Report No.

Investigation on E-Krete High Friction Antiskid Surface Layer from Polycon

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Y. Xiao

Technische Universiteit Delft

Challenge the future

Investigation on E-Krete Antiskid Surface Layer from Polycon

Yue XIAO [1]

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Contact Person: Bradley Wilson. Email: bradley@polyconintl.com

[1] Road and Railway Engineering, Faculty of Civil Engineering & Geosciences
Delft University of Technology

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CONTENT

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1. Introduction

In 2010, research was carried out at TU Delft to set benchmarks for alternatives to tar-containing antiskid layers for runway applications, bridge deck applications and roadway applications where high friction wearing surfaces not affected by U.V. and water are needed. [1]. After prior research a specification was finalized to guide the industry for developing new products [2]. At the end of 2011 another project was started to verify the specification by testing several new binders and newly designed antiskid layers.

In 2012 Polycon provided a new antiskid surfacing, named as E-Krete[1], for testing. E-Krete, with a polymer liquid mixed with cement and fine mineral, was laid on polymer modified asphalt mixture slabs. It has already been used as antiskid surfacing for airfields and roadways in the USA. The polymer liquid and mix of cement and fine aggregate were also delivered to TU Delft for further analysis.

This report presents the test results that were obtained from this E-Krete antiskid surfacing.

2. Materials

Figure 1 shows a picture of the E-Krete antiskid surfacing that was laid on a slab made from a dense asphalt mixture. Unlike the antiskid surfacings involved in the mentioned projects, E-Krete is a grooved cement based surface layer. In the test plan the sand patch test, pull test and Leutner shear test are included.

The sand patch test is specified to investigate the texture depth that is affected by the aggregate size and orientations. A high texture depth can ensure sufficient friction as well as avoid hydroplaning.

However, this traditional test method cannot be used on the E-Krete surface, simply because the E-Krete does not have the texture depth that is required on antiskid surfacings. Furthermore, the surface of the E-Krete is ‘discontinuous’ because of the grooves. The E-Krete provides friction by the roughness of the cement surface and the grooves. At the meantime, the grooves can also prevent hydroplaning by letting the water running away during rainy

[1] http://polyconintl.com/

days. A laser scan is then proposed to understand the surface profile, which will include the depth and width of the grooves, and the roughness of the other areas.

Figure 2 gives an overview of the cores drilled out of the slab for Leutner shear test.

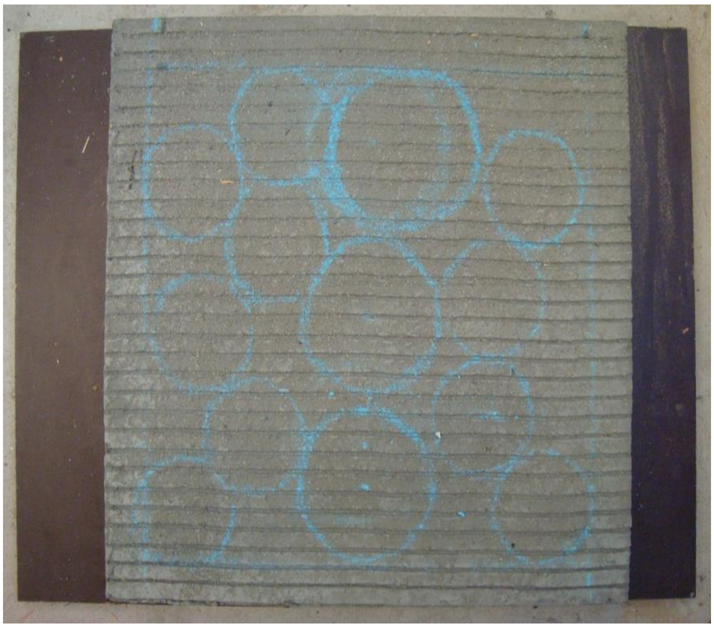

Figure 1 Photo of E-Krete antiskid surfacing

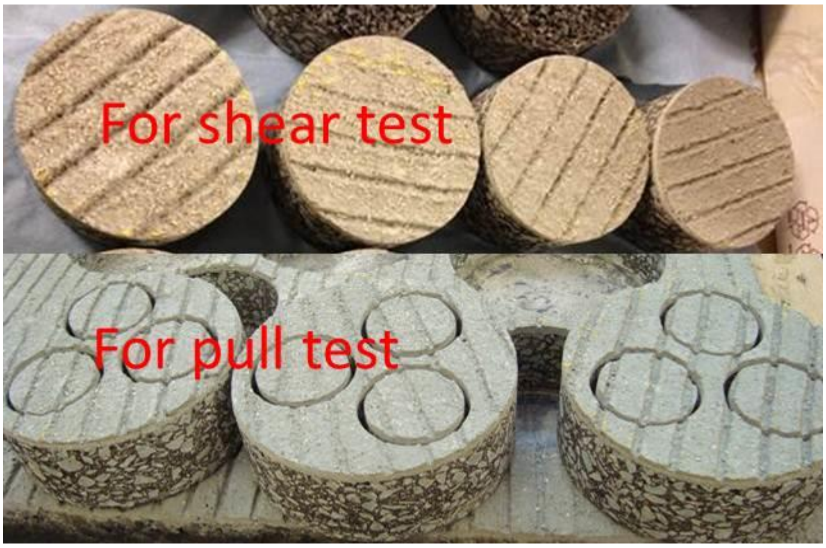

Figure 2 Overview of E-Krete cores

E-Krete is a polymer cement based product. The ratio of every component is 3.7 liters of the liquid resin to 27 kilograms of the powder, plus 1.89 liters of water. Figure 3 shows the three components for the cement mix.

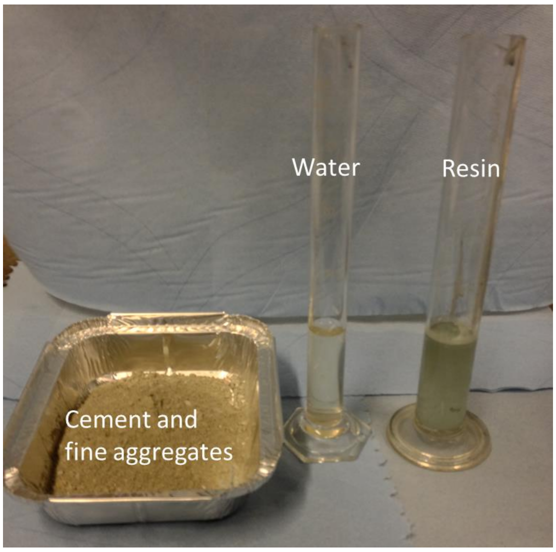

Figure 3 Three components for cement based mix

In the proposed test plan the ASTM C-882; Dynamic Shear Rheometer test and relaxation test were listed to investigate the original and aged binders for antiskid applications. However, cement based materials are totally different from bitumen based materials. Cement based materials cannot be heated to make specimens. It is not temperature sensitive neither frequency sensitive. It does not get aged like bituminous materials do because of high temperature and environmental issues. Therefore, it seemed not wise to use the same test plan for this cement based material.

However, as promised in the test plan, the modulus value has to be investigated. Therefore some changes have to be compromised.

In the laboratory the Dynamic Shear Rheometer can be used to test the modulus and phase angle by applying a sinusoidal torque on the specimen. The specimens listed in Figure 4 are mainly used.

