Stripping in HMA produced by aggregates from C&D Waste

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Abstract

This paper analyzes the effect of water on the durability of hot asphalt mixtures made with recycled aggregates from construction and demolition debris. Indirect Tensile Stress tests were carried out to evaluate stripping behavior. The mixtures tested were fabricated with 0, 20, 40 and 60% recycled aggregates. Two types of natural aggregates were used: schist and calcite dolomite. An increase in the percentage of recycled aggregates was found to produce a decrease in the Tensile Stress Ratio of the hot asphalt mixtures. To study this phenomenon, two and three factor Analyses of Variance (ANOVA) were performed with Indirect Tensile Stress being used as the dependent variable. The factors studied were the percentage of recycled aggregates (0, 20, 40 and 60%), the moisture state (dry, wet) and the type of natural aggregate (schist, calcite). On the basis of the ANOVA results, it was found that the most important factor affecting resistance was the moisture state (dry, wet) of the specimens. The percentage of recycled aggregate also affected Indirect Tensile Stress, especially in the dry state. The type of natural aggregate did not have a significant effect on Indirect Tensile Stress. The hot asphalt mixture specimens made with different percentages of recycled aggregates from construction and demolition debris and of natural quarry aggregates showed poor stripping behaviour. This stripping behaviour can be related to both the poor adhesion of the recycled aggregates and the high absorption of the mortar of cement adhered to them.

Keywords: Stripping, Construction and Demolition Waste, Hot mix asphalt

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1. Introduction

Waste has become one of the most serious environmental problems plaguing modern societies, particularly those that are more advanced and industrialized. This increasingly difficult situation has been aggravated by the sheer volume of waste that is generated and the close relationship between income levels and quality of life and the amount of waste produced. Spain produces approximately 13 million tons of construction and demolition waste materials (C&D waste) annually, less than 5% of which are reused or recycled, while the European Union recycles or reuses an average total of 28% of the C&D waste it generates (Symonds et al, 1999). Most of these waste materials are hauled off to landfills, causing a negative environmental impact. In view of this situation, in 2001 the Spanish National Construction and Demolition Waste Plan 2001-2006 (Ministerio de Medio Ambiente, 2001) was passed, with one of its main objectives being to recycle or reuse 60% of the C&D waste by 2006. To date, this goal has not been achieved. In 2008 the new Spanish National Construction and Demolition Waste Plan 2008-2015 (Ministerio de Medio Ambiente, 2008) was passed and it targets the recycling or reuse of 55% of C&D waste by the year 2015. To achieve this ambitious objective it has become necessary to define more processes to recycle C&D waste. Given that flexible road pavements consume huge amounts of aggregates, from an environmental standpoint it would be of interest to consider the possibility of using of C&D waste aggregates in the construction of flexible road pavements.

Although much research has focused on the use of recycled aggregates (RA) from C&D waste as unbound granular materials (Bennert el al, 2000; Poon and Chan, 2006) and as materials treated with hydraulic conglomerates (Hansen, 1992; Cross et al 1996; Rahshir and Barai, 2006) only a limited number of technical experiments have dealt with the use of this type of waste material in Hot Mix Asphalt (HMA).

In this sense, according to Shen and Du (2004, 2005), HMA containing RA exhibited satisfactory mechanical behavior and the stripping impact was also considered satisfactory. In keeping with these authors, Aljassar and Al-Fadala (2005) reported that HMA produced using aggregates from demolition waste met all the requirements of the Kuwait specifications. On the other hand, Paranavithana and Mohajerani (2006) observed that HMA made with RA presented mechanical results comparable to those of conventional mixtures. Nevertheless, when they evaluated stripping behavior, a 34% loss of Stress in mixtures with RA was observed. According to these authors, this poor behavior was due to high water absorption and the easy separation of the mortar adhered to the recycled concrete aggregates. In keeping with Wong et al (2007) the mechanical behavior of mixtures containing RA achieved better performance than conventional mixtures. However, no test of any kind was carried out to evaluate stripping.

