Bearing capacity assessment of recycled asphalt pavements

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ABSTRACT: Full-depth cold in place recycling technology was used for the rehabilitation of a heavily trafficked highway asphalt pavement. For the evaluation of the bearing capacity of the foamed asphalt treated recycled pavement, the NTUA Laboratory of Highway Engineering undertook research on the subject, including continuous monitoring of the pavement performance through detailed analysis. The trial field investigation was based primarily on non-destructive tests using the falling weight deflectometer (FWD) along several trial sub-sections of a rehabilitated pavement. According to the data analysis, the FWD was proven a useful tool for reliable assessment of the bearing capacity of recycled pavement. Deflection indicators give useful information about the structural condition of the recycled pavement, but more precise results are drawn with backanalysis and strain response analysis of the in-situ collected data. The distress in the body of the recycled layer is lower than expected, indicating adequate bearing capacity of the recycled pavement.

1 INTRODUCTION

Cold full-depth recycling is an advantageous rehabilitation technique, since it is eminently suited for the reworking of the upper layers of distressed pavements to depths up to 30 cm. There are multiple reasons why this process has gained wide acceptance in the road pavement industry, including economic, technical and environmental advantages over alternative road rehabilitation options (PIARC 2001). Benefits of cold recycling have been widely publicized, among others by Jenkins et al. (1995). The foamed asphalt technique offers multiple advantages, including the ability to re-open the rehabilitated road to traffic shortly after construction, lowered construction costs in comparison to other standard methods of rehabilitation and the ability to effectively use marginal aggregates in pavement layers.

In international literature there is sufficient information about laboratory tests for the estimation of the performance and the bearing capacity of the recycled material. However, insufficient information is available concerning in-situ estimation of the bearing capacity of the recycled asphalt pavement using non-destructive tests (NDT) including the falling weight deflectometer (FWD) technique. For this reason, a field experiment on a rehabilitated pavement of a heavily trafficked Greek highway using the foamed asphalt technique was undertaken by the Laboratory of Highway Engineering of the National Technical University of Athens (NTUA). The aim of the experiment is to investigate whether the implementation of simple NDT can be a useful tool for the assessment of the bearing capacity of a recycled asphalt pavement.

2 BACKGROUND

In order to assess the bearing capacity of a recycled pavement, a trial section was constructed, comprised of six trial sub-sections. The foamed asphalt in depth recycling technique (Fig. 1) was used for the rehabilitation of the above mentioned trial sub-sections with semi-rigid

Figure 1. Implementation of the cold in depth recycling technique using foamed asphalt.

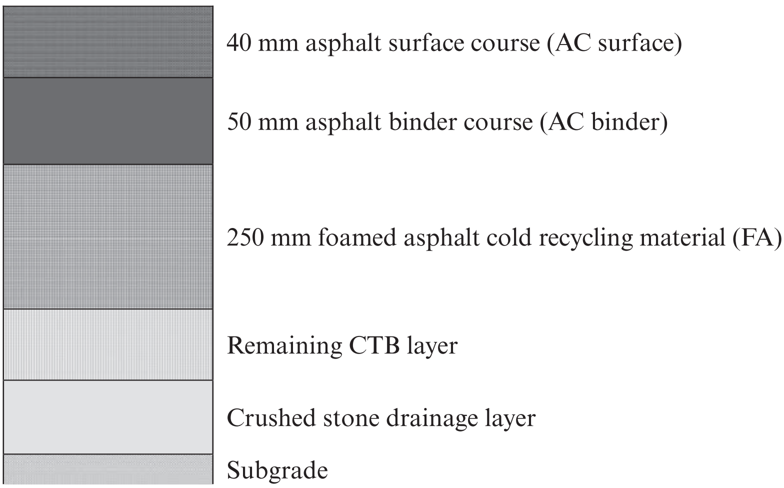

Figure 2. Recycled pavement structure.

pavement, i.e. a pavement constructed above the subgrade with two layers of cement treated base (CTB), overlaid with asphalt concrete (AC) layer material. The rehabilitated trial sub-sections were subjected to continuous monitoring by the NTUA. Prior to the implementation of cold recycling, a thorough testing program was performed, as documented by Loizos et al. (2004).

