forests

Technical Note

Technical Assessment of the Bonding Quality of Composite Plywood with a Thin Cork Core

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Abstract: The bonding quality is a key property for wood-based composites. Determination of the bonding quality of sandwich panels with veneer faces and <50 mm thick cork core is not covered either by the EN 314-1, which refers to plywood, nor by its Annex B, which refers to insulating cores with a thickness of at least 50 mm. This technical note assesses the possibility of using the prescriptions of Annex B of EN 314-1 to test the bonding quality (shear strength) of the concerned panels. For this purpose, sandwich panels were realized by bonding fromager (*Ceiba pentandra*) veneers to a 5 mm thick core, and their bonding quality was tested. Two types of panels were realized, based on the adhesive used (glue spread 340 g/m^2 for double glue lines): urea–formaldehyde (UF) and urea–melamine–formaldehyde (UMF); the panels were pressed at 103 °C for 8 min at a nominal pressure of 0.4 MPa. Pre-treatments were dry-conditioned at 20 °C/65% relative humidity until attainment of the equilibrium moisture content, and immersed in water: cold water for UF panels (5.1.1 of EN 314-2) and boiling water for UMF panels (5.1.2 of EN 314-2). The effect of pre-treatment was statistically significant, with shear resistance reductions of 56% and 43% in UF and UMF panels, respectively. Based on this first investigation (2 panels × 10 specimens per panel = 40 specimens), the test method can be considered suitable for providing reliable results. This study constitutes a useful reference to test the bonding quality of sandwich panels with veneer faces and thin cork cores.

Keywords: bonding quality; cork core; EN 314-1; sandwich panels; testing; wood-based composites

Citation: Negro, F.; Bigando, R.; Ruffinatto, F.; Zanuttini, R. Technical Assessment of the Bonding Quality of Composite Plywood with a Thin Cork Core. *Forests* **2022**, *13*, 1839. https://doi.org/10.3390/f13111839

Academic Editor: Petar Antov

Received: 30 September 2022
Accepted: 31 October 2022
Published: 4 November 2022

1. Introduction

Wood-based composites (WBCs) are engineered products in which wooden elements are bonded together with other wooden or non-wooden materials [1]. A relevant sub-category of WBCs is that of wood-based sandwich panels [2]. These have a layered composition which typically consists of external skins made of wood-based panels (e.g., plywood) bonded to an inner core that can comprise a wooden or non-wooden material. As a rule, the skins distribute the loads in the panel plane and can have an aesthetic function, whereas the core provides bending stiffness and/or additional properties. Several types of cores can be used, depending on the desired properties, including honeycombs (whose cells can be made of various materials), synthetic foams, and cork. The latter is appreciated because it provides lightweight and thermal insulation due to its highly porous structure [3]. The natural origin of cork is also a relevant aspect, given the growing attention to eco-friendly products and sustainability; however, cork is more expensive than alternative materials such as synthetic foams.

Assessing bonding parameters and checking the aptness of test methods to be applied are key to the development of new WBCs [4]. In the case of wood-based sandwich panels, bonding can be considered particularly challenging, especially when different materials have to be glued together. In practice, the bonding quality of these panels is often measured by means of an inner cohesion test, such as that prescribed by the EN 319 standard [5]. In this method, intended for particles and fiberboards, the faces of the specimens are bonded to the plates of the testing device, and traction perpendicular to the panel plane is applied until rupture.

The EN 314-1 standard instead specifies the method for determining the bonding quality of plywood through a shear test parallel to the panel plane induced by tension [6]. This method is intended for veneer plywood, blockboard, and laminboard. However, it is also used for cork-layered plywood [7,8].

