Quantifying the Principal Parameters for Flexural-deflection Response of Stabilized Materials Using a Stand-alone Strain-at-break Device

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ABSTRACT: The determination of strains and stresses within a pavement layer is essential during the structural pavement design process, particularly when using the mechanistic design approach. Laboratory tests that closely simulate the stress states of a layer subjected to a wheel loading are used to quantify required pavement design parameters. The flexural beam test is one such test. A simple stand alone device suitable for field laboratory testing has been developed for carrying out the four-point bend test. The device is described and its performance is demonstrated. Using the simple device it was possible to qualitatively quantify the effect of curing method on the intrinsic parameters of cement stabilized beams.

KEY WORDS: Four-point bend test, strain-at-break, stabilized material, mechanistic design.

1 INTRODUCTION

The analysis of strains and stresses within a pavement layer is essential during the structural pavement design process, particularly when using the mechanistic design approach. In order to quantify the strains and stresses in a laboratory setting, the testing condition should closely simulate the stress states of a layer subjected to a wheel loading, that is, with tensile stress at the bottom and compressive stress at the top. The four-point bend test, in which a beam is loaded in flexure, is used in the pavement engineering field to simulate the stress and strain conditions in a layer under traffic loading. The most important parameter obtained from the test, is the strain-at-break, that is the value of the strain at which a standard sample breaks. The strain-at-break value is used together with transfer functions to provide an indication of the expected life of a stabilized or bound layer in a pavement (Steyn, 2004). The importance of the test from the pavement engineering point of view, and the fact that the available machines are large and extremely expensive and therefore only found in research laboratories, made it necessary to develop a simple test device that can be used in a field laboratory to evaluate stabilized materials. The test device was developed based on similar testing principles used in existing standard test method, ASTM Test Method for Strength of Soil-Cement Using Simple Beam with Third-Point Loading (D 1635-00) for the determination of flexural strength. Currently the term for the device is strain-at-break.

A brief description of the device is given below. The details for the development are given in Steyn (2004) who based the development of the device on previous work (Otte, 1972). The objective of the paper is therefore to demonstrate the potential use of the developed simple device.

2 THE STRAIN-AT-BREAK DEVICE

The device comprises of a loading frame with the top loading system, a stepper motor, capable of applying load at 0.03 mm/sec with a 5 kN capacity. It has an integrated electronic system that provides all critical control and data acquisition function linked to a personal computer. The control software for the device was developed in Labview®. The loading-jig moves with the actuator to ensure that the initial load that is placed on the sample can easily be monitored and prevent the self-weight of the jig from loading and breaking the specimen prematurely, before any measurements are made. The total span for the specimen is 450 mm; however the supports are at 420 mm apart, with the loading points at 150 mm apart. Two LVDTs are used for the measurement of the deflections at the mid-span of the beam. The LVDTs rest directly on the sample. Figure 1 shows the set-up of the device. Figure 2 shows the detail mounting on a sample ready for testing.

Figure 1: Strain-at-break-device set up

3 PERFORMANCE OF THE STRAIN-AT-BREAK DEVICE

The accuracy in the determination of the response of the materials being tested in the laboratory depends on the equipment performance. The evaluation of the performance of the equipment includes the calibration of the system. In the case of the strain-at-break device, its performance will hinge on the ability to accurately measure the deflection and the effective load consistently. A series of tests were first performed to assess the calibration systematically. Following this an assessment of the response of the deflection and load measurement components was also conducted. The following results are based on a testing program which involved the optimization of the instrumentation and reliability testing. The comparative testing program was conducted using the large Cox machine. Figure 2 illustrates the results of the performance assessment with respect to the response of the measuring components. The comparative tests were performed on synthetic samples. The results compare reasonably well indicating a good consistency in the measured values between the two devices showing excellent performance of both the load and deflection measurement components of the strain-at-break device.

It is acknowledged that an inter-laboratory study is important in assessing the performance of equipment and test methods. However, there is currently no other laboratory locally with a similar device to carry out such an exercise.