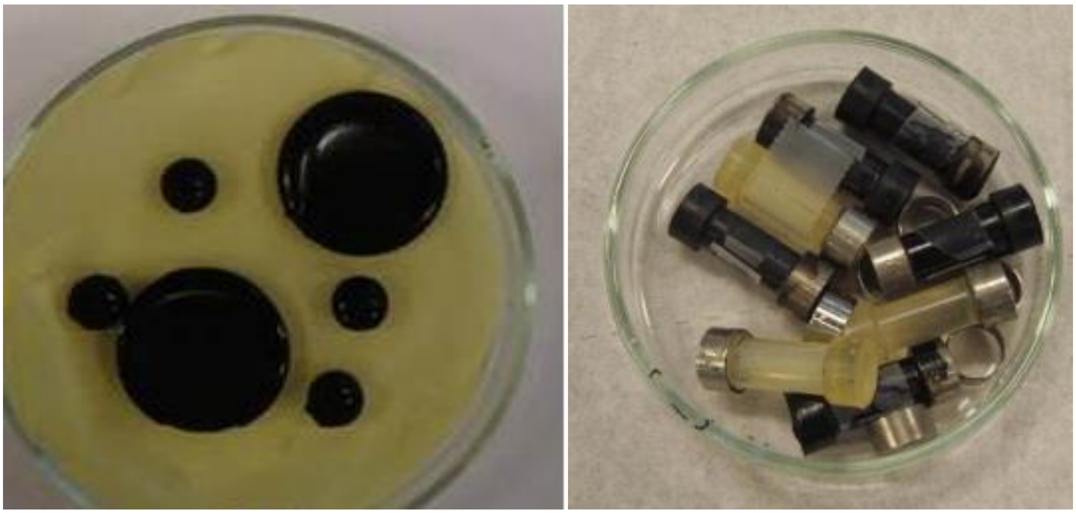

Figure 4 DSR specimens for bituminous materials

But for the polymer cement based material, involved in this research, there is no way to use these types of specimen for testing, or cannot be prepared into these shapes. Therefore, two methods were tried to make specimens to test its modulus.

Method 1:

It was planned to cut the cement based mix to small beams for 3-point bending tests by means of the Dynamic Mechanic Thermal Analysis device. Figure 5 shows the cement mix which can be used to prepare small beams. However, it appeared to be difficult to control the size of the beams. Making a beam with homogenous thickness without a special mould is unreasonable.

Figure 5 Photo of cement based mix

Method 2:

The columns shown in the right picture in Figure 4 cannot be used because the mold used to prepare these columns is not acceptable in case of a cement based mix. If the mixed three components were poured into the mold (see Figure 6), in the liquid state the material easily flow out. Therefore a new silicon rubber mold was made. As Figure 7 shows, columns can be obtained in this way.

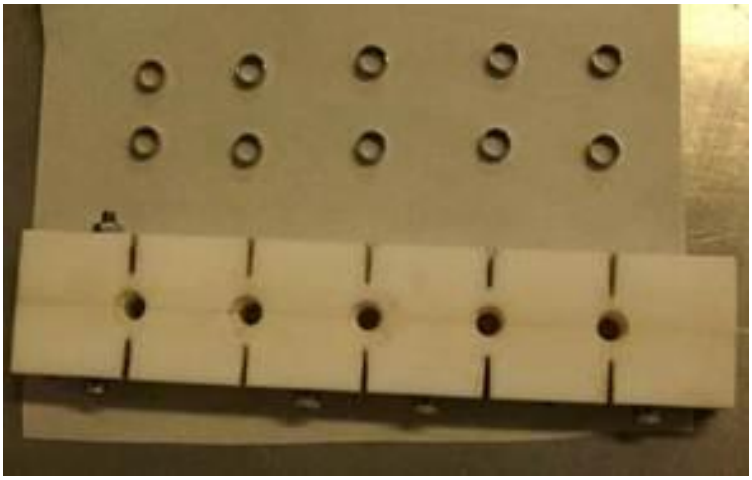

Figure 6 Available mold to prepare columns, but not acceptable for cement based mix

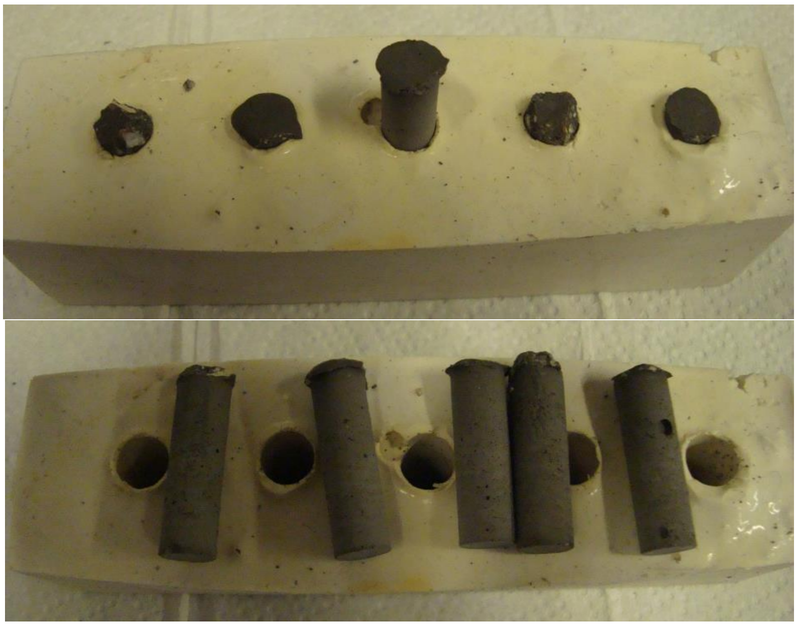

Figure 7 Photo of columns of cement based mix

By comparing method 1 and method 2, one can clearly find out that method 2 is more controllable and much easier than method 1. So method 2 was used and several columns of the cement based mix were prepared for further tests with the Dynamic Shear Rheometer.

The weatherometer ageing will not be conducted on this cement based mix simple because UV light has a slight influence on cement based materials. Although a high temperature (60-80 ºC) will also have a very limited influence, the oven ageing was carried out in this research to check its ageing behavior.

Oven ageing:

The cement based mix columns were placed in a ventilated oven at 85 ºC for 7 days.

3. Test Methods and Results

3.1 Visco-elastic Properties of the Mix – Flexural Strength

The visco-elastic properties of the cement based mix were investigated by means of the Dynamic Shear Rheometer (DSR) test. This method will meet ASTM C-238 Flexural Strength test method for the E-Krete materials, The specimen's complex shear modulus and phase angle can be measured when a sinusoidal shear torque is applied. The columns shown in Figure 7 were tested. Figure 8 shows the test setup. The flexural test results for this test method for the E-Krete material in in excess of 1,835 psi. This is the highest flexural test result this laboratory has experienced in paving materials without cracking results.

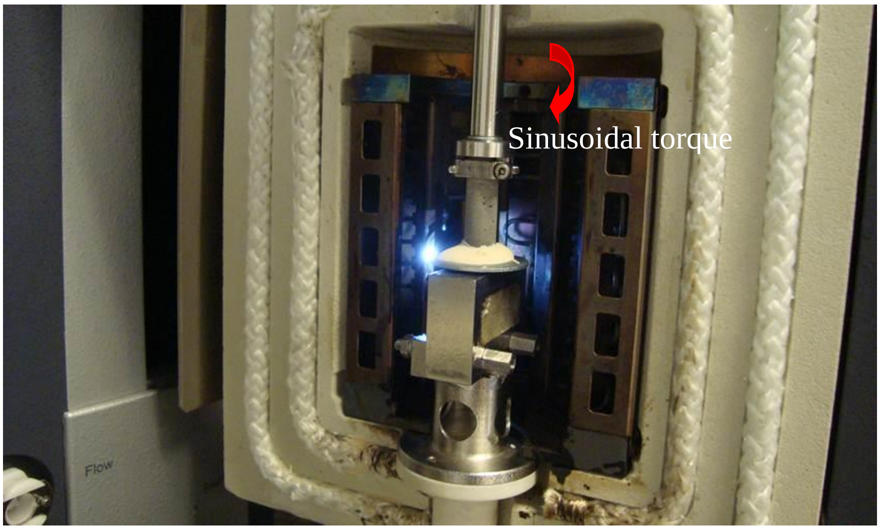

Figure 8 Dynamic shear test on the cement based binder

The stress-strain relation tests were first conducted with strain sweep test to determine the Linear Visco-Elastic (LVE) range of the mix. These tests were needed to make sure that the following frequency sweep tests were conducted in the linear visco-elastic range. The dynamic shear modulus is relatively strain-independent at sufficient small strains.

Strain sweep tests were performed at -10ºC, 0ºC, 10ºC, 20ºC, 30ºC, 40ºC, 50ºC, 60ºC, 70ºC and 80ºC, with a fixed frequency of 10 Hz. Figure 9 and Figure 10 show the modulus-strain curves at lower and higher temperatures, respectively.

