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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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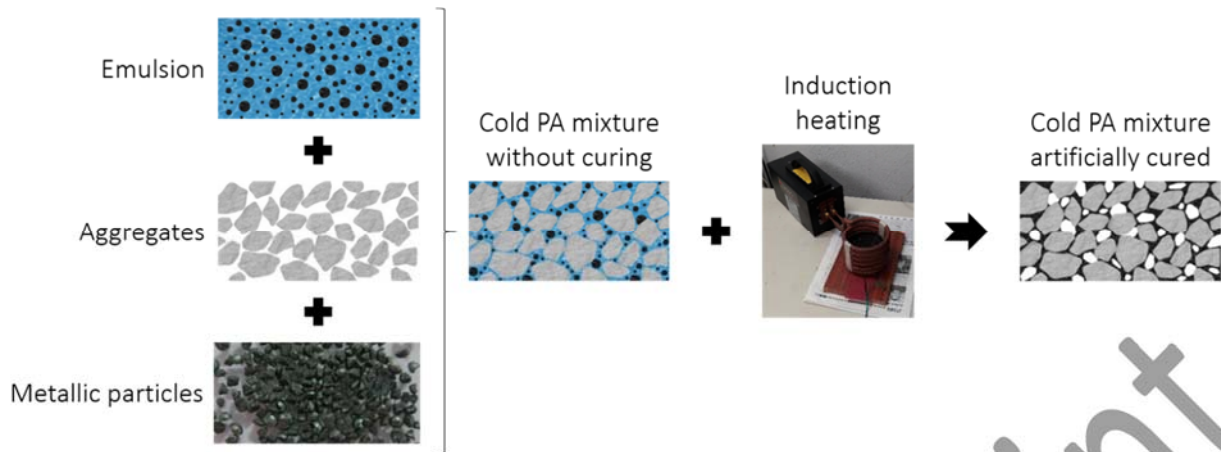
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## **Abstract**

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<sup>1</sup>. 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<sup>2</sup>. 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<sup>3</sup>.

Induction heating is a technology that has been explored in the last years to speed up the self-healing of bituminous mixtures<sup>4</sup>. 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<sup>5</sup>. This is a high energy-efficient technology mainly because the bitumen and metal particles within the asphalt mixture are heated<sup>6</sup>. This technology is currently assessed with reclaimed asphalt (RA)<sup>7</sup>, by-products as alternative aggregates and heating inductors<sup>8</sup>, even as method to maintain the roads by melting binder pellets<sup>9</sup>. 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 <sup>3</sup> )	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 <sup>3</sup> )	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

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



75  
76 **Figure 2. Marshall sample of cold porous asphalt before being dried by induction heating**

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



80  
81 **Figure 3. Bottom of a Marshall sample presenting a drainage problem after heating by induction**



82 For the re-designed mixtures, the induction heating was applied for 30 minutes at different intensities.  
83 The heating process was carried out in two phases. Firstly, in order to reach an average temperature of  
84 the samples of 120 °C, 300 A intensity was applied for approximately 15-20 minutes. In the second  
85 phase, and in order to keep the temperature in the range of 120-130 °C, the intensity was reduced to  
86 200 A until the end of the test (around 10-15 minutes). No drainage of the bitumen was observed this  
87 time. Figure 4 presents the configuration of the induction machine.

