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# Creating a connection between asphalt wearing surface and timber bridge decks

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## Abstract

Timber bridges are increasingly popular again in infrastructure networks nowadays. Protection of timber structural elements from direct exposure to rain and sun is essential to prevent biological degradation of the wood material when using softwoods. In case of a timber deck, the asphalt wearing surface must be watertight. Creating connected layups has advantages over layups where the asphalt is not connected as traffic loads are transmitted directly to the bridge deck: asphalt surfaces can be loaded with heavier traffic, slopes of bridges can be higher, breaking and acceleration loads are directly transmitted to the bridge deck, and fatigue life of the asphalt is improved. The Swiss standard VSS 40 451 standardized an unconnected mastic asphalt surfacing on timber bridges. Research project VSS 2016/326 was performed to investigate road layups where asphalt wearing surfaces were connected to the bridge deck. This work presents only a part of the results, focused on the bonding issues. Results show that such a layup proves to deliver satisfactory performances, and that shear capacity is comparable to that of concrete and steel decks. Good surface quality of the timber deck is important before application of the bonding agent to avoid short term blistering of the asphalt.

## 1 Introduction

Timber bridges know a long tradition within Europe and the rest of the world [1]-[5]. Use of raw materials continues to become more efficient, new timber products are developed and load bearing systems are developed. Timber is now recognized next to steel and concrete as a main structural material [6]-[9]. The development of Glued Laminated Timber (GLT), Cross Laminated Timber (CLT), and Stress Laminated Timber (SLT) has contributed to this regained interest [10]-[14].

Along with the introduction of the motorized vehicles, so have the requirements to the wearing surface, not only on timber bridges. Use of Mastic Asphalt (MA) or Asphalt Concrete (AC) became an important research topic in the development of new timber bridges [15]-[17]. The asphalt not only serves as a skid resistance, but it is also offers a water-proof layer for the timber [9][17][19]. This is essential for the longevity of softwood timber decks [20]-[22]. The asphalt wearing surface can be separated from the supporting timber deck or connected to it, thus establishing a shear bond or a composite layup in the bridge deck (Figure 1). The shear bond is used on concrete and steel bridge decks, and it is standardized in the EN 12970 [23] or SN 640 450 [24]. Despite the performed research on connected layups for timber bridges [15][16][17][25], the authors are only aware of standardized unconnected layups in VSS 40 451 [26].

When the road layup is connected, it typically consists of the (timber) road deck, a bonding agent, a modified polymer bitumen membrane (PBM) and the asphalt wearing surface. In a floating layup, the bonding agent is replaced by a glass-fiber mat or oil-paper to separate the timber deck from the PBM and thus from the asphalt wearing surface, too [15]-[17][24][26]. In a connected layup, the service life of the asphalt on concrete and steel bridges is longer: in the order of 40 years in connected layup compared to 20 years in unconnected condition [27]. When asphalt and bridge deck are connected, the asphalt is loaded primarily in compression and less in bending, which is better for the fatigue life of the asphalt surface every time a

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bridge deck with asphalt wearing surface

| | connected layup | floating layup |
|---|---|---|
| wearing layer<br>binding layer<br>base/protection layer | asphalt wearing surface of<br>Mastic Asphalt or Asphalt Concrete | |
| waterproofing membrane | Polymer Bitumen Membrane or liquid plastic | |
| bonding agent | primer or sealant | glass fiber mat or oil paper |
| substrate/bridge deck | bridge deck of concrete or<br>wood based material like CLT/SLT/GLT/LVL | |

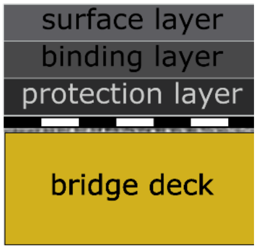


*Figure 1: Bridge deck layup as described in the SN 640 450 and VSS 40 451[24][26]*

vehicle crosses. The need for a connection between the supporting wooden deck and asphalt layer is further recommended for the following cases [16]: (1) For bridges that are designed for heavy traffic, (2) In bridges with road inclinations of more than 6%, (3) In bridges located in curves, close to traffic lights or locations where traffic is expected to accelerate or to decelerate.

