Monitoring the Performance of Cold In-depth Recycled Pavements

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ABSTRACT: Cold In-depth Recycling (CIR) of asphalt pavements is an environmentally friendly technique implemented worldwide for the rehabilitation of damaged road pavements. The current paper deals with the monitoring of the early life performance of pavements recycled using the CIR technique through the implementation of mainly Non-Destructive Tests (NDT). In order to achieve this goal the Laboratory of Highway Engineering of the National Technical University of Athens (NTUA) undertook a field experiment on a heavy-duty pavement recycled using foamed asphalt as a stabilization treatment. The investigation is based on measurements taken along a trial section of a rehabilitated highway that is part of the Trans European Network (TEN), using both the Falling Weight Deflectometer (FWD) and Ground Penetrating Radar (GPR). Data analysis results seem to indicate that the in-situ calculated critical strains, as well as the backcalculated moduli appear to be promising criteria to reflect the performance of CIR pavements. GPR data is possible be used for such analysis purposes without a significant deviation in accuracy in comparison with core thickness data. Detailed findings are included and discussed in the present paper.

KEY WORDS: Foamed asphalt, FWD, GPR, backcalculated moduli.

1 INTRODUCTION

One of the main benefits of the Cold In-depth Recycling (CIR) technique is that the material of a distressed road pavement is simultaneously recycled and mixed with a stabilizing agent, enabling the road pavement to be strengthened without the need to import expensive aggregate. Other benefits include a short construction period, as well as significant improvements to traffic safety. These advantages contribute to significantly lower unit costs for road rehabilitation, in comparison with other methods (Lewis et al. 1999). In addition, environmental issues related to the reuse of reclaimed materials increase the advantages of the technology.

The recycling method requires a certain time period necessary to allow the newly produced mixture to cure and build up enough internal cohesion before being covered by the asphalt overlay (binder and/or wearing course). Studies have shown that recycled mixes do not develop their full strength after compaction until a large percentage of the mixing moisture is lost. This process termed “curing” is a process whereby the recycled mix gradually gains strength over time accompanied by a reduction in the moisture content (Muthen 1999).

The majority of research related to the CIR techniques has focused on material characterization and mix designs performed in the laboratory, including the curing progress. The procedure in the laboratory cannot simulate conditions in the field after short-term curing periods. The strength developed after an early or intermediate cure represents the most critical time period. Consequently field monitoring of the early life performance of the recycled pavement is critical for the evaluation of the structural adequacy of the recycled pavement.

The present study aims to investigate several aspects related to the monitoring of the early life performance of Cold In-depth Recycled pavements. For this reason, a field experiment was undertaken by the NTUA's Laboratory of Highway Engineering through the implementation of a thorough non-destructive testing (NDT) program along a representative trial section of a Greek highway that is part of the Transport European Network (TEN) and has been rehabilitated with CIR using the foamed asphalt technique. Both Falling Weight Deflectometer (FWD) and Ground Penetrating Radar (GPR) tests were conducted along the trial section. This paper outlines the related considerations and results.

2 DESIGN CONSIDERATIONS

For the given pavement recycling experiment foamed asphalt (FA) mix design was undertaken to establish the application rates for foamed bitumen and active filler (cement) to achieve optimal strength and to determine the strength characteristics for use in the structural design exercise. Several different blends of material recovered from the test pits were treated with foamed bitumen using the appropriate laboratory unit and several briquettes were manufactured for testing purposes to determine the indirect tensile strength (ITS), the tensile strength retained (TSR), 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). In agreement with the mix design 2.5% foamed bitumen and 1% cement was mixed with the recycled material. The decision to introduce 1% cement was based on the improvement in the achieved soaked strengths.

An analytical design approach was used for the estimation of the structural capacity of the pavement. Taking into account traffic volume history, a structural capacity requirement of more than 10 million 13 ton equivalent single axle loads was anticipated for any work to be undertaken on this highway. According to the analytical design, a thickness of 280 mm was adopted for the FA layer, over which two asphalt concrete (AC) layers were laid (90 mm total thickness) that was comprised of a dense binder leveling course with a nominal thickness of 50 mm and a 40 mm semi-open graded polymer modified asphalt mix surface course. The final pavement design is presented in Figure 1.

