Practical aspects of interaction between mastic asphalt and waterproofing components in bridge and tunnel construction

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Due to their technical advantages, waterproofing systems with Gussasphalt mastic asphalt, polymer-bitumen water proofing membranes and asphaltic plug joints are widely used for bridges and tunnels in Switzerland. Experience shows that type of solution is very successful and durable if planning, selection of material quality and application are conducted professionally and with special care regarding the interaction between the different components of the system.

This article focuses firstly on the interaction between polymer bitumen asphaltic plug joints and the adjacent pavement, especially on the debonding which may occur due to incorrect planning or construction. Secondly, the practical aspects of the compatibility between the mastic asphalt and the polymer bitumen waterproofing membranes, as well as the application of mastic asphalt, are explained and discussed.

1 INTRODUCTION

In Switzerland most of the waterproofing systems and asphaltic plug joints for bridges and tunnels are constructed with Gussasphalt (GA) mastic asphalt, a dense bituminous mix which is poured to the waterproofing surface at a comparatively high temperature of maximum 250°C without mechanical compaction. GA has many advantages such as good waterproofing properties, high durability and easy application. However, practical experience clearly demonstrates, that serious failures may occur, if planning, design, materials selection, quality assurance and application is not taken into account sufficiently [1, 2, 3]. Such failures promote the penetration of water and de-icing agents into the waterproofing system and may thus result in dangerous corrosive structural damage, expensive maintenance and re-construction work as well as costly traffic jams and risky temporary change of traffic flow requiring extremely narrow lanes especially in tunnels. As an example, *Figure 1* demonstrates what happens when defects in the waterproofing system are discovered too late. In case of this Swiss alpine tunnel, penetrating water together with de-icing agents produced severe corrosion and the whole construction has to be replaced now under enormous costs.

Typically, these failures are often caused by interaction problems between the different materials of the waterproofing system, such as loss of adhesion between Gussasphalt and the other waterproofing components of the system and generally not a problem of the single component itself. This paper concentrates on the interaction between Gussasphalt (GA) and the polymer-bitumen asphaltic plug joints (APJ), especially with respect to debonding effects due to poor pre-treatment, dirty or humid contact surfaces as well as tension failure at the adhesion interfaces in winter time. In addition, practical aspects of compatibility between GA and polymer bitumen waterproofing membranes (PBM) are explained and discussed.

Figure 1: Deterioration of a concrete traffic plate at a joint promoted by de-icing agents due to failure of the waterproofing system in an alpine Swiss tunnel.

2 GUSSASPHALT (GA) AND ASPHALTIC PLUG JOINTS (AJP)

2.1 *APJ Systems in Switzerland*

Figure 2 shows a cut through a polymer-modified APJ which is typically 500mm wide and 70..160mm thick. The gap has a width of 10...60mm and is covered by a steel plate, which prevents the APJ material to be squeezed into the gap under traffic load. To avoid stress concentrations and cracks, friction between the steel plate and the joint material should be reduced to a minimum. APJ systems are required to work within a temperature range of the building from -20°C to +35°C and to take gap closing and opening from -12.5mm to 25mm (assuming zero-opening at 10°C). With respect to bridge bearing replacements they should also be able to suffer vertical gap movements to a maximum of 5mm.

In Switzerland, the first asphaltic plug joints were build in the eighties of the last century promoted by considerable enthusiasm because of their advantages over traditional solutions: simple and fast application, low costs, simple maintenance, good waterproofing and expansion properties under Swiss climatic conditions, positive influence on traffic noise reduction and driving comfort as well. However, the increasing use of APJ resulted in various damages as schematically shown in Figure 3.

Typical damage may occur in summer time when the APJ may be too soft and material may be squeezed out by the tire pressure, e.g. in case of breaking. In the winter, damage may show up as cracks or, even worse, as debonding between APJ and GA.