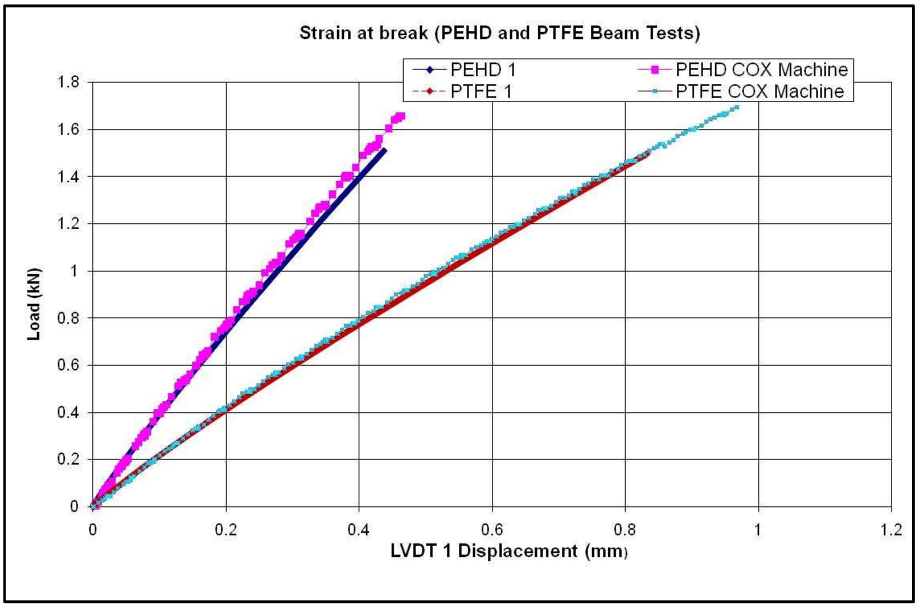

Figure 2: Results of comparative tests on synthetic beams

4 TESTING ON CEMENT STABILIZED BEAMS

As pointed out, the parameters determined from the strain-at-break test are used in conjunction with transfer functions to determine the expected life of stabilized layers in the mechanistic design approach. The strain-at-break parameter is seen as indicative of crack initiation in a sample, and thus a limiting tensile strain that should be avoided. This has been well demonstrated in (Otte, 1978 and Jordaan, 1988). Therefore, the data from the test would provide relevant information for the purpose of strain and stress analysis in a stabilized pavement layer. In addition, the simple test device can be used in parametric studies. The next phase in the development of the strain-at-break device was therefore to carry out a testing program on beams manufactured from cement stabilized material to quantify the relevant parameters. In the current work, the device was used to quantify beam elastic modulus, maximum stress and strains as a function of the method of beam curing.

4.1 Preparation and curing of beam specimens

The mixed material was compacted into the beam mould in 3 layers using a Modified AASHTO hammer with 56 blows per layer and final compaction was done using a press to ensure that a specific density was achieved in the mould. The target density was 95 % Mod AASHTO for the beams. Cement content values used were 2, 3 and 5 %. Four methods for curing the beams were used. Method 1: samples were covered on the sides and bottom with cling wrap plastic sheets, except for the top face which was left uncovered for 2 days, but was then covered and samples sealed until the testing day. Samples were left in a chamber. Method 2: samples were covered on all sides sealed and placed in a chamber until testing day. Method 3: samples were left in the sun for 2 hours before being placed in moist sand with the top face exposed. Method 4: samples were left in the open under room condition until testing date.

Testing was planned to be done after 14 days of curing, however all samples were tested after 15 days.

4.2 Testing

During the testing of stabilized materials, the specimen was placed on the round supports which are spaced 420 mm apart as shown in Figure 3. The loading-jig was slowly lowered onto the specimen, without loading it to allow for specimen alignment with the loading-jig and to ensure uniform seating of the loading-jig. Once the specimen was aligned, the light aluminium frame assembly with the two LVDTs was then placed on top of the specimen, aligned to ensure that the LVDTs are at the mid-span of the specimen for the measurement of the beam displacement. The LVDTs were then adjusted for near zero reading and secured. The test was carried out in displacement controlled mode with the loading frame operating at about 0.03 mm/sec. The applied load and deformation were automatically recorded. Upon completion of the test, the moisture content of the specimen was determined.