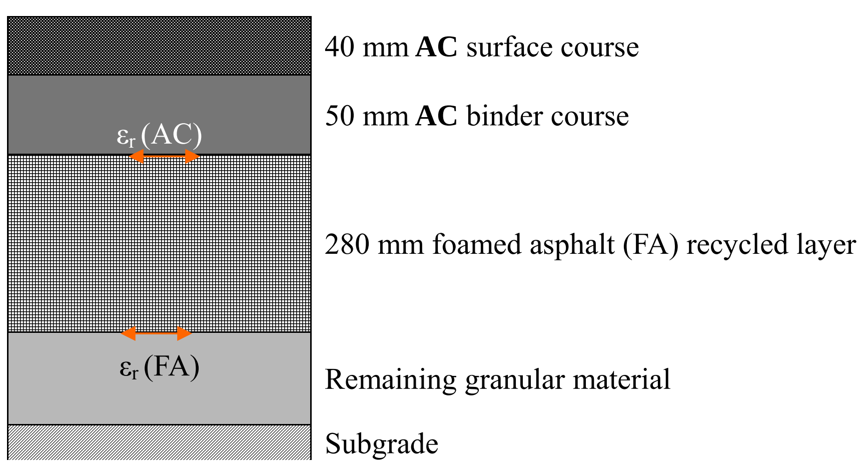

Figure 1: Cross-section of the recycled pavement.

For the analytical pavement design the AC layers stiffness modulus was considered to be 3500 MPa. Design of the recycled pavement was dictated by structural capacity requirements based on the ITS results for the 100mm briquettes and the UCS results for the 150 mm diameter (120 mm high) briquettes and the underlying support conditions. Characteristic laboratory testing results are presented in Table 1.

Table 1: Laboratory testing results

Mixture	RAP [%]	Granular material [%]	ITS 100 mm briquettes (kPa) Dry	ITS 100 mm briquettes (kPa) Wet	TSR 100 mm briquettes (%)	ITS 150 mm briquettes (kPa) Eq.	ITS 150 mm briquettes (kPa) Wet	TSR 150 mm briquettes (%)	UCS 150 mm briquettes (kPa) Eq.
1	75	25	318	238	75	301	237	79	1900
2	50	50	472	379	80	279	252	90	2400

A conservative modulus value of 1500 MPa was considered for the FA recycled material. This was supplemented by using the stress ratio limit method based on the results of the tri-axial tests. Success of the mix and pavement design in terms of the pavement performance is however strongly influenced by both the structural condition of the AC layers and the curing progress of the recycled material as well.

3 IN-SITU DATA COLLECTION AND PROCESSING

In the present research work FWD testing was carried out in order to estimate the bearing capacity of the pavement in terms of layer materials moduli. For this purpose a backanalysis was performed using measured deflections and collected thickness data. Traditionally, layer thicknesses have been determined through test-pits or by extracting cores from the pavement. However, in the case under investigation and in cases where the pavement has been rehabilitated using CIR techniques, it is extremely difficult and in some cases near impossible to gather thickness data through coring shortly after construction due to the “non-cured” nature of the recycled material.

For this reason, GPR surveys were conducted to assess pavement layer thicknesses. GPR’s applicability is dependent on the dielectric properties of pavement materials. These properties vary strongly as a function of composition, curing stage, age, water content and temperature. A measure of the dielectric properties is the relative dielectric permittivity or dielectric constant, which refers to the capacity of a material to store and then allow the passage of electromagnetic energy when an electrical field is imposed upon it. The dielectric constant affects the propagation of radar pulses through materials. Therefore a direct or indirect estimation of the dielectric constant of pavement materials are required for all GPR applications including layer thickness estimation.

GPR and FWD surveys were conducted on a trial pavement section of the rehabilitated highway at different levels as referred to in Table 2. The trial section was approximately 2 km’s in length. FWD measurements were taken approximately every 50 meters on the heavy-duty trafficked lane of the trial section. The different pavement monitoring levels (Mi) were comprised of measurements: on the surface of the recycled layer, after the laying of the binder course and finally on the surface course, according to the schedule showing in Table 2.

Table 2: Monitoring levels.

Monitoring level	Measurements on	Time since construction	Coring	GPR
M1a	Recycled layer	1 day		yes
M1b	Recycled layer	2 days		yes
M2	Binder course	5 days		yes
M3	Surface course	20 days		yes
M4	Surface course	16 months	yes	yes

During the post-construction monitoring level M4 cores from the AC layers as well as from the FA recycled layer were extracted at several FWD test locations. Before curing of the recycled material (M1a to M3) it was not possible to extract cores from the FA layer.

For the purpose of the present study, the collected geophysical NDT data was analyzed using proper software (Roadscanners 2001).

