Novel synthetic and natural adhesives: performance evaluation using ABES
Cecilia Fuentealba, Technological Development Unit - UDT, Chile

R.A. Cancino[1], D.E. García[1], P. Garcés[1], C. Fuentealba[1]*

[1]*Technological Development Unit, Universidad de Concepción, Concepción, Chile.*
E-mail: r.cancino@udt.cl

*Speaker: +56 41 266 1805, Fax: +56 41 275 1233.
E-mail address: c.fuentealba@udt.cl (C. Fuentealba)

Introduction

Adhesives are involved in several industrial processes and comprise a wide range of applications (e.g., construction, aerospace, automotive, marine and bio-medical). Despite significant scientific progress, the design and modeling of joint adhesives remains under constant research. The mechanical behavior of composite materials is very complex due to inter- relationships among different factors, such as adhesive-substrate interaction, substrate nature, surfacing characteristics and operational conditions in board manufacturing. To address some of these issues, the Automated Bonding Evaluation System (ABES) was developed; it optimizes resources and improves the accuracy of board laboratory manufacture. ABES shows how strength is developed and affected by temperature, adhesive type, as well as substrate nature and process conditions. The present study illustrates the potential of ABES for several adhesives and test configurations. By varying the adhesives and substrate conditions it is possible to obtain information about adhesion performance and adhesive bond development under a wide range of conditions. Moreover, this contribution intends to explore how adhesion affects the design of board composite materials.

Experimental

An ABES instrument was used in order to evaluate several adhesives and wood veneers as substrate. The wood veneer samples were stored in a conditioned chamber at 20 °C and relative humidity of 53% prior to testing; two dimensions (0.7 and 2.6 mm) were tested. The probes were cut into 117 mm × 20 m strips using a pneumatically driven sample cutting device for ABES sample preparation (supplied by Adhesive Evaluation Systems, Corvallis, Oregon). In this study, a new overlapped area of 4 mm^2 was proposed, in comparison with the standard of 1 mm^2 that is most often used. The change in overlap area was introduced to reduce the effect of the small area and possible surface defects which affect adhesive performance and induce drawbacks. Figure 1 illustrates the general scheme of ABES for bonding evaluation.

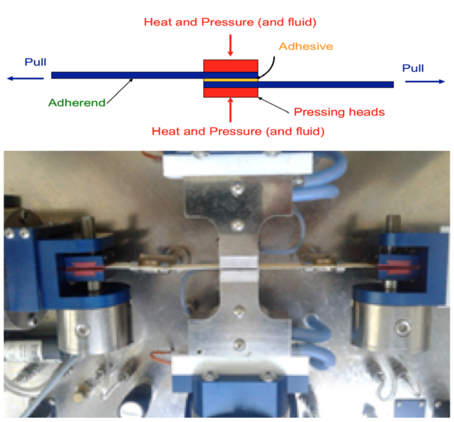

Figure 1. General scheme of equipment and traction of wood veneer using ABES.

For the bonding test, the adhesive was applied manually and the spread rate was controlled in an analytic balance. After the desired temperature was reached, adherent pairs of strips were mounted in the system with an overlapping area of 1 or 4 mm^2 (depending on the test), then pressed together at 1.2 N/mm^2. After the pressing time was elapsed, the probe was pulled with a standard loading rate of 1 kNs^{-1}. The bond strength was tested in shear mode, the system being digitally controlled and pneumatically driven, as illustrated in Figure 2.

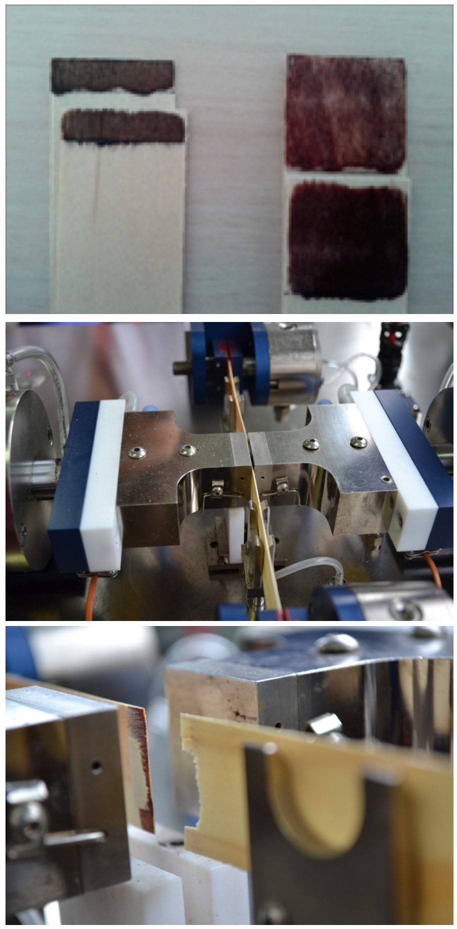

Figure 2. ABES Testing using standard and new area for bonding evaluation.