During and after the application of mastic asphalt (MA), there is a risk of blistering that can result in damage of the asphalt layer [28]-[30]. Any (leftover) water in the substrate is potentially transformed into vapour (short term blistering). Blisters formed shortly after application of the base layer can continue to grow in the continuing years due to heating and cooling of the asphalt due to solar heating (long term blistering). The formation of the latter type is often a consequence of weak quality procedures due to tight, weather affected, building schedules.

In 2007, the Obermatt bridge (30 meter and 40 tons, Lauperswil CH) was equipped with such a system [31], just like the Isalas (20 meter and 10 ton traffic load, Celerina CH) and the Ova da Bernina (22 meters and 40 ton traffic load, Pontresina CH) built in 2020 [32]. Until now, good long-term experience has been obtained using the composite system in the Obermatt bridge.

The presented research aims at examining the composite layup and its different aspects: used substrate materials (bridge decks) and bonding agents, development of temperature in different layers during application of the base layer of the MA, blistering under different thicknesses of the base layer (MA8 and MA11), and mechanical aspects such as shear and adhesion capacity [18].

## 2 State of the Art

### 2.1 Connected layup on timber bridges

As mentioned in the introduction, GLT, SLT, and CLT are popular materials when it comes to the bridge deck, so is Laminated Veneer Lumber (LVL). GLT beams are used in stress laminated bridge decks [12] [31]. Relatively new  to the wood products market is the CLT.

SLT is a relative stiff material for the road deck. This was used with bonding agent (Isoglasyr 11P) and PBM (SBS) to determine the bonding quality of the road layup [15]. Whether the boards in the SLT where rough sawn, planed, or sanded did not affect on the adhesion strength. Secondly, blisters in the PBM were also seen to occur already before the application of asphalt due to heat from solar radiation.

Optimal properties of MA for timber decks we investigated [16]. An inert oil coating was one of the main bonding agents before waterproofing with MA (10 mm thick), PBM (5 mm thick), and bitumen B80 (2 mm thick). Specimen sizes were 0.2 m x 0.2 m and wood-based panels (amongst others LVL) were used, many only several cm thick. Moisture in the wood increased the risk of blistering of the asphalt base layer, even if the moisture content was below 13%-m. Authors also stated that the thinner the base layer (MA8 instead of MA11), the better the blistering could be mitigated.

Timber deck layups similar to those for concrete (SN 640 450) were also made [17]. Both LVL and CLT were used as substrate and compared to references on steel and concrete. Epoxy (EP) as bonding agent together with PBM and liquid plastics were used as a waterproofing membrane, too. The test specimen size was 0.2 m x 0.2 m, however significantly thicker panels were used than in [16]. The road structure layup consisting of wood, EP, PBM and MA could be made without any short-term blistering. However, blistering could occur in sealings made with liquid plastics. Shear capacities with connected layups on CLT and LVL led to equal values as on steel and concrete substrates.

## 2.2 Asphalt wearing surfaces

MA has a higher content of binding agent of 6.5 - 8.5%-m, compared to conventional AC and proved to be very stable and resistant to aging. It is generally heated to 230 °C to obtain a good workability for the laying phase. The working temperature can be reduced to 190 °C when using additives as for instance wax.

MA is self-compacting whereas (AC) must be compacted. The compacting can lead to high vibrations of the bridge deck. AC is not recommended either on bridge decks, as the timber deck is often believed to be too flexible and the required compaction energy, up to a void content of 3%-Vol, cannot be introduced with common asphalt mixtures [16]. Examples where AC was used, have varying success [16][17][25].

## 2.3 Bonding agent/sealing

The bonding or sealing agent enhances the connection between the bridge deck and the PBM. For instance, after the casting of concrete, lighter fine material is left on the upper surface. This is removed by sand or shot blasting [33], simultaneously removing smaller air bubbles which might have formed just below the upper surface. The bonding or sealing agent is then applied which fills smaller cracks and holes during its curing, thus creating a strong top layer in the bridge deck to which the PBM can be melted. The SN 640 450 mentions minimum requirements to the quality of the bridge deck before applying a bonding agent.

Examples of modern bonding agents on concrete and steel are bituminous lacker, EP or liquid plastics such as Polymethyl Methacrylate (PMMA) or Polyurea (PUA) [24][33]. PMMA has gained in popularity due to its short curing times, reducing time of construction and dependency of weather in comparison to the EP bonding agent.

In practice, EP is preferred over inert oil as it solvent free, is easy to apply, quality is better controlled and has an excellent adhesion to concrete, higher than 1.5 N/mm$^2$. It is often applied in two layers, and sand is used to roughen the surface of the bonding layer and to improve shear capacity once the PBM is melted [34].