Finally, Pérez et al (2007) revealed that HMA made with RA offer a greater resistance to permanent deformation than mixtures that contain only natural aggregates (NA). They observed that in HMA produced with RA, stiffness was higher and a deterioration of the fatigue law was produced. Additionally, Pérez et al (2009) designed pavement sections for flexible pavements bearing medium or low volumes of traffic with a service life comparable to that of conventional materials. Unfortunately, HMA containing RA had a considerably high stripping potential.

Given that the different authors do not share the same opinion as to the stripping potential of C&D waste in asphalt mixes, the aim of this research work is to evaluate the impact of construction and demolition waste aggregates on stripping of HMA. The Analysis of Variance (ANOVA) model was applied to obtain results with statistical significance.

2. Materials and methods

2.1 Characterization of the Basic Materials

The basic materials were characterized in accordance with the Spanish technical standards NLT (Ministerio de Obras Públicas y Transportes, 2002) (Tests for Roads Materials) from the Spanish Road Study Centre and the UNE-EN standards from the Spanish Association for Standardization and Certification (Asociación Española de Normalización y Certificación, 2001). The UNE-EN specifications are the Spanish version of the EN European standards. The mixtures were designed according to the Spanish General Technical Specifications for Road and Bridge Construction, also known as PG-3 (Dirección General de Carreteras, 2002). Table 1 presents the results of the tests on the materials and the PG-3 requirements.

Natural Aggregates

Two kinds of natural aggregates were used. The first NA was schist supplied by a quarry in fractions of 0/6, 6/12 and 12/25 mm. The rock was composed of quartz (35%), albite (30%), mica (20%) and chlorite (15%). This aggregate complied with the Spanish specifications (Table 1): i.e., the flakiness index was less than 35%; all the particles were fractured; the sand equivalent was greater than 50% and the Los Angeles fragmentation coefficient was under 30%. The bulk specific gravity was between 2.76 and 2.68. The water absorption coefficient ranged from 0.12% (fraction 12/25) to 0.21% (fraction 6/12). The second NA used was calcite dolomite supplied by a quarry in fractions of 0/6, 6/12 and 12/25 mm. The rock was composed of calcite (40%), dolomite (40%) and quartz (20%). This calcite dolomite aggregate complied with the Spanish specifications (Table 1). The bulk specific gravity was between 2.88 and 2.82. The water absorption coefficient ranged from 0.55% (fraction 12/25) to 0.82% (fraction 6/12).

Recycled Aggregates

The recycling of materials from C&D waste to be used as a recycled aggregate in HMA entailed the following process: a selection of the appropriate materials at source, crushing at the C&D waste plant, the removal of pollutants, sieving and classification of the aggregates and washing. In this sense, an RA production plant is very similar to an NA crushing plant. It is equipped with crushers, sieves, conveyor mechanisms, equipment for pollutant removal and electromagnets to separate the steel.

The C&D waste plant (Figure 1a) produces an 0/40-mm fraction used as an unbound granular material (Figure 1b) in pedestrian and cycling paths with the following composition in weight: concrete (72.5%); stone (21.5%); miscellaneous bituminous (4%), ceramic materials (1%), and some impurities such as clay, metals, wood, plastics, rubber and gypsum plaster (1%). Figure 2 shows the grading curve of the RA provided by the C&D waste plant. Table 1 indicates that the flakiness index and sand equivalent values meet the requirements stipulated in the Spanish specifications. All of the particles are fractured. The RA do not comply with the Los Angeles fragmentation coefficient specification (Table 1). The bulk specific gravity was 2.63. The water absorption coefficient value of the RA was 6.1%, much higher than that of the NA due to the presence of cement mortar from the concrete, and adhered to the RA. During the investigation, only coarse RA (>4 mm) were used for HMA production. Prior to production, all ceramic materials, clay, metals, wood, plastic, rubber and gypsum plaster were eliminated by visual inspection.

Filler

The filler used in all the types of mixtures was Portland cement. The Blaine surface area was 3350 cm^2/g and the specific gravity, 3.12 g/cm^3.

Asphalt

The asphalt used had a penetration grading of 69.10^{-1} mm and a softening point with the ring and ball method equal to 48.5º C. Pfeiffer's penetration index had a value of -0.8 with a density of 1.03 g/cm3 (Table 1). It was confirmed that the asphalt complied with all the Spanish specifications.

