EFFECT OF METHOD OF CURING ON THE FLEXURAL CHARACTERISTICS OF A CEMENT STABILISED MATERIAL

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ABSTRACT

This paper presents experimental results of the flexural response of cement stabilised beams subjected to static pure bending using a simple four-point bending device. The device has been developed and manufactured for the purpose of field laboratory application. The main focus of the work is to demonstrate how the simple device can be used to qualitatively quantify the flexural response of a cement treated material and as a tool for quality control. Weathered granite was used as the host material. The material was treated by the addition of 2%, 3% and 5% cement by weight and four methods were used to cure the specimens. The effects of method of curing and cement content are illustrated. The deflection coefficient, the resistance to flexural deformation and the resilience are used to quantify the effect of method of curing and cement content. The test results indicate that the effect of the method of curing on the flexural characteristics of the cement-stabilised soil is dominated by the amount of moisture induced during curing and has also a significant influence on the impact of increasing cement content.

1 INTRODUCTION

1.1 Background

The South African mechanistic pavement design method incorporates the tensile strain ratio, obtained from the results of the “strain at break” test, as input to the structural model for theoretically computing the life to crack initiation (Otte, 1978) and effective fatigue life for advanced stage of cracking (Jordaan 1988 and De Beer, 1993). First application of the test method at the CSIR was in the early 70’s. However, until recently, the test has been carried out in highly advanced equipment, which can cost in excess of R900 000. This has resulted in such equipment being only available at research and academic institutions. In addition, this type of equipment is not portable for use in the field laboratory. The CSIR Built Environment recognized the need to design and build a low cost device for use in the road construction industry.

In designing and building the device, it was critical that the equipment should be low cost, but nonetheless be robust enough for field conditions. A systematic process was followed in the development of the device, by considering critical factors in testing principles used in existing standard test methods for the determination of flexural strength such as the ASTM Test Method for Strength of Soil-Cement Using Simple Beam with Third-Point Loading (D 1635-00). The full details for the development of the device at the CSIR Built Environment are given in Steyn (2004). The evaluation of the performance of the prototype device, including the calibration of the system and its performance to accurately measure the deflection and the effective load consistently are discussed in Mgangira and Steyn (2010).

The use of the beam test, commonly known as the flexural test, which is performed by subjecting a beam specimen to pure bending in a four-point loading system, is nothing new in the characterization of material for cement stabilized pavement layers. The justification of using the bending test and its significance has been discussed and demonstrated in several studies, which include studies by researchers as early as late 60s, for example, Larsen and Nussbaum (1967) and Gregg (1967). In the beam test the maximum fibre stress is uniformly distributed between the loading points, and therefore deemed closely to represent the stress distribution under the wheel load. The beam bends as would be expected of a layer under a wheel load in a pavement.

The overall response of the cement-treated material to stress and the magnitude of the breaking strain will however be affected by several factors, which include curing conditions, cement content used for treatment and initial levels of deformation that the beam is subjected to. On the basis of extensive laboratory beam tests of cement-treated materials, Otte (1978) makes the observation that the strain at failure varies much less than the flexural stress and therefore proposed that the strain be used as a design criteria instead of stress, He suggested that strain may be used for initial design. Thus in this study, the deflection response is used to quantify the effect of method of curing. The simple four-point bending device has been used to evaluate the effect of method of curing on the flexural characteristics of cement stabilised beam specimens, using the deflection response of the beams.

1.1 Objective

Cement stabilized layers are commonly used in order to ensure strong and long-term better performing road pavement. However, the initial and long-term performance of the stabilized materials in terms of strength and durability will depend on the curing conditions and cement content used, among other factors. Thus the specific objective of this paper is to present and discuss the results of the investigation regarding the response of cement stabilised beams, cured in four different ways and treated with three different levels of cement dosage. From the results, the effects of method of curing and cement content are illustrated and the use of the simple flexural test device as a tool for the purpose of performance assessment of cement stabilised materials for pavement layers is demonstrated.

