INFLUENCE OF SPECIMEN GEOMETRY ON THE COMPLEX MODULUS OF COLD RECYCLED MATERIAL MIXTURES

Vittoria Grilli, Sara Spadoni, Francesco Canestrari, Andrea Graziani
Università Politecnica delle Marche, Department of Civil and Building Engineering and Architecture, Italy

Abstract

Cold recycling of bituminous pavements is becoming increasingly important because it leads to the reduction of costs of pavement maintenance and to lower pollutant emissions with respect to hot recycling. The stiffness characterization of cold recycled material (CRM) mixtures is essential to predict the stress-strain behaviour of the pavement structure. The present paper describes a laboratory experiment for evaluating the effects of specimen geometry on the complex modulus of CRM mixtures manufactured with bitumen emulsion and cement. In particular, the focus was on cylindrical specimens with diameter of 38 mm, adopted to improve the efficiency of laboratory specimen fabrication. Specimens with three different diameters (100 mm, 75 mm and 38 mm) were obtained by coring samples compacted using a gyratory compactor. Their complex modulus was measured by means of cyclic compression tests, using the Asphalt Mixture Performance Tester. The testing temperatures were 5, 15, 25, 35, 45 and 55 °C and the testing frequencies were 20, 10, 5, 1, 0.5, 0.1 Hz. The tests were carried out after long-term curing in a climate chamber. Results showed that the complex modulus measured on 38 mm specimens, although with a greater dispersion, is comparable to that measured on 100 mm and 75 mm specimens, thus it can be used for evaluating the mechanical behaviour of CRM mixture.

Keywords: cold recycling, bitumen emulsion, complex modulus, specimen geometry

1 Introduction

Nowadays, the reuse of construction materials at the end of their service life leads to several beneficial effects for the environment, such as waste reduction and preservation of natural resources. This context includes cold recycled bituminous materials (CRM) whose main objective is to maximise the reuse of the reclaimed asphalt (RA), resulting from the demolition of end-of-life pavements, without heating. In fact, the whole recycling process of CRM can be performed at ambient temperature employing the bitumen in form of emulsion or foam, significantly limiting the carbon footprint. Several studies have demostrated that CRM mixtures can be used to build pavement structures characterized by an excellent long-term performance [1-6]. However, at the current state of the knowledge, the structural design of cold recycled pavements, is carried out using empirical methods. Therefore, in order to promote a wider use of CRM mixtures, it is essential to develop and implement mechanistic-empirical design methods. In this context, the stiffness characterization of a mixture provides the stiffness modulus that is a fundamental property required when characterizing the performance of a pavement structure, and serves as a key input for mechanistic-empirical pavement design procedures [7]. In this study, specimens with three different diameters (100 mm, 75 mm

DOI: https://doi.org/10.5592/CO/CETRA.2022.1450

and 38 mm) were cored from samples compacted using a gyratory compactor. In particular, the focus was on specimens with diameter of 38 mm. They offer a significant opportunity to improve the efficiency of laboratory-fabricated uniaxial testing and also multiple small specimens can be extracted from a single gyratory sample. The smaller specimen size reduces the time required for thermal equilibration, which minimizes testing time and improves efficiency [1]. The objective of this study was to assess, through complex modulus tests, the effect of the specimens geometry on the measurement of the stiffness behaviour of the CRM mixtures and its dependence on temperature and frequency. A volumetric analysis was also carried out to investigate the specimen-to-specimen variability.

2 Materials and methods

2.1 Composition of mixture

The CRM mixtures investigated in this study were produced in the laboratory by mixing at ambient temperature RA aggregate, limestone filler, Portland cement, bitumen emulsion and water. The RA aggregate was sampled from a stockpile located in a cold recycling plant in central Italy. Its nominal maximum aggregate size was 16 mm. The grading distribution of the mixture, used in the previous studies [8], was obtained with 80 % of RA and 20 % of filler. The bitumen emulsion was a commercial slow setting type, designated as C 60 B 10 (EN 13108), in percentage of 4 % by mass of the dry aggregate blend. The Portland cement dosage (CEM II/B-LL 32.5 R) was 2 % and the total water content of the mixture was 4 %, including pre-wetting water and emulsion water.