2.2 Mechanical Test

Since the least strict HMA requirements are those for the base layers of low volume roads, an AC 22 base coarse HMA was chosen for the investigation. Table 2 shows the grading curve selected. A total of eight mixtures were designed with the same grading but different percentages of RA. The RA used in the mixtures were the coarsest fractions of the grading curves (between 4 and 20 mm). Listed below are the eight mixtures designed in the lab:

- Four HMA using schist as NA and containing the following RA %: 0, 20, 40, 60%.
- Four HMA using calcite as NA and containing the following RA %: 0, 20, 40, 60%.

A specific nomenclature system was used to record the mixtures. First a capital letter to indicate the type of NA: schist (S) or calcite (C), secondly a number referring to the RA % (0, 20, 40, 60%). Thus, for example S-20 indicates a mixture that uses schist as NA and contains 20% RA.

All mixtures were designed with the Marshall Method. This test was performed according to the Spanish NLT-159 standard (Ministerio de Obras Públicas y Transportes, 1992). Five series of cylindrical samples compacted with 75 blows per side were made with different asphalt percentages. The average value of the following parameters was calculated for each percentage of asphalt: Voids in Mineral Aggregate, VMA (%); Air Voids in Compacted Mixture Va (%); Voids Filled with Asphalt VFA (%); Flow Value, F (mm); Stability, S (kN); and Unit Weight, UW (g/cm^3).

Next, eight series consisting of six specimens each were designed in order to carry out the Indirect Stripping Tensile Test (ISTT). The specimens were produced with the optimum asphalt content (B_o) selected from the Marshall test. The specimens were compacted with 50 blows per side using the Marshall test molds and compactor. The trial temperature of the specimens was 15º C. The ISTT was used to measure the loss of cohesion produced by saturation and water acting on the HMA. In this case, the test was conducted in compliance with the European standard EN-12697-12 (Asociación Española de Normalización y Certificación, 2004). The ISTT provides a ratio of the average Stress of a conditioned set of three specimens submerged in water at 40ºC for three days to the average Stress of an unconditioned set of three specimens maintained in air at 20ºC for three days (Equation 1). Since the test is an indirect tensile test, the ratio is called a Tensile Stress Ratio (TSR), and it is expressed as a percentage.

$$TSR = \frac{ITS_w}{ITS_D} \times 100 \qquad [1]$$

Where TSR = Tensile Stress Ratio (%), ITS_w = average wet Indirect Tensile Stress (MPa), ITS_D = average dry Indirect Tensile Stress (MPa.). In the HMA base courses in Spain, the TSR values must be over 80%.

2.3 ANOVA Analysis

The use of Analysis of Variance (ANOVA) models provides the researcher with a statistical based technique capable of producing meaningful models of the importance of the factors studied in an experiment. A three-way ANOVA analysis using Statgraphics (Statistical Graphics Corporation, Rockville, MD, USA) was selected to investigate factor effects and interactions among them. The dependent variable used was the Indirect Tensile Stress. The three factors were: moisture state (dry, wet), NA type (Schist, calcite dolomite), and the % of

RA (0, 20, 40 and 60%). The moisture state and NA type are qualitative variables and the percentage of RA is a quantitative variable.

Two, two-way ANOVAs were later carried out depending on the moisture state. The purpose of this was to determine the effect of these factors on the ITS.

In ANOVA models, the effect of each factor is measured as a percent of the total variance of the data. The effect of each individual factor is called the main effect. The effect of each pair of combined factors or of a trio of factors is called an interaction effect.

The sum of the main effects and the interaction effects would be 100 if the ANOVA model were to fully explain the sources of the variance of the data. Usually, however, the model is unable to relate all of the variances of the data to the effects of the factors. Therefore, the sum of the effects is less than 100 and the difference is called the residual value. This value expresses the percent of the variance of the system that the model does not explain.

An effect is considered of statistical significance for a 95% confidence level if the p-value in the Fisher distribution is less than 0.05.

