Indirect Tensile Test for the Determination of the Stiffness and the Resilient Modulus of Asphalt Concretes: Experimental Analysis of the EN 12697 -26 and the ASTM D 4123 Standards

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ABSTRACT: The results are presented of a laboratory study on the Stiffness and the Resilient Modulus of bituminous mixes determined by the Indirect Tensile Test, conducted according to the EN 12697-26, Annex C and the ASTM D 4123 standards. The testing was performed on high-performance bituminous mixtures, including polymer modified base-binder and wearing course asphalt concretes, stone mastic asphalt and porous asphalt. The course aggregate grading of all the mixtures contains Electric Arc Furnace (EAF) steel slags, up to a maximum content of 45%. The purpose was first of all to analyze quantitatively the controlled strain and the controlled stress loading procedure, that characterize the EN and the ASTM standards respectively, at various temperatures, strain levels, repetition periods and rise times. A second aim was to check the applicability of the above-mentioned regulations to both dense, as well as porous asphalt mixtures. The results of this study demonstrate that the standard controlled strain loading procedure could have limited applicability, dependant on the mix and testing temperatures. The controlled stress loading procedure is necessary to evaluate the asphalt concretes response at extremely low testing temperatures and high loading frequencies. Finally, the Stiffness and the Resilient Modulus give similar results in most cases.

KEY WORDS: Stiffness modulus, resilient modulus, indirect tension test, asphalt concretes.

1 INTRODUCTION

Knowledge of the "stiffness" of bituminous mixtures is obviously a key element for the analysis and "rational" structural design of flexible pavements. Regarding this, a topic of discussion for some time has been which "modulus" is the most appropriate for the mechanical characterisation of asphalt mixes.

Markedly different points of view can be found in the literature, but which in a final analysis all identify the Complex Modulus and Resilient Modulus as the two most suitable parameters for an efficient representation of the stress-strain response of the bituminous mixtures. Some authors (Mamlouk and Sarofim 1988), consider the Resilient Modulus as the most appropriate parameter for the analysis of elastic multi-layer systems; others (Montepara et al. 2003) recognise that the two moduli have separate but complementary roles. In any case, the test protocols on which their determination is based and that are most widely used are the two American ones: ASTM D 3497 Standard for the Complex Modulus, and the ASTM D 4123 standard for the Resilient Modulus.

Within this context, there has been the recent addition of the European EN 12697-26 standard, which should to some extent harmonise the more widely-used test methodologies on this continent. More precisely, this standard describes the determination of what is called the "*Stiffness Modulus*" of bituminous mixtures, according to a series of laboratory test procedures that include a 2 point bending test on trapezoidal or on prismatic specimens (Annex A), 3/4 point bending test on prismatic specimens (Annex B), indirect tension test on cylindrical specimens (Annex C), direct tension-compression test on cylindrical specimens (Annex D) and direct tension test on cylindrical or on prismatic specimens (Annex E).

This paper presents the results of tests aimed at analysing some significant aspects of the determination procedure of the Stiffness Modulus with IT-CY, "Indirect Tension test on CYlindrical specimens", also known as the ITSM test (Indirect Tensile Stiffness Modulus), as described in Annex C of the EN 12697-26 standard and of the Resilient Modulus, as regulated in the ASTM D 4123. Comparisons have also been made between the two procedures, in relation to the most relevant aspect that characterizes and differentiates the two standard: the control of the stress, rather than of the strain.

In the study the authors have assumed the largest precision allowed by the equipments, even beyond that required by the Standards, in order to investigate with the greater possible accuracy all the parameters considered in the research.

For all the Modulus tests conducted, both with the EN standard and with the ASTM standard, a Poisson's ratio has been used of 0.35, independently from the test temperatures.