2.2 Mixing, compaction and curing

In order to control the water content, RA aggregate was dried at 40 ± 2 °C in oven until reaching constant mass, and then water absorption amount was added. To allow a uniform absorption, the wet samples were stored in sealed plastic bags, at room temperature for 12 hours. Mixing was carried out alternating manual to mechanical mixing. During the process, pre-wetting water, cement, and bitumen emulsion were gradually added to the aggregate blend [9]. A gyratory compactor (GC) was used to prepare four specimens with diameter of 150 mm, adopting a constant pressure of 600 kPa, a speed of 30 rpm, and an angle of inclination of 1.25°. In this study, both the voids content and height of the GC specimens were fixed at V_m = 12 % and H = 180 mm. Figure 1a shows the compaction curves, which represent the reduction of voids in the mixture (V_m) during the compaction obtained by measuring the GC specimen height at every gyration, until the target height of 180 mm was reached. Since curing plays a fundamental role to develop the mechanical properties of cold recycled mixtures, at the beginning and during the curing process, each GC specimen was weighed in order to assess its mass loss due to the evaporation of the water. The four GC specimens were placed in oven at 40 °C for the first 3 days (dry environment) and then transferred to the climatic chamber, at 40 °C, for 28 days. The specimens were weighed to measure the water loss in the first 7 days and then at 14 and 28 days (Figure 1b).

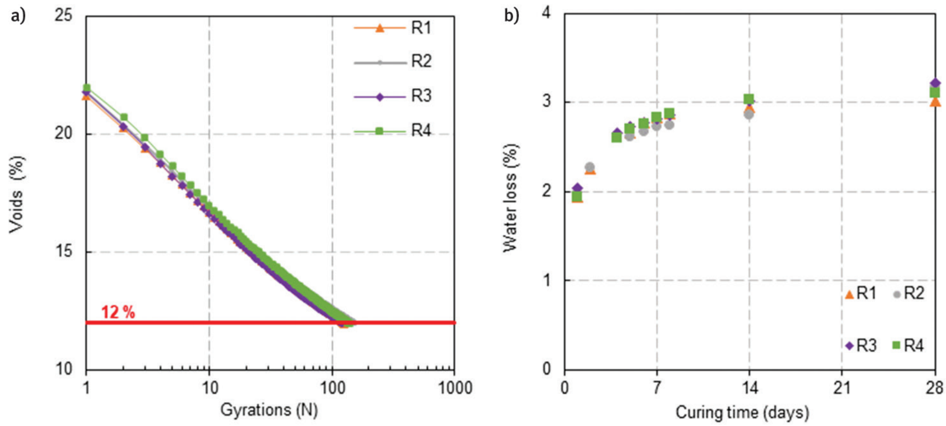

Figure 1 Compaction and curing of the GC specimens: a) compaction curves; b) water loss.

2.3 Specimen coring

Specimens characterized by three different geometries were cored from the GC specimens. One 75 mm and one 100 mm diameter specimens were obtained from two 150 mm diameter samples. Three 38 mm diameter specimens could be cored from one giratory sample. However, damage occured during coring procedure and, as a consequence, it was necessary to core two GC specimens in order to obtain four 38 mm specimens. The specimens were coded as S75, S100, S38_1, S38_2, S38_3, S38_4.

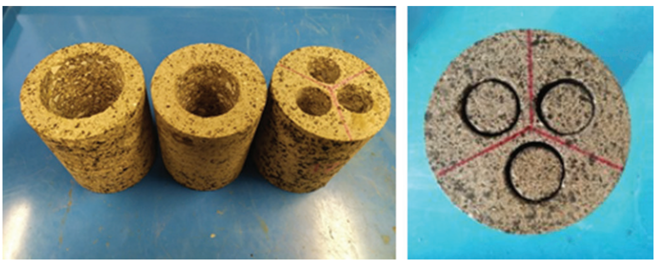

Figure 2 Coring procedure

A volumetric analysis in the hardened state was carried out on the cored specimens in order to make a direct comparison between the voids calculated during compaction (Figure 1a) and those actually present in the cored specimens. The aim was to check if the target value of 12 % was reached, considering that other processes might affect the voids content during the curing time (i.e. water loss, chemical reaction between cement and water). The voids of the specimens were calculated as follows (UNI EN 12697-8):

$$V_m = \frac{\rho_{max} - \rho_b}{\rho_{max}} \cdot 100 \quad (1)$$

Where ρ_{max} is the maximum density determined through the mathematical method (UNI EN 12697-5) and ρ_b is CRM density of the specimens. In this study, the density was calculated both with geometric and hydrostatic methods (UNI-EN 12697-21).

2.4 Complex modulus testing

A servo-hydraulic testing system (AMPT PRO) was used to measure the complex modulus. The axial stress was measured with a load cell, whereas the axial strain was measured on the middle part of the specimen using three linear variable differential transformers placed 120° apart [10]. The specimens were subjected to a haversine compression loading to obtain a strain amplitude of 30 microstrain at temperatures of 5, 15, 25 ,35 ,45 and 55 °C. At each temperature, reached by conditioning in enviromental chamber, tests were carried out at frequencies of 20, 10, 5, 1, 0.5 and 0.1 Hz. Specimens were conditioned in an external climatic chamber and were consecutively tested at the same temperature. This procedure is time-saving, however the specimen must be removed after each frequency sweep and positioned and centered again at the next temperature.