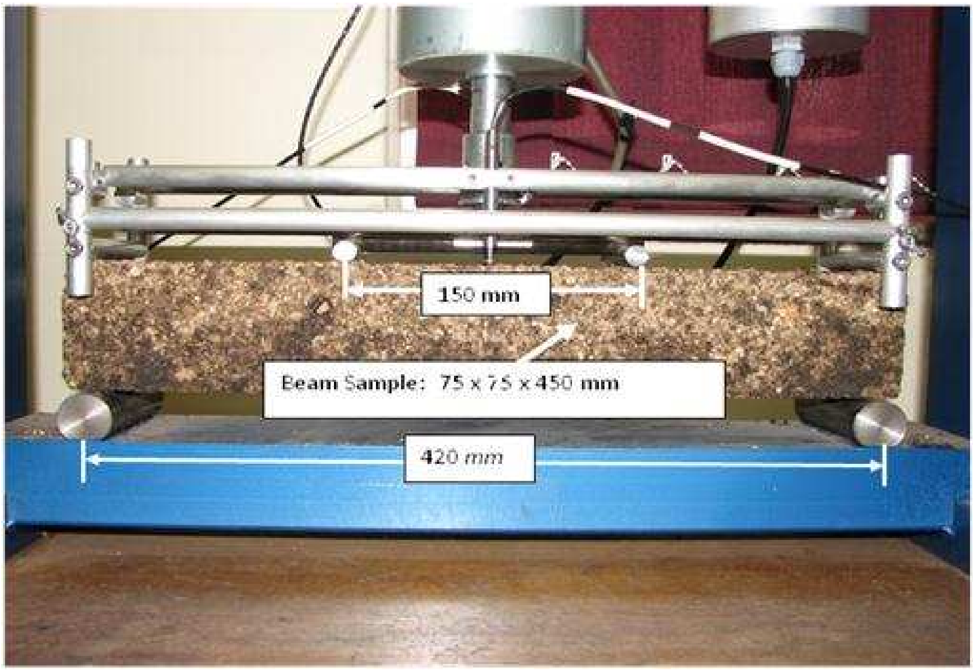

Figure 3: Detail of sample mounting in the strain-at-break device

4.2 Results

Specimens were tested destructively. Figure 7 shows a beam at failure. Although cracks at failure generally formed within the middle third, an attempt was made to measure strain using strain gauges mounted on sides of the beams, but this was abandoned due to the effects of crack propagation on measurements with increased loading.

Figure 4: Typical specimen failure mode

Since the load and mid-span deflections were recorded, the elastic modulus, strain and stresses could be calculated using the Equation 1, Equation 2 and Equation 3 respectively.

$$E = \frac{2.a\left[3.L^2 - 4.a^2\right]}{8bh^3}\frac{P}{\delta_L} \tag{1}$$

$$\varepsilon_{\max} = \frac{12.h}{3.L^2 - 4.a^2}\delta_{\max} \tag{2}$$

$$\sigma_{\max} = \frac{3.a}{bh^2}P \tag{3}$$

Where a is the loading span distance, b is the width of the beam, h is the thickness of the beam, δ_L is the displacement at the mid-span of the beam and P is the load.

The stress-strain behavior of the beams was investigated. Figure 5 shows typical results. The results presented are for beams treated with 3% cement but cured differently according to the methods described in section 4.1. The number in the specimen identification refers to the method, for example WG-1B stands for specimen cured using Method 1. Typically, the curves show an elastic portion at low strains and a non-linear portion at higher strains, approaching the “strain at break”, which is defined as the strain at the maximum stress. Specimen cured under Method 2 has the lowest maximum stress value while specimen cured under Method 4 has the highest maximum stress value. Calculated maximum strains for the beams tested, based on Equation 2 ranged between 105 and 390 microstrain.

