INNOVATIVE TESTING PROTOCOL FOR THE EVALUATION OF BINDER-RECLAIMED AGGREGATE BOND STRENGTH

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INTRODUCTION

- An increasing amount of Reclaimed Asphalt Pavement (RAP) is used for the production of new bituminous mixtures. The most widespread technique used to include RAP in new mixtures is the Hot Recycling method: when RAP is mixed with virgin aggregates and virgin binder at high temperatures, chemical and physical interactions occur and strongly affect the properties of recycled mixtures making the hot mix asphalt more prone to premature failure.
- The adhesion developed at the interface between aggregates and asphalt binder is one of the main mechanisms that influences the behavior and the performance of a mixture: no specific test methods exist to study and quantify the adhesion between RAP aggregates (aggregates coated with a thin film of aged asphalt binder) and virgin asphalt binder.
- An effective and practical method, successfully employed to identify the bitumen-aggregate affinity and the related moisture damage, is the Binder Bond Strength (BBS). It allows to quantify the bond strength developed at the interface between aggregates substrates and binders in both dry and wet condition.
- In this study an innovative testing protocol has been developed in order to integrate the current BBS test. In particular, the experimental investigation proposes an original procedure to prepare in laboratory aggregate substrates aimed to properly simulate the RAP surface. The aggregate plates prepared following this method are then used to perform the standard BBS test.

EXPERIMENTAL PROGRAM

- **MATERIALS:** *2 AGGREGATES* (basalt and a limestone) were selected. Horizontal square aggregate plates were prepared (10 × 10 cm²) to allow the positioning of five specimens. *3 SBS POLYMER MODIFIED BINDERS* were investigated, characterized by three modification levels: 1.8, 2.8 and 3.8% by bitumen weight (respectively S, M and H).

Binder	SBS %	Pen @25 °C	R&B soft.point	Ductility @25°C	Dyn.viscosity @135 °C
	%	0.1 mm	°C	cm	Pa·s
S	1.8	59	66.8	97	0.81
M	2.8	54	68.6	> 100	1.02
H	3.8	52	70.8	> 100	1.24

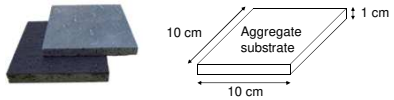
- **EXPERIMENTAL PROGRAM:** two different surface treatments were considered, a virgin aggregate with untreated surface and an artificial RAP aggregate having a surface coated with a thin film of binder H. For each test configuration, all the samples were conditioned in dry or wet environment.

Binder	Aggregate	Surface treatment	Conditioning	Replicates
S, M, H	Basalt	Virgin	Dry	5
			Wet	5
		Coated	Dry	5
			Wet	5
	Limestone	Virgin	Dry	5
			Wet	5
		Coated	Dry	5
			Wet	5

SPECIMEN PREPARATION PROCEDURE

Artificial RAP substrate

- Heat binder to obtain a fluid consistency and heat aggregate plates at 135 °C for 1 hour in a forced-draft oven.
- Coat aggregate surfaces with a uniform binder thin film (0.2 ÷ 0.3 g), ensuring a binder film thickness of ~ 9.5 µm able to adequately reproduce the bitumen thickness coating a RAP aggregate.

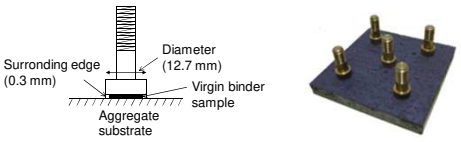


- Age the coated plates at short and long term according to AASHTO Standard R30 (135±3 °C for 4±0.5 h and subsequently 85±3 °C for 120±0.5 h). This last step aimed to properly simulate the oxidation experienced by the RAP during the whole service life that can have significant effects also in terms of bond strength interactions at the interface between virgin and aged binder.

TESTING

BBS test method

- The test is performed by means of a specific equipment, composed by a portable pneumatic adhesion tester. The device is also equipped by a piston, a reaction plate, and a metal pull-stub.
- Place 0.08 g of virgin binder onto the pull-stub surface previously heated at 65 °C for of 30 minutes like the aggregate plates.
- Afterwards, the pull-stub is pressed onto the aggregate surface.



