ROUND ROBIN TEST OF STIFFNESS MODULUS BY INDIRECT TENSILE METHOD ACCORDING TO EN 12697-26:2004 ANNEX C

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ABSTRACT

Stiffness modulus of asphalt concrete is a fundamental parameter used in pavement design models to evaluate pavement mixes and in function-based contracts related to pavement layers. The European standard EN 12697-26:2004 Annex C has been established for measurement of stiffness modulus using the Indirect Tensile Test, which has been found to be efficient for practical use in testing specimens manufactured in the laboratory or cored from pavement. This work presents repeatability and reproducibility based on measurement of two mixtures tested with three different apparatus manufactured by different companies. It is concluded that the test is very sensitive to testing parameters, which must be considered when evaluating mixes. A better definition of loading form and analysis of measured strain pulses is therefore needed.

Keywords: stiffness modulus, indirect tensile test, loading time, round robin test

1. INTRODUCTION

One of the most fundamental properties of asphalt concrete mixtures is the modulus of stiffness, which is an important input for pavement design and evaluation of asphalt materials. The term stiffness or stiffness modulus has been used by Van der Poel [1] to define the stress to strain ratio of bitumen, and to avoid using the elastic modulus (Young's modulus), i.e. the stress directly proportional to strain and independent of the strain rate for perfect elastic materials. Indirect tensile test is frequently used for measuring stiffness modulus in asphalt concrete specimens. In the test, the specimen is loaded vertically by means of loading strips, which results in a relatively uniform tensile stress in the horizontal direction perpendicular to the plane of loading, Kennedy [2] and Hondros [3]. The stress to strain ratio of asphalt materials is primarily dependent on loading time and the stress magnitude at elevated stress levels in relation to temperature. The material is thus defined as non-linear viscoelastic material, whereas, at relatively low stress levels, asphalt materials may for practical purposes be defined as approximately linear viscoelastic material. Strain can be based on the total deformation (maximum deformation during one loading cycle) or just on the elastic (resilient) deformation or an average of the two. How different standards (EN *12697-26:*2004, DD 213:1993, FAS 454-98, ASTM D 4123-82) measure deformation for the calculation of stiffness modulus is illustrated in Figure 1.
Elastic deformation generally means all recoverable deformation irrespective of whether it is elastic (time independent) or viscoelastic (time dependent). Likewise, "E-modulus" is used for the ratio between dynamic stress and the elastic part (all recoverable) of the strain [4]. Elastic (recoverable) deformation is shown in Figure 1. Differences between stiffness moduli based on total deformation and elastic deformation depend on the test temperature and the asphalt material's properties. It is therefore important to explain which deformation was used when calculating stiffness modulus. Normally, pavement design response models and pavement performance models require a stiffness modulus representing the elastic properties of the material. ASTM 4123, AS 2891.13.1 and the national Swedish standard FAS 454, therefore, use the recoverable (called elastic or resilient) deformation to determine stiffness modulus in asphalt concrete. However, EN 12697-26:2004 uses the average deformation, which is a sum of the resilient and some of the permanent deformations. Further details regarding the effect of testing parameters and differences between testing methods have been reported elsewhere [5]