## 2.4 Adhesion strength tests

The adhesive tensile strength of the PBM membrane is temperature related [24]. Adhesive tensile capacity of the seals were tested for both PMMA and EP/PBD [17]. Similar tests were also performed with PBM on different bonding agents, mainly inert oil [16]. The adhesive strength of the layup with PMMA was better than that of EP/PBM. Published results mentioned above are compared to experiments performed in this research project (Table 1).

## 2.5 Shear strength

Shear tests that can prove the suitability of the road layup over the entire service life are not available yet [35]-[37], however, relative comparisons can be made. The most common methods to test the shear strength are based on monotone loading like the Leutner test or the related Advanced Shear Test (AST). Dynamic test methods have been developed but have not found their way yet into international standardization, yet [38].

Shear capacities between SLT timber decks and asphalt wearing surfaces were tested using specimens of 115 mm x 175 mm (square specimens) [15]. These were simultaneously loaded by a normal load. Similar tests, without normal load, were performed with samples of 200 mm x 200 mm, both on substrate materials of LVL and CLT [17]. Specimens with PMMA waterproofing membrane were stiffer in shear than those with PBM seals, but also showed a brittle fracture behavior, too. There were no measurable differences between the shear response of the MA on concrete, steel, and wooden panels when a PBM waterproofing membrane was used. The Leutner test (150 mm and test at speed of 50 mm/min) was used to test the shear strength of MA on concrete using different types of PBM membranes [35]. Published results from both sources are presented in Table 2, together with experimental results from tests performed in this research.

## 3 Material and methods

### 3.1 Variants

CLT, GLT (resembling the setup for SLT), and LVL were selected as representative materials for a timber bridge deck in these experiments. The CLT and GLT were ordered using C24 strength calss boards of spruce and pine. The surface qualities differed from: (1) Quality D/Industry: material failures are visible and not sealed (CLT and GLT). (2) Quality C/Industry+Visible: smooth planed and sanded surface. Material failures are filled and leveled out (CLT). To simulate cases where bridges decks had higher moisture content, for instance if repair work needed to be carried out, some panels were climatized to achieve humidity of 18%-m and 24%-m instead of the more common 12%-m. The panel size was 1.0 m x 1.0 m x 100 mm (length x width x thickness). The moisture of the panels was measured before application of the bonding layer using a GANN Hydromette M4050.

Four concrete slabs with dimensions of 0.8 m x 0.8 m x 100 mm were produced to do reference test.

Wood and concrete panels were sealed with EP (Sikadur® -188) [34] and PMMA (ALSAN REKU P70 [39] and Eliminator Par1 [40]). The EP was applied in two layers of about 500 g/m$^2$ each, and sand was mixed into the first layer. The PBM was the SOPRALEN IMPACT MA/AC Flam with a thickness of 5 mm. The PMMA waterproof sealings were applied on the PMMA bonding agents too [41]. MA8 and MA11 was applied in layers of 25 mm and 40 mm, respectively. Only in one case, the MA11 was applied with 230 °C, in all other cases between 190 °C and 200 °C.

### 3.2 Adhesive bonding test

The adhesive bond was tested according to the SN EN 1542 [42], using stamps of 50 mm in diameter per variant. The adhesive bonding test was performed on (1) the primer, (2) the combination of primer and waterproofing membrane, and (3) the combination of primer, waterproofing membrane, and base layer of asphalt. In each test, the weakest layer was expected to fail. The standard requires that the average capacity of three tests must be higher than 1.5 N/mm$^2$ on the bonding agent, but is temperature dependent on the waterproofing membrane, for instance 0.46 N/mm$^2$ at 20 °C.

### 3.3 Leutner and Advanced Shear Test

Leutner and AST tests are performed using cylinders cut from the road of 150 mm diameter. In the AST, a normal load is applied to the road surface, too, to realistically simulate the forces of a braking vehicle on the road layup [33][35] (Figure 2). The normal load during execution of the AST is applied using loaded springs, so the normal load decreases or increases as the surface deforms in normal direction. Experiments were performed with a 10 kN normal load.