2 SIGNIFICANCE OF THE STIFFNESS AND OF THE RESILIENT MODULUS

It should firstly be mentioned that the European standard identify the Stiffness Modulus with the absolute value of the Complex Modulus, irrespective of the type of test considered (clause 3.1.1. EN 12697-26 standard). However, a careful analysis of the theoretical-experimental procedures reported in Annex C of the standard shows that this assumption is highly debatable in the case of the IT-CY. The indirect tension procedure imposes the repeated application of vertical load pulses, alternating with a precise rest period (recovery time) in a strain rate controlled mode; the load has a haversine waveform, composed of a semi-sinusoid completed by a different curve that represents the unloading phase, thus making it impossible to create the sinusoidal signal that the EN standard requires for the definition of the Complex Modulus. A further complexity concerning the analysis of the European standard is concerned with the phase angle, which is very important for the evaluation of the Complex Modulus, but there is no mention of its determination in the cited Annex C.

According to Annex C, calculation of the Modulus is based on the average of 5 load pulses, for each of which the Modulus is determined with the well-known equation:

$$S_m = \frac{F(\nu + 0.27)}{z \cdot h} \tag{1}$$

where S_m is the Stiffness Modulus [MPa], F represents the peak value of the applied vertical load [N], z the amplitude of the horizontal deformation obtained during the load cycle [mm], h the mean thickness of the cylindrical specimen [mm] and ν the Poisson's ratio [-]. Given the particular shape of wave used, a strong similarity can be expected between the Stiffness Modulus thus determined and the Resilient Modulus after diametral compression. The Resilient Modulus (R_m) is also computed with Equation 1, but the load, instead of the deformation, is controlled. This similarity was stressed by Brown et al. (Brown and Cooper 1993), who were among the first researchers to work on the test protocol of cyclic indirect tension, with controlled strain rate, on which the EN 12697-26 Annex C and the British DD 213 standards are based. These authors preferred to use the concept of Elastic Stiffness Modulus. This approach, again taken up by Santagata et al. (Santagata and Bassani 1999), is justified by the fact that with the IT-CY, the deformation recoverable at each load pulse is not taken into consideration, but the maximum deformation: it is therefore not conceptually correct to consider the Modulus as "resilient", because the peak horizontal deformation is used and not the recoverable one. Keeping in mind that the level of controlled deformation is low and application time of the load is less than 150 ms, it would appear reasonable to judge the permanent deformation level as insignificant, in particular for medium to low test temperatures ($T \leq 20$ °C), and therefore to use the peak horizontal deformation as being recoverable, recognising in a final analysis that the controlled deformation has a substantially elastic nature (this leads to the *Elastic stiffness modulus* utilised by the above-cited British authors). In the light of these considerations, the Stiffness modulus according to Annex C can therefore be interpreted as more or less a type of Resilient Modulus at diametral compression, whilst pointing out that the controlled stress rate procedure, typical of the above-mentioned ASTM D 4123 standard, is much more widely used for its evaluation.

For both the Stiffness Modulus and the Resilient Modulus, the frequency of the test is of paramount importance. The period (duration) of the cycle that is most often used in the literature (Montepara et al. 2003, Ar-Rabti and Judychi 2000), to which the test frequency is associated, is the repetition time of the pulse, since, for the determination of the Resilient Modulus, the unloading time and rest period are necessary to ensure the effective recovery of the deformation between one load pulse and the next. However, in the ITSM test the focus is on the rise time, defined as the time necessary for the load to reach the peak value, because the Modulus is evaluated in correspondence to the maximum vertical load that determines the controlled deformation; therefore, in order to determine the frequency of the test, it is reasonable to assume a temporal interval equal to 4 times the rise time, as the "virtual" period of the cycle (Pasetto and Baldo 2006). This assumption explains the correspondence established in the EN 12697-26 Annex C, between a rise time of 124 ms and a frequency of approximately 2 Hz. While the ASTM D 4123 standard takes into consideration three different cycle periods (1 s, 2 s, 3 s), which are associated to the fixed rise time of 50 ms, the EN 12697-26 Annex C standard prescribes one fixed pulse repetition time (3 s) and suggests a rise time of 124 ms, but it is allowed to vary this parameter in the range between 50 ms and 150 ms.

