The Effect of Oriented Strand Board Substrate Treatments on the Adhesion of Cement Adhesives and Coatings

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Abstract. Thanks to its properties, wood as a building material has unbelievable potential. It simultaneously provides answers to frequently discussed questions concerning the renewability of resources and the energy performance of buildings. The material most frequently used as sheathing for timber structures is planar large-format oriented strand board (OSB). The unfavourable effects of the weather on unprotected wood and timber products can cause changes to the mechanical and chemical properties of the wood, and if unchecked can do irreversible damage. It is therefore always necessary to apply additional surface finishes to sheathing. In the case of peripheral walls, these surface finishes usually comprise an outer thermal insulation system, while in the case of internal surfaces, extra sheathing made from board materials is added via adhesion or mechanical attachment. It is possible to glue extra layers directly onto OSB, but only if suitable adhesives are used, and the range of products is limited. The research described in this article focuses on the treatment of OSB substrate so that it is possible to employ cement adhesives that are commonly used for the gluing of thermal insulation but which cannot normally be used on an untreated base without the danger of adhesion loss. The research concerns a comparison of test specimens with various kinds of penetrative coating or bonding primer applied under predefined conditions and subjected to different forms of applied loading. The contribution contains a definition of the substrate material, test specimens, test methods and a selection of 5 different types of material for the surface treatment of the test specimens. Tables comparing the influence of the individual finishes on the adhesion itself are included in the outputs. The conclusion contains the test results as well as a presentation of the effects of individual treatments, and potential further research is suggested. The results are of benefit to subjects involved in the preparation and realization of construction work that deal not only with timber structures in particular but also with the general use of OSB structures as a part of the building envelope.

1. Introduction

Wood has been used for the construction of dwellings in every phase of human history, and is one of the oldest building materials. Some of the first structures to have been build from wood include dugout shelters, roofed dugouts, stake-based structures, palisade-walled houses, tents, huts and screening walls. Later various construction systems began to develop, including log houses, half-timbered dwellings, frame and skeletal structures and buildings formed from solid wood [1]. The advantages of the material are primarily its easy workability, high strength in relation to weight and good insulation properties [2].
Last but not least, there is also the very important ecological aspect of timber structures, as wood is a unique 100% renewable construction material whose use instead of unrenewable materials based on fossil fuels significantly reduces environmental impact (carbon footprint). Additionally, the processing of timber requires but a fraction of the energy needed for the production of other construction materials, such as concrete, steel, aluminium or plastics. It is the only construction material capable of producing energy even in the final phase of its existence [3, 4, 5]. Timber structures are very resistant against earthquakes, and if designed appropriately for the risk, are also suitable for regions subject to regular flooding [3].

Planar, large-format oriented strand board (OSB) is a material essential in modern timber construction. Thanks to its advantages, which include high strength and stiffness, resistance to surface bulging, dimensional stability, good fire resistance properties, harmlessness to human health and pest resistance, OSB sees universal use. In timber structures it is mainly employed as sheathing for load-bearing structures both in the interior and exterior of buildings, and it may even act as a load-bearing material itself, as is the case with traditional American SIP (Structural Insulated Panel) technology [6]. Particularly in outdoor applications, oriented strand board is affected by weather conditions. Accelerated ageing treatment indicates that weather, and particularly moisture, has an adverse affect on OSB, causing swelling [7, 8] and changes to mechanical characteristics [8, 9, 10, 11]. Building envelopes made up of OSB need to be protected from adverse weather conditions via the application of surface finishes. For OSB these can take the form of thin layers of coating [12, 13] or spray finish, though the gaps between the boards (and the treatment of such gaps) represent a critical problem. Because external insulation systems are often fitted on buildings in order to save energy and lower atmospheric pollution, the amount of carbon dioxide and sulphur dioxide decreases with declining energy consumption. It can generally be stated on the basis of international research that the users of buildings expect a high level of thermal insulation and comfort in the interiors of buildings [14]. When the optimum insulation thickness is used, energy savings can be achieved, which is an important part of every national energy strategy. As a result, there is a lot of research focusing on optimizing the thickness of thermal insulation [15, 16, 17, 18]. The question however remains as to how insulation which is not built into the load-bearing structure of a timber building can be anchored to the building envelope.

