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17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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PRELIMINARY INVESTIGATION OF MECHANICAL AND FUNCTIONAL PROPERTIES OF COLOURED ASPHALT PAVEMENT SURFACES

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Abstract

Coloured pavements utilization is rapidly increasing, mostly in urban areas, as valuable mitigation strategy for the phenomenon of heating concentration through the cities connected to the presence of black and high-reflective surfaces favouring the air warming. Moreover, coloured road pavements are already employed as traffic calming measures for the pedestrians and cyclist protection and as eco-friendly solutions in terms of aesthetic preservation. In view of a wide diffusion of such technologies, a consistent knowledge of the mechanical and thermal behaviour is needed. In this regard, the present paper proposes a laboratory investigation aimed at assessing some preliminary characteristics of different construction solutions to obtain coloured asphalt pavements. Different materials for wearing courses were investigated. Red, yellow, green and blue specimens were produced alternatively utilizing mortars and resins for surface treatments, or tinted oxides for the colour modification of the asphalt mixes. Roller compactor was used to obtain slabs suitable to be tested with thermic analysis, determining in-service reached temperatures. Functional properties were investigated through empirical assessments, analysing peculiarities such as horizontal drainability, skid resistance and macro-texture. Mechanical properties were also analysed in case of black and coloured asphalt concretes. Dynamic tests were carried out at different temperatures both on prismatic specimens, in 4-point bending configuration, and cylindrical samples, in indirect tensile configuration. Preliminary rheological tests were also performed on the plain and the oxide-coloured bitumens utilized to produce the “fully-coloured” asphalt concretes. Main findings allow to recognize the strong contribution of colour in terms of heating processes and in-field reached temperatures, which also sensibly affect the performance of in-service pavements. Stiffening effects due to oxides were evinced for asphalt mixtures and were confirmed by preliminary tests at binder scale.

Keywords: coloured asphalt, thermal behaviour, mechanical properties, oxides addition

1 Introduction

Among the different types of unconventional pavements, developed in the attempt to combine traditional functions and modern issues, coloured road pavements are nowadays emerging, in particular within urban areas. Research in this field is mainly focused on the mitigation of typical negative externalities connected to the urbanization processes such as environmental impact and accidents density. In this regard, coloured asphalt pavements could represent a practical response to the Urban Heat Island (UHI) phenomenon, i.e. temperature increases in cities, the needs of aesthetic preservation as well as a mean of traffic calming for the protection of pedestrians and cyclists [1-3]. With respect to UHI, the pressing development of urban areas caused a deep territorial change, with the green spaces gradually replaced by buildings,

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roads and infrastructures. Such modification due to anthropic activities is charging negative effects on energetic performance and costs of buildings, on the air quality, the human health and quality of life. Containing of anthropic emissions, conservation or insertion of vegetation and rearrangements in urban spaces are often difficult to achieve. Otherwise, crucial benefits could be obtained with the use of suitable materials in terms of thermic and permeability properties [4], [5]. In this sense, "cool" road pavements, manufactured for the reduction of heat concentration responsible of urban temperature increase, consist of coloured or clear surfaces able to reflect light and infrared radiations. In this regard, the influence of colours and textures of surfaces on properties such as albedo (reflected energy of solar shortwave radiation), emissivity (radiant infrared energy emitted) and solar reflex index (measure of the ability to maintain cool temperature) are well known [6, 7]. Moreover, great emphasis concerning these aspects must be accounted since transportation infrastructures cover a significant amount of the urban space of high-mobility cities [8]. Coloured or clear roads pavements can be realized using several materials and techniques. As examples, synthetic transparent resin, modified decoloured bitumens, additives and pigments for mixtures, varnishes and paintings for wearing courses can be cited [9]. In this regard, quite a few literature studies documented of wide experimental activities and successful in-service applications of these kinds of materials [10-12]. Otherwise, regardless the use of different solutions and technologies, thermal-optimized pavement must provide adequate functional and safety standards, while ensuring acceptable mechanical performance.

2 Experimentation

The present paper illustrates a laboratory investigation aimed at assessing some preliminary characteristics of different solutions for coloured asphalt pavements. Several materials for wearing courses were investigated analysing thermal and functional characteristics as well as mechanical and rheological performance.

