Evaluation of tools for measuring the workability of bituminous asphalts

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ABSTRACT

Since the beginning of 2000's, the development of WMA, Warm Mix Asphalt, allowed the Road companies to meet expectations regarding sustainable development by lowering the fabrication and laying temperatures (reduction of 30 to 50°C). However, this development also highlighted, on the jobsite, an unidentified problem with HMA, Hot Mix Asphalt: a lesser workability during mechanized and especially manual laying, for several WMA processes.

This experimentation, part of research thesis results, aims to study the development of a relevant and discriminating test for the evaluation in laboratory of the workability of bituminous asphalt. Two ways were explored; the one uses a classic equipment of road laboratories, the GSC, Gyratory Shear Compactor test, by varying the parameters (vertical strength, rotation speed); the other one is based on the use of the workability device called "Nynas", from now European standardized, with varied parameters. The work was conducted on the same classic asphalt formula with different bitumen grades, and variable temperatures of manufacturing. This parametric study allowed, first of all, to confirm the reduction in workability of asphalts with the reduction in the temperature of manufacturing. It showed the limits of the GSC, a very good test for compactibility but not for workability of asphalt. It also highlighted the interest of the Nynas workability device after a good choice of test parameters for a real relevance of the test result.

Keywords: Gyratory, Physical properties, Warm Asphalt Mixture, Workability

1. INTRODUCTION

In European countries, many road industries have used the technologies of Warm Mix Asphalt (WMA), to reduce the temperatures at which asphalt are mixed, laidand compacted, from 30 to 50°C. But the development of these WMA created a workability issue that was not so much important in the case of conventional Hot Mix Asphalt (HMA), especially during manual implementation, largely due to the viscous properties of bituminous binders and their thermal susceptibility.
To develop warm mix technologies and additives that assure a good workability of asphalt in spite of mixing and laying temperatures reduction, it is necessary to develop a laboratory procedure to characterize this workability property. An important work described in NCHRP Report 691 [1] has synthesized several possible devices that could assess asphalt mixtures workability.
The purpose of this study is to compare two testing devices and to evaluate their ability to characterize the workability of asphalt: the Gyratory Shear Compactor, varying its standard parameters, and the Nynas Workability Device.

2. LABORATORY TESTS USED AND MATERIALS

2.1 Gyratory Shear Compactor test

The Gyratory Shear Compactor (GSC) is an essential tool to formulate bituminous mixtures and measure their compactibility properties, because it is sensible to their granular formula and their binder content [2]. It allows measuring voids content and shear strength according to the rotation number. Nevertheless, many published studies [3] [4] illustrate the fact that the GSC test is insensible to mixing and testing temperatures reduction, and so is insensible to workability differences.
A large part of the experimental study was conducted with a French GSC manufactured by Vectra. The parameters recommended for use according to NF EN 12 697-31standard are a vertical force F of 11.7 kN, a rotation speed of 30 rpm, an inclination angle α of 1° and three specimens tested for one GSC test.
The vertical force of the GSC may be changed varying the gauge pressure. The gauge calibration is presented in Table 1. As regards rotation speed, it may be changed with a potentiometer from 3 to 30 rpm.

Table 1: GSC gauge calibration

Gauge Pressure [bar]	Vertical force [kN]
30	11.70
25	10.22
20	8.33
15	6.46
10	4.54
5	2.67
4	2.27
3	1.95

2.2 Nynas Workability Device test

The Nynas workability device test was developed to characterize the workability of Cold Mix Asphalt (CMA) and has recently been standardized for its use on CMA, WMA and HMA (NF EN 98-258-1). It measures the strength needed to spread an asphalt mix sample, simulating the mechanized and manual laying on a road work [5].
The Nynas workability device (Picture 1) used in the study was manufactured by the French company ICS (Instrumentation Contrôle Service) according to the standard. The model used is equipped with several jacks that allow to perform tests at various speeds from 0.01 to 4 cm/s, and with two molds, a large one (6600 cm^3 containing approximately 11 kg of asphalt mixture) and a smaller one (3300 cm^3 for a specimen of approximately 5 kg).
In a previous study [6], the influence of several parameters of the Nynas workability device test has been analyzed, and two experiment procedures have been developed: the first one keeping a constant volume leveling the asphalt (according to NF EN 98-258-1 standard), and the second one keeping constant mass and volume regardless of the temperature, to test every specimen at constant density. The second procedure (constant density) was chosen here.