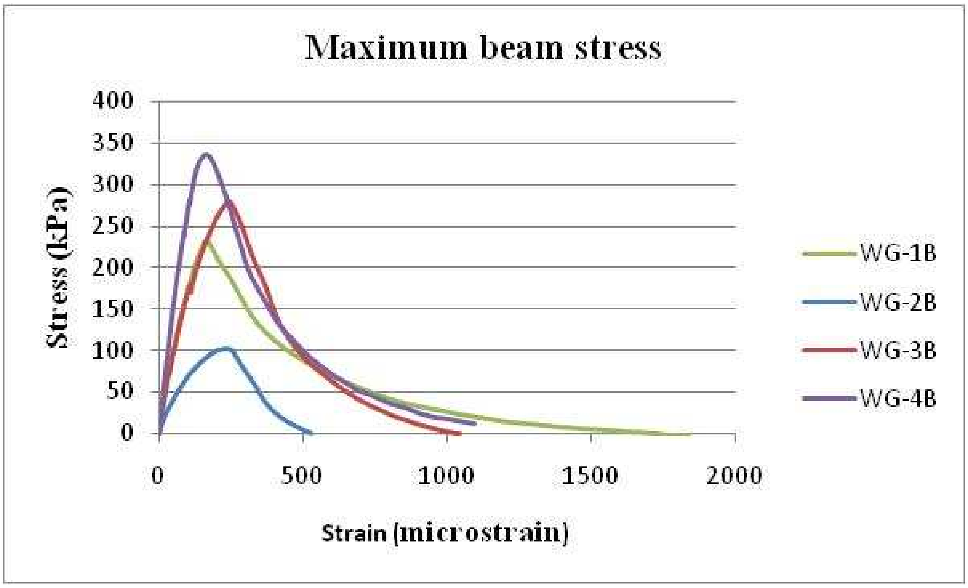

Figure 5: Stress vs. strain for specimens treated with 3 percent cement cured under different conditions

Figure 6 shows all the test results. The results show that samples cured using Method 2, after 15 days of curing did not gain as much strength as was the case with the other samples.

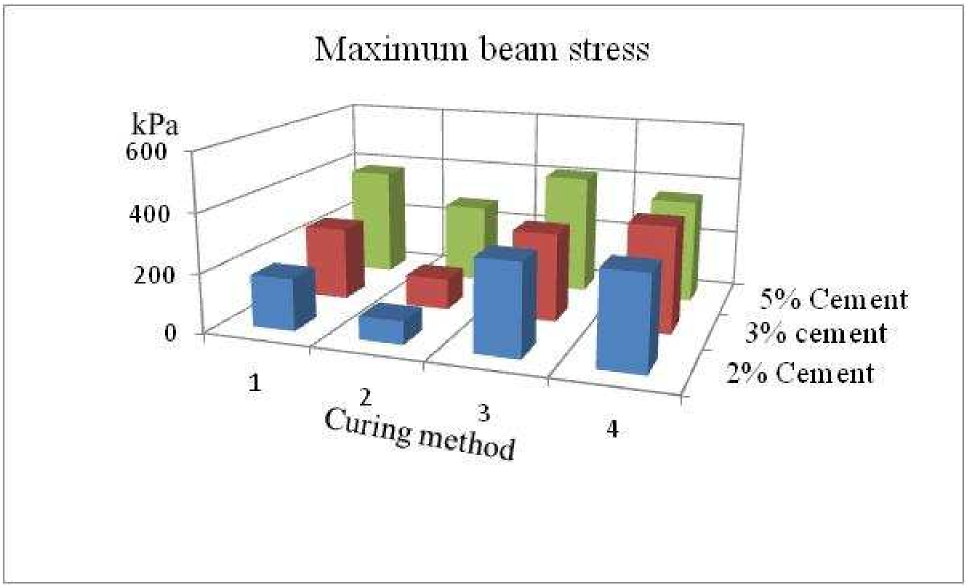

Figure 6: Maximum stress variation with method of curing and cement content

The elastic portion of the stress-strain curves was used for the determination of the elastic modulus of the beams. The results are presented in Figure 7. It provides clear evidence of the influence of method of curing and cement content on the elastic modulus. For the specimens with 2% and 3% cement content, Method 4 gave the highest modulus values.