2 LABORATORY TESTING

2.1 Test specimens

The experimental work involved the compaction of test specimens to similar dimensions. Weathered granite soil was treated at different dosages of CEMII 32.5 N cement (2, 3 and 5% of dry weight of the soil). The size of the specimens in the bending test will depend on the maximum size aggregate of the host material. According to Otte (1978), for 25 mm aggregate, the beam size should be at least 75 x 75 x 450 mm, but preferably 100 x 100 x 600 mm and for 16 and 13.2 mm aggregate to use a 50 x 50 x 300 mm beam size. In this study the beams were 75 x 75 x 450 mm, compacted using a modified AASHTO hammer, followed by static compaction to ensure that all the material calculated to achieve the target density is in the mould. The compaction was done in three layers, applying 56 blows per layer.

2.2 Specimen curing

Four methods for curing the beams were used. The first method was to simulate a condition where only surface drying is allowed to occur for sometime, while the bottom fairly maintains the moulding moisture. Thus in method 1 the specimens were covered on the sides and bottom with cling wrap plastic sheets, except for the top face which was then covered after 2 days. The specimens were then placed in a chamber to cure until the testing day. The second method of curing was to simulate a condition where the moulding moisture is fairly maintained throughout the specimen. In method 2 the specimens were therefore covered on all sides immediately after compaction, sealed and placed in a chamber for curing until testing day. The third method simulates a varied drying condition. In method 3 the specimens were left in the sun to dry for 2 hours before being placed in moist sand with the top surface exposed, but left to cure under room temperature condition, until testing day. In the fourth method, the specimens were allowed to dry in the open under room condition until testing date. All the specimens were in their curing condition for 14 days prior to testing.

2.3 The testing device

The device developed at the CSIR Built Environment for the purpose of conducting the bending test is shown in Figure 1. The device comprises of a loading frame with the top loading system, a stepper motor, an integrated electronic system that provides all critical control and data acquisition function linked to a computer and the LVDT holding frame. It has sufficient capacity and control to apply a constant deformation rate of 0.03 mm/sec with a 5 kN capacity load cell and an accuracy of ± 10 N. The displacement measurement has a range of ± 5.0 mm. The distance between supports and points of load application remain constant during testing. Two LVDTs are used for the measurement of the deflections at the mid-span of the specimen. The arrangement for the loading ensures that equal forces are applied to the two loading rollers.

2.4 Testing of specimens

Each specimen is positioned in the test device, ensuring that it is positioned centrally across the support rollers and centralised under the loading axis, guided by the loading jig. This is achieved by slowly lowering the loading-jig onto the specimen, without loading it to allow for specimen alignment and to ensure uniform seating of the loading-jig. Once the specimen is aligned, the light aluminium frame assembly with the two LVDTs is 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 are then adjusted for near zero reading and secured. The test is carried out in displacement controlled mode with the loading frame operating at about 0.03 mm/sec until failure. The applied load and deformation are automatically recorded. Upon completion of the test, the position of failure is measured from the end support rollers and the moisture content of the specimen is then determined. Data can then be processed.

Figure 1: Simple flexural strength determination device

3 RESULTS AND DISCUSSION

3.1 Specimens for discussion of results

It should be pointed out that the main purpose of the presented results is not the determination of strength values for design, but to provide an indication which can help in determining the influence of method of curing on flexural characteristics using the simple flexural test device. There were only three beams moulded at each cement content level for each curing condition. However, a single beam from a batch is used for discussion. These beams were selected based on their strength values, which were close to the characteristic strength for the three specimens.

