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Mechanical assessment of the induction heating as a method to accelerate the drying process of cold porous asphalt mixtures

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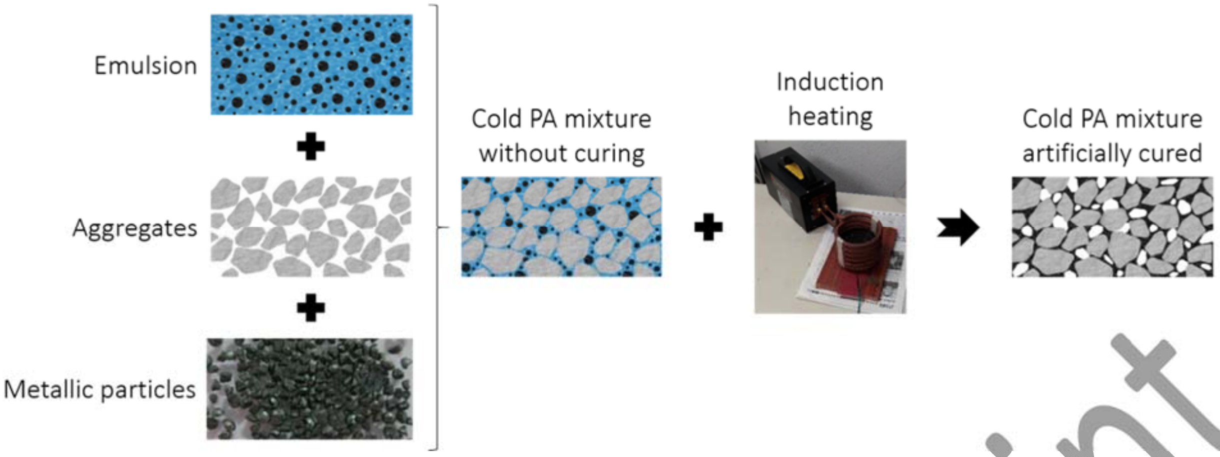
Abstract

Cold mix asphalts present clear advantages such as the fact that they do not need to be heated, what results in lower energy consumptions and emissions, or the possibility to be transported long distances and manufactured on an offsite. However, their use is highly limited due to the long curing times that are needed to reach their final strength and the lower mechanical performance achieved comparing to hot mix asphalts. This paper studies induction heating as a process to accelerate the drying time of the emulsion and compares it, in terms of the mixture mechanical performance, with a more conventional method in which the cold sample is heated up in an oven. Different tests, as Cantabro, stiffness and Indirect tensile strength have been carried out. The mechanical results have shown that the induction heating could be a feasible alternative to increase the initial strength and reduce the opening time for this type of layers, although more research is necessary concerning the optimization of the mixture and the improvement of the induction device configuration.

Graphical abstract



Keywords: Porous asphalt; cold mixture; induction heating; emulsion.

1. Introduction

Cold mix asphalts have some clear environmental advantages because the aggregates and binder do not have to be heated up, so the energy consumption and the greenhouse gas emissions are greatly reduced[1]. However, these type of mixtures have also significant disadvantages, such as the lowest mechanical performance comparing to hot mix asphalts or the need of several weeks to evaporate the water included in the emulsion and therefore to achieve their full strength[2]. In this sense, the porosity of the mixture is one of the main parameters affecting the drying process, because of its influence on the trapped water[3].

Induction heating is a technology that has been explored in the last years to speed up the self-healing of bituminous mixtures[4]. It consists on asphalt mixtures incorporating metallic particles in their composition that can be heated via induction. The bitumen around the particles is heated and due to the thermal expansion and viscosity reduction, flows and fills in the existing fissures[5]. This is a high energy-efficient technology mainly because the bitumen and metal particles within the asphalt mixture are heated[6]. This technology is currently assessed with reclaimed asphalt (RA)[7], by-products as alternative aggregates and heating inductors[8], even as method to maintain the roads by melting binder pellets[9]. However, its use with cold asphalt mixtures has not been deeply analysed yet. In this paper, the induction heating is proposed as a potential method to selectively heat the emulsion and accelerate the evaporation of the water contained in a cold porous asphalt mixture, trying to decrease the required curing time of this type of mixtures.