Picture 1: Nynas Workability Device (ESTP-IRC)

2.3 Experimental materials

The asphalt mix used in this study is a classic semi-coarse asphaltic concrete 0/10 (French BBSG 0/10), with diorite aggregates coming from the French Noubleau quarry and Total bituminous binders. As regards the binders, two bitumen manufactured by Total and having different grades were used: a classic bitumen 35/50 and a softer one 160/220 (Table 2).

Table 2: bitumen characteristics

	35/50 binder	**160/220 binder**
Penetration (25°C) (1/10 mm)	43	188
Ring & Ball Point (°C)	52.4	40.8

Two warm mix technologies were used. The first one is a viscosity reducer (a wax) developed by the French company Eurovia and added to the mixture with 35/50 bitumen at a dosage rate of 0.3%. The second one is a surfactant compound CecaBase.

Afterwards, the four asphalt mixes tested will be named in this way:

- Mixture 1: with pure 35/50 binder
- Mixture 2: with pure 160/220 binder
- Mixture 3: with 35/50 binder + viscosity reducer (0.3%)
- Mixture 4: with 35/50 binder + surfactant additive (0.3%)

3. GYRATORY SHEAR COMPACTOR TEST AND RESULTS

3.1 Test parameters

A first experimental study was conducted to determine the influence of the GSC parameters, vertical force and rotation speed, on the voids content measure. For that, mixture 1 is tested with these parameters:

- Two mixing and testing temperatures: 110 °C and 160°C
- Two vertical forces: 11.7 kN (30 bar) and 1.95 kN (3 bar)
- Two rotation speeds: 30 and 3 rpm

The results obtained (mean of 3 trials) are shown in Figures 1 and 2 and in Table 3. Every single test was conducted until 100 gyrations, but only the first ten are relevant to appreciate workability differences.

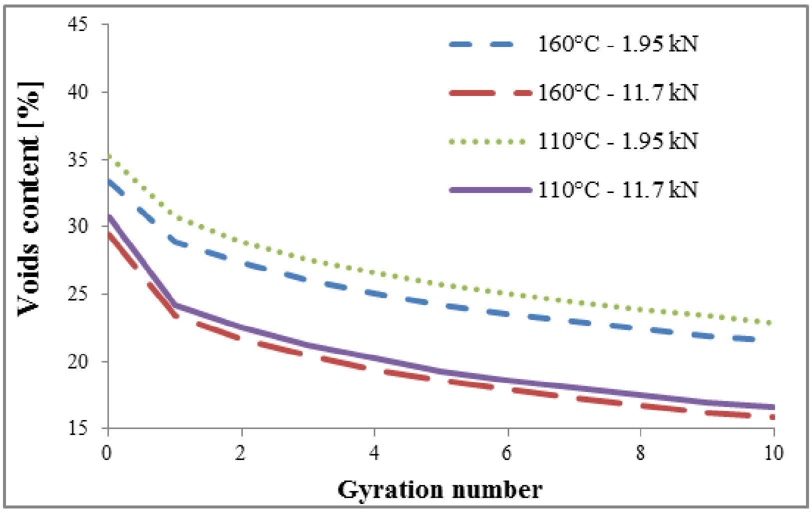

Figure1: GSC tests varying the vertical force, at 30 rpm

Table 3: Difference between voids content at 160°C and 110°C, according to the vertical force, at 30 rpm

Gyration number	Difference between 160 and 110°C at 11.7 kN	Difference between 160 and 110°C at 1.95kN
1	0.8	1.8
2	0.8	1.6
3	0.8	1.6
4	0.8	1.6
5	0.8	1.5
10	0.8	1.4

