Comparison of Different Foaming Agents in Making Plywood Glue

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ABSTRACT: Foaming of a phenol formaldehyde resin was studied. Twenty-one foaming agents were tried out in the experiments. Foaming was evaluated by viscosity, density, and surface tension measurements. The study shows that spray dried blood and β-lactoglobulin-enriched whey were the best foaming agents to foam phenol formaldehyde resin. There are also some other materials, which might work as foaming agents for phenol formaldehyde resin after some formula optimization. They include sodium lauryl sulfate, sodium-*n*-alkyl (C_{10}-C_{13}) benzene sulfonate, and a fatty acid amine derivate. © 2004 Wiley Periodicals, Inc. J Appl Polym Sci 93: 1060–1064, 2004

Key words: phenol formaldehyde resin; foaming agent; plywood; resins; foam extrusion; adhesives

INTRODUCTION

Phenol formaldehyde resins are used in a variety of applications, among which is plywood gluing.[1] Customer demand, economical concerns, and environmental issues have created pressure to find substitutes for traditional plywood gluing. One of the methods is to use foamable plywood glue. In foam extrusion, the glue is foamed with air to five- or sixfold. Once the glue is foamed and extruded, it is spread as strands onto the veneer surface. At this point, the glue covers less than half of the wood surface: this will diminish solvent evaporation from the glue as well as over penetration of glue into the wood prior to the prepressing of plywood. After the prepress, the glue covers the entire veneer surface. The glue is applied to only one side of the veneer, which gives foam extrusion an advantage in having greater tolerance for veneer surface roughness and thickness variation. There is also less trim and cleanup waste compared to roll coater application.[2–6] Glue waste is minimized as well, because the foamed glue can be recycled. In addition, foam extrusion has a greater tolerance to veneer moisture content, because the glue contains less water than conventional plywood glue.[2] Overall, foam extrusion can reduce glue consumption significantly, up to 25% compared to roll coater application.[2–3,7–8]

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In nature, foams can be organic, inorganic, or metallo-organic. These foams can also be thermoplastic or thermosetting. They can be either synthetic or derived from natural products. Polymers can be manufactured into foams by mechanical, physical, or chemical means.[9] In the case of foaming plywood glue, the foaming phenomenon is mechanical. Air is mechanically mixed into the plywood glue mixture with foaming agent and eventually the volume of the glue rises considerably.

Investigations on foaming of phenol formaldehyde plywood resin were made. So far, only spray dried blood was used as a foaming agent in this kind of application.[2,5–8,10–12] Cone reported the advantages of foam extrusion in 1969 by using spray dried blood as foaming agent. From that point on, spray dried blood was used as foaming agent in plywood foam extrusion applications.[5–6] Lately, there have been concerns about using spray dried blood as a foaming agent in plywood gluing. This substance is pulverulent and it might also be a source for bacterial growth in industrial environment. These factors have to be taken into account when using spray dried blood in making plywood. There has been research done with various sources of soy proteins (meal, flour, concentrate, and isolate) acting as foaming agents in manufacturing plywood glue. This work was carried out by Hojilla-Evangelista et al.[10,12] Their research showed that soy flour can be used as a foaming agent in gluing plywood. In some countries, synthetic foaming agents have also been used.

This study investigates foaming agents that could also be used in the plywood industry. Twenty-one different foaming agents were used in the experiments. They include spray dried blood, two different soy flours, three different lignins, casein, potato cell sap, carboxymethyl cellulose, ethoxylated polyacrylic copolymer, sodium acrylate, sodium lauryl sulfate, ammonium lauryl sulfonate, sodium-*n*-alkyl (C_{10}–C_{13}) benzene sulfonate, fatty acid amine derivate with betaine structure, sodium alginate, and two different propylene glycol alginates.

EXPERIMENTAL

Foaming agents

Foaming agents, medium-density propylene glycol alginate, low-density propylene glycol alginate, and sodium alginate were obtained from Kelco International Ltd. Ammonium lauryl sulfate, sodium-*n*-alkyl (C_{10}–C_{13}) benzene sulfonate, and fatty acid amine derivate with betaine structure were acquired from Henkel KGaA. Spray dried blood was purchased from Regal Processors Ltd. Soy flours were obtained from two different manufacturers (Sigma and Lucas Meyer GmbH and Co.). Lignin-based materials, sodium lignosulphonate, polymeric kraft lignin, and calcium lignosulphonate, were provided by LignoTech Sweden AB. Regular whey was received from Ingman Oy (Sipoo, Finland), and Valio Oy (Helsinki, Finland), produced the β-lactoglobulin-enriched whey. Casein and potato cell sap were delivered by Kainuun Osuusmeijeri (Sotkamo, Finland) and Lapuan Peruna Oy (Lapua, Finland), respectively. Carboxymethyl cellulose was obtained from Metsa Specialty Chemicals Oy (Äänekoski, Finland). Rhodia Oy (Helsinki, Finland) provided ethoxylated polyarylphenol, a sodium salt of an acrylic copolymer, sodium acrylate, and the sodium lauryl sulfate used in the experiments.