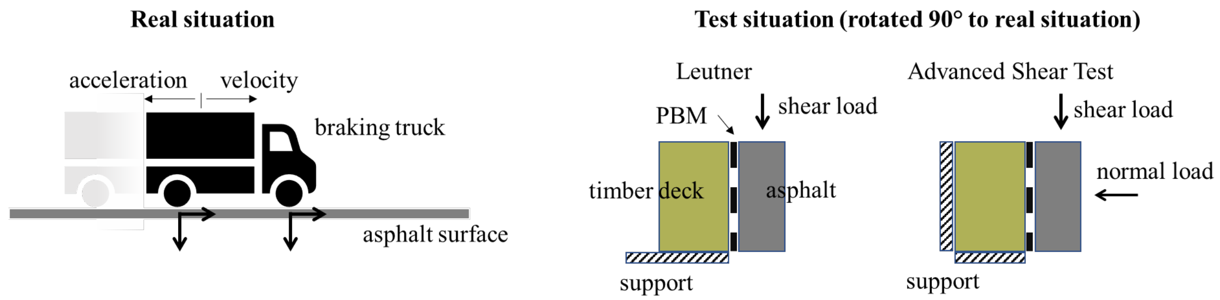


*Figure 2: Illustrated difference between real situation and simplified situation and load application during Leutner and ADS test*

### 3.4 Temperature measurements

The temperature levels in different layers of the timber panels during application of the MA are unknown. The temperatures in multiple layers of the road layup and timber panel were measured in both P31 and P32, where MA8 and MA11 were applied, respectively. Figure 2 shows the position of the sensors on the PBM waterproofing layer, in the EP bonding agent, and in the middle of the four upper layers of the CLT panel (five layers 20 mm thick). Before application of the asphalt, the temperature in the asphalt heater was measured using a Metra© Asphalt Thermometer.

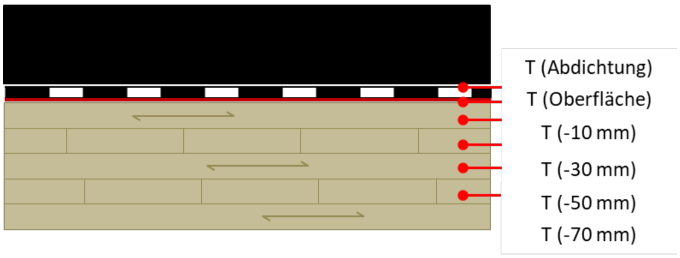


*Figure 3:Instrumentation of panels P31 and P32 with temperature thermocouplee type K-sensors.*

### 3.5 Glass transition temperature

The glass transition temperature $T_g$ helps to determine the temperature when the phase of materials changes, e.g., from solid to liquid. The method measures the difference in the amount of heat required to increase the temperature of a sample. This point was determined for both the EP and PMMA using the Differential Scanning Calorimetry (DSC) method.

## 4 Results

### 4.1 Climate conditioning of the timber panels

Panel P03 and P11 were obtained straight from the production line and had a moisture content below 12%-m. The rest of the panels were climatized and humidity was achieved to a satisfactory level of the target values of 12%-m, 18%-m and 24%-m. The humidity of the concrete panels was higher than targeted (3%-m), but within the limits of application of the bonding agents (Table 1).

*Table 1: Average values of the adhesive bonding tests on the primer, the membrane, and asphalt with panel humidity and testing temperature (where relevant and available)*

