

Issue of Changes in Adhesion of Bitumen Sheet to Primary Layer over the Course of Time in Multilayer Waterproofing during Shear Testing

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Abstract. This paper is based on research dealing with defects that appear on concrete bridge decks with an insulating layer from asphalt strips on the interface between the asphalt strip and its basis. The durability and lifespan of the bearing structure of concrete bridge is determined by insulating layer that constitutes, together with the primary layer and a protective layer, the insulation system of the concrete bridge deck. Paints based on low viscosity epoxy resins are one of the possibilities of primary layer implementation. These paints may be performed as anchoring-impregnation paints that usually represent single layer paint on the bridge deck surface. Sealing layer is another variant. Sealing layer is a multilayer consisting of anchoring-impregnation paint and sealing paint. The primary layers mainly provide vapour closing of the concrete surface, and partly, through roughening the surface, contribute to adhesion of bitumen (asphalt) insulation (waterproofing) layer. Application of the primary layer has been spreading in the Czech Republic since the 1990s. Now, after approximately 30 years of use defects in these epoxy based sealing layers at the interface between primary layer and waterproofing layer of reinforced bitumen sheets (RBS) are being solved in the Czech Republic. After performance of the first test focusing on breaking-strength, it was found that the strength between the asphalt and the primary belt layer in some types of low-viscosity resin-epoxy decreases and after a certain period of time again increases, depending on the time. Tensile strength test is carried out on a sample of asphalt strip, which is fused onto the substrate with a primer coat. It was therefore proceeded to test the shear adhesion. Testing of the shear adhesion is conducted on the entire concrete deck waterproofing system. It was supposed that the decrease of adhesion at this test become evident in higher extent. Adhesion tests in shear were performed on the primary layer consisting of an anchoring impregnation coating and sealing layer.

1. Introduction

This paper is based on the research dealing with defects that take the form of blistering (lumps) and appear on concrete bridge decks with insulation (waterproofing) layers of reinforced bitumen sheets (RBS) at the interface of RBS and its base.



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The durability and lifespan of the concrete bridge bearing structures are essentially determined by their multilayer insulation, which consists of a waterproofing layer on the primary layer, applied on the concrete base, and a protection layer connected to the multilayer pavement. A typical pavement structure (an asphalt overlay), which includes the waterproofing system on a bridge deck according to ČSN 736242:2010 [1] and ČSN EN 14695:2010 [2], is shown in Fig. 1.

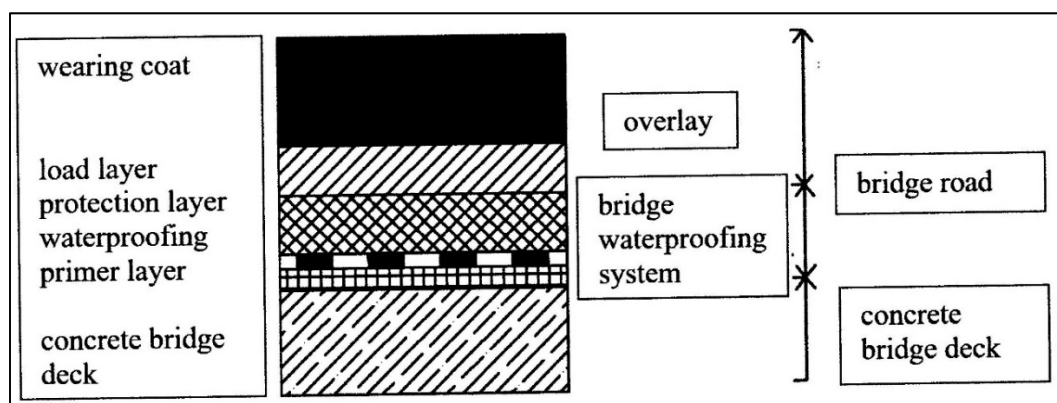


Figure 1. Bridge road. Source: Author's compilation according to [1, 2].

