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The plasticity of composite material based on winter rapeseed as a function of selected factors

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ABSTRACT

The development of new composite materials using alternative sources of raw materials is of great importance nowadays due to the lack of raw wood material and the economic development of the market. The main objective of this article is to determine selected mechanical properties of new composite materials based on cellulose and lignin. We focused on the mechanical properties measured in the plastic range during the bending of composite materials. We monitored the effect of factors such as the method of modification (raw, boiled in water and soaked in a lye bath), and the effect of the adhesive used to bind components (polyester powder and urea formaldehyde). The monitored characteristics were the bending strength **"MOR"**, plastic potential **"Pp"** and the moduli of plasticity $\mathbf{CH_M}$, $\mathbf{E_E}$, $\mathbf{E_{MV}}$ and $\mathbf{E_P}$. The results constitute an important basis that is inevitably necessary in the production of new types of materials with specific properties for their intended use. The output of this article forms a part of a project whose goal is to create a mathematical model that will enable us to anticipate changes in the monitored characteristics, with regard to the required modifications.

1. Introduction

Composite materials can generally be defined as a combination of two or more materials that differ in size or composition on a macroscale. The components in them retain their identity, although they appear to be in synergy (synergistic effect). Each component can be physically identified, and there is a boundary between it and other components [1]. In the wood industry, composite materials predominantly contain either wood elements or wood fibers. A natural or synthetic adhesive is used to bond these elements [2].

Today, there is an effort to develop new composite materials using alternative sources. The main reason for this trend is population growth, which is closely linked to a scarcity of natural resources [3]. Agricultural waste is an excellent alternative material to replace wood components in composite materials, because it is inexpensive, easy to process and there is a lot of it [4,5]. Natural fibers have many remarkable advantages over synthetic fibers. Today, we are familiar with different kinds of natural fibers [6]: flax, hemp, jute straw, wood, rice bran, wheat, barley, oats, rye, sugar cane, grass, reed, kenaf, ramie, coconut fiber, water hyacinth, silk paper, banana fiber, pineapple fiber, papyrus, and rapeseed have been examined for utilization in composite materials [7]. Rapeseed (*Brassica napus L.*) currently has a strong position in both Czech and European agriculture as a result of its extensive use, with markedly increasing non-food utilization. Rapeseed is primarily used to produce fat. From the global production (about 50 million tons) of seeds, about 19 million tons of fat is extracted, of which 13–14 million tons of oil goes to the food industry. Therefore, the remaining 5–6 million tons are primarily used for biofuels. This non-food utilization of rapeseed is almost exclusively tied to EU27 [8].

In terms of applicability, composite materials have to achieve certain mechanical properties. Flexural characteristics in the plastic range are an important mechanical property. Loading composite materials by bending is a very topical issue. In terms of the use of composite materials in the exterior and interior, these bending characteristics are very important. These characteristics include bending strength, plastic potential and modulus of plasticity. Most research deals with the elastic range of the diagram up to the limit of proportionality, while only a small amount of research deals with deformations in the plastic range, from the limit of proportionality to the yield point where plastic deformation occurs. The existence of plasticity moduli is nothing new. In literature, these moduli can be found under different names [9]. Plasticity moduli can be defined as the relationship between the stress and strain at a certain point of the curve between the limit of proportionality and the bending strength [10]. It is clear from much research that the mechanical properties of composite materials are generally significantly affected by the type of adhesive and its modification [11].

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The mechanical properties of composite materials in terms of the adhesive used are largely influenced by the chemical composition of the adhesive, in interaction with the chemical components of the components used in the composite materials [12].

The aim of this study was to determine the effect of rapeseed modification in interaction with the use of urea formaldehyde and polyester adhesive on the bending characteristics of composite material in the plastic range, and to subsequently compare these characteristics with those of standard composite materials. Standard composite materials such as chipboard and OSB boards were selected to compare the monitored characteristics. In addition, the plastic properties of both commercially produced materials (PB, OSB) and newly developed materials have not yet been investigated.

2. Experimental

2.1. Materials

The main component of the test specimens used in the research were chips from rapeseed stalk (*Brassica napus L.*). A network analysis was used to determine the percentage of individual chip fractions, as shown in Table 1.

The monitored bending characteristics (Fig. 1) were compared using boards produced with different chip modifications. The reference values were found in boards produced from raw chips without further modification (this type of chip was labeled R). The bending characteristics were further observed in boards with hydrothermally modified chips; this modification was performed by boiling the chips in water for 45 min at approx. 100 °C (this type of modified chips were labeled H_2O), and chips modified by soaking in a chemical solution, which was performed by soaking them for 45 min in a 2% NaOH solution under laboratory conditions (this type of modified chips were labeled NaOH).

