



# Mechanical Behavior of SMA 8 Modified with Nano Hydrotalcite

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**Abstract.** Nanotechnology is currently being applied in pavement engineering and, in particular, asphalt mixtures. This emerging technology can enhance materials' properties and in recent years there has been research carried out on the influence of modifications through different nanomaterials. Hydrotalcite, which is a type of layered double hydroxide (LDH), has been regarded as a promising modifier, particularly on account of its ability to reflect UV radiation (improving UV aging resistance), delay oxygen permeability and retard the loss of volatile components. Such properties can actively contribute to enhance the aging resistance of the asphalt binder, and consequently of the asphalt mixtures. The objective of this paper is to present the effect of nano hydrotalcite modification in the mechanical behavior of Stone Mastic Asphalt with an 8 mm upper sieve size of the aggregate (SMA 8). The gap-graded aggregate skeleton bounded with a mastic mortar that is very rich in modified bitumen (7.5%), and contains 0.5% of natural cellulose fibers, are special characteristics that are able to induce a more significant effect of the nanomodification. The dosage of hydrotalcite was 3% by mass of asphalt binder. The study of the mechanical behavior comprised laboratory tests of resistance to permanent deformation (EN 12697-22), indirect tensile strength (EN 12697-23), water sensitivity (EN 12697-12), stiffness (EN 12697-26), and resistance to fatigue (EN 12697-24). The main conclusions were established by comparing the results obtained with those of an unmodified SMA 8. Although the unmodified SMA 8 already exhibited good mechanical performance, it was possible to observe that the nanomodified SMA 8 also showed an adequate behavior for application in surface layers. The most relevant enhancement was obtained in the evaluation of water sensitivity by the indirect tensile strength test, achieving a 100% indirect tensile strength ratio. In general, the results revealed the potential of hydrotalcite for the modification of asphalt mixtures, indicating positive effects in terms of durability.

## 1 Introduction

Technological innovations in pavement engineering are currently being explored to improve materials' performance from the mechanical, economic, and environmental points of view. In the case of surface layers, the asphalt mixtures have to withstand a

wide range of environmental and traffic conditions and, at the same time, provide special and more exigent conditions of skid and rutting resistance, among other characteristics. In addition to this, bitumen is a material that is sensitive to aging, and its properties deteriorate over time also affecting the performance of asphalt mixtures (Sirin et al. 2018). Aging is a particularly important factor in surface layers because those pavement layers are exposed directly to environmental conditions such as ultraviolet (UV) radiation, moisture, oxygen, and greater temperature variations. New asphalt mixtures have been developed, such as Porous Asphalt (PA) and Stone Mastic Asphalt (SMA), using a wide variety of additives in order to enhance the performance of asphalt mixtures during the pavement's life cycle. In recent years, different additives were developed for different purposes: adhesion improvers, fibers, rubber, warm mix asphalt additives, rejuvenators, and polymers (Behnood 2019, 2020; Caputo et al. 2020; Gupta et al. 2019; Habbouche et al. 2020; Picado-Santos et al. 2020; Rossi et al. 2017; Slebi-Acevedo et al. 2019). These new asphalt materials not only provide more resistant and resilient, and longer life pavements but also protect the environment and reduce maintenance costs.

Self-healing is aimed at increasing the lifespan of road pavements by reducing the aging effect on asphalt pavements. Three main self-healing technologies are currently available for asphalt pavement construction and maintenance: nanoparticles, induction heating, and rejuvenation (Behnood 2019 Crucho et al. 2019; Pasupunuri et al. 2017; Tabaković and Schlangen 2016; Vo et al. 2020).

The application of nanomaterials as an additive in asphalt mixtures is being considered today as an option in pavement technology. Indeed, like other additives, nanomaterials are suitable for asphalt binder modification with a view to improving asphalt mixtures' performance. Several studies have demonstrated the benefits of the modifications with nanomaterials – such as nanosilica, nanoclays, and nanoiron – on the mechanical performance and aging resistance (Crucho 2018; Crucho et al. 2018, 2019; Filippi et al. 2018; Martinho and Farinha 2017; Yanga and Tigheb 2013).

Hydrotalcite is a type of layered double hydroxide (LDH) (Evans and Slade 2005; Wang and O'Hare 2012). LDHs are ionic lamellar compounds made up of positively charged brucite-like layers of organic-inorganic or inorganic-inorganic nanomaterials. Compared to clays mineralogical structure, LDHs are less prone to delamination due to stronger interactions interlayers. The substance has already been considered to be a promising modifier for construction materials, particularly on account of its ability to reflect UV radiation (improving UV aging resistance), delay oxygen permeability, and retard the loss of volatile components. There are research studies on potential applications of LDH in concrete materials with very positive results (Duan et al. 2013; Xu et al. 2009). The application of LDH in asphalt mixtures has also been studied in recent years mainly thanks to its ability to be a physical barrier against UV and, as a consequence thereof, to delay the aging of bitumen (Cui et al. 2016; Liu et al. 2014; Pang et al. 2014; Peng et al. 2015; Xu et al. 2015, 2016, 2017; Zhao et al. 2015; Zhu et al. 2019).