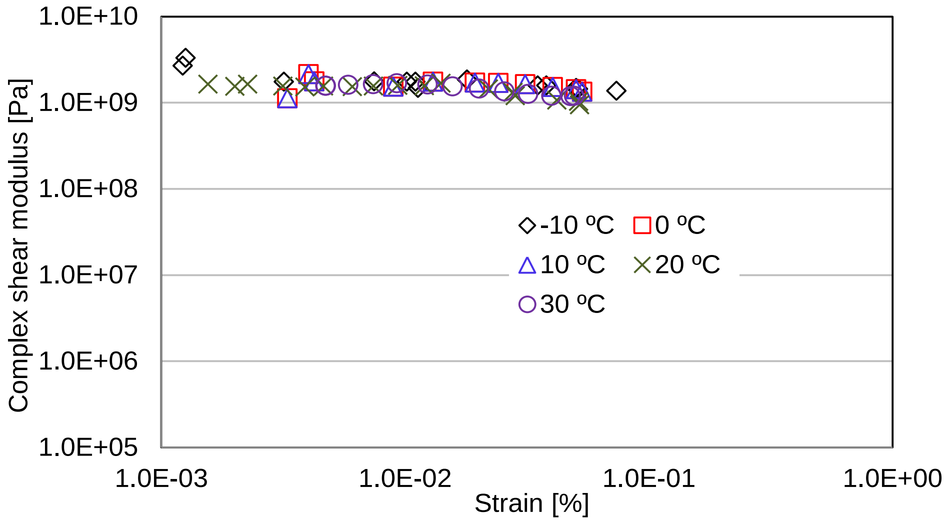

Figure 9 Strain sweep at lower temperatures

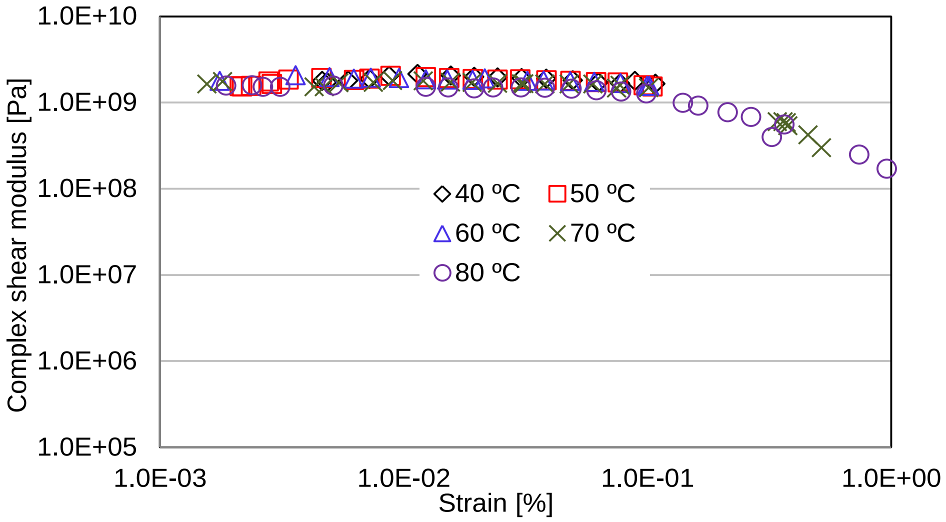

Figure 10 Strain sweep at higher temperatures

The complex shear modulus values at 10 Hz are given in Table 1. It is clearly to see that the complex shear modulus is about the same at all the different test temperatures, when the test frequency is the same. This indicates that the complex shear modulus of the investigated cement based mix is hardly temperature dependent, so a change of the temperature has hardly any influence on the modulus.

Table 1 Complex shear modulus at 10 Hz

Temperature [ºC]	Complex shear modulus [Pa]	Temperature [ºC]	Complex shear modulus [Pa]
-10	1.75×10^9	40	1.8×10^9
0	1.75×10^9	50	1.8×10^9
10	1.7×10^9	60	1.8×10^9
20	1.7×10^9	70	1.72×10^9
30	1.68×10^9	80	1.6×10^9

Based on the strain sweep test results, the proper strain level, 0.01% strain, was selected from the LVE range at each temperature for the frequency sweep tests. Frequency sweep tests from 0.01592 Hz to 47.73 Hz were conducted on fully cured cement based mix and oven aged cement based mix. The specimens of oven aged cement based mix were obtained by placing the fully cured specimen in a ventilated oven at 85ºC for 7 days.

Figure 11 and Figure 12 show the curves of complex shear modulus. These two graphs clearly indicate that the modulus of this investigated cement based mix is independent on temperature and frequency. The influence of the test temperature and the test frequency on the modulus is very limited and can be considered as no influence at all.

