THE INFLUENCE OF TEMPERATURE ON THE PERFORMANCE OF WATERPROOFING MATERIALS APPLIED TO ORTHOTROPIC STEEL BRIDGE DECK PAVEMENT

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ABSTRACT

This paper is aimed at the service performance of waterproofing materials used in orthotropic steel bridge deck pavement, and studies the influence of temperature on the performance of waterproof and adhesive layers, which consisted of Bostik 9225 type adhesive primer, and rubber modified mastic. The different technical indices of the waterproofing system are discussed, such as cohesive strength, interface adhesive strength and shear strength. The relationships between the different indices and temperatures were investigated. By applying the finite element method and the material parameters obtained from experiments, the shear behaviour of the materials was modelled numerically. When comparing the results of the laboratory tests and the FEM model, the error possibility, especially under high temperature, was found to be comparatively small, which means that the effectiveness of prediction seems satisfactory and the simulation and prediction of the shear strength by FEM are reasonable and effective. It is also meaningful to use the numerical method as a substitute for the field test from a cost point of view.

1. BACKGROUND

Pavements laid directly on steel bridge plates usually comprise an asphalt surfacing and bitumen waterproofing underlayer or an adhesive primer (Medani, 2001). In spite of the fact that the waterproofing of bridge decks is thinner than the asphalt surfacing, it is still recognised as a vital and necessary strategy to enhance the longevity and durability of the structure. On the one hand, it forms the first line of defence against attack by water, pavement de-icing salts and aggressive chemicals which could corrode the steel deck plate under the concrete and cause severe damage or even total failure eventually. On the other hand, it bonds the asphalt pavement to the steel deck to form a complete constituent to withstand the complex action of traffic load. Furthermore, when horizontal distortions of the steel deck surfaces occur under the action of fluctuating temperature or traffic load, the waterproofing can absorb the relative movement between the asphalt pavement and the

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steel plate and thereby decrease inter-stress in the paving system. If the shear resistance of the waterproofing is insufficient, it will encourage the paving system to undergo a sheet-to-sheet action which may lead to some deterioration such as rutting, humping, shearing and so on. Such degradations, due to insufficient attention paid to the interface adhesion, have even occurred in early steel surfaces in China. In Guangdong Province, the interface separation of the steel surface of Humen Bridge began only three months after it was opened to traffic. In Xiamen City, various problems in the steel pavement of Haicang Bridge appeared two years after it was opened to traffic, such as blisters, potholes, deformation and so on (Chen, 2003). By stripping the surface, it was found that some asphalt sections had completely separated from the steel plate. Shearing problems in steel surfaces have also occurred abroad. In Australia, the waterproofing interface separation distress of the West Gate Bridge required the surface to be repaved (Lu, 2002). Naturally, the material stiffness and working properties are significantly different as are the temperature variations. Therefore, owing to the rapid development of long-span steel bridges in China, it is essential to make an intensive study of the influence of temperature on the performance of the waterproofing system and materials in respect of both theory and field application.

2. MATERIAL DESIGN

Originally, the characteristics of waterproofing materials were only considered in roofing, tank and flooring applications, and later the study was extended to water-resistant and corrosive chemical-resistant protective layers in steel paving structures. Different waterproofing materials and layer thicknesses for orthotropic steel bridges were used in different countries, based solely on their own experience. In Holland, the typical waterproofing system included an epoxy adhesion and rubber bitumen underlay with a total thickness of 10 mm. In Germany and Belgium, between the guss asphalt pavement and the steel plate one finds the OKTO type adhesion and modified mastic underlay with a total thickness of 10 mm. In Denmark, the 4-mm-thick waterproofing layer comprises an adhesive primer, and mastic underlay was used in the Great Belt East Bridge and Little Belt Suspension Bridge (Wegan and Bloomstine, 2004). In Sweden, 3.5-mm-thick modified waterproofing mastic was used in the High Coast Bridge. In Japan, special technical criteria were published for the selection of materials and evaluation of their performance (Tada, 1996).

