Solar Reflectance Index of Pedestrian Pavements and Their Response to Aging

N. L. Alchapar, E. N. Correa, and M. A. Cantón

***Abstract*—Due to the impact of the optical characteristics of the materials composing the urban envelopes on the energy balance of cities, their categorization according to their ability to decrease urban temperatures is an indispensable tool for sustainable development. This work presents the evaluation results of the thermal performance of the different pedestrian pavements available in the region, so as to classify them according to the Solar Reflectance Index (SRI). The study was carried out during a 2-year period, involving the analysis of the behaviour of 28 pavements in widely used compositions, shapes and colours. Additionally, the aging effect of the material was quantified over the SRI. The results show that 74% of pavements diminished their initial ability for decreasing temperatures, while 50% of the dark material, with initial negative performances, improved their thermal behavior.**

***Index Terms*—Aging, solar reflectance index, optical properties of materials.**

I. Introduction

Just as materials have been traditionally characterized according to their mechanical, electrical or magnetic properties, this study proposes to characterize them according to their optical properties, expressed by means of the Solar Reflectance Index (SRI), in order to evaluate their energy-environmental behavior in an urban medium.

High Solar Reflectance Index (SRI) materials do not raise their temperature much when exposed to sun radiation. In cities, the use of cold materials is a passive cooling strategy appropriate for preventing excessive heat increase and accumulation. This also enables the improvement of urban space habitability in terms of comfort and decreasing the air-conditioning consumption in buildings, thus allowing a rational use of energy and contributing to environmental sustainability [3], [4], [8]. Albedo (â) and thermal emittance (ε) are important factors which affect the surface temperature of the material and the air temperature close to the surface. Surfaces with low solar reflectance absorb a greater fraction of incident solar energy [2], [5], [7], [9], [10].

A fraction of this energy goes into the ground and buildings, another fraction is transmitted by convection to the air (leading to an increase of air temperature), and the last one is radiated to the sky [1]. In equivalent conditions, a surface with less emissivity will radiate in less proportion and cool less, therefore presenting higher temperatures [2].

Thus the determination of solar reflectance, thermal emmitance *(ε)* and the relative temperature of surfaces *(Ts)* with respect to the reference temperature of a black and white pattern (determined by the *SRI*) could help designers and consumers to choose adequate materials for energy consumption efficiency of buildings and communities.

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II. Methodology

A. Cases of Study

The sample is made up of 38 pedestrian pavements frequently used in the local urban medium. The pavements were classified into four compositions: *Monolayer (mono)*: Concrete and Natural Stone, and *Bilayer (bi)*: Concrete-stone, and Concrete-calcareous.

TABLE I: Material Classification According to its Composition, Color and Texture.

LAYER	COMPOSITION	COLOR		TEXTURE
Mono	Concrete	Red Yellow	Gray Black	Rustic
	Natural Stone	Travertine Red-multicolor	Gray-multicolor Black-withe	Smooth
Bi	Concrete-stone	Bordeau Jade Green	Black-multicolor Murcia Black	Rustic Smooth
	Concrete-calcareous	Red Yellow	Black	Smooth

TABLE II: Material Classification According to its Shape.

SHAPE				
Straight	Square	Single Line	Multi Line	Diagonal
Circular	Spider	Fan	Andalucía	
Flat	Mosaic	Start	Boulder	

The *monolayer (mono)* compositions are pieces made up of only one material: concrete or natural stone. However, the *bilayer (bi)* materials are made up of a concrete-calcareous layer and a concrete-stone layer.

In Tables I y II pedestrian pavements are classified according to their composition, color, texture and shape.

B. Experiment and Instrumentation Description

To analyze the thermal behaviour of these samples, they were arranged on a 7cm thick horizontal platform of expanded polystyrene located in the premises of the Centro Regional de Investigaciones Científicas y Técnicas, in

Mendoza, Argentina.

The aging of the surfaces was estimated by registering the emissivity, surface temperature, solar radiation over horizontal surface and air temperature corresponding to 13.00 used to calculate the SRI according to the established regulations (ASTM E1980-11, 2011) [2].

The monitoring was carried out during the 2011 and 2012 summer seasons. Among the series of registered measurements, the data reported in this study corresponds to two days when meteorological variables present representative local climate conditions (March, 10th 2011 and February, 10th 2012). On March 10th, 2011 the registered sun radiation flux was 883.7 W/m2, average air temperature 29.7ºC, relative humidity 24.5% and average wind speed 2.0 m/s. On February 10th, 2012 the registered sun radiation flux was 929.9 W/m2, an average air temperature of 28.3ºC, 31.5% of relative humidity and 1.3 m/s of wind speed. In order to determine the value of albedo (â), a Kipp & Zonen CMA11 albedometer was used. A temperature sensor with type T thermocouple associated with a U12 data logger hobbo was employed for the emissivity (ε) calculations in accordance with regulations ASTM E-1933-99[a] [11], 2006. The surface thermal measurements (Ts) were taken with an IR Fluke Ti 55 camera (Table II).

C. SRI Calculation

The *SRI* is a composite value in a scale from 0 to 100 based on the reflectance and emittance *(ε)* of the material's surface. It is calculated using the equations in ASTM E1980-11 [12].

SRI quantifies the accumulated heat of material in relation to a black and white reference surface, under standard ambient conditions.

D. Calculation of SRI Difference between 2011 - 2012 Thermal Registers

In order to quantify the response of the thermal behavior of materials to aging, weather and dirt, the following formula was used:

$$SRI_2 - SRI_1 = \Delta SRI \qquad (1)$$

where,

SRI_1= initial Solar Reflectance Index;

SRI_2= SRI of aged materials;

ΔSRI= Difference between SRI_1 and SRI_2 values.