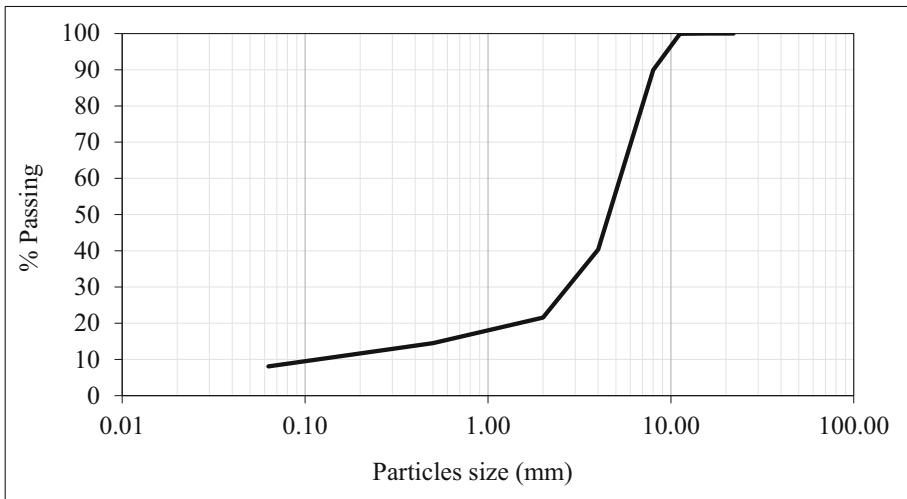
We believe that these properties of nano hydrotalcite can actively contribute to enhancing the aging resistance of an asphalt binder, and consequently of asphalt mixtures. The influence could be more effective in the case of binder-rich asphalt mixtures. The innovative objective of this paper is to present a study on the feasibility of the nano hydrotalcite modification of SMA 8. The paper describes a preliminary laboratory

study on the mechanical behavior characterized by indirect tensile strength and water sensitivity, stiffness, and resistance to fatigue and permanent deformation.

## 2 Methodology

### 2.1 Materials

An SMA 8 asphalt mixture was used in this study. The aggregates mixture consisted of the following percentages (relative to the total mass of aggregates mixture) of the three fractions based on the minimum and maximum nominal sizes ( $d/D$ ): 20% of 6/12 fraction; 54% of 2/6 fraction; and 19% of fraction 0/6. Figure 1 shows the grading curve of the aggregates mixture. Aggregates were obtained from crushed gabbro rock.



**Fig. 1.** Particles size distribution

The SMA was made up of 7% (relative to the total mass of aggregates mixture) of filler (limestone) and 0,5% (relative to the total mass of asphalt mixture) of natural cellulose fibers. This mixture was designed in accordance with EN 13108-5. The asphalt mixture was made up of 7.5% (relative to the total mass of asphalt mixture) of PMB 45/80-65 modified bitumen (control binder). Table 1 presents the main Marshall properties of the asphalt mixture.

The asphalt mixture was modified with 3% (relative to the total mass of asphalt binder) of nano hydrotalcite. Crucho (2018) describes the modification procedure followed in this study. The properties of penetration (EN 1426) and softening point (EN 1427) of the control and modified binders are presented in Table 2. Two similar asphalt mixtures were produced in the study: the control mixture (unmodified with hydrotalcite), and the modified mixture (modified with 3% of hydrotalcite).

**Table 1.** Marshall properties of control asphalt mixture

Property	Unit	Value
Stability	kN	6.7
Flow	mm	3.2
Marshall quotient	kN/mm	2.1
Porosity	%	4.9

**Table 2.** Properties of control and modified binders

Binder	Penetration	Softening point
	$\times 10^{-1}$ mm	$^{\circ}\text{C}$
Control	52.5	90.0
Modified	47.1	93.0

## 2.2 Laboratory Tests

Table 3 lists the properties and test standards followed in the laboratory study according to the European specification framework in EN 12697 for hot mix asphalt. Indirect tensile strength and water sensitivity were determined according to EN 12697-23 and EN 12697-12, respectively. Stiffness evaluation was based on EN 12697-26 and adopting the four-point bending beam equipment, under controlled strain, at 20°C. Resistance to fatigue was determined using the four-point bending beam equipment, under controlled strain, at 20°C and with 10 Hz sinusoidal loading, in accordance with EN 12697-24. Evaluation of permanent deformation was based on EN 12697-22 (wheel-tracking), using the small-size device and specimens conditioned in air.

