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Effect of mixing time on reclaimed asphalt mixtures: An investigation by means of imaging techniques

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HIGHLIGHTS

- Asphalt mixtures containing reclaimed material were mixed and compacted at five different European laboratories.
- Same protocols were used but gyratory compactors were from different manufacturers.
- Imaging techniques were applied to study the mixing of reclaimed material within fresh asphalt mixture.
- At double mixing time, the asphalt was found well mixed with less variation in the air voids distribution throughout the specimen height.
- X-ray Computed Tomography (CT) and Optical Microscopy techniques were found useful for microstructural study of reclaimed asphalt mixtures.

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ABSTRACT

This paper presents an application of imaging techniques to investigate the distribution of reclaimed asphalt and air voids within gyratory compacted specimen. Stone Mastic Asphalt specimens containing reclaimed asphalt, were produced at five different laboratories participating in the collaborative project Re-Road: University of Nottingham, Belgium Road Research Centre, Danish Road Directorate, TU Braunschweig and Laboratoire Centrale de Ponts et Chaussees (now IFSTTAR). This study applies the X-ray Computed Tomography and Optical Microscopy techniques to view the internal structure of the specimen with particular focus on the air voids and reclaimed asphalt distributions within the specimen. The observations revealed that with doubling the mixing time the reclaimed asphalt is well mixed with the fresh materials within the gyratory compacted specimen and also the air voids distribution along the specimen height result to be more consistent.

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1. Introduction

There are various studies on the use of imaging techniques to characterise microstructure of asphalt mixtures using either the destructive or non-destructive methods [7,12,13,8]. The X-ray CT and Optical Microscopy have been applied for the study of internal microstructural components of asphalt mixtures [16,11]. Image analysis techniques are in-use to characterise the asphalt mixture components such as the air voids content and aggregate structure [5,10,6,7,12,13,8,9,17]. The processing and analysis of images (slices) have been used to collect limited information about the real object. This has led to the development of various methods and algorithms to enhance the image quality, threshold the object of interest and measure the properties [11,1,18,7,14]. The benefit of using this approach is, the understanding of material properties at the micro level and the distribution of the constituents which has a significant contribution in the material response at macro-level. In addition, this offers a potential of developing a new approach or complement to the existing methods of the asphalt mixtures properties evaluation and forensic studies. In this study, the X-ray CT and Optical Microscopy techniques were used to take images from the compacted specimens of asphalt and study the air voids and reclaimed asphalt distribution within specimens produced in different laboratories, and using different mixing times.

2. Objectives

This investigation was aimed at providing more realistic information for a better understanding of the microstructural

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properties of the gyratory compacted asphalt specimen containing reclaimed asphalt. A comprehensive laboratory investigation was conducted in order to achieve the following objectives:

(i) To study the effect of adding Reclaimed Asphalt (RA) material and mixing time on the internal structure arrangement within the Stone Mastic Asphalt.
(ii) To analyse the distribution of the air voids and RA within compacted specimens.

3. Materials and methods

3.1. Materials and compaction variables

Stone Mastic Asphalt of maximum 8 mm aggregate size (SMA8) containing 15% RA was used to produce specimens. Various laboratory gyratory compactors and same mixing protocols, based on EN 12697-35:2004/prA1:2006 were applied during the preparation of specimens at the different labs involved. Binder was put in a ventilated heating chamber at 165 ± 5 °C for 3.5 ± 0.5 h and aggregate at 170 ± 5 °C for 8 h. The RA was placed in a ventilated heating chamber at 110 ± 5 °C for 2.5 ± 0.5 h .The mixer was heated to 165 ± 5 °C. Dry aggregates including fibres and filler were put in the mixer and mixed for 30 s. RA was added and mixed for another 30 s. New binder was added and mixed for another 90 s. Before filling the mould the temperature of the mixture was checked to confirm the achievement of 150 °C. At 145 °C ± 5 °C, the samples were compacted in gyratory compactor following a protocol based on EN 12697-31 and with the following settings: the internal angle to 0.82°, compaction pressure to 600 kPa and speed of rotation to 30 revolutions/minute. Details of the material including component and design gradation are given in Table 1. The specimens produced were 100 mm in diameter and 70–100 mm in height considering requirements of various proposed testing.

Three replicates of the gyratory specimen for normal and double mixing time were produced at five different laboratories named as: (1) UNOTT: University of Nottingham, (2) BRRC: Belgium Road Research Centre, (3) DRI: Danish Road Institute (now Directorate), (4) ISBS: TU Braunschweig, and (5) LCPC: Laboratoire Centrale de Ponts et Chaussees (now IFSTTAR). Laboratory mixers and gyratory compactors used in preparing specimen were of different manufacturers. Thirty (30) samples in total were produced.