This paper describes the investigation of a type of solvent rubber modified asphalt bonding material, which had good ductility to accommodate the distortions of the steel plate. Because of the excellent shear resistance and waterproofing characteristics of the materials, waterproofing and bonding structures are widely used for orthotropic steel bridges, such as the Humber Bridge and the Severn Bridge in England, the Bosporus Channel Bridge in Turkey, the Tsingma Bridge in Hong Kong, and others. Investigations by the British Transportation and Road Research Laboratory (TRRL) showed that steel bridge deck surfacing with this type of waterproofing material had a typical life expectancy of 20 to 30 years (Dussek, 1998).

The Bostik 9225-type adhesive glue manufactured by Bostik Findley Limited of Britain was used as the bonding primer exclusively in the membrane system of the bottom of the deck. The waterproofing material was mixed with rubber modified asphalt supplied by the Shell Bitumen group and limestone filler supplied by UK Longcliffe Quarries Corporation in a proportion of 25%:75%. The technical characteristics of the rubber asphalt binder and fine aggregate are given in Tables 1 and 2.

Table 1. Characteristics of the rubberised asphalt binder

Description of item		Results	Test methods
Penetration 25 ^{o}C, 100 g 0.1 mm		43	DIN EN 1426
Ductility 15 ^{o}C, 5 cm/min cm		39	DIN EN 52 013
Softening point R&B ^{o}C		58	DIN EN 1427
Fraass breaking point ^{o}C		-10	DIN EN 12593
Density 15 ^{o}C g/cm^{3}		1.045	DIN EN ISO 3838
Flash point COC ^{o}C		280	DIN EN ISO 2592
Elasticity recovery rate %		55	DIN V 52 021-1
Storage stability ^{o}C		2.0	DIN EN 1427 Anhang
Membrane oven test	Loss on heating %	0.34	DIN EN 12607-3
	Penetration ratio (25 oC) %	45	
	Ductility (15 oC) cm	21	

Table 2. Characteristics of the limestone*

Sieve size mm	Passing rate %	Leaving rate %	Criterion range %
2.36	100	0	0-3
0.6	87	13	5-25
0.212	66	21	10-30
0.075	47	47	40-55

Note:*The calcium carbonate assay test value is 98% – 100%.

3. TEST EVALUATIONS

To simulate the influence of temperature on the performance of steel deck waterproof binding materials in the laboratory, researchers adopt different evaluation methods (Li, 2004). Huang Wei et al. (2002) evaluated the performance of waterproofing materials for the Nanjing Second Yangtze River Bridge by shear and adhesion tests. Yu Shufan et al. (1998) used cohesive strength to evaluate the waterproofing material for Humen Bridge. Edwards and Westergven (2001) applied adhesion, shear and sliding tests to the waterproofing on the High Coast Bridge. On the basis of the above investigations, tests such as cohesiveness, adhesion and shear were used in this study.

3.1 Cohesiveness

A special cohesiveness test instrument was used to investigate the waterproof bonding layer. The test velocity was kept within 100 – 200 N/s until the sample was destroyed. Figure 1 shows a diagram of the test set-up and Figure 2 graphically represents the empirical test data.

