Effect of Air Void Content and Repeated Testing on Stiffness of Asphalt Mix Specimen

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ABSTRACT: The viscoelastic behavior of hot mix asphalt (HMA) is influenced by several factors, e.g. by the mix design, aggregate source, filler, binder and compaction quality. Therefore, a variation of one characteristic has an impact on the viscoelastic behavior of the HMA. Various laboratory conditioning procedures, e.g. ageing or water sensitivity, attempt to simulate field processes as realistically as possible. Lab tests for evaluating the mechanical changes of the material due to conditioning are necessary. However, comparing specimens with different characteristics, like air void content, may often be a difficult task. Tests on the same specimen before and after a lab conditioning procedure would be a preferred approach for quantifying the effects of the conditioning.

Thus, for the study presented in this paper, the air void content of HMA specimens is varied in a rage from 3 to 16 % per volume. Cyclic indirect tensile tests (IT-CY) are carried out on all specimens at a temperature of +10°C and frequencies ranging from 0.1 Hz to 20 Hz. The dynamic modulus |E*| is determined and evaluated to study the impact of air void content on the viscoelastic behavior of HMA. Furthermore, it is investigated whether repeated IT-CY tests on the same specimen are possible, without obtaining significant changes in the material behavior due to multiple testing. This would enable to test specimens before and after certain laboratory conditioning procedures.

INTRODUCTION

In this paper, the effect of the air void content of specimens cored from lab-compacted slabs and repeated testing of cylindrical asphalt mix specimens on performance parameters are investigated.

Bulk densities or rather air void contents have an influence on the mechanical behavior of hot mix asphalt pavements. Air voids reduce the cross sectional size of the material, that can be utilized for load transmission. Therefore conventional design approaches set maxima for air void contents of hot mix asphalt pavements and use it as a sign of quality for the construction process. Otherwise the stiffness would be to low and damages would occur with higher probabilities and would not comply with the criteria of the road administration. Similar to the acceptance test of subgrade levels, bulk density is used as a quality parameter. There is a fundamental correlation between bulk density and material behavior, but slight deviations may appear due to inhomogeneity of air voids and inaccuracy of the procedures for determining the air void content. As early as in the 1960s, (Shook et al. 1969) showed relationships between dynamic modulus and mix characteristics, such as air voids and binder content. A decrease of the air void content results in an increase in the modulus. A decrease in the binder content leads to an increase in the modulus. (Hofko et al. 2012) investigated the influence of the air void content on dynamic modulus of four point bending test and the influence of compaction direction. A linear interrelation between the dynamic modulus and the air void content was observed for all test frequencies. The higher the void content is, the lower will be the stiffness (Hofko et al. 2014). (Kok et al. 2014) stated in his research, that field compacted and laboratory compacted specimens differ in the performance even with the same air void content. The laboratory specimens with the same air-void contents as those of field specimens displayed much better performance than the field specimens. Also a variation of the production temperature slightly affects the volumetric properties of mixtures and introduces significant changes in the stiffness modulus (Perez-Jimenez et al. 2014).

Several other research projects studied the effect of air voids on other performance parameters of Hot Mix Asphalt (Epps et al. 1969, Harvey and Tsai 1996). (Seo et al. 2007, Caro et al. 2010, Singh et al. 2011) present studies on an air void model for performance prediction of HMA.

Various laboratory conditioning procedures, e.g. HMA specimen ageing (Bell et al. 1994, Steiner et al. 2015) or water sensitivity (Terrel and Al-Swailmi 1994), attempt to simulate field processes as realistically as possible. Therefore, tests for evaluating the mechanical changes of the compacted material due to conditioning are necessary. Basically, there are two options:

- Comparing two different specimens, one of them unconditioned and the other one conditioned.
- Comparing the behavior on the same specimen, by testing it before and after the conditioning process.

Specimens with different air void contents result in different mechanical behavior, mostly represented by the stiffness. Thus, the first option mentioned above requires the relationship between the air void content and stiffness. However, comparing specimens with different characteristics, like air void content, may often be a difficult task. Tests on the same compacted specimen before and after a lab conditioning procedure would be a preferred approach for quantifying the effects of the conditioning. Nevertheless, there is a danger that specimens change their behavior, e.g. due to a re-densification. This would lead to an increased stiffness. Therefore the influence of the conditioning procedure has to be more significant than the impact of repeated tests.

