SAPROPEL AS AN ADHESIVE: ASSESSMENT OF ESSENTIAL PROPERTIES

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Abstract
Recently, a renewed interest in non-harmful, environmentally friendly adhesives has ensued among the industry professionals, both environmental and healthcare scientists. In this study, organic rich lake sediments (sapropel) from two lakes located in Latgale Region of Latvia were used as a glue to investigate the potential use of such adhesive for manufacture of composite materials from wood. Sapropel is a valuable resource with multiple areas of application, e.g., agriculture, balneology. Available amount of sapropel in Latvia is estimated at up to 2 billion m^3. Prior the tests, characterization of sapropel samples was done. Properties of the obtained composite material samples from wood and sapropel, as well as the mechanical properties were investigated. Tests involved the assessment of static bending strength and shear strength tests, durability according to their operating performance (D_1-D_4), as well as dried natural peat tensile strength perpendicular to the grain direction were determined and compared to the literature data; and the opportunities to use new composite materials in accordance with to the standards were discussed. The results of the study revealed an insight into possibilities to develop products of higher added value from sapropel as adhesive in combination with various resources. Results indicated that the samples made from Lake Pilvelis sapropel gain to better results of bending strength determination (parallel bending - 88.7 MPa). The aim of this study was to explore options to produce veneer using two kinds of sapropel as a glue and to determine the optimal properties according to the standards, as well as to characterize properties of the obtained composite material.
Key words: natural adhesive, sapropel, static bending strength, tensile strength, wood composite materials.

Introduction

Over the past century, there has been a dramatic increase in the growth of the material consumption; thus, the necessity for a wider use of local resources and available natural materials is among the priorities worldwide. Development of natural adhesives is a highly innovative research area, as the product range and the expansion of global consumption will also increase the adhesive consumption. The global market of adhesives was estimated to be 8 977 m^3 in 2013, and it is expected to reach 12 392 m^3 by 2020, growing at a CARG of 4.7% from 2014 to 2020 (Kattakota, 2015). At the world level, sectors of civil engineering and building construction consume 60% of raw materials extracted from the lithosphere; thereby, the construction sector is one of the largest consumption sectors of adhesives in the world. Due to the rising environmental and economic concerns, there is an acute need for natural glues made from materials of animal and plant origin containing, for example, proteins or starch as a binding agent (Bribián, Capilla, & Usón, 2011; Stefano *et al*., 2009).

Most of the adhesives currently used contain toxic substances, pollute the environment and induce serious human and animal health risks. Major groups of glue are produced on a formaldehyde and vinyl basis, covering 92% of the overall adhesive consumption. Furthermore, formaldehyde adhesives are made from non-renewable resources. Accordingly, the wood composite industry currently has one of the challenges to look for possibilities of environmentally friendly adhesives derived from renewable resources (Yuan & Kaichang, 2006).

Sapropel is a partially renewable geological resource (Segliņš & Brangulis, 2002); it is a fine-grained organic-rich sediment or sedimentary rock and refers to inland waters of lacustrine environment (Emeis, 2009). Sapropel is a valuable resource of natural origin. It is estimated that available reserves of sapropel in Latvia amount to 700 – 800 million m^3, and 1.5 billion m^3 underlie the peat layer, but in total 2 billion m^3 are deposed (Segliņš & Brangulis, 2002). Sapropel can be used in different economic fields such as agriculture, veterinary medicine, livestock farming, construction, medicine, balneology, and cosmetic applications. It is assessed that sapropel has adhesive properties with high ability to bind as well as a plasticity and shape holding ability (Obuka *et al*., 2015). Therefore, it can be used as a binder for manufacturing of environmentally friendly materials. In this research, water repellence and adhesive properties are underlined as significant characteristics of sapropel (Brakšs *et al*., 1960; Gružāns, 1960; Штин, 2005). The aim of this study was to explore options to produce veneer using two kinds of sapropel as a glue and to determine the optimal properties according to the standards, as well as to characterize properties of the obtained composite material.

Materials and Methods

Descriptionof sapropel samples

Organic rich freshwater sediments (sapropel) were extracted from the lakes and used as an adhesive material. Sapropel sediments were sampled from two lakes in Latvia – Lake Veveru and Lake Pilvelis, located in Rezekne District, Latgale Region.