Foamed asphalt mix design was undertaken to establish the application rates for foamed asphalt and active filler (cement), to achieve optimal strengths and to determine the strength characteristics for use in the structural design exercise on several different blends of in-situ recovered material. These blends were treated with foamed asphalt using the appropriate laboratory unit and several briquettes were manufactured for tests to determine the indirect tensile strength (ITS), the unconfined compressive strength (UCS), the cohesion (c) and the angle of internal friction (Φ), as well as the determination of the indirect tensile stiffness modulus (ITSM) (ASTM 2004). Details of the mix design blends can be found in

(Loizos et al. 2004). A standard mix design of 3% foamed asphalt and 1% cement was used in the recycled material. The decision to introduce 1% cement was based on improvement in the achieved soaked strengths.

An analytical rehabilitation design approach was used based both on national and international experience to estimate the structural capacity of each pavement configuration. For the analytical pavement design the stiffness modulus of the AC and the recycled (FA) layers was considered to be 3000 MPa. According to the analytical design with a structural capacity requirement in excess of 10 million 13-ton axle-loads, the pavement structure is described by an asphalt concrete (AC) layer (90 mm thick) and a cold in-place recycled and stabilized with foamed asphalt (FA) layer (250 mm thick). The AC layer was constructed of two courses, a 50 mm binder course and a 40 mm final semi-open graded surface course using polymer modified asphalt. Figure 2 shows the pavement cross-section after rehabilitation.

3 DATA COLLECTION AND ANALYSIS

3.1 *In-situ measurements*

During and after completion of the recycling works at the test section, a comprehensive FWD survey was undertaken. The FWD generates a load pulse by dropping a weight on a damped spring system mounted on a loading plate as shown in Figure 3. The peaks of the vertical deflections were measured at the center of the loading plate and at several radial positions (200, 300, 450, 600, 900, 1200, 1500 and 1800 mm) by a series of 9 deflection sensors.

In-situ measurements were conducted on the surface of the recycled layer (FA), on the binder course (AC binder) and finally on the surface course (AC surface) 3 weeks after the rehabilitation work (see Table 1). The post-construction monitoring was comprised of measurements on the surface course approximately 6 months and 1–6 years after construction.

Table 1. In-situ measurements.

Time since construction	Measurements on
2 days	Recycled layer (FA)
4 days	AC binder course
3 weeks, 6 months, 1–6 years	AC surface course

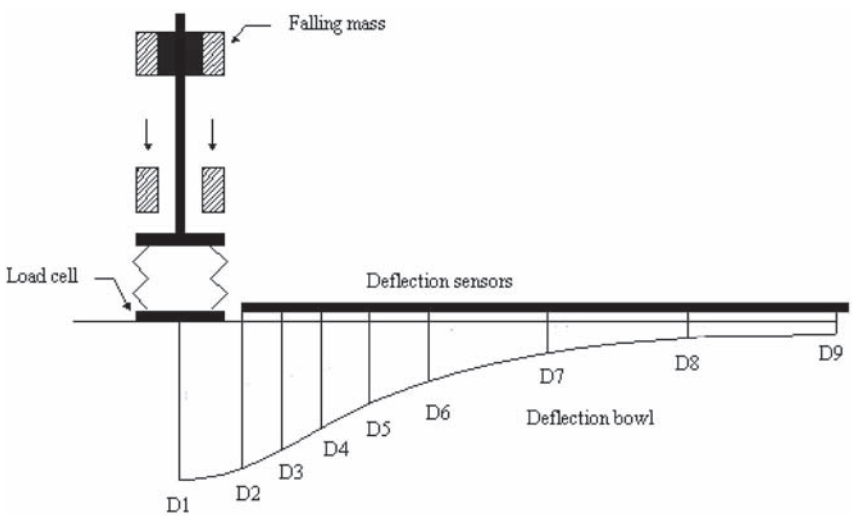

Figure 3. Schematic presentation of the FWD sensors instrumentation.

All in-situ non-destructive tests were performed on the outer traffic wheel path of the heavily trafficked lane. Six trial sub-sections were investigated: Westbound AK1 (900 m) and AK2 (1200 m) and eastbound KA1 (450 m), KA2 (800 m), KA3 (250 m) and KA4 (600 m).