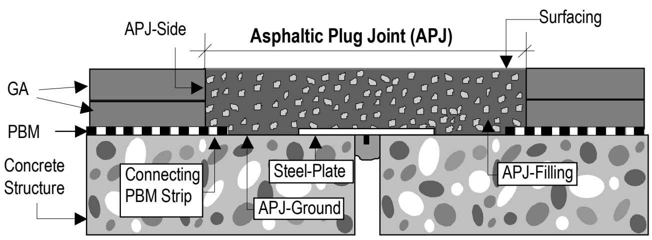


Figure 2: Cross section of a polymer-modified asphaltic plug joint (APJ)

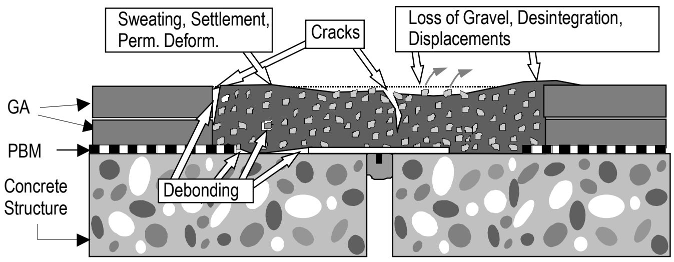


Figure 3: Typical distress types with APJ

Triggered by the damages and the fact that no planning, installation and test procedures were available in Europe at that time, a task group was formed in Switzerland consisting of government officials, planners, industry representatives, laboratory testing experts in order to prepare an ASTRA-guideline (ASTRA: Swiss federal roads office) for APJ in fall 1998 [4]. This work was done in close coordination with the activities of a corresponding task group in Germany. The new guideline defines system structure and application range. It contains system and material requirements including appropriate test procedures as well as instructions on quality management and practical execution of the construction.

2.2 *APJ and GA Interface*

According to the Swiss ASTRA-guideline the pull-off adhesion strength between APJ and the adjacent pavement must exceed 1.5N/mm^2. In addition, these pavements must have an air void content of less than 6 Vol-% otherwise a 1m wide pavement patch of a dense pavement, such as GA, should be placed on both sides of the APJ in order avoid lateral water penetration during construction and under service conditions (barrier effect).

In case of pavements with high air void content and rainfall lasting for days immediately before the APJ construction, it is practically not possible to achieve a dry interface between the pavement and APJ. As shown in *Figure 4,* during construction, wet pavements can produce poor interfacial bond between the pavement and APJ. In such cases, water penetration from the pavement is often prevented by applying melted APJ sealing material. However, this measure may help momentarily but does not solve the problem because of debonding phenomena, which will most likely occur at these locations.

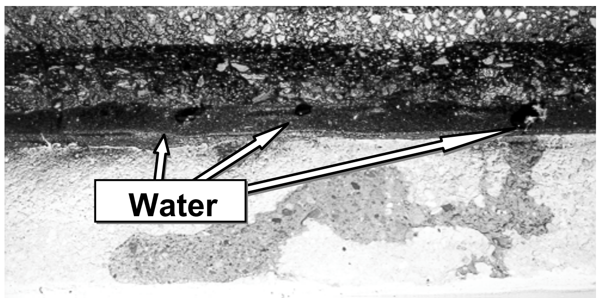


Figure 4: Water is dripping sideways from a pavement with high air void content into a bed open for APJ installation

During service life, water from the neighboring adjacent pavements with high air void content may build up at the APJ-side and destroy the adhesion between APJ and the pavement in summer time. During winter this water may freeze and ice-induced debonding may occur as shown in case of *Figure 5* where a porous asphalt pavement was used. The damaged part is located at the zone where most of the water could accumulate within the porous asphalt pavement. Clear side debonding occurred in the asphalt shoulder after only 2.5 years