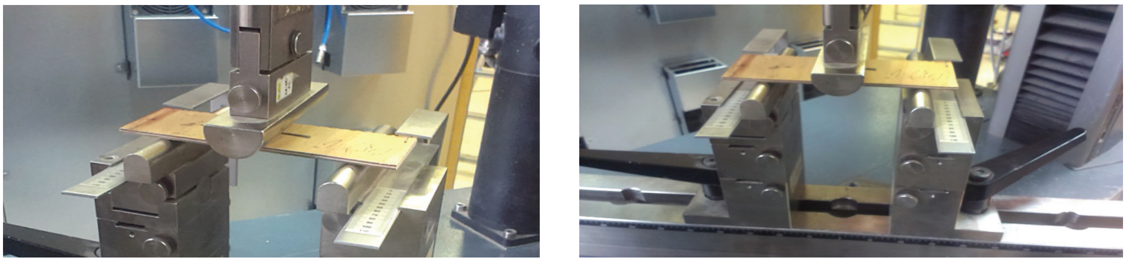

Figure 1. Veneer – sapropel static bending strength test.

Raw material of composites

Birch wood veneer with a thickness of 1.5 mm and moisture content of 6% was used for the preparation of plywood. Samples for determination of tensile shear strength: beech wood planks with a thickness of 5 mm and moisture content of 6% and with density 700 – 750 kg m^3 were used for the preparation of composite material samples for the tests. Peat samples: dried natural peat was used for tests with the moisture content of 16.4% and with density 90 – 250 kg m^3.

Loss on ignition

Loss on ignition (LOI) method was applied in order to estimate the content of carbonate matter, moisture content and the organic matter of sediments. Moisture content of sapropel was determined after drying at 105 ± 1 °C, following organic matter estimation at 550 °C for 4 h. The content of mineral substances was determined after heating at 900 °C for 2 h (Heiri, Lotter, & Lemcke, 2001). The content of dry matter was estimated after drying at 105 ± 1 °C according to standard EN 827.

Sample preparation and testing

Static bending strength (parallel and perpendicular to the grain direction), shear strength test according EN 314-1 (requirements) and EN 314-2 standards were tested (Figure 1). The sapropel samples were mixed completely just before the preparation of three-layer plywood of dimensions 4×250×250 mm. Glue spreading level for Lake Veveru sapropel was 276 – 290 g m^2 and 264 – 288 g m^2 for Lake Pilvelis sapropel. The plywood was pressed under the pressure of 2.0 MPa for 24 hours, at 100 °C for first 16 hours. The samples were stored for one day at temperature 20 ± 3 °C with 65 ± 5% relative humidity until reaching equilibrium moisture content. Subsequently, the plywood panel was cut into shear specimens with the dimension of 4×50×150 mm to determine its bending strength and 4×25×200 mm to define shear strength.

Adhesive strength of sapropel durability according to their operating performance conformity to EN 205 standard was measured. The sapropel samples were mixed completely just before the preparation of beech blanks fabrication of dimensions 10×75×600 mm. Glue spreading for Lake Veveru sapropel and Lake Pilvelis sapropel was 290 – 310 g m^2. In addition to understanding the sapropel properties used as a glue, comparing to glue that already exists in market, the samples made with PVA - Polyvinyl acetate glue were used. The planks were pressed at 100 °C under the pressure of 1.0 MPa for 24 hours. The samples were stored for one day at 20 ± 3 °C with 65 ± 5% relative humidity until reaching equilibrium moisture content. Subsequently, the plywood panel was cut into shear specimens with the dimension of 10×20×150 mm to determine the tension shear strength.

Dried natural peat and sapropel as a glue were tested for tensile strength perpendicular to the grain direction according to standard EN 319. The sapropel samples were mixed completely just before the preparation of the samples of dimensions 32×50×50 mm. Glue spreading level was 1600 g m^2 for Lake Veveru and Lake Pilvelis sapropel. The driedpeat-sapropel samples were pressed under the pressure of 0.1 MPa for 48 hours. The samples were stored for one day at 20 ± 3 °C with 65 ± 5% relative humidity until reaching equilibrium moisture content. The material samples made from dried natural peat and sapropel were tested for tensile strength perpendicular to the grain direction.