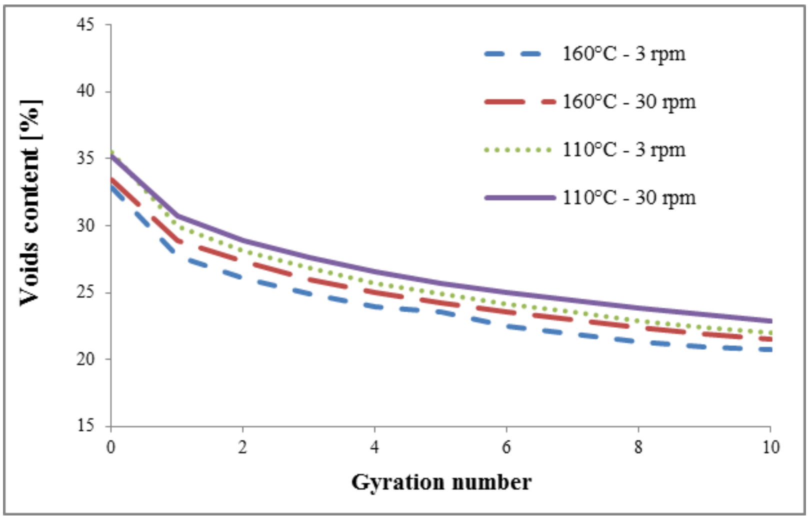

Figure2: GSC tests varying the rotation speed, at 1.95 kN

A difference of the voids content measured is noticed between the two vertical forces (Figure 1): the level of compaction is higher at 11.7 kN than at 1.95 kN. The difference betweentests at 160°C and 110°C is higher at 1.95 kN (3 bar) than at 11.7 kN (30 bar). At 1.95 kN, this gap is higher than the GSC test repeatability recommended by NF EN 12 697-31 standard (repeatability = 1%).But whatever its value, for a same vertical force, the difference in void content at 160°C and 110°C is constant at the various levels of gyrations: we can suppose that the vertical force causes immediately a good compaction on the bulk asphalt (%void between 30 and 35%) and then the pre-compacted asphalt isn’t sensitive to the level of vertical force.
The gap between 160°C and 110°C tests is a little higher at 3 rpm than at 30 rpm (Figure 2).

To test the various mixtures, we chose to lower the vertical force and the rotation speed of the GSC to their minimum (1.95 kN and 3 rpm), to escape the compactibility field and get into the workability one.

3.2 Voids content

3.2.1 Impact of the temperature

GSC tests are conducted on mixture 1, with the new parameters chosen (vertical force of 1.95 kN and rotation speed of 3 rpm), varying the temperature. The results obtained are illustrated in Figure 3.
The void content at gyration number -1 represents the void content of the mixture sample just poured into the mold, before putting the mold into the GSC and applying the preload. This void content has been measured manually. The void content at gyration number 0 represents the void content of the sample after applying the preload (15 N). This preload could not be changed on the GSC. From the gyration number 1, the GSC test begins.

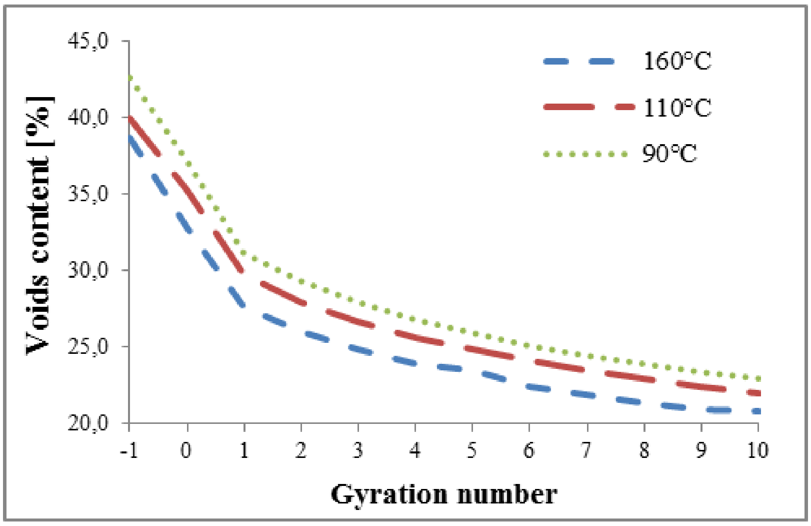

Figure3: GSC tests on mixture 1, at 3 rpm and 1.95 kN, varying the temperature

Figure 3 shows logical results: the void content is higher when the temperature is lower. But even if the gap between tests at 160°C and 110°C is higher than 1% (repeatability according NF EN 12 697-31 standard), it remains low(less than 2.5%). This gap is not enough to characterize the workability differences between mixture 1 at 160 and 110°C observed during the laboratory experiments.
The same conclusion may be drawn from the tests at 160°C and 90°C: the gap is lower than 4.5%, nevertheless mixture 1 at 90°C has a much lower workability than at 160°C, as will show the Nynas device test.