Another relevant difference between the two standards is the temperature range that is assumed as reference. The EN standard recommends test temperatures of 2°C, 10°C and 20°C, while the ASTM standard uses as reference temperatures: 5°C, 25°C and 40°C.

3 MATERIALS

In order to verify the suitability of the ITSM and the Resilient test to characterise the stiffness of dense and porous mixes of high performance asphalts, four types of asphalts were analysed, including one High Modulus (HM), one Splitt Mastix Asphalt (SMA), one Porous (PA) and one modified "Wearing Course Asphalt Concrete" (WCAC). The composition of these mixtures have been described in a previous paper by the authors (Pasetto and Baldo 2008). Table 1 reports the principal volumetric (Va, VMA, VFA, bulk density) and mechanical (Marshall Stability and Indirect Tensile strength) characteristics of the mixtures, which were produced using slag from the steel industry in partial place of the aggregate.

Table 1: Volumetric and mechanical properties of asphalt mixes.

Volumetric and Mechanical Properties	Unit	Mixture Type			
		HM	SMA	PA	WCAC
Bulk Density	kg/m^3	2,796	2,532	2,348	2,672
Voids content after compaction	%	4.9	4.9	16.2	3.2
Voids in the Mineral Aggregate	%	17.2	18.6	27.7	16.3
Voids Filled with Bitumen	%	71.6	73.6	41.5	80.4
Marshall Stability	daN	2,637	2,017	868	2,901
Marshall Quotient	daN/mm	730	320	260	438
Indirect Tensile Strength at 0°C	MPa	5.94	5.65	4.30	6.47
Indirect Tensile Strength at 10°C	MPa	4.32	3.78	2.49	4.20
Indirect Tensile Strength at 20°C	MPa	2.71	2.47	1.55	2.46
Optimum Bitumen Content	%	4.5	5.5	5.0	5.0

4 STIFFNESS MODULUS ANALYSIS

In a first step of the investigation, the ITSM tests were conducted at 20°C, in correspondence to three different cycle periods (3 s, 2 s, 1 s) derived from the ASTM D 4123 standard, with the same rise time (125 ms) and the same horizontal deformation (5 µm), in order to clarify specifically the effect of the pulse repetition time.

Table 2 presents the results of the ITSM tests conducted, as well as the percentage differences (Δ) among the Modulus at 3 s and those at 2 s and at 1 s. The Modulus for each mixture were determined as the average of 10 specimens; the standard deviation was never higher than 10%.

Table 2: Stiffness Modulus at 20°C and 125 ms rise time vs cycle repetition period.

Mix Type	Stiffness Modulus [MPa]		
	3 s	2 s	1 s
HM	4,761	4,817	4,881
Δ	-	1.2%	2.5%
SMA	3,892	3,930	3,963
Δ	-	1.0%	1.8%
PA	2,592	2,652	2,767
Δ	-	2.3%	6.8%
WCAC	4,007	4,136	4,190
Δ	-	3.2%	4.6%

All the asphalt concretes show increasing Stiffness Modulus with the decrease of the cycle repetition period, but for each specific bituminous mixture, the differences among the three values are very small, with a maximum variation equal to 6.8%. The Stiffness Modulus is less influenced by the variation of the pulse repetition period then was expected. This is because, in the controlled strain methodologies used in the ITSM, the evaluation of the Modulus is strictly related to the rise time and therefore, the pulse repetition period and the effective duration of the rest time is considered of lower relevance.

With respect to the response of the mixtures, it seems that the porous asphalt is more sensitive to the variation of the pulse repetition period; from the dense bituminous mixtures, the WCAC mix is most affected by the increments of the frequency.