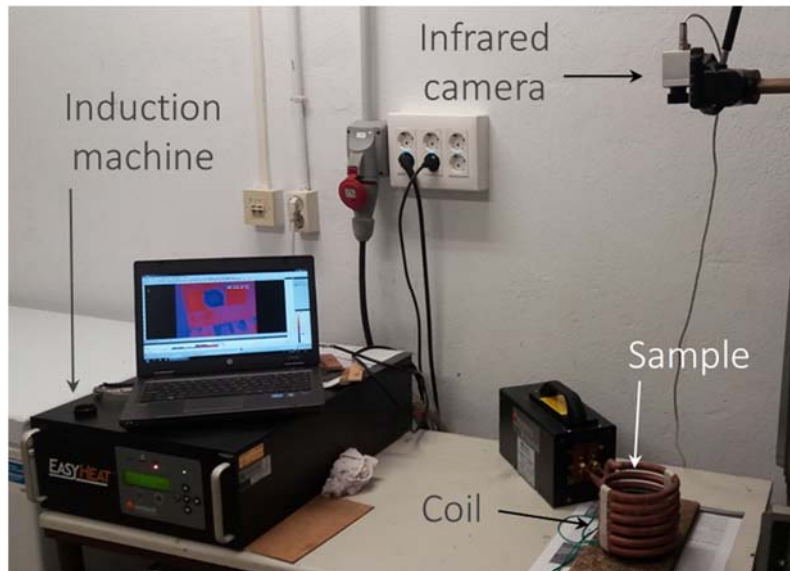


Figure 4. Induction machine configuration

88  
89 Finally, to assess the feasibility of using induction heating as a method to cure cold mixes, both designs  
90 (reference and experimental) were compared in terms of their mechanical performance. The voids (EN  
91 12697 – 8), the particle loss in the Cantabro test (EN 12697 – 17), the indirect tensile strength (EN 12697  
92 – 23) and the stiffness (EN 12697 – 26, Annex C) were calculated. To do so, at least 3 samples per type  
93 of mixture were tested.  
94

## 95 4. Results and discussion

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

100 Following, the main results are presented.

### 101 4.1. Design of a cold PA mixture

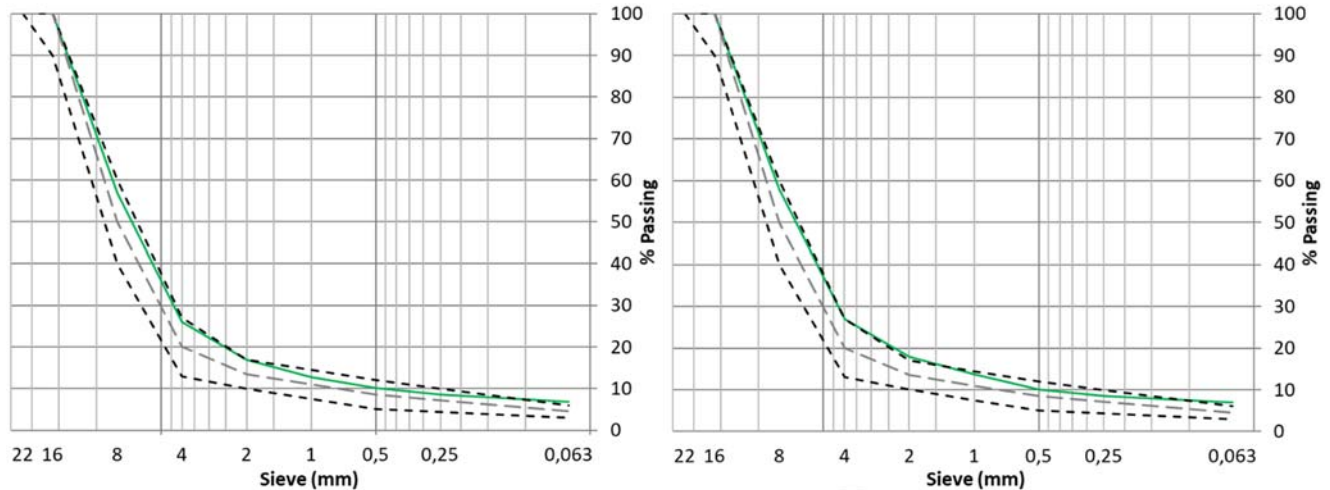
102 The aggregate grading of the experimental and reference mixes designed are shown in Figure 5. As it  
103 can be observed, the grading was adjusted to the higher limit to avoid drainage problems during the  
104 testing. This is because the main objective of this preliminary research was evaluating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

107 need be optimized to avoid bitumen drainage.

108 Regarding the design of the mixtures, in the case of the experimental PA, the only difference compared

109 to the reference mixture was the addition of 1% of steel grit by volume of total aggregate. The

110 percentage of bitumen was kept the same in both mixes (4.5% by weight of mixture).



111  
112 **Figure 5. Particle size distribution of reference (left) and experimental mixture (right)**

#### 113 4.2.Mechanical performance of cold PA mixture

114 To evaluate the feasibility of the induction heating technology for this application, different tests have

115 been carried out and their results compared with the oven-heated samples.

