.90	1508.02	14.65
Average	19.54	1815.12	1531.61	16.15
Standard Deviation	0.98	50.92	50.64	1.69
F_A_b_01	16.44	1383.15	1343.18	26.89
F_A_b_02	15.11	1274.39	1238.48	26.11
F_A_b_03	16.87	1403.96	1356.57	25.63
Average	16.14	1353.83	1312.74	26.21
Standard Deviation	0.92	69.58	64.66	0.64

Roll peel tests

In order to estimate the adhesive strength of the outer layers on the balsa core, roll peel tests according to DIN EN 1464 were executed. The average peel resistance is determined in N/mm of the sample width, which must be applied in order to separate the joining parts from each other. In order to prepare the starting points for the peeling process, the sandwich specimens were manufactured with 100 mm surplus of fabric, which was subsequently fixed as a flexible joining part in the clamping device of the tensile testing machine. Thus, specimens with a width of 25 mm and a length of 250 mm were mounted in the device. The tests were carried out at the feed rate of 100 mm/min. During the experiment, the applied force and the peeling distance were recorded by measuring instruments. According to DIN EN 1464, peeling of the flexible joining part has to be recorded on a minimum distance of 115 mm. Thus, all the performed tests were aborted at a maximum distance of 150 mm.

During the peel tests of the specimens with flax fabrics, the face sheets of several samples were torn off of the core before the minimum recording distance was reached. Thus, most of the results were not suitable for further evaluation steps. It was noticed that the adhesion of the face sheets to the balsa core of these specimens was too strong in comparison to the strength of the composite itself. The results that could be used yielded an average peel resistance of 1.38 N/mm which was slightly lower than the average value of the glass fabric specimens (1.54 N/mm). Consequently the adhesive bonding of the glass sheets to the balsa core was higher than the bonding of the compared flax samples. These results confirm the findings of the examined microscopic images.

CONCLUSIONS

In this study a test plan was developed to determine the material characteristics of balsa sandwich structures with fiber reinforced epoxy face sheets. In order to prepare the required specimens, glass and flax fabrics in combination with A.S.SET POWDER were attached to balsa cores during a hot pressing process. Specimens produced with glass and flax face sheets were examined during several experiments which included mechanical tests such as 4-point-bending tests according to DIN 51227 and roll peel tests according to DIN EN 1464. Furthermore, the quality of the manufactured samples was investigated during microscopic analyses. During the examination of several images, it became obvious that the infiltration processes of the samples with glass fabric face sheets were more successful than those of the flax specimens. This can be explained by the irregular structure of natural materials. Mechanical tests yielded higher flexural strengths of the glass sandwich structures. Furthermore, the specimens with glass face sheets yielded slightly higher peel resistances than those manufactured with flax fibers.

By evaluating the gathered data, several conclusions can be drawn. First, the usage of different kinds of fibers in face sheets has a significant effect on the infiltration process of the fiber bed. In this context, glass filaments have certain advantages compared to natural filaments such as flax. Second, the mechanical properties of the face sheet materials have a direct effect on the characteristics of the sandwich structures. In this context, the usage of fibers with higher bending stiffnesses results in advanced bending resistance of the whole composite.

Further investigations should include the effect of different process parameters on the characteristics of sandwich structures. Investigating the consequences of various temperatures and pressures on the mechanical behavior of specimens is recommended. In this context, the resulting quality of the bonding between the face sheets and the core after varying the process parameters should be examined.

REFERENCES

[1] Hufenbach W., Helms O., Leitfaden zum methodischen Konstruieren mit Faser-Kunststoff-Verbunden, Leichtbau-Zentrum Sachsen GmbH 2010.

[2] Degischer H., Lüftl S., Leichtbau: Prinzipien, Werkstoffauswahl und Fertigungsvarianten, WILEY-VCH Verlag GmbH & Co. KGaA, 2009.

[3] Schürmann H., Konstruieren mit Faser-Kunststoff-Verbunden, Springer-Verlag, 2007.

[4] Michaeli W., Wegener M., Einführung in die Technologie der Faserverbundwerkstoffe, Carl Hanser Verlag, 1989.

[5] Sun Z., Li D., Zhang W., Guo X., Topological optimization of biomimetic sandwich structures with hybrid core and CFRP face sheets, Composites Science and Technology 2017.

[6] Wiedemann J., Leichtbau - Elemente und Konstruktion, 3rd edition, Springer-Verlag, 2007.

[7] Klein B., Leichtbau-Konstruktion, 8th edition, Vieweg Verlag 2009.

[8] Hufenbach W., Gude M., Czulak A., Pilawka R., Gajda T., B. Przybyszewski, Application of novel A.S.SET epoxy resin in batch manufacturing process of CFRP, Composites 2014, Theory and Practice, The 18th Symposium (23-25.04.2014).

[9] Bach M.R., Chalivendra V., Alves C., Depina E., Mechanical characterization of natural biodegradable sandwich materials, Journal of Sandwich Structures and Materials 2015.

[10] Blei R., Möbius T., Pérez C., Osswald T.A., Modler N., Influence of selected process parameters on changes of the fiber orientation in unidirectional reinforced thermoplastics during a hot pressing process, Polymer Composites 2016.

[11] Wehsener J., Weser T., Haller P., Diestel O., Cherif C., Textile reinforcement of multidimensional formable wood, Eur. J. Wood. Prod. 2014, 72(4), 463-475.

[12] Nairn J.A., Numerical simulations of transverse compression and densification in wood, Wood and Fiber Science: Journal of the Society of Wood Science and Technology 2006, 38(4).

[13] Liu Y., Norimoto M., Morooka T., The large compressive deformation of wood in the transverse direction (I), Mokuzai Gakkaishi 1993, 39, 867-874.

[14] Haller P., Wehsener J., Festigkeitsuntersuchungen an Fichtenpressholz (FPH), Holz als Roh- und Werkstoff 2004, 62, 452-454.

[15] Navi P., Sandberg D., Thermo-Hygro-Mechanical Processing of Wood, EPFL Press 2012.

[16] Sandberg D., Haller P., Navi P., Thermo-hygro and thermo-hygro-mechanical wood processing: An opportunity for future environmentally friendly wood products, Wood Mat. Sci. Eng. 2012, 8, 64-88.

[17] Przybyszewski B., Czulak A., Gude M., Lewandowska M., Broda P., Effect of pressing parameters and chemical modifications of flax fabrics on microstructure and mechanical properties of natural fiber-reinforced composites, 18th International Conference on Composite Structures (15-18 June 2015).

