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Acrylic resin as a potential formaldehyde-free binder for plywood

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Abstract: *Acrylic resin as a potential formaldehyde-free binder for plywood.* A commercial styrene-butadiene aqueous emulsion was used as a binder for plywood. The manufactured 3–ply plywood was subjected to shear strength tests, bending and bondline density X-ray profiling. It was found that bonding temperature as low as 80°C allowed meet plywood the requirements of EN 314 standard in terms of shear strength, while modulus of rupture was comparable to that of the UF-bonded plywood.

Keywords: plywood, styrene-butadiene emulsion

INTRODUCTION

Since 2004 when formaldehyde was recommended by International Agency for Research on Cancer (IARC) to be classified as "carcinogenic to humans" (IARC 2004), the release of formaldehyde from wood-based panels has become a subject of concern. Although international forum of representatives of industry and science concluded in 2007 that the evidence for cancerogenic activity of formaldehyde was not clear and "common use of formaldehyde in consumer products and other applications does not pose a risk to human health" (FormaCare 2007), emission limits for wood-based composites have been lowered. So that new emission classes E0 (F***, <3 mg/100g) or Super E0 (F****, <2 mg/100g) became recommended. The emission mainly comes from the use of urea-formaldehyde resins as adhesives. Therefore, resin manufacturers developed new types of aminoresins that comply with new requirements. There are three main approaches to reduction of formaldehyde emission: (1) lowering formaldehyde/urea ratio of the resin, (2) addition of formaldehyde scavengers and/or melamine, (3) use of formaldehyde substitute e.g. glyoxal (Mansouri et al. 2007) and (4) use of formaldehyde-free binder (ITD 2011). Thus, the search for alternative non-formaldehyde binders seems to be justified. In this work environmentally friendly aqueous carboxylated styrene-butadiene emulsion was examined as a binder for plywood manufacturing.

EXPERIMENTAL

3-ply plywood was made of beech (*Fagus sylvatica*) veneers of dimensions 250 × 250 × 1.9 mm^3. A commercial acrylic emulsion kindly donated by Omnova Solutions Inc. was characterized as follows: dynamic viscosity at 20°C 138 mPa·s, surface tension 37 mJ/m^2, solids content 50.0 %, pH 8.6. Viscosity of the adhesive was adjusted to 1500–1520 mPa·s with wheat flour: 6 parts by weight of the carboxylated styrene-butadiene emulsion and 1 part by weight of flour. Glue load was 200 g/m^2. Pressing parameters were as follows:

- platen temperature 80, 100 or 120°C,
- unit pressure 1.2 MPa,
- time 5 minutes.

Shear strength tests were performed after 7-day conditioning in normal conditions according to EN 314 standard. Wet tests were run after 24-hour water soaking. Lap dimensions were 20 × 20 mm^2. Modulus or rupture (MOR) and modulus of elasticity (MOE) were determined from bending tests performed for longitudinal direction only (EN 310). Shear strength tests were made on a universal testing machine at tension speed 7 mm/min. X-ray density profiling of the bondines was made on a Da-X (GreCon) instrument at scanning speed 0.05 mm/s. Sample dimensions were 50 × 50 mm^2.

RESULTS AND DISCUSSION

From the MOR and MOE values shown in Table 1 one sees that modulus of rupture increased with increasing bonding temperature. MOR increase reached 14% when temperature rose from 80°C to 120°C. That difference was statistically significant. Middling value of MOR for plywood bonded at 100°C confirmed the trend. The obtained values were higher those reported by Borysiuk et al. (2012) for glass, aramid or carbon fabric-reinforced plywood (104–118 MPa).

When modulus of elasticity is concerned, the relation is much alike. Statistically significant increase in MOE was observed for the series bonded at 80°C and 120°C, while that for the series bonded at 100°C occurred ambiguous. The recorded MOEs are 3 times higher than those reported for 3-ply plywood bonded with thermosetting formaldehyde-containing resins (Witek 2012) which denotes reduced stiffness of the material and remains in accordance with viscoelastic characteristics of the acrylic resin (glass transition temperature 20°C), so that at the temperature of the test 23ºC resin is in viscoelastic state.

Tab. 1 The effect of pressing temperature on plywood modulus of rupture (MOR) and modulus of elasticity (MOE)

temperature	**MOR**	**MOE**
°C	MPa	MPa
80	116 ± 9	32942 ± 3149
100	118 ± 16	30339 ± 5560
120	132 ± 6	39844 ± 3040

The results of shear strength tests are presented in Table 2. It is clear that there was no effect of bonding temperature on the dry shear strengths. The recorded bondline strengths were comparable and fully met the requirements of the EN 314 standard (R_t >1.0 MPa). The effect of temperature was revealed for wet strengths. As indicated in Table 2, 24-hour water soaking of the specimens bonded at 80°C resulted in delamination. On the other hand, bonding at 100°C or 120°C provided comparable wet shear strengths which complied with the requirements of the EN 314 standard for water resistant plywood (R_t^{wet} >1.0 MPa). Therefore, the observations allow concluding that effective bonding temperature suitable for the acrylic emulsion is not lower than 100°C if increased water resistance of the bondline is expected.