2. Materials

Apart for the metallic particles, conventional materials were used to design the cold porous asphalt mixture. Thus, limestone and ophite (porphyry igneous rock) were used as fine (including filler) and coarse aggregates, respectively. Their properties are presented in Table 1 and Table 2.

	Result	Standard
Angels coefficient	16	EN 1097-2
Specific weight (g/cm^3)	2,937	EN 1097-6

Polished stone value (PSV)	> 56	EN 1097-8
Flakiness Index (%)	8	EN 933-3

Table 1. Properties of ophite aggregate

	Result	Standard
Angels coefficient	28	EN 1097-2
Specific weight (g/cm^3)	2,725	EN 1097-6
Sand equivalent	78	EN 933-8

Table 2. Properties of limestone aggregate

In addition, a slow breaking cationic emulsion with 60 % of residual asphalt content was employed to design the porous asphalt, whose properties are included in Table 3. It should be highlighted that this emulsion does not contain any flammable diluent (i.e. kerosene), which could ignite due to the high temperatures reached during the induction heating process.

	Minimum	Maximum	Standard
Particle polarity	Positive		EN 1430
Breaking value (g)	170	-	EN 13075-1
Efflux time (s, 2 mm, 40 °C)	15	70	EN 12846-1
Residual binder content (%)	58	62	EN 1428
Residue on sieving (%, 0.5 mm)	-	0.10	EN 1429
Settling tendency (%, 7 days)	-	10	EN 12847
Adhesivity (%)	90	-	EN 13614
Penetration (0.1 mm, 25 °C, 100 g, 5 s)	-	270	EN 1426
Softening point (°C)	35	-	EN 1427

Table 3. Properties of emulsion

Finally, steel grit (Figure 1) was added as the metallic particle to be heated by induction. Normally used for blasting, it is a granular material with 100 % broken surfaces and uniform gradation between 2 mm and 1 mm grain size. The particle size distribution was designed by volume of total aggregate due to the high density of the steel grit.

Figure 1. Steel grit particles

3. Methodology

Two porous asphalts were designed, one without metallic particles, used as a reference, and the other one incorporating the metallic particles; both with the same grading expressed in percentage by volume of the total aggregate. The samples of the reference mixture (without metal particles) were cured in an oven following a procedure divided in two steps [10,11]. In the first step, they were kept at 75 °C for two days and as the samples did not present binder drainage, in a second step, they stayed at 90 °C in the oven for other five additional days. On the other hand, the samples with the metal particles (experimental PA) were dried using the induction machine and varying the time and temperature of the heating process. As cold mixtures do not have enough consistency after compaction, the sample was contained in a silicon ring in which holes were made to allow the water vapour to get away (Figure 2). It should be noted that the material used to keep the consistency of the mixture should withstand high temperatures without melting and that metallic meshes or grids should be avoided because they are heated by the magnetic field and this could affect the test.

Figure 2. Marshall sample of cold porous asphalt before being dried by induction heating

Initially, the high temperatures reached when heating the experimental PA by induction produced the drainage of the residual binder (Figure 3). In order to solve the problem, both mixes (reference and experimental) were redesigned increasing the percentage of fine aggregate and filler.

Figure 3. Bottom of a Marshall simple presenting a drainage problem after heating by induction

For the re-designed mixtures, the induction heating was applied for 30 minutes at different intensities. The heating process was carried out in two phases. Firstly, in order to reach an average temperature of the samples of 120 °C, 300 A intensity was applied for approximately 15-20 minutes. In the second phase, and in order to keep the temperature in the range of 120-130 °C, the intensity was reduced to 200 A until the end of the test (around 10-15 minutes). No drainage of the bitumen was observed this time. Figure 4 presents the configuration of the induction machine.