3 Results and discussion

3.1 Volumetric analysis

Figure 3 shows a comparison between the voids calculated with the geometric method and with the hydrostatic method. As it can be noticed, a discrepancy was evident between the geometric and the hydrostatic methods. The geometric method overestimateed the volume of the specimens because, as a result of the coring, they were never perfectly cylindrical. This effect was evident especially in 38 mm diameter specimens due to the greater difficulties during the coring procedure. Considering all the specimens, the average value of the voids based on the hydrostatic method, was 11,4 %, close to the target value of 12 %.

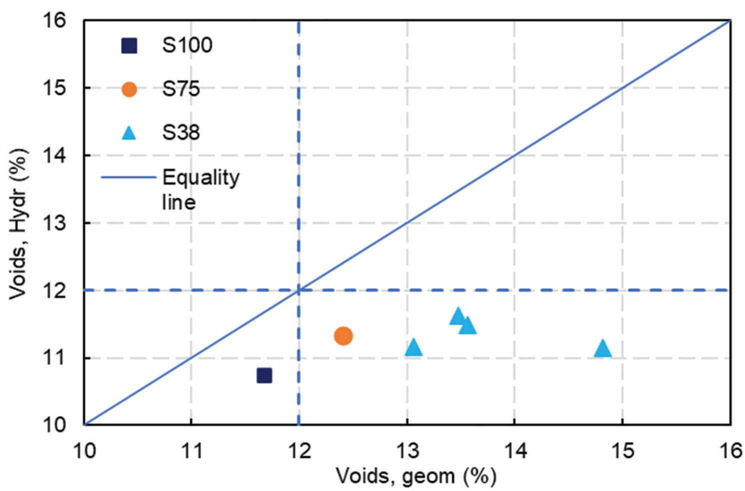

Figure 3 Voids calculated with geometric and hydrostatic methods

3.2 Complex modulus results

Figure 4 shows the complex modulus results in the Black diagram (stiffness modulus as a function of loss angle) and in the Cole-Cole diagram (loss modulus as a function of storage modulus). From the Black diagram the variability of E_0 and φ can be observed, in general all the specimens showed the same behavior characterized by high stiffness modulus at high frequencies and low temperatures and high values of the phase angle at high temperatures and low frequencies. As can be seen, the experimental data obtained from each specimen were aligned along the same curves, indicating that the Time-Temperature Superposition Principle (TTPS) was valid for both the stiffness modulus and the phase angle. For 38 mm specimens, the variability of the stiffness modulus values may be due to small differences among the frequency sweeps carried out at different temperatures, because the specimen positioning and centering was repeated each temperature.

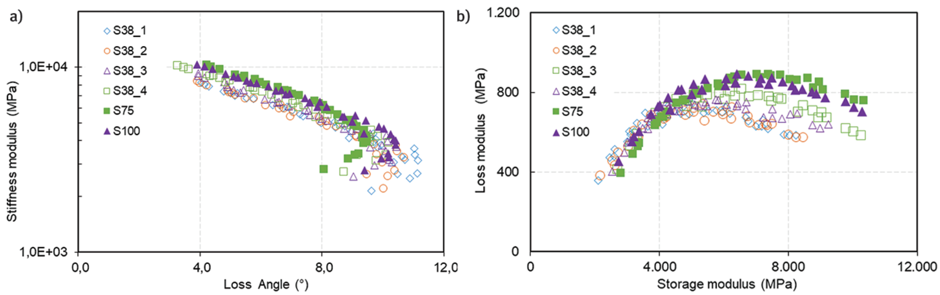

Figure 4 a) Black diagram for CRM; b) Cole-Cole diagram for CRM

Figure 5 shows the ratio between the stiffness moduli of 75 mm and 38 mm specimens, at temperatures of 5 °C and 55 °C and all test frequencies, with respect to the 100 mm specimen. The mean value of the stiffness modulus of 38 mm specimens was comparable with that of 75 and 100 mm, showing a lower stiffness of about 15 %. In addition, the ratio between the stiffness of 100 mm and 75 mm specimens was almost equal to 1, wereas the stiffness of 38 mm specimens was, on the average, about 15 % lower.