The abovementioned modifications were used to improve the adhesion of the glue to the chip. After the modification, the chips were thoroughly rinsed with water and dried.

For mixing adhesive DAKOTEX2600, which is a powder glue based on polyester and epoxy resin (Dakota Coatings N. V., Belgium) with our modified particles we used a laboratory adhesive applicator (Imal, Modena, Italy). After that we layered these mix into molds to form a chip sheet. These prepared molds were placed in a laboratory press (Strozatech, Brno, Czech Republic) and pressed at a pressure of 2.3 MPa. Temperature of a pressing plate was 185 °C for 10 min. After 10 min, a temperature of 170 °C was reached in the middle of the boards. The closing speed of the press was 150 s. This procedure is shown in Fig. 2.

All the obtained results were compared with commonly sold material. For comparison, we chose a 14 mm thick three-layer P2 particleboard (PB) and a 14 mm thick type 3 oriented strand board (OSB).

The specimens were conditioned to a standardized equilibrium moisture content (EMC) under conditions of $\phi = 65 \pm 1\%$ and $t = 20 \pm 1$ °C, in climate chamber HCP 108 (Memmert, Germany). 30 samples were used for each set of specimens.

The density profile was also measured for all the tested materials; these density profiles are shown in Fig. 3. The figure shows that the highest density values in PB and OSB boards were measured in the surface layers. However, in the case of the boards pressed by us (H_2O, NaOH and R), there was an opposite trend, i.e. a higher density was measured in the middle layers than in the surface layers.

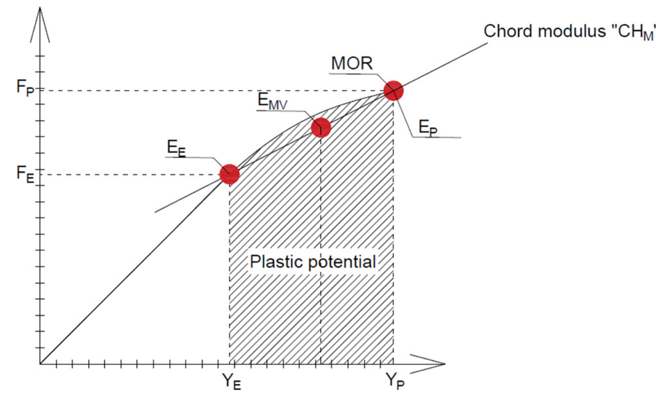

Fig. 1. The monitored bending characteristics in plastic area of force deformation diagram.

3. Methods

3.1. Determination of the monitored characteristics

The support span was adjusted to $L_1 = 20 \times h$ (support span was changed in relation to thickness of specimens). The samples were loaded by three-point bending with single force in a universal testing machine UTS 50 (TIRA, Germany) according to EN 310 [13]. The loading speed was set to 3 mm/min so that the test duration would not exceed 2 min. Loading forces were measured using datalogger ALMEMO 2690-8 (Ahlborn GmbH, Germany).

All the necessary data were obtained from the measured force-deformation diagrams. To identify the characteristics, a program developed by us with the task of accurately identifying and quantifying data that can be obtained from the force-deformation diagram was used.

3.2. Evaluation and calculation

1. The bending strength (MOR) was calculated in accordance with ISO 13061-3 [14] and Eq. (1),

$$MOR_w = \frac{3F_{\max} l_0}{2bh^2} \tag{1}$$

where MOR_W is the modulus of rupture of wood (MPa), Fmax is the maximum (breaking) force (N), l_0 is the distance between the centers of the supports (mm), b is the width of the specimen (mm), and h is the thickness of the specimen (mm). The bending strength values were converted to a moisture content of 12% in accordance with ISO 13061-3 [14].

2. The plastic potential was calculated based on Eqs. (2) and (3) published in the article [9]:

$$\overline{A} = \frac{a}{3}\cdot[Y_P^3 - Y_E^3] + \frac{b}{2}\cdot[Y_P^2 - Y_E^2] + c\cdot[Y_p - Y_E] \tag{2}$$

By dividing Eq. (6) by the volume of the specimen within the stressed area, the calculation of the potential in the viscoplastic range can be obtained according Eq. (7):

$$P_P = \overline{A}/(b\cdot h_0\cdot l) \tag{3}$$

where Pp is the plastic potential (MPa), A is the work of deformation in the viscoplastic range (mJ), b is the width of the specimen (mm), h is

Table 1
Representation in individual fractions of chopped rape straw.

Fraction (mm)	0–0.25	0.25–0.5	0.5–0.8	0.8–1.6	1.6–2	2–3.15	3.15–8
Representation (%)	1.2	2.8	4.8	39.4	20.1	23.1	8.6