- Conditioning: dry specimens are left at 25 °C for 24 hours whereas wet specimens are conditioned at 40 °C for 24 hours in a water bath and then at 25 °C for 2 hours in air dry conditions.
- After the conditioning, the piston and the reaction plate are screwed to the stub and the air pressure is steadily transmitted through the pneumatic system until failure. The pressure value displayed in the test equipment is recorded and the failure type is visually identified.

RESULT ANALYSIS

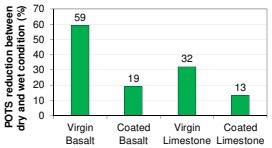
Failure type

Type A
FAILURE AT THE INTERFACE: loss of adhesive bond strength between binder and aggregate

Type B
INTERMEDIATE FAILURE

Type C
FAILURE WITHIN THE BINDER: loss of cohesion within the binder

Moisture sensitivity



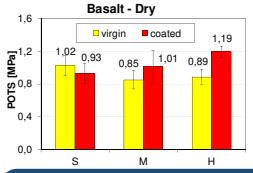
- Failure type A for virgin aggregates in dry and wet condition, regardless of the virgin bitumen adopted.
- Failure type C for artificial RAP aggregates.

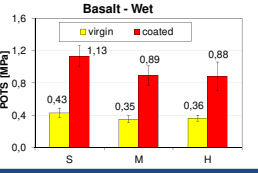
Coated aggregates guarantee improved bonds between the substrate and the binder, also improving the material performance in wet condition. In fact, the failure within the binder for dry coated aggregates does not change into failure at the interface after the water conditioning. The oxidation process experienced by the RAP substrate reduces the free radicals of the material, making the artificial aggregate more resistant to stripping. Moreover, the film of aged binder that coats the aggregate surface reactivates developing chemical interactions with the virgin binder and ensuring optimum collaboration between the two bituminous components.

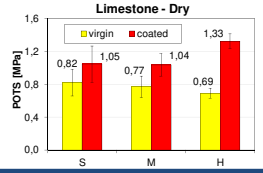
BBS test

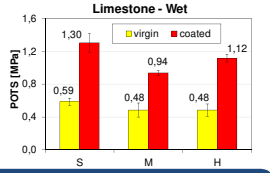
Binder	Aggregate	Surface treatment	Conditioning	Failure type	POTS (MPa)
S	Basalt	Virgin	Dry	C	1.02
			Wet	A	0.43
		Coated	Dry	C	0.93
			Wet	B	1.13
	Limestone	Virgin	Dry	A	0.82
			Wet	A	0.59
		Coated	Dry	C	1.05
			Wet	C	1.30
M	Basalt	Virgin	Dry	A	0.85
			Wet	A	0.35
		Coated	Dry	C	1.01
			Wet	B	0.89
	Limestone	Virgin	Dry	A	0.77
			Wet	A	0.48
		Coated	Dry	C	1.04
			Wet	C	0.94
H	Basalt	Virgin	Dry	A	0.89
			Wet	A	0.36
		Coated	Dry	C	1.19
			Wet	C	0.88
	Limestone	Virgin	Dry	A	0.69
			Wet	A	0.48
		Coated	Dry	C	1.33
			Wet	C	1.12

Pull-Off Tensile Strength results









CONCLUSIONS

- The protocol proposed is able to discriminate among several test parameters and material configurations.
- The presence of a thin film of aged binder in the artificial RAP aggregates ensures the development of a higher adhesion with the virgin binder. This result is detectable both in terms of failure type (failure within the binder) and bond strength values.
- The binder modification level (up to 3.8%) does not affect the bonding properties significantly.
- Limestone aggregates showed higher performance under water condition, due to their hydrophobic nature that creates improved chemical affinity with binder. However, when the artificial RAP aggregates are considered, this difference is sensibly reduced.
- The loss in performance due to the effect of water experienced by the virgin aggregates is much more evident than the loss experienced by the coated aggregates.