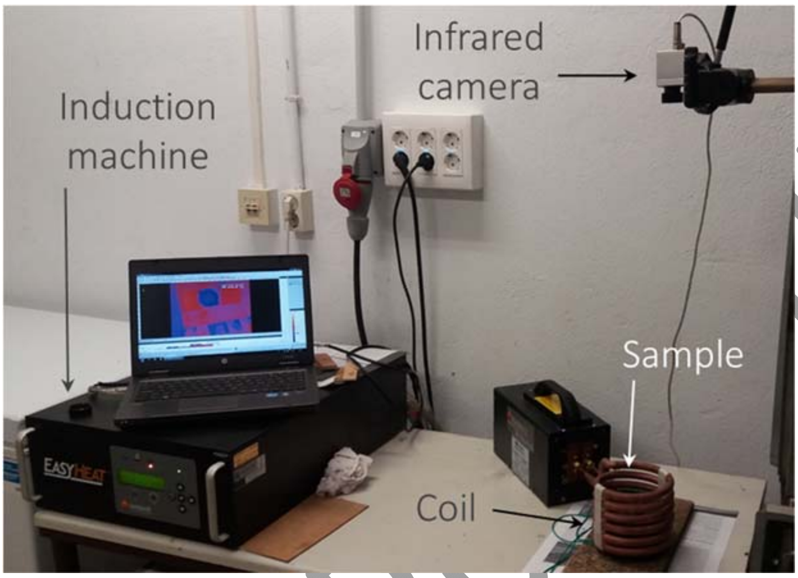


Figure 4. Induction machine configuration

Finally, to assess the feasibility of using induction heating as a method to cure cold mixes, both designs (reference and experimental) were compared in terms of their mechanical performance. The voids (EN 12697 – 8), the particle loss in the Cantabro test (EN 12697 – 17), the indirect tensile strength (EN 12697 – 23) and the stiffness (EN 12697 – 26, Annex C) were calculated. To do so, at least 3 samples per type of mixture were tested.

4. Results and discussion

The results were analysed with the software Minitab. When the data fulfilled a normal distribution and there was homogeneity of variances the Student t-test was performed. Otherwise, the U of Mann–Whitney test was used. The confidence interval was always 95 %, so a statistical significance of 0.05 states the threshold level of acceptance or rejection.

Following, the main results are presented.

4.1. Design of a cold PA mixture

The aggregate grading of the experimental and reference mixes designed are shown in Figure 5. As it can be observed, the grading was adjusted to the higher limit to avoid drainage problems during the testing. This is because the main objective of this preliminary research was evaluating the technical feasibility of using induction heating to reduce the time for evaporating the water in cold mixes. In a future continuation of this research, the time and temperature parameters for the induction heating need be optimized to avoid bitumen drainage.

Regarding the design of the mixtures, in the case of the experimental PA, the only difference compared to the reference mixture was the addition of 1% of steel grit by volume of total aggregate. The percentage of bitumen was kept the same in both mixes (4.5% by weight of mixture).

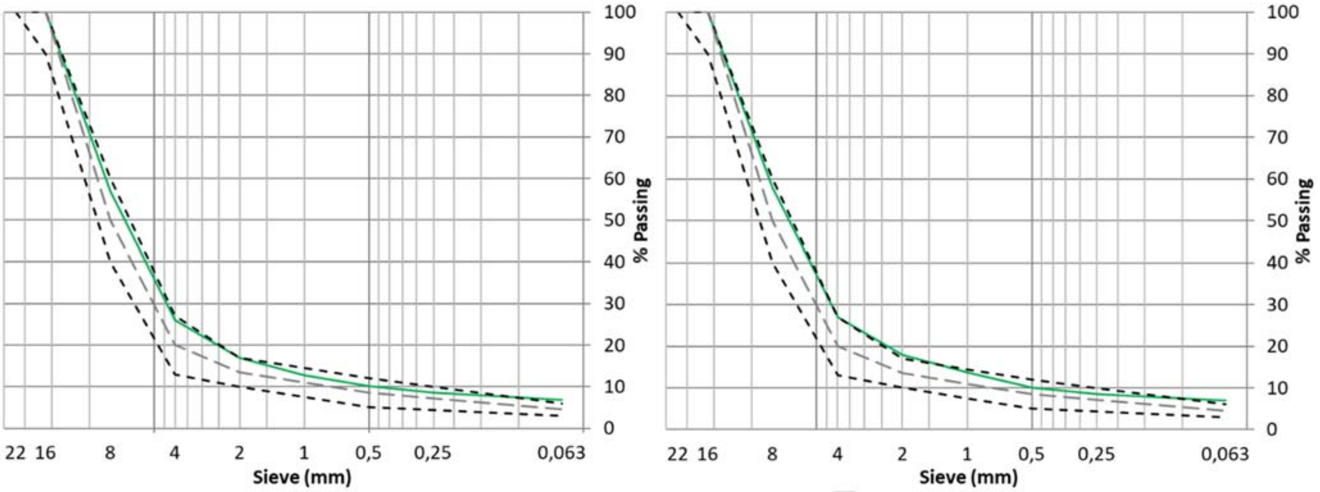


Figure 5. Particle size distribution of reference (left) and experimental mixture (right)