MATERIALS AND TEST METHODS

Materials

For the presented study, an asphalt concrete with a maximum nominal aggregate size of 11 mm (AC 11) was employed. The coarse aggregates used for the mix is a porphyrite, the filler is powdered limestone. As a binder an unmodified 70/100 pen (PG 58-22) was used. The main characteristics of the binder are listed in Table 1.

Table 1. Main Characteristics (Mean Values) of Binders

Parameter	70/100 pen
Penetration [1/10 mm]	91
Softening Point Ring & Ball [°C]	46.8
SHRP Performance Grade [°C]	58-22

The binder content was set to 5.2 % by mass with target air void contents for 3 slabs of 4.5, 7.6 and 13.2 % by volume.. The maximum density of the AC 11 70/100 was determined to be 2.282 kg/m³. The grading curve is shown in Figure 1.

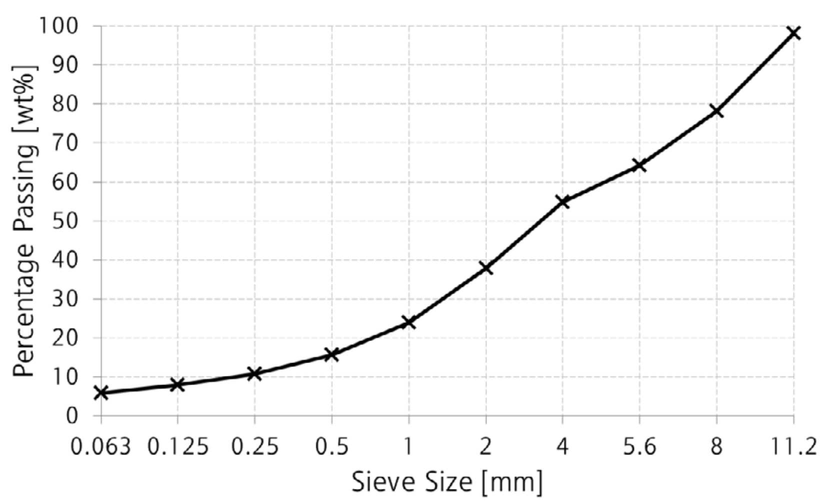

FIG. 1 Grading Curve of AC 11

Specimen Preparation

The mix was prepared in a laboratory reverse-rotation compulsory mixer, according to EN 12697-35 (CEN 2007b) with a mixing temperature of +165°C. HMA Slabs (50x26x4 cm) were compacted in a roller compactor according to EN 12697-33 (CEN 2007a), with a path-controlled compaction. All slabs were compacted with one lift. From the slabs, eight specimens are cored out with a diameter of 100mm. (See Figure 2)

The air void content of all specimens were determined by procedure D: “Bulk density by dimensions” according to EN 12697-6 (CEN 2012). Adaptions of the standard procedures were carried out, because of the wide range of air void contents. Specimens with higher bulk density requires procedure B “Bulk density – Saturated surface dry (SSD)” or procedure C “Bulk Density - Sealed specimen”. Procedure C would cause problems for further laboratory conditioning procedures.

Dynamic Modulus Testing of HMA

Cyclic indirect tensile tests (IT-CY) (Di Benedetto et al. 2001) were carried out on all specimens before and after aging at a temperature of +10°C and frequencies ranging from 0.1 Hz to 20 Hz by applying a sinusoidal load. From test data the dynamic modulus |E*| and the phase angle φ can be determined to describe the viscoelastic behavior of the specimen. To avoid differences in the performance characteristics due to the compaction direction, the slabs were marked with lines before the specimens were cored out. All specimens were tested in compaction direction (see Figure 2).

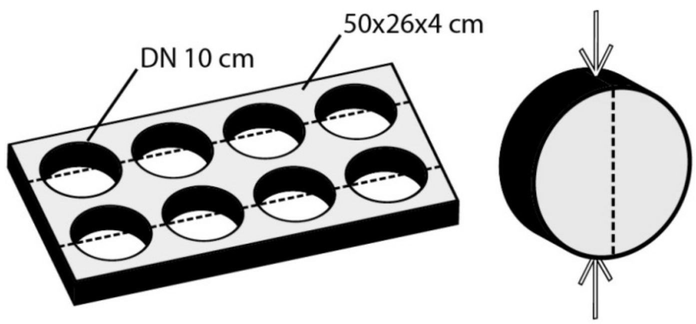

FIG. 2 Slab with cores and testing direction

In a series of pretests, the upper stress level of the sinusoidal load (see Table 2) was determined so that the elastic horizontal strain amplitude of the specimen during testing is between 5*10-5 m/m and 6*10-5 m/m. This is necessary for repeated testing to prevent the specimens from suffering permanent deformation.