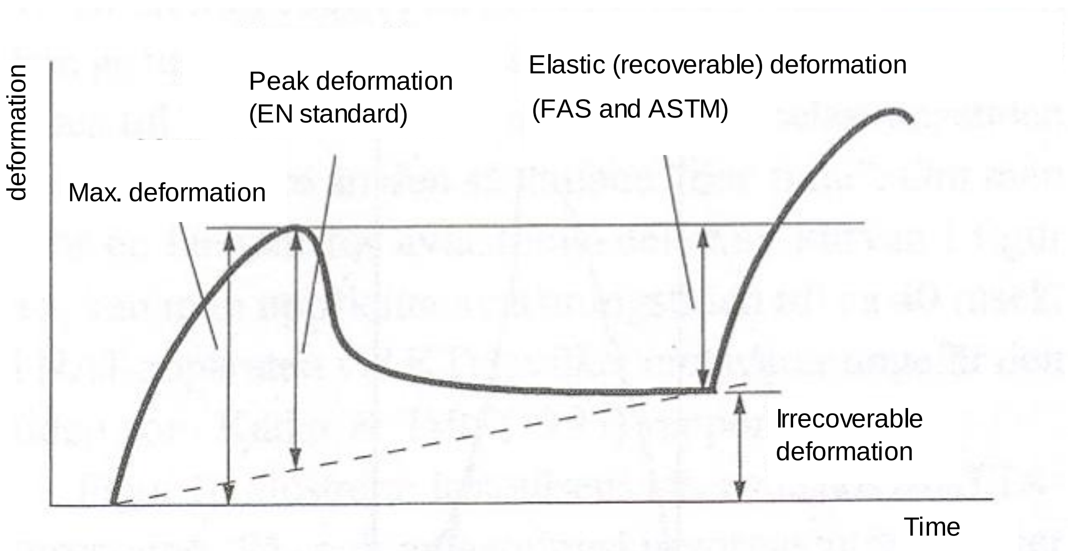

Figure 1: Methods of measuring deformation according to different standards

2. PARTICIPANT LABORATORIES

It is worth mentioning that not many laboratories were able to report the actual measurements of deformation and force in relation to time. Most of the laboratories are dependent on the software supplied by the manufacturer. Three laboratories were able to record measurements with time and participated in the round robin test with different equipment as shown in table 1. They were able to report deformation and load measurements in relation to time. It was therefore possible to analyse the results and calculate the stiffness moduli in exactly the same way regardless of the equipment's origin. It should be mentioned here that deformation gauges are mounted on the sample in two different ways. In NU14 and UTM-25, deformation transducers (LVDT) are fixed in a frame and measure the deformation on each side of the sample at its midpoint. A torque force of 25 cNm is used to fix the frame around the specimen since it might influence the measured deformation. VTI's laboratory uses two extensometers fixed on two strain strips glued on opposite sides of the sample, thus measuring deformation over the entire thickness of the specimen. How deformation transducers are mounted on the sample is illustrated in Figures 2 and 3.

Table 1: Participant laboratories and their equipment

Laboratory	Testing machine	Loading system	Strain gauge
SCREG Ile de France Normandie	COOPER NU14	pneumatic	LVDT
Skanska	UTM-25	hydraulic	LVDT
VTI	MTS 454	hydraulic	Extensometer

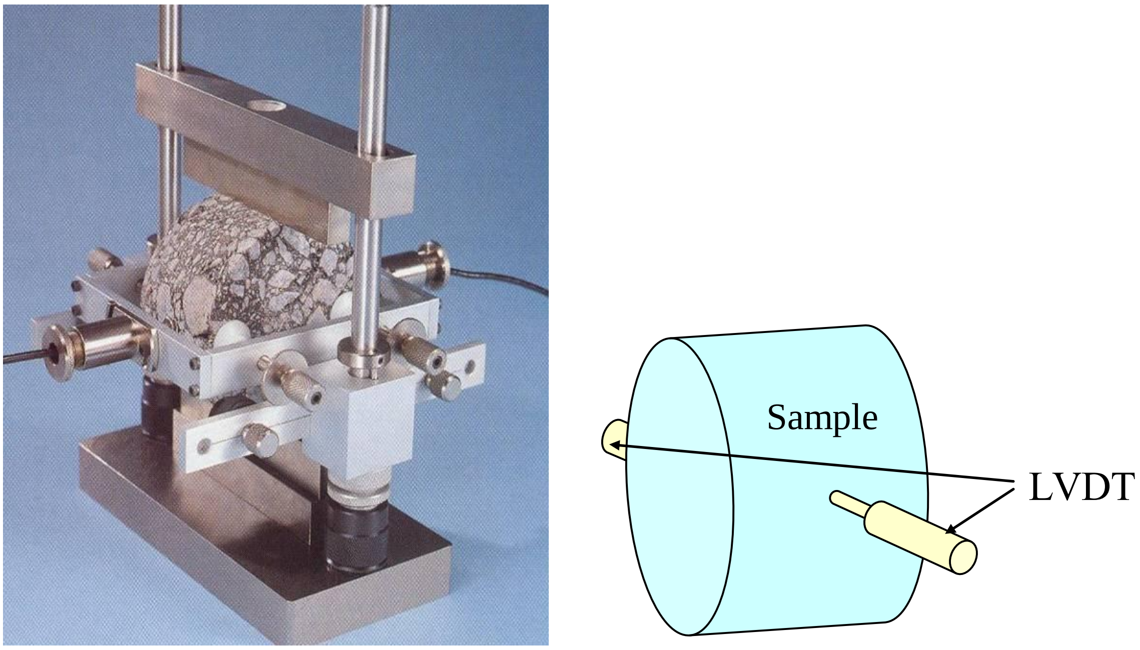

Figure 2: LVDT mounted on the sample (at Skanska and Screg IDFN)