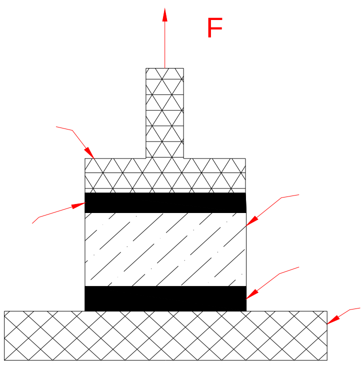

Figure 1. Set-up for cohesiveness test

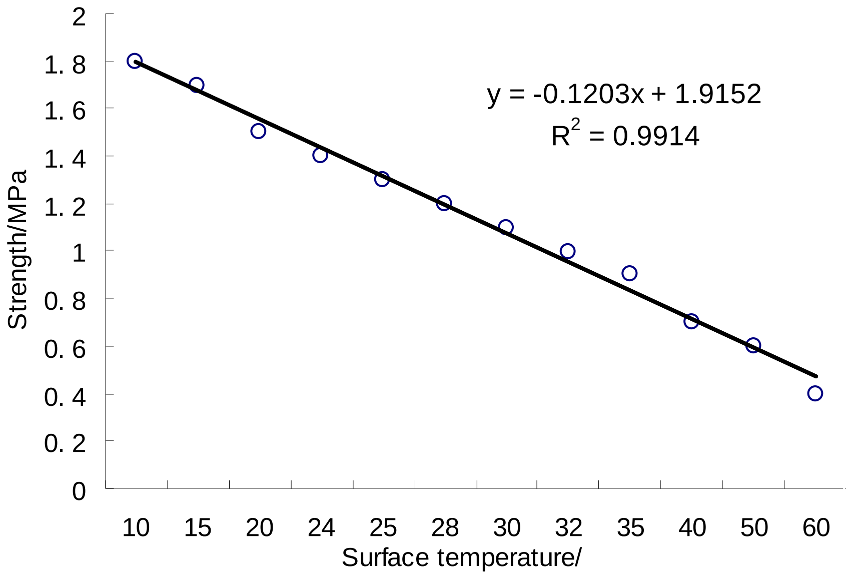

Figure 2. Influence of temperature on cohesiveness strength

The empirical test data presented in Figure 2 confirm that the cohesiveness strength decreases with the increase of temperature. When the temperature was increased from 10 to 60 ^{o}C, the cohesiveness strength was reduced by 77.8%, which means that the material can be regarded as highly sensitive to temperature.

3.2 Adhesion

Tests on the adhesion between the surfacing system and the steel deck plate were based on the UK DMRB BD 47/99 (1999) standard. The tests were conducted at a rate of 20 mm/minute. The test set-up is illustrated in Figure 3 and a summary of the test results is presented in Figure 5.

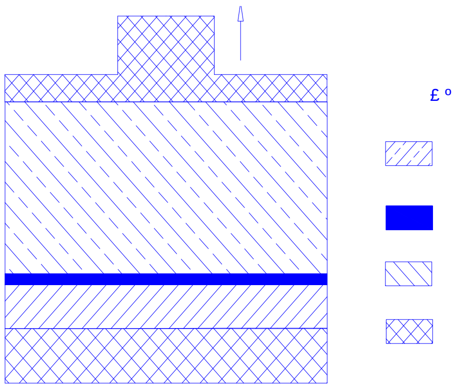

Figure 3. Set-up for adhesion strength test

3.3 Shear

Shear resistance tests were based on the UK DMRB BD 47/99 (1999) standard. The tests were conducted at a rate of 20 mm/minute. The test set-up is illustrated in Figure 4 and the test results are presented in Figure 5.

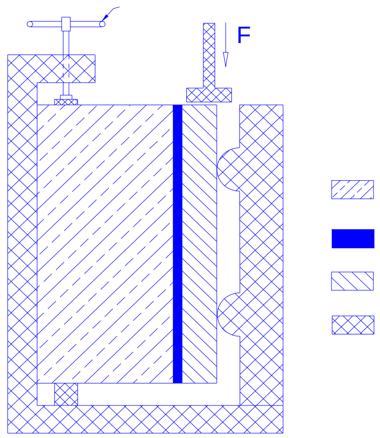

Figure 4. Set-up for shear strength test

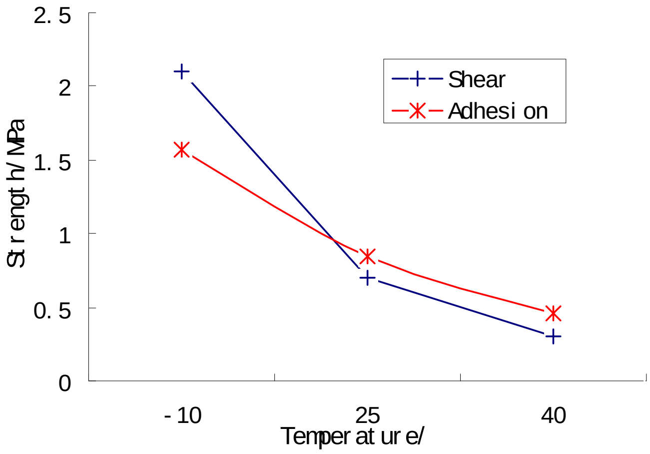

Figure 5. Influence of temperature on adhesion and shear strength

The test results in Figure 5 show that the adhesion and shear strength values decreased with a corresponding increase in temperature. When the temperature rose from -10 to 40 ^{o}C, the adhesion and shear strengths decreased by 70.7% and 85.7% respectively, which suggests that the shear resistance was comparatively smaller at high temperatures.