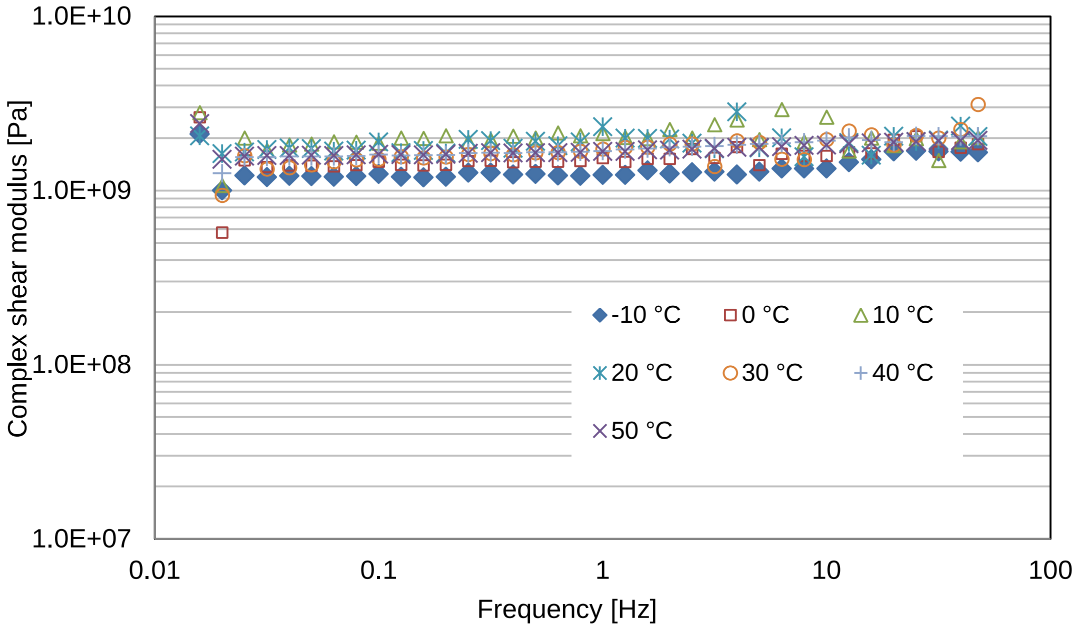

Figure 11 Complex shear modulus of cured cement based mix

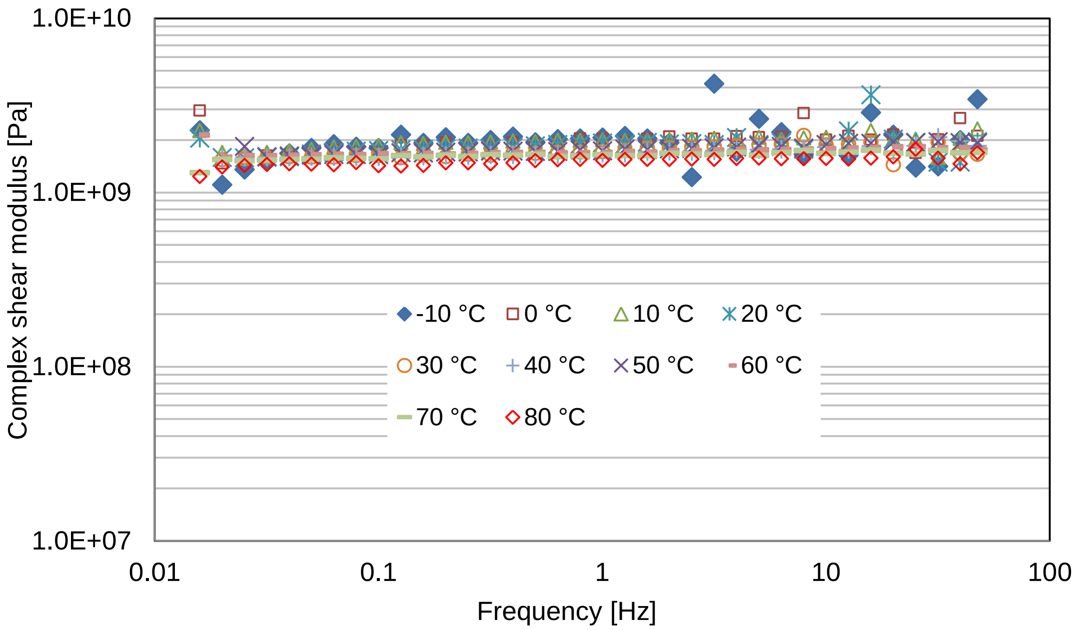

Figure 12 Complex shear modulus of cured cement based mix after oven ageing

Furthermore, the oven ageing process (ASTM G-23) was conducted to investigate the high temperature ageing. By comparing the complex modulus values between Figure 11 and Figure 12, no significant differences can be observed. This illustrates that the high temperature has a very limited effect on the modulus of the tested cement based mix, and no ageing was introduced during the high temperature ageing process.

3.2 Shear Bond Strength ASTM C-882

Leutner shear bond tests were conducted. Figure 13 shows the Leutner shear bond test that was carried out an E-Krete specimen. A steel cylinder, with a diameter of 100 mm and height of 40 mm, was first glued onto the antiskid surface with X60 glue. The liquid glue may penetrate into the interface or even get into the underlying mix layer. In order to avoid this undesired situation, the specimen was kept upside down during the preparation process until the glue got cured. In this way, the shear test can be performed at the interface between the E-Krete layer and the underlying asphalt layer.

Figure 13 Pictures showing the Leutner shear test on an E-Krete specimen

During the test, a constant vertical displacement rate of 50 mm/min is applied across the interface. The resulting shear force is measured. The average Direct Shear Strength (DSS) can be calculated by the following equation:

$$DSS = \frac{4P}{\pi \times D^2} \quad (1)$$

Where,

DSS = direct shear strength [MPa]

P = the maximum force [N]

D = the diameter of test specimen [mm]

The shear tests were conducted at 20ºC, 10ºC and 0ºC. Figure 14 presents a typical force-displacement curve from the shear test on an E-Krete specimen (No.1 test at 20ºC). Figure 15, Figure 16 and Figure 17 show the force-displacement curves at 20ºC, 10ºC and 0ºC, respectively. The failure surfaces are presented in the Appendix 1. Table 2 shows the test results.

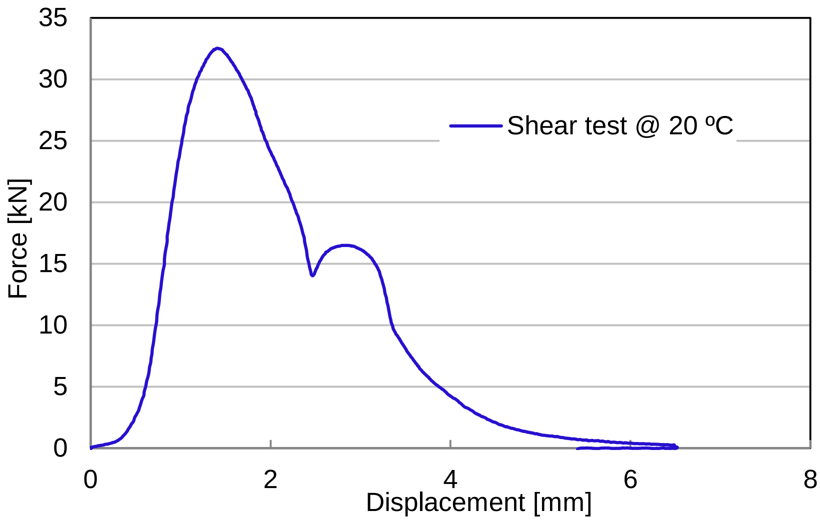

Figure 14 A typical shear test curve on E-Krete

Table 2 Leutner shear bond test results

Temperature [°C]	Failure force [kN]	Shear strength [MPa]	Average [MPa]	Displacement at failure [mm]	Average [mm]
0	54.92	6.99	**7.17**	0.35	0.29
	55.89	7.12		0.25	
	58.14	7.40		0.26	
10	39.46	7.02	**7.44**	0.40	0.45
	50.88	7.48		0.51	
	45.75	7.83		0.44	
20	32.51	7.14	**7.46**	0.80	0.82
	37.51	7.78		0.84	
	Not available			--	

Most of the failures occurred at the interface, but the first shear test at 10°C and the third shear test at 20°C were exceptions.

Figure 18 illustrates at 10°C. At the area close to the applied force the failure occurred at the interface of two layers, while in the middle of the specimen the failure occurred at the interface between the steel cylinder and the glue. This was caused by the uneven glue applied during the sample preparation. This is a result of a poor sample preparation not the E-Krete.

The third specimen tested at 20°C nearly completely failed at the interface between the glue and the steel cylinder (see Appendix 1, picture at the bottom of Figure 24) and therefore its test result is not taken into account. This is a result of a poor sample preparation not the E-Krete.