The modulus is a major parameter to study the structural condition of both the AC layer and the FA recycled layer. Backcalculated modulus values when compared with the design modulus, which refers to cured material, can give information about the structural condition and the curing of the recycled material. If the in-situ values are equal or higher than the design value, the recycled material can be considered as cured. Otherwise the recycled material may not be fully cured, or is cured with mechanical properties lower than expected. In this case, the authors' suggestion is to take into account in the analysis process the AC layers as well.

4 BACKANALYSIS RESULTS

Backanalysis was undertaken using the MODCOMP software (Irwin 2002). For the thickness input backcalculations were conducted in three ways: by using the design values, GPR thickness estimations and by the use of core thickness measurements from cores extracted during M4 (16 months after construction). For comparison purposes the use of core thickness estimation is the reference backanalysis procedure. In all cases the thickness of the layer beneath the recycled layer (unbound material) was estimated from the GPR analysis.

4.1 Foamed Asphalt (FA) recycled layer modulus

Figure 2a shows the backcalculated FA moduli (E_{FA}) based on the core thickness measurements, in comparison with the ones based on GPR thickness estimation (monitoring levels M1-M4). Figure 2b shows E_{FA} based on core thickness measurements, in comparison with the ones based on the design values (monitoring levels M1-M4). For both cases the correlation factor is high (>0.94). In addition, for the first case the RMS of differences is 13.1%, while for the second one the RMS of differences is 9.6%. These results produces evidence in support of the statement that the backcalculated moduli E_{FA} based on GPR or design thickness values are almost equivalent to the ones based on core thickness values.

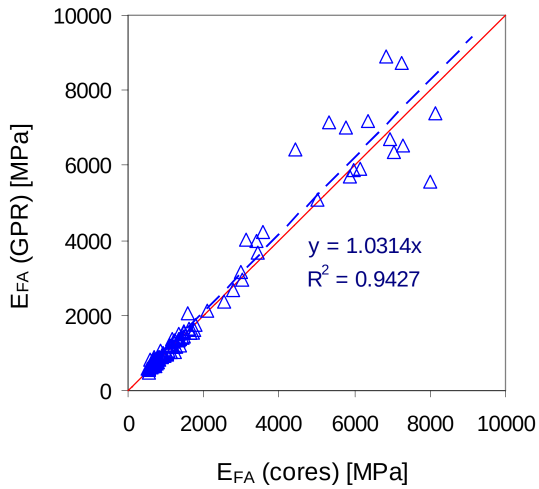

Figure 2a: E_{FA} based on GPR & core thicknesses

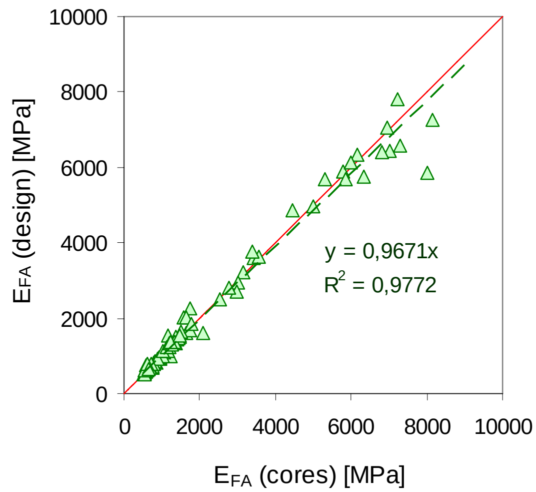

Figure 2b: E_{FA} based on design values & core thicknesses

The backcalculated FA moduli (E_{FA}) during the early life of the pavement (until 20 days after construction) using GPR thickness data and the reference backanalysis procedure are presented in Figure 3. For comparison, E_{FA} used for design purposes is also shown. The following conclusions are drawn:

– There is a substantial increase in E_{FA} with the time.
– In most cases E_{FA} values were lower than the design value.