4.2. Mechanical performance of cold PA mixture

To evaluate the feasibility of the induction heating technology for this application, different tests have been carried out and their results compared with the oven-heated samples.

Thus, in the first place, the effect of the heating procedure on the bitumen properties was analysed. To do so, two samples of bitumen were extracted for both the experimental and reference mixes after the heating process (oven and induction) and the penetration and softening point of the recovered samples were analysed (Table 4). In both cases, the bitumen is clearly aged, but the aging is more pronounced when the sample is oven-heated.

	Reference	Experimental	Standard
Penetration (0.1 mm, 25 °C, 100 g, 5 s)	16	26	EN 1426
Softening point (°C)	63.3	54.1	EN 1427

Table 4. Binder properties after heating

Afterwards, the density and void content of both mixes were compared (Table 5). Despite the different heating method used, the density and void content are practically the same and the difference was found to be insignificant (see p-values in Table 8). However, in both mixes, experimental and reference, the void content was quite high compared to traditional PA mixes (around 20%).

	Reference	Experimental
Density (g/cm^3)	1.948 ± 0.043	1.977 ± 0.020
Voids (%)	28.4 ± 1.6	27.3 ± 0.7

Table 5. Voids test

The different mechanical behaviour of both mixes (experimental and reference) was evaluated with the application of different tests: Cantabro test, indirect tensile strength test and resilient modulus test.

Concerning the Cantabro test, it was performed at 25 °C by measuring the loss of particles occurred every 50 drum revolutions until reaching 300 revolutions (Figure 6). Figure 7 shows the particle loss ratio every 50 drum revolutions.