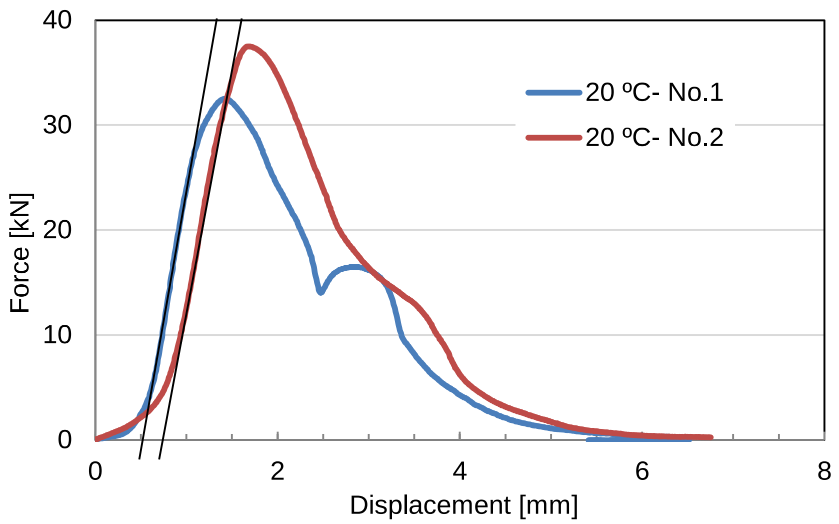

Figure 15 Displacement-force curves at 20°C in shear test

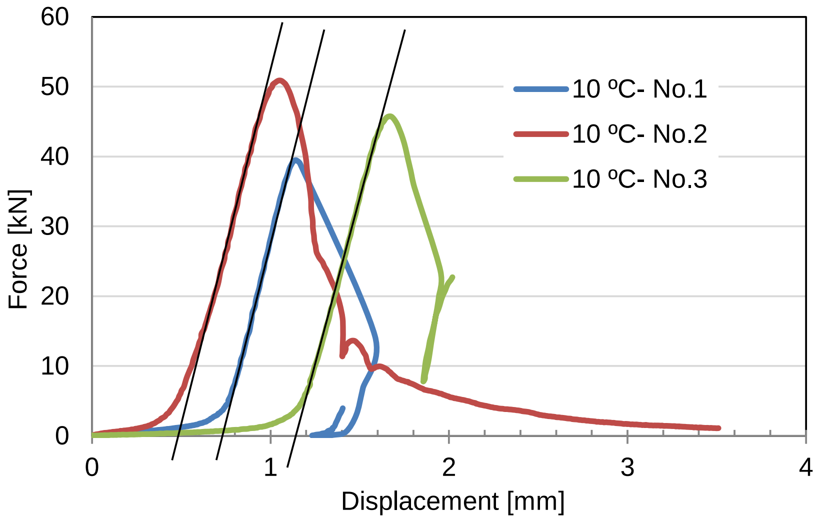

Figure 16 Displacement-force curves at 10ºC in shear test

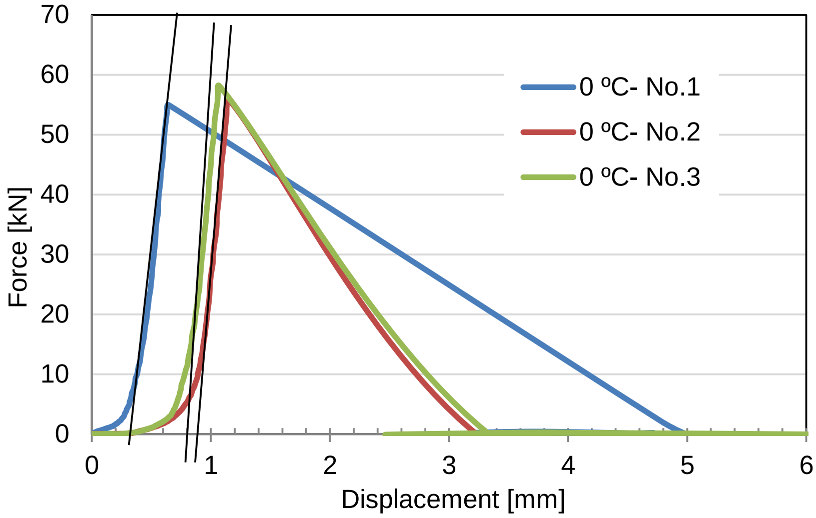

Figure 17 Displacement-force curves at 0ºC in shear test

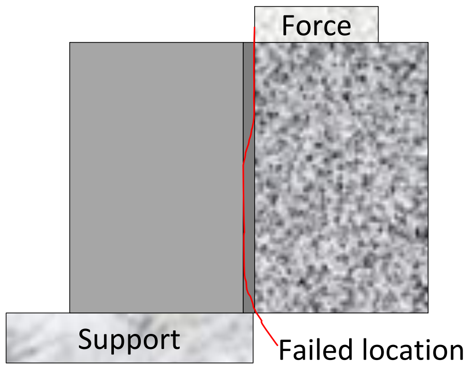

Figure 18 Failure mode in the first shear test at 10ºC due to poor sample preparation

The shear test results indicate that the shear strength at the interface between the E-Krete antiskid surfacing and the underlying asphalt mixture layer is consistent at various temperatures. At 0ºC the shear strength is about 7.2 MPa, while it is 7.4 MPa at 10ºC and 7.5 MPa at 20ºC.

The draft specification [2] requires a shear strength of at least 1 MPa at 20ºC at a displacement rate of 50 mm/min. **Therefore it can be concluded that the shear strength at the interface between the E-Krete surface layer and the underlying asphalt layer is very good and exceeds most paving materials reviewed by this laboratory and satisfies the requirements**.

3.3 Tensile Strength ASTM C-190

Pull tests were conducted to ASTM C-190 specifications to investigate the tensile adhesion strength at the interface between the E-Krete surface layer and the underlying asphalt mixture layer. Figure 19 shows the specimens for the pull test. Figure 19 shows the sample preparation and test setup. Cylindrical cuts with a diameter of 50 mm were first cored into the core to a depth of 10 mm to make sure that the drill passed the E-Krete surface layer. A steel plate was then glued to the dried and cleaned surface with X60 glue. After the glue got its full strength, the entire sample was placed upside down on the test table in a temperature controlled chamber. The surface layer was pulled off with a load speed of 0.025 MPa/s, and the tensile force was measured.

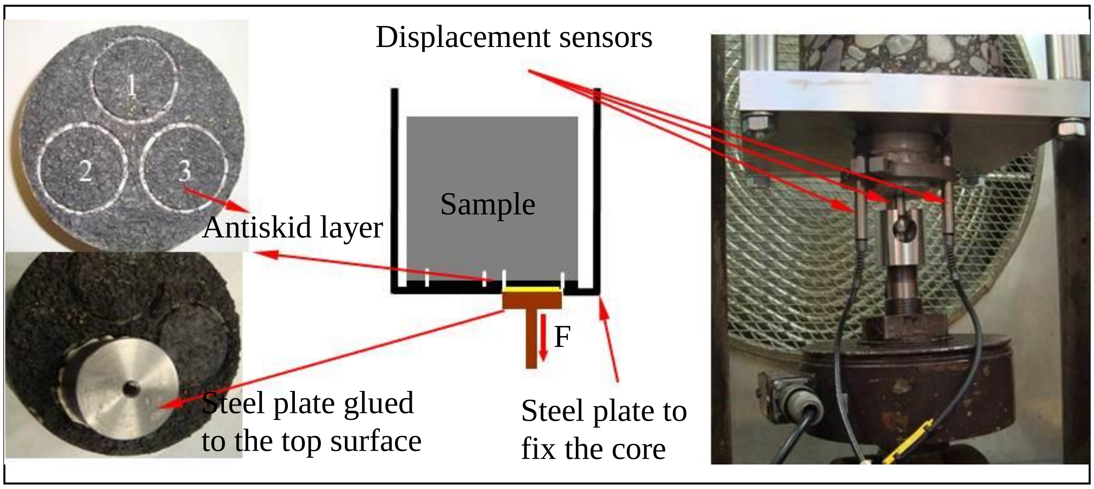

Figure 19 Sample preparation and test setup for pull test [1]

The Direct Tensile Strength (DTS) is defined as the maximum tensile force divided by the area of fractured surface:

$$DTS = \frac{4F}{\pi \times D^2} \quad (2)$$

Where,

DTS = Direct Tensile Strength, [MPa];
F = the maximum force, [N];
D = the diameter of test specimen, [mm].

Figure 20, Figure 21 and Figure 22 present the applied force and resulting displacement curves versus time at three test temperatures. The tests show three cold temperature mixes (coldmix). Figure 20 shows that at high temperature, 20ºC, a period of failure propagation can be observed. But at low temperature, 0ºC, the force-displacement curves are almost linear till the point of brittle failure. The displacement at failure (at the highest applied force) at 0ºC is less than 3 mm, while at 20ºC it can reach to more than 10 mm.