The Ground Penetrating Radar (GPR) system of the Laboratory of Highway Engineering of the NTUA (GSSI 2002) was used for the analysis, with the aim to assess pavement layer thicknesses. This data is useful for backanalysis procedures. The system used, is appropriate for the evaluation of the upper part of the pavement structure, since it produces reliable information to an approximate 0.7 m penetration depth (Al-Qadi et al. 2005). The system follows the principles of ASTM (2005) and is supported by the appropriate software (RoadScanners 2001).

A limited number of cores from the asphalt layer as well as from the foamed asphalt recycled layer were extracted at specific FWD test locations, in accordance to a predetermined coring schedule. The cores were used as ground truth data for the validation of the FWD GPR thickness data.

3.2 *Backanalysis and strain response analysis*

A thorough field data analysis was performed including a backanalysis with the aim to verify the robustness of the recycled pavement. The backanalysis was undertaken using ELMOD software (Dynatest 2001). Considering the level of the subgrade at the top of the drainage layer (Fig. 2), the backanalysis model consisted of four layers. The backcalculation was performed using layer thicknesses obtained from GPR analysis.

The ELMOD software was also used for the estimation of the horizontal tensile strain (ε_{xx}) at the bottom of the recycled layer. Strains were also calculated using pavement design data (Loizos et al. 2004), following the related pavements model of Figure 2.

4 DATA ANALYSIS RESULTS

4.1 *Deflection indicators*

The overall pavement condition of the recycled pavement was determined using internationally accepted indicators (COST-336 1998), which are relevant to the measured elastic deflections. For this purpose, the center (maximum) deflection (D1) was taken into account, which represents the overall pavement performance at the time of the investigation (Hakim et al. 2002). The surface curvature index (SCI) based on the deflection deference was also calculated, for the evaluation of structural condition of the new constructed layers (FA and AC). The in-situ collected data were normalized to the reference temperature of 20ºC (Van Gurp 1995). The results (average values for the measurements until one year after construction) are presented graphically in Figures 4 and 5.

Figures 4 and 5 clearly show a decrease of the average maximum deflection D1 and the SCI with time. This is an indication of improvement of the overall pavement structural condition over time (see Figure 4), mainly due to the increase of the bearing capacity of the recycled layer (curing of the FA) and the overlay with AC layers (binder and surface courses) as well (see Figure 5). Significant differences in the average values between the trial sub-sections were observed during the first 3 weeks. This might be due to differences in the curing of the recycled material. Differences between the trial sub-sections were also observed in the rate of decrease of the average D1 and SCI values. This is an indication of different impact of the AC overlays on the structural condition of the recycled trial sub-sections during the early life of the pavement.

The average deflection differences SCI values for the measurements 1–6 years after construction presented graphically in Figure 6 show a tendency of reduction or stabilization with time. This is an indication of the structural improvement or stabilization of the upper pavement layers (AC and FA). A tendency of reduction of the differences in the structural condition of the trial sub-sections KA and AK can also be noticed.

The level of homogeneity was determined using the coefficient of variation (CV). This parameter is defined as the ratio of the standard deviation over the mean value per sub-section.

