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Comparison of mechanical responses of asphalt mixtures manufactured by different compaction methods

Pengfei Liu [b], Huining Xu [a], Dawei Wang [a,b,*], Chonghui Wang [b], Christian Schulze [b], Markus Oeser [b]

[a] School of Transportation Science and Engineering, Harbin Institute of Technology, 150090 Harbin, PR China
[b] Institute of Highway Engineering, RWTH Aachen University, Mies-van-der-Rohe-Street 1, D52074 Aachen, Germany

HIGHLIGHTS

- Aachen compactor can provide better correlation with field specimens.
- Digital image processing is used to analyse internal structure of asphalt mixtures.
- Microstructural finite element models of asphalt mixtures are created.

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ABSTRACT

The compaction of an asphalt mixture is greatly important for ensuring durable pavement performance. In the past decades, laboratory compaction methods have been widely used to produce the test specimens, which undergo testing to infer the behaviour of asphalt pavements in the field. To ensure the consistency of samples both on the laboratory scale and from the field, a new laboratory compaction device (Aachen compactor) has been developed. Specimens manufactured by different compaction methods including field compaction, Aachen compaction and Marshall compaction were comprehensively compared and evaluated in this research using experimental tests, digital image processing techniques and the finite element method. The Aachen compactor specimens tend to show a better correlation with field samples than Marshall specimens. Therefore, the Aachen compactor is a feasible alternative for manufacturing asphalt specimens in the laboratory and thus can be used to better simulate the mechanical properties of asphalt mixtures in the field.

1. Introduction

A high-quality compaction of the asphalt mixture is of great importance for the proper design and construction of high performance asphalt pavements. Compared with the field compaction, the laboratory compaction can provide more controlled environmental factors including temperature and humidity, compaction energy and less material consumption. Moreover, the laboratory compaction can reduce the previous loading for some tests by omitting the drill core removal from an intact asphalt pavement [1]. As a result, laboratory samples are widely used to produce the test specimens to predict the behaviour of asphalt pavements. Therefore, consistent samples from laboratory compaction and a good correlation with field compaction samples are necessary.

Generally, there are several types of laboratory compaction methods including impact compaction, kneading compaction, gyratory compaction and rolling wheel compaction [2,3]. The Marshall compaction is a typical impact compaction, which is the oldest but still the most widely used one [3]. However, different compaction methods in the laboratory may manufacture identical samples regarding the density whilst exhibiting different mechanical properties [4–7]. Moreover, different methods of laboratory compaction often result in asphalt mixtures with varying mechanical properties; furthermore, the mechanical properties of laboratory samples also differ considerably from those of field specimens [1]. In recent years, numerous studies have been conducted to investigate the underlying reasons for the differences between laboratory and field compaction and to assess the influence of the compaction method on the mechanical performance [5,6,8–13]. Based on a detailed literature review, the compaction method has been found to influence the aggregate orientation

* Corresponding author at: School of Transportation Science and Engineering, Harbin Institute of Technology, 150090 Harbin, PR China.
E-mail address: wang@isac.rwth-aachen.de (D. Wang).

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and therefore plays a role in determining the performance [4,12,14]. Mould-based compaction methods such as the impact and gyratory compaction, result in more stiff material properties in comparison to field samples [15]. The reason behind this observation is thought to be the lack of kneading motions. The impacts applied by the Marshall hammer do not represent real compaction conditions in the field [16]. The best results regarding the internal aggregate structure and mechanical properties were observed for a laboratory scale roller compaction used in the production of hot mix asphalt (HMA); however, this method is not convenient and requires much effort [4,17].

In recent years, digital image processing (DIP) has been increasingly applied to study the internal aggregate orientation and air void distribution and morphology. DIP consists of non-destructive X-ray computed tomography (XCT) [14,18–20] and two dimensional (2D) imaging coupled with destructive (sawing) techniques [12,13,21–23]. Research using DIP has concluded similar results and the particle orientation due to different compaction methods has also been proposed as the underlying reason for differences in mechanical performance for mould-based compaction methods, roller-compaction and field cores of comparable air voids [1].

Recently, numerical modelling and simulations have been applied more frequently in order to improve the design, construction and maintenance of pavements [24–29]. In the last few decades, DIP and numerical methods have been coupled to reconstruct the internal structure and evaluate the morphology of asphalt samples [30,31]. In the beginning, this approach was used to simulate asphalt mixtures in two dimensions in combination with the discrete element method (DEM) [32] or finite element method (FEM) [33]. In recent years, three-dimensional (3D) numerical models were created for this purpose based on XCT imagines or by means of artificial generation algorithms [34–40].

In order to ensure consistency both in the laboratory compaction and in field compaction, a new standardized laboratory compaction method has been developed, namely the Aachen compactor. In this study field compaction, Aachen compaction and Marshall compaction were compared and evaluated. Firstly, the uniaxial cyclic compression test was used to assess the distortion resistance of all specimens. Comprehensive analyses using DIP techniques and FEM were carried out to investigate the effect of the different compaction methods on the asphalt specimens with regard to the internal structure, mechanical response, and fracture behaviour and so on.

2. Description of Aachen compactor

2.1. Background

In the mid-1990s, the Institute of Highway Engineering at the RWTH Aachen University began with the development of a new compaction method for asphalt specimens suitable for application in the laboratory. The main objective was to replace the Marshall compaction method with a new standardized laboratory compaction method; mainly because the principle of the Marshall compaction method is an "impact compaction" which does not correspond with compaction in the field [3]. In particular, the effects of the new compaction method on the mechanical properties of the asphalt specimens are expected to differ from the Marshall compaction method substantially but exhibit a high similarity to compaction in the field. The result of these requirements is the "Aachen compactor" developed by the Institute of Highway Engineering in cooperation with the Institute for Engineering Design at the RWTH Aachen University.

2.2. Description of the device and the compaction procedure

The Aachen compactor can produce cylindrical asphalt samples with diameter of 100 mm or 150 mm (other diameters are technically possible with some adjustments to the setup). Since the main purpose is to simulate the field compaction, the principle of roller compaction is realized by means of two conical rotating steel rollers with a smooth banding, which compact the asphalt mix in a cylindrical mould as shown in Fig. 1.

Before the compaction program is initiated, a circular piece of paper is placed on the base plate of the pre-heated compacting mould, and the pre-heated asphalt mix is filled into it by means of a spoon and spatula. A circular chipboard with a thickness between 0.5 and 1 mm is placed on the asphalt surface to prevent the asphalt mix from adhering to the conical steel rollers. The compaction program is started after the compacting form has been installed and fixed in the Aachen compactor.

The whole compaction procedure with the Aachen compactor can generally be divided into three stages as shown in Fig. 2. As the conical rollers are lowered, the compacting form is rotated and as soon as the steel cones make contact with the asphalt surface, they begin to spin and even out the asphalt surface. The main compaction stage begins as soon as the conical rollers are completely loaded on the asphalt surface and the specified static linear load is applied to the rollers. It is only once this has occurred, that the number of rotations (i.e. roll-overs) is recorded. After reaching a pre-determined number of roller passes, the conical rollers are lifted from the asphalt surface and the device is reverted into the upper "parking position". After removal of the mould and subsequent cooling, the asphalt sample can be obtained by pressing it out through the cylindrical mould.

Apart from the static linear load and the oscillating mass, the following compaction parameters are also entered into the compaction program: rolling speed with optional speed change, lowering speed [mm/s], number of static rolling passes, number of dynamic roll passes, and vibration frequency and amplitude. The program is then executed automatically via the operating unit of the Aachen compaction device.

Fig. 1. Aachen compactor.