In a second step of the laboratory trials, the Stiffness Moduli were determined at three different temperatures (0 °C, 10 °C and 20 °C). At each temperature the stiffness of the asphalt mixtures was evaluated in correspondence to four different rise times, with the same horizontal deformation (5 μm). The rise times of 50 ms, 100 ms, 125 ms and 150 ms used in the tests correspond to frequencies of 5 Hz, 2.5 Hz, 2 Hz and approx. 1.7 Hz, while maintaining the pulse repetition period constant at 3 s.

Table 3 presents the results of the ITSM tests conducted; the percentage differences (Δ) between the Modulus at 150 ms and those at 50 ms, at 100 ms and at 125 ms are also reported. The values of the Modulus for each mixture were evaluated as the average of 3 specimens; the standard deviation have never been greater than 10%.

Table 3: Influence of the rise time on Stiffness Modulus at three Temperatures.

Mix Type	**Stiffness Modulus [MPa]**											
	Temperature 0°C				**Temperature 10°C**				**Temperature 20°C**			
	50ms	**100ms**	**125ms**	**150ms**	**50ms**	**100ms**	**125ms**	**150ms**	**50ms**	**100ms**	**125ms**	**150ms**
HM	24,378	23,153	22,589	22,057	14,661	13,082	12,241	11,847	5,380	4,833	4,761	3,828
Δ	10.5%	5.0%	2.4%	-	23.8%	10.4%	3.3%	-	40.5%	26.3%	24.4%	-
SMA	22,868	21,859	21,406	20,694	12,115	10,781	10,240	10,014	5,135	4,188	3,892	3,641
Δ	10.5%	5.6%	3.4%	-	21.0%	7.7%	2.3%	-	41.0%	15.0%	6.9%	-
PA	16,879	16,062	15,595	15,379	9,159	7,990	7,794	7,426	3,911	3,142	2,592	2,513
Δ	9.8%	4.4%	1.4%	-	23.3%	7.6%	5.0%	-	55.6%	25.0%	3.1%	-
WCAC	24,024	22,514	22,033	21,588	13,216	11,477	10,951	10,678	5,476	4,213	4,007	3,746
Δ	11.3%	4.3%	2.1%	-	23.8%	7.5%	2.6%	-	46.2%	12.5%	7.0%	-

The ITSM test could evaluate the stiffness of all the mixtures analysed in all the test conditions used, even in those not included in Annex C, such as the temperature of 0 °C. Through a careful check of the so-called "load area factor", defined as the ratio between the area subtended by the first quarter-wave of the load-time graph and the product of the rise time and peak load, it was verified that for these particular test conditions the wave shape was not anomalous (with values of the above-mentioned factor between 0.5 and 0.7).

Comparing the data reported in the Tables 2 and 3, it is possible to note how, for all the mixtures, with reference to the temperature of 20°C, the Stiffness Modulus variation corresponding to the reduction of the pulse repetition period from 3 s to 1 s, for a rise time fixed at 125 ms, is largely lower to that obtainable assuming a constant value for the pulse repetition period equal to 3 s and diminishing the rise time from 150 ms to 50 ms. In other words, the test frequency affects the Stiffness Modulus much more if it is caused by a rise time variation, compared to a pulse repetition period variation.

The Modulus increment related to a reduction of the rise time, is larger at the highest temperature; depending on the type of mixture, the stiffness variations are around 10% at 0°C, whilst they are above 40% at 20°C.

5 RESILIENT MODULUS ANALYSIS

Annex C of the EN standard does not include the controlled stress rate configuration of the indirect tension test, which is instead typical of test protocols like the ASTM D 4123, in which the diametral compression load remains constant. Different approaches are possible for establishing the most suitable stress level for the evaluation of the Resilient Modulus. ASTM D 4123 prescribes that the load may vary between 10% to 50% of the indirect tensile strength, whereas some researchers, such as Said (Said, 1990), suggest studying the Stress – Strain ratio, focussing attention on its linear part. In this study it was decided to follow the indications of the ASTM D 4123 standard regarding the loading levels, using two stress values, respectively 10% and 40% of the indirect tensile strength (R_t), as well as the rise time (50 ms) and the loading frequencies, with three pulse repetition periods (3 s, 2 s, 1 s). Instead, the test temperature range has been assumed equal to that used for ITSM investigation, for the lower loading level, in order to allow comparison between the Moduli determined with the two standard; for the higher stress level, the tests have been done only at 20°C.