The gluing of additional layers straight onto OSB panels is possible, though conditional on the use of appropriate adhesives, of which the available range is limited. The source of the problem is the substrate itself, i.e. the OSB. It is a homogenous, smooth and nonabsorbent material, which has a marked influence on the adhesion of any layers attached to it. Adhesion can generally be improved by mechanically abrading the substrate [19, 20], modifying the adhesive layers [21, 22], or using penetrative coatings [23] or bonding primers.

The research detailed in this article focuses on the treatment of OSB substrate using penetrative coatings or bonding primers. The aim of the whole experiment is to select approaches that will enable the results of the laboratory work to lead to unambiguous conclusions regarding the long-term reliability of the bond between the substrate (modified by a suitable treatment) and the cement adhesives used to glue the components of the thermal insulation system to it. Such adhesives could not be used at all without the treatment of the substrate, as in this case there would be a risk of loss of adhesion, so the use of the optimum treatment can result in major savings for the constructed building.

2. Materials and methods

2.1. Specification of the OSB substrate

The substrate chosen for the purposes of the experiment was selected with regard to the function it fulfils in the real world. The purpose of the external sheathing of a structure, which often also acts as a load-bearing element, is equivalent (according to the classification of the OSB/4 standard) to an individually
loadable load-bearing panel for use in moist environments [24]. The basic parameters of the substrate are given in the table below (Table 1). The sizes of the test specimens were chosen with regard to the proposed experimental procedures: 100 × 100 mm and 100 × 25 mm, with a thickness of 15 mm.

| Table 1. Production characteristics of the OSB/4 test specimens. |
|---------------------------------------------------------------|
| **Type of base material** | **Content of base material** |
| Absolute dry wood weight (mainly softwood, type pine and spruce, hardwood content up to max. 30%) | 85-92 % |
| Water (wood moisture) | 4-6 % |
| PMDI glue in the surface and core layer | 3-6 % |
| Paraffin wax emulsion | ≤1 % |
| Pressure | 150-250 bar |

2.2. Penetrative coatings, bonding primers

It should be possible to improve the adhesion of cement adhesives to the substrate using a penetrative coating or bonding primer. The purpose of such products is to markedly increase the adhesion of the surface after they have dried. During the selection of adhesives for testing, consideration was given to the properties of the substrate, and products were chosen that are normally available on the market. A detailed overview of the specifications of the products used is given in the following table (Table 2). The manufacturer’s instructions concerning the application of their products were followed completely. The required pause to allow the applied penetrative coating / bonding primer to dry before additional layers were added was observed. In order to be able to determine the effect of the surface finish applied to the substrate on adhesion, one set of samples were left as reference specimens without any treatment.

| Table 2. Specifications for penetrative coatings and bonding primers |
|---------------------------------------------------------------|
| **Treatment number** | **Product description** | **Product type** |
| 1 | Modified dispersion with quartz sand | Bonding primer |
| 2 | One-component solvent-free coating, mixture of fillers and aggregates in a water styrene-acrylate dispersion with additional additives | Bonding primer |
| 3 | Solvent-free water-soluble primer based on a synthetic resin dispersion and mineral additives | Bonding primer |
| 4 | Mixture of water and a nanodispersion of styrene-acrylate copolymer and additives | Penetrative coating |
| 5 | Acrylic copolymer water emulsion penetration primer | Penetrative emulsion |

Figure 1. Samples treated by penetrative coatings and bonding primers (from the left, treatment numbers 1–5 according to Table 2)

2.3. Cement adhesive

Cement adhesive designed for the gluing of all types of insulation used in thermal insulation systems (polystyrene, mineral wool) was applied to the test specimens according to the appropriate technical
procedure. The test specimen was placed in a mould-like fixture which held it while adhesive was applied in a 3mm layer and smoothed out to make the surface uniformly level with the top of the fixture so that the test discs could be glued there. The test specimens used for shear strength determination during the tensile loading of overlapping bonded assemblies (see Section 2.6) were formed from two strips of basal material with the dimensions 100 × 25 mm which were joined together by a 3mm layer of cement adhesive over a length of 12.5 mm (± 0.25 mm). The samples were stored for a period of 28 days in a standard 23/50 environment according to ČSN EN ISO 291 [25] in order to allow the adhesive to cure. The cement adhesive can be used as a plaster upper reinforcing layer.