The first step of this study was to validate the change of the test area (1 to 4 mm^2) and the thickness of the veneer (0.7 to 2.6 mm), the last one corresponding to *radiata* pine veneer, widely utilized in industrial processes. Table 1 summarizes the test conditions.

Table 1. General ABES testing ccharacteristics.

Parameter	Value
Adhesive, type	Commercial PF and tannin*
Thickness, mm	0.7 and 2.6
Press temperature, °C	135
Press time, s/mm	12 - 150
Spread rate, g/m²	180
Substrate	Strips and veneer

*Tannin adhesive formulation developed in UDT used for plywood manufacture.

ABES bond strength performance test.

Increasing test area.

The new area configuration (4 mm^2) was evaluated using standard thickness for new tannin-based and commercial adhesive (Figure 3a). In both cases the shear strength response increased for the higher area. At the same time, better consistency was observed for three repeated tests, as shown in Figure 3b.

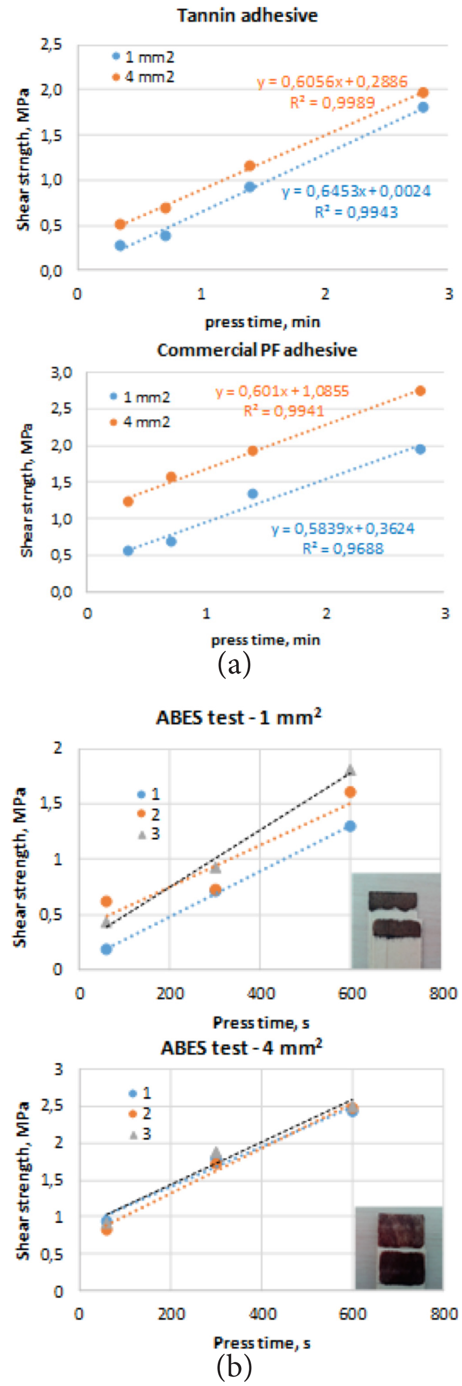

Figure 3. ABES comparison
a)Different areas for two adhesive systems; b)Response with three repeated tests.

Effect of crosslinking agent.

Two different probe thicknesses were evaluated, using industrial veneer samples of radiata pine (2.6 and 0.7 mm). The results show that the ABES methodology proposed here is a good alternative for the study of adhesives with industrial veneer for plywood manufacture. The development of bond strength, including features of the veneer (roughness, moisture content and nature), was close to real conditions for adhesive application (spread rate: 180 g/m^2; press temperature: 135 °C and veneer thickness: 2.6 mm). The evaluation test for veneer of 2.6 mm is therefore adequate for adhesive performance evaluation (Figure 4).

Based on previous results, probe configuration for ABES was established in order to obtain consistent response for industrial radiata pine veneer (2.6 mm and overlap area of 4 mm^2).
The next step was to study the ABES performance of tannin adhesives, with a crosslinking catalyst, to study the press temperature and tannin type effects.

Results and Discussion

Effect of catalyst on the performance of radiata pine tannin-based adhesive.

The effect of crosslinkers (hexamine) and/or "catalysts" was evaluated over tannin-based adhesive performance, considering radiata pine veneer thickness of 2.6 mm (Figure 4). At the same time, the effect of different crosslink percentages was evaluated, as shown in Figure 5.