**Table 3.** Test methods

Property	Test standard	Parameters
Indirect tensile strength	EN 12697-23	Indirect tensile strength (ITS)
Water sensitivity	EN 12697-12	Indirect tensile strength ratio (ITSR)
Stiffness	EN 12697-26	Stiffness modulus Phase angle
Resistance to fatigue	EN 12697-24	Fatigue lines
Permanent deformation	EN 12697-22	Rut depth in air ( $\text{RD}_{\text{air}}$ ) Proportional rut depth in air ( $\text{PRD}_{\text{air}}$ ) Wheel-tracking slope in air ( $\text{WTS}_{\text{air}}$ )

### 3 Results and Discussion

#### 3.1 Indirect Tensile Strength and Water Sensitivity

The mixture modified with 3% hydrotalcite presented good performance in the indirect tensile strength (ITS) and indirect tensile strength ratio (ITSR). Compared with the control mixture, the modified mixture presented 3% increase in  $ITS_{dry}$  (under dry conditions, with no water sensitivity conditioning) and 9% increase in  $ITS_{wet}$  (after water sensitivity conditioning). The results of ITS and ITSR of the control and modified mixtures are presented in Fig. 2. The control mixture also presented a good performance for these parameters, indicating no problems with ITS or ITSR. This means that the margin for enhancement using the modification was limited. Nevertheless, in the modified mixture the increase in  $ITS_{wet}$  superior to the increase in  $ITS_{dry}$  led to an increase in ITSR, with the modified mixture presenting a ratio of 100%. Such results provide a good indication of the positive effect of the modification with hydrotalcite on ITS and water sensitivity.

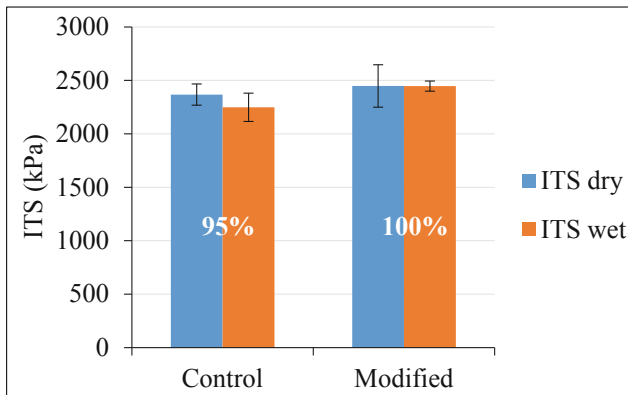
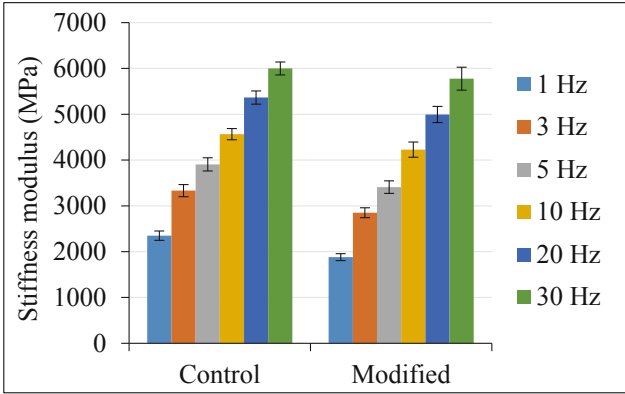


Fig. 2. ITS and ITSR of control and modified mixtures

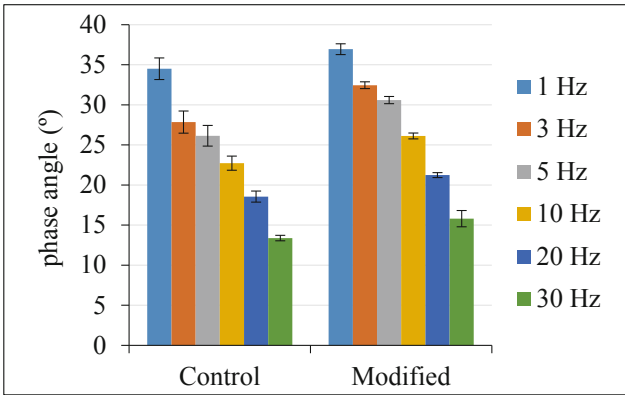
#### 3.2 Stiffness

The modification with hydrotalcite had some effect on the stiffness of the asphalt mixture. Compared with the control mixture, the modified mixture presented a slightly lower stiffness modulus, with a variation dependent on the loading frequency. The reduction in stiffness modulus of the modified mixture was 20% and 4% at 1 Hz and 30 Hz respectively, and for the intermediate frequencies, the observed reduction was approximately linear. With regard to phase angle, the modified mixture presented slightly higher values than the control mixture. At 1 Hz the increase in phase angle was 7% and at 30 Hz the increase in phase angle was 18%, meaning the values of the intermediate frequencies were within these two extremes. The results of the stiffness modulus and phase angle of the control and modified mixtures are presented in Fig. 3 and Fig. 4 respectively.