Table 4 and 5 show the results of the Resilient tests conducted at a stress level of 10% and 40% respectively of the indirect tensile strength, as well as the percentage differences (Δ) among the Modulus at 3 s and those at 2 s and at 1 s. The Moduli for each asphalt concrete were determined as the average of 3 specimen tests; the standard deviation was always below 10%.

Table 4: Resilient Modulus at 10% R_t vs Temperatures according to cycle repetition period variations.

Mix Type	**Resilient Modulus [MPa]**								
	Temperature 0°C			**Temperature 10°C**			**Temperature 20°C**		
	3 s	**2 s**	**1 s**	**3 s**	**2 s**	**1 s**	**3 s**	**2 s**	**1 s**
HM	24,833	25,096	25,245	15,029	15,116	15,177	5,623	5,644	5,742
Δ	-	1.1%	1.7%	-	0.6%	1.0%	-	0.4%	2.1%
SMA	23,622	23,766	23,878	12,645	12,786	12,914	5,305	5,334	5,406
Δ	-	0.6%	1.1%	-	1.1%	2.1%	-	0.5%	1.9%
PA	18,239	18,576	18,596	10,018	10,051	10,090	4,128	4,132	4,278
Δ	-	1.8%	2.0%	-	0.3%	0.7%	-	0.1%	3.6%
WCAC	25,054	25,235	25,948	13,687	13,737	13,889	5,665	5,724	5,740
Δ	-	0.7%	3.6%	-	0.4%	1.5%	-	1.0%	1.3%

Table 5: Resilient Modulus at 40% R_t and 20°C vs cycle repetition period.

Mix Type	**Resilient Modulus [MPa]**		
	3 s	**2 s**	**1 s**
HM	4,214	4,243	4,263
Δ	-	0.7%	1.2%
SMA	3,780	3,788	3,789
Δ	-	0.2%	0.2%
PA	3,273	3,278	3,293
Δ	-	0.2%	0.6%
WCAC	4,563	4,569	4,589
Δ	-	0.1%	0.6%

Obviously, for both the stress levels, the cycle repetition period reduction produces an increase of the Resilient Modulus; however this increment results quite small (maximum variation lower than 4%) independently from the temperature investigated. This experimental result is particularly evident at the higher stress level, for which the Resilient Modulus increment is no more large than 1%. Moreover, the amplitudes of the Resilient Modulus variations are basically equivalent for all the mixtures studied; no one of them show a large sensitivity to test frequency increments.

Table 6 presents the comparison between the Resilient Modulus values determined for stress levels equal to 40% and 10% of the R_t, for the same rise time (50 ms) and the same temperature (20°C). For all the frequencies it is possible to note that the percentage difference (Δ) can not be neglected, varying from a minimum of 24.2% to a maximum of 42.7%, depending to the type of mixture; especially the sensitivity of the SMA mix results are more pronounced. Therefore, it is extremely important to assume a proper stress level for a reliable determination of the asphalt concretes stiffness. This should also be checked at the other temperatures.

Table 6: Comparison between Resilient Modulus at 40% R_t and 10% R_t at 20°C and 50 ms rise time according to cycle repetition period variations.