2.1 Materials and specimens preparation

Coloured asphalt mixtures were obtained with different techniques. "Fully-coloured" asphalt concretes were achieved by adding coloured oxides (red or green pellets dosed at 5 % by aggregate weight) during the preparation of a dense graded asphalt concrete (AC16) obtained using limestone aggregates and 50/70 penetration-grade bitumen. Diffusion of such pigments occurred during the blending of mixtures inside the laboratory automatic mixer. Mixes were then compacted through a roller compactor to obtain 50 mm thick slabs (400×300 mm^2 plan dimensions). Oppositely, surface-coloured mixes were obtained just by painting the black upper surface of "black" reference AC16 slabs using alternatively mortars or resins for surface treatment. A reference "black" slab was also tested for comparison purposes. Cylindrical (150 mm diameter) and prismatic samples for the mechanical characterization were then obtained by coring or sawing slabs. In order to perform preliminary rheological tests (to assess the oxide effects on the plain bitumen), black and coloured binders were tested through a Dynamic shear rheometer (DSR). Coloured bitumens (red or green) were obtained dosing oxide-pigments with a 1:1 bitumen-oxide weight ratio to reproduce the same dosage used for coloured mixtures. Figure 1 and Table 1 summarize characteristics and colours of all prepared asphalt concretes. Table 2 shows properties of tested binders.

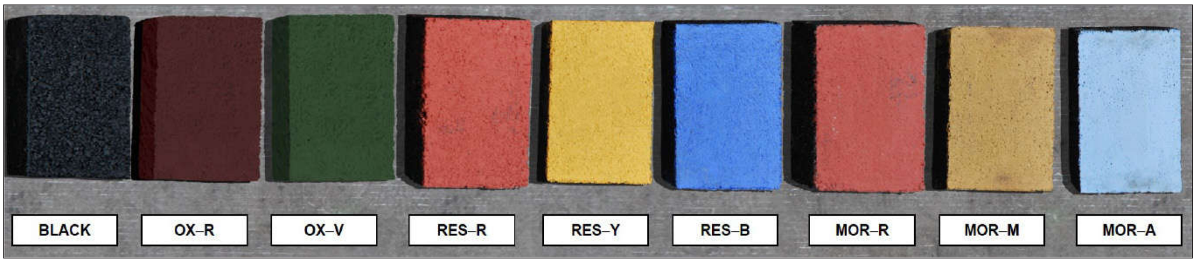

Figure 1 Coloured asphalt concretes

Table 1 Summary of materials characteristics

Code	Color type	Color	Pigment	Surface treatment	Dosage
BLACK	Reference	Black	---	---	---
OX–R	Full	Red	Ferrous oxide	---	5% by agg. w.
OX–V	Full	Green	Chrome oxide	---	5% by agg. w.
RES–R	Surface	Red	---	Resin	2 kg/m^2
RES–Y	Surface	Yellow	---	Resin	2 kg/m^2
RES–B	Surface	Blue	---	Resin	2 kg/m^2
MOR–R	Surface	Red	---	Mortar	2 kg/m^2
MOR–M	Surface	Mustard	---	Mortar	2 kg/m^2
MOR–A	Surface	Azure	---	Mortar	2 kg/m^2

Table 2 Binder properties

Property	Standard	Traditional bitumen	Red-oxidized bitumen	Green-oxidized bitumen
Code	---	BIT	BIT–OX–R	BIT–OX–G
Penetration at 25 °C	EN 1426	55 • 0.1 mm	22 • 0.1 mm	20 • 0.1 mm
Softening point	EN 1427	49.7 °C	84.2 °C	80.9 °C

2.2 Test methods

2.2.1 Thermal analysis

Thermal performance of studied materials were assessed analysing material responses in terms of simulated in-service reached temperatures. Using an advanced thermal camera, an extended monitoring activity on slabs directly exposed to the sunlight radiations was scheduled. In particular, thermic distributions on slabs were recorded every 15 minutes (between 9.00 a.m. and 18.00 p.m.) during 10 consecutive summer days. Experimental setting up was organized to minimize the influence of boundary conditions such as, for example, heating conduction from ground or refreshing effect due to breeze. Further variables connected to the environmental conditions (ambient temperature, humidity, wind speed, amount of cloud cover) were registered and accounted in the elaborations [13]. Emissivity ε, i.e. the infrared light emission attitude, was previously calibrated with a comparative procedure using a known-emissivity black body and then imposed as input parameter of the recording instrument. In analogy, albedo ρ (attitude to light rays' reflection) was also calculated by digitally elaborating some pictures taken during sunlight and comparing subjects with a known-emissivity white mass. Figure 2 gives some information about the applied thermal protocol. Monitoring the temperature reached by different materials, the entire activity allows identifying thermic gradients due to colour and material type, which could sensibly affect performance of in-service pavements (temperature is a crucial parameter for mechanical performance of asphalt pavement) and UHI.