The elastic slopes (slope of the regression line of the natural logarithms of the loading frequency and elastic modulus) calculated from the stiffness data were 0.316 and 0.377



**Fig. 3.** Stiffness modulus of control and modified mixtures



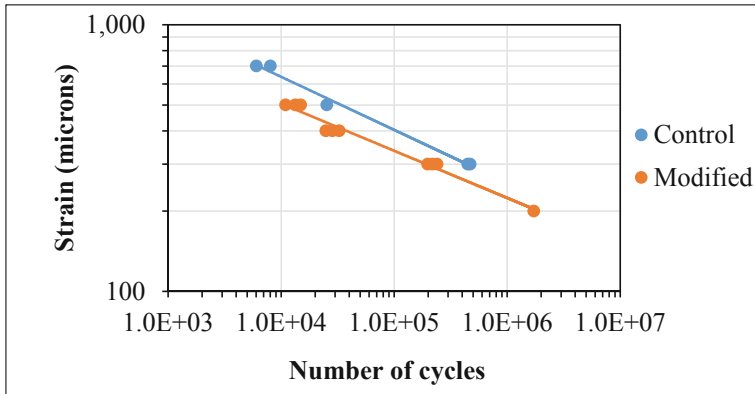
**Fig. 4.** Phase angle of control and modified mixtures

for the control and modified mixtures respectively. The elastic slope alone is not an accurate indicator of the aging level of the asphalt mixture; nevertheless, this parameter does decrease as the aging increases (Crucho 2018). As the modified binder presented a lower penetration value and higher softening point, one possible explanation for the higher elastic slope of the modified mixture, in line with a slightly lower stiffness modulus and slightly higher phase angle, could be that it is an effect of aging protection of the asphalt binder and mixture, particularly in the mixing and compaction stages. This property requires further investigation.

### 3.3 Resistance to Fatigue

The modification with hydrotalcite had an effect on fatigue resistance. However, the differences observed were relatively small considering the high dispersion commonly observed in fatigue tests. The fatigue lines of the control and modified mixtures are presented in Fig. 5. The strain corresponding to the application of one million loading

cycles ( $\epsilon_6$ ) was  $255 \mu\text{m/m}$  for the control mixture and  $224 \mu\text{m/m}$  for the modified mixture. Thus, the modified mixture presented a reduction in  $\epsilon_6$  of 12%. The slopes of the fatigue lines were  $-5.0$  and  $-5.7$  for the control and modified mixtures respectively. In the case of the slope of the fatigue line, the modified mixture presented an increase of 13%.



**Fig. 5.** Fatigue lines of control and modified mixtures

### 3.4 Permanent Deformation

The parameters obtained with the wheel-tracking tests, i.e. rut depth in air ( $RD_{\text{air}}$ ), proportional rut depth in air ( $PRD_{\text{air}}$ ), and wheel-tracking slope in air ( $WTS_{\text{air}}$ ), for the control and modified mixtures are presented in Table 4. For each parameter, the respective value of standard deviation is presented in brackets. The modified mixture presented higher values for all parameters, indicating a softer behavior, which to some extent, is in line with the results for stiffness. Nevertheless, the results obtained can be considered within the range expected for SMA 8 mixtures.

**Table 4.** Wheel-tracking results of control and modified asphalt mixtures

Asphalt mixture	$RD_{\text{air}}$	$PRD_{\text{air}}$	$WTS_{\text{air}}$
	mm	%	mm/ $10^3$ cycles
Control	3.9 (3.1)	7.5 (5.9)	0.286 (0.206)
Modified	10.9 (1.7)	21.4 (3.2)	0.343 (0.134)

## 4 Conclusions

This paper presents and discusses the results of a laboratory study aimed at assessing the effect of nano hydrotalcite modification on the mechanical behavior of an asphalt

mixture. The selected mixture, a binder-rich (with 7.5% bitumen) Stone Mastic Asphalt with 8 mm upper sieve size of the aggregate (SMA 8), was modified with 3% hydrotalcite. The unmodified and the modified asphalt mixture were tested for indirect tensile strength, water sensitivity, stiffness, resistance to fatigue and permanent deformation.

The results obtained from the experimental study allow for the conclusion that nano modified SMA 8 presents in general an adequate mechanical performance for application in surface layers. The modification with hydrotalcite had effects on the mechanical performance of the SMA 8. The most important enhancement was obtained in the evaluation of water sensitivity by the indirect tensile strength test, achieving 100% indirect tensile strength ratio. The hydrotalcite modification gave positive indications regarding a potential effect in terms of aging protection and consequent improvements in durability.

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