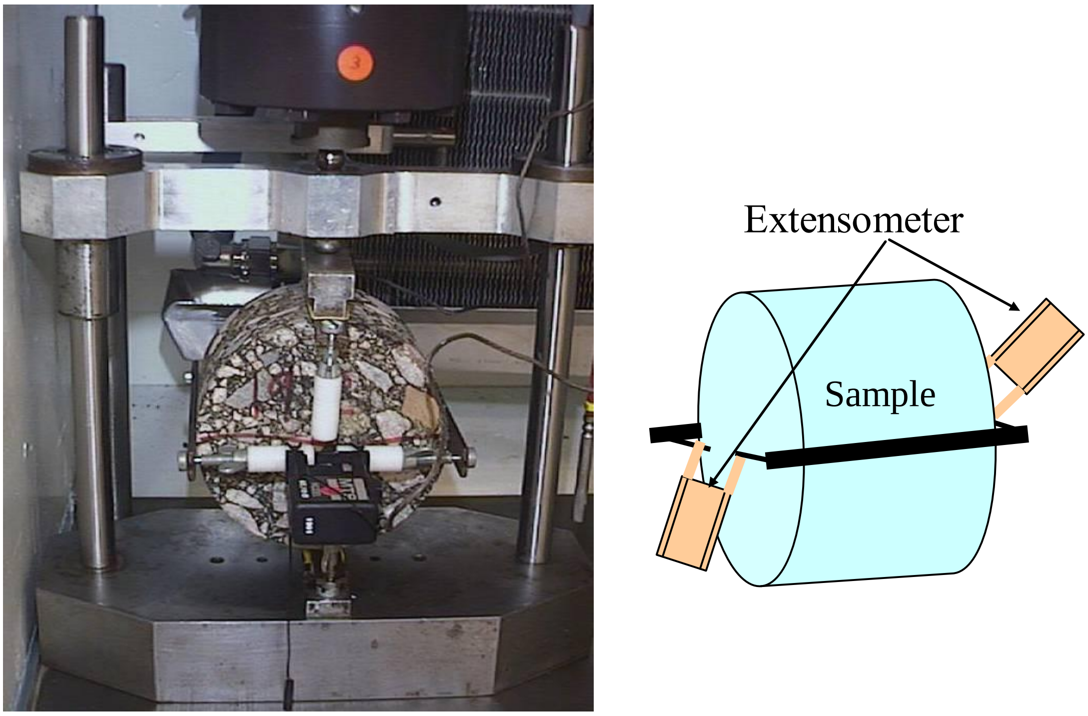

Figure 3: Extensometer mounted on the sample (at VTI)

3. METHODOLOGY

Two mixtures from field and laboratory have been chosen for this round robin test (10 samples in all). Five samples are cores from a base layer called AG 22 70/100 in a field pavement. The other five samples were manufactured in the laboratory by gyratory compaction are called ABT 11 160/220. Both mixtures were prepared according to the Swedish standard ATB väg. The tests were performed at 10°C at two different pulse load times, 100 and 250 milliseconds (ms), corresponding to a rise time of 50 and 125 milliseconds, respectively. Loading time consisted of two equal parts, rise time (c) and unloading time (d), as shown in Figure 4. Each load pulse was followed by an unloaded period. The load pulses were repeatedly loaded every 3 seconds with 5 conditioning pulses followed by a further 5 pulses for stiffness measurements. Curve fitting was applied for load and deformation measurements and linear fitting for unloaded periods. The resilient deformation was used to determine stiffness modulus, as shown in Figure 5 (after curve fitting). All measurements were performed at a strain level of less than 5 micro-strains in order to be in the linear viscoelastic zone and eliminate excessive permanent deformations.

A total of 10 specimens were circulated between the laboratories for determination of resilient moduli at the two different loading times described above. For control of testing temperature, a dummy sample with two thermometers was used during the measurements.

The repeatability of the test was determined by two procedures. Since the method is non-destructive, one sample of each series was tested three times over a period of two days. After each measurement the sample was moved from the device before starting the next measurement. According to the 2nd procedure the specimens in each series were assumed to be identical for the purposes of calculating repeatability. These two procedures were used to eliminate the effect of variation between specimens on the repeatability of the test. However, repeatability according to the second procedure should be used in routine testing since the variation between samples is assumed to be part of the variation of a standard.