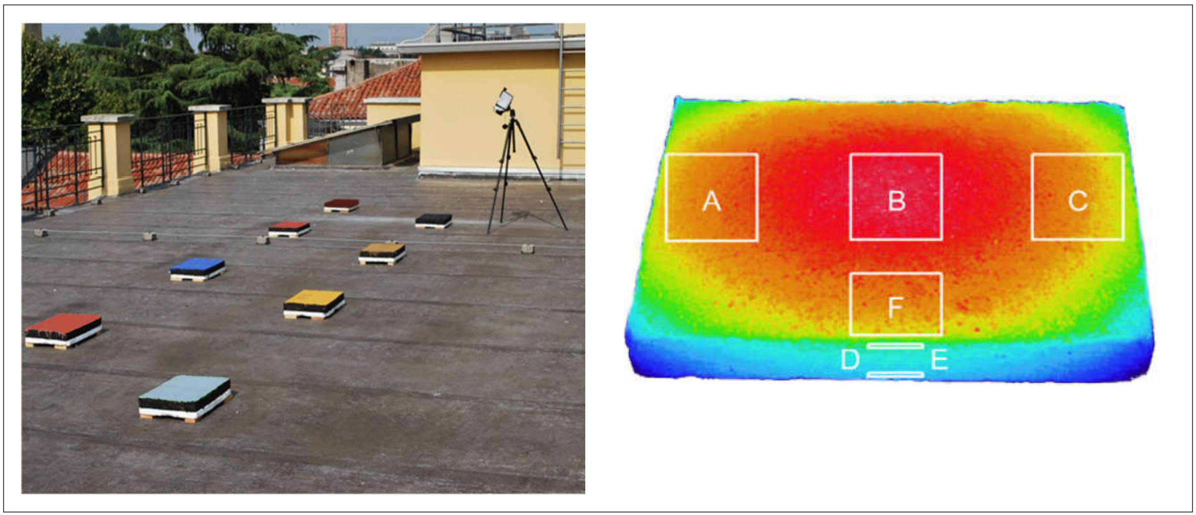

Figure 2 Thermal monitoring: experimental setting up (left), recorded temperature distribution (right)

2.2.2 Mechanical and functional testing

Mechanical and rheological tests were carried out on black and oxide-coloured materials whereas surface characteristics were investigated also on surface-treated (with resins or mortars) slabs. Complex shear modulus G* of binders (plain and oxide-modified bitumens) was assessed through the DSR according to EN 14770. Frequency sweeps were carried out at 10 °C, 20 °C and 30 °C (within linear visco-elastic domains) in the frequency range 0.1 Hz – 30 Hz. Similarly, dynamic complex modulus |E*| of the corresponding mixes was measured in 4-point bending configuration according to EN 12697-26/Annex B (five replicates for each test condition) at three different temperatures (10 °C, 20 °C, 30 °C). Tests were carried out at 50 μm/m peak deformation level by applying a sinusoidal loading at six frequencies ranging from 0.1 Hz to 30 Hz. Master curves at 20 °C of G* and E* were also obtained by applying the time-temperature superposition principle using the well-known Williams–Landel–Ferry (WLF) formulation [14] to determine the shift factors. Stiffness of mixes were also investigated at 20 °C through Indirect Tensile Stiffness Modulus (ITSM) tests according to EN 12697-26/Annex C (5 replicates for each material). Fatigue tests in 4-point bending configuration were also carried out at 20 °C according to EN 12697/Annex D in stress-control mode (5 peak stress levels from 0.55 to 0.75 MPa) applying sinusoidal loads at 10 Hz. Failure was conventionally established to the number of cycles at which a 50% reduction in initial (at 100th cycle) complex modulus occurred. Finally, surface properties such as Mean Texture Depth MTD (EN 13036-1), Permeability P (EN 13036-3) and Pendulum Test Value PTV (EN 13036-4) were assessed to determine how resin and mortar surface treatments affect functionality bituminous pavements.

3 Results and discussions

3.1 Thermal behaviours

Figure 3 depicts daily temperature trends, whereas Table 3 summarizes all collected data. All presented data are intended as average values of ten days recordings (Okta scale level 0 represents completely clear sky, 1 rare cloudy and 2 few cloudy). Both table and figure are referred to box B (see Figure 2) for the accounting of the most heated areas of slabs.
Emissivity calibration did not give significant information; differently, albedo values indicate highest attitude to light rays' reflection for azure mortar slab MOR–A (0.442) and yellow resin slab RES-Y (0.323). These findings were in accordance with average thermic trends deduced from in-service monitoring; in this case, best heat mitigation was achieved by azure mortar slab (MOR–A), with sensibly lower peak (–13.46 °C) or medium temperature (–9.95 °C). In

general, ρ and trends comparison suggested that colour seems more effective with respect to material type in the case of surface treatment, as well as oxide pigments were not strongly able to mitigate heat concentration regardless the colour used (red or green).