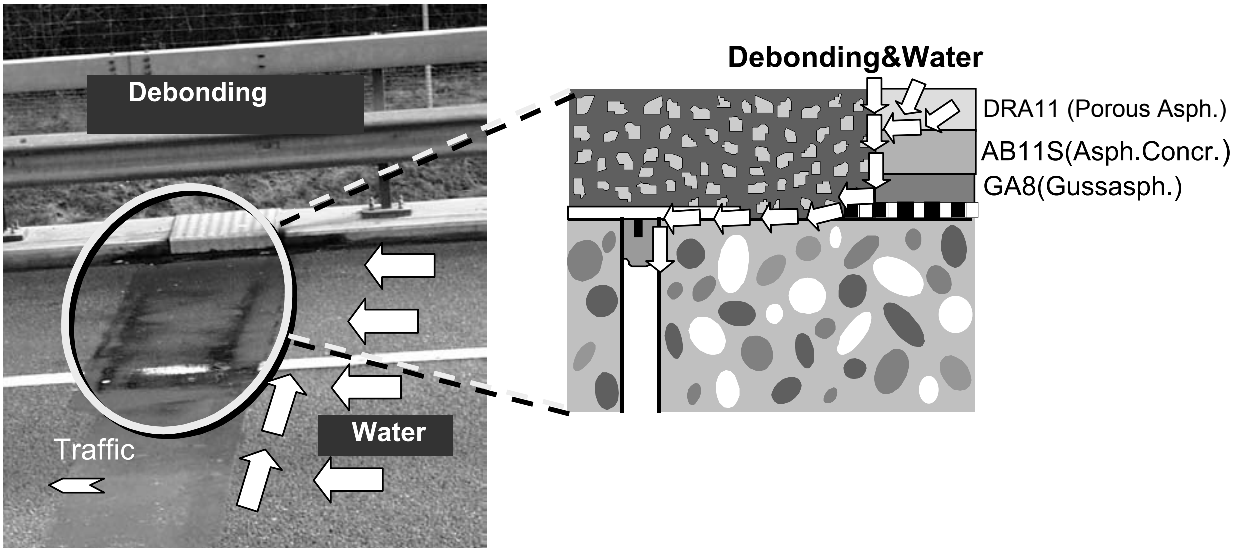


Figure 5: Debonding between APJ and porous asphalt

2.3 *APJ Installation*

2.3.1 *Activation of the contact surface between GA and APJ*

Activation of the GA surface at the APJ-side by heating before APJ installation is of predominant importance for perfect adhesion between APJ and the neighboring pavement. It is recommended to use a hot-air fan because of its additional advantage that the strong hot-air wind removes weak zones of the pavement. Activation of the GA surface at the APJ-side surface has to be carried out carefully to avoid partial burning and overheating of the connecting PBM strip (*Figure 2*). In some cases, the top layer of the PBM sealing compound may flow away and the PBM carrier material may become visible. This may lead to a debonding of the connecting PBM strip from the concrete surface. Thus, during service, lateral water infiltration below the PBM strip may occur, leading to blistering or debonding of the APJ-filling (*Figure 6*)

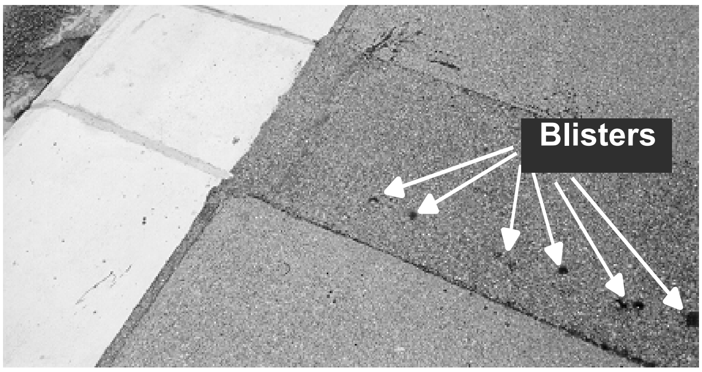


Figure 6: Blistering due to water infiltration below the connecting PBM-strip.

2.3.2 *Adhesion between GA and APJ*

For some APJ systems in Switzerland bonding agents (primers and tack coats) with organic solvents are used for the APJ-ground and the APJ-sides as well. However, results from adhesion test according to the ASTRA-guidelines demonstrate that an application of such bonding agents on the APJ-side surfaces of the pavement is not necessary [5] but may be counterproductive because new problems and risks may occur. During application of solvent-based bonding agents the pavement may absorb a certain amount of solvent, which is prevented from evaporating completely and therefore remains, trapped in the surface zone of the pavement. This weakens the adhesion between APJ and pavement and may result in debonding during the APJ extension in wintertime.

