3rd International Conference on Self-Healing Materials
Bath, UK. 27-29 June 2011

SELF HEALING OF ROAD-USE BITUMINOUS MATERIALS: MECHANICAL CHARACTERIZATION AND ITS MODELLING

Jian Qiu[a, b], Martin van de Ven[a], André Molenaar[a], Shaopeng Wu[b] and Jianying Yu[b]

[1]Road and Railway Engineering, Civil Engineering and Goesciences, Delft University of Technology, 2600GA Delft, the Netherlands
Email: j.qiu@tudelft.nl; m.f.c.vandeven@tudelft.nl; a.a.a.molenaar@tudelft.nl

[2] Key Laboratory of Silicate Materials Science, Engineering of Ministry of Education, Wuhan University of Technology, Wuhan 430070, China
E-mail: wusp@whut.edu.cn; jyyu@whut.edu.cn

Keywords: Self-healing, Bitumen, Viscoelastic, Crack closure, Strength

ABSTRACT

Asphalt pavement can repair its distress and improve the service life significantly thanks to the hot summers and long rest periods. This phenomenon is called the self healing behaviour and is believed to be one of the important factors for designing of the durable asphalt pavement. This phenomenon has been noticed for more than forty years [1]. Yet the underlying mechanism is not clear so far.

Laboratory healing experiments were carried out as shown in Figure 1. By applying a loading-healing-reloading cycle to the specimen, the damage self healing capability of various bituminous materials were investigated [2]. Experimental results confirm the existence of self healing phenomenon (Figure 1c). Less damage, higher healing temperature, longer healing time and compressive stress are beneficial for self healing improvement.

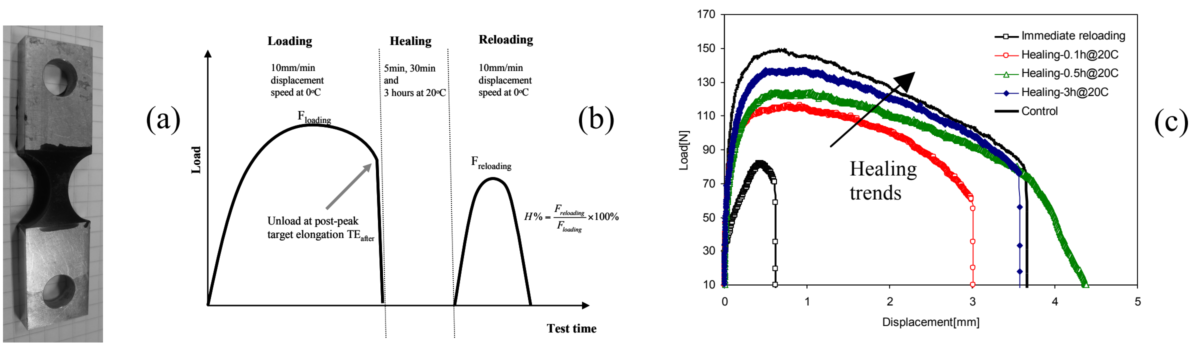

Figure 1: Laboratory self healing measurements: (a) direct tension self healing test specimen; (b) test program; (c) example of test results at TE_{after} of 3mm

As a visco-elastic material, the damage-healing process of bituminous materials is always coupled with visco-elasticity. A damage-healing model is developed in Equation 1 based on viscoelastic continuum damage mechanics [3]. $1-\alpha(t)$ is defined as a degradation factor due to damage, and a nonlinear damage evolution law is also applied as shown in Equation 2.

$$\sigma(t) = \varepsilon(t)\cdot\left[1-\alpha(t)\right].\left\{E_{\infty}.t + \sum_{j=1}^{p}\eta_j\left(1-\exp\left(-\frac{E_j}{\eta_j}t\right)\right)\right\} \quad (1)$$

$$\dot{\alpha} = c\cdot\varepsilon(t)^m\cdot\left[1-\alpha(t)\right]^n \quad (2)$$

Where, $\sigma(t), \varepsilon(t)$ denote for the stress and strain; E_{∞}, E_j, η_j are parameters for Generalized Maxwell model for visco-elasticity; c, m, n are the damage parameters.