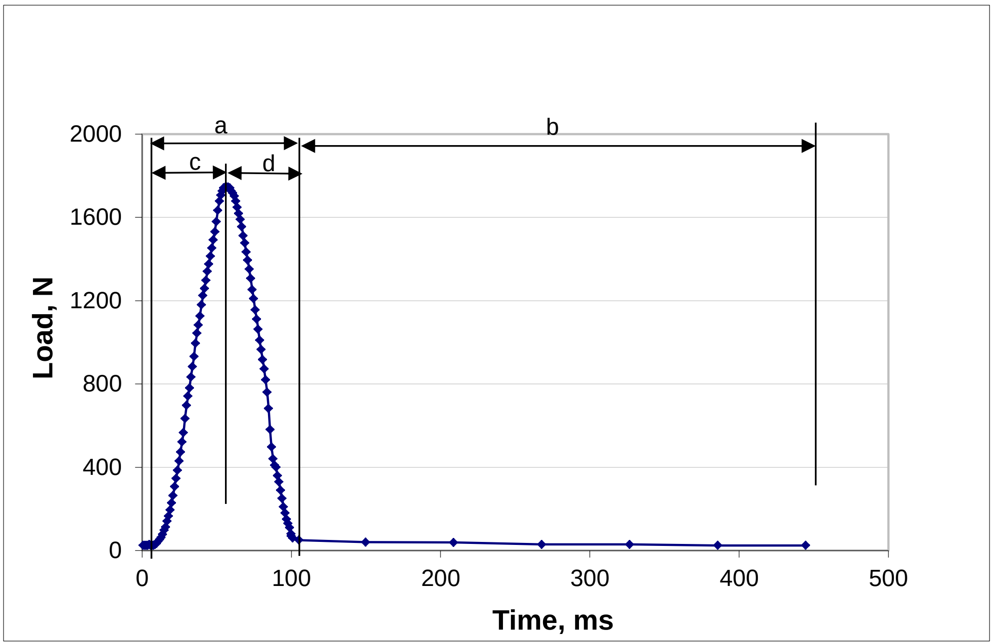

Figure 4: Definition of the loading time

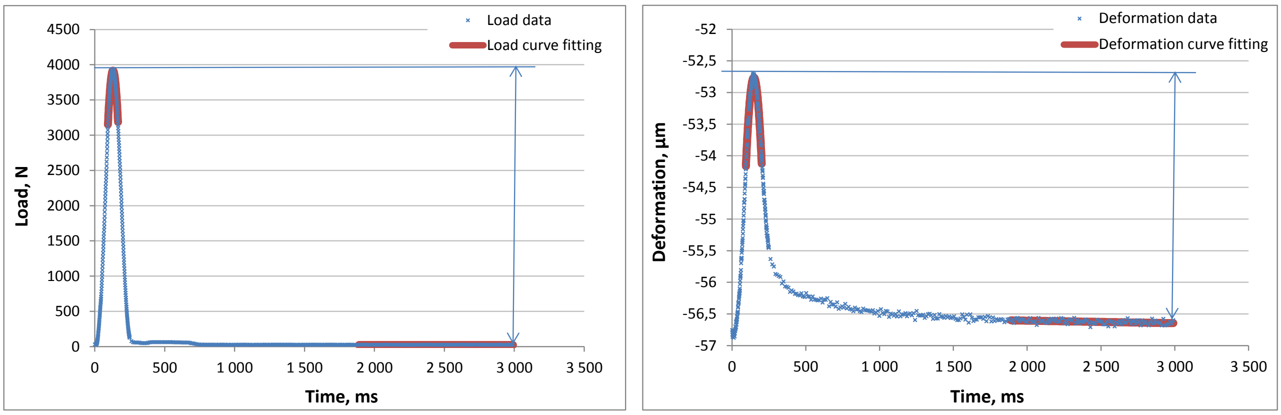

Figure 5: Load and deformation pulses and corresponded curve fittings

4. TEST RESULT

4.1 Effect of loading time

Figure 6 shows the loading from the three testing machines used in this work based on measurements from the load cell of each equipment at 100 milliseconds. It is noticeable that there is a good agreement between these apparatus (this was easily performed with the possibility of checking the actual measurements). The stiffness moduli were measured at two different loading times, 100 and 250 milliseconds, at 10°C. In this study, as expected, stiffness modulus increases with shorter loading time. The effect of loading time is illustrated in Figures 7 and 8. It is noticeable that there are systematic differences between laboratories testing the ABT11 mix. However, this is not the case (no systematic differences between laboratories) when testing the AG22 mix. Table 2 shows the average value of stiffness moduli for each mix and laboratory. The average reduction in stiffness moduli is 14% and 24% for AG 22 and ABT 11, respectively. It is obvious that the loading time is an important parameter and should be controlled before testing and possibly corrected to a specific loading time before reporting. It is also remarkable that according to this study the influence of loading time is different for different mixes. It may be that the effect of loading is related to the stiffness modulus values; at high stiffness moduli the measurements are less sensitive to loading time. However, further investigations are needed for verification.