Table 3. Technical parameters of cement adhesive.

| Properties                              | Average values |
|-----------------------------------------|----------------|
| Adhesion to the base after 28 days – concrete | 0.25 N/mm²     |
| Adhesion to the base after 28 days – polystyrene | 0.08 N/mm²     |
| Adhesion to the base after 28 days – mineral wool | 0.08 N/mm²     |

2.4. Test for surface finish adhesion of building structures to the base

The test procedure is defined in the technical standard ČSN 73 2577 [26]. The test involves measuring the tensile force – applied perpendicular to the surface of the specimen – needed to tear the surface finish from the substrate. To perform the test it is necessary to bond a test disc to the test specimen using epoxy resin adhesive according to the technical instructions provided by the manufacturer. The specimen is then placed in a mould and an FP 10/1 pull-off tester with a maximum strength of 10 kN is used to carry out the test. Measurements are taken during the application of tensile loading at a speed of 5 mm/min (Figure 2). Adhesion to the substrate is calculated according to formula (1) below. The number of samples is set at 6 for each surface finish according to the relevant standard.

\[ \sigma_{adh}(\tau) = \frac{F_{\text{max}}}{A_{\text{ef}}} \]  

where

- \( \sigma_{adh}(\tau) \) adhesion (tensile strength), alternatively shear strength, in N/mm²
- \( F_{\text{max}} \) maximum strength achieved at joint failure, in N
- \( A_{\text{ef}} \) effective area of the bonded joint, in mm²

![Figure 2. Test equipment for measuring tensile strength](image)
2.5. Test for frost resistance of surface finish of building structures
The test procedure is based on the standard ČSN 73 2579 [27]. The aim is to monitor the effect of frost on the adhesion of bonded layers to a substrate. The test specimens are subjected to an alternating cycle of freezing (18 hours at –20 ± 3 °C) and thawing (6 hours at +20 ± 2 °C) for a total amount of fifteen cycles. This is followed by the determination of adhesion according to the test procedure given in ČSN 73 2577 [26].

2.6. Test for resistance or surface finish of building structures to acute temperature variations
The test according to ČSN 73 2581 [28] subjects the test specimens to alternating cycles of heating (to 70 ± 3 °C) and cooling (to 20 ± 2 °C). The effect of the 25 cycles on adhesion to the substrate is subsequently determined according to ČSN 73 2577 [26].

2.7. Determination of tensile lap-shear strength of bonded assemblies
The method of determining the shear strength of overlapping bonded assemblies under tensile loading (Figure 3) specified according to ČSN EN 1465 [29] ascertains the strength of the joint itself. The shear strength is then determined according to formula (1) in Section 2.4.

3. Results and discussions
OSB test specimens treated with 5 types of coating designed to increase the adhesion of the cement adhesive to the substrate were subjected to testing according to the procedures listed above. The achieved results are presented in tables below. The values stated in red have been left as they were measured, though they are lower than 70% of the arithmetic mean and were not included in the evaluation of the results according to the relevant standard.

The samples tested according to ČSN 73 2577 [26] were subjected to their tests after the cement adhesive had been allowed to cure for 28 days (at a temperature of 23 °C and a relative humidity of 50 %). The results of these tests are given in Table 4. It is possible to say that almost all of the surface finishes had a positive effect on the adhesion itself. The samples without a surface finish, and those treated with product No. 4, achieved such low adhesion that the cement adhesive simply fell off the substrate by itself during normal handling (Figure 4). On the basis of the measured values it would seem
that the best surface finish was product No. 1 (modified dispersion with quartz sand), followed by product No. 2 (one-component solvent-free coating, mixture of fillers and aggregates in a water styrene-acrylate dispersion with additional additives).

