STUDY ON THE CONSERVATION OF BITUMINOUS MIXES IN HIGH MOUNTAIN ROADS AND COASTAL ZONES

Ángel Vega-Zamanillo
Professor of Roads and Traffic, University of Cantabria, Spain
Luis Juli-Gándara
Research of Highways, University of Cantabria, Spain
Miguel Ángel Calzada-Pérez
Professor of Roads, University of Cantabria, Spain
Evelio Teijón-López Zuazo
Professor of Construction Engineering, University of Salamanca, Spain

ABSTRACT

The main objective of road conservation is to maintain the characteristics of the platform elements to ensure that vehicle mobility is carried out comfortably and safely. The orographic conditions of Spain, with a large length of high mountain roads and others at sea level; and winter weather events, with low temperatures, wind, water, ice, snow,…, which cause deposits of particles, filler, soils, small metals, or sea salt on the pavement surface, can be dangerous in the circulation of vehicles.

One of the traditional methods for maintaining wheel-pavement adhesion is to apply flux products, mainly salt (sodium chloride, NaCl) and calcium chloride (Cl_2Ca), solidly or humidified (salt brine). This chemical fluxes have the property of preventing the formation of ice as antifreeze, or facilitating their melting if it has already formed.

This research studies the influence of salt in the surface layer of pavement made of hot mix asphalt with conventional binder. The effect of the salt is analyzed under three different conditions: immerse the specimens in salt water; add salt as aggregate in the manufacture of the mix; and submerging the natural aggregate in water with several amounts of salt, dry it and then manufactured the mixture with it. The mechanical parameters of the mixture have been analyzed in the laboratory: density, air voids, adhesion, indirect tensile strength and plastic deformation. To do this, Marshall test, Water Sensitivity Test (ITSR) and Wheel Tracking Test have been performed.

The properties of hot mix asphalt do not decrease significantly when it is manufactured of salt added as aggregate, neither when it is submerged in salt water. The bituminous mixture offers negative results when it is manufactured with natural aggregate submerged in water with salt previously, because the adhesion between the aggregate and the binder is low.

1. INTRODUCTION

The conservation of roads is defined by actions aiming at restoring the initial properties of the road, homogenizing the quality of the pavements, correcting construction mistakes and adapting pavements to new traffic loads, getting a comfortable and safe circulation.

Some conservation activities are intended for the maintenance of the road in the winter season, avoiding or eliminating the presence of snow or ice on the road surface, because they have direct influence on the circulation of vehicles. In other places, such as roads in port and coastal areas, actions are performed that protect or reduce the damage of the pavement by aggressive elements (seawater, soils, chemical elements, wastes, oils,..).

However, the construction and conservation of highways implies an environmental impact, mainly with the consumption of natural materials, or the modification of others, to improve the mechanic properties and durability of the pavements (Organisation for Economic Co-operation and Development 1997). This implies in a large investment in winter road viability. For example, in the winter road viability campaign 2015-2016, Spain's Ministry had 1334 snowplow machines, 240,877 tons of fluxes, mainly salt, and 36 emergency car parks on the State Road Network, which cost more than 65 million of euros (ACEX 2017).

Fluxes are products, natural or not, that have the property of preventing the formation of ice, lowering the freezing point of the water to temperatures below 0ºC, or melting it in case it is already formed. The most commonly used materials in road winter viability are sodium chloride (NaCl) and calcium chloride ($CaCl_2$), in solid form or in brine form (water with a dissolved salt concentration greater than 5 %). Magnesium chloride ($MgCl_2$) is also used, but less than the previous ones. In other infrastructures, such as ports and airports it is common to use acetates (calcium acetate – magnesium and potassium acetate) and urea, less aggressive with this type of roads, but its cost is higher.

When salt is spread over the surface of the icy or snowy pavement, the salt dissolves in the layer of water that covers the icy surface, but without incorporating into the ice. The effect is that the freezing temperature of the solution decreases by increasing with the amount of salt. However, this decrease stops from a certain concentration. There is a concentration called “eutectic”, from which the addition of salt does not decrease any more the freezing temperature. If this amount of flux is exceeded, the freezing temperature of the solution starts to rise again until it reaches 0ºC. In conservation activities the salt extends as brine; with a sodium chloride (NaCa) concentration of approximately 23.1%, in order to achieve an eutectic concentration, so that the road surface will not freeze, or it may melt ice if it already exists, up to a temperature of -21.1ºC. Below this temperature, the effect of the de-ice will be lost. In theory, the de-ice effect occurs up to the eutectic temperature, but it really is before, because there is an increase in time for salt to act, even depending on humidity (García 2010).