After cooling specimens at ambient conditions, the test specimens were measured for the previously mentioned methods using Zwick Z100 universal testing machine. The data in this research were processed by routine statistical analysis and displayed by the standard deviation.

Results and Discussion

Within the study, an adhesive for veneer was made using two kinds of sapropel derived from Lake Pilvelis (cyanobacteria sapropel) and Lake Veveru (green algae sapropel). The following characteristics of the sapropel samples were determined: solid content, moisture, density, and dry ash content (Heiri *et al.*, 2001). Sapropel samples differ from one another in terms of moisture (%), organic matter content (%), amount of carbonates (%) and solid content (%). For example, the Lake Pilvelis sapropel sample contains 1.26% carbonates, its moisture is 85.97%, and the

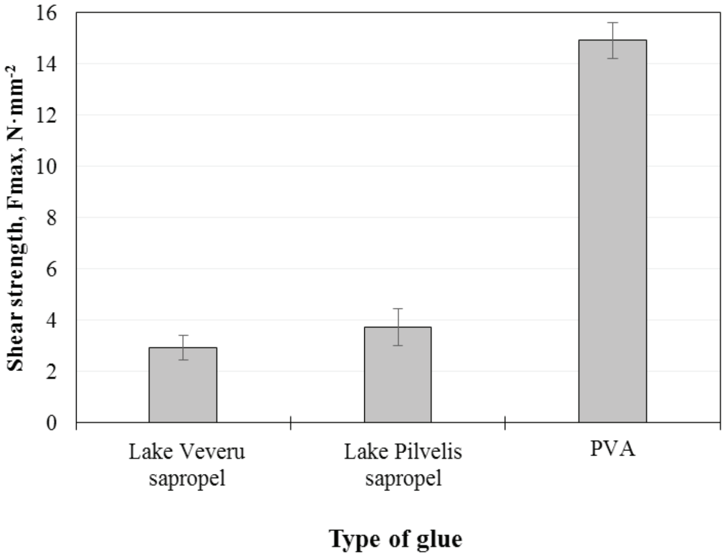

Figure 2. Durability test according to adhesive operating performance.

colour is dark greenish brown with homogeneous and jelly-like structure, with density 1.10 g cm^3 and solid content 30.1%. The moisture level of Lake Veveru sapropel sample is higher – 97.66%; it has lower density – 1.08 g cm^3 and the organic matter content reaches 86.25%, but solid content is 27.1%.

Adhesive strength of sapropel was tested by gluing veneer, plywood and natural dried peat. Several tests were performed: static bending strength (parallel and perpendicular to the grain direction) and shear strength testing, durability according to their operating performance dried natural peat (sapropel as a glue) tensile strength perpendicular to the grain direction. The total number of tested samples is 110.

Shear strength properties of wood composites bonded with Lake Pilvelis and Lake Veveru sapropel, as well as PVA (Polyvinyl acetate) glue was compared according to standard EN 205 (Figure 2).

As anticipated, the PVA bonded wood composites yielded the highest strength comparing to Lake Veveru and Lake Pilvelis sapropel samples. Comparing both sapropel samples, Lake Pilvelis sapropel showed a bit higher bonding strength by 28%. Compared to PVA, the dry strength of Lake Pilvelis sapropel used as an adhesive was about 4 times lower, respectively, while PVA-beech plywood sample achieved 15.11 N·mm^{-2}, but Pilvelis beech test result was only 3.67 N·mm^{-2}. In literature it is possible to find information about similar tests done with recovered sludge protein used as an adhesive (Pervaiz & Sain, 2011). If comparing in the article stated results with results of sapropel used as an adhesive in the current study, it is possible to say that shear strength properties are quite similar. Shear strength for recovered sludge protein used as an adhesive was about 2 N·mm^{-2} (Pervaiz & Sain, 2011).