3. Results and discussion

3.1 Production of mixtures in the laboratory

During the production of the mixtures, it was observed that the quartzites as well as the siliceous particles coming from the recycled material were covered with great difficulty. This is due, in part, to the chemical nature of these materials, but also to the fact that other particles originating from the concrete have mortar on their surface and, because of the high absorption capacity of the mortar, less effective binder is left to cover the recycled quartzite and siliceous aggregates. This is demonstrated in Figure 3: mixture S-0 has an appropriate color and shine (a), while mixture S-20, despite containing 1% more binder, exhibits coarse aggregate that was left uncovered (b).

3.2 Marshall Parameters

Table 3 shows the Bulk Specific Gravity (G_{sb}) in paraffin oil of aggregates used in the mixture designs. Paraffin oil was utilized because of its absorption, which is similar to that of asphalt. Also given are the optimum asphalt contents (B_o) used in the production of the specimens for the Indirect Stripping Tensile Test. The Marshall parameters corresponding to B_o are included as well.

According to the results presented in Table 3, compliance is achieved with the Spanish PG-3 requirements for HMA used as a base course material in low volume roads having heavy traffic category T3. Traffic category T3 refers to the following interval of Annual Average Daily Heavy Traffic: $50 \leq AADT_H < 200$.

It can be seen in Table 3 that the specific gravity (Gsb) of the aggregates diminishes upon the incorporation of the RA. This translates to a lower unit weight (UW) of the mixtures. This tendency is accentuated by the increase in air voids (Va) and in voids in the aggregate (VMA) upon the addition of greater percentages of RA, despite the simultaneous increase in binder content. That is to say, the compaction operation was less efficient in the mixes incorporating RA.

Considering the appearance of the mixtures during their production (Figure 3), these tendencies can be related to the high level of absorption of the cement mortar in the RA which causes a higher binder demand. This results in the mixtures with RA being short on binder, despite containing more binder than the reference mixtures.

It would be advisable, when working in the laboratory with this type of recycled material, to give the mixture time to stand at a high temperature before being compacted. This would allow time for the absorption of the binder by the cement mortar, resulting in a higher binder content than what would be obtained without the standing time allotted to facilitate absorption.

3.3 Tensile Stress Ratios

Table 4 gives the results of the resistance of the 48 specimens subject to the indirect tensile stress test. The table has been subdivided according to the following factors:

- Percentage of RA: 0, 20, 40, 60%.
- Aggregate type: schist or calcite dolomite.
- Moisture state of the specimens: wet or dry.

Table 4 shows that, in keeping with the increasing trend of the Marshall stability values, the rising RA percentages increase the resistance of the bituminous mixture to tensile stress. However, upon increasing the RA content, the action of the water has a more severe impact; that is to say, the TSR is lower as the RA content increases.

This could be due to the air void content, which goes from 5% to 5.5% with the schist NA and from 5% to 7% with the calcite NA. But it does not appear that such drastic losses in TSR (from 88% to 60% with the schist NA and from 96% to 52% with the calcite NA) could be due solely to the increase in voids. It is more likely related to the lack of adhesion of the RA. As can be seen in Figure 3, during production adhesion was poor in the mixture with RA. Furthermore, Figure 4 shows that after immersion, the water managed to displace the binder of the RA and the breakage of the specimen occurred at the interface RA – bituminous mortar. By contrast, in the dry state specimen the breakage was produced, for the most part, by the bituminous mortar.

Figure 4a shows the symmetry of a broken specimen of mix S-20 in the dry state. All the mineral particles (green marks) can be found on the left and on the right of the symmetry axle at the same time. However, Figure 4b shows the lack of symmetry in a specimen that broke after immersion. A number of mineral particles of RA (red marks) appear just on the right.

This demonstrates that the crack affected the interface RA – bituminous mortar rather than the mineral particles.

Therefore, the decrease in the tensile stress ratio is due to the lack of adhesion of the RA – bituminous mortar and the high level of absorption of the cement mortar adhered to the RA.