The reaction with salt is endothermic, needing an external supply of heat to be able to dissolve the salt in water. This heat is generated from the elements in contact with flux, pavement and air. If the existing temperatures are -5ºC, it may be necessary to apply a ratio of calcium chloride (approximately one third), which functions as exothermic agent, generating heat to dissolve the salt better. If the temperature is below -15ºC, sodium chloride loses its fluxing effect. Salt acts as a flux because it is hygroscopic, and reacts with humidity and atmospheric temperature from relative humidity of 75%. When a film of water is formed on the surface of the ice or snow layer, there is a contact with the salt and a heat transfer to the outside, resulting in a cooling of salt and water, theoretically until the temperature of this solution reaches the corresponding value of the saturated solution (-21.1ºC). The initial heat that melts the snow, allows the absorption of the cold of the salt, generating a heat of the condensation that is released, generating the defrosting process (ACEX 2017). When salt dissolves in water the sodium (positive) and chlorine (negative) ions are floating, and one attracts hydrogen and the other to oxygen, breaking the hydrogen bonds of water. The problem is that the brine absorbs humidity, dissolving more and more, forming a saturated solution, and therefore decreases its antifreeze capacity, favoring new layers of ice. Therefore, it is often necessary to extend new layers of brine.

There are also studies on the behavior that bituminous mixtures have when they are in contact with de-icing salt. A direct effect of salt on the surface of the road, is that it stiffens the bituminous mixture, decreasing the penetration of bitumen. When salt ions dissolve in water, sodium ion (Na+) is poorly reactive in bitumen, while chlorine ion (Cl^-) reacts with sulfur ions (S^-) that bind the different carbon chains of binders , so that ion (Cl^-) is introduced into these carbon bonds, rigidizing them and weakening bitumen, decreasing adhesiveness between bitumen and aggregate. Hassan et al. (2012) studied the mechanical properties of the bituminous mixes affected by different types of de-icing agents and freeze-thaw cycles. For the specimens submerged in salt water, observed an increase in indirect tensile strength respect the specimens submerged in distilled water for 25 and 50 freeze-thaw cycles. Giuliani (2012) or Zheng et al. (2015) studied different types of additives added to the asphalt mixture as aggregate, to avoid the formation of ice in the roadways, composed basically of salt (NaCl and $CaCl_2$).

Others studies are not based on the deicing salt due to winter road processes. Seawater is a salt water with a salt concentration of approximately 3.5%. Seawater freezing temperatures are lower than distilled water, and in coastal areas, salt can modify the mechanical properties of the bituminous layers of roads near the coast. Feng et al. (2010) studied the effect of the salt in asphalt mixtures with some specimens submerged in seawater and have remained under freeze-thaw cycles. They simulated it by adding salt to the bitumen and subjecting the specimens to freeze-thaw cycles. They concluded, for all mixes studied (AM-16, OGFC-19 and AC-16), a decrease in the indirect tensile strength ratio, more evident in the AM mixture and less in the AC mixture.

The purpose of this study is to evaluate the mechanical properties of asphalt concrete mixtures that have been submerged in saltwater, manufactured with salt (salt added as aggregate or as anti-icing additive), and manufactured with aggregates that had been submerged in salt water. The tests carried out have been density, air voids, indirect tensile strength (ITS), water sensitivity test (ITSR) and wheel tracking test.

2. MATERIALS

2.1 Aggregate

The aggregate used is ophite. Some properties of aggregate are:

- Density = 2.92 gr/cm^3.
- Los Angeles Abrasion Test (UNE-EN 1097-2: 2010) = 16.0%.
- Water Absorption (UNE-EN 1097-6: 2014) = 1.0%.
- Flakiness Index (UNE-EN 933-3: 2012) = 9.0%.