In addition, the informative Annex B of the EN 314-1 standard describes a method for determining the bonding quality of plywood with an insulating core. The method consists of a compression test performed on two sets of specimens, dry-conditioned and subjected to immersion pre-treatment, and is intended for panels at least 50 mm thick. However, the Annex does not concern panels with cork or synthetic foam cores <50 mm thick which are used in various applications where lightness and good mechanical properties are required, for instance, in the transport sector [9]. In summary, the determination of the bonding quality of sandwich panels with veneer faces and cork or synthetic foam cores with thickness <50 mm is not covered by EN 314-1 because the core is not a veneer; nor is it covered by Annex B of EN 314-1, because the thickness of the core is <50 mm.

This technical note intends to assess the possibility of using the prescriptions of Annex B of EN 314-1 to test the bonding quality (shear strength) of sandwich panels exhibiting veneer faces and <50 mm thick cork cores. To this purpose, sandwich panels with exotic veneer faces and 5 mm thick cork core were realized in the laboratory. In particular, compared with the main text of EN 314-1, Annex B requires a larger size of the stressed area (sides length 50 × 50 mm instead of 25 × 25 mm), and the evaluation of the results obtained from two pre-treatments: dry conditioning and immersion. Furthermore, Annex B does not set threshold levels for acceptance, because of the large range of possible core materials and resulting sandwich panels.

This study was performed to research the following aims: (i) provide results that refer to the bonding shear resistance parallel to the panel plane, as usually envisaged for plywood; (ii) test specimens with dimensions suitable for obtaining reliable results, considering that cork cores exhibit limited resistance; and (iii) assess the differences between specimens tested dry and after immersion. This latter aspect is of particular interest because, to the best of the authors' knowledge, no similar data are available in the literature to date. Overall, the outcomes of this study can constitute a useful reference to test the bonding quality of similar sandwich panels.

2. Materials and Methods

For this study, 11 mm thick sandwich panels with dimensions of 60 × 50 cm were realized in the laboratory. The composition consisted of 5 layers: the front and rear faces were made of two fromager (*Ceiba pentandra*) veneers, 1.5 mm thick and perpendicularly bonded. The core was composed of a 5 mm thick cork panel (nominal density 190 kg/m^3, compression strength 0.15 kg/cm^2, λ at 10 °C = 0.044 W/mK).

Two experimental panels were bonded using two adhesives available on the market: urea–formaldehyde (UF), suitable for gluing plywood in compliance with bonding Class 1 of EN 636 [10]; and urea–melamine–formaldehyde (UMF), suitable for gluing plywood in compliance with bonding Class 2 of EN 636. The urea–formaldehyde resin had a solid content of 65 ± 1% weight (2 h at 120 °C), average viscosity of 400 cP (Brookfield DV II +), and average gel time of 54 s (at 100 °C); the urea–melamine–formaldehyde resin had a solid content of 64 ± 1% weight (2 h at 120 °C), average viscosity of 75 cP (Ford cup ∅ 4, 20 °C), average gel time 65 s (at 100 °C). These adhesives were used for preparing suitable gluing mixes.

The adhesive was spread around 340 g/m^2 for double glue lines. The panels were realized by hot pressing, in a single operation, at 103 ± 2 °C for 8 min at a nominal pressure of 0.4 MPa, similarly to [11].

Bonding quality was determined by a shear test according to the procedure prescribed by EN 314-1 for plywood. Briefly, the test pieces were wiped and placed in the center of the testing device (universal testing machine PMA5 GALDABINI, Galdabini S.p.A., Cardano al Campo, Italy). Clamping was performed on the specimen faces in order to transmit the load from the testing machine to the shear area without applying any transversal loads. The load was applied at a constant rate so that failure occurred within 30 ± 10 s. During testing, the absence of specimen slipping by the clamping and of lateral deformation were always verified.