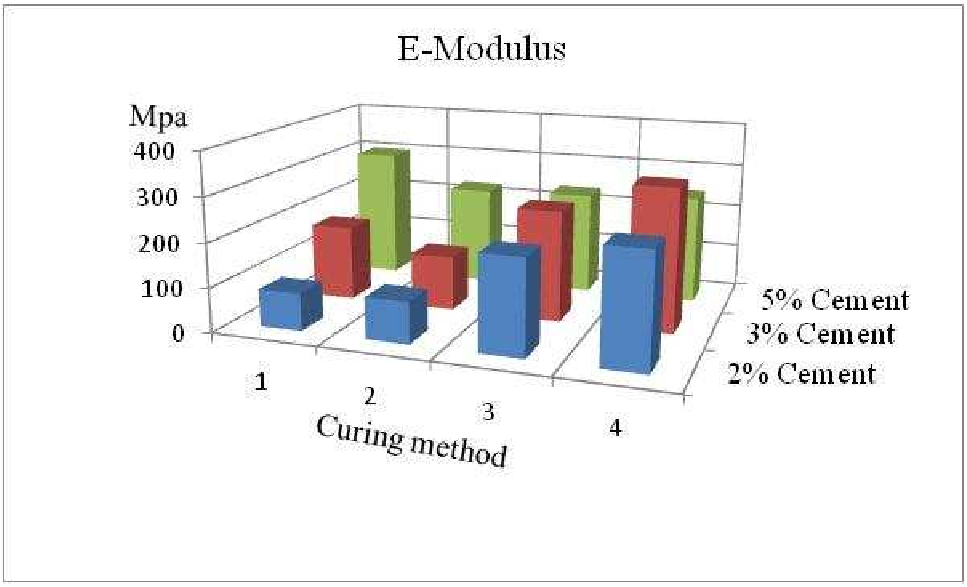

Figure 7: E-modulus variation with curing method and cement content

Figure 8 shows the moisture content of the beams at the time of testing. The effect of the moisture content on the obtained maximum stress in the beams is revealed from these results. Note that samples with Method 2 had the highest moisture contents, explaining the observation made with respect to the results presented in Figures 5 to 7.

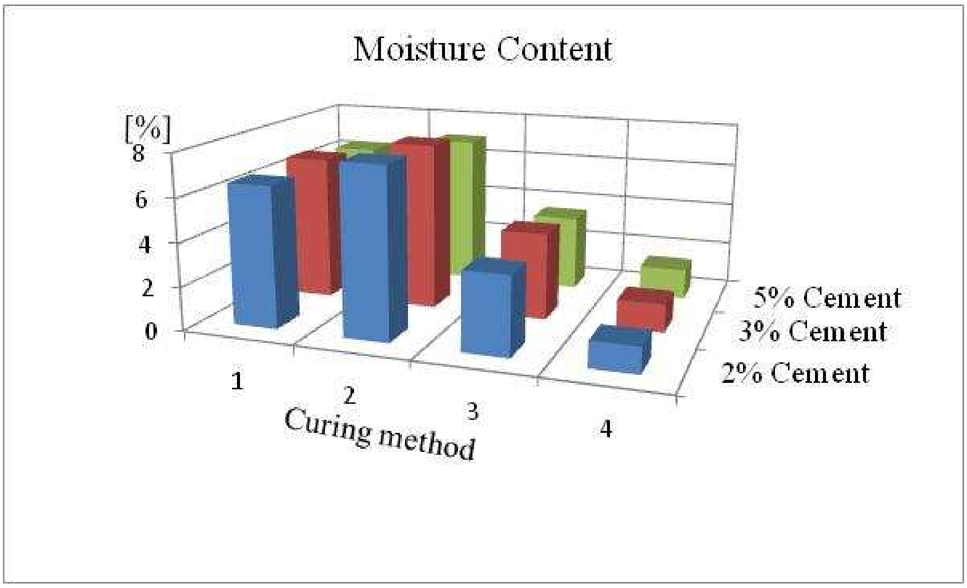

Figure 8: Sample moisture content at the time of testing

5 CONCLUSIONS

A strain-at-break test device has been developed and tested. The presented results were used to demonstrate the capability of the simple stand alone device for performing the four-point bend test to determine the strain-at-break value which is an essential parameter in the mechanistic pavement design method. The results show that the prototype stand alone strain-at-break device is functional and can be used to characterize stabilized beam samples. Using the simple device it was possible to qualitatively quantify the effect of curing method on the intrinsic parameters of cement stabilized beams. The potential use of the device has been demonstrated. It is acknowledged that an inter-laboratory study is important in assessing the performance of equipment and test methods. However, there is currently no other local laboratory with a similar device to carry out such an exercise

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