3.2 Deflection coefficient and stress

The loading configuration in the device is based on the theory of beams. Thus the test condition is modelled as a beam that is simply supported at the ends and the load consisting of two point forces at equidistant from end supports. The distortion or deformation of the portion between the point loads is assumed to be the same. The results of the tests are therefore discussed with respect to mechanical properties that are defined based on applicable beam theory. Under such loading configuration, the relationships between deflection, applied load and the elastic modulus and the geometry of the beam, according to Fuller and Johnston (1919) can be expressed as follows:

maximum deflection

$$\Delta = \frac{P.a}{24EI}\left[3L^2 - 4a^2\right] \qquad (1)$$

where,
Δ = the maximum deflection
L = is the distance between the outer supports
a = L/3, the distance from the outer supports to the point loads
P = applied load

The distance between the supports in the device used for the current study was 420 mm and the beams had a square cross section, width and depth equal to 75 mm. In this study the above equation is expressed in terms of a deflection coefficient as follows:

$$\Delta = Y\frac{P.a\left(3L^2 - 4a^2\right)}{bd^3} \tag{2}$$

Where all parameters are as previously defined and Y is the deflection coefficient which is then given by the following relationship:

$$Y = \frac{\Delta.b.d^3}{P.a\left[3L^2 - 4a^2\right]} \tag{3}$$

The stress is computed from the applied load by considering the resulting moment, the second moment area of the beam section and the distance from the neutral axis to the outer fibre, where the beam experiences maximum stress. The stress is computed from equation 4.

$$\sigma = \frac{3.a}{bd^2}P \tag{4}$$

The deflection coefficient is plotted against flexural stress in Figures 2 to 5. The results illustrate the difference in resistance to deformation provided by the beams, depending on method of curing and the cement content.

The general observation is that the response of the beams with respect to deflection coefficient and stress, show three phases of behaviour. In phase I, the deflection coefficient initially increases at low stresses. In phase II, a gradual increase in the deflection coefficient with increasing stress is observed. In phase III, there is a rapid increase in the deflection coefficient with little increase in stress level. It is interesting to note that the observed response of the beams, presented in this way, is similar to the phenomenon observed in creep and fatigue testing. The steady rate of increase of the deflection coefficient under phase II is indicative of elastic deformation until the initiation of the rapid increase of the deflection coefficient. The point at which the slope of the curve starts to increase, showing the initiation of the rapid increase in the deflection coefficient, is indicative of the initiation of plastic deformation, no failure occurs. This point marks what is referred to as the critical load or stress in this paper.

In general the results show that the higher the cement content, irrespective of the curing method, the lower is the slope of the trend line of the curve marking phase II of the observed beam behaviour and the larger the cover of the range of the stress level in this phase. Beams treated with 2 % and 3 % cement and cured using method 2 show the highest rate of increase of the deflection coefficient and the lowest maximum stress. The maximum stress is marked by the upward portion of the curves. The beam treated with 5 % cement shows a significantly larger cover of the range of stress compared to the beams that were treated with 2 and 3 percent cement. The maximum stress is the lowest for beams cured using method 2 in comparison to the other beams, treated with the same cement content but cured using the other methods. Beams that were cured using method 4 had the largest cover of the range of stress level. However, under this method of curing, the relative influence of cement content, from 2% to 5%, is not as pronounced as is the case in method 1 and method 2. Curing methods 1 and 2 induced the highest levels of average moisture content in the specimens compared to method 3 and method 4. Method 4 in which the specimens were air dried induced the lowest moisture content The average moisture content values, at the time of testing, for the specimens cured using method 1 and method 2 were 6.5 % and 7.5 % respectively and for method 3 and method 4, they were 3.7 % and 1.3 % respectively. The impact of the cement content on the flexural characteristics for a particular method of curing is apparently related to the moisture content condition, induced by the method of curing. On the other hand a higher moisture uptake results in lower flexural strength.