3.2.2 Impact of the mixture

Three different mixtures are tested at the three temperatures (160, 110 and 90°C). In Figures 4, 5 and 6 are shown the results obtained at 160, 110 and 90°C.

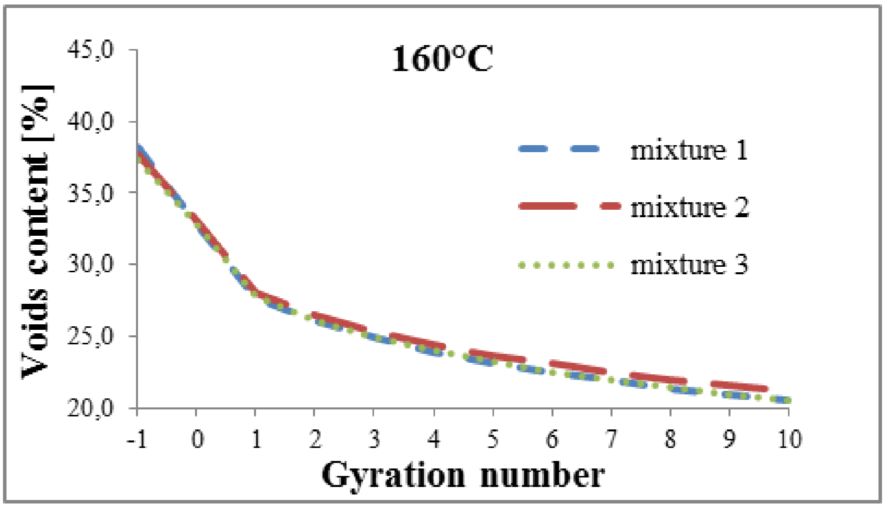

Figure4: GSC tests on mixture 1, 2 and 3, at 3 rpm, 1.95 kN and 160°C

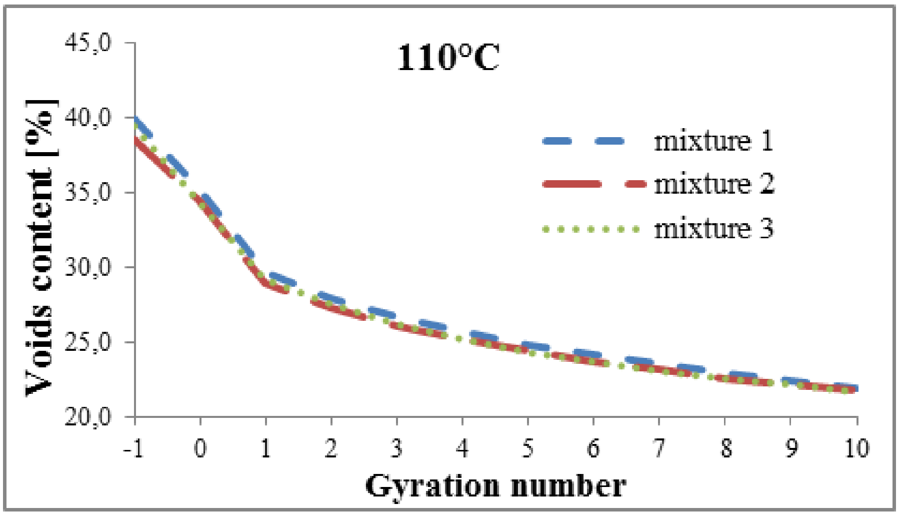

Figure5: GSC tests on mixture 1, 2 and 3, at 3 rpm, 1.95 kN and 110°C

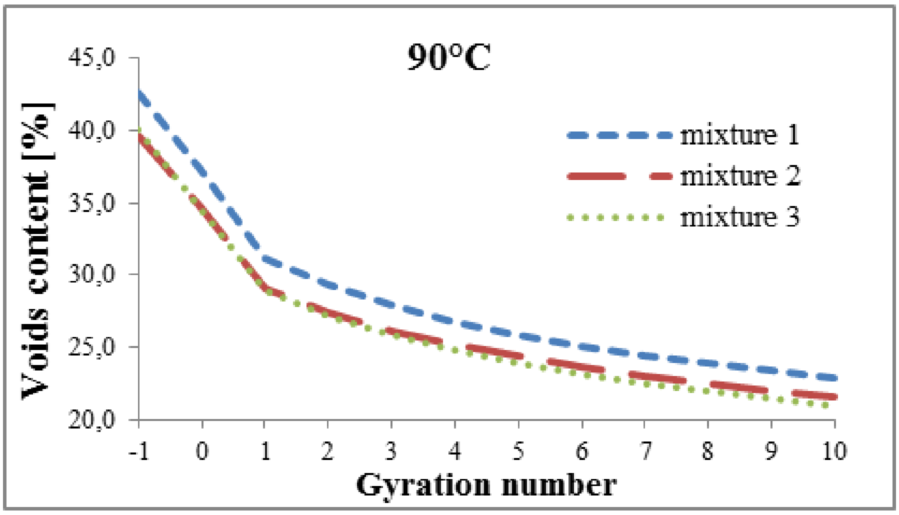

Figure6: GSC tests on mixture 1, 2 and 3, at 3 rpm, 1.95 kN and 90°C

At 160 and 110°C, the evolution of the void content is nearly the same for the three mixtures, whereas mixture 1 (with 35/50) is largely less workable than mixtures 2 and 3 at 110°C.
The curves at 90°C show a certain gap between mixture 1 and mixtures 2 and 3, but this gap is lower than 3% and so insufficient to characterize the workability differences observed during the laboratory experiments.

3.3 Shear strength

During every GSC tests, the shear strength applied to the samples was measured and analyzed for the first 11 gyrations. The shear strength at gyration number 0 represents the shear strength on the