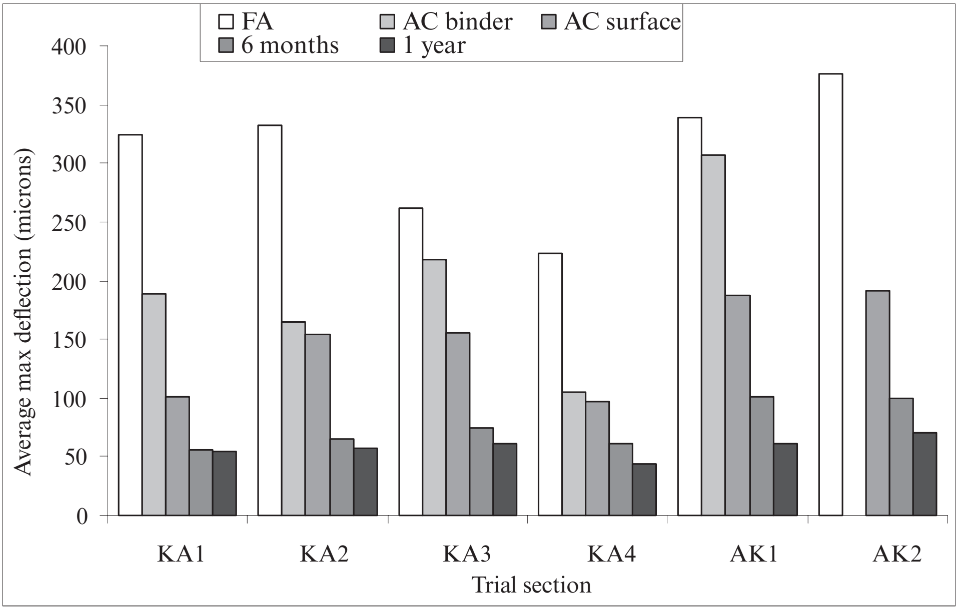

Figure 4. Average maximum deflection (D1, 20ºC).

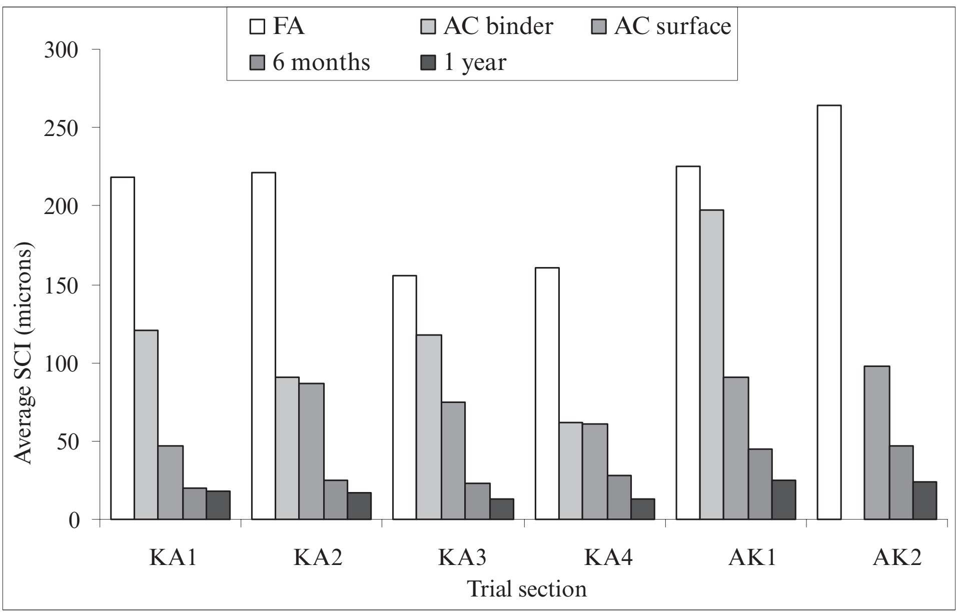

Figure 5. Average SCI values (20°C).

The CV of the center deflection D1 and the SCI as well for the different monitoring levels ranged from 10% to 30%, indicating good to moderate homogeneity of the structural condition of the recycled pavement (COST-336 1998). The results for the measurements one and six years after construction are presented in Table 2.

Six years after construction almost in all trial sub-sections (except KA1) the CV was lower in comparison with the CV one year after construction, indicating stabilization of the deflection indicators values.

Table 2. Coefficient of variation (CV).

	Trial sub-sections					
	KA1	KA2	KA3	KA4	AK1	AK2
CV (D1)						
1 year	15.8	11.9	19.1	24.8	30.5	20.1
6 years	25.0	11.3	15.3	24.0	20.0	16.5
CV (SCI)						
1 year	14.8	16.3	27.8	29.5	29.5	32.8
6 years	22.2	15.8	25.5	23.3	19.9	22.8