Tab. 2 Dry and wet tensile shear strength

temperature	R_t^{dry}	R_t^{wet}
°C	MPa	MPa
80	3.5 ± 1.0	delam.
100	3.7 ± 1.0	1.1 ± 0.3
120	3.7 ± 0.9	1.6 ± 0.5

X-ray measurements allowed the imaging of cross-sectional density profile in the plywood. It was revealed that in all cases the density of the bondline ranged from 890 to 960 kg/m^3 which means density increase by 200–260 kg/m^3 above that of the veneers (Fig. 1). The densities were slightly lower than those reported for other types of adhesives: 980 kg/m^3 for 2k PUR, 1090 kg/m^3 for EPI (Mamiński et al. 2011) and close to 900–1000 kg/m^3 for UF-pMDI hybrid system (Mansouri et al. 2006).

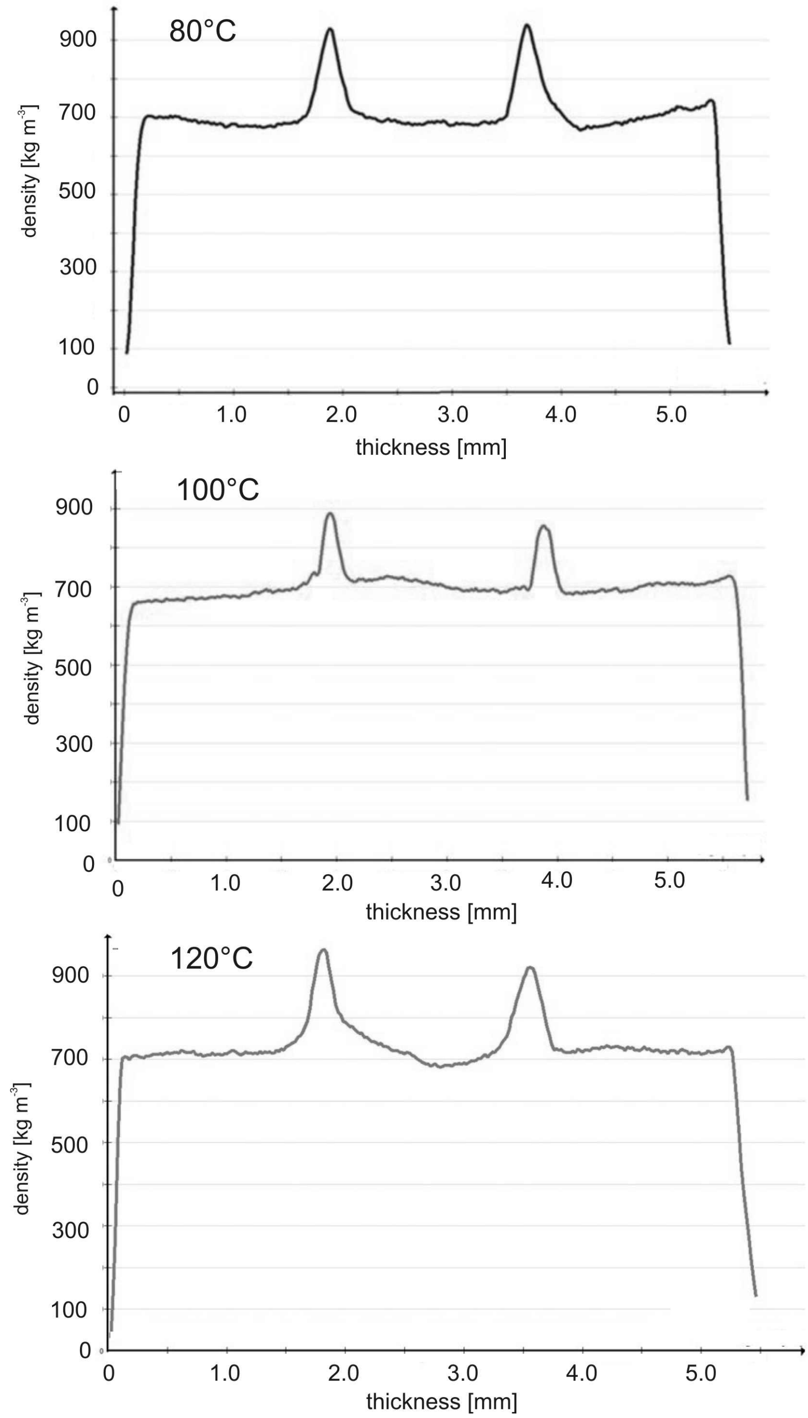

Fig. 1. Plywood density profiles

CONCLUSIONS

The presented results showed that formaldehyde-free acrylic binder might potentially be used as a binder in plywood bonding. Plywood mechanical properties like MOR and shear strength were not inferior to the UF-bonded material. It was shown that the temperature as low as 80°C was sufficient for interior-grade material while at least temperature 100°C was necessary for the upgraded water resistance of the bondlines. Although process involving acrylic emulsion as binder is less energy consuming than typical, the cost of the resin should be considered, since it may affect overall economy of the approach.

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Streszczenie: *Żywica akrylowa jako potencjalny bezformaldehydowy klej do sklejki.* Handlowa żywica butadienowo-styrenowa w postaci emulsji wodnej została wykorzystana jako środek wiążący w produkcji sklejki. Wytworzona sklejka 3-warstwowa poddana została badaniom wytrzymałości na ścinanie, wytrzymałości na zginanie oraz metodą rentgenowską zbadano jej profil gęstości. Wykazano, że sklejka wytworzona już w temperaturze od 80°C spełnia wymagania normy EN 314, a wytrzymałość na zginanie statyczne i moduł sprężystości pozostają porównywalne ze sklejką otrzymaną przy użyciu kleju UF.

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