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Influence of veneer densification on the shear strength and temperature behavior inside the plywood during hot press

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HIGHLIGHTS

- The temperature behavior inside the densified veneer plywood was analyzed.
- The plywood core temperature strongly depends on the number of veneer layers.
- The use of densified veneer does not affect the shear strength of the plywood.

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ABSTRACT

In this study the effect of veneer densification on the temperature change inside the plywood during the hot pressing step was analyzed. In addition, the shear strength of the plywood was determined. Rotary-cut birch veneer and phenol-formaldehyde resin were used to make the plywood samples. The multi-layers plywood structures made of densified and non-densified veneers with and without adhesive were investigated. Plywood products of 3, 5, 7, 9 and 11-layers were manufactured under laboratory conditions. It was found that the multi-layers plywood made of densified veneers was heated faster when compared to the plywood made of non-densified veneers. This will reduce the pressing time of plywood made of densified veneer by 2–29% depending on the number of veneer layers. The shear strength values of the plywood made of densified veneers were found two times higher than the normalized value of 1.0 MPa, meeting the EN 314-1 standard requirements. Findings of this work are useful for industrial applications to optimize the plywood production.

1. Introduction

Increased demand for the natural resources including wood leads to develop potential new materials for countless industrial applications. It is fact that plywood and other veneer-based products are facing a strong competition by other substituting composite based products such as strand types of panels [1]. Plywood can be used for different applications such as the manufacturing of furniture, musical instruments, means of transportation, packings, sporting goods, as well as in constructions.

The plywood production still needs optimization under industrial scale in order to achieve the best production line capacity. The operation of hot pressing is one of the most important in the production of wood-based composite materials, including plywood. During this operation, the structure and quality of the finished product are formed. The key parameters of hot pressing of plywood, which determine its quality, as well as the cost of plywood manufacture, are the press temperature, time and pressure, glue spread, moisture content of veneer [2,3].

For economic reasons, the temperature and time of pressing are desirable to be as low as possible. The pressing time is the most important one which has to be as short as possible to maximize the process efficiency, but long enough to allow the adhesive curing. The temperature required to cure the phenol-formaldehyde (PF) adhesive is about 100 °C. The pressing temperature is adjusted so that during the hot pressing step to heat as fast as possible the adhesive layer to a temperature at least of about 100 °C. Such approach is significant mostly when pressing thicker multi-layer plywood.

Most of the studies on heat and mass transfer were performed for the hot-pressing of particleboards and fiberboards. Target density, panel thickness, pressing temperature, and moisture content were found influencing factors for the hot-pressing process [4–6]. The heat transfer by moisture evaporation from the veneer surface

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and its migration to the plywood core is not so easily produced when compared to a more open particleboard mat [7,8]. A solution to shorten the plywood pressing time by applying the steam injection was offered by Jokerst and Geimer [9]. The heat transfer rate was affected by the steaming process variables. A 15% reduction of the time span to reach 104 °C in the core glueline of five-ply Douglas-fir plywood was found. Also the steam injected panels presented greater thickness loss. Such losses were shown to be greater for rough veneer while a higher pressure is needed to achieve intimate contact across the gluelines [10].

Veneer incising and steam injection together were applied by Troughton and Lum [11]. A reduction of about 32% in the pressing time for a 40 mm thick 13-ply plywood when compared to standard technology was determined, while for a similar LVL product, Dai et al. [12] stated no significant influence on the plywood pressing time.

The preliminary veneer densification is another efficient method used to reduce the pressing time during the plywood fabrication [13]. Wood compression techniques have been applied for various applications. Asako et al. [14] reported an increase in the thermal conductivity of compressed Japanese cedar. Veneers can be dried and densified simultaneously using the contact type veneer drier with saving energy and process time [15]. Limited research studies on bonding of compressed veneers may be found in the specialty literature [16–18].

Thermomechanical modification is a densification method that combined heat and compression. A side effect of the thermal treatment is the surface inactivation which influences the glue line strength of the consolidated product [19]. However, improvements in such area were already achieved through the surface activation of wood veneer when using various chemicals [20–22]. The results obtained in previous studies also suggest some benefit for a more efficient use of glue in the production of plywood and LVL panels with improved characteristics through application of a thermo-mechanical densification process of veneer sheets before glue application [16–18]. It was reported that initial veneer densification allows lowering the glue spread by 40% and the pressure by 45% [17]. Therefore, it was proposed that the sub-process of thermo-mechanical densification of veneer sheets should be included into the manufacturing process of veneer-based products before adhesive application [23]. This facilitates not only the improvement of veneer surface roughness but also the surface roughness and shear strength of the final plywood, and reducing the consumption of coatings during the finishing of plywood.