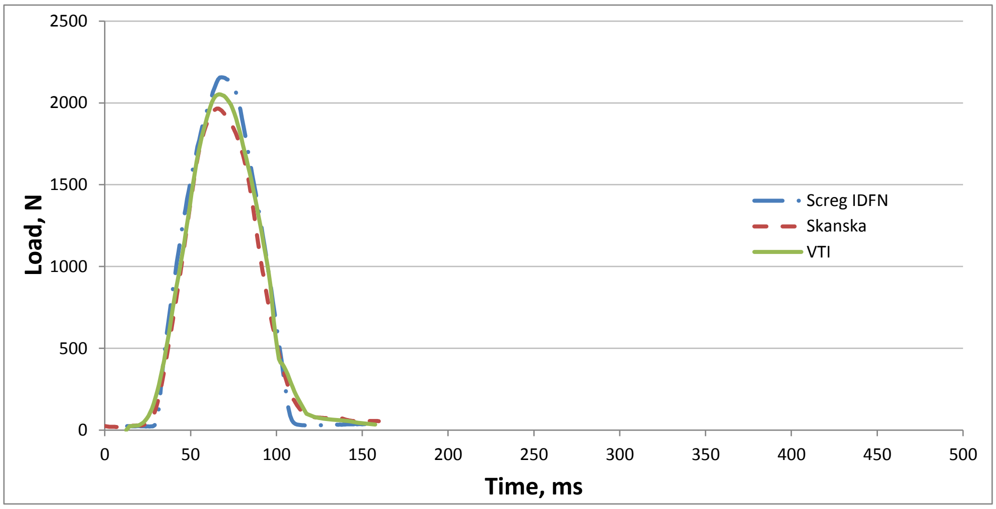

Figure 6: Loading time from different equipment

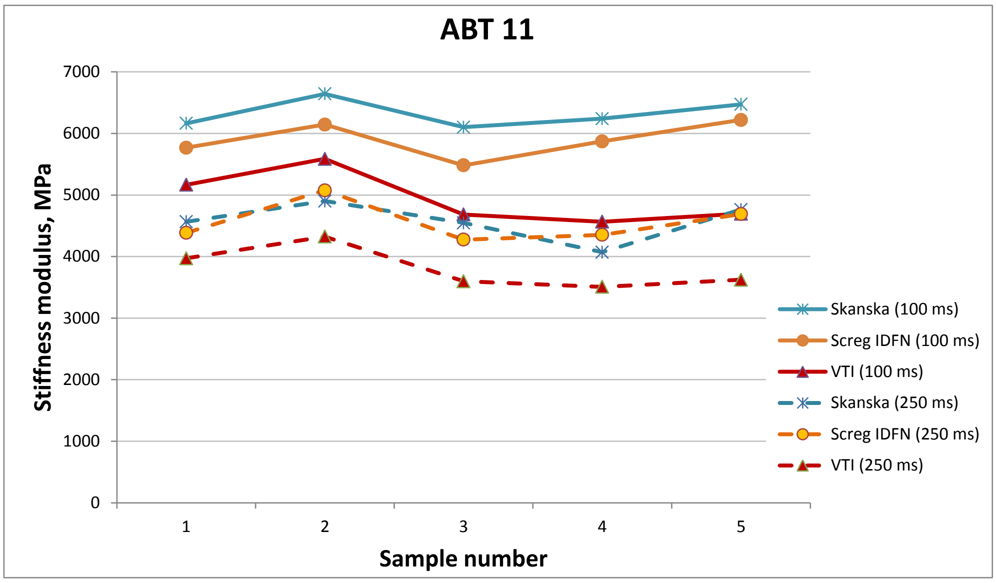

Figure 7: Stiffness modulus of ABT 11 mix at 10°C with 100 and 250 millisecond loading time