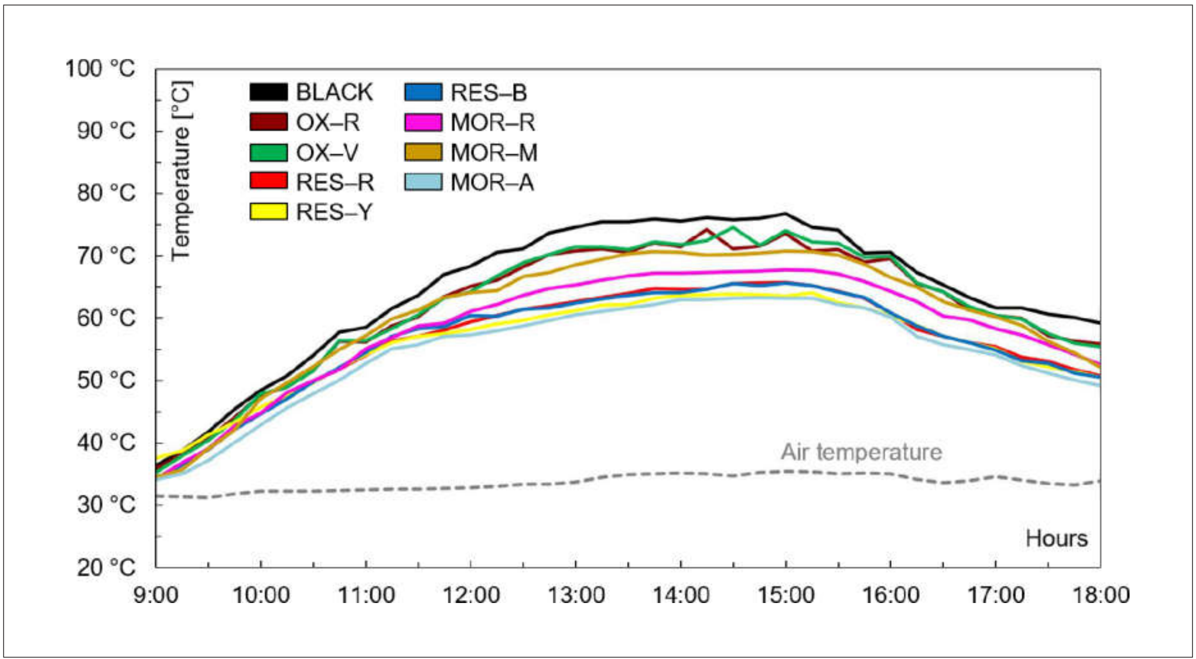

Figure 3 Average (10 days) of daily temperature trends

Table 3 Thermal results (left); summary of weather during monitoring (right)

Slab	ε	ρ	T_{max} [°C]	T_{min} [°C]	T_{mean} [°C]
BLACK	0.90	0.116	76.64	38.69	65.26
OX–R	0.92	0.150	74.14	38.15	62.55
OX–V	0.91	0.127	74.45	37.85	62.74
RES–R	0.93	0.235	65.67	36.47	57.11
RES–Y	0.94	0.323	63.95	38.69	56.55
RES–B	0.92	0.241	65.53	36.51	57.10
MOR–R	0.93	0.215	67.60	36.77	59.12
MOR–M	0.92	0.251	70.68	35.68	61.36
MOR–A	0.93	0.442	63.18	35.02	55.31
**** Average of 10 days – Temperature referred to box B (Fig. 2 right)*					

Okta Scale	
Day 1	1
Day 2	0
Day 3	0
Day 4	0
Day 5	1
Day 6	2
Day 7	1
Day 8	1
Day 9	0
Day 10	0

3.2 Mechanical and functional performance

Mechanical results concerning stiffness and fatigue are expressed in Figure 4. Since results obtained for red and green oxidized materials (binder and mixtures) were similar, only the data referring to one oxidized material are reported for the sake of readability.
In general, oxides provided clearly stiffening effects with respect to reference materials, even if this finding seemed to be less pronounced in the cases of mixtures probably because of the contribution of limestone lithic matrix. Comparing 4-point bending and ITSM results (assuming 2 Hz test frequency on the case of ITSM test), acceptable correspondence among alternative procedures can be identified (ITSM average stiffness of 3259 MPa and 1784 MPa were respectively measured at 20 °C for coloured and black asphalt concretes). Thus, further analysis of fatigue properties was suggested accounting the greater stiffness of modified

materials, which can cause dangerous brittleness and pavement cracking failure. Despite previous considerations, fatigue performance of oxidized mixes was comparable or even enhanced with respect to reference black asphalt concrete.