3.4 ANOVA Analysis

Three Way-Analysis

Table 5 offers the results of the three-way ANOVA analysis testing for interaction. The model explains 90% of the total variance (Residual = 9.99). The three main effects are statistically significant for a 95% confidence interval. The most important main effect was the moisture state. This effect explained 53.16% of the total variance (with statistical significance: $p=0.000 < 0.05$). The other main effects, i.e. RA % ($p=0.000$) and NA type ($p=0.021$) were also significant. However, the effect of RA % proved to be of greater importance, as it explained 10.41% of the total variance, while the effect of the NA type only explained 1.83%.

In second-order interactions (Table 5), the interaction between RA % and the moisture state was significant ($p=0.000$), accounting for 18.01% of the total variance. This is reflected by the opposite behavior of the specimens in the dry vs. the wet state for the different RA percentages. The resistance of the specimens in the dry state increases with RA percentage; while the resistance of the specimens in the wet state does not undergo any increase. The interaction between the RA % and NA type is also significant, although to a lesser extent ($p=0.009$), since it is only able to explain 4.24% of the total variance. Table 4 shows the discrepancy between the behavior of the specimens made with NA calcite (C) and those containing NA schist (S). The resistance of the specimens is consistently lower with NA calcite except for the 60% RA mixture where resistance was higher with NA schist. Lastly, there was no interaction between NA type and moisture state ($p=0.566 > 0.05$), as it only accounted for 0.10% of the total variance. It is interesting to note that the ITS of NA calcite and NA schist increases in the same proportion when going from the wet state to the dry state. On the basis of the ANOVA, it can be deduced that the most influential factor in specimen resistance is the moisture state. Moisture state is involved in 73.52% of the total variance. Therefore, the effect exerted by both RA % and NA type on resistance would seem to be different depending on the moisture state (dry or wet). For this reason, two separate ANOVAs for each moisture state were performed as follows.

Two-Way Analysis

The results of the separate two-way ANOVAs (by moisture state) are given in Table 6. In the wet state the model explains only 58.14% of the total variance, whereas in the dry state, it accounts for 81.48% of the total variance.

From the table it is evident that for the wet moisture state, both the RA % ($p=0.125 > 0.05$) and NA type ($p=0.075 > 0.05$) are not significant as single factors. However, the double interaction between RA % and NA type has a significant effect on the resistance of the specimens in the wet state ($p= 0.027 < 0.05$). In keeping with this, the RA % is found in 48.84% of the total variance.

In the dry state, the RA % main effect significantly influences ($p=0.000 < 0.05$) resistance, while the NA type main effect ($p=0.105$) does not have any significant impact. The double interaction is also significant, although to a lesser degree than in the wet state. Here the RA % is found in 78.08% of the total variance.

On the basis of the two-way ANOVAs, it was found that when specimens are in the wet state, the RA % does not significantly affect resistance. What does, however, affect it significantly is the interaction between RA % and NA type. In contrast, in the dry state, the RA % (as a single factor) has a significant effect on the ITS of the specimens. In keeping with this, when the RA

% increases, the ITS of the specimens in the dry state also rises significantly. This, however, does not occur in the wet state, where resistance tends to diminish. Logically, the above demonstrates that an increase in RA % leads to a decrease in the TSR values of HMA specimens.

4 Conclusions

It has been demonstrated that the RA content of the HMA translates to an increase in ITS in the dry state specimens and a drop in TSR. This behaviour upon exposure to water is due to the poor adhesion of the RA. To evaluate these results, it must be remembered that only coarse fraction RA was used, without any fine contaminants, and that all the particles of gypsum plaster and ceramic material were removed prior to the tests. Hence, the unsatisfactory adhesion is due to the coarse quartzite and the siliceous mineral particles.

Another circumstance able to accentuate the stripping of the mixtures is the high level of absorption of RA. The cement mortar adhered to them is porous and requires a greater binder demand. During the laboratory tests the mixture was compacted directly after mixing. Therefore the absorption was not complete and this might have contributed to a general weakness of the mixture when exposed to water.

Considering that the RA do not comply with the Los Angeles requirements and that the mixtures demonstrate very little resistance to the action of water, the Spanish specifications for asphalt mixtures are not met. Moreover, these specifications are not even met for bituminous mixtures used in base layers of low volume roads.