2.1 Binder

For this study, a conventional B 50/70 bitumen has been used for the bituminous mixes. Some properties are:

- Penetration (25ºC; 100g, 5s) (UNE-EN 1426:2015) = 65.0 dmm.
- Softening Point (UNE-EN 1427:2015) = 47.2ºC.
- Frass Breaking Point (UNE-EN 12593:2015) = -9.0ºC.

2.3. Salt and seawater

The density of salt used is 2.165 g/cm^3. Its content of filler (under 0.063 mm) is 6.6%.

The seawater used comes from the Bay of Santander (Spain) near the Maritime Museum of the Cantabrian Sea. This was filtered by a 50 μm sieve. It has a salt concentration of 3.5%, completely dissolved.

2.4. Asphalt concrete

The bituminous mix analyzed is AC-16 Surf B 50/70 D. It is normally used in the surface layer of the pavements. The composition for the mix is in Table 1.

Passing rate (%)									Asphalt s/m (%)
Sieve size (mm)	22.00	16.00	8.00	4.00	2.00	0.50	0.25	0.063	
	100.0	95.0	71.5	51.5	38.5	21.5	15.5	6.0	5.0

Table 1 – Composition of asphalt concrete (AC-16 Surf B 50/70 D)

The manufacture of the asphalt concrete is done in a mixer with vertical shaft and planetary rotation. First, the aggregate is introduced in it and the bitumen are added. The binder content is 5.0% s/m, by weight of the mixture. They are mixed for one minute. After, the filler is added and mixing continues for 3 minutes more.

Marshall samples were used to calculate the air voids of the mix (UNE-EN 12697-34:2013) and the water sensitivity test (UNE-EN 12697-12:2009), while for the wheel tracking test (UNE-EN 12697-22:2008) slabs of 50 mm were manufactured.

3. METHODOLOGY

3.1 Salt treatments

The effect of the salt in the asphalt concrete is studied in three different ways.

3.1.1. Specimens submerged in salt water

In this case, specimens of asphalt concrete are submerged in water with different concentrations of salt. The salt is completely dissolved.

The amount of salt by weight of water are based in the percentage of salt in seawater (3.5%), and two different contents (5.0% and 10.0%). The quantity, the temperature and time that the specimens are submerged in water varies according to the test conditions.

The series of specimens are:

- Series 0: Reference. They are submerged in distilled water and 0.0% of salt by weight of water.
- Series 11: They are submerged in seawater with 3.5% of salt by weight of water.
- Series 12: They are submerged in distilled water with 5.0% of salt added by weight of water.
- Series 13: They are submerged in distilled water with 10.0% of salt added by weight of water.

3.1.2. Salt added to the mixture as aggregate

In this case, salt is added into the mixer when aggregates and binder are being mixed. Salt is a new aggregate and it is not a substitute for any initial aggregate (Giuliani et al., 2012, or Zheng et al., 2015). When the mixture is being manufactured, salt does not dissolve in the binder.

The series of specimens are:

- Series 0: Reference. 0% of salt by weight of binder.
- Series 21: 5.0% of salt by weight of binder.

- Series 22: 10.0% of salt by weight of binder.
- Series 23: 38.0% of salt by weight of binder.
- Series 24: 95.0% of salt by weight of binder.

3.1.3. Aggregate saturated in salt water

The aggregate is submerged for 72 hours at 20 °C in water with different salt concentrations. It is enough time to saturate the aggregate. After, the aggregate is dried at 60°C for 24 hours. Then, the particles are heated to obtain the mixing temperature. The amount of salt by weight of water to saturate the surface of the particles are based in the concentration of salt in seawater (3.5%), and two different contents (2.0% and 5.0%).

The series of specimens are:

- Series 0: Reference. Aggregate is not submerged in water with salt.
- Series 31: Aggregate is submerged in water with 2.0% of salt by weight of water.
- Series 32: Aggregate is submerged in water with 3.5% of salt by weight of water.
- Series 33: Aggregate is submerged in water with 5.0% of salt by weight of water.

3.2 Laboratory tests

3.2.1. Density and air voids

Density and air voids percentage of the bituminous mix are obtained according to the Marshall Test (UNE-EN 12697-34, 2013).