Paints based on the low viscosity epoxy resins (ER) are one of the material possibilities of primary layer implementation. These paints may be performed as anchoring-impregnation paints (AIP) that usually represent single-layer paint on the bridge deck surface with quartz sand. Sealing layer (SL) is another variant – it is a multilayer consisting of anchoring-impregnation paint and paint laid on the anchoring-impregnation paint of the same type of epoxy resin.

The primary layers mainly provide vapour closing of the concrete surface, and partly, through roughening the surface, contribute to adhesion of bitumen (asphalt) insulation (waterproofing) layer. In the Czech Republic, application of this type of primary layer dates back to the 1990s. At present, after approximately 30 years of using, defects in these multilayers at the interface of primary epoxy layer and waterproofing layer of RBS are being solved.

Blistering of bridge objects is a global problem and individual states strive for its solutions. Despite this fact, no clear conclusion about the causes or guidelines on how to solve the problem has been found. Detailed information and / or specific detailed results of experimental programs are not practically available. Several texts refer to non-private studies and list only summaries of the results – e.g. [3].

In most cases, the main cause of blistering is thought to be an expansion of gases enclosed under the RBS induced by an elevated temperature. The most comprehensive works dealing with blister formation are [4-6]. The main source of gases is mainly considered to be the moisture, enclosed under the bitumen (asphalt) sheet, as well as the air itself, contained in the porous surface system of concrete, i.e. cavities in the surface, aerated concrete caverns, improperly compacted surface of the bridge deck, etc.

Virtually none of the publications address the problem of blistering in chemical terms, i.e. potential chemical effects on the cohesion between the primary layer and the RBS. Only marginally, yet not significantly, are mentioned and accentuated possible impacts in terms of materials that do not meet the prescribed quality requirements.

Conducted part of the research was aimed at possible impacts of materials that do not meet the prescribed quality requirements and affect other layers of multilayer insulation.

In the usual manner, the first tests focused on tensile strength testing according to ČSN EN 13596 [7]. It was found that, depending on the time, some types of low-viscosity epoxy resin tend to decrease. However, after a certain period of time, there is an increase in the strength of cohesion between the asphalt sheet and the primary layer [8, 9]. The tensile strength testing was merely performed on a sample of RBS, which was put onto the primary layer base.

Furthermore, it was proceeded to testing shear adhesion according to ČSN EN 13 653 [10], see test scheme in Fig. 2. Here, the testing was conducted around the whole waterproofing system of concrete bridge deck, including protection layer of mastic asphalt (MA).

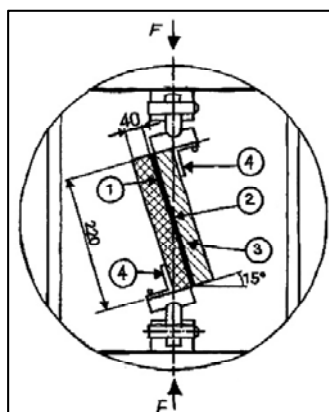


Figure 2. Test Specimens for Shear Strength Test. Key: 1 Specimen base, 2 Bitumen waterproofing sheet, 3 Cast asphalt layer, 4 Adjustable support Source: Author's compilation according to ČSN EN 13653:2005 [10]

The purpose of these control tests [10] was to verify (in a more sensitive method) potential changes in the cohesion of multilayer waterproofing. The testing mode was focused on model behaviour of multilayer insulation over the course of time, when using a more sensitive test procedure, i.e. assuming a more significant difference between the individual measured values than for the adhesion test in a simple tension [7]. The other aim was to compare the course of shear strengths, when using different variants of the primary layer. Here, anchoring-impregnation paint (AIP) and sealing layer (SL) were selected.

Within this research, the established hypothesis was that decrease in adhesion over the course of time will be more significant for this type of testing, and the theory of disruption of RBS by ER will be confirmed.