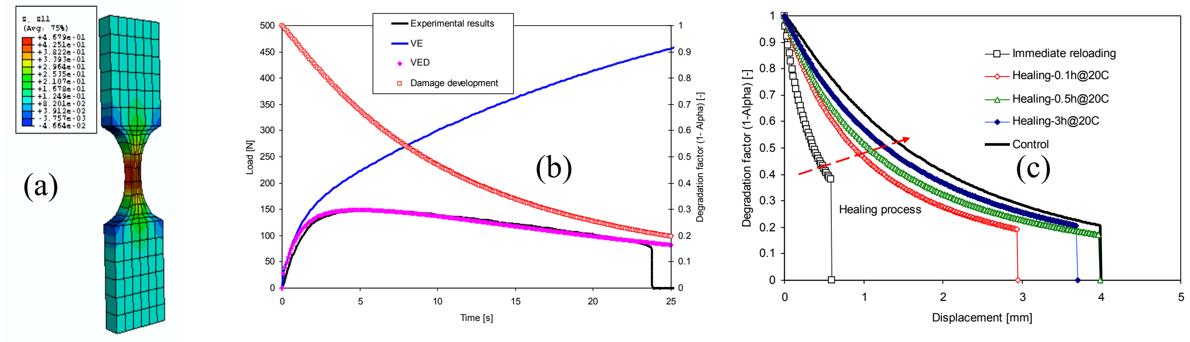

Figure 2: Modelling of self healing tests: (a) Example of stress distributions;
(b) Monotonic simulation; (c) healing simulation

Table 1: List of damage parameters before and after healing

	c	m	n
Control	0.009	0.01	1.4
Immediate reloading	0.042	0.01	1.8
Healing-0.1h@20C	0.017	0.01	1.65
Healing-0.5h@20C	0.014	0.01	1.65
Healing-3h@20C	0.011	0.01	1.5

The simulation was done using ABAQUS with a user defined subroutine UMAT. Within the model, healing is treated as the recovery of the viscoelastic behaviour as a reverse process to damage.
Figure 2 shows the stress distribution of the simulated direct tension specimen. Figure 2b shows the simulation of the monotonic test and the degradation factor $1-\alpha(t)$. Figure 2c shows the development of the degradation factor eliminated visco-elasticity before and after healing. Table 1 lists the damage parameters used in the simulation.

The simulation shows that healing decreases the damage speed, which can also be seen from the decrease of the damage parameter c as shown in Table 1.
The proposed model can simulate the damage-healing process successfully. More attention should be paid to further interpret the change in damage parameters and the internal healing mechanisms (delayed visco-elastic healing or viscous healing). It is believed that understanding of this phenomenon is very important for designing more durable asphalt pavement as well as modifications on bituminous materials.

The first author would like to thank the China Scholarship Council for the financial contribution. The authors appreciate the cooperation between Wuhan University of Technology and Delft University of Technology and express their wish to prolong and strengthen the current cooperation between the mentioned institutes of technology. Special thanks to Ir. Milliyon Woldekidan for discussion of the modeling work.

REFERENCES

[1] P. Bazin and J.B. Saunier, Deformability, fatigue and healing properties of asphalt mixes, *Proceedings of the Second International Conference on the Structural Design of Asphalt Pavements*, Ann Arbor, Michigan, USA, 1967, pp. 553-569.

[2] J. Qiu, M.F.C. Van de Ven, S. Wu, J. Yu and A.A.A. Molenaar, Asphalt pavements are self healing, *Proceedings of 1st International Conference on Sustainable Construction Materials: Design, Performance and Application*, Wuhan, China, 2010.

[3] Y. Kim, D.H. Allen, and D.N. Little, Damage-induced modeling of asphalt mixtures through computational micromechanics and cohesive zone fracture, *Journal of Materials in Civil Engineering*, **17**(5), 2005, pp. 477-484.