4. FEM ANALYSIS

4.1 The model and the load

The FEM comprised a three-dimensional ANSYS 8.0 model of shear arrangement. The model allowed a composite action between the deck and the waterproofing. The following assumptions were applied for the FEM: 1) The material properties of the deck and the surfacing constituents were assumed to be linear elastic, homogenous and isotropic; 2) The elastic modulus and Poisson's ratio of the steel deck, trough and diaphragm were 210 GPa and 0.3; 3) The thicknesses of the mastic surfacing and the waterproofing layer were 47.5 mm and 2.5 mm respectively.

4.2 Results

The maximum shear stresses at layer interfaces were calculated at three temperatures. The influence of the three temperatures of -10, 25 and 40 ^{o}C on the mechanical properties of the materials was analysed using the FEM model. The results are shown in Figure 6.

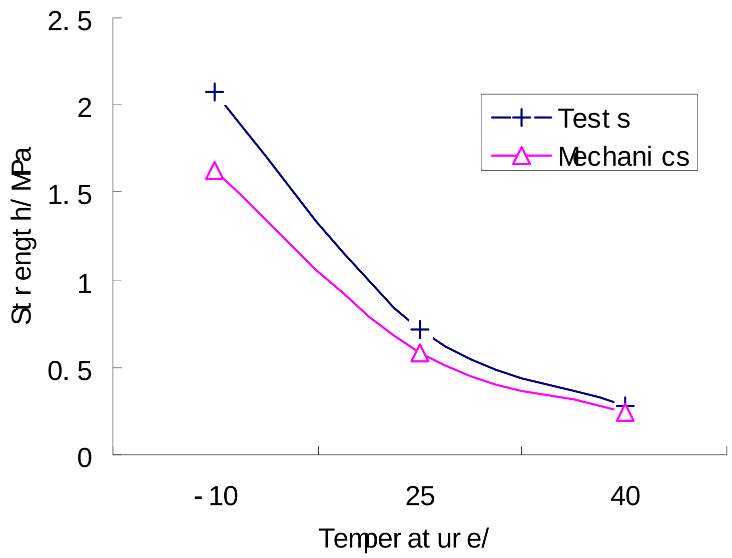

Figure 6. Test and FEM model data on shear strength

From Figure 6 it was observed that when the temperature was -10, 25 and 40 ^{o}C, the errors between the shear strengths of the tests and the value obtained from the FEM model were reduced by 21.63%, 18.31% and 14.28% respectively, which suggests that the possibility of error is comparatively small. In this way the effectiveness of prediction can be regarded as satisfactory and the simulation and prediction of shear strength by FEM seems reasonable and effective.

5. CONCLUSIONS AND SUGGESTIONS

In this study, the influence of temperature on the performance of waterproof and adhesive materials composed of the Bostik 9225 type adhesive primer and rubber modified mastic were investigated. The following conclusions can be drawn from the results:

1. Temperature has a significant influence on cohesiveness, adhesion and shear strengths of the waterproofing and bonding materials. The values of the strengths are reduced when the temperature of the waterproofing is increased.
2. The regression equation of the cohesiveness strength y and the waterproofing surface temperature, x, is $y = -0.1203 x + 1.9152$ $R^2 = 0.9914$.
3. By applying the finite element method and the material parameters obtained from the experiments, the shear behaviour of the materials can be modelled numerically. When comparing the results of the laboratory tests and the FEM model, the possibility of error, especially under high temperature, is comparatively small.

Further studies should be done on the influence of the visco-elasticity and visco-plasticity of the materials on the deformation of the interface layer. The relationship and correlation between FEM analysis strengths, laboratory strengths and field results should also be investigated.

6. ACKNOWLEDGEMENTS

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