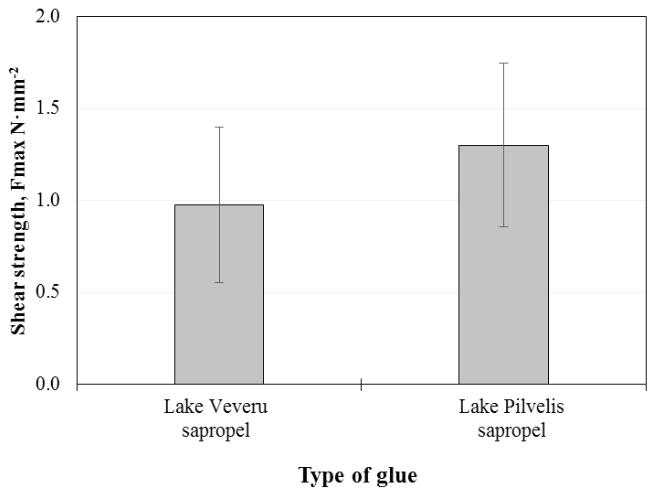

Figure 3. Plywood bonding quality using sapropel as a glue.

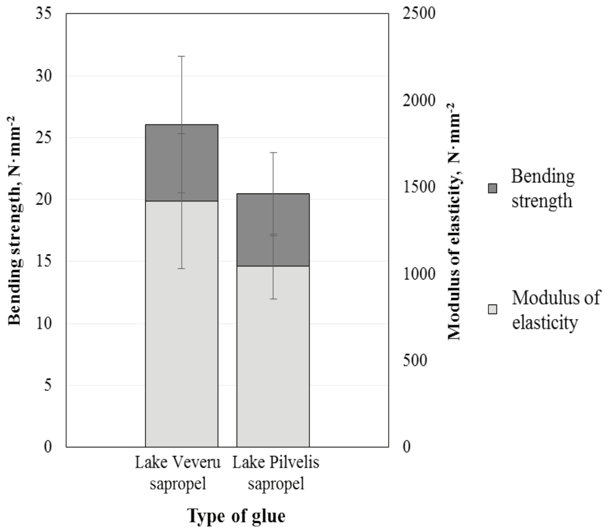

Figure 4. Bending strength parallel of plywood composites.

Bonding quality was determined according to the requirements of standard EN 314-1, the only exception was that samples were not treated in water. Two types of sapropel were tested (Figure 3).

Bonding quality test results using Lake Veveru sapropel showed shear strength Fmax 0.98 ± 0.42 N·mm^{-2}, while using Lake Veveru sapropel Fmax 1.30 ± 0.45 N·mm^{-2}. Results of samples made with Lake Pilvelis sapropel showed higher results by 33%. According to the requirements of standard EN 314-2 for plywood bonding, the quality of composite material must be at least 1 N·mm^{-2}, otherwise wood particles left on tested bond area have to be taken in consideration. All tested samples had 0% of wood particles. It was possible to state, that the sapropel as a glue was not penetrating into wood. Since the requirements of standard EN 314-1 were applied only for sample formation, it was not possible to find any comparison of other similar composite materials described in literature.

Values of elasticity modulus were estimated for specimens with plywood orientation parallel (Figure 4) and crosswise (Figure 5) to the specimen longitudinal direction. Modulus of elasticity and bending strength was done according to the requirements of standard EN 310.

Bending strength for Lake Veveru sapropel samples orientated parallel to the specimen longitudinal direction was 26.08 ± 5.50 N·mm^{-2}, modulus of elasticity 1419.80 ± 387.74 N·mm^{-2}. Bending strength for Lake Pilvelis sapropel samples orientated parallel to the specimen longitudinal direction was 20.47 ± 3.36 N·mm^{-2}, modulus of elasticity 1043.80 ± 187.70 N·mm^{-2}. Samples using Lake Veveru sapropel as an adhesive showed by 27% higher bending strength and by 36% higher modulus of elasticity.

Bending strength for Lake Veveru sapropel samples orientated crosswise to the specimen longitudinal direction was 88.55 ± 19.68 N·mm^{-2}, modulus of elasticity 16424.10 ± 2558.30 N·mm^{-2}. Bending strength for Lake Pilvelis sapropel samples oriented crosswise to the specimen longitudinal direction was 86.44 ± 11.79 N·mm^{-2}, modulus of elasticity 1043.80 ± 187.70 N·mm^{-2}. Samples using Lake Veveru sapropel as an adhesive showed by 2% higher bending strength and by 15% higher modulus of elasticity.