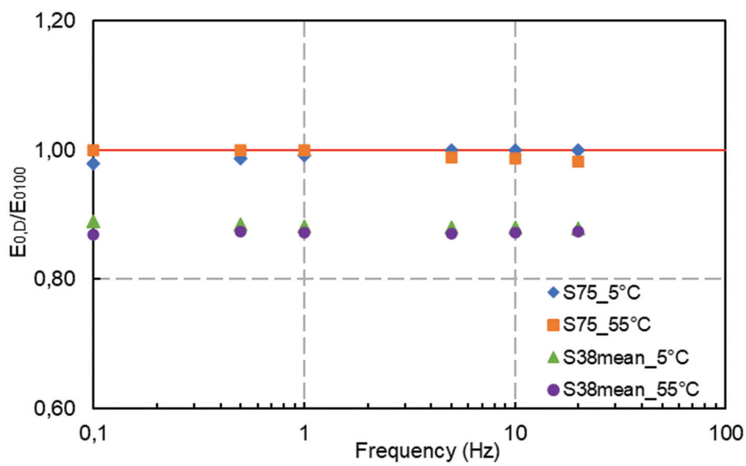

Figure 5 Ratio between stiffness modulus of 100 mm, 75 mm, 38 mm

4 Conclusions

The main goal of this research was to evaluate the effects of specimens geometry on the the complex modulus of cold recycled mixtures through cyclic compression tests. The use of specimens with a diameter of 38 mm had the advantage of improving the efficiency in the laboratory in the production of specimens, as well as a significant reduction in the conditioning times before the tests. Based on the laboratory results, the following conclusions can be drawn:

- The volumetric analysis gave satisfactory results as the void content determined with hydrostatic method were close to the target value of 12 %. The difference between 75 and 100 mm specimens was minimal. The voids of 38 mm specimens calculated with the geometrical method varied in a wider range, due to small imperfections of the specimen geometry;
- The complex modulus values of 75 mm and 100 mm specimens were almost identical, a small difference can be attributed to uncertainties introduced by the test method and during the production of the mixture.
- The complex modulus of 38 mm specimens had a higher variability than the 75 and 100 mm, probably due to greater difficulties found during the centering stage in the testing equipment.

Overall specimens with diameter of 38 mm were suitable for measuring the complex modulus through cyclic compression tests, even though a slightly lower stiffness (15 %) was assessed in comparison with 75 mm and 100 mm specimens.

References

[1] Godenzoni, C., Graziani, A., Bocci, E., Bocci, M.: The evolution of the mechanical behaviour of cold recycled mixtures stabilised with cement and bitumen: field and laboratory study, Road Materials and Pavement Design, 19 (2018) 4, pp. 856-877

[2] Stimilli, A., Ferrotti, G., Graziani, A., Canestrari, F.: Performance evaluation of a cold-recycled mixture containing high percentage of reclaimed asphalt, Road Materials and Pavement Design, 14 (2013) 1, pp. 149-161

[3] Iwański, M., Chomicz-Kowalska, A.: Application of the foamed bitumen and bitumen emulsion to the road base mixes in the deep cold recycling technology, The Baltic Journal of Road and Bridge Engineering, 11 (2016) 4, pp. 291-301

[4] Dołżycki, B., Jaskuła, P.: Review and evaluation of cold recycling with bitumen emulsion and cement for rehabilitation of old pavements, Journal of Traffic and Transportation Engineering (English Edition), 6 (2019) 4, pp. 311-323

[5] Vaitkus, A., Gražulytė, J., Baltrušaitis, A., Židanavičiūtė, J., Čygas, D.: Long-term Performance of Pavement Structures With Cold in-place Recycled Base Course, Baltic Journal of Road & Bridge Engineering, 16 (2021) 2, pp. 48-65

[6] Vaitkus, A., Gražulytė, J., Juknevičiūtė-Žilinskienė, L., Andrejevas, V.: Review of Lithuanian experience in asphalt pavements cold recycling, International Conference on Environmental Engineering, Vilnius Gediminas Technical University, 27-28 April 2017

[7] Castorena, C., Kim, Y.R., Pape, S., Lee, K.: Development of small specimen geometry for asphalt mixture performance testing, NCHRP IDEA Project N-181, 2017.

[8] Mignini, C., Cardone, F., Graziani, A.: Experimental Study on the Grading Distribution of Cold Recycled Asphalt Mixtures Produced with Bitumen Emulsion and High Strength Cement, RILEM International Symposium on Bituminous Materials, pp. 887-893, Lyon, France, December 2020.

[9] Graziani, A., Raschia, S., Mignini, C., Carter, A., Perraton, D.: Use of fine aggregate matrix to analyze the rheological behavior of cold recycled materials, Materials and Structures, 53 (2020) 4, pp. 1-16

[10] Graziani, A., Mignini, C., Bocci, E., Bocci, M.: Complex modulus testing and rheological modeling of cold-recycled mixtures, Journal of Testing and Evaluation, 48 (2019) 1, pp. 120-133