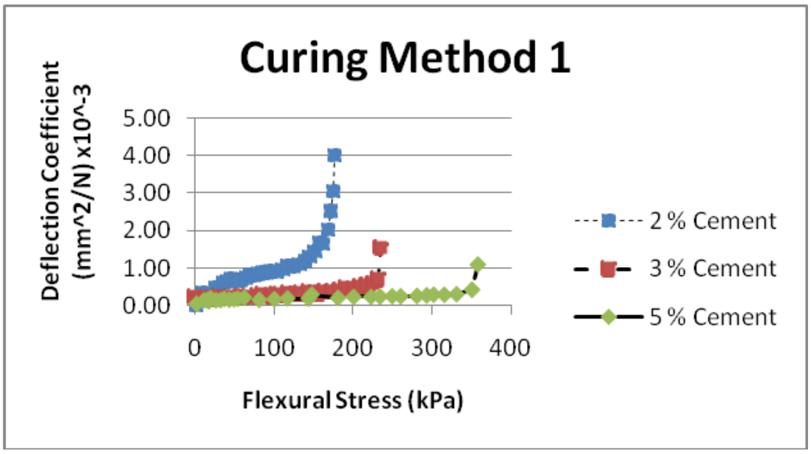

Figure 2: Variation of deflection coefficient with flexural strength

Bentz et al. (1997) have shown that curing environment can have a significant effect on the cement hydration kinetics and that the removal of capillary water from the specimen through exposure can terminate the hydration process, which in this case, is the condition simulated in curing method 4. Moore et. al. (1970) investigated several factors that affect the tensile strength of cement-treated materials. One of the factors they investigated was the effect of moulding water content, in which samples were moulded at different moisture contents. They found that increased moulding water content resulted in significantly higher strength because of improved hydration rather than improved compaction. It is most likely that the beams cured using methods 1 and 2 would indicate higher strength gain with curing age.