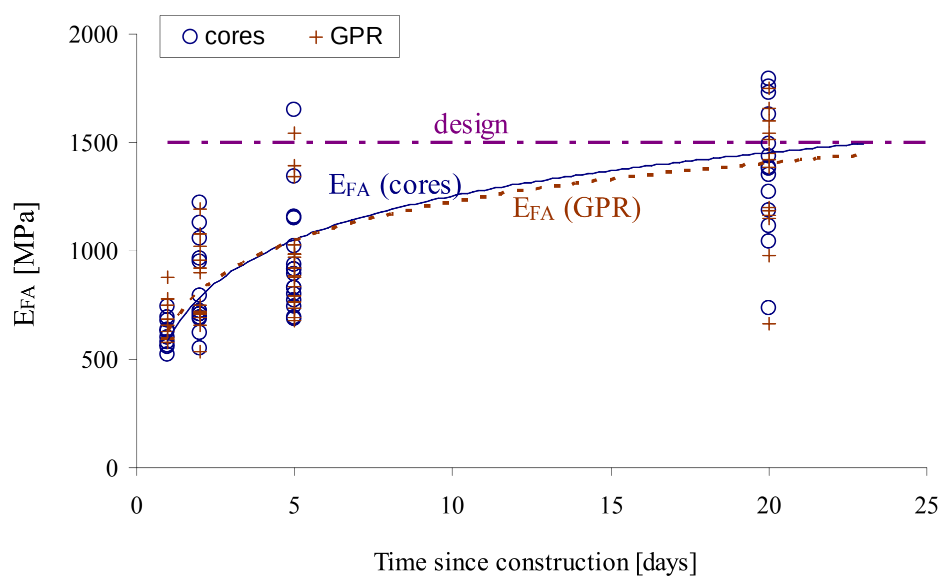

Figure 3: Backcalculated E_{FA} (GPR thickness data & core thicknesses).

According to the above results, 20 days after construction, the FA recycled material is not fully cured, or has cured with mechanical properties lower than expected. In order to investigate the structural adequacy of the recycled pavement during this period (early life) it is suggested to incorporate in the analysis process the AC layers.

At the monitoring level M4 (16 months after construction) the average E_{FA} were much higher (about 4700 MPa) than the design value (1500 MPa), indicating adequate structural condition of the recycled layer.

4.2 Asphalt Concrete (AC) layers modulus

The backcalculated AC layers moduli (E_{AC}) were corrected to 25°C according to (Baltzer et al. 1994). Figure 4a shows E_{AC} based on cores thickness measurements in comparison with the ones based on GPR thickness estimation (monitoring levels M3 & M4). Figure 4b shows E_{AC} based on cores thickness measurements in comparison with the design values (monitoring levels M3 & M4). For both cases the correlation factor is in general high (>0.88). However, for the first case the RMS of differences is 9.6%, while for the second one the RMS of differences is 24%.

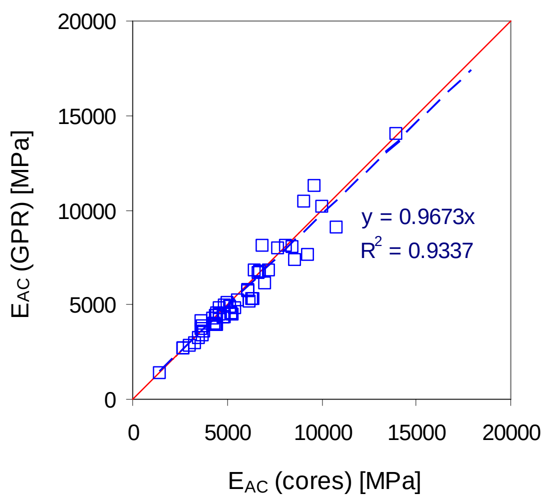

Figure 4a: E_{AC} based on GPR & core thicknesses

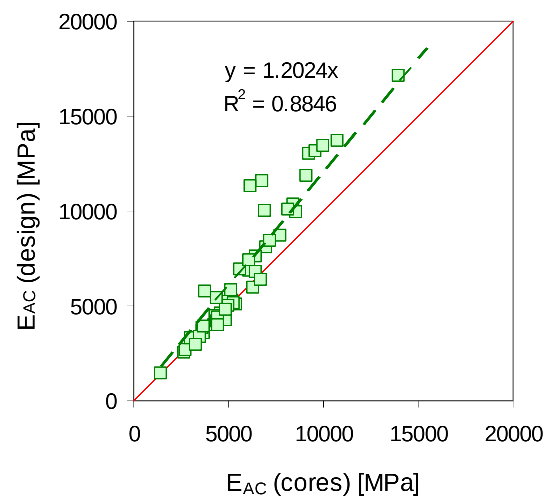

Figure 4b: E_{AC} based on design values & core thicknesses

The above results produces evidence in support of the statement that the backcalculated moduli E_{AC} based on GPR thickness values are almost equivalent to the ones based on core thickness values, something that does not happen in the case of design thickness values. Furthermore the AC backcalculated moduli (E_{AC}) using GPR thickness data during the early life of the pavement (monitoring level M3: 20 days after construction) ranged from 4500 MPa to 14000 MPa (average value 7580 MPa). These values were much higher than the design value (3500 MPa). In order to investigate whether the high E_{AC} compensate for the low (non-cured) E_{FA} (contribution of AC layers to the structural condition of the recycled pavement), the critical strains in the body of the recycled pavement were calculated.