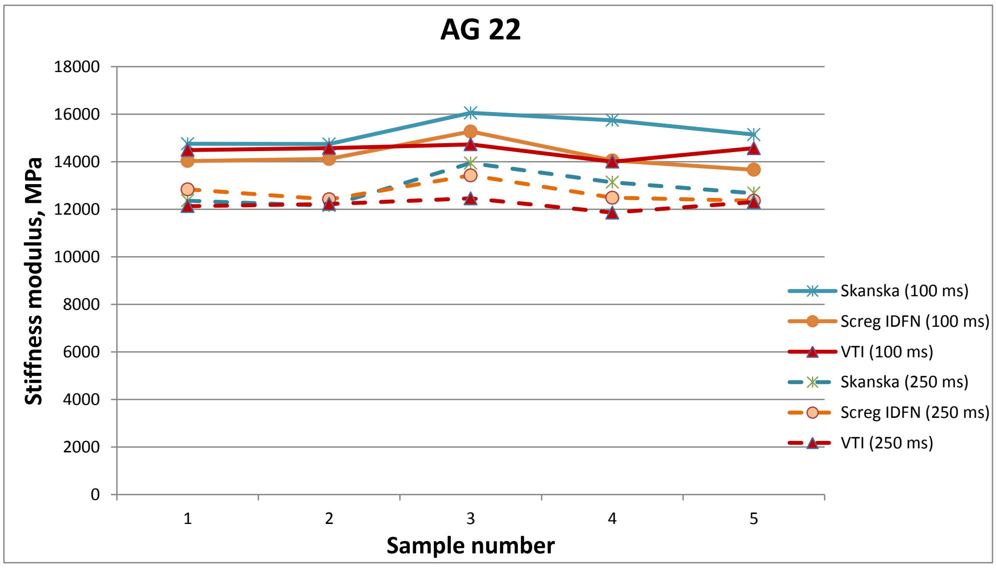

Figure 8: Stiffness modulus of AG 22 mix at 10°C with 100 and 250 millisecond loading time

Table 2: Average stiffness moduli and standard deviation with different loading time

Loading time milliseconds	Stiffness modulus, MPa					
	AG 22			ABT 11		
	Screg IDFN	Skanska	VTI	Screg IDFN	Skanska	VTI
100	14228±610	15290±590	14476±278	5897±297	6324±227	4940±429
250	12708±446	12856±713	12197±222	4556±331	4570±315	3805±339

4.2 Calculation of repeatability and reproducibility

In the first experiment one of the samples in each series were tested three times by each laboratory to calculate repeatability "r" and reproducibility "R". This is in order to eliminate the effect of variation between specimens on the repeatability of the test. The tests were performed at 100 and 250 millisecond loading time as shown in figure 9.
The results were statistically analysed according to Mandel's h (relation between each laboratory deviation from all laboratories' average values and their standard deviation) and Mandel's k (relation between each laboratory standard

deviation and pooled within laboratory standard deviation) (ISO Standard 5725-2). Figure 10 shows that all laboratories' results are acceptable for calculation of precision values in respect of variation between and within laboratories according to ISO Standard 5725-2. The "r" and "R" values can also be interpreted as the relative repeatability and reproducibility relative to the average values of stiffness moduli to make comparisons easier, see Table 3. It is noticeable that the AG22 mix, which has higher stiffness modulus, has significantly lower "r" compared to the ABT mix.