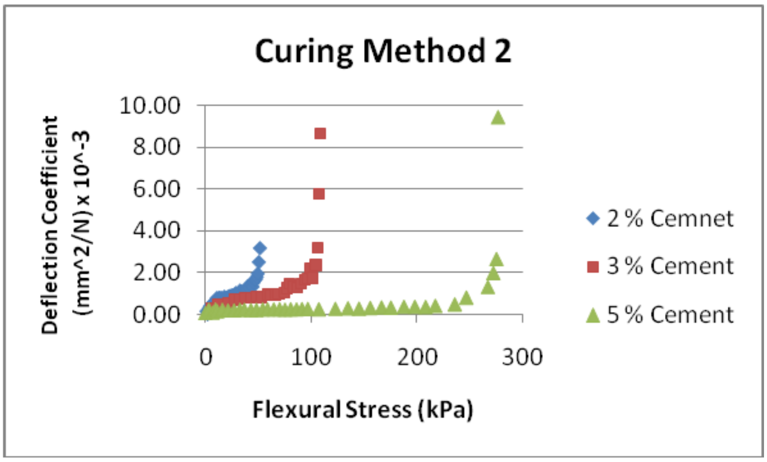

Figure 3: Variation of deflection coefficient with flexural strength

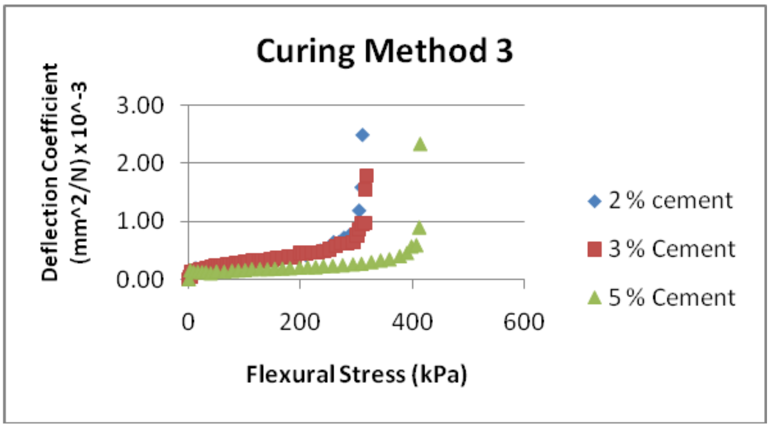

Figure 4: Variation of deflection coefficient with flexural strength

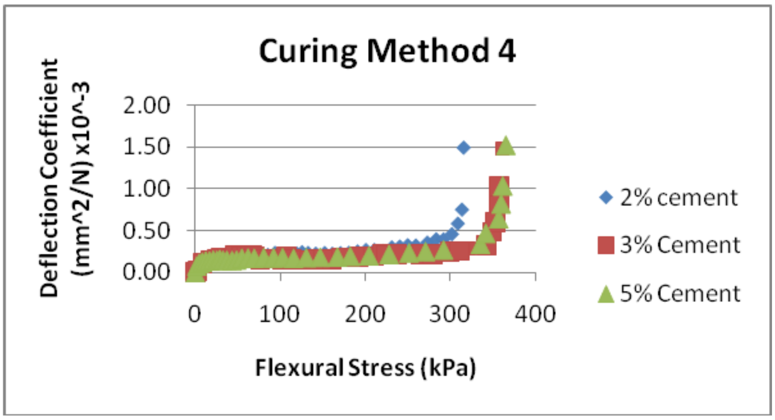

Figure 5: Variation of deflection coefficient with flexural strength

3.3 Elastic modulus in bending

The addition of cement imparts the strength and the stiffness to the host material. Figure 6 shows the effect of method of curing and influence of cement content on the determined elastic bending modulus. The elastic bending modulus was calculated from equation 1, but using the second phase of the deflection coefficient-stress curve. The elastic modulus is related to the stiffness of the beam. The higher the elastic modulus the higher is the stiffness and therefore the higher the capacity to resist deformation. The results show that the beams that were cured using method 1 and method 2 had the highest relative increase in stiffness with increasing cement content. However, the maximum values were lower relative to those of beams cured using method 3 and method 4, at similar cement content levels. The goodness of fit as determined by the R^2 values, show a strong relationship between the elastic modulus and the cement content. The R^2 values range between 0.94 and 1.00. Method 1 has R^2 value of 1.0 and for methods 2, 3 and 4, the values are 0.98, 0.98 and 0.94 respectively.

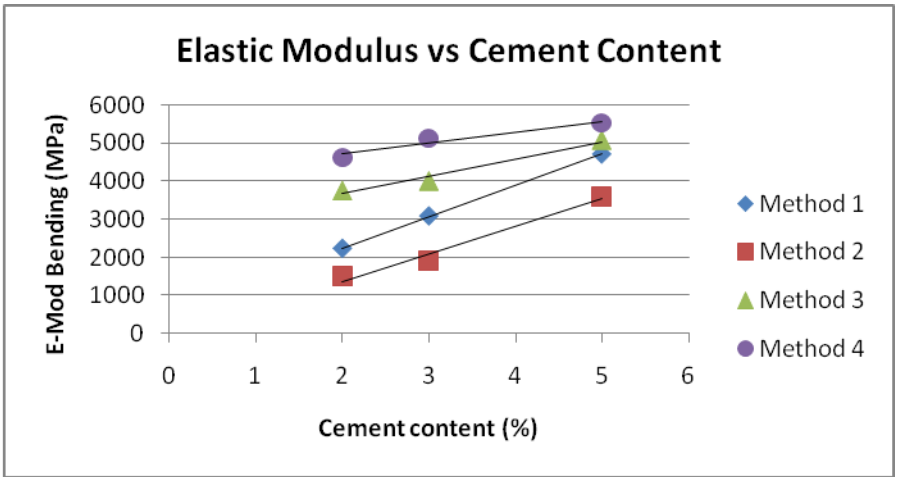

Figure 6: Effect of curing method and cement content on the elastic modulus

3.4 Resilience

According to Fuller and Johnston (1919), for the four-point beam loading configuration, the following equation is applicable in the determination of the resilience of the beam:

$$R = \frac{P_c^2 a^2 (3L - 4a)}{6EI} \tag{5}$$

In this study P_c has been used in the equation, corresponding to the critical load, marking the limit of the steady-state phase of the deflection coefficient curve in Figures 2-5.