With these results in mind, it is recommended that for further research on Construction and Demolition waste aggregates in HMA the following should be taken into account:

- Fine fraction RA should not be utilized, as it contains significant amounts of cement mortar and impurities. Gypsum plaster and ceramic content should be eliminated from the coarse fraction of RA.
- Laboratory tests for the design of the asphalt mixture should allow time for the asphalt mixture to settle at a high temperature to ensure the absorption of the binder by the cement mortar and concrete particles. In this way the design will take into account the effective binder after absorption.
- Furthermore, the use of anti-stripping agents should be included in further investigations.

The same recommendations apply to large-scale production. In particular, enough time should be allowed for the transport and laying-down of the asphalt mix in order to complete the absorption of the binder by the cement mortar in the recycled materials. In some cases, regulation heated hoppers might be necessary to increase the available time for the absorption of the binder by the mortar and the cement particles.

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Figure 1 a) C&D Waste Plant, b) Recycled Aggregates (Coarse Fraction)

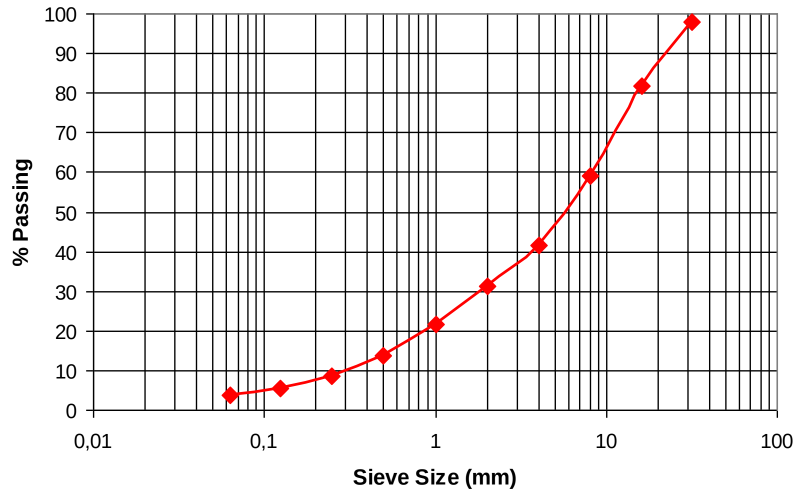

Figure 2 Grading curve of RA

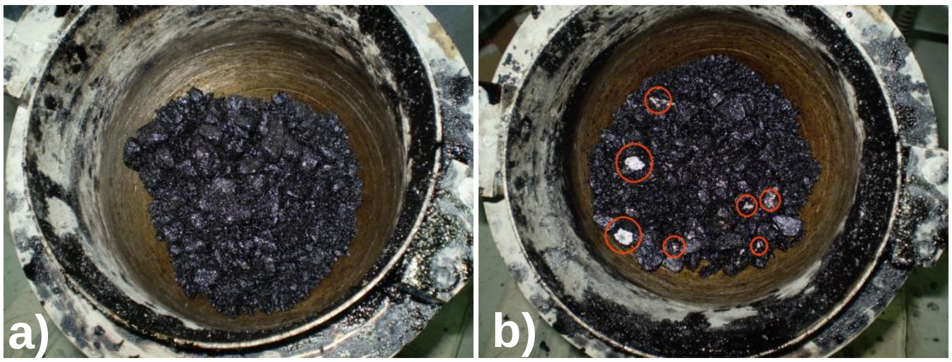

Figure 3. Appearance of **HMA** after mixing a) S-0, b) S-20

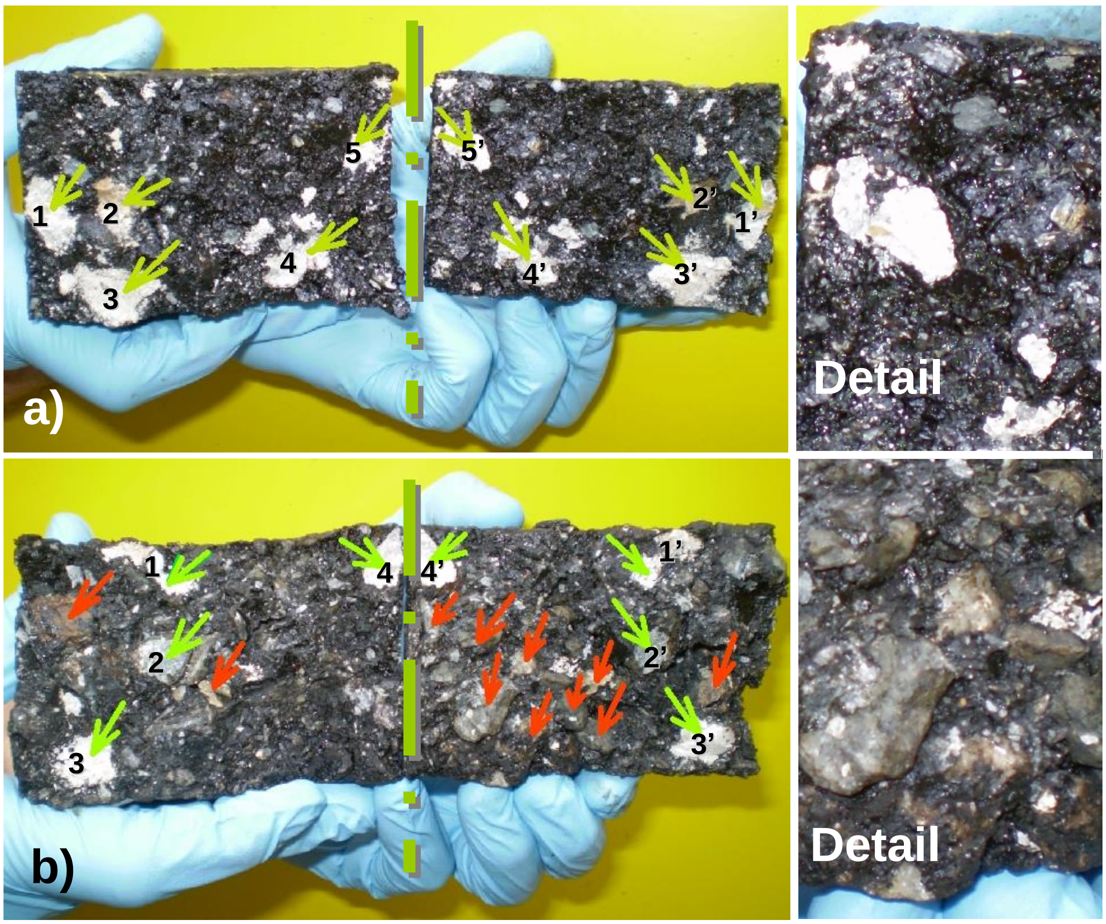

Figure 4. Appearance of mixture S-20 specimens after indirect tensile test.
a) Dry state, b) Wet state.

Table 1 Characterization of aggregates and binder. PG-3 requirements.

Test	Standard	PG-3	NA						RA
			Schist			Calcite dolomite			
			0/6	6/12	12/25	0/6	6/12	12/25	0/40
Flakiness index (%)	EN 933-3	<35	--	17.2	19.4	--	11.3	14.6	34
Fractured particles (%)	EN 933-5	100	100	100	100	100	100	100	100
Sand equivalent (%)	EN 933-8	>50	85	--	--	66	---	---	67
Methylene blue test (g/kg)	EN 933-9	--	0.22	--	--	0.25	---	---	--
LA fragmentation (%)	EN 1097-2	<30	--	--	22.1	--	---	24.1	34
Bulk Specific Gravity	EN-1097-6	--	2.76	2.69	2.68	2.88	2.83	2.82	2.63
Water absorption (%)	EN 1097-6	--	--	0.21	0.12	--	0.82	0.55	6.1
			Asphalt						
Penetration (0.1 mm)	EN 1426	50/70	69						
Softening point (ºC)	EN 1427	48/57	48.5						
Penetration index	NLT-181	+1/-1	-0.8						
Density (g/cm^3)	NLT-122	--	1.03						

Table 2 Asphalt Mix Grading

	Coarse aggregate (including RA)					Fine aggregate (only NA)				Filler
Sieve (mm)	25	20	12.5	8	4	2	0.5	0.25	0.125	0.063
% Passing	100	95	75	60	37.75	28.5	13	10	7	4.75