Resin

The resin used in the foaming experiments was obtained from Bakelite Oy (Puhos, Finland). The resin was ordinary phenol formaldehyde plywood resin, viscosity being 400–600 mPa, alkalinity 5.8–6.2%, pH 11–12, density at least 1180 kg/m^3, and resin solids 46 ± 1%.

Plywood glue

The plywood glue included phenol formaldehyde resin, wheat flour, chalk, water, surface active agent, and foaming agent. The amount of these substances was kept the same in the experiments.

Foaming experiments

Viscosities, densities, and surface tensions of unfoamed glue mixtures were determined as well as densities and surface tensions of foamed glue mixtures. Viscosity was measured with a Brookfield viscometer; density was determined by means of constant volume, and surface tension was measured with a tensiometer from Oy Lorentzen and Wettre Ab. The measurements were done at 20°C.

Foam collapsing experiments were done with some foaming agents. The measurements were done immediately after the preparation of the foamed glue mixture, and then after standing periods of 10 and 30 min, 1, 1.5, 2, 2.5, and 3 h. The measurements were done in a beaker at 20°C.

TABLE I
Viscosities of Unfoamed Glue Mixtures

Foaming agents	Viscosity (mPas)
Propylene glycol alginate, medium density	—
Sodium alginate	—
Propylene glycol alginate, low density	—
Ammonium lauryl sulphate	—
Sodium-*n*-alkyl (C_{10}–C_{13}) benzene sulphonate	3350
Fatty acid amine derivate with betaine structure	2160
Spray dried blood	4110
Soy flour from Sigma	1830
Soy flour from Lucas Meyer GmbH & Co.	2540
Sodium lignosulphonate	470
Polymeric kraft (alkali) lignin	890
Calcium lignosulphonate	640
β-Lactoglobulin enriched whey	2840
Regular whey	1600
Casein	1850
Potato cell sap	700
Carboxy methyl cellulose	1260
Ethoxylated polyarylphenol	1000
Sodium salt of an acrylic copolymer	750
Sodium acrylate	650
Sodium lauryl sulphate	3500

RESULTS AND DISCUSSION

The viscosities of unfoamed glue mixtures were measured. The viscosity values are presented in Table I. The viscosity of the glue mixture should be high, because according to the measurements, it seems that the higher the viscosity of the unfoamed glue mixture, the better the foaming results gained in the whipping experiments. The pump used in the actual foam extrusion apparatus sets limits to the viscosity value of the glue. In general, the limit can be as high as 10,000 mPa · s. The viscosities of the unfoamed glue mixtures varied between 470 and 4110 mPa · s, depending on the used foaming agent. The lowest values were gained with two lignins (470 and 640 mPa · s) and two acrylic substances (650 and 750 mPa · s). The highest viscosity values came from the glue mixtures foamed

TABLE II
Densities of Unfoamed and Foamed Glue Mixtures

Foaming agent	Density of unfoamed glue mixture (g/L)	Density of foamed glue mixture (g/L)
Propylene glycol alginate, medium density	—	463
Sodium alginate	—	436
Propylene glycol alginate, low density	—	397
Ammonium lauryl sulphate	—	239
Sodium-*n*-alkyl (C_{10}–C_{13}) benzene sulphonate	361	185
Fatty acid amine derivate with betaine structure	354	198
Spray dried blood	477	197
Soy flour from Sigma	643	250
Soy flour from Lucas Meyer GmbH & Co.	909	337
Sodium lignosulphonate	693	257
Polymeric kraft (alkali) lignin	693	248
Calcium lignosulphonate	737	261
β-Lactoglobulin enriched whey	439	205
Regular whey	564	252
Casein	806	297
Potato cell sap	646	246
Carboxy methyl cellulose	648	424
Ethoxylated polyarylphenol	674	250
Sodium salt of an acrylic copolymer	658	355
Sodium acrylate	600	308
Sodium lauryl sulphate	393	183

with spray dried blood (4110 mPa · s) and sodium lauryl sulfate (3530 mPa · s).