The Swiss ASTRA-guideline provides a test protocol for adhesion testing between pavement and APJ-filling. This test can be conducted either on laboratory specimens or on cores from a bridge with a speed of 10mm/min at –20°C. The test specimens have a diameter of 100mm and are cored centrically from the adhesion plane between GA and APJ (*cf. Figure 7*). Results from an ongoing research project [5] show that average maximum adhesion strengths of 2.3N/mm^2 can be expected and data for different APJ on bridges with good performance after a few years may well exceed 2.0 N/mm^2. However, the lowest value found in this research was 1.88 N/mm^2. It was determined on specimens of a bridge where three years after APJ installation debonding in the traffic lane and sidewalk zone was detected, requiring a total replacement of this APJ. Hence, from these findings, it is obvious that a low adhesion strength of 1.88 N/mm^2 is clearly not sufficient and does imply the risk of bad performance in the field.

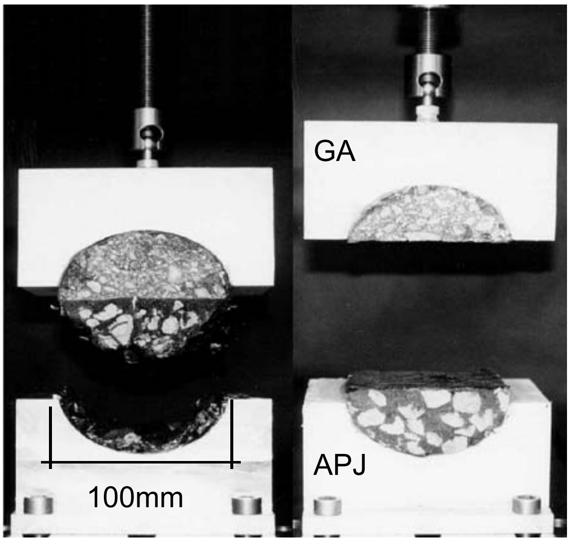


Figure 7: Testing of adhesion between GA and APJ at –20°C*:* fracture within the APJ-filling *(left)* and in the adhesion plane of GA and APJ (*right*)

3 GUSSASPHALT (GA) AND POLYMER-BITUMEN SEALING MEMBRANES (PBM)

3.1 *PBM/GA Waterproofing Systems for Bridges and Tunnels in Switzerland*

Waterproofing systems with PBM and GA can be considered nowadays as standard construction in Switzerland (*Figure 8*). Experience with these systems are generally positive but negative examples with heavy structural damage are also reported, especially in cases where material defects, unsuited waterproofing membranes, bad application (e.g. excessive heating) were involved [7].

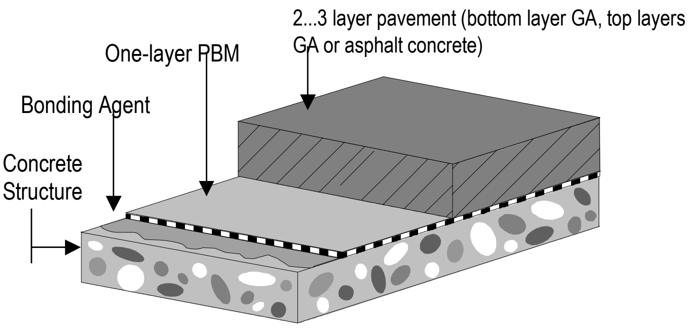


Figure 8: Scheme of the waterproofing systems with PBM and GA [7]

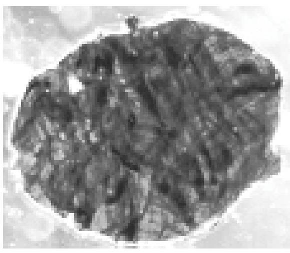
Unlike asphalt concrete or porous asphalt, Gussasphalt is waterproof and does not require any drainage of the pavement. During placing of GA and after opening to traffic, damage risk for the PBM is a minimum and due to the dense structure of GA frost is of no effect. There is, however, a risk of blistering between PBM and GA, because there is no possibility of steam pressure reduction in this zone. In addition, if a PBM is used which is not classified "GA resistant" according to the special test procedure defined in Swiss Standard SIA 281/1 [6], polymer may raise from the PBM and penetrate into the GA were it gets trapped (*Figure 10*).