The specifications of Annex B for insulating core plywood were followed to cut the specimens to size. These were 50 mm wide, with saw cuts placed 50 mm apart (Figure 1), resulting in a 50 × 50 mm area subject to testing (for standard plywood, 25 × 25 mm areas are instead subjected to test). According to Annex B of EN 314-1, specimens were tested after two pre-treatments:

- Dry, i.e., conditioned at 20 °C/65% relative humidity until attainment of the equilibrium moisture content;
- After immersion: UF panels were subjected to 24 h immersion in water at 20 ± 3 °C (pre-treatment 5.1.1 of EN 314-2, required for bonding Class 1 of EN 636 [12]); UMF panels were subjected to 6 h immersion in boiling water, followed by cooling in cold water at 20 ± 3 °C for 1 h (pre-treatment 5.1.2 of EN 314-2, required for bonding Class 2 of EN 636).

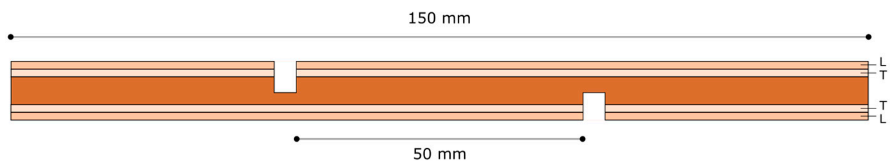

Figure 1. Outline of a specimen subjected to shear test: the cork core is colored dark brown, and the fromager veneers are colored two different, lighter colors according to their wood fiber orientation (L, longitudinal; T, transversal to the specimen major axis).

This resulted in four combinations: panel UF dry, UF after immersion, UMF dry, and UMF after immersion.

As required by Annex B of EN 314-1, 10 specimens per each pre-treatment were randomly cut from each panel (20 specimens per panel, overall amount of 40 tested specimens). The bonding test was performed to assess bonding shear resistance (N/mm^2), wood and cork failure percentage, and failure type. The latter was distinguished between adhesive and cohesive, which can be compared with the evaluation of the percentage of fiber release in plywood, required by the reference standard.

Independent t-tests were performed using SPSS 28.0 (IBM Corp., Armonk, NY, USA) to assess the differences in average shear resistance of specimens tested as dry-conditioned or after immersion pre-treatment for both UF and UMF panels (EN 314 5.1.1 or 5.1.2, respectively). Homogeneity of variance was verified by Levene's test. Significance was always set at the level of 0.01.

3. Results and Discussion

Figure 2 illustrates the results of the bonding quality test.

The average shear resistance of specimens tested after immersion was consistently significantly lower ($p < 0.001$) than that of dry-conditioned specimens. In detail, the decrease was 56% in the UF panel (wet: 1.23 N/mm^2; dry: 2.21 N/mm^2;) and 43% in the UMF panel (wet: 0.84 N/mm^2; dry: 1.95 N/mm^2). Such differences are not surprising, because cork is a hygroscopic material and immersion pre-treatment is purposedly intended to challenge the bonding quality. However, the extent of the reduction in shear resistance between specimens tested in dry condition and after immersion can be a useful reference value for similar studies and product development activities in the future.