2. Material and methodology

2.1. Primary layer

Provide sufficient detail to allow the work to be reproduced. Methods already published should be indicated by a reference: only relevant modifications should be described. This section also may include theory, background, calculations which represent practical development from a theoretical basis. Etc.

Both of the constituents of each epoxy resin composition were examined by chemical analytical techniques (FT-IR - Infrared Spectroscopy with spectra evaluation using the Fourier Transform Infrared Spectroscopy; GC / LC + MS - Gas / Liquid Chromatography- Mass Spectrometry).

In the next step, the epoxy resins were examined in terms of their physicochemical properties, as defined in the Department of Transportation regulations TP 164 [11]. Descriptions of individual test methods are stated in TP-BEL-EP [12]. According to [12], the tested properties include viscosity composition, remainder after annealing, pot life, curing time, sensitivity to moisture (composition), non-volatile proportions (cured epoxy), extractable proportions (without residue analysis), water absorption. Then, further tests and chemical analyses were carried out to quantify other measurable parameters, or to possibly indicate causal links affecting stability of the multilayer waterproofing parameters, particularly adequate adhesion of RBS to the primary layer of ER. This category of testing also includes the analyses of gases, swabs, determination of loss after annealing, the degrees of turbidity, the changes in the pH component "B" and density of individual components.

The physical and mechanical tests, conducted according to the recommendations of [12] (i.e. peak time and hardening time), characterize the speed of curing time of ER in normal conditions (the peak time) and the stability of RBS during aging (the hardening time). According to the above regulations, non-volatile matters (dry matters) and extractable matters were also determined in epoxy resins. The aim of this group of analyses was to accurately determine the proportion of the volatile matters in the observed epoxy resins, since their increased presence in the matrix may cause a reduced adhesion between ER and RBS. Tests of water absorption and loss after annealing were implemented to discover the total quantity of water taken up through the polymer system. Excess of that and of the condensed moisture may, under some thermal load, also contribute to blistering in the layers under the RBS.

Two epoxy resins were selected having different character of hardening according to [12], chapter 3.2.4, through the Bucholz Indentation Hardness Test according to ČSN EN ISO 2815[13]. Selected were an epoxy resin (sample E1), which fulfils the conditions of the relevant regulation [12] at different hardening times, and an epoxy resin (sample E2), which does not fulfil the conditions and cannot be evaluated. The fact that it is not possible to evaluate the E2 sample means that the resin has longer reaction and hardening times, despite meeting the workability time according to [12], see Tab. no. 1.

Table 1. Hardening time according to [13]. Source: Authors' compilation.

Hardening time	Unit	Required value	E1 – Indentation Hardness αB		E2 – Indentation Hardness αB	
			Median	(%)	Median	(%)
Hardness after 7 days at 100% cure	-	min. 60	110	100	100,8	100
Hardness after 18 hours	-	min.50%	77	70	Non-evaluable	-
Hardness after 40 hours at 12°C and relative humidity of 85%	-	min.50%	74	67,2	Non-evaluable	-

2.2. Waterproofing

As the insulation layer, RBS was used in insulation (waterproofing) systems approved by the Ministry of Transport. Specifications: coarse-grained grit, i.e. 5 mm thick, modifications of plastomeric character.

2.3. Concrete Bridge Deck and Protection Layer

Concrete tiles were manufactured in accordance with ČSN EN 13375 [14]. Specification of concrete tiles: 400x400x40 mm, concrete age of 28 days, concrete C 30/37 XF4. Protection layer comprised cast asphalt according to [14].



Figure 3. Test Specimen with Side Sealed Edge. Source: Author's compilation

2.4 Methodology

Preparation of test specimens was carried out according to [14] with minor modifications required by the research project. To reduce the evaporation of solvents from the ER, specimens' sides were circumferentially sealed with plastic tape (see Fig. no. 3). Shear tests were performed according to [10] at time intervals of 1, 14, 30, 60 and 120 days, with the interposition of one series, when, after 14 days, the specimens were inserted into 50 °C for 5 days, and, after 24-hour cooling, they were tested for shear.