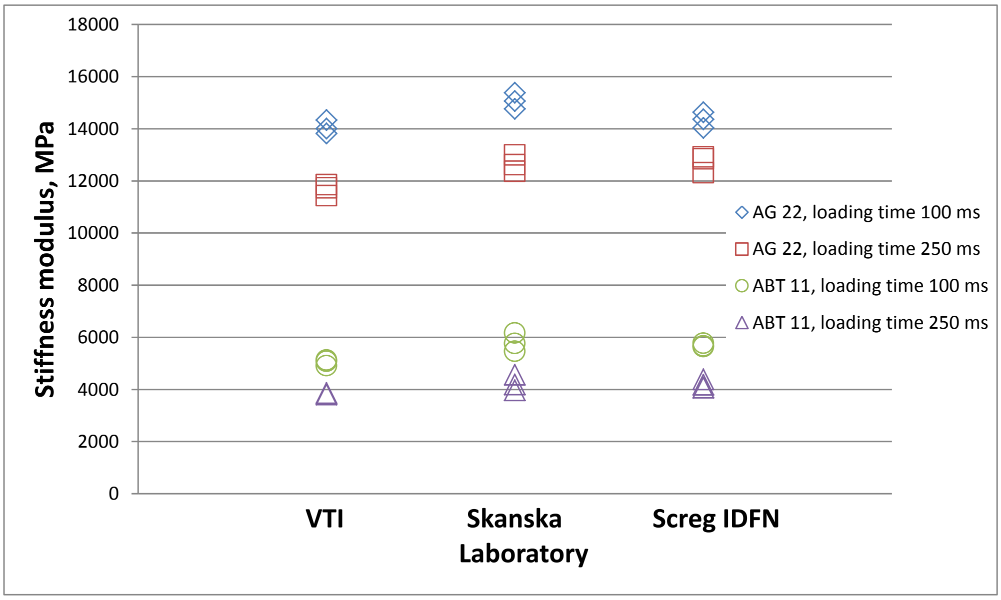

Figure 9: Repeated measurements of the stiffness moduli of the same specimens at each laboratory

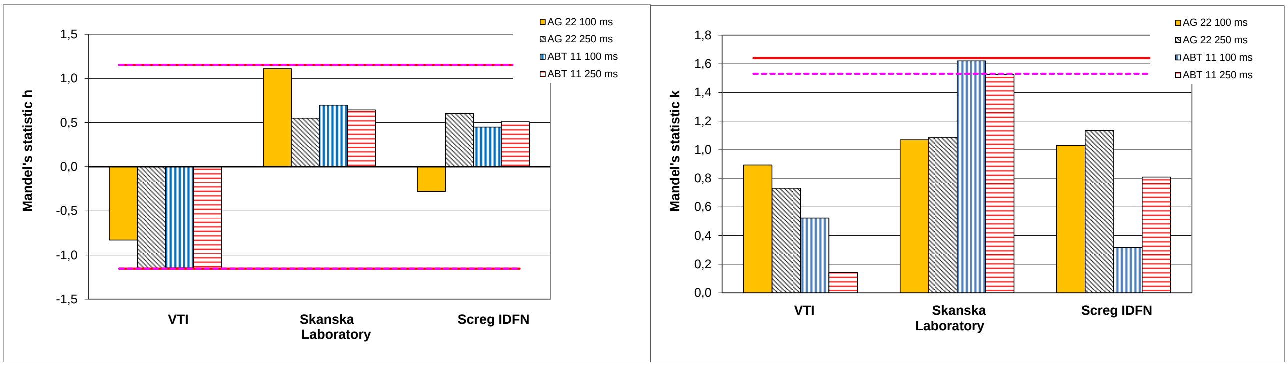

Figure 10: Mandel's h and Mandel's k grouped by laboratories testing the same specimen

Table 3: Relative repeatability and reproducibility when the same sample tested several times

	AG 22 with loading time		ABT 11 with loading time		Average
	100 ms	**250 ms**	**100 ms**	**250 ms**	
r%	5.6	6.7	11.2	13.8	9.3
R%	11.2	14.4	23.0	19.2	16.9

In the second experiment, all samples were assumed to be identical. The results of these measurements are shown in figures 7 and 8. Mandel's h and k are presented in Figure 11 and indicate that all data in this work can be considered in the calculation of the precision values. The relative repeatability and relative reproducibility are presented in Table 4 and show reasonable values.

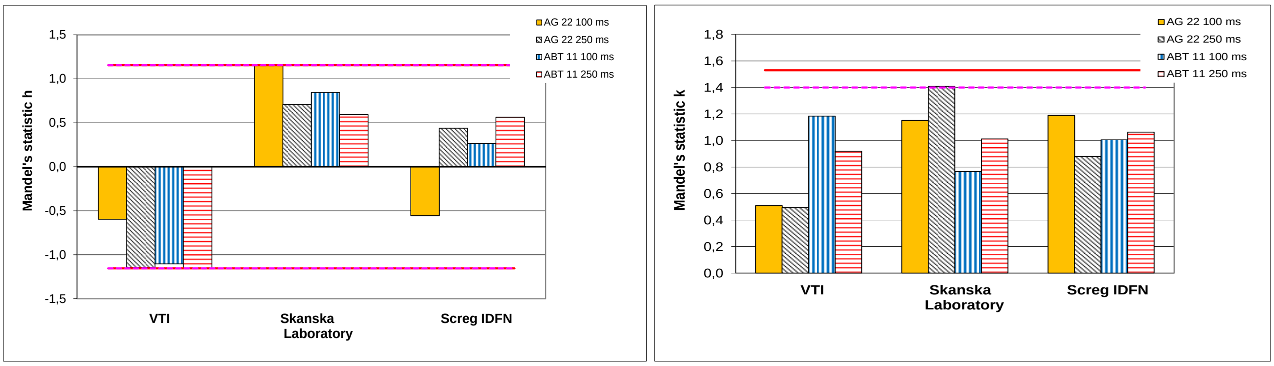

Figure 11: Mandel's h and Mandel's k grouped by laboratories testing five different specimens