The results obtained from the bending strength parallel and crosswise to the grain direction of plywood composites revealed that the composites where Lake Veveru sapropel was used as an adhesive had better results among the analysed sapropel samples. According to the standard EN 636, it is possible to determine bending strength and bending modulus classes for plywood. Referencing to the standard EN 636, samples with Lake Veveru and Lake Pilvelis sapropel used as an adhesive corresponded to the class F10/40 E5/120.

In addition, tests according to the standard EN 319 were performed to detect dried natural peat and sapropel as a glue for tensile strength perpendicular to the grain direction. The results obtained were as follows: 0.077 MPa for Lake Pilvelis sapropel used as an adhesive, but for Lake Veveru sapropel used as an adhesive - 0.067 MPa. This test of dried natural peat and sapropel used as a glue for tensile strength test showed that the material strength (dried natural peat) is relatively lower; thus, the test results do not reveal the real properties of sapropel used as a glue. It is important to mention that the adhesive seam strength is higher than the material's ability to hold off the tensile test. High porosity is the reason of low mechanical strength of the derived dried peat composite material.

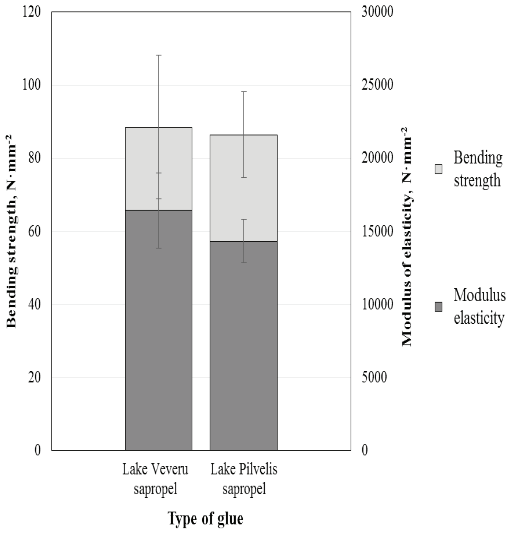

Figure 5. Bending strength crosswise of plywood composites.

As a further study area, the modification in adhesion strength of sapropel adhesives might incorporate bio-chemical modifications, such as enzymatic treatments, and the purification of crude proteins to the next level. Various different crosslinkers (Lei *et al*., 2014), for example, epoxy resin (EPR), melamine-formaldehyde (MF) and their mixture EPR+MF, SPI (soy protein based glue) were used and compared in other studies. More promising possibility lies in mixing sapropel with other high strength adhesives such as PF, which can also improve water resistant characteristics of these bio-based glues.

Several reports have shown that secondary sludge (SS) from a kraft paper mill can be used as a source of biomass to recover protein and investigate its potential use as a wood adhesive. As mentioned in the literature review, other results are comparable to this research (Pervaiz & Sain, 2011), and the results of our study showed shear strengths of wood composites bonded with different adhesives, in this case secondary sludge, 1.0 MPa, Therefore, recovered sludge protein (RSP) adhesive showed two times better result than sapropel as a glue in this research.

Conclusions

Returning to the question posed at the beginning of this study, that it is a challenge to produce plywood from organic rich lake sediment (sapropel) applied as a glue, it is now possible to state that the first test results reveal that there is an opportunity to use sapropel as a potential adhesive, but there is a need for further experiments. Performed tests indicated that higher adhesive properties can be attributed to Lake Pilvelis sapropel which is richer in solid content. Shear strength properties tests showed Lake Pilvelis samples possessing a higher bonding strength by 28%. Bonding quality test also showed higher results by 33%. It would be interesting to assess the effects of sapropel modification and after that to form new experiments with more detailed investigation. The present study confirms previous findings and offers additional evidence, which suggests that the granulometric composition of the material (size of particles), surface area and other characteristics of the material used as a glue, binder or filler have an effect on the binding with sapropel. The advantage of this study was a practical demonstration that sapropel can be used as an adhesive for plywood manufacturing. The research extends our knowledge of using natural materials and local resources, such as sapropel, as well as birch wood veneer, and it is possible to develop environmentally friendly composite materials for the construction industry, adjusting for the need of utilization in future.

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