3.2 *GA and PBM Interaction druing System Installation*

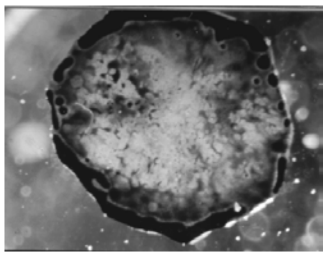
PBM are composed of one or two reinforcing carrier layers that are coated on both sides with polymer-bitumen sealing material. The polymer-bitumen sealing material is a mixture of bitumen, mineral fillers and polymers. Polymers are almost exclusively modified either with an elastomer, i.e. styrene-butadiene-styrene copolymer (SBS), or with a plastomer, i.e. atactic polypropylene (APP). A typical SBS-PBM contains 10 to 15 Mass-% SBS-copolymer and 30 to 40 Mass-% filler whereas an APP-PBM contains about 25 to 30 Mass-% APP-polymer and 10 to 30 Mass-% filler.

The top surface of the PBM is coated with talcum, sand or flakes for surface protection. The carriers consist of fabrics, felts or foils. For engineering constructions, non-woven or woven high strength polyester is used as main carrier, often reinforced with glass felt or glass fabric. Polyester has a melting point of about 254°C which is only a little bit higher than the standard placing temperature of GA.

Due to the fact that the softening point R&B of SBS polymer-bitumen ranges from 110°C...130°C and in case of APP from 140°C ...150°C, the polymer-bitumen sealing material of the PBM melts during GA placing. Some polymer-bitumen sealing material even show segregation between the polymer and bitumen phase (*Figure 9*)



20°C



160°C

Figure 9: Light microscopy picture of an APP sealing material from a PBM at 20°C (left) and 160°C (right). Above 160°C segregation of the bitumen phase occurred (black edge)

Temperature measurements at EMPA during GA placing show that the polymer-bitumen sealing material remains in liquid state for 30 to 50 minutes (*Figure 13*). Due to the weight of the GA and the fact that the polymer-bitumen of the PBM has about half the density of GA, the sealing material can penetrate into the GA, thus reducing the thickness of the PBM. The right picture of *Figure 11* was produced with an aluminum foil interlayer between PBM and GA to prevent penetration of the sealing material into GA. Hence, this picture shows the original thickness of a PBM. The picture on the left depicts the case without aluminum foil interlayer and demonstrates clearly the possible thickness reduction during GA-placing. Because of this advantage, PBM with aluminum foil was still used in Switzerland some years ago. However, after damage and bad experience caused by the high thermal expansion of aluminum, this types of PBM do no longer play a significant role on the Swiss market.

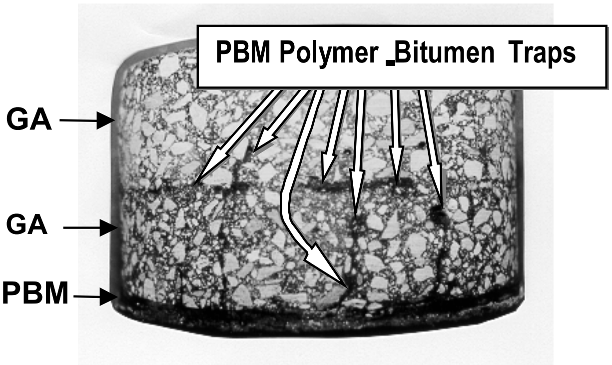


Figure 10: Core after 2-layer GA placing on top of a PBM which is not classified "GA resistant" according to Swiss Standard SIA 281/1 [6].