116 Thus, in the first place, the effect of the heating procedure on the bitumen properties was analysed. To

117 do so, two samples of bitumen were extracted for both the experimental and reference mixes after the

118 heating process (oven and induction) and the penetration and softening point of the recovered samples

119 were analysed (Table 4). In both cases, the bitumen is clearly aged, but the aging is more pronounced

120 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

121 **Table 4. Binder properties after heating**

122 Afterwards, the density and void content of both mixes were compared (Table 5). Despite the different

123 heating method used, the density and void content are practically the same and the difference was

124 found to be insignificant (see p-values in Table 8). However, in both mixes, experimental and reference,

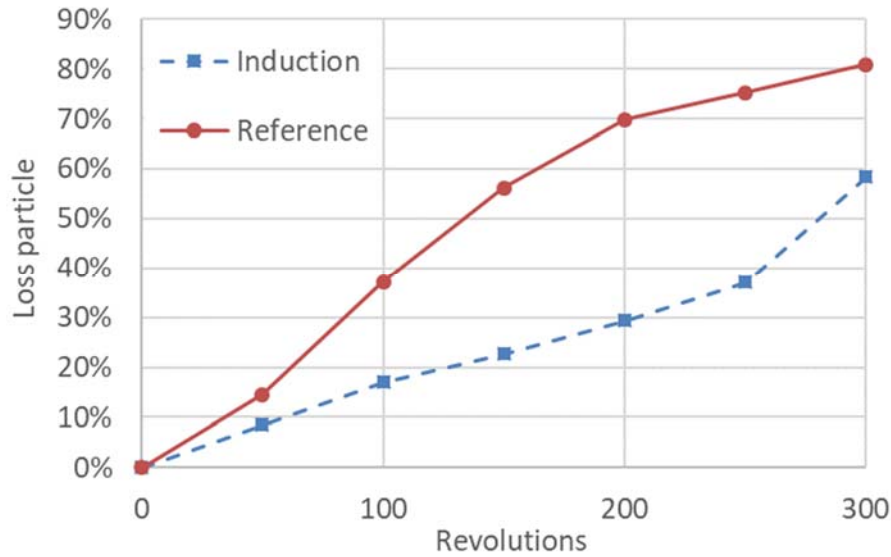
125 the void content was quite high compared to traditional PA mixes (around 20%).

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

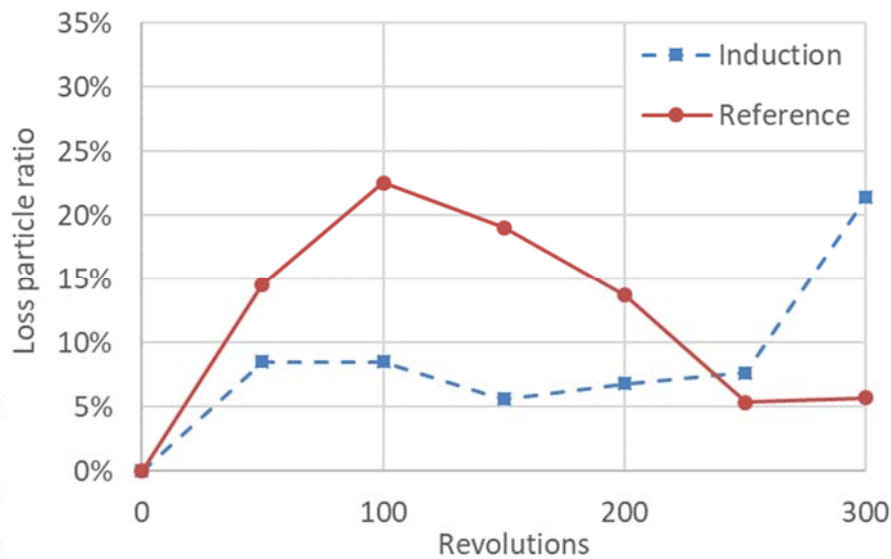
126 **Table 5. Voids test**

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

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



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



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

135  
 136 Important differences were found concerning the particles loss of the experimental and reference  
 137 mixtures after induction and oven- heating, respectively. The particle loss was higher in the case of the  
 138 mixture heated in the oven. Since the percentage of voids was similar in both mixtures, the differences  
 139 could be related to, as observed before, the higher aging level of the bitumen of the reference mixture  
 140 compared to the bitumen of the experimental mixture. In addition, the main loss in the fragmentation  
 141 resistance for the reference mixture occurred in the first 100 drum revolutions, so likely the  
 142 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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