sample after applying the preload (15 N). From the gyration number 1, the GSC test has begun. Figure 7 shows the results obtained for mixture 1 according to the testing temperatures. There is no mention of the shear strength and the precision of its measure in NF EN 12 697-31 standard.

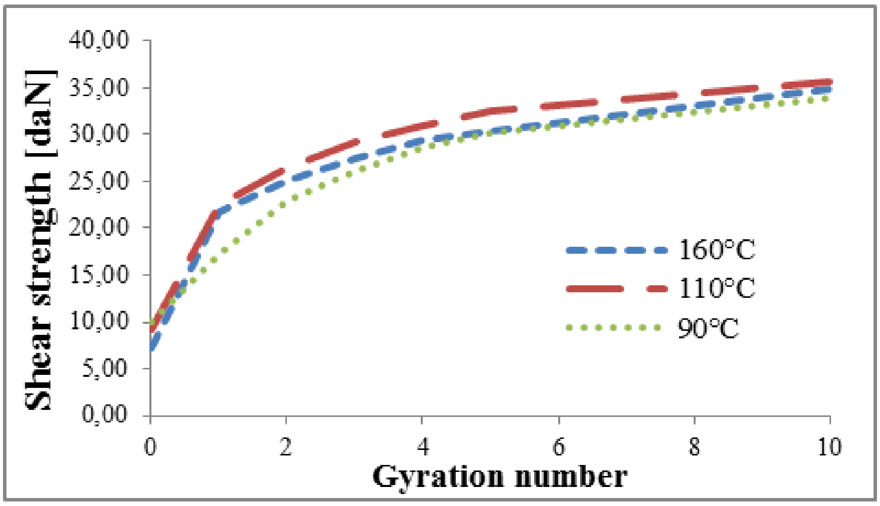

Figure7: Shear strength evolution during GSC tests on mixture 1, at 3 rpm and 1.95 kN, varying the temperature

The shear strength curves shown on Figure 7 do not allow a classification of the tested samples in terms of workability. Indeed, the shear strength applied on the specimen at 90°C is lower than the one applied at 110°C or 160°C, while mixture 1 is less workable at 90°C than at 110°C and 160°C.
If the shear strength measured was a workability criterion, it should be significantly lower at 160°C than at 110°C and 90°C, for mixture 1 (with 35/50 binder and without warm mix additive).
Figure 8 gives the evolution of shear strength for the three mixtures at 110°C. The results obtained at 110°C are almost the same for the three mixtures while mixture 1 is less workable than mixtures 2 and 3 at 110°C.