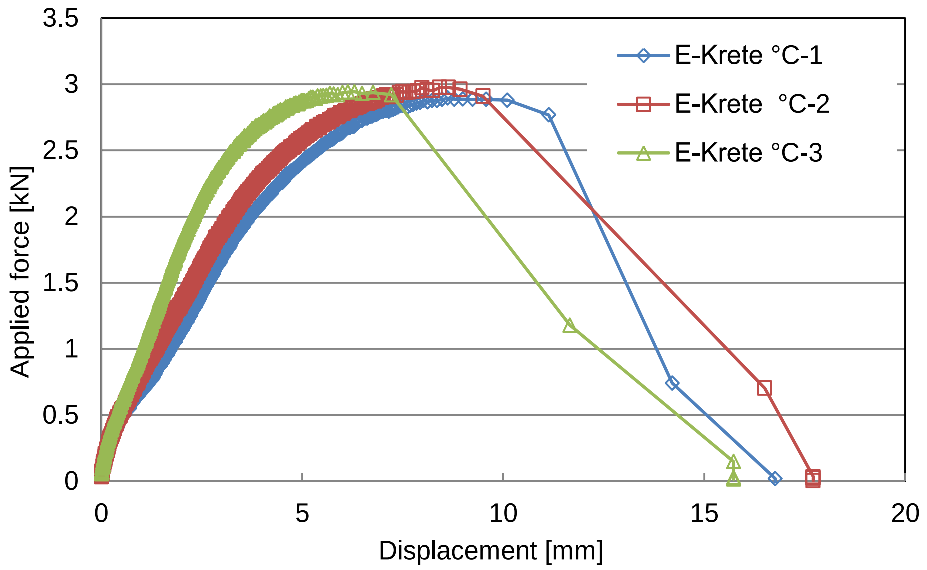

Figure 20 Displacement-force curves at 20ºC in pull test

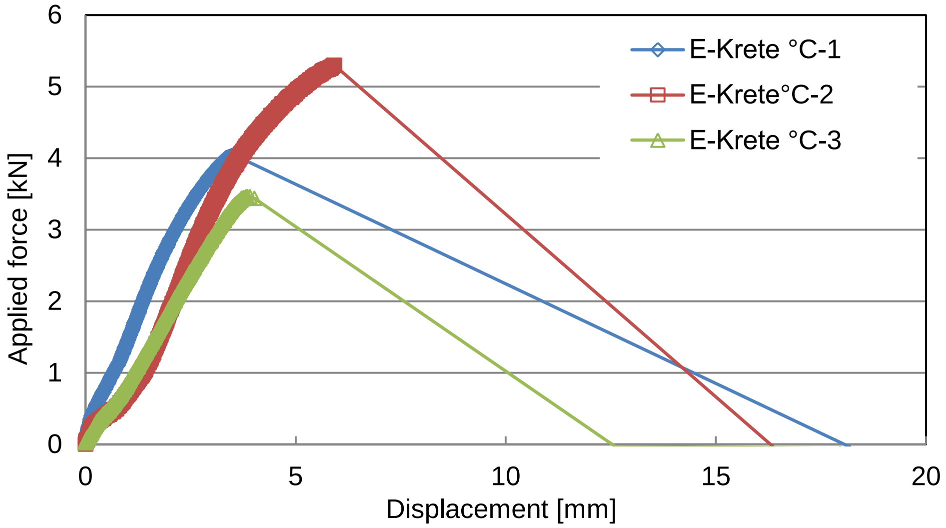

Figure 21 Displacement-force curves at 10ºC in pull test

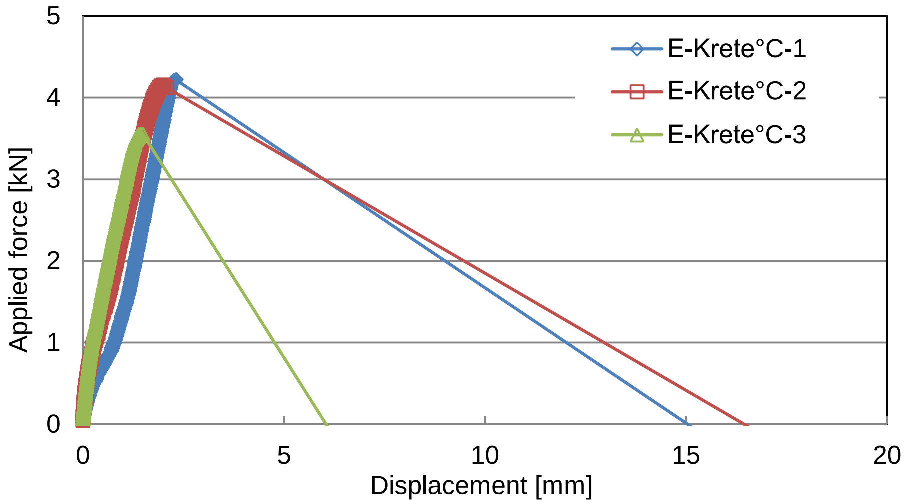

Figure 22 Displacement-force curves at 0ºC in pull test

The results obtained from the pull tests are given in Table 3, and the failure modes are given in and Appendix 2.

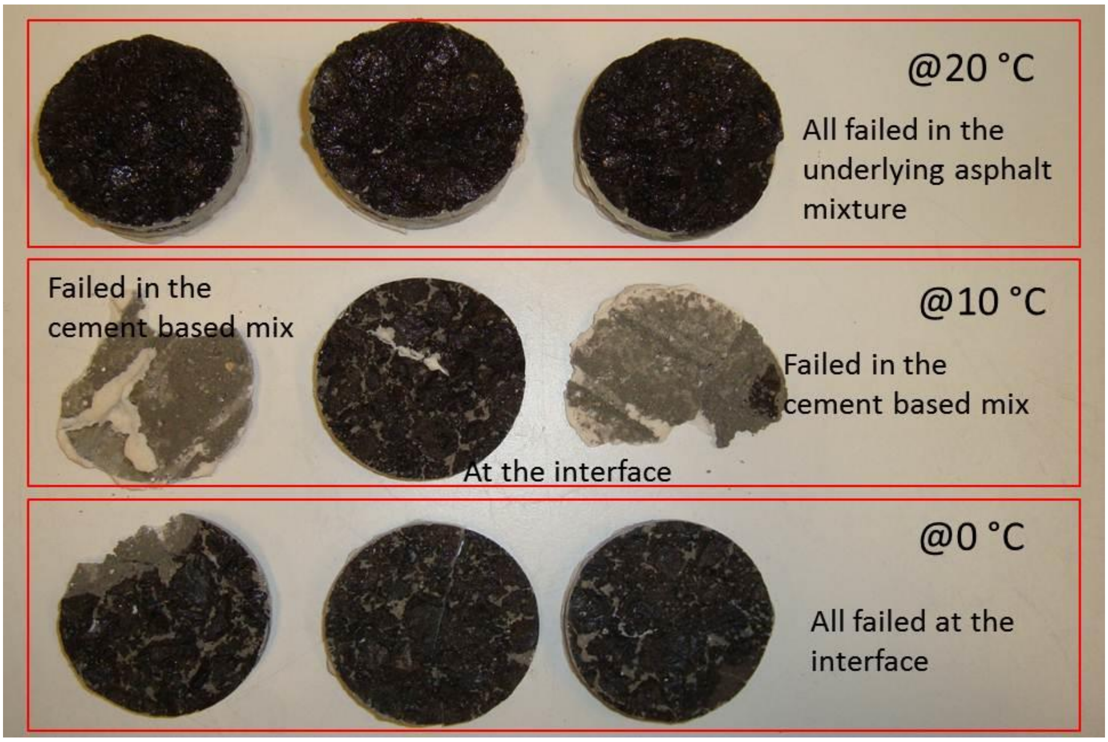

Figure 23 Failure modes during pull test

At 20ºC all the failures occurred in the underlying asphalt mixture layer. This means that at test condition of 20ºC the asphalt mixture has the lowest tensile strength. The tensile adhesive strength at the interface is higher than the average test result, which is 1.496 MPa. Therefore the E-Krete is stronger and has a much higher strength than the substrate material it is applied to.

At 10ºC two tests failed in the underlying asphalt base layer and one failed at the interface. The tensile strength at the interface is higher than this value, and therefore higher than the required tensile strength (1 MPa at 10ºC and load rate 0.025 MPa/s) in the CROW specification [2]. The third specimen tested at 10ºC failed at the interface and exhibited an exceptionally high tensile strength. This test translate to a higher than 615 psi to 700 psi test result.

At low temperature, 0ºC, all the tests failed at the interface. The tensile adhesive strength at the interface at 0ºC is on average 2.024 MPa.

Table 3 Pull test results

Temperature	Failure force [kN]	Tensile strength [MPa]	Average [MPa]	Displacement at failure [mm]
20 ºC	2.895	1.474	1.496[1]	8.62
	2.976	1.516		8.42
	2.943	1.499		6.3
10 ºC	4.037	2.056	1.909[2]	3.51
	3.458	1.761		3.85
	5.294	2.696	2.696[3]	5.93
0 ºC	4.217	2.148	2.024[3]	2.32
	4.154	2.116		2
	3.55	1.808		1.44

1 failure in asphalt mix 2 failure in cement based mix 3 failure at interface

4. Conclusions

The visco-elastic property (ASTM C-238) and high temperature accelerated weathering ageing resistance (ASTM G-23) of the polymer cement based mix were investigated with the Oven and Dynamic Shear Rheometer tester in this research. The tensile adhesive strength (ASTM C-190) and the shear bond strength (ASTM C-882) at the interface between the E-Krete surface layer and the underlying asphalt mixture layer were investigated by means of the pull test and Leutner shear test, respectively. Based on the results presented in this report, the following items can be concluded:

1. The tested cement based mix has a complex shear modulus of 1.7×10^9 Pa to 1.8×10^9 Pa. Its modulus value is independent on the temperature and frequency. No ageing was introduced in the cement based mix due to high temperature and exceeds the ASTM requirements for the stated test materials.