Mix Type	Resilient Modulus [MPa]					
	3 s		2 s		1 s	
	40%Rt	10%Rt	40%Rt	10%Rt	40%Rt	10%Rt
HM	4,214	5,623	4,243	5,644	4,263	5,742
Δ	-	33.4%	-	33.0%	-	34.7%
SMA	3,780	5,305	3,788	5,334	3,789	5,406
Δ	-	40.3%	-	40.8%	-	42.7%
PA	3,273	4,128	3,278	4,132	3,293	4,278
Δ	-	26.1%	-	26.1%	-	29.9%
WCAC	4,563	5,665	4,569	5,724	4,589	5,740
Δ	-	24.2%	-	25.3%	-	25.1%

Tables 7 and 8 report the horizontal resilient strain values induced by stress levels equal to 10 % and 40% of the R_t, respectively. Obviously, for the higher stress level, the resilient strain results are always much larger and for the high modulus asphalt, they are really close to the maximum threshold of 25 µm allowed by the ASTM standard; for the SMA mix, the values are a bit above this threshold.

Table 7: Horizontal resilient strain at 10% R_t vs Temperatures according to cycle repetition period variations.

Mix Type	Horizontal resilient strain [µm]								
	Temperature 0°C			Temperature 10°C			Temperature 20°C		
	3 s	2 s	1 s	3 s	2 s	1 s	3 s	2 s	1 s
HM	2.36	2.33	2.32	2.84	2.82	2.81	4.78	4.76	4.68
SMA	2.42	2.38	2.39	2.97	2.93	2.90	4.62	4.59	4.53
PA	1.16	1.14	1.13	1.21	1.20	1.21	3.71	3.71	3.58
WCAC	2.52	2.54	2.46	3.03	3.02	2.99	4.31	4.27	4.28

Table 8: Horizontal resilient strain at 40% R_t and 20°C vs cycle repetition period.

Mix Type	Horizontal resilient strain [µm]		
	3 s	2 s	1 s
HM	24.95	24.74	24.58
SMA	25.68	25.64	25.61
PA	17.49	17.48	17.40
WCAC	21.22	21.18	20.98

5 COMPARISON BETWEEN THE STIFFNESS AND THE RESILIENT MODULUS

Table 9 presents, for the temperatures investigated, the comparison among the Stiffness (Sm) and the Resilient Modulus (Rm) evaluated at 10% R_t; both Moduli have been determined for a rise time and a cycle repetition period, equal to 50 ms and 3 s, respectively.

As would be expected, given the visco–elastic nature of the mixtures, the Stiffness Modulus, as well as the Resilient Modulus, increase at lower temperature. The Resilient Modulus is a little bit higher than the Stiffness Modulus; however the maximum variation is lower than 10%. Both Moduli are much greater for the dense mixtures than for the porous ones.

Table 9: Stiffness and Resilient Modulus vs Temperatures at 50 ms rise time and 3 s cycle repetition period.

Mix Type	**Temperature 0°C**		**Temperature 10°C**		**Temperature 20°C**	
	Sm [MPa]	**Rm [MPa]**	**Sm [MPa]**	**Rm [MPa]**	**Sm [MPa]**	**Rm MPa]**
HM	24,378	24,833	14,661	15,029	5,380	5,623
Δ	-	1.9%	-	2.5%	-	4.5%
SMA	22,868	23,622	12,115	12,645	5,135	5,305
Δ	-	3.3%	-	4.4%	-	3.3%
PA	16,879	18,239	9,159	10,018	3,911	4,128
Δ	-	8.1%	-	9.4%	-	5.5%
WCAC	24,024	25,054	13,216	13,687	5,476	5,665
Δ	-	4.3%	-	3.6%	-	3.5%

From Tables 7 and 8 it can be seen that the resilient strains amplitude at 10% of the R_t, is always lower than 5 µm, as prescribed in the ITSM procedure; whereas this threshold is largely exceeded for the higher stress level.

In order to establish an experimental relationship between the two Moduli, useful for the determination of the Resilient one, given a known Stiffness, a regression analysis of the Modulus data reported in Table 9 has been performed, using a linear model of the type:

$$R_m = a \cdot S_m + b \quad (2)$$

where R_m is the Resilient Modulus, S_m is the Stiffness Modulus, a and b are regression coefficients depending on the type of material. In Table 10 the regression coefficients and the coefficient of determination R^2 are given.