Table 2. Test Conditions for IT-CY | +10 °C

Frequency [Hz]	**0.1**	**1**	**5**	**10**	**20**
Lower Stress Level [kPa]	35	35	35	35	35
Upper Stress Level [kPa]	210	240	300	360	390
Number of Load Cycles [-]	9	15	50	100	100

TEST PROGRAM

Table 3 gives an overview of the test program. For both parts of the study, specimens with air void contents from 3.6 % by volume to 15,9 % per volume were tested two times. 3 slabs with different target air void content were compacted. 24 specimens in total (8 each slab) were cored out of the slabs. The results of these tests give an overview of the increase of dynamic modulus |E*| with falling air void content (evaluation of the first IT-CY testing) and the influence of repeating stiffness tests (evaluation of the second IT-CY testing compared to first IT-CY testing).

Table 3. Specimens for IT-CY | +10 °C

Specimen Number	Air void content [vol%]	Specimen Number	Air void content [vol%]	Specimen Number	Air void content [vol%]
E620A	3,6	E619F	5,6	E631F	10,6
E620C	3,9	E619C	5,7	E631D	10,8
E620F	4,1	E619E	5,7	E631E	10,8
E620D	4,3	E619G	5,7	E631B	11,8
E620G	4,5	E619H	6,2	E631G	12,2
E620B	4,6	E619B	6,4	E631H	12,2
E620H	5,0	E619A	7,1	E631C	13,6
E620E	5,5	E619D	9,6	E631A	15,9

RESULTS AND DISCUSSION

Impact of Air Void Content

16 specimens were tested to find the correlation between the air void content and the dynamic modulus |E*|. Figure 3 shows the detailed results of the dynamic modulus |E*| vs. air void content. Linear regressions are also presented for each testing frequency in the figure. The coefficient of determination R^2 are equal or above 0.9, which indicates a good correlation of dynamic modulus vs. air void content with a linear regression.

To compare the influence of the testing frequency on the relative changes of the stiffness over the full air void range, the linear regressions are normalized in Figure 4. The reference is the value of the linear regression at 5% air void content. Thus, the graphs of all frequencies intersect at the value 1.00. The relative change of the stiffness with the air void content is shown with the value m, the gradient of the lines. The results show, that the changes of the stiffness with the air void content do not depend on the testing frequency. The deviation of the gradient at 0.1 Hz could be justified, that less loading cycles were carried out at this frequency, which can result in a wider scattering or results.