To simplify the analysis a range of values was established to determine that the thermal behavior of material is stable when the *SRI* differences are lower than (±) 5% between both periods.

Aging is favorable when the initial *SRI* (SRI_1) is lower than the aged material's *SRI* (SRI_2). On the contrary, SRI_1 registers higher than SRI_2 were classified as materials whose ability to decrease urban temperatures falls when submitted to the passing of time, i.e. $\Delta SRI < -5\,\% =$ *Degraded*; $\Delta SRI \leq (\pm) 5\% =$ *Stable*; $\Delta SRI > 5\,\% =$ *Improved*.

III. Results

The SRI for pedestrian pavements was obtained through the calculations made according to the ASTM E1980-11 equations and parameters. Under the analyzed conditions, new material (SRI1), aged material (SRI2) and their corresponding differences (Δ SRI). (Table I y II).

TABLE III: Enumeration of Pedestrian Pavements Studied During the First and Second Year, with Their Respective Assigned Codes; Albedo ($\hat{a}$), Emissivity (ε), Solar Reflectance Index (SRI_1 - SRI_2) in Percentages; and SRI Differences (ΔSRI). (Part 1)

Cod.	Layer		Description	1º Year			2º Year			Δ SRI
	Mono	Bi		SRI_1 %	â	ε	SRI_2 %	â	ε	
P01	x		Concrete gray rustic circular fan	71	0.54	0.90	60	0.48	0.90	-11
P02	x		Concrete black rustic circular spider	59	0.42	0.95	59	0.45	0.95	0
P03	x		Concrete red rustic circular andalucía	77	0.59	0.95	59	0.45	0.95	-18
P04	x		Concrete red rustic circular fan	71	0.55	0.90	54	0.41	0.95	-17
P05	x		Concrete black rustic circular fan	52	0.35	0.95	51	0.38	0.95	-1
P06		x	Concrete-stone gray rustic flat boulder	73	0.57	0.90	56	0.43	0.95	-17
P07	x		Concrete black rustic straight square	55	0.39	0.95	51	0.38	0.95	-4
P08	x		Concrete gray rustic circular spider	79	0.62	0.90	61	0.47	0.95	-18
P09	x		Concrete red rustic circular spider	74	0.57	0.90	58	0.44	0.95	-16
P10		x	Concrete-stone murcia black smooth circular fan	53	0.36	0.95	48	0.35	0.95	-5
P11		x	Concrete-stone black-white smooth circular andalucía	72	0.56	0.90	57	0.43	0.95	-15
P12		x	Concrete-stone murcia black smooth straight square	54	0.38	0.95	56	0.42	0.95	2
P13		x	Concrete-stone gray-multicolor smooth circular andalucía	80	0.64	0.85	64	0.50	0.95	-16
P14	x		Concrete yellow rustic stright diagonal	71	0.55	0.90	61	0.47	0.95	-11
P15	x		Concrete red rustic flat mosaic	61	0.44	0.95	58	0.44	0.95	-3
P16		x	Concrete multicolor rustic flat boulder	72	0.55	0.90	59	0.47	0.90	-13
P17	x		Concrete yellow rustic flat start	75	0.58	0.90	58	0.44	0.95	-17
P18	x		Concrete gray rustic flat start	73	0.56	0.90	55	0.41	0.95	-18
P19	x		Concrete black rustic flat mosaic	59	0.42	0.95	52	0.39	0.95	-7

(PART 2)

Cod.	Layer Mono	Layer Bi	Description	1º Year SRI₁ %	1º Year â	1º Year ε	2º Year SRI₂ %	2º Year â	2º Year ε	Δ SRI
P20	x		Concrete gray rustic stright square	77	0.60	0.90	60	0.46	0.95	-17
P21		x	Concrete-stone jade green smooth circular andalucía	65	0.48	0.95	53	0.40	0.95	-12
P22		x	Concrete-stone black-white smooth straight square	55	0.38	0.95	51	0.38	0.95	-3
P23		x	Concrete-stone murcia black smooth circular	64	0.49	0.90	52	0.41	0.90	-12
P24		x	Concrete-stone bordeau smooth straight square	72	0.56	0.90	55	0.41	0.95	-17
P25	x		Natural Stone gray smooth flat mosaic	85	0.68	0.85	66	0.53	0.90	-18
P26		x	Concrete-stone black-multicolor smooth circular andalucía	85	0.67	0.90	59	0.45	0.95	-26
P27	x		Concrete black rustic circular andalucía	52	0.35	0.98	63	0.48	0.98	11
P28		x	Concrete-stone red smooth straight square	75	0.59	0.90	61	0.47	0.95	-14
P29	x		Natural Stone murcia black smooth flat mosaic	62	0.47	0.90	54	0.42	0.90	-8
P30		x	Concrete-stone gray-multicolor smooth straight square	76	0.59	0.90	66	0.53	0.90	-10
P31	x		Natural Stone jade green smooth flat mosaic	69	0.53	0.90	55	0.43	0.90	-14
P32		x	Concrete-stone jade green smooth straight square	69	0.53	0.90	53	0.40	0.95	-17
P33	x		Concrete black rustic straight square	59	0.43	0.95	55	0.42	0.95	-4
P34	x		Natural Stone travertine smooth flat mosaic	100	0.93	0.80	100	0.82	0.80	0
P35		x	Concrete-calcareous black smooth straight	58	0.42	0.95	64	0.50	0.95	6
P36		x	Concrete-calcareous red	72	0.56	0.90	56	0.42	0.95	-17
P37		x	Concrete-calcareous yellow smooth straight single line	69	0.53	0.90	56	0.42	0.95	-13
P38		x	Concrete-calcareous yellow smooth stright multi line	74	0.58	0.90	55	0