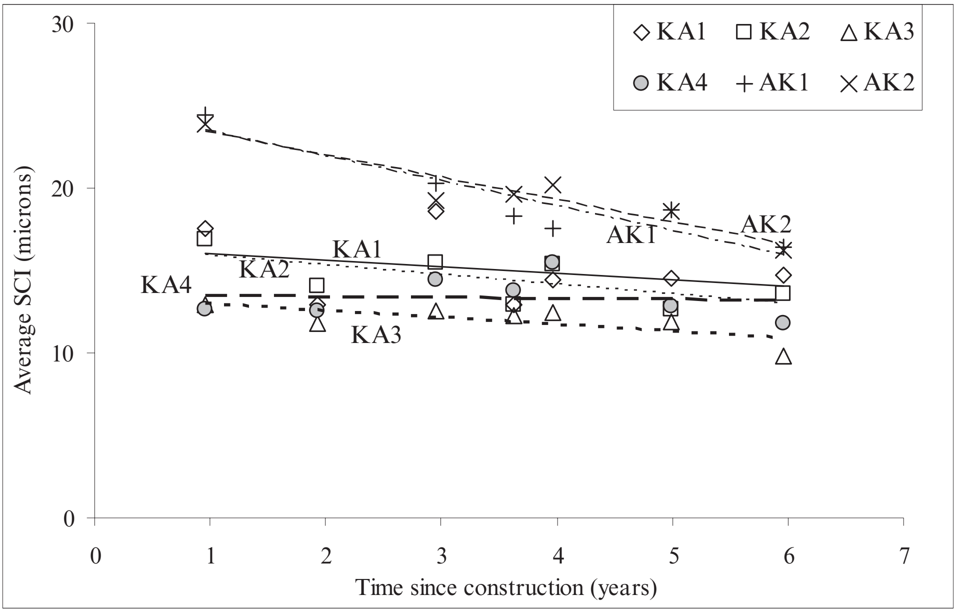

Figure 6. Average SCI graphed with time.

4.2 *Backanalysis results*

The most recent (6 years after construction) in-situ collected deflection data were backanalyzed in order to estimate the modulus of the AC and the recycled material (FA) and to compare with the modulus that was taken into account during the pavement design. The average temperature of the bituminous overlay during the measurements ranged between 22 and 26ºC. These temperature values allow comparison between the moduli without further correction of the results. The minimum, average and maximum backcalculated values are presented graphically in Figures 7–8. It can be seen, that six years after construction the minimum backcalculated moduli of the AC and FA layers were higher than the related pavement design values, indicating adequate bearing capacity of the recycled pavement.

4.3 *Strain response analysis*

Following the backanalyzed data during the most recent monitoring (6 years after construction), the horizontal tensile strain (ε_{xx}) was calculated at the bottom of the recycled layer. The max ε_{xx} was also calculated using pavement design data (Loizos et al. 2004) following the related pavements model of Figure 5. The calculations were conducted using linear elastic analysis software (BISAR 1998). A 40 kN single wheel load was used, with a 15 cm radius.

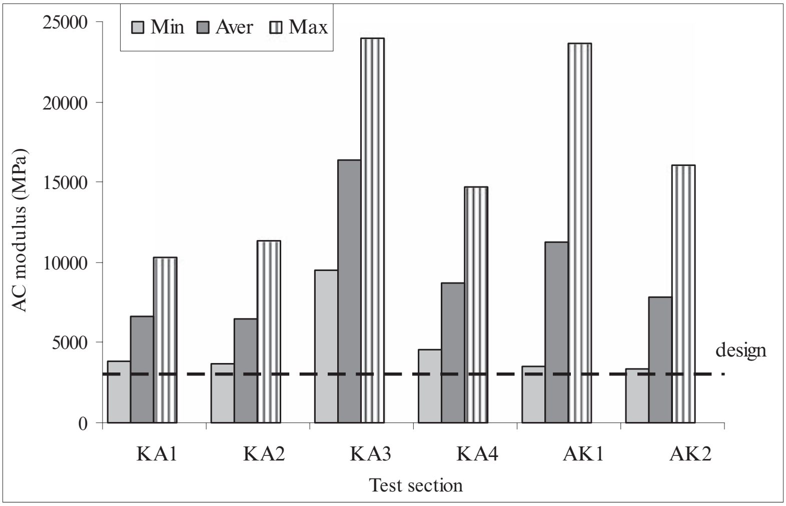

Figure 7. Backanalysis results (AC, 6 years).