3.2. Optical Microscopy

The Optical Microscopy assessment method was selected to identify the binder/mortar RA within the mortar phase of the analysed asphalt mixes. In fact, X-ray CT scanning results are based on differences in density of the constituents and hence differences in grey level for each component within the mixture [11], but are not able to highlight differencies when two component have similar densities. Because of approximately similar densities of fresh asphalt mix components and those from the RA, a similar grey level is observed hence difficult to identify differencies with X-ray CT techniques [3,4,2]. The Optical Microscopy technique works on the principle that a high pixel image is captured from the object and microstructural properties of various constituents are determined irrespectively of their densities [15,16]. With this in mind, Optical Microscopy was conducted on thin sections of the analysed asphalt mixes, prepared to examine the distribution of polymer and reclaimed asphalt within the compacted specimens. For each sample, two thin sections were prepared, one for the standard evaluation and the other to identify presence of the polymer. The Optical Microscopy was carried out at Danish road institute (now Danish Road Directorate) for all the specimens prepared in five different laboratories. The conclusion drawn from the analysis is based on the total area of the thin section with selected small areas as examples. Experience has shown that when at least three thin sections provide similar results then, as in this case study, these results representative of the asphalt specimen.

Table 1
Details of material and mix design.

Material	Size (mm)	Percent (%)
Aggregate	5/8	39.8
	2/5	11.6
	0/2	16.4
	Filler	6.9
Fibres		0.3
Steel slag		10
Reclaimed asphalt (RA)		15
*Binder(SBS modified 25/55–55A)		6.3

* The percent of added binder is for 100% of other components.

3.2.1. Specimen and surface preparation

20 mm thin sections were prepared from all the specimens. Two types of thin sections were considered in this study, named as standard thin sections and polymer thin sections. For standard thin sections, the sections are impregnated with epoxy resin that contains fluorescent dye which fills all the air voids, porous rocks and cracks. While for polymer thin section, the resin does not contain fluorescent dye. The analyses of thin specimens require different type of microscope lighting. Standard thin section scanning was carried out using transmitted light and the polymer thin section was performed using UV-light.

3.3. X-ray Computed Tomography (CT) scanning and image analysis

The X-ray CT scanning was conducted at the Nottingham Transportation Engineering Centre, University of Nottingham. A Venlo H-350/225 X-ray CT system with IMPS operating software was used for scanning the specimens. The 350 kV X-ray source was used to obtain 2D image slices. The X-ray CT scanning devices are shown in Figs. 1 and 2.

This scanning technique makes use of the ability of short wavelength electromagnetic radiations to penetrate an object. Basically, the system consists of two main devices, the controller and the X-ray room. The scanning components, including X-ray source, detector and specimen manipulator which is placed in the middle. The scanning parameters (primary filters, back filters, voltage, current and exposure time) were selected after several trials. These parameters are dependent on the density of the material and the size of the specimen. After several trials it was found that a good quality image was obtained using the following parameters:

Voltage	342 kV
Current	2.0 mA
Exposure	7.5 min
Primary filter	Copper, 2 mm in thickness
Back filter	Aluminium, 25 mm in thickness

During the scanning, the intensity of X-ray is measured before and after it passes through an object. Scanning of a slice is complete after collecting the intensity measurements for a full rotation of a specimen cross section at approximately 7.5 min. The specimen is then shifted vertically by a fixed interval between slices and the entire procedure is repeated to generate additional slices. The higher the difference in materials' density, the better each of the individual material components can be identified and distinguished from each other. The resulted X-ray image is a set of different grey colours that show the different density of materials within the specimen. For an 8-bit image it consists of 256 (2^8) grey levels starting from 0 (black) to 255 (white) which correspond to lowest density material to the highest density within the specimen. Imaging software package; ImageJ was used to process and analyse the images [11]. In a typical asphalt mixture specimen, aggregates are the brightest region with the highest density, followed by mastic (bitumen and fine particles) and the darkest is the air void with the lowest density. From this study, the specimen was mixed with different materials, including the virgin aggregates, RA and steel slag. In order to pre-determine the grey value for the constituents, the materials were scanned separately as loose particles without bitumen (Fig. 3). The steel slag was included in the mix to compare its distribution with the RA. In fact, because of its higher density steel slag shows a brighter region compared to the virgin aggregates and recycled material. The darkest region represents the air voids.

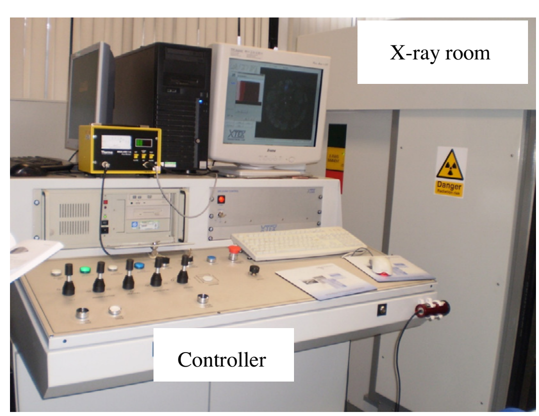

Fig. 1. X-ray CT system at University of Nottingham.

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