The goodness of fit as determined by the R^2 values, also show a strong relationship between the resilience and the cement content. The R^2 values range between 0.92 and 1.00. Method 1 has a goodness of fit of 0.97, and for methods 2, 3 and 4, the values are 1.0, 1.0 and 0.92 respectively.

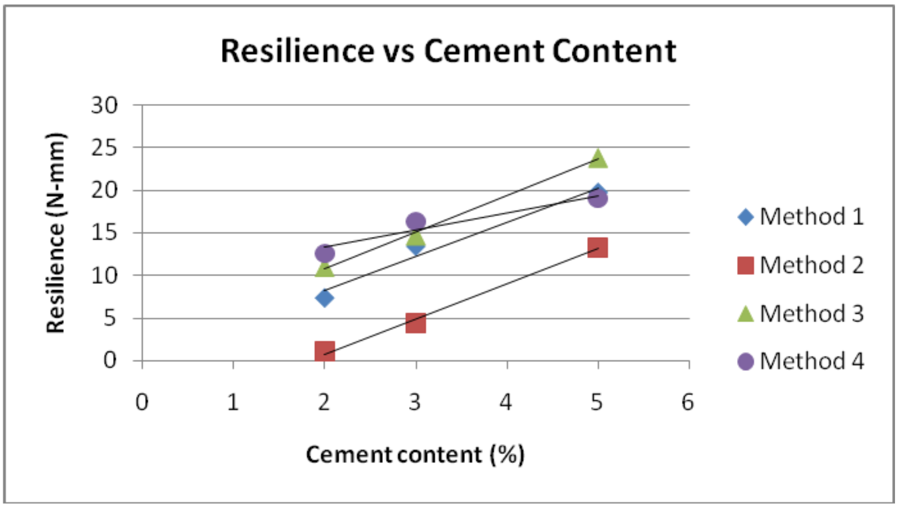

Figure 7: Effect of curing method and cement content on resilience

The impact of increasing cement content on resilience, using curing method 4 is again not as pronounced as with curing methods 1 and 2. However, curing methods 1 and 2 result in low resilience, based on the age of testing in the current study. The resilience of a beam specimen is significantly affected by both moisture content induced during curing and cement content.

4 SUMMARY

As pointed out earlier, the main purpose of the presented results is not the determination of strength values for design, but to provide an indication which can help in determining the influence of method of curing on flexural characteristics using the developed simple flexural test device. Under the test conditions used in this study, the findings can be summarized as follows:

a) Curing methods that induce higher moisture content resulted in beams that developed lower flexural strength, bending elastic modulus and resilience, tested after 14 days of curing. However, it is more likely that the beams cured under such conditions would show higher strength gain with age.

b) Curing methods that induce lower moisture content resulted in beams with initial higher flexural strength, bending elastic modulus and resilience. However, the impact of increasing cement content is not as pronounced as in the methods where higher moisture content is induced during curing.

A simple device developed for flexural strength determination has been used to demonstrate its application in qualitatively evaluating the effects of method of specimen curing on flexural characteristics of a cement-treated material. The device can be used in a field laboratory and is much cheaper than the more advanced and sophisticated testing equipment, only available to research and academic institutions. Currently the cost of the device is estimated at R120 000. Experimental results on beams, tested in the device, provide clear indication of the influence of method of curing and cement content on the resistance to flexural deformation, which in this study is measured by the deformation coefficient. It has been shown that using the deformation coefficient clearly illustrates the beam response to loading and the influence of cement content. With more data, it does appear that the deflection coefficient can be developed into an indicator for quality control against specification requirements in terms of required stress levels and deflection limit for treated materials in pavement layers.

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