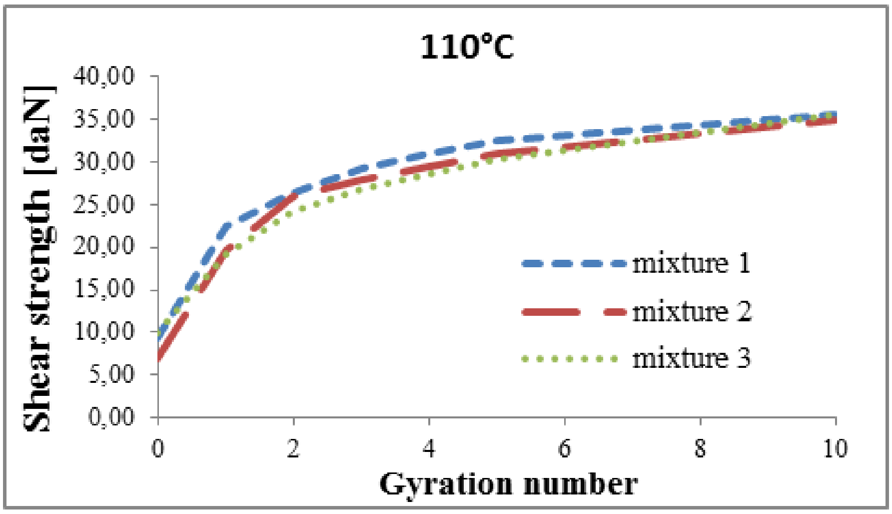

Figure8: Shear strength evolutions during GSC tests on mixtures 1, 2 and 3, at 3 rpm, 1.95 kN and 110°C

4. NYNAS WORKABILITY DEVICE TEST AND RESULTS

4.1 Test parameters

As said before, the Nynas device used in this study is equipped with several jacks that allow to perform tests at various speeds from 0.01 to 4 cm/s, and with two molds, a large one (6600 cm^3 containing approximately 11 kg of asphalt mixture) and a smaller one (3300 cm^3 for a specimen of approximately 5 kg). Every Nynas Device test shown in this paper was conducted keeping constant mass and volume regardless of the temperature, to test every specimen at constant density, and every result is the average of four tests.

NF EN 98-258-1 standard recommends conducting the test at 1 cm/s in the small or large mold. With a preliminary study, we chose to see the effect of speed by varying it and the influence of the mold's size. After that, we determined the parameters (speed and mold size) that would be chosen to test the various mixtures.
For that, mixture 1 is tested with these parameters:

- Four mixing and testing temperatures: 90, 110, 130 and 160°C
- Three speeds: 0.1, 1 and 3 cm/s
- Two mold size: 3300 and 6600 cm^3.

The results are shown in Figures 9 and 10.

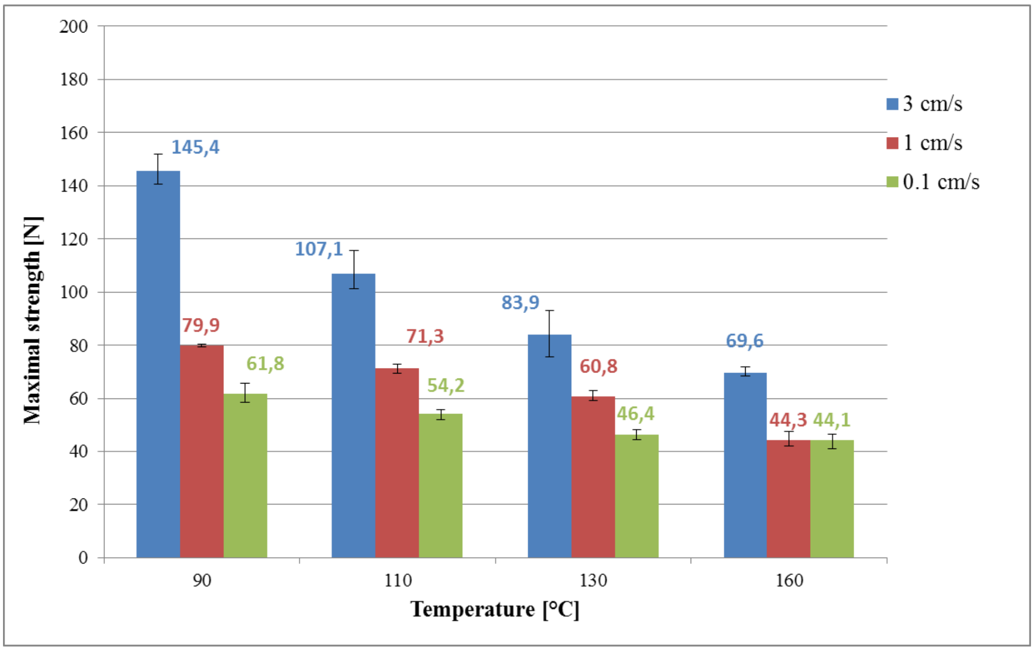

Figure9: Maximal strength obtained with the Nynas workability device for mixture 1, in the small mold