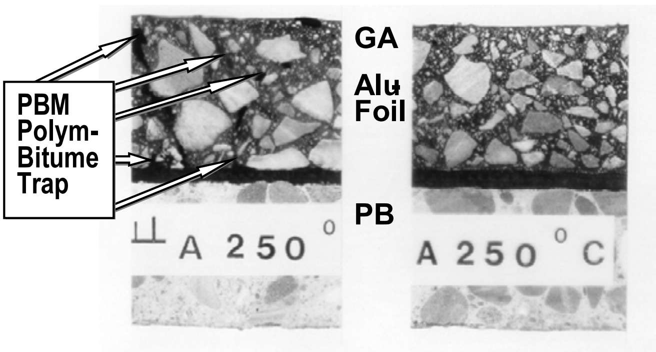


Figure 11: Influence of GA placing on thickness change of PBM without (left) and with (right) aluminum foil

After GA-placing, some quantities of polymer-bitumen sealing material remain trapped within the pavement whereas other quantities emerge on the GA surface and produce spots, which are easily visible under UV light (*Figure 10 and 12*). However, large zones of polymer-bitumen on the GA surface may have an influence on the adhesion to the upper layer. As SBS sealing material penetrates slower into the GA than material with APP, there is likeliness that SBS gets trapped within the GA whereas APP emerges on the GA surface. Note, that the polymer-bitumen traps in the GA layers are often combined with small cavities which are the result of the greater thermal expansion of the polymer-bitumen sealing material as compared to the GA. Depending on their extend and quantity, these cavities may have a negative effect on the system because they may serve as starters for blisters or as tubes for moisture and air transport.

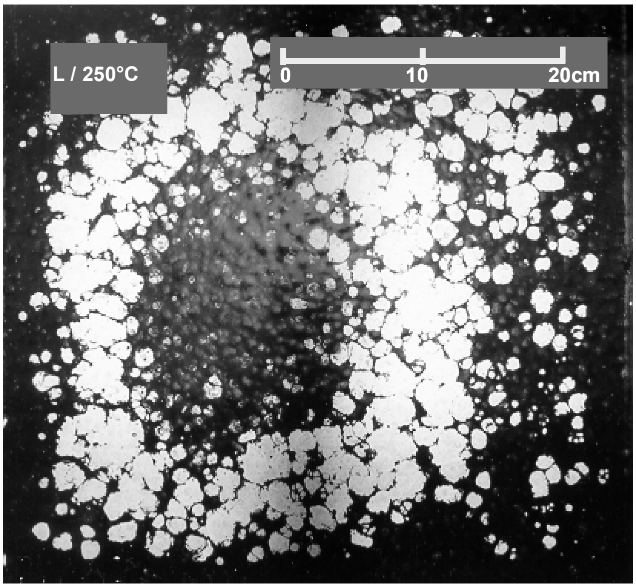


Figure 12: Polymer-bitumen sealing material emerged on the GA surface from a PBM (not classified "GA resistant") after GA resistance testing according to Swiss Standard SIA 281/1 [6]

3.3 *GA-Temperature*

In Switzerland GA can be placed on PBM with pavers at maximum temperatures of 250°C. In case of manual installation (e.g. local maintenance), the GA temperature may even reach 280°C. These temperatures are close to the damage temperatures of the polyester carrier materials. However, measurements in the lab and on engineering structures demonstrated that the maximum surface temperature of the PBM is in most cases about 20°C below the GA placing temperature (Figure 13). At these temperatures no significant change of tear strength was observed.