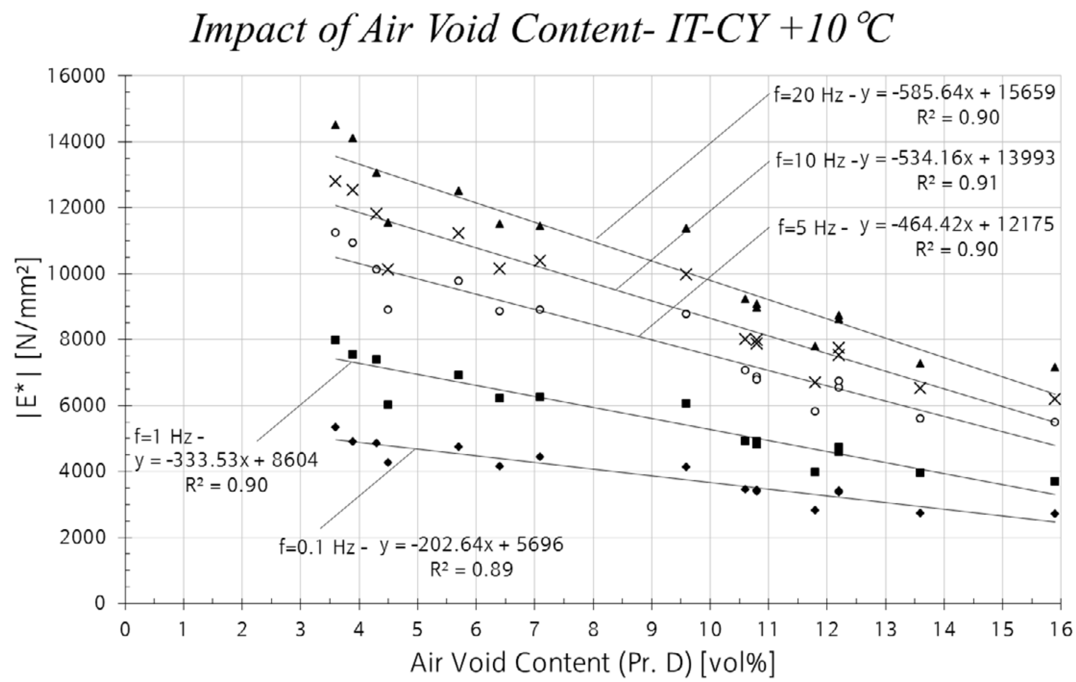

FIG. 3 Impact of Air Void Content on Dynamic modulus |E*|

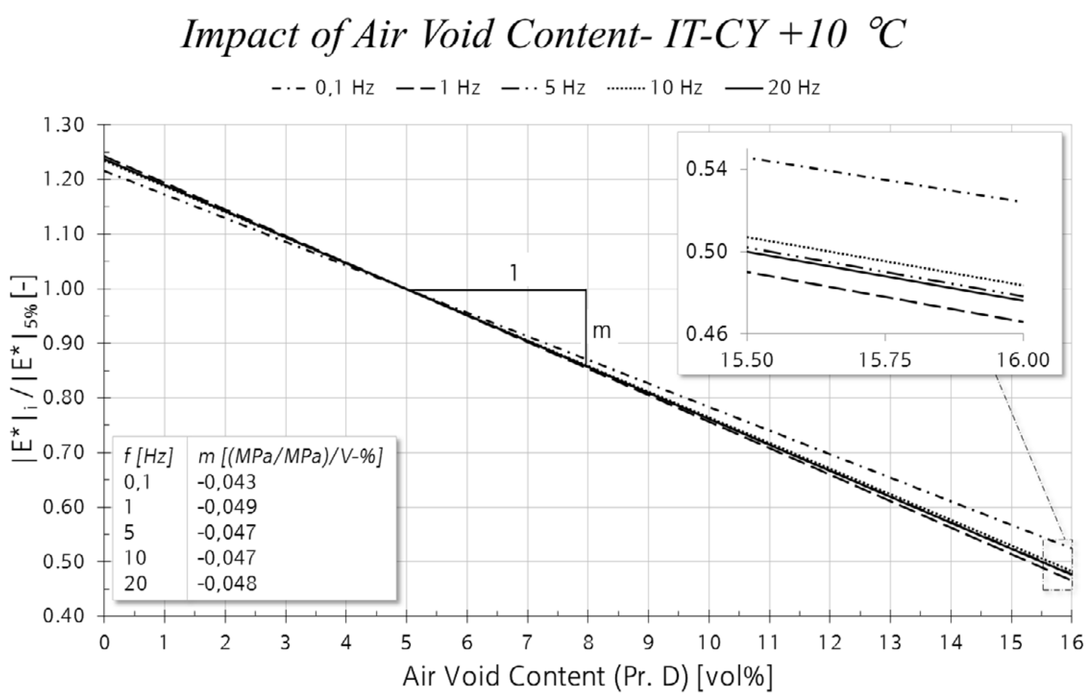

FIG. 4 Impact of Testing Frequency on Relative Change of Dynamic modulus |E*| due to different Air Void Contents

Impact of Repeated Tests

To evaluate the impact of repeated tests, 7 specimens with a wide range of air void contents were chosen. It was not possible to find a correlation between the air void content and the shift of the stiffness. As it can be seen from Figure 5, the dynamic modulus |E*| undergoes a slight increase by testing a specimen twice. Apart from the lowest testing frequency 0,1 Hz, at all other frequencies, ranging from 1 Hz to 20 Hz, the shift of the dynamic modulus is approximately equal. The deviation at 0.1 Hz can be explained by the fact, that only 9 loading cycles (see Table 2) were applied on the specimens at 0.1 Hz. Thus, the number of loading cycles could be linked to the standard deviation of the results. The higher the frequencies, the higher are the loading cycles, due to the time capacities, and the smaller is the spread of the results. Furthermore, it can be stated that with good probability the relative change of the dynamic modulus |E*| is between 0.95 and 1.05 when the second test is compared to the first test.