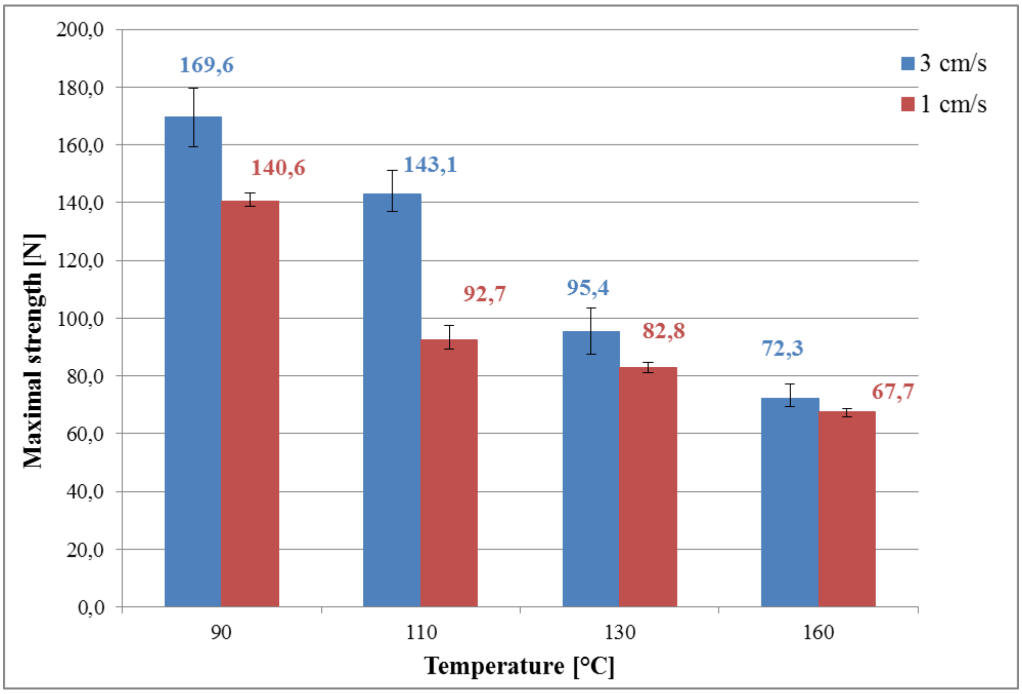

Figure10: Maximal strength obtained with the Nynas workability device for mixture 1, in the large mold

As shownin Figures 9 and 10, the maximal strength measured by the Nynas device significantly increases when the speed increases and the levels of strength are higher when tests are conducted in the large mold than in the small one. It also appears that the more the speed is high and the more the increase of maximal strength when temperature decreases is important.
It is also notable that the results obtained in the small mold at 3 cm/s are consistent with those obtain in the large mold at 1 cm/s.

In conclusion, we chose to test the different mixtures in the small mold (to reduce the quantities of materials needed and facilitate the laboratory work),at 3 cm/s (to have a test enough relevant).

4.2Influence of the mixture

Three different mixtures are tested at several temperatures and the results are shown in Figure11.