Table 4. Adhesion of cement adhesive to the substrate in MPa.

| Test specimen | Finish No. 1 | Finish No. 2 | Finish No. 3 | Finish No. 4 | Finish No. 5 | Without finish |
|---------------|--------------|--------------|--------------|--------------|--------------|----------------|
| 1             | 0.266        | 0.229        | 0.029        | 0.000        | 0.195        | 0.000          |
| 2             | 0.156        | 0.149        | 0.031        | 0.000        | 0.284        | 0.000          |
| 3             | 0.252        | 0.326        | 0.074        | 0.000        | 0.233        | 0.000          |
| 4             | 0.319        | 0.282        | 0.000        | 0.000        | 0.372        | 0.000          |
| 5             | 0.368        | 0.246        | 0.000        | 0.000        | 0.077        | 0.000          |
| 6             | 0.293        | 0.317        | 0.000        | 0.000        | 0.221        | 0.000          |

Figure 4. Spontaneous adhesion failure of cement adhesive

The set of specimens exposed to cyclic freeze-thaw testing according to ČSN 73 2579 [27] achieved significantly worse results (Table 5). This fact can be attributed to the effect of the action of water. After the freezing part of the cycle, the specimens are thawed out in a water bath for 6 hours at a temperature of +20 ± 2 °C. The OSB thus has the opportunity to absorb water, causing the substrate to undergo changes in volume (swelling) as a direct result. In other words, adhesion failure can occur specifically due to the dimensional instability of the substrate. None of the tested products can be considered a suitable surface finish for the substrate in the case of this test. None of the tested sets were shown to perform suitably throughout the whole extent of the 15 freeze-thaw cycles, as the adverse conditions had the effect of causing the cement adhesive to spontaneously fall off the substrate. Nonetheless, finishes No. 3 and 4 can be said to be absolutely unsuitable, as their results are the same as that of the untreated sample.

Table 5. Adhesion to the substrate in MPa after frost resistance testing.

| Test specimen | Finish No. 1 | Finish No. 2 | Finish No. 3 | Finish No. 4 | Finish No. 5 | Without finish |
|---------------|--------------|--------------|--------------|--------------|--------------|----------------|
| 1             | 0.248        | 0.248        | 0.000        | 0.000        | 0.133        | 0.000          |
| 2             | 0.011        | 0.200        | 0.000        | 0.000        | 0.018        | 0.000          |
| 3             | 0.027        | 0.006        | 0.000        | 0.000        | 0.005        | 0.000          |
| 4             | 0.119        | 0.017        | 0.000        | 0.000        | 0.008        | 0.000          |
| 5             | 0.000        | 0.000        | 0.000        | 0.000        | 0.000        | 0.000          |
| 6             | 0.000        | 0.000        | 0.000        | 0.000        | 0.000        | 0.000          |
The test specimens subjected to sudden temperature changes according to ČSN 73 2581 [28] attained the results presented in Table 6. The adhesion values obtained were not high, but finishes No. 1, 2 and 5 had a positive effect. In particular, surface finish product No. 5 exhibited the highest values for adhesion to the substrate, performing favourably even in relation to the specimens which were not exposed to temperature changes (Table 4). This fact is attributed to the phase when the specimens were heated to 70 ± 3 °C, when the effect of the high temperature caused the water emulsion of the acrylic copolymer to permeate below the surface of the substrate. The product attained such a high adhesion to the base that the failure of the bonded joint occurred according to ČSN 10365 [30] as a combination of partial CSF-type failure (failure of one of the adherends) and CF-type failure (cohesion failure), which is clear from Figure 5. The ability of the products labelled No. 3 and 4 to improve the adhesion of layers bonded to the treated substrate was not demonstrated in the case of this test, as they failed to exhibit values higher than zero.