| panel | primer/ waterproofing | humidity | adhesive capacity primer | adhesive capacity membrane (temperature) | adhesive capacity asphalt (temperature) |
|---|---|---|---|---|---|
| P11 (CLT)<br>P31 (CLT)<br>P51 (SLT)<br>K6 (LVL) | EP/PBM | 9.8%-m<br>13.9%-m<br>12.4%-m<br>16.1%-m | 3.5 N/mm²<br>3.9 N/mm²<br>3.5 N/mm²<br>1.7 N/mm² | 1.17 N/mm² (13.0 C)<br>1.21 N/mm² (21.7 C)<br>-<br>1.21 N/mm² (22.0 C) | 0.97 N/mm² (15.0 C)<br>1.03 N/mm² (23.9 C)<br>-<br>1.00 N/mm² (23.8 C) |
| P41 (CLT)<br>K2 (LVL) | EP/PBM | 19.4%-m<br>18.1%-m | 4.9 N/mm² | 1.25 N/mm² (21.4 C) | 1.07 N/mm² (24.0 C)<br>1.03 N/mm² (24.1 C) |
| P1 (CLT)<br>K1 (LVL) | EP/PBM | 21.2%-m<br>24.1%-m | 2.3 N/mm²<br>- | 0.64 N/mm² (21.3 C)<br>- | -<br>1.00 N/mm² (24.2 C) |
| P03 (CLT)<br>P38 (CLT)<br>K3 (LVL) | PMMA/PMMA | 8.8%-m<br>13.7%-m<br>16.4%-m | | 3.3 N/mm²<br>4.0 N/mm²<br>1.8 N/mm² | |
| P22 (C) | EP/PBM | 3.8%-m | 4.25 N/mm² | 1.28 N/mm² (13.0 C) | |
| P24 (C) | PMMA/PMMA | 4.0%-m | | 4.25 N/mm² | |
| Different [15] | | | | Between 0.40 N/mm² and 0.55 N/mm² | |
| CLT [17]<br>LVL [17] | EP/PBM | | | 0.33 N/mm²<br>0.43 N/mm² | |
| CLT [17]<br>LVL [17] | PMMA/PMMA | | | 1.41 N/mm²<br>1.12 N/mm² | |

### 4.2 Adhesive bond

The adhesive tensile capacities of the different layers are observed in Table 1. The table lists the panel number, the material, the humidity and average adhesive capacity of the different layers. Wherever relevant, logged temperatures of the panels, are listed, too.

The following results are formulated: (1) All the minimum capacities (of bonding agent, membrane, and MA) were met, (2) the panel humidity has little effect on the capacity of the bonding agent, (3) the tensile capacity of the bonding agent on LVL panels is systematically lower than that of the CLT and SLT panels, and (4) capacity on the timber panels and on the concrete panels is similar.

During the testing of the adhesive capacity of the primer, the glue between stamp and primer sometimes failed instead of the bond between primer and substrate itself. Adhesive bonding values for the combination of EP/PBM are better than those measured by [17] (temperature unknown). For the PMMA waterproofing membranes, values are similar.

### 4.3 Shear capacity

The shear capacity of six different layups is shown in Figure 3. The comparison of the results to values found in literature and mentioned in the state of the art is made in Table 2. From the six diagrams, two important conclusions can be drawn:

- Whether the panel is made of CLT, SLT/GLT, LVL, or concrete, the resistance is determined by the combination of bonding agent and waterproofing membrane. No dilitation of any layers in the layups was observed, i.e. EP/PBM connected exellent to the substrate or MA even though it was applied with low temperature (190 °C)
- Using either EP/PBM or PMMA determines the properties of the development of shear resistance, hence weak and plastic or strong and brittle, respectively.