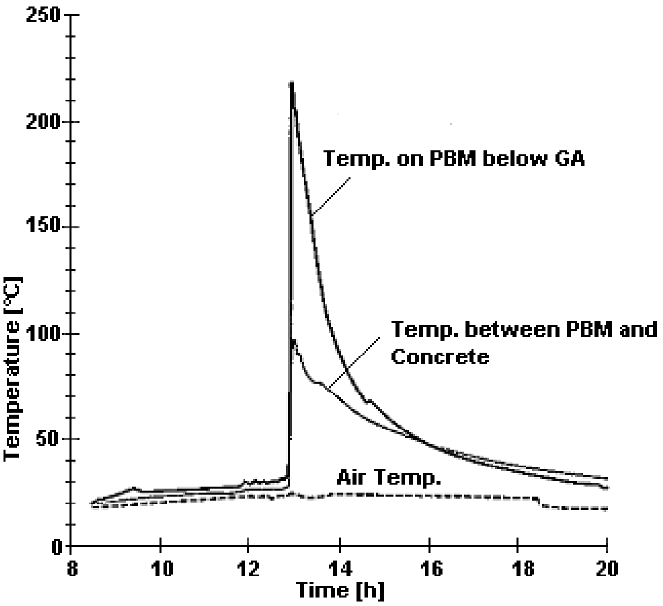


Figure 13: Temperature change during GA placing at 240°C

3.4 *Swiss Standard Procedure to Classify GA Resistance of PBM*

In order to reduce the risk of PBM damage during GA-placing, since 1996, PBM in Switzerland have to fulfill the requirements of the Swiss Standard SIA 281/1 [6]. This test method developed by EMPA has proven very suitable in practice and led to the situation that PBM have to be produced in a way that the polymer-bitumen sealing material penetrates as little as possible into the GA pavement.

Specimens are produced in the lab by jamming the PBM with a wooden frame to a concrete slab 500mm x 500mm before carefully pouring 250±3°C hot GA into the wooden frame up to a height of 125±25mm. Pouring of the GA should be accomplished within 2 minutes. After 8h cooling, the specimen is examined with respect to surface spots and subsequently cut into three parallel strips. Both cut areas of the middle strip are marked at equal distance of 25mm in order to determine the PBM thickness values and the number of polymer-bitumen traps.

The requirements are based on the thickness, the number of polymer-bitumen traps in the GA and the percentage of polymer-bitumen spots on the GA surface are summarized in *Table 1*. PBM meeting these requirements are classified "GA resistant" in Switzerland. At present, this method is also discussed within CEN TC254/SC1/WG6

Criteria	Mean Value of two specimens	Single Value of one specimen
PBM thickness after GA placing at 250°C	≥ 4mm	≥ 3.8mm
Maximum percentage of polymer-bitumen spots on the GA surface within a window area of 50 x 50 mm	≤ 50 area-%	≤ 60 area-%
Number of polymer-bitumen inclusions longer than 12mm connected to the PBM surface plus number of isolated polymer-bitumen traps longer than 7mm	≤ 6	≤ 6

Table 1 Criteria for PBM to be classified as "GA resistant" according to Swiss Standard SIA 281/1 [6]

4 CONCLUSIONS

Asphaltic plug joints (APJ) and waterproofing systems with Gussasphalt (GA) and polymer-bitumen membranes (PBM) are widely used for bridges and tunnels in Switzerland with good success.

APJ should be combined with dense GA pavements to prevent primary damage from lateral water infiltration through the pavement into the APJ bed during installation and to protect the APJ from water build up at the APJ-side with open asphalt concrete pavements during service life. This water accumulation can destroy the adhesion between APJ and the pavement in summer time and promote ice-induced debonding during winter. Ongoing research by EMPA shows that adhesion strength at –20°C according to ASTRA-guidelines should not be lower than 2.0 N/mm^2. The use of bonding agents with organic solvents on the APJ-side surfaces of the pavement does not improve adhesion properties and may be counterproductive because the solvents become partly absorbed by the pavement where they can only evaporate gradually promoting debonding and blistering.

Waterproofing systems with GA and PBM show good field performance if system interaction for the specific building is carefully taken into account during the whole building process from planning to installation. This includes the evaluation of PBM which are best suited for the job, such as PBM classified as "GA resistant" according to Swiss Standard SIA 281/1. Nevertheless, it has to be kept in mind that good quality of the PBM alone is by no means sufficient, if it is thermally damaged by overheated GA. For this reason the maximum limits for the installation temperatures must not be exceeded.

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