Table 10: Stiffness and Resilient Modulus regression parameters at 50 ms rise time and 3 s cycle repetition period.

Mixture	**a [-]**	**b [MPa]**	**R^2**
HM	1.0111	+190.360	0.9999
SMA	1.0319	+57.978	0.9999
PA	1.0864	-50.557	0.9998
WCAC	1.0457	-88.057	0.9999

To quantify and compare the effect of temperature on the value of the Modulus, a Stiffening Index was determined defined as an increase of the Stiffness Modulus or the Resilient Modulus in correspondence to a unitary reduction in temperature.

Tables 11 and 12, related to the Stiffness Modulus and to the Resilient Modulus respectively, show that this Index assumes markedly higher values in the 10 °C ÷ 0 °C range, compared to the 20 °C ÷ 10 °C range, for all mixes and both the Modulus, thus demonstrating that at low temperatures, an error in the test temperature can cause much greater Modulus variations (therefore errors in its determination) than those obtained at medium temperatures.

Table 11: Stiffening Index vs. Rise Time (Stiffness Modulus increasing at steps of 1 °C).

Mix Type	**Stiffening Index [MPa/°C]**							
	ΔT = 10°C ÷ 0°C				**ΔT = 20°C ÷ 10°C**			
	50ms	**100ms**	**125ms**	**150ms**	**50ms**	**100ms**	**125ms**	**150ms**
HM	972	1,007	1,035	1,021	928	825	748	802
SMA	1,075	1,108	1,117	1,068	698	659	635	637
PA	772	807	780	795	525	485	520	491
WCAC	1,081	1,104	1,108	1,091	774	726	694	693

Table 12: Stiffening Index vs. Rise Time (Resilient Modulus increasing at steps of 1 °C).

Mix Type	**Stiffening Index [MPa/°C]**					
	ΔT = 10°C ÷ 0°C			**ΔT = 20°C ÷ 10°C**		
	3 s	**2 s**	**1 s**	**3 s**	**2 s**	**1 s**
HM	980	998	1,007	941	947	944
SMA	1,098	1,098	1,096	734	745	751
PA	822	853	851	589	592	581
WCAC	1,137	1,150	1,206	802	801	815

All the mixtures display a substantially unvaried thermal susceptibility with the rise times in the 10 °C ÷ 0 °C range, whilst in the 20 °C ÷ 10 °C range, a unitary variation in temperature shows more change in the Stiffness Modulus with the lowering of the rise time, i.e., at higher temperatures, the dynamic response at high frequencies, evaluated with the ITSM, is more sensitive to errors in the test temperature, compared to that at low frequencies. Instead, the Stiffening Index expressed by the Resilient Modulus, is basically constant with the cycle repetition period, for both the temperatures range, in which therefore, the American procedure appears less influenced, than the European one, from errors in the test temperature, both at high and low frequencies.

6 CONCLUSIONS

Annex C of the EN 12697-26 standard and ASTM D 4123, describe a cyclic indirect tension test protocols for determination of the Stiffness and the Resilient Modulus respectively, which the results of the studies conducted have confirmed as being flexible procedures that can efficiently characterise the mechanical response of both porous and dense bituminous mixtures, over a wide range of temperatures and frequencies. The possibility has also been successfully verified of establishing an experimental relationship among the two Modulus.

The Stiffness Modulus is more sensitive to the rise time than to the cycle repetition period. This confirms the major relevance given by EN Standard to the rise time.

In the ASTM procedure, the stress level is of paramount importance for the evaluation of the Resilient Modulus. Moreover, although necessitating more testing, the controlled stress approach offers the possibility of a more detailed characterisation of the mechanical behaviour of the mixtures.

Quite similar results for the Stiffness Modulus and for the Resilient Modulus have been obtained using, in the ASTM procedure, the lowest stress level.

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