INNOVATIVE SILENT JOINT SEALANT CONCEPT FOR BETTER DURABILITY AND FASTER APPLICATION

Erik Scholten[1], *Bert Jan Lommerts*[2], *Henk Hanselaar*[3]
[1]*Kraton Polymers, Amsterdam, The Netherlands*
[2]*Latexfalt BV, Koudekerk a/d Rijn, The Netherlands*
[3]*Gebr. Van Kessel Wegenbouw BV, Buren, The Netherlands*

ABSTRACT

Joint sealants are applied to absorb the movements of a bridge or viaduct, movements that usually occur due to temperature differences. Apart from the deformation stemming from thermal expansion and contraction, these sealants are also heavily loaded by traffic. In many countries joint sealants have a limited life time, often less than the adjacent pavement. This applies particularly to bituminous (soft) joint sealants which are preferred because of their ability to reduce noise emissions.
Rijkswaterstaat, the Dutch road authority, started an innovative project in 2008 in which different parties present on the market were invited to develop more durable, silent joint sealants. Kraton Polymers (polymer producer), Latexfalt (polymer modified bitumen producer) and Van Kessel (road contractor) teamed up in this challenge to develop a new joint sealant system, and thus combining the expertise of these three companies. The new solution included a prefabricated sealant that combines high resistance to permanent deformation, e.g rutting, with the ability to follow the expansion and contraction movements of the bridge and pavement surface layers. The core of the joint was prefabricated in slabs with standard dimensions. This allowed a better quality control and saved significant time during application. The concept was selected amongst the four solutions to be extensively tested at Delft University of Technology, The Netherlands and at the research institute EMPA in Switzerland. A detailed description of the tests and experiences with the concept are shared in this paper.

Keywords: joint, bituminous sealant, noise reduction, prefabricated, innovation, bituminous elastomer

1. INTRODUCTION

Joint structures have to bridge the gap between roads and bridges or viaducts. They have to form a smooth transition and have to fulfil different requirements with a small amount material placed between the viaduct/bridge and road. Joints require frequent maintenance. Damage to these joints are causing traffic safety risks, and can also lead to damage to the bridge or viaduct. Apart from the structural and durability requirements, the joint should also have a limited noise emission when a vehicle passes. Conventional joint structures are not able to meet all requirements, particularly when it comes to noise emissions and durability.
The Dutch road authority Rijkswaterstaat set up an innovation program in 2008 to invite parties in the market to develop better solutions for joints. Kraton Polymers™, Latexfalt and Van Kessel teamed up and developed a new joint system that combines durability and limited noise emission in a solution that can also be applied faster on the road, thus limiting traffic delays.

As part of the innovation program the new solution is being tested extensively. The concept as well as the testing of the new joint sealant are reported in this paper.

2. TYPES OF JOINTS AND REQUIREMENTS

There are two categories of joints: soft or flexible joints and hard joints. The hard joints (for example cantilever joints) are mostly durable but give high noise emissions due to passing traffic. Flexible joints are mostly silent joints, but their durability is limited to typically 3,5 years when applied in highways [1]. This is much shorter than the adjacent asphalt and therefore extra road closures are needed which cause significant delays and therefore costs. Bituminous joints are part of the family of flexible joints and are widely applied in The Netherlands for noise reduction purposes.

The main requirement for joint structures is to absorb movements in the adjacent structure due to thermal expansion variations. At the same time the material should be deformation resistant and provide a smooth, skid resistant surface. The challenge is to fulfil these requirements in both extreme states: when the bridge has its maximum expansion in summer and when it has its maximum contraction in winter. There is a delicate balance that needs to be found between stiffness and elasticity.

Traditional bituminous joints tend to be either soft and well able to absorb movements, but then not so resistant to permanent deformations. Harder formulations provide better resistance to permanent deformation but may crack at low temperatures or when movements exceed the maximum strain in the material.

Bituminous joints are mostly prepared on site: the bituminous compound is heated and poured into the joint. This hot mass needs quite some time to cool down. This delays the opening of the road and if the core of the mass has not fully cooled down, deformations may occur immediately due to traffic.