Fig. 1 - Marshall Test

The specimens of asphalt concrete are compacted by 75 blows per side (Figure 1). The diameter of the specimens is 101.6 mm and the height is 63.5 mm height. The test is carried out with four specimens for each series.

3.2.2. Water Sensitivity Test (ITSR)

This test calculates the Indirect Tensile Strength Ratio (ITSR), to evaluate the adhesion between aggregate and binder, according to the procedure “Method A” of the UNE-EN 12697-12 standard (2009). The resistance to traction of the specimens kept dry (ITSd) and wet (ITSw) was obtained (Figure 2). The Indirect Tensile Strength Ratio (ITSR) was calculated by dividing (ITSw) between (ITSd). In Spain, the Spanish Standard requires an Indirect Tensile Strength Ratio of at least 85% for mixtures for the surface layer, tested at 15ºC (PG-3, 2008).

Fig. 2 - Indirect Tensile Strength Test

The dimensions of the specimens are the same than Marshall Test. They are compacted with 50 blows per side, as it is established by PG-3 (2008). Each group of samples was separated into two groups. One of the groups was kept for three days in a room at 20ºC and the other was submerged in water at 40ºC for three days after a vacuum treatment for 40 minutes. After three days, the mixes were put into a room at 15ºC for two hours prior to the test. Then, an indirect tensile strength test was performed on both groups of specimens, according to UNER-EN 12697-23 (2004), using a universal static machine.

3.2.3. Wheel tracking test

This test evaluates the plastic deformation of the mixture when a moving vertical load is applied on the surface of the specimens. This test was done for cases in which the ITSR result in the sensibility water test was closest to 85%, according to the Spanish Standard. The test is carried out in accordance with the standard UNE-EN 12697-22:2008, “Procedure B in air” and “Procedure B in water”, compacted by roller compactor (UNE-

EN 12697-33:2006+A1, 2007). The dimensions of the specimens are 410.0 mm length, by 260.0 mm width, by 50.0mm height (Figure 3). Two specimens of each series have been tested. In Spain, the Spanish Standard requires a Wheel Track Slope (WTS) in air, at 60ºC, between 0.07 - 0.10 mm/103 cycles depending on the heavy vehicles categories.

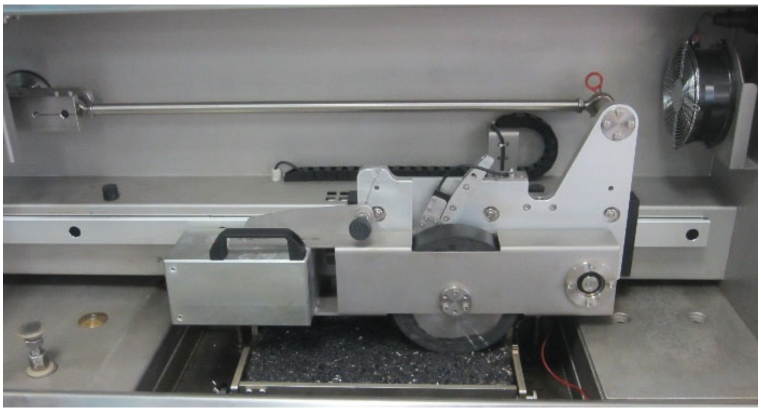

Fig. 3 - Wheel tracking Test

4. RESULTS

4.1. Density and air voids

The results of densities and air voids percentage obtained for AC-16 Surf B 50/70 D are shown in Table2.

Series		Air Voids (%)	Density (gr/cm^3)
Reference	A	6.1	2.51
Specimens submerged in salt water	11	6.1	2.51
	12	6.0	2.51
	13	6.4	2.50
Salt added as aggregate	21	6.0	2.51
	22	6.7	2.49
	23	6.6	2.49
	24	7.3	2.45
Aggregate saturated in salt water	31	6.5	2.50
	32	8.2	2.46
	33	6.4	2.50

Table 2 – Density and air voids content

The specimens submerged in seawater (series 11) or submerged in salt water with similar salt concentration than seawater obtained equals results than reference series A. Series 13, specimens submerged in salt water, with 10.0% of salt added by weight of distilled water, resulted with higher air voids content, and therefore, lower density.