2. The average shear strength at the interface between the E-Krete surface layer and the underlying asphalt mixture layer is 4.46 MPa at 20ºC and displacement rate 50 mm/min. Therefore it satisfies the required values in the draft CROW specification and exceeds the

ASTM requirements for the stated test materials. The E-Krete polymer cement material exceeds all DOT requirements for these stated tests

3. Test results indicate that the tensile strength at the interface at 10ºC and load rate 0.025 MPa/s is higher than 1.909 MPa. This means that the tensile adhesive strength meets the required values in the draft CROW specification. The E-Krete polymer cement material exceeds all DOT requirements for these stated tests

The tests included in this research all shows positive results. However, one should keep in mind that the investigate material in this research is a cement based mix. Its basic material characteristics are far different from those of the underlying asphalt mixture, which may cause problems during its service life, e.g. the different thermal expansion coefficients could result in delamination and the different stiffnesses may cause micro cracks. Therefore further research, for instance field trials, are recommended to get more accurate predictions with respect to these phenomena.

5. References

[1]. Xiao, Y., et al., Assessment Protocol for Tar-containing Antiskid Layers for Runways, in 7-10-185-2. 2010, Delft University of Technology.
[2]. CROW-D11-01, Specifications for runway surface dressings on airfields. 2011, the Netherlands.