The densities of unfoamed glue mixtures and foamed glue mixtures were determined. The densities of unfoamed and foamed glue mixtures are shown in Table II. The density values of unfoamed glue mixtures were determined after all the glue formula components were mixed together. The glue was not yet foamed, but unavoidably, some foaming did occur. The foamed glue densities perhaps correlated the best with the quality of the foam: the lower the density value of the foamed glue mixture the better. The densities of the unfoamed glue were 354–909 g/L. The lowest density value (354 g/L) for the unfoamed glue mixture was obtained when fatty acid amine derivate was used as a foaming agent. The highest value (909 g/L) was achieved, if soy flour from Lucas Meyer GmbH and Co. acted as the foaming agent. Overall, the foam density values varied between 183 and 463 g/L. These values were attained with sodium lauryl sulfate and propylene glycol alginate, respectively. The best foam densities were obtained when sodium lauryl sulfate, sodium-*n*-alkyl (C_{10}–C_{13}) benzene sulfonate, spray dried blood, fatty acid amine derivate, or β-lactoglobulin-enriched whey were used as foaming agents. These glue mixtures had foam densities of 185–205 g/L.

The foam density is not the only measure to determine the quality of the foam. The glue mixture may have a low foam density, but at the same time the foam can be loose and therefore not suitable for foam extrusion application (i.e., the foam has to form strands). Surface tension was used as a guideline measurement for the stiffness of the glue. The surface tensions of the glue mixtures were measured both before and after foaming the glue and surface tension values of the glue mixtures are presented in Table III. The surface tension values before foaming were from 40 to 50 mN/m. The surface tension value after foaming the glue mixture was between 42 mN/m (propylene glycol alginate) and 83.7 mN/m (soy flour from Lucas Meyer GmbH and Co.). No relation can be seen between the high surface tension values of unfoamed glue mixtures and the high surface tension values of foamed glue mixtures. The surface tension of water is 72.6 mN/m (20°C). During these experiments, it was observed that when the foam surface tension was above or near the surface tension value of water, the foam was firm. Foaming agents that filled this criterion were spray dried blood, soy flour from Lucas Meyer GmbH and Co., β-lactoglobulin-enriched whey, and casein.

Foam collapsing experiments were done with some of the foaming agents. They included spray dried blood, soy flour from Sigma, β-lactoglobulin-enriched whey, casein, and sodium lauryl sulfate. The results are presented in Figure 1. The most stable foam was gained with β-lactoglobulin-enriched whey. After a 3-h standing period, this foam collapsed only 10%. Foam gained with casein dropped 17.5% from the original volume. The volume of the foam made with soy flour from Sigma diminished 20% and the one containing spray dried blood diminished 25%. The

TABLE III
Surface Tensions of Unfoamed and Foamed Glue Mixtures

Foaming agent	Surface tension of unfoamed glue mixture (mN/m)	Surface tension of foamed glue mixture (mN/m)
Propylene glycol alginate, medium density	—	42.4
Sodium alginate	—	43.6
Propylene glycol alginate, low density	—	49.7
Ammonium lauryl sulphate	—	43.3
Sodium-*n*-alkyl (C_{10}–C_{13}) benzene sulphonate	39.0	64.0
Fatty acid amine derivate with betaine structure	46.8	52.9
Spray dried blood	50.6	81.8
Soy flour from Sigma	46.5	66.2
Soy flour from Lucas Meyer GmbH & Co.	47.7	83.7
Sodium lignosulphonate	47.3	48.7
Polymeric kraft (alkali) lignin	48.3	51.1
Calcium lignosulphonate	48.4	49.7
β-Lactoglobulin enriched whey	48.5	70.3
Regular whey	47.8	54.9
Casein	47.4	70.5
Potato cell sap	49.5	60.4
Carboxy methyl cellulose	48.1	51.7
Ethoxylated polyarylphenol	46.3	53.4
Sodium salt of an acrylic copolymer	46.5	48.4
Sodium acrylate	47.2	45.2
Sodium lauryl sulphate	42.5	60.2

foam made with sodium lauryl sulfate collapsed the most during this experiment, 35%.