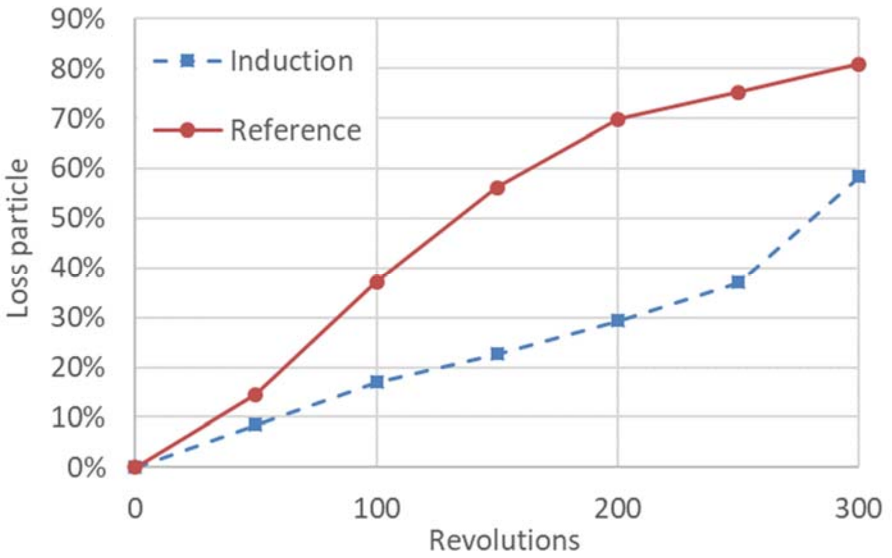


Figure 6. Particle loss of mixtures heating up by both methods

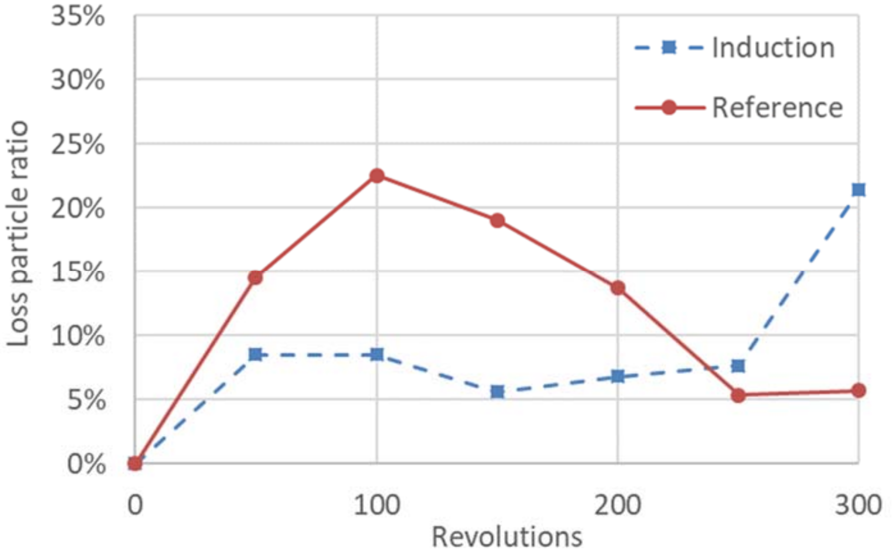


Figure 7. Particle loss ratio of mixtures heating up by both methods

Important differences were found concerning the particles loss of the experimental and reference mixtures after induction and oven- heating, respectively. The particle loss was higher in the case of the mixture heated in the oven. Since the percentage of voids was similar in both mixtures, the differences could be related to, as observed before, the higher aging level of the bitumen of the reference mixture compared to the bitumen of the experimental mixture. In addition, the main loss in the fragmentation resistance for the reference mixture occurred in the first 100 drum revolutions, so likely the experimental mixture will present a higher service life. On the other hand, despite the great differences observed between the mixes, the results were not statistically significant due to this test showed a high variability (Table 8).

The indirect tensile strength (I.T.S) was calculated according to EN 12697-12 with dry samples. Based on the results (Table 6), the reference mixture showed a higher strength, probably also related to the higher stiffness of the binder. However, in consonance with the statistical analysis, the differences were not significant (Table 8).

	Reference	Experimental
I.T.S. (KPa)	590.4 ± 93.9	409.9 ± 82.4

Table 6. I.T.S. in dry conditions for both type of mixtures

Finally, the resilient modulus according to EN 12697-26 Annex C was carried out at 20 °C. In agreement with the other test results, the reference mixture showed a higher stiffness than the experimental mixture (Table 7), although, only in this case, the result was statistically different (Table 8). It should be highlighted that as these mixtures are destined to surface layers and their function is not bearing loads, the difference found in the stiffness is not critical.

	Reference	Experimental
Stiffness (MPa)	1783 ± 285	472 ± 52

Table 7. Resilient modulus of both type of mixtures

	Voids	Cantabro	I.T.S	Stiffness
P -value	0.094	0.218	0.112	0.030

Table 8. P-values of the mechanical tests

5. Conclusions

Two cold PA mixtures have been designed using the same percentage of residual binder and a similar grading, with the only difference of the addition of 1% steel grit by volume of aggregate in one of them. The evaporation of the water included in the emulsion has been carried out using two different methods: the traditional method used to design cold mixes at the laboratory consisting in heating the mixture in an oven and a new innovative method consisting in heating the mixture via induction. In order to evaluate the feasibility of the latter, once the water is evaporated, the mixes were subjected to different mechanical tests. The conclusions can be summarised as follows:

- The oven-heating method seems to age the residual binder of the emulsion more than the induction heating, even though the latter reached higher temperatures.
- In terms of mechanical performance, the mixture heated via induction presented, on the one hand, a better behaviour on the Cantabro test with a less particle loss and, on the other hand, a lower stiffness. Based on the statistical analysis, only the latter result was significant.
- The induction heating seems a feasible technology to shorten the time needed for curing the emulsion of the cold porous asphalt mixture. Although preliminary, the results are promising since

similar mechanical performance has been obtained reducing the time to evaporate the water from 7 days to 30 minutes.

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