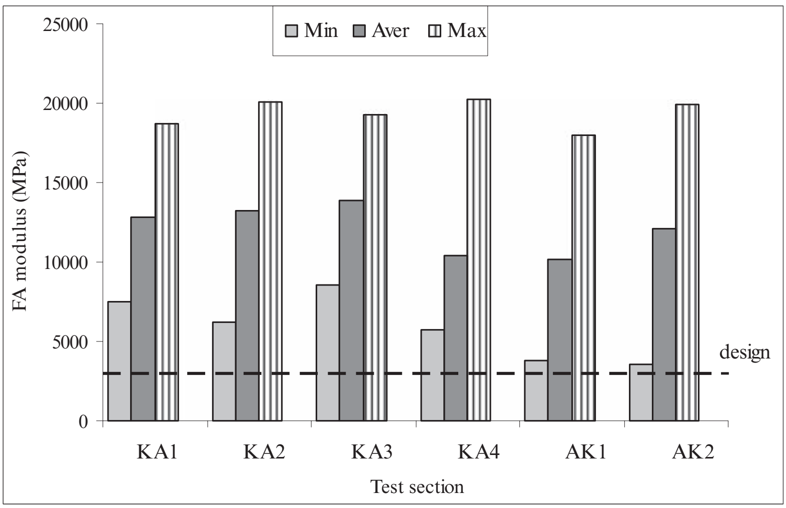

Figure 8. Backanalysis results (FA, 6 years).

The in-situ max ε_{xx} for every sub-section was compared with the relative one using the design data. The results presented in Figure 9 show that the maximum tensile strain at the bottom of the recycled layer was much lower than the relative strain based on the design data. According to these results, the distress in the body of the recycled layer is lower than expected and consequently the bearing capacity of the recycled pavement is adequate.

5 CONCLUSIONS

In the present research study an effort was made to investigate whether the implementation of simple NDT can be a useful tool for the assessment of the bearing capacity of a recycled asphalt pavement. The major findings and discussion points are the following:

The analysis taking into account the FWD deflection indicators (center deflection, surface curvature index) gives useful information about the overall pavement structural condition

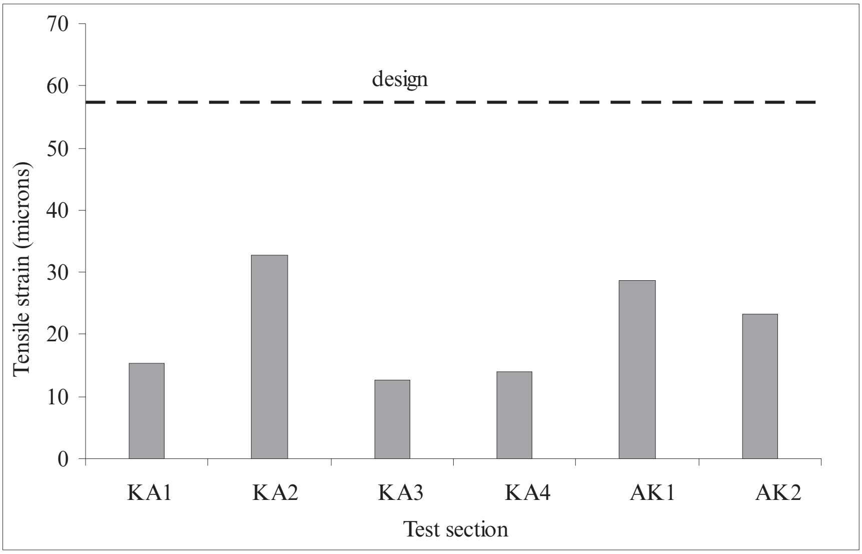

Figure 9. Maximum tensile strain (recycled layer).

of the pavement. It can also show differences between several sub-sections, but not enough information is available in regards to the bearing capacity of the recycled pavement.

The backcalculated moduli of the AC and the recycled layer (in comparison with the related pavement design values), can give more useful information about the structural adequacy of the recycled pavement.

However, a better concept for obtaining useful in-situ bearing capacity information can be achieved using the backanalysis approach in terms of strain response analysis.

The FWD was proven a useful tool for the assessment and comparison of the bearing capacity of recycled asphalt pavements. Deflection indicators give useful information about the structural condition of the recycled pavement, but more precise results are drawn with backanalysis and strain response analysis of the in-situ collected data.

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