5 STRAIN RESPONSE ANALYSIS

The in-situ critical tensile strains (ε_r) in the body of the recycled pavement are an important factor for the evaluation of the early life performance, because it reflects the distress and consequently the rate of damage in the body of the recycled pavement. Although the calculation procedure is rather complicated, the in-situ max ε_r can be used for comparison with the relative one using the design data. If it is lower than the relative strain based on the design data, the distress in the body of the recycled pavement is lower than expected and consequently the structural condition is adequate.

For the purpose of the present study, the in-situ max ε_r was calculated using linear analysis software (Bitumen Business Group, 1998). However, it should be mentioned that the flexible pavement systems often exhibit stress-dependent behaviour. Advanced models may help to explain the discrepancies between the theoretical analysis and the observed pavement behaviour and pavement responses, an issue that merits further investigation beyond the limits of the present research study. The load used for the calculations was a 50 kN single wheel with 15 cm radius, in accordance with the load used during the FWD survey. For the in-situ evaluation of the early life performance of the recycled pavement, the backcalculated moduli of 20 days, as well those of the 16 months after rehabilitation works were used. These monitoring levels allow the study of the layer properties at an early stage (M3) as well as at a later performance stage (M4) where full curing of foamed treated materials has occurred.

The strain calculations based on field data were conducted using GPR thickness estimations. The critical ε_r was calculated at the bottom of the AC layers and the bottom of the FA layer (see Fig. 1). Strains (average values) are shown in Table 3 and results are presented graphically in Figures 5 and 6.

Table 3: Strain response analysis results.

Monitoring level	Time since construction	Average tensile strain (ε_r) [microns]	
		Bottom of AC layers	Bottom of FA layer
M3	20 days	81	85
M4	16 months	21	45
Design data		68	95

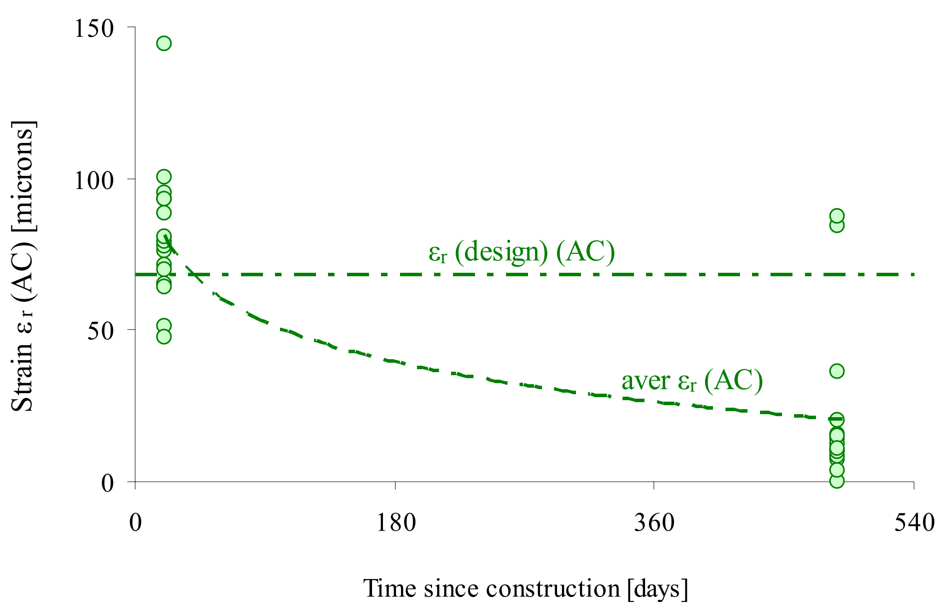

Figure 5: Tensile strain at the bottom of the AC layer.