3. CONCEPT OF THE KLK BITUMINOUS JOINT

Kraton Polymers, Latexfalt and Van Kessel teamed up to come up with an innovative solution for the project that Rijkswaterstaat had initiated. This has resulted in a concept that brings together three areas of expertise:

- Optimized elastomer technology
- New binder and prefabricated production technology
- Robust application and detailing

3.1 Components

The main idea was to make a joint sealant that could be applied easily and fulfil high quality standards. Prefabricated elements are prepared in a factory. The prefabricated elements have dimensions of 1000 x 500 x 40 or 50 mm and consist of polymer modified bitumen, aggregate and rubber reinforcement. The binder has been modified with a styrenic blockcopolymer (SBC) that brings both elasticity as well as stiffness to the final product. The inclusion of a rubber reinforcement has improved the resistance to horizontal strains (movement of the joint) and vertical strains (rutting). The prefab concept improves the quality and homogeneity of the product to a significant extent, compared to in-situ made sealants. Also the speed of installation is increased, because of a shorter cool down time. The prefab concept allows separation of functions. The core with the rubber reinforcement is designed for elasticity and rutting resistance while the in-situ applied binder between prefab core and adjacent asphalt is optimized for adhesion. Rubber granulate is used as filler in the bituminous joint to improve the noise reducing performance.

3.2 Application of the joint sealant

The application of the joint sealant is outlined in different steps with pictures:
After the wearing course has been applied, a groove is being cut at the location of the joint. The concrete base is cleaned and the joint opening is covered with a strip. In figure 1 the strip is being prepared for placement on the joint opening. Hot polymer modified bitumen is poured over the concrete base and strip to make an adhesion layer (figure 2). The photos were taken at the Lintrack test facility of Delft University of Technology where the joint sealants were tested as part of the Rijkswaterstaat program.

Figure 1: Preparations for covering the joint

Figure 2: Pouring of hot polymer modified bitumen over the base to create adhesive layer

The first prefab element is put in position centrally on the base (figure 3). Then more polymer modified bitumen is placed over the first prefab element. Now the second prefab element is put in place (figure 4). The remaining space needs to be filled with gussasphalt. The finished joint is show in figure 5.

Figure 3: Placement of bottom prefab element

Figure 4: Second prefab element has been placed

Figure 5: finished joint

4. INNOVATIVE ELASTOMER CONCEPT

The complex interaction of forces in a joint sealant lead to requirements for the binder that cannot be met with standard materials. The binder needs to have adequate stiffness to prevent permanent deformations in the sealant. At the same time the binder should be flexible to resist the deformations that come from the expansion and shrinkage of the bridge or viaduct.

Stiff and flexible are contradictory requirements so an optimum between the two has to be found. Many binders for joint sealants contain SBS which belongs to the family of Styrenic Block Copolymers polymers (SBCs). SBCs are unique for their interaction with bitumen where the polymer is actually dissolved in. The absorption of bitumen components make the polymer swell which leads to an extended polymer volume that is up to 10x as big as the SBC mass that was added in the first place. The network that is formed consists of polystyrene domains with elastic polybutadiene links in between as depicted can see in figure 6.
SBC polymers bring elasticity, toughness and high viscosity at service temperatures, but stiffness is in most cases somewhat reduced. Elasticity is not only important for the longitudinal deformations, but also for vertical deformations. It allows the material to relax when the load is removed. SBCs help to make deformations reversible but a minimum stiffness is needed to ensure the deformations are not too big (leading to other problems such as lack of adhesion to adjacent asphalt).

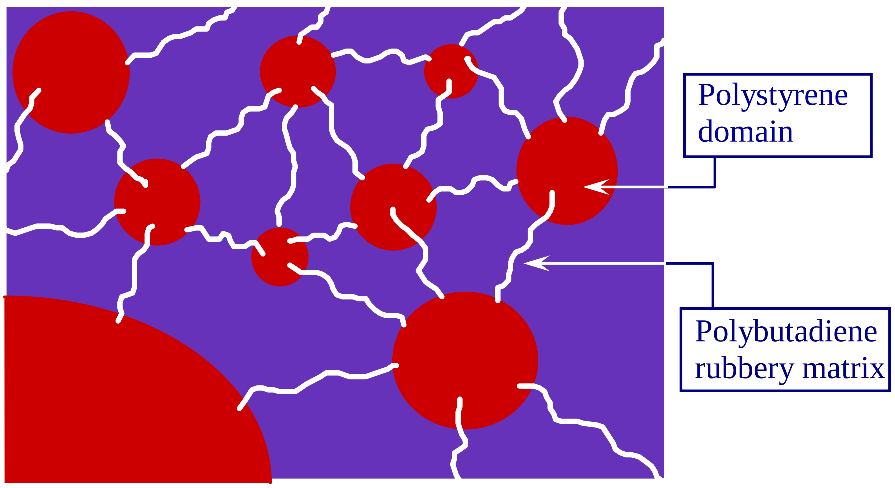

Figure 6: three dimensional network of styrenic block copolymers in bitumen

The response of bitumen can be described with the Burgers model which consists of a spring and dampener in series and a spring and dampener in parallel (figure 7). By adding SBCs both springs become stronger and therefore increase the elastic component in the response of bitumen.
For this joint sealant concept an SBC has been chosen that combines stiffness with elasticity. In terms of the Burgers model, all elements, springs and dampeners have been made stronger (figure 8). In the joint sealant binder this is combined with both rubber and stone aggregate. The stone aggregates create a skeleton to prevent too large deformations, while the rubber aggregate helps to reduce vibrations. The binder has not been chemically cross-linked; therefore the network is reversible. For recycling purposes the binder can be heated. The network will soften and allow processing of the material. Upon cooling the styrene blocks re-group into domains and the network is back in place.