In previous studies it was assumed that a densified veneer would have better thermal conductivity than non-densified veneer [16,17]. Therefore the plywood made of densified veneers would be heated faster with a brief result in reducing the plywood pressing time. Moreover, the temperature evolution within the package during hot-pressing is important for the chemical and physical processes that contribute to the bonding between veneers, and thereby also to the physical and mechanical properties of the plywood panel. That's why, this information is also important for choosing the optimal pressing schedule of plywood made with compressed veneer. Time and temperature are important factors in the curing of glues and for this reason the effect of the heat retained by the veneer and its distribution may have an important effect on the durability of the bonding. Consequently, information on temperature changes inside veneer package during hot pressing can contribute to the improvement of plywood quality. In the literature we didn't found any data on the temperature distribution inside veneer package during hot pressing of plywood with compressed veneer.

Therefore, the objective of the present study was to evaluate the influence of veneer densification and number of veneer layers on the shear strength and temperature behavior inside veneer package during hot pressing of multi-layers plywood panels made with densified veneer.

2. Materials and methods

2.1. Materials

Defect free samples of birch (*Betula verrucosa* Ehrh.) veneers purchased from the LLC "ODEK" Company in Ukraine with dimensions of 300 × 300 mm^2, 1.5 mm thick and a moisture content of 6.6% were used in the experiments.

2.2. Veneer densification

The densification process was applied to each veneer sheet and it was performed between smooth and thoroughly cleaned heated plates of a laboratory press at the temperature of 150 °C under a constant pressure of 3 MPa for 1 min time span. In the basic series of tests, 210 veneer sheets were thermally densified in the laboratory press and 210 veneer sheets were used as non-densified (control). The moisture content of densified veneer was 3.8%.

2.3. Plywood preparation

Birch veneers were used for the plywood preparation. The multi-layer plywood samples made of 3, 5, 7, 9 and 11 layers were produced under laboratory conditions (Fig. 1). For each plywood type a constant hot-pressing schedule was applied as presented in Table 1. Three plywood panels were manufactured for each one of the five plywood types using non-densified (control) and densified veneers with adhesive application, resulting in a total of 30 panels. Thereafter, test samples (a total of 450 samples) per shear strength were prepared from these panels.

The multi-plywood samples with dimensions of 300 × 300 mm were made under the following conditions: the specific pressure of 1.8 MPa, the pressing temperature of 130 °C, and different pressing times (Table 1). The pressure was continuously reduced to 0 MPa for the last 30 s of the pressing cycle. A commercial phenol-formaldehyde (PF) adhesive with a solid content of 42% and the viscosity of 120 s with a spread rate of 150 g/m^2 based on the wet mass was used for the plywood production. The adhesive was manually applied onto one side of each uneven veneer sheet by using a brush. To form the plywood structures both densified and non-densified veneers were used. The veneers were perpendicularly oriented, layer by layer, in each plywood product. Prior

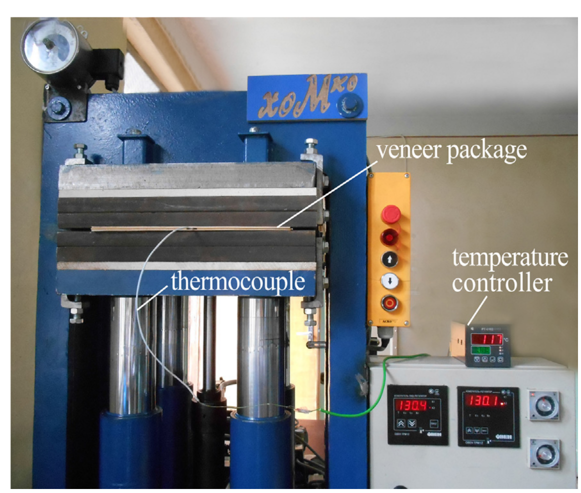

Fig. 1. The pressing of plywood panel when measuring the core temperature.