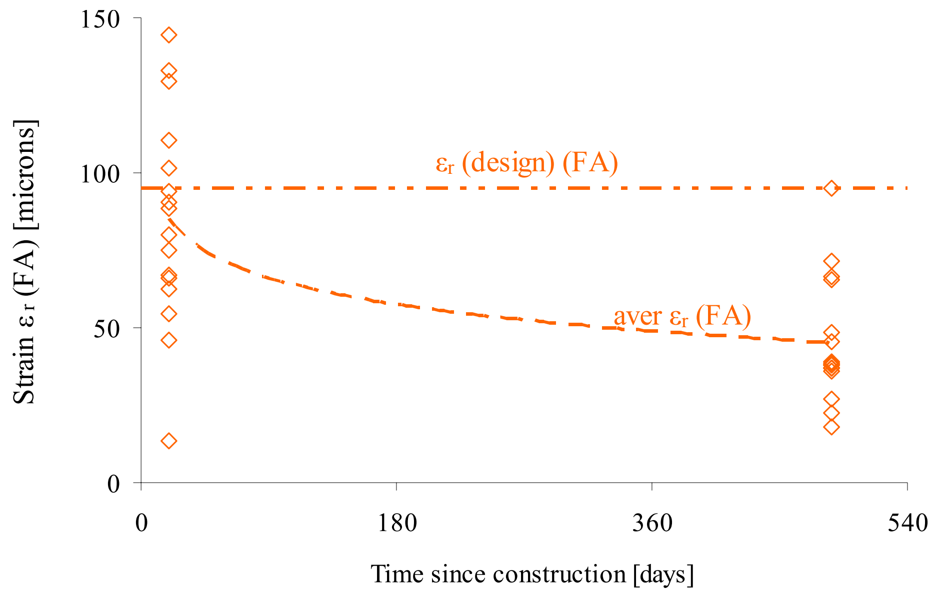

Figure 6: Tensile strain at the bottom of the FA recycled layer.

According to the results above, the following conclusions are can be drawn:

– In many cases the in-situ calculated strains were higher than the design values during the early life of the pavement (M3), indicating increased rate of damage of the recycled pavement during this period.

– The strain at the bottom of the AC layer is more critical during the early life of the pavement, (the average value was higher than the design value). Consequently, an increase of the AC layer thickness would benefit the structural condition of the recycled pavement.

– There is a substantial decrease in the tensile strains with the time.

– The decrease of strains at the bottom of the AC layer is more significant after the completion of the curing of the recycled material.

– In-situ calculated strains at full curing condition (M4) were almost in all cases much lower than the strains based on the design data. This fact is an indication of improved structural performance of the recycled pavement.

6 CONCLUSIONS

The present research study has attempted to investigate the feasibility of monitoring the performance of Cold In-depth Recycled (CIR) pavements using Non-Destructive Tests (NDT). The field investigation is based on FWD and Ground Penetrating Radar (GPR) tests along a representative trial section of a highway pavement rehabilitated with foamed asphalt. The main findings and discussion points are the following:

GPR is a useful tool for the backanalysis during the early life of the pavement while the curing process is ongoing and in-situ thickness data may not be available. According to backanalysis results, GPR can be used for such analysis purposes without significant deviation in accuracy, in comparison with core thickness data.

The modulus of the recycled layer is an indicator for the structural condition and the curing of the recycled material during its early life. If the in-situ obtained modulus is lower than the design value, the recycled material may not have reached the expected curing level or its structural adequacy. Whether this fact is critical or not for the structural condition of the recycled pavement, must be further investigated taking into account in the analysis process the presence of the asphalt concrete layers as well.

Although strain response analysis cannot be considered as a simplified procedure, the maximum tensile strain in the body of the recycled can be used as the major tool for the estimation of the structural adequacy of the recycled pavement. It reflects the distress and consequently the damage in the body of the recycled material, which is a critical factor during the early life of the pavement. If the in-situ maximum tensile strain is lower than the strain calculated using the design data, the distress in the body of the recycled layer is lower and consequently the structural condition of the recycled pavement is adequate. Using relative simple strain response analysis software, the following conclusions are drawn

During the early life of the pavement, there is an indication of increased rate of damage of the recycled pavement. The strain at the bottom of the AC layer is critical. Consequently, an increase of the AC layer thickness would benefit the structural condition of the recycled pavement.

There is a substantial decrease in the tensile strains with time. The decrease of the strains at the bottom of the AC layers is more significant after the completion of the curing of the recycled material.

The in-situ calculated strains at full curing condition were almost in all cases much lower than the strains based on the design data. This fact is an indication of improved structural performance of the recycled pavement.

The NTUA Laboratory of Highway Engineering continues to undertake further research on the subject, including continuous monitoring of pavement performance through detailed analysis. Due to the importance of the Trans European Highway under rehabilitation, the investigated trial section is considered, both for the National and the European database, as an official LTPP site.

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