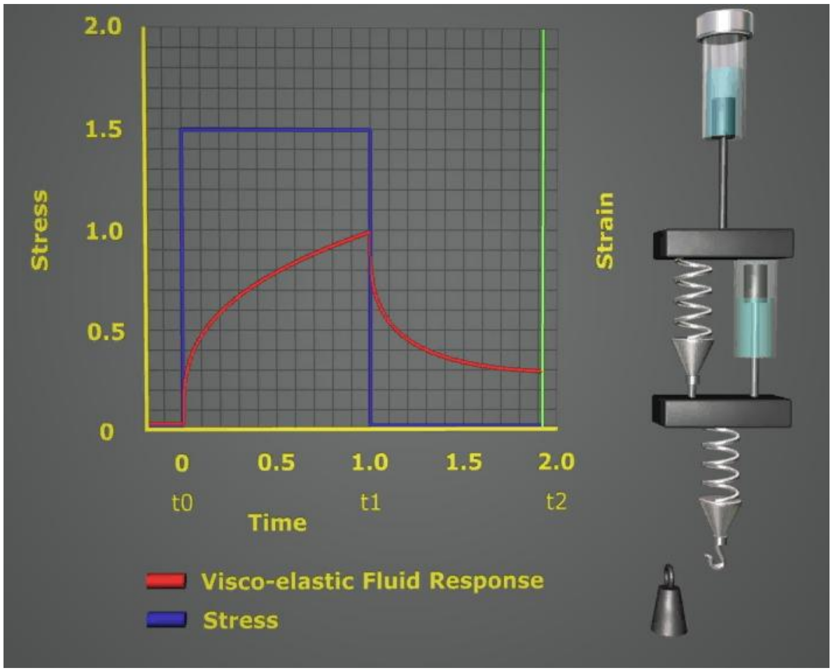

Figure 7: the Burgers model

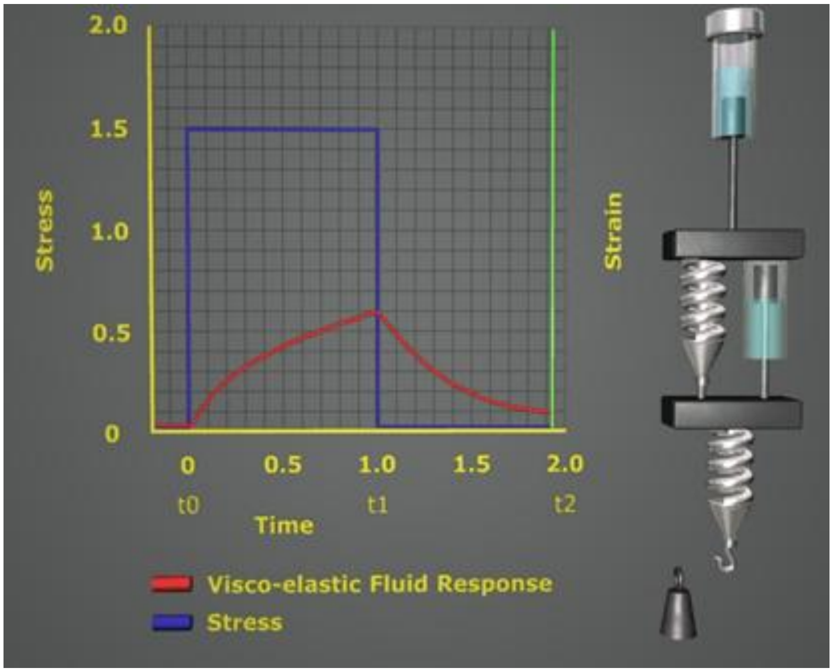

Figure 8: Burgers model for binders with SBC modifications (stronger springs)

5. TEST RESULTS LINTRACK AND EMPA

The joint sealants have been tested at the Lintrack accelerated loading facility of Delft University of Technology in The Netherlands and at the EMPA laboratories in Switzerland. At the Lintrack facility two full-scale 3 m. wide concrete bridges were placed together with abutment. There is a joint on both sides of the abutment so that two joints can be tested at the same time. The Lintrack test is conducted as follows [2]:

- First of all the joints are slowly opened up to the maximum dilatation opening.