CONCLUSION

The best foam density values were obtained when sodium lauryl sulfate, sodium-*n*-alkyl (C_{10}–C_{13}) benzene sulfonate, spray dried blood, fatty acid amine derivate, or β-lactoglobulin-enriched whey were used as the foaming agents. On the other hand, the highest surface tension values were gained when soy flour from Lucas Meyer GmbH and Co., spray dried blood, casein, or β-lactoglobulin-en-

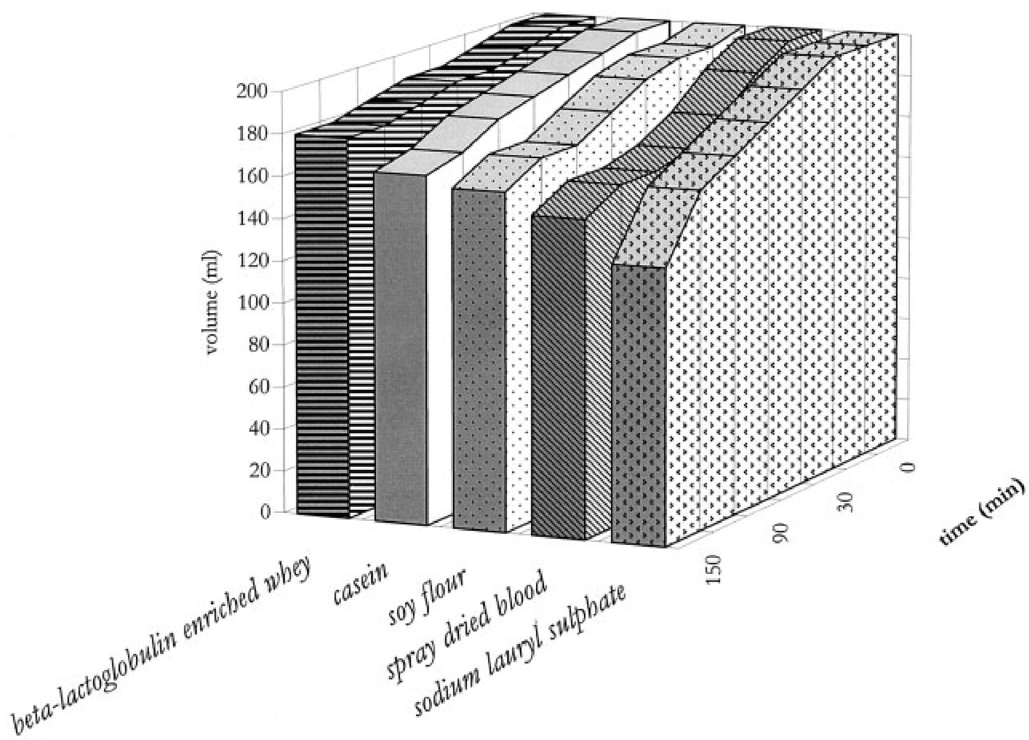

Figure 1 The results of foam collapsing experiments.

riched whey were used as foaming agents. Sodium lauryl sulfate and spray dried blood gave the highest viscosity values. By combining these results, the best choice for foaming agent in the plywood glue would be either spray dried blood or β-lactoglobulin-enriched whey. They both give good foam density and foam surface tension results. The results from foam collapsing experiments favor β-lactoglobulin-enriched whey. The five other foaming agents, sodium lauryl sulfate, sodium-*n*-alkyl (C_{10}–C_{13}) benzene sulfate, fatty acid amine derivate, soy flour from Lucas Meyer GmbH and Co., and casein, showed promising results, too. With some formula optimization, these substances could also act as glue foaming agents.

References

1. Knop, A.; Scheib, W. Chemistry and Application of Phenolic Resins; Springer-Verlag: Berlin, 1979.
2. Sellers, T., Jr. Plywood and Adhesive Technology; Marcel Dekker: New York, 1985.
3. Spelter, H.; Sleet, G. Forest Prod J 1989, 39, 8.
4. Baldwin, R. F. Plywood and Veneer-based Products: Manufacturing Practices; Miller Freeman: San Francisco, 1995.
5. Cone, C. N. Forest Prod J 1969, 19, 14.
6. Cone, C. N.; Steinberg, J. M. U.S. Pat. 3,895,984, 1975.
7. Myers, G. E. Adhes Age 1988, 31, 31.
8. Lambuth, A. L. in Wood Adhesives: Chemistry and Technology; Pizzi, A., Ed.; Marcel Dekker: New York, 1989; Vol. 2; Chapter 1.
9. Frisch, K. C. in Plastic Foams, Part I; Frisch, K. C.; Saunders, J. H., Eds.; Marcel Dekker: New York, 1972; Chapter 1.
10. Hojilla-Evangelista, M. P.; Haig, R. Agric Res Mag 2001, 49, 9.
11. Sellers, T., Jr. Forest Prod J 2001, 51 12.
12. Hojilla-Evangelista, M. B.; Dunn, L. B., Jr. JAOCS 2001, 78, 6.