3. Results and discussions

Shear strength test results according to [10] are shown in Tab. No.2. The table is also accompanied by a shift in the maximum shear force.

Table 2. Resulting Values of Shear Strength and Shift according to [13] for Various Types of Primary Layers at Different Ages. Source: Authors' compilation.

Age	1 day		14 days		14 days + 50 °C for 5 days		30 days		60 days		120 days	
Specimen type	Shear strength [MPa]	Shift [mm]	Shear strength [MPa]	Shift [mm]	Shear strength [MPa]	Shift [mm]	Shear strength [MPa]	Shift [mm]	Shear strength [MPa]	Shift [mm]	Shear strength [MPa]	Shift [mm]
E1-SL	0,48	3,5	0,24	4,3	0,21	3,5	0,27	3,5	0,29	3,3	0,33	4,0
E1-AIP	0,51	3,9	0,29	4,1	0,25	3,8	0,27	4,0	0,31	4,0	0,38	4,1
E2-SL	0,43	3,9	0,24	3,9	0,21	3,6	0,25	4,8	0,30	3,5	0,34	3,4
E2-AIP	0,46	3,9	0,31	4,3	0,25	3,3	0,28	4,0	0,36	3,3	0,38	3,5

The results of the shear strength tests showed that:

- at constant laboratory temperature and hence relatively favourable conditions, (in the first 14 days) the decrease in strength was significant in all measurements – it was even down to half of the initial value.
- as for SL, the decrease was slightly more significant in comparison with AIP.
- over the course of time, the joint strength is gradually increased up to the level of the initial values (presumably in accordance with the evaporation of volatile components from the epoxides).
- as for AIP, a failure always occurs in the asphalt sheet in proximity to the reinforced liner; in the case of SL, a failure often occurs during etching in the RBS-SL joint; at the times of higher strength, the failure is combined - partly adhesive RBS-SL, partly cohesive in the RBS substance.
- softening of RBS occurs. Thermal stress increases the rate (of speed) of penetration of the ER components into the RBS, thus causing a reduction in the joint strength.
- when comparing the strength decrease with regards to AIP and SL, it may be found that the differences are not as large as it would correspond to doubling the amount of epoxy resin in the SL, but there is an overall softening of the RBS. Therefore, it may be concluded that the rate (of speed) of diffusion of the unreacted epoxy resin components into the RBS is approximately equal to the discharge of these components into the environment through the RBS and the asphalt protection layer. When making subsequent repairs, multiple coats (paints) of ER thus do not increase the risk of excessive reduction in the RBS-SL joint strength. Yet, this merely extends the time of release of dissolving components through the asphalt sheet and the protection layer.

- g) as opposed to the concrete base, shift of the RBS was not greatly changed in different time measurements (etching intensity) and remained approximately the same - the spread of detected shift results was within the experimental errors. Therefore, the hardening time of epoxy layers does not affect the shift length.

Under the given conditions, it was discovered that the cohesion of multilayer waterproofing is at its lowest about 14 days after implementation, so in this period, one can expect the greatest detrimental effect of influences that can weaken or damage the above joint.

From a practical standpoint, the most significant thermal effects appear to be:

- direct insolation of laid waterproofing layer of RBS,
- implementing of protection layer of mastic asphalt (MA).

Hot summer days can therefore cause such a significant decrease in the joint strength that separation of AIP from the base is frequent, and in case of minor faults in the sealing layer, there is a bulge formation eventually taking the form of lumps.

4. Conclusion

The results of the performed measurements confirmed the hypothesis of decrease in the shear strength over the course of time, and proved probability of the theory of etching asphalt sheet with the unreacted ER components. Etching is particularly apparent at first, and is further primarily manifested only as the softening of the RBS (lower strength). When determining the shear strength, the length of shift of asphalt on the base remains constant up to a maximum loading stress. After reaching a certain minimum, the strength again increases to the initial values.

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