Appendix 1 Leutner Shear Test Results

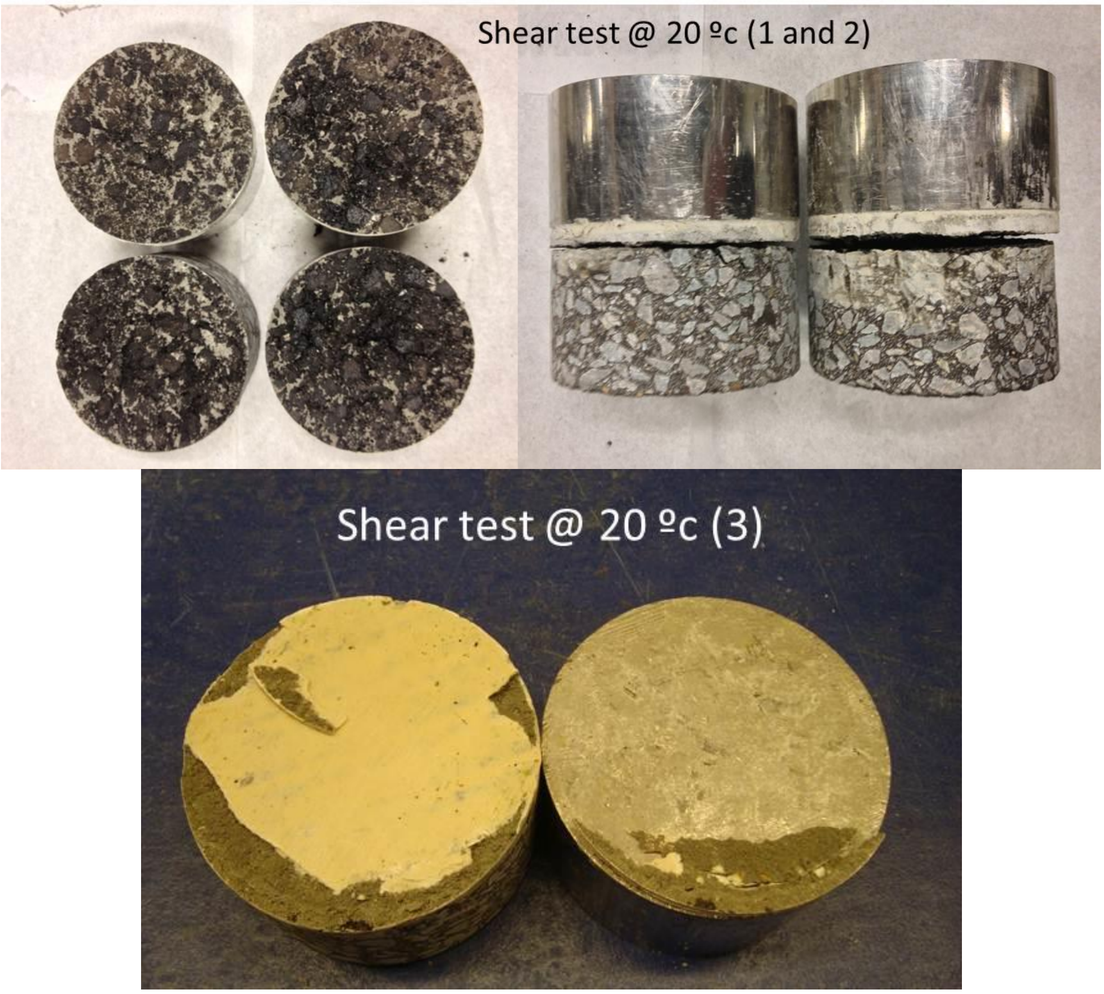

Figure 24 Failure surfaces at 20ºC

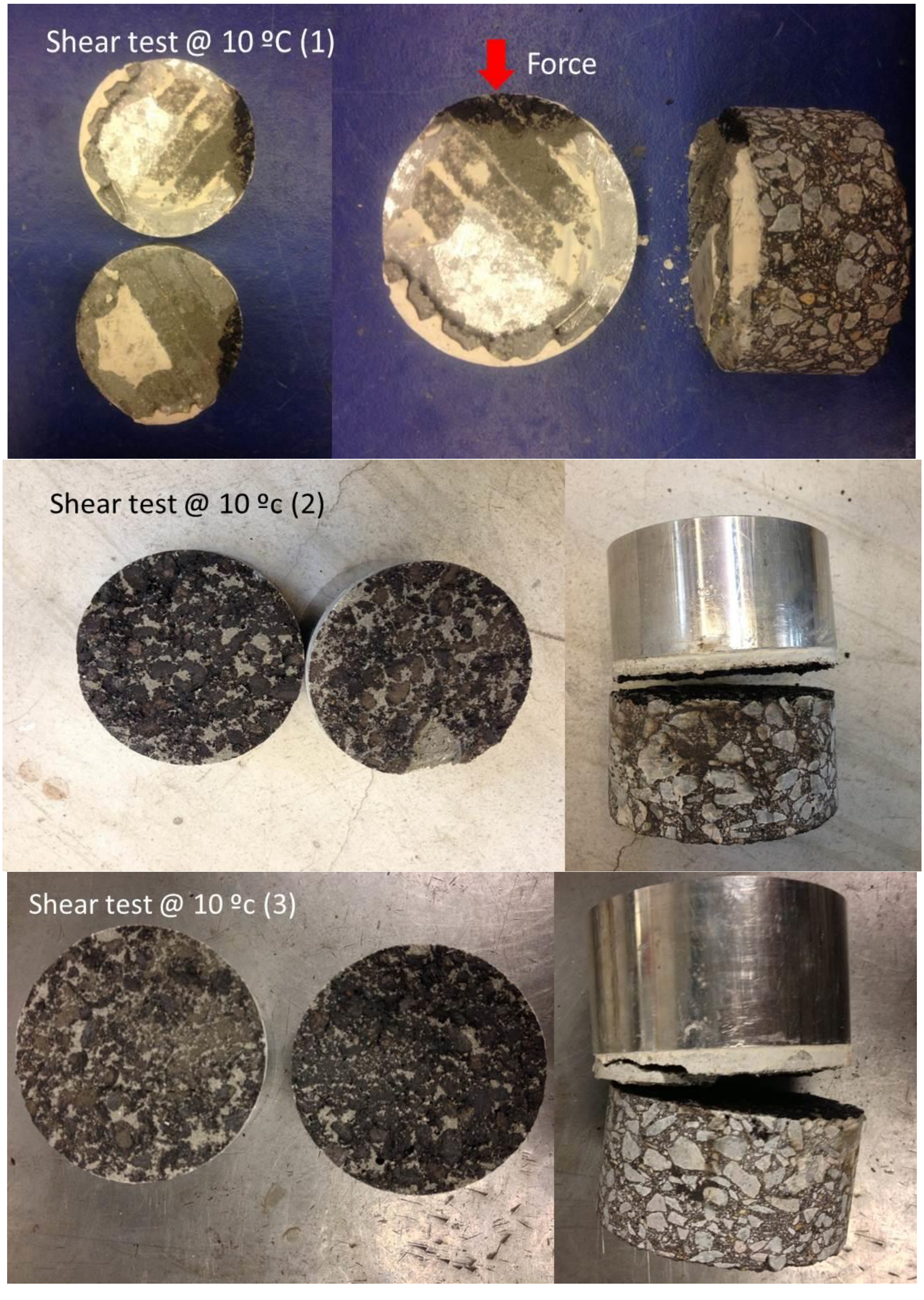

Figure 25 Failure surfaces at 10ºC

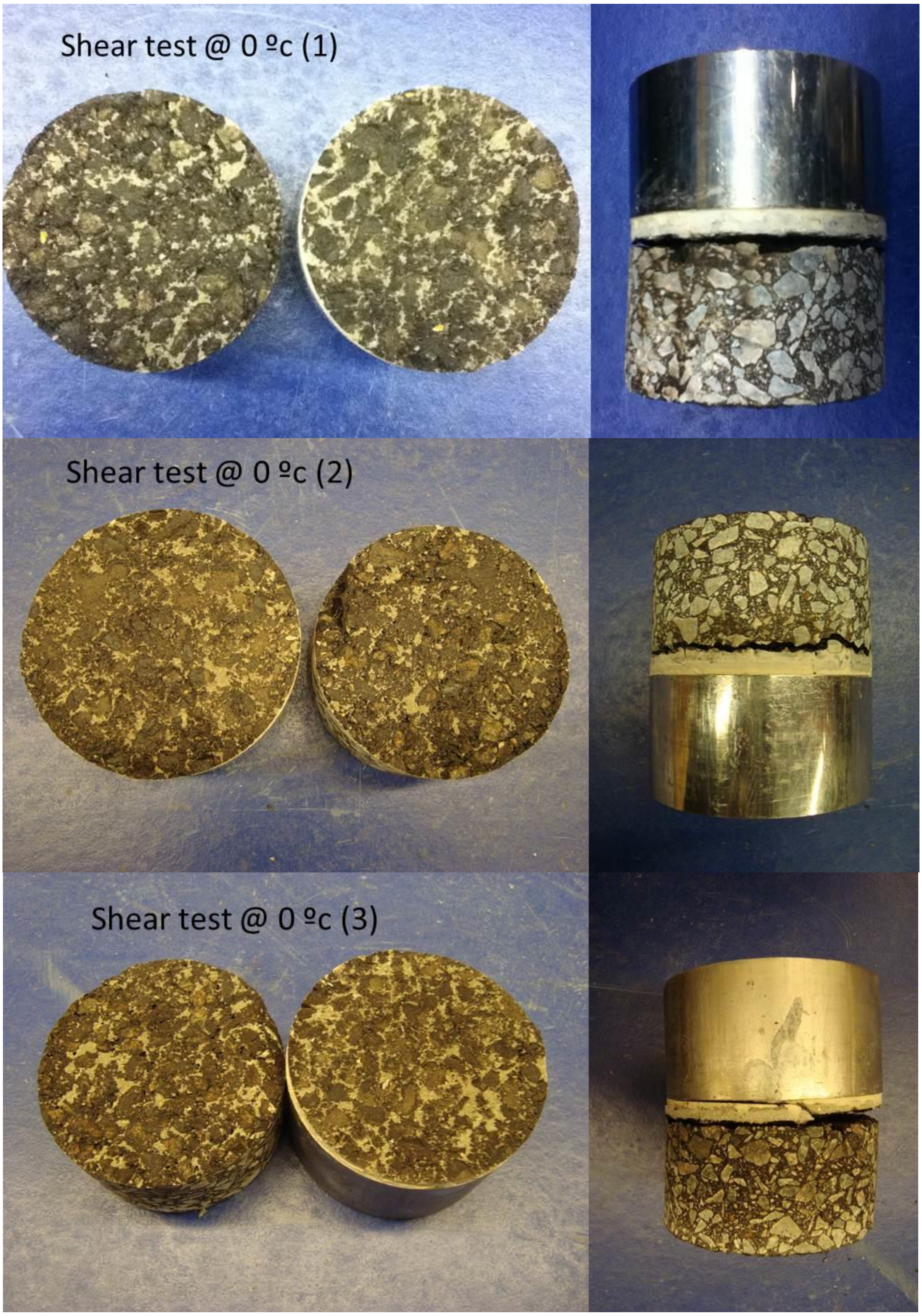

Figure 26 Failure surfaces at 0ºC

Appendix 2 Pull Test Results

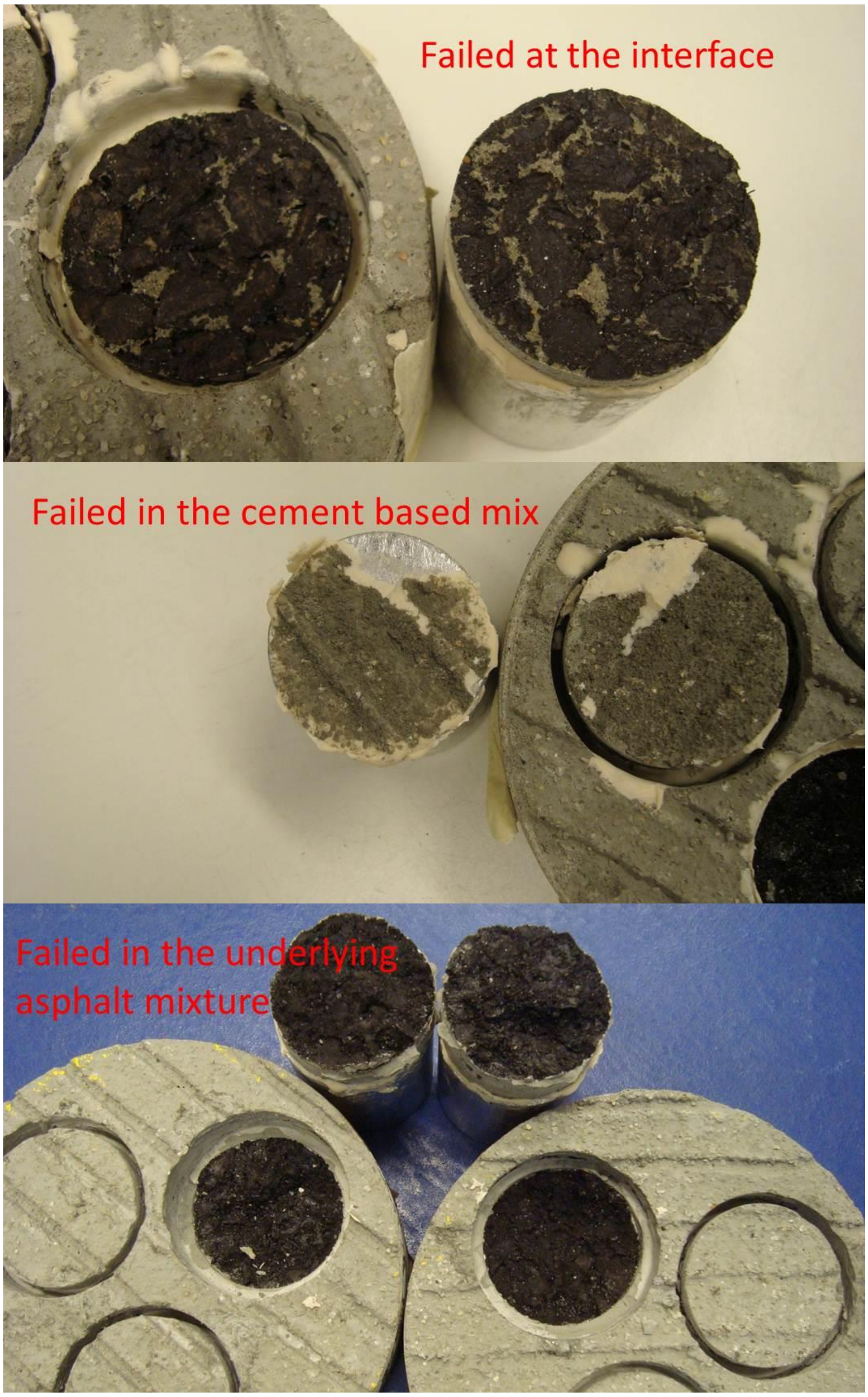

Figure 27 Failure modes during the pull test