**Table 6. Resistance of cement adhesive against sudden temperature changes in MPa.**

| Test specimen | Finish No. 1 | Finish No. 2 | Finish No. 3 | Finish No. 4 | Finish No. 5 | Without finish |
|---------------|--------------|--------------|--------------|--------------|--------------|----------------|
| 1             | 0.285        | 0.238        | 0.000        | 0.000        | 0.600        | 0.000          |
| 2             | 0.126        | 0.052        | 0.000        | 0.000        | 0.553        | 0.000          |
| 3             | 0.254        | 0.038        | 0.000        | 0.000        | 0.477        | 0.000          |
| 4             | 0.023        | 0.019        | 0.000        | 0.000        | 0.145        | 0.000          |
| 5             | 0.009        | 0.000        | 0.000        | 0.000        | 0.226        | 0.000          |
| 6             | 0.000        | 0.000        | 0.000        | 0.000        | 0.720        | 0.000          |

![Figure 5. Failure of the bonded joint via a combination of CSF and CF-type failure](image)

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The cement adhesive of the specimens with overlapping joints (Figure 6) was cured for 28 days before being subjected to a test performed according to ČSN EN 1465 [29]. The test basically confirmed the results gained from the test according to ČSN 73 2577 [26]. The best results were achieved by product No. 1, though the treatment with product No. 2. also attained good results. However, it was again confirmed that the surface finish provided by product No. 4 does not fulfil its function, and finishes No. 3 and 5 do not seem to be effective either.
Table 7. Shear strength in MPa.

| Test specimen | Finish No. 1 | Finish No. 2 | Finish No. 3 | Finish No. 4 | Finish No. 5 | Without finish |
|---------------|-------------|-------------|-------------|-------------|-------------|----------------|
| 1             | 1.406       | 0.229       | 0.029       | 0.000       | 0.133       | 0.000          |
| 2             | 0.765       | 0.149       | 0.031       | 0.000       | 0.018       | 0.000          |
| 3             | 1.330       | 0.326       | 0.074       | 0.000       | 0.005       | 0.000          |
| 4             | 1.682       | 0.282       | 0.000       | 0.000       | 0.007       | 0.000          |
| 5             | 0.743       | 0.317       | 0.000       | 0.000       | 0.221       | 0.000          |

Figure 6. Failure of an overlapping joint via failure type AF

4. Conclusions
The aim of the project was to ascertain whether, and to what extent, the treatment of an OSB substrate with a penetrative coating or bonding primer has an effect on the adhesion of cement adhesive. To a certain extent, the results of the experiments confirmed the assumption that adhesion would increase after treatment of the substrate with suitable products. The samples which had not been treated in any way failed to achieve any adhesion between the cement adhesive and the substrate, and neither did the penetrative coating based on a mixture of water, a nanodispersion from styrene-acrylate copolymer and additives. The solvent-free water-soluble primer based on a synthetic resin dispersion and mineral additives didn’t achieve much better results, and only had a minimal effect on adhesion in comparison with the untreated samples. It is possible to rate the remaining treatments positively, as they had a beneficial impact on adhesion, even though they did not achieve particularly high values in the case of the samples exposed to alternating cycles of freezing and thawing, or sudden temperature changes involving heating and cooling. The primary function of cement adhesive is the bonding of thermal insulation to a substrate. It can thus be said that with regard to its final placement in a structure, cement adhesive will not be exposed to the effects of freezing in real-world applications. Similarly, under normal weather conditions it is not probable that structures will be subjected to such marked and sudden temperature variations. It can be said that the application of a suitably chosen surface finish to a substrate can significantly affect the degree of adhesion of subsequent layers to that base. It is evident that an OSB substrate is a problematic type of base and will require further research using an expanded set of tested materials not only for the treatment of the substrate itself, but also for the gluing of ETICS insulation boards. Aside from cement-based adhesive mortars, it would also be beneficial to add other glues which are without cement content to the group of tested adhesives.

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