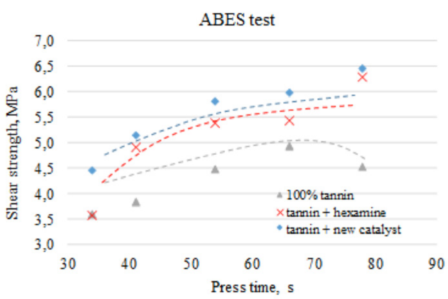

Figure 4. ABES evaluation for different adhesive systems based on tannin with and without hexamine and catalyst.

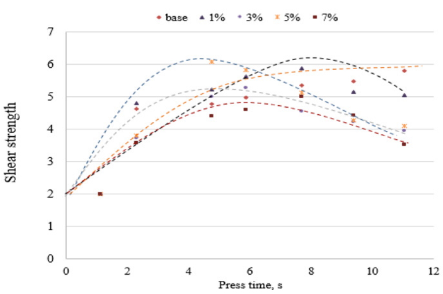

Figure 5. ABES evaluation for different catalyst contents in the new tannin adhesive.

The addition of hexamine, the traditional crosslinking agent used in tannin-based adhesives, was as expected. A higher shear strength with respect to tannin-based adhesives without a crosslinking agent was observed. Catalyst addition increased the curing rate as well, but beyond 5% a negative effect on adhesive performance was observed; it is attributed to dry-out potentiated by high catalyst content. In this sense too, ABES is a good tool to detect changes in adhesive formulation.

Effect of press temperature on the performance of radiata pine tannin-based adhesive.

The effect of press temperature was analyzed for the new tannin adhesive, as summarized in Table 2.

Table 2. ABES test conditions for new tannin adhesive.

Parameter	Value
Adhesive, type	Tannin*
Thickness, mm	2.6
Press temperature, °C	100, 135 and 150 °C
Press time, s	12 to 72
Spread rate, g/m^2	180
Substrate	*radiata* pine veneer

*Tannin adhesive formulation developed in UDT used for plywood manufacture.

As expected and shown in Figure 6, the shear strength development is faster at higher temperatures. The adhesives tested have very different curing behaviours, depending on the press temperature; this is observed clearly using ABES.

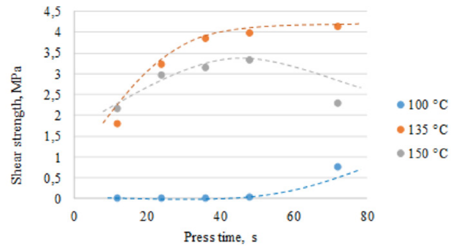

Figure 6. ABES for tannin-based adhesives at different press temperatures.

The corresponding pressing conditions, at the industrial level, should be adapted according to these results. In each case, for tannin-based adhesives, high temperature was needed for good performance. Therefore, for the new tannin systems, 135 °C is the recommended press temperature for higher bond strength results. At 100 °C it is not possible to produce the curing reaction, and a higher temperature, such as 150 °C, pre-curing phenomena likely compete with adhesive diffusion which can impede veneer penetration prior to curing.

Effect of tannin type on adhesive performance.

Comparative analyses for commercial PF resin with adhesives based on different tannin sources (radiata pine, mimosa and quebracho) are shown in Figure 7. Radiata pine tannin exhibited similar behavior to the commercial PF adhesive.

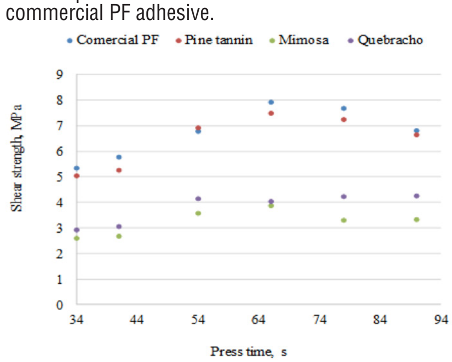

Figure 7. Comparative results from ABES of adhesives used in plywood manufacture.

Conclusion

The ABES instrument is a powerful predictive tools for adhesive performance evaluation, including conditions that approach industrial requirements. Its application could obviate the need to use more expensive resources for research and development in the adhesives field. It is possible to cover a wide range of formulations and substrates in less time and this allows one to identify, in a first stage, the most promising formulations. Although ABES cannot replace board manufacturing and characterization according to standard tests, it can minimize the number of runs to be performed in the process and product design stages. The ABES testing equipment using 2.6 mm veneer for plywood manufacture is thus a good tool for industrial-level prediction of adhesion performance.

Acknowledgement.

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References

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