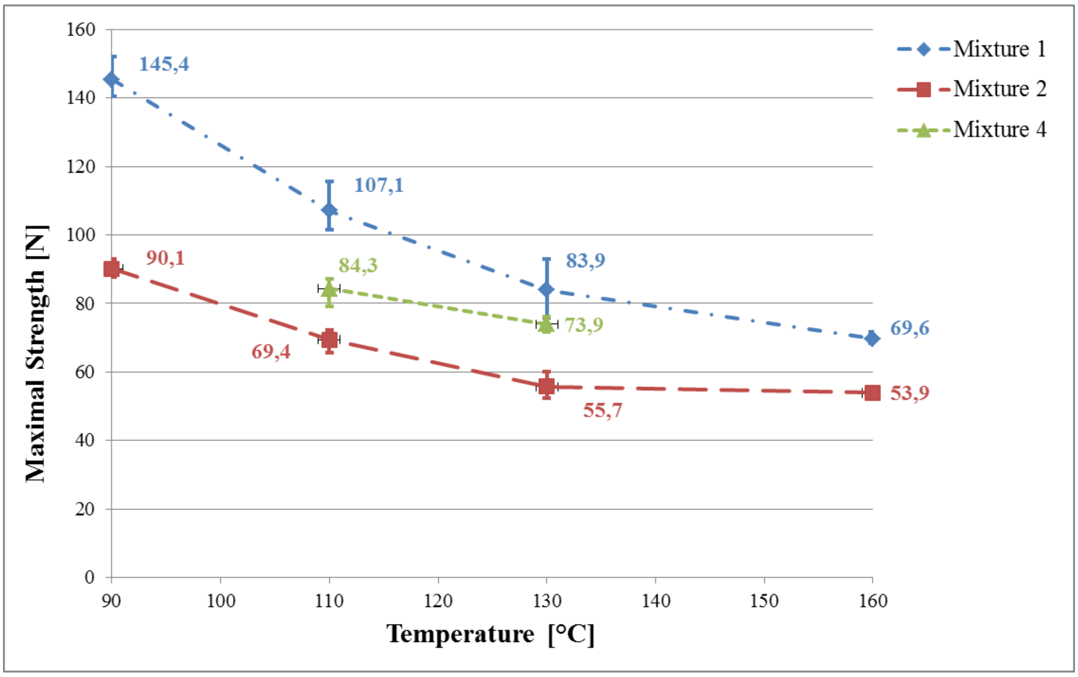

Figure11: Maximal strength obtained with the Nynas workability device for mixtures 1, 2 and 4, in the small mold, at 3 cm/s

Figure 11 shows that the maximal strength measured by the Nynas device significantly increases for mixtures 1 and 2 when the temperature decreases. That confirms what is really observed (during laboratory tests and on road sites): the fact that mixtures 1 and 2 workability decreases when the temperature decreases.

It is also notable that mixture 2 keeps a higher workability than mixture 1. These results could be explained by the difference of viscosity between the 35/50 binder and the 160/220 one: there is a 30°C temperature difference for the same viscosity of 35/50 and 160/220. These results may be compared to the GSC tests results highlighting that the GSC is insensible to workability lowering.

As regarding mixture 4, its maximal strength seems to be lower at 110 and 130°C than the one of mixture 1: the asphaltmix used in this study seems to have, with the surfactant additive (mixture 4), the same workability at 110°C than the asphaltmix without (mixture 1) at 130°C.

5. CONCLUSIONS

The aim of this study was to compare two testing device and to evaluate their ability to characterize the workability of asphalt: the Gyratory Shear Compactor, varying its standard parameters, and the Nynas Workability Device. The GSC vertical force and rotation speed were lowered to their minima, allowed by the device, and an experimental study was conducted on different mixtures with really different workabilities. In parallel, Nynas workability device tests were conducted and the results were compared.

The first thing to be said is that the laboratory evaluation of workability is very delicate and that a lot of parameters need to be well controlled (temperature, storage time before the test, test period). This study was conducted keeping constant these parameters as far as possible.

The results obtained with the GSC in terms of void content and shear strength highlighted the fact that this device, even set with minimal parameters, is not enough sensitive to workability lowering. Indeed, the values of the void content and the shear strength were essentially the same while the temperature (160, 110 and 90°C) was lowered and the mixture (with 35/50, with 160/220, with viscosity reducer) was changed.

On the contrary, the results of the Nynas workability device tests showed important workability differences according to the temperature (160, 130, 110 and 90°C) and to the mixture (with 35/50, with 160/220 and with surfactant additive).

To conclude, even set with minimal vertical force and rotation speed, the GSC cannot be used as a workability measure device, whereas the Nynas device gives conclusive results. Indeed, the strength levels (some newton) measured by the Nynas device are much lower than those applied by the GSC (some kilonewton).

To complete the study conducted on the Nynas device, it would be necessary to test several aggregates nature, several sample density and maybe several warm mix technologies.

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