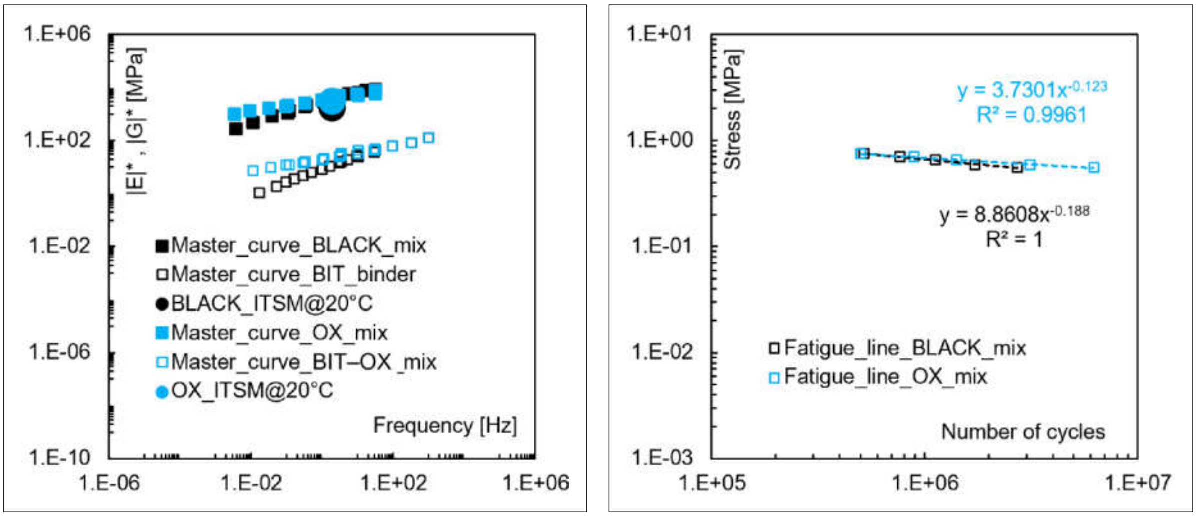

Figure 4 Stiffness (left) and fatigue (right) results

Therefore, it can be asserted that the studied coloured mixtures showed comparable structural contribution and similar in-service life at intermediate temperatures with respect to the reference bituminous material. Concerning functionality of surface-treated concretes (Table 4), both mortars and resins displayed slightly increased skid resistance (greater PTV results) than not-treated reference slabs. Permeability resulted weakly correlated with the type of painting (probably influenced by paint applying procedures, regardless the dosage) but anyway reduced with respect to the reference surface according to a reduced surface texture (low MTD). In any case, all measured values in the laboratory resulted within typical technical specifications limits.

Table 4 Functional properties of reference and surface-coloured slabs

Prop.	BLACK	RES–R	RES–Y	RES–B	MOR–R	MOR–M	MOR–A
MTD [mm]	1.05	0.87	0.91	0.73	0.62	0.72	0.58
P [s]	92.0	851.0	223.5	3240.0	645.0	258.0	531.5
PTV [--]	66.2	72.5	77	70.6	83.1	81.8	82.5

4 Conclusions

The present paper dealt with an extensive experimentation concerning different materials and technologies for the manufacturing of coloured road asphalt pavements. Thermal analysis suggested that surface colour (rather than material types) provided a sensible contribution to contain in-field surface temperatures. Mechanical characterization about oxide-modified “fully-coloured” mixtures highlighted a strong stiffening effect due to the oxide presence. Otherwise, fatigue performance resulted comparable with those of a reference dense-graded “black” bituminous concrete. Macrotexture and skid resistance properties of surface-coloured asphalt mixes resulted within limits typically prescribed by technical specifications even if a reduced macrotexture and horizontal permeability can be detected. Given these preliminary findings, tested products seem able to represent both adequate materials for road pavements and suitable solutions to achieve thermal-optimized surfaces able to mitigate urban heat island phenomenon.

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