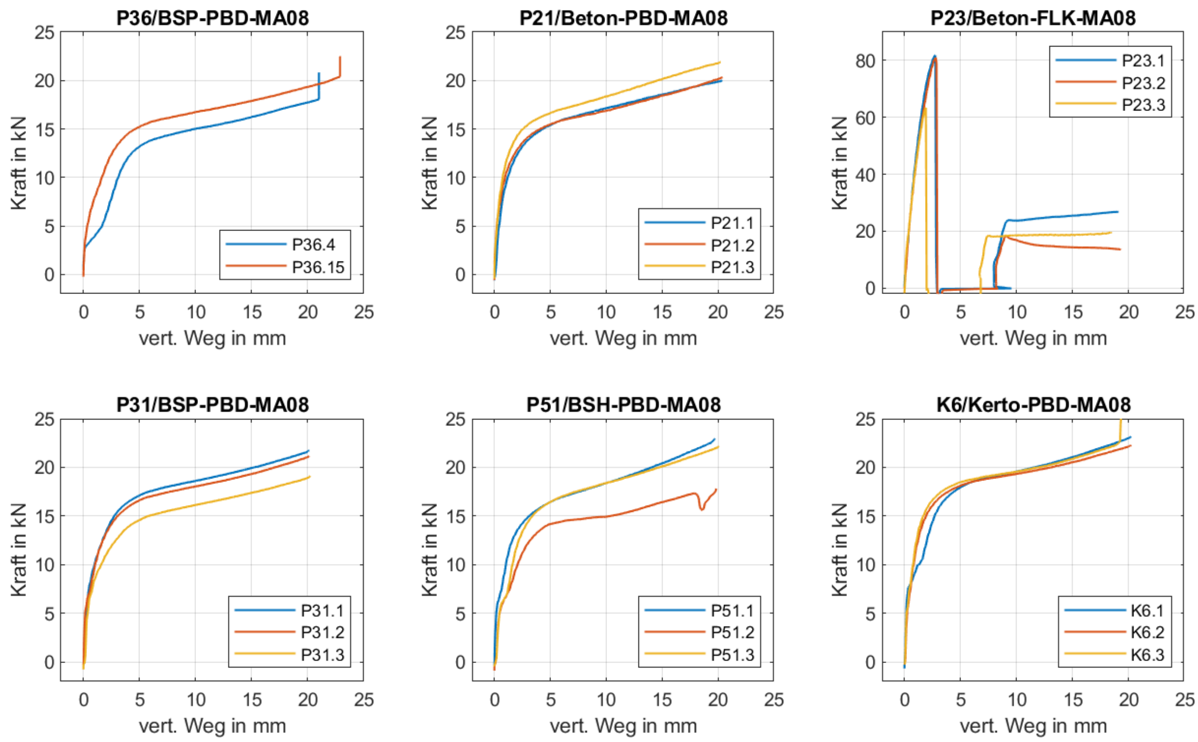


*Figure 4: load displacemnt diagrams of different road layups*

*Table 2: Measured capacity of shear bond*

| | **Pousette (1998)** | **Müller und Scharmacher (2013)** | **Raab und Partl (2014)** | **AST (deformation 10 mm)** | **AST (deformation 10 mm)** |
|---|---|---|---|---|---|
| | **literature** | **literature** | **literature** | **experiment** | **experiment** |
| Specimen size | 115 mm x 175 mm | 200 mm x 200 mm | Ø 150 mm | Ø 150 mm | Ø 150 mm |
| Load application | 10 mm/min | 5 mm/min | 50 mm/min | 1 mm/min | 50 mm/min |
| Normal load (perp. to layup) | 0.7 N/mm$^2$ | no | no | 10 kN | 10 kN |
| Substrate | Timber | Timber | Concrete | Concrete | Timber |
| Capacity [kN] | | | 10.6 kN | 5 kN | 15.9 kN to 18.0 kN |
| Capacity [N/mm$^2$] | 0.17 to 0.23 N/mm$^2$ | 0.2 N/mm$^2$ | 0.60 N/mm$^2$ | 0.28 N/mm$^2$ | 0.90 to 1.26 N/mm$^2$ |

The shear strengths obtained in experiments compare well with the results of Raab and Partl [36], with shear strengths between 0.4 N/mm$^2$ and 0.7 N/mm$^2$ (SBS-PBM). However, those drill cores were tested without any normal load (Leutner test). Results depend on speed of load application too, those with low speed (1 mm/min) have about 3.6 lower resistances than those at high speed.

### 4.4 Blistering of the MA after application of the base layer

Most of the MA was applied with target temperature of 190 °C. Nevertheless, blistering could not be avoided, and was sometimes even provoked on purpose. The extent of the blistering was determined visually. They usually appeared within 10 minutes after application of MA. The following conclusions apply to these tests:

- on the concrete panels, regardless of EP/PBM and PMMA waterproofing system, no blisters appeared.
- In CLT and LVL panels with PMMA waterproofing systems blisters appeared in panels with the eliminator® and ALSAN® products.
- The CLT panels sealed with bituminous products and PBM, very large blisters developed.
- The CLT panels with poor surface quality (industry) and EP/PBM sealing systems, several larger blisters appeared.
- In the CLT panels with good surface quality (industry visible) and EP/PBM sealing systems being, no blisters appeared using either MA08 or MA11 below 200 °C.
- In the SLT panels with industry quality and EP/PBM sealing systems no blisters appeared in the panels with MA08, and only small blisters appeared in the panel with MA11. These could theoretically be repaired on-site.
- In the LVL panels with normal quality and EP/PBM sealing systems, no blisters appeared.

Summarizing, this means that although PMMA systems function well on concrete, these do not work well on timber. EP/PBM systems work on wood, but only if a good surface quality is used. Moisture of the timber panels did not show a visible difference in blistering: on the LVL panels no blisters were visible whereas these were on all the CLT panels. Finally, there was a tendency of panels with MA11 (40 mm) had more blisters than those with MA08 (25 mm).