It was shown that repeated tests on the same specimen are possible when the elastic horizontal strain amplitude of the specimen during testing is between 5*10-5 m/m and 6*10-5 m/m . This is a necessary precondition for showing the effects of laboratory conditioning procedures by testing them before and after conditioning.

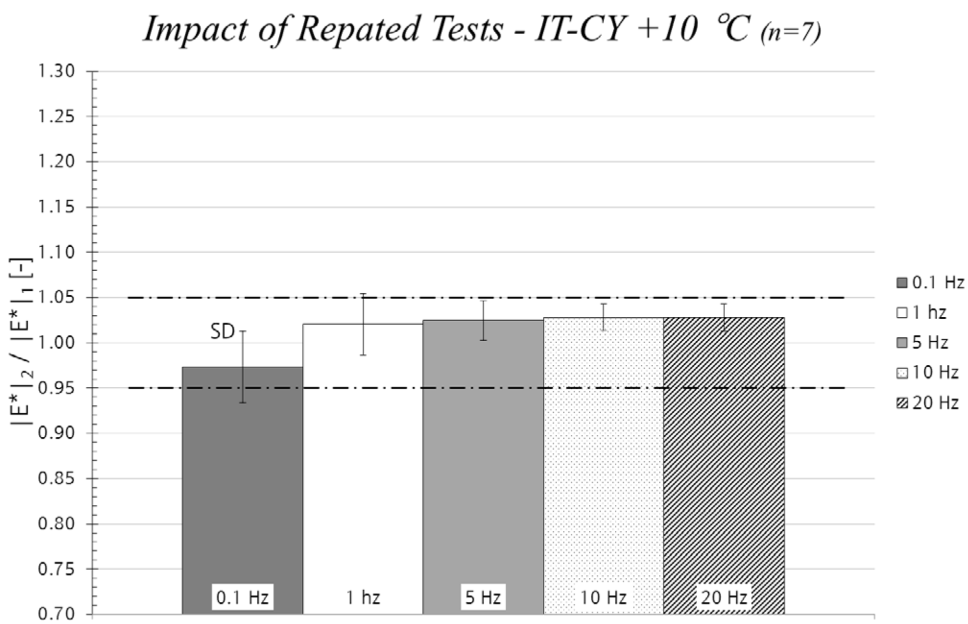

FIG. 5 Impact of Testing Frequency on Relative Change of Dynamic modulus |E*| due to different Air Void Contents.

SUMMARY AND CONCLUSION

The main motivation for the research project presented within this paper is to study the impacts of stiffness tests on HMA, in particular indirect tensile tests on cylindrical specimens (IT-CY), to get an evaluation possibility for laboratory conditioning procedures. Two issues are addressed: the impact of air void content on the viscoelastic behavior of HMA and the influence of testing one specimen twice to enable to test specimens before and after laboratory conditioning procedures.

The presented results are based on tests of 24 cylindrical hot mix asphalt specimens with a wide range of air void contents from 3.6 to 15.9 % by volume. Changes in the dynamic modulus |E*| were compared and analyzed. The correlation of air void content and dynamic modulus |E*| and the influence of the testing frequency on this correlation are illustrated. Furthermore the changes of testing specimens twice are shown for each testing frequency.

For the results of the air void content tests, it becomes obvious that the stiffness in terms of dynamic modulus |E*| decreases in a linear way with increasing air void content. To quantify the changes, an increase of 1 % air void content by volume leads to an decreased dynamic modulus by approximately 5°%. The relative change is independent of the testing frequency.

For the results of the repeated testing, it can be concluded, that an increase of more than 5 % of the dynamic modulus |E*| at the second test at a laboratory conditioning test can be designated as a significant change due to the procedure. Below this limit, changes can be attributed to the stiffness testing.

In practice, air void contents are respective values for the quality control of hot mix asphalt layers. In international standards, bandwidths are specified, which are acceptable for contracting authorities. Assessing the wide variety of the dynamic modulus |E*| from the limit values of acceptable air void contents, it can be concluded, that the performances of this layers can be reduces significantly. Thus, shorter life cycles have to be expected. More concretely, a 2 % higher air void content leads to a reduction of the stiffness of 10 %.

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