- The temperature of the structure is raised to 40°C
- The structure is loaded by the Lintrack wheel, fitted with a super single tyre. In total 100,000 load repetitions are applied, which consist of 20,000 repetitions at each of the following wheel loads: 3.5 tonne, 4.5 tonne, 5.5 tonne, 6.5 tonne and 7.5 tonne.
- If the joint sealant has not failed after 100,000 load repetitions, the temperature is reduced to 20°C. Then a static tension test is done to determine the force required to break the sealant.

Figure 9 and 10: Joint structure after opening prior to commencing Lintrack testing (left: opening +13 mm, right: opening –13 mm)

The opening and closing of the joint did not lead to any visual damage as reported by Delft University in [3] and can be seen in figures 9 and 10.

Four important conclusions can be drawn based on the Lintrack tests

1. Despite the harsh conditions of the conducted Lintrack test, the KLK joint reached the maximum number of cycles (100,000 cycles) at which the test was stopped. Since the reference traditional bituminous joint lasted only 40,000 cycles it is clear that the KLK joint performs significantly better than the reference.
2. The KLK joint shows very low rutting in the prefab joint section. Rutting in the surrounding gussasphalt is more severe than in the KLK joint, so stiffness and strain recovery are sufficient to allow the KLK joint to be used for highly demanding applications. Figure 11 shows the absolute and relative rutting of the KLK joint. The relative rutting was higher because the surface treatment material was squeezed away from the wheelpath. The surface treatment material needs to be improved.
3. No internal cracks in the KLK were formed during the Lintrack test, indicating that the pliability of the system under conditions applied during the Lintrack test is sufficient to allow fast stress relaxation and energy dissipation so fatigue-like failure modes do not occur.
4. Large scale stress-strain deformation of the KLK joint was performed at different strain rates after the Lintrack testing was stopped. These stress-strain experiments revealed that large-scale deformation of the KLK joint results in formation of first critical cracks in the porous asphalt directly adjacent to the joint.

Based on the Lintrack experiments the research team concluded that the basis concept of the KLK joint is looking very promising, however, crack information and stress build-up during large scale deformation has to be improved in order to maximise its properties.

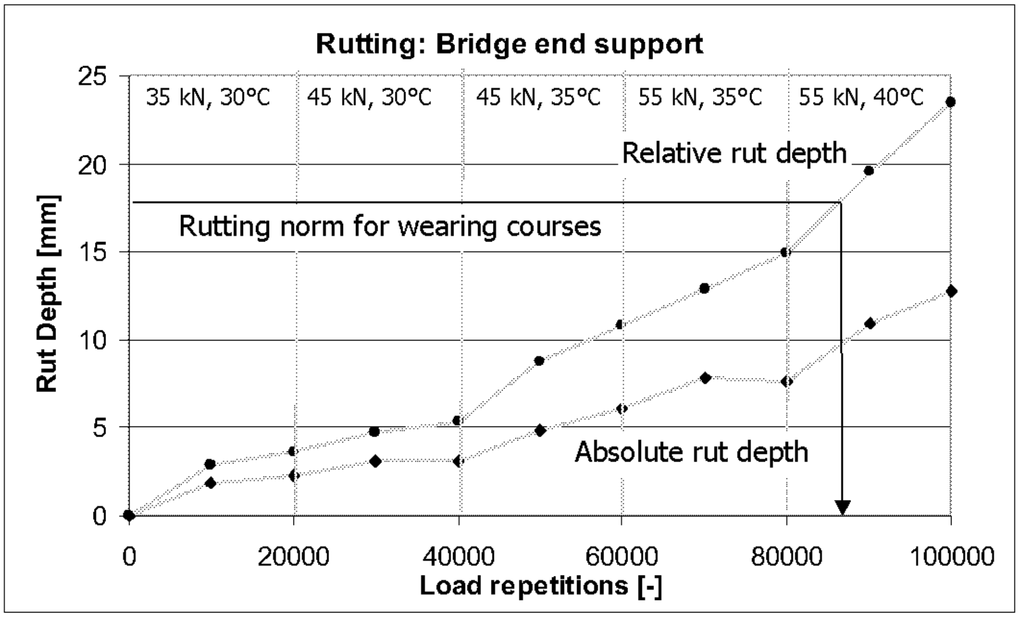

Figure 11: Absolute and relative rutting for the KLK joint. Relative rutting was higher due to surface treatment material which was moved away from the wheelpath