### 4.5 Temperature developments in P31 and P32

Temperature measurements in panels P31 and P32 during and after application of the asphalt are seen in presented in Figure 4. The measurements made in the different layers during the application of MA8 (P31, MA temperature 188 °C) and MA11 (P32, MA temperature 194 °C). The temperature of the panels right before application of the asphalt was. The following observations are made.

- The maximum temperature in the sealing of both panels lies at 105 °C (P31) and 109.5 °C (P32). It is noted that the temperature of the panels was nearly equal (22 °C and 21 °C, respectively) and that of the MA11 asphalt was only 6 °C higher than that of the MA08.
- The development of the temperature in both panels is similar, although stretched in P32 (MA11) compared to P31 (MA8).
- The differences between the temperatures measured in the sealing and 10 mm deeper into the wood panel are 30 °C (3.5 °C/mm in the P31 and 4.0°C/mm in P32). Shortly after application of the MA, these are higher because the development of heat in the wood material is delayed.

### 4.6 Glass transition temperature

The *Tg* for both tested bonding agents was difficult to determine, as the energy required for the phase change was very small. For the PMMA (3% Catalysator), a Tg (at 139°C) and with the EP, a *Tg* of 94 °C, was measured.

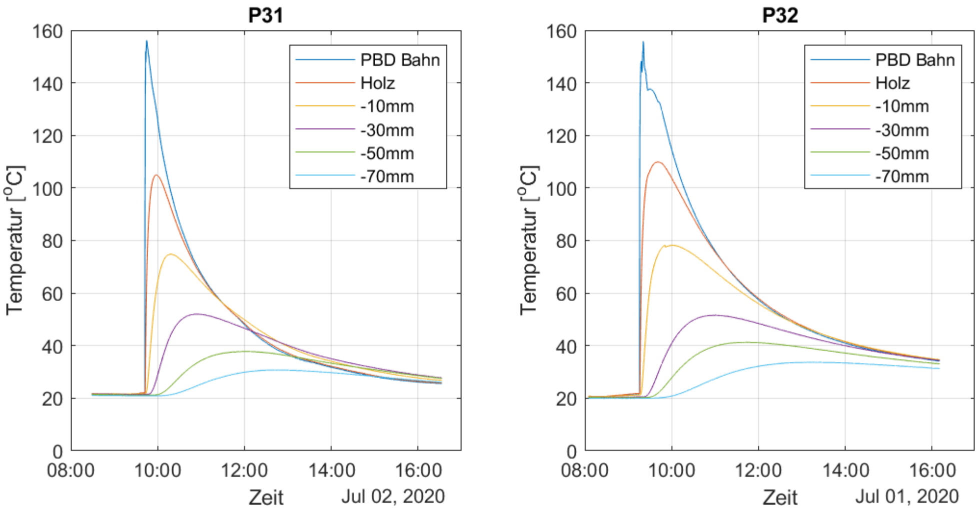


*Figure 5: Developement of temperatures in different layers of panels P31 and P32 during the application of asphalt MA8 (25 mm) and MA11 (40 mm).*

## 5 Discussion

### 5.1 Adhesion capacity

The adhesion capacity of different sealing systems met requirements set by standards and compared well with values found in literature. Above 18%-m a slight reduction in adhesion strength was observed, but not to the extent that values failed the minimum requirements. This suggests that the connected layup can also be applied on existing timber bridges where moisture contents are higher than during construction. The adhesion strength of the bonding agent on LVL was lower than that on CLT, plausibly be due to the peeling of the veneers in the production of LVL where small micro-cracks develop in the wood.

Whether set by standard or found in literature, tensile capacity is higher than the characteristic tensile strength perpendicular to the grain 0.45 N/mm$^2$ set by the SN 14080 [43] or the design strength perpendicular to the grain of 0.15 N/mm$^2$ set by the SIA 265 [44]. It is reasonable to assume that there is a volume effect. The above-mentioned values are used for a reference volume of 1 dm$^3$, whereas the diameter of the stamp is in only 50 mm and the tested volume is at best a tenth of that (0.1 dm$^3$, 50 mm diameter and 50 mm depth).

### 5.2 Shear capacity

Although brittle, the shear capacity of PMMA showed outstanding results on concrete panels, up to 70 kN with a cylinder of 150 mm diameter. On either CLT or LVL, these layups could not be produced due to extensive blistering. On sealing systems using EP and PBM, the shearing behavior on CLT, SLT/GLT, and LVL panels was equal to that observed on concrete panels. There seems to be no reason for concern in shear capacity of the bond.