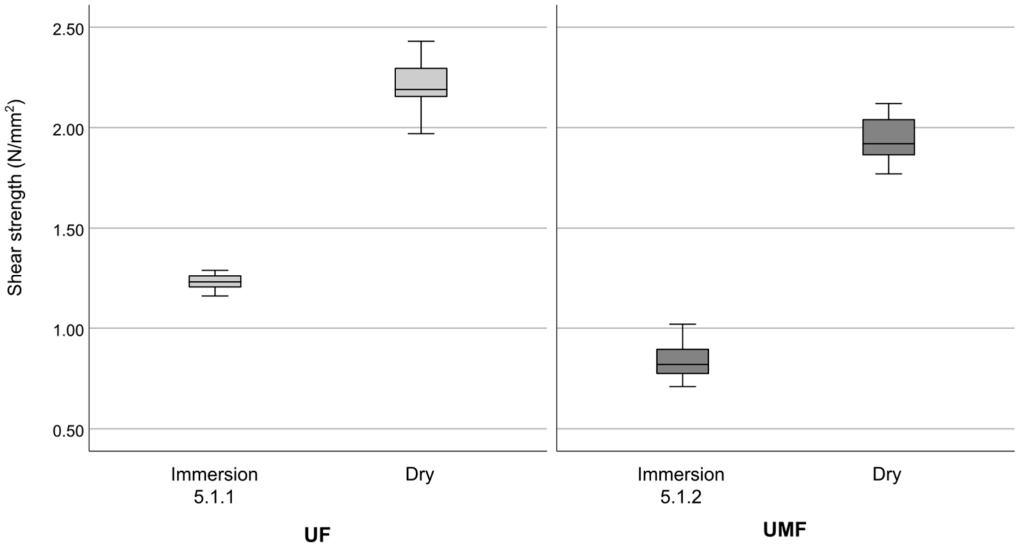

Figure 2. Shear strength of tested sandwich panels.

Even if the focus of this study was not on differences among UF and UMF performance, some appropriate notes are worth mentioning here. First, it should be clarified that shear resistance after the immersion of UF and UMF cannot be compared because the pre-treatments to which panels were subjected were different, namely, as prescribed by EN 314-2, immersion in cold water for UF panels and immersion in boiling water for UMF panels. As for the dry shear resistance, the average shear strength of UF panel was significantly higher ($p < 0.01$) than that of UMF panels. This is somewhat surprising, because UMF resins have greater adhesion strength than UF resins due to the presence of two reactive monomers, namely, urea and melamine [13]. However, UMF resins are specifically used to improve the water resistance [14] of wood-based panels, whereas, in this case, the specimens were tested after dry conditioning. Additionally, the fact that the failure always occurred in the core indicated that both UF and UMF bonding fully resisted the applied loads, and were not challenged up to their limit strength, where differences between them could have appeared. The measured shear resistance was therefore due to the resistance of the core. Moreover, the variation inside the cork core, which had grains of different size and was therefore not fully homogeneous, can justify the observed differences in dry shear strength. Further investigation should be carried out to explore this aspect.

Notably, the test area prescribed by EN 314 for plywood is 25 × 25 mm, whereas that prescribed by Annex B of EN 314-1 for insulating core plywood, and that used in this study, is 50 × 50 mm. Provided that results are always expressed in N/mm^2, testing specimens with a wider area enables the application of higher maximum loads (in N). This increases the test reliability and can be particularly useful when testing cores made of materials with low resistance, such as cork.

In all specimens, the failure was consistently entirely cohesive (100%, Figure 3), indicating efficient bonding between the fromager veneers and the cork core. This was expected, because the commercial adhesives used are available on the market as suited for the manufacture panels able to satisfy the requirements for bonding Classes 1 and 2 of EN 636 [10].

Figure 3. Total (100%) cohesive failure of the cork core (0% wood failure) on specimens tested after dry conditioning (**left**) and immersion in boiling water (**right**). The numbers 1 and 3 on the specimens are testing codes referring to the panels from which they were cut.

4. Conclusions

Based on this first investigation (2 panels × 10 specimens per panel = 40 specimens), the test method appears adequate to provide reliable results that refer to the bonding quality evaluation of the concerned composite. Assessing adhesive vs. cohesive failure of the cork core should be part of the testing procedure. In addition, performing the inner cohesion test would result in an even more comprehensive characterization, because the method here applied refers to loads parallel to the specimen plane (shear strength); the inner cohesion test applies instead loads perpendicular to the specimen plane (tensile strength). Overall, the results reported here can be taken as reference data for the shear resistance of cork-cored sandwich panels.

Author Contributions: Conceptualization, F.N. and R.Z.; methodology, F.N. and R.B.; formal analysis, F.N. and F.R.; investigation, F.N. and R.B.; writing—original draft preparation, F.N., F.R., R.B. and R.Z.; writing—review and editing, F.N., F.R. and R.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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