For the second series, some differences appear when salt is added as aggregate to the bituminous mixture. When the salt particle content increases, the density of the mix decreases, and therefore, the air voids content increases. This happens when the salt modifies the particle size of all aggregates. Also, the density of the salt is lower than the density of the aggregate. The salt is added but it does not fill voids. Salt produces an increase in the total volume of the specimen and the air void volume increases.

For the third series, when only the aggregate has been saturated in salt water, small differences were observed. For a concentration of 3.5% of salt in water, the percentage of air voids is higher than the reference mixture; but the aggregate covered by salt does not modify the particle size of the mixture.

4.2. Indirect Tensile Strength and Water Sensitivity Test

The values of ITS and ITSR are in Table3.

Series		ITSd (kN)	ITSw (kN)	ITSR (%)
Reference	A	1687	1610	95
Specimens submerged in salt water	11	1687	1575	93
	12	1687	1636	97
	13	1687	1590	92
Salt added as aggregate	21	1595	1559	97
	22	1477	1493	101
	23	1625	1471	90
	24	1468	1432	98
Aggregate saturated in salt water	31	1595	1299	81
	32	1369	1040	76
	33	1544	1156	75

Table 3 – ITS and ITSR

For the first series, there is not significant variation between the specimens submerged in salt water and series A. The results of Indirect Tensile Strength Ratio fulfill the specifications of the Spanish standard, clearly above 85%.

For the second series, in which the salt is added as aggregate, the results of all ITS for dry and wet specimens are lower than ITS for the reference series. Anyway, the values of the all ITSR are very good and similar to the reference series, fulfilling the specifications of the Spanish standard. It could be caused by the fact that the asphalt concrete has more quantity of aggregates by the salt added to the mixer. The density of salt and its size are lower than the density and particle size of the ophitic aggregates, but filler/binder ratio of the bituminous mix is higher when salt is added. So, the Indirect Tensile Strength for wet specimens does not decrease as much as in dry specimens. In the case of a 10.0% of salt added by weight of binder the ITSR is greater than 100%.

The results for the specimens in which the aggregate is saturated in salt water are very low, and the ITSR values are below 85%. The Indirect Tensile Strength for wet specimens decreases significantly. In this case, the adhesiveness between aggregate and binder is affected by the salt that envelops the particles of the aggregate.

4.3. Wheel Tracking Test

For this test, one case of each salt treatment was selected in which the ITSR result in the sensibility water test was closest to 85%, according to the Spanish Standard. The test was carried out in air at 60ºC, and in wet.

The results of wheel track slope at 10000 cycles (WTS) and rut depth (RD) are presented in Table4.

Series		WTS (mm/10^3 cycles)		RD (mm)	
		In Air	In Water	In Air	In Water
Reference	A	0.08	0.07	3.2	4.0
Specimens submerged in salt water	13	0.08	0.05	3.2	2.3
Salt added as aggregate	23	0.07	0.07	3.2	3.7
Aggregate saturated in salt water	31	0.07	0.07	3.0	3.0

Table 4 – Wheel track slope and rut depth

All the values obtained are similar than series A, and wheel track slope comply the Spanish Standard for all heavy traffic categories. Salt does not affect the plastic deformation of the mixture.

5. CONCLUSIONS

The mechanical properties of a bituminous mixture AC-16 Surf B 50/70 D are not affected by salt dissolved in water with amounts similar to the concentration of salt in seawater, in high mountain and coastal roads.

When the asphalt concrete is submerged in salt water, density, percentage of air voids, adhesiveness between aggregate and binder, and plastic deformation resistance is maintained in the same conditions as the same mixture under non-aggressive environmental conditions.

The mechanical behavior of the bituminous mixture when the salt is added to the mix as aggregate is the best of all the treatments analyzed. The best results have been obtained with 10.0% of salt added by weight of binder. The density decreases by increasing the added salt, and filler/binder ratio is higher. Water does not worsen the characteristics of concrete asphalt when salt is added as aggregate.

The worst results have been obtained when the aggregate is previously saturated in salt water, especially for the water sensitivity. The salt creates a film around the surface of the aggregate particles, decreasing the adhesiveness.

No treatment affects the resistance to plastic deformations.

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