### 5.3 Temperature

Earlier work recommends base layers of MA8 (25 mm) only, because MA11 (40 mm) base layers lead to significantly higher input of energy and temperature. It is relevant to note that inert oil was used as a bonding agent in those tests [16]. However, a comparison of the temperature developments measured in P31 and P32, only showed a couple degrees difference in maximum temperatures in the bonding agent. Such temperature measurements have not been made up to now.

A comparison of the measured temperatures with the glass transition temperatures is perhaps more interesting. At a *Tg* of 95 °C, EP already enters the liquid phase. However, during experiments, only a softening of the EP was visually observed on chips of material left around the panels after application of the bonding agent. The question is raised if the 4.5 °C (105 °C MA8 and 109.5 °C at MA11) difference is really decisive for the EP, in such a way that it is absolutely not recommended to use MA11. The transition from the solid to the liquid phase is smooth, perhaps so smooth that the determination of the *Tg* here is probably more of an estimate. The *Tg* on the concrete panels is perhaps never passed.

In measurements which were not presented here, the *Tg* of PMMA are almost reached as well. The temperatures in the bonding layers were at least 35 °C higher than on the EP/PBM layup. It is reasonable to assume too, that the pressure of vapour gas developed in the top layer of the wood was higher, too.

Calculated temperature gradients were around 3.5 °C/mm, meaning that that the high temperatures only develop in the first couple of millimeters of the wood panel.

### 5.4 Blistering

Blisters always appeared on wood panels with poor surface quality, regardless of the type of bonding agent. It is recommended to use CLT panels with high surface quality where the edges of the boards are glued to each other too. Using SLT or LVL, production quality was sufficient, but still, it is recommended to monitor the presence of cracks, knots, holes, etc., and if necessary seal these before application of the EP primer.

On concrete, long-term blistering is often observed after two or three years [29][30]. This was also observed in timber bridges in Sweden [25] where other bonding agents were used. No blisters are yet observed on the Obermatt bridge, even after 13 years where an EP primer and PBM was used.

### 5.5 Compatibility of PMMA with resin

PMMA would not cure when terpenes (resin pockets and knots), were present in wood. This makes it practically impossible to use PMMA, unless a primer or method can be found to bind or fix these terpenes before the PMMA is applied.

## 6 Conclusions

MA surfacing on timber wood panels can be made under the following conditions:

- Good wood-panel surface quality. On CLT, this means that Quality C is a minimum, in SLT/GLT or LVL, production quality (D) is generally sufficient.
- Only EP as a bonding agent, applied in two layers, as prescribed by the SN 640 450 can be used.
- Adhesive bond test showed that a minimum average value of 1.5 N/mm$^2$ per three stamps can be expected, although it exceeds the characteristic tensile capacity perpendicular to grain.
- The adhesive bonding properties of EP are not affected by moisture below 18%-m and only minimally reduced above 18%-m. Hence, EP can also be applied on existing bridges when repair work is needed.
- Equal shear resistances are obtained when using wood or concrete bridge decks in the above-mentioned layups.
- Temperature in the bonding agent needs to be kept low. MA is to be applied with a temperature below 200 °C, both in MA8 or MA11. Risk for blistering can slightly be reduced, for instance on warm days, with MA8 in a base layer of 25 mm thickness. Any surface irregularities in the first layer of the MA are eliminated once the intermediate or top layer is applied again.

Further development of PMMA systems is recommended. Application could alternatively be used if upper layers of bridge decks are made in hardwood for instance, where no terpenes are present. The system with the highest potential for application on wood was the ELIMINATOR® system. Apart from short curing time, the sealing of PMMA is much harder than that of PBM, which increases service life of frequently crossed bridges such as in highways (>50000 vehicles a day).

During application of the base layer of MA, the maximum temperatures achieved in the bonding agent are slightly higher than the *Tg*. The extent of the softening of the bonding agent is to be investigated further.

To reduce the risk of delays on the construction site due unfavorable weather, it is recommended to seal bridge decks already in a production hall. Joints can be sealed on site.

Experience with asphalt surfacing on timber bridges is gained by building an applying these systems in real bridges. Roadway authorities are asked to provide objects where these systems can be applied and monitored. This also allows to investigate the properties of long-term blistering and compare these to bridges made in concrete for instance.

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