Table 4: Relative repeatability and reproducibility when five different specimens were tested

	AG 22 with loading time		**ABT 11 with loading time**		**Average**
	100 ms	**AG 250 ms**	**ABT 100 ms**	**ABT 250ms**	
r%	9.7	11.3	14.4	20.1	13.9
R%	14.7	15.9	38.1	35.3	26.0

4.3 Control of stiffness modulus after round robin test

In order to make sure that the samples had not been damaged at the laboratories, stiffness modulus was also measured at VTI after the specimens had been tested by the participant laboratories. Figure 12 shows the stiffness modulus for both mixes. All samples show almost the same stiffness modulus values before and after circulation to the laboratories.

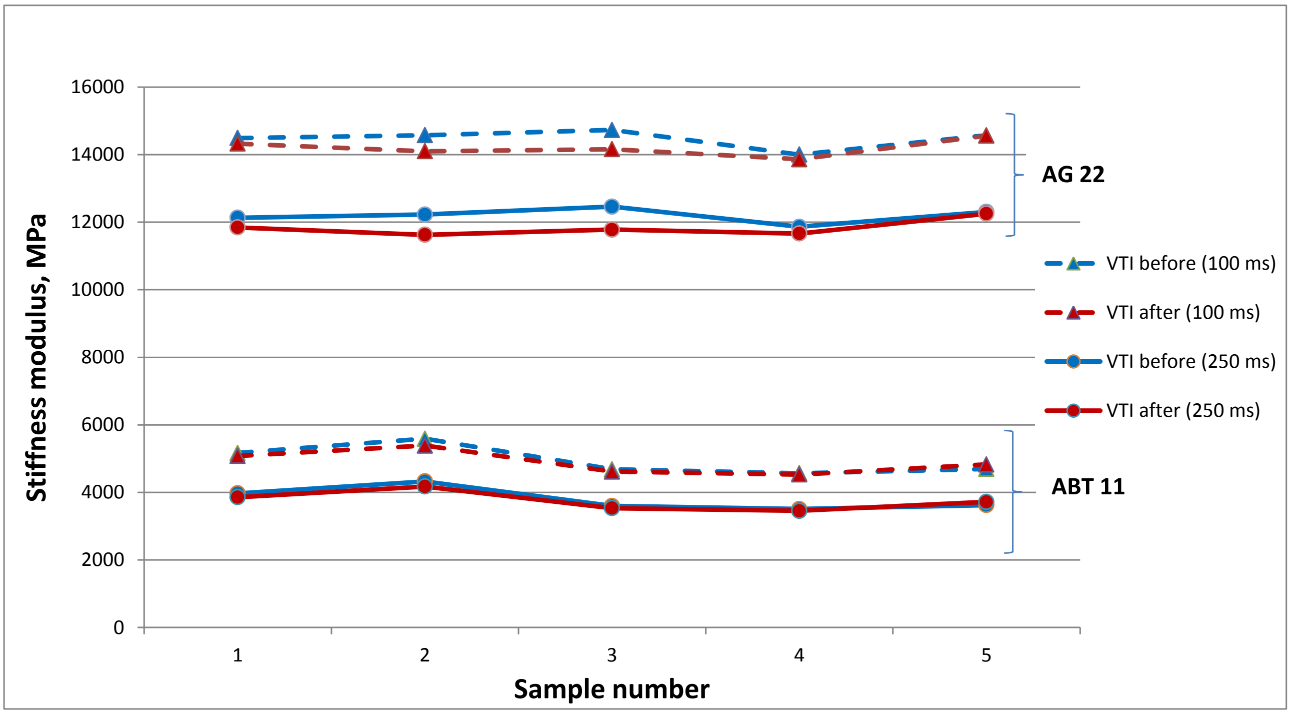

Figure 12: Stiffness modulus tested at VTI before and after circulation of the specimen

5. Conclusion

Regardless of testing equipment there is a good agreement between results when both loading time and strain level were controlled. Increasing the loading time from 100 to 250 milliseconds resulted in a significant decrease in the stiffness moduli. The repeatability and reproducibility of the indirect tensile test were determined and judged to be reliable considering the limited number of participant laboratories.

Acknowledgement

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