At the EMPA laboratory for Road Engineering additional tests were done [4]. The joint's movement capacity was tested by horizontally opening and closing the joints repeatedly at low temperatures (-10°C) using the Joint Movement Simulator (JMS). The joint is expanded at a rate of 10 mm/h from an original gap width of approx. 30 mm to a maximum joint opening of +13 mm. Then it is pushed back at the same rate of 10 mm/h to simulate one maximum opening and closing of the joint at low temperatures. This movement cycle is repeated at least 10 times. These test conditions are extremely severe and intend to simulate the fatigue behaviour of the joint system over a period of 10 years without taking into account the long term effects of traffic and climate.

The test showed that cracking did not occur in the joint sealant itself. Also no debonding took place of the joint sealant from the gussasphalt. There was however debonding of the gussasphalt from the adjacent bridge structure. This is a point that needed to be improved.
During the joint opening there was a small reduction in thickness of the joint (max. 2 mm) and there was lateral contraction of the through width (max. 3 mm).
The mean value of the maximum force during the first cycle was approx. 46 kN with the joint opening to 13 mm at -10°C. This is an extreme case and will not occur in practice because when the joint opens in practice, the joint sealant has sufficient time to relax as the movement occurs slowly. Also, at higher temperatures these forces will be much lower.

These tests reveal that although the KLK joint sealant body performs very well in terms of resistance to rutting and cracking, there is scope to improve the pliability joint system under large scale deformations.

By adjusting various components of the bituminous compound used in the prefab KLK joint the modulus, and hence, the pliability can easily be altered to meet the set requirements. Additional formulations have been tested in the lab which showed that pliability and elongation at break are influenced positively by slightly altering the formulation of the bituminous binder used. In this way both the observed performance during large scale deformation as during the Lintrack and the EMPA tests is improved.

In the current study the KLK joint was compared to a standard commercial material in the Dutch market. Based on the performance data obtained in the Lintrack and EMPA tests, it is envisaged that a simple adjustment of the KLK joint compound will further yield significant improvement of the durability and end-use properties of the joint.
An assessment of the relative performance of the improved product is provided in table 1.

Table 1: Relative comparison of standard joint, KLK joint and KLK joint with improved compound

	Standard Joint	KLK Joint	KLK Joint with improved compound
Product homogeneity	++--	++++	++++
Rutting	++--	++++	++++
Aggregate adhesion	++++	++++	++++
Large scale pliability	+++-	+++-	++++
Elastic recovery (vertical)	++--	++++	++++
Elastic recovery (horizontal)	++--	++++	+++-
Internal stress build-up	++++	+++-	++++
External stress build-up	++++	+++-	++++
Ease of application	+----	++++	++++
Durability noise reduction	++--	+++-	++++
Mechanical Durability (compared to hard joints)	++--	+++-	+++-
Low Temperature performance	++--	++--	++++
High Temperature performance	++--	++++	+++-
Costs of materials	++++	+++-	+++-
Costs of application	+++-	++++	++++

6. CONCLUSIONS

The KLK joint system is a prefab bituminous joint system that is designed to combine the low noise levels of bituminous joints with a better durability and a faster application on the road than the traditional bituminous joints.
The full scale testing of the KLK joint system at Delft University of Technology and EMPA has provided valuable insight into the performance of this product. The improved durability of the KLK joint was confirmed in the accelerated loading test at the Lintrack facility of Delft University of Technology where the KLK joint lasted until the end of test (100,000 load repetitions) while the traditional reference joint failed at 40,000 load repetitions. Also the tests at EMPA demonstrated that the KLK joint has an excellent resistance to rutting and cracking. Points for improvement are the rut resistance of the gusaasphalt directly adjacent to the joint. Also the surface treatment of the joint needs to be improved as this was squeezed away during the test leading to a slippery surface in the wheel path. The tests in the Joint Movement Simulator at EMPA showed that under the extreme circumstance of relatively fast opening of the joint at low temperatures adhesive failure occurred between the gussasphalt and the adjacent bridge deck asphalt. No cracks occurred in the joint sealant itself. The pliability of the joint system has been improved by making small changes in the composition of the sealant compound. The rutting resistance of the gussasphalt and the surface treatment are currently being addressed.

By combining know-how and efforts of various partners in the chain of knowledge, i.e. Kraton Polymers for chemical interaction and polymer design, Latexfalt for material science and formulation know-how, Van Kessel as the construction and application specialist and Rijkswaterstaat as a launching customer, research on complicated topics can result in cost-effective, quick and innovative developments.

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