Table 3. Marshall Parameters

	S-0	S-20	S-40	S-60	C-0	C-20	C-40	C-60	PG-3 Requirements
Bulk Specific Gravity, G_{sb} (g/cm^3)	2.661	2.634	2.592	2.571	2.572	2.701	2.633	2.563	-------
Optimum Asphalt content, Bo (%)	4.5	5.0	5.5	5.5	4.0	4.3	4.5	4.8	Min. 3.5
Voids in mineral aggregates, VMA (%)	14.5	15.5	17.0	17.0	14.0	15.0	16.5	16.0	≥14
Air voids, Va (%)	5.0	5.0	5.0	5.5	5.0	5.0	7.0	6.0	5-9
Voids filled with Asphalt, VFA (%)	66.8	69.6	69.1	67.0	71.0	65.5	62.1	63.3	-------
Flow, F (mm)	2.3	2.4	2.4	2.6	2.3	2.4	2.7	2.7	2-3.5
Strength, S (kN)	10.5	11.0	11.0	12.2	10.2	11.2	11.2	12.2	>10
UW (g/cm3)	2.36	2.33	2.27	2.26	2.45	2.39	2.30	2.26	-------

Table 4 Indirect Tensile Stress (ITS) results (MPa)

% RA	Specimen	Aggregate type			
		Schist		Calcite	
		State		State	
		Wet	Dry	Wet	Dry
0	Sample #1	0.99	1.19	0.79	0.78
	Sample #2	0.97	0.91	0.72	0.90
	Sample #3	0.91	1.18	0.85	0.79
	Average	0.96	1.09	0.79	0.82
	TSR (%)	88 (S-0)		96 (C-0)	
20	Sample #1	0.89	1.04	0.93	1.27
	Sample #2	0.81	1.32	1.02	1.05
	Sample #3	0.84	1.30	0.84	0.93
	Average	0.85	1.22	0.93	1.08
	TSR (%)	70 (S-20)		86 (C-20)	
40	Sample #1	0.78	1.25	0.65	1.16
	Sample #2	0.87	1.33	0.84	1.23
	Sample #3	0.92	1.40	0.79	1.30
	Average	0.86	1.33	0.76	1.23
	TSR (%)	65 (S-40)		62 (C-40)	
60	Sample #1	0.86	1.25	0.80	1.46
	Sample #2	0.77	1.45	0.76	1.65
	Sample #3	0.86	1.48	0.85	1.55
	Average	0.83	1.39	0.80	1.55
	TSR (%)	60 (S-60)		52 (C-60)	

Table 5 Three-Way ANOVA

Source of Variation	Sum of Squares	Df	% Total Sum of Squares	Mean Square	F	p
Main effects						
% de RA	0.319	3	10.41	0.106	11.11	0.000
NA type	0.056	1	1.83	0.056	5.88	0.021
State	1.629	1	53.16	1.629	170.33	0.000
2 –Way-Interactions						
% de RA-NA type	0.1305	3	4.24	0.043	4.55	0.009
% de RA-state	0.552	3	18.01	0.184	19.24	0.000
NA type-state	0.003	1	0.10	0.003	0.34	0.566
3-Way-Interaction						
% de RA-state- NA type	0.069	3	2.25	0.023	2.41	0.085
Residual	0.306	32	9.99	0.009		
Total	3.065	47	100.00			

Table 6 Two-Way ANOVAs at each moisture state

		Wet				Dry			
Source of variation	Df	Sum of Squares	% Total Sum of Squares	F	p	Sum of Squares	% Total Sum of Squares	F	p
Main effects									
% de RA	3	0.030	17.44	2.83	0.125	0.841	66.53	10.15	0.000
NA type	1	0.016	9.30	3.62	0.075	0.043	3.40	2.95	0.105
2-way-interactions									
% de RA-NA type	3	0.054	31.40	3.99	0.027	0.146	11.55	3.32	0.047
Residual	16	0.072	41.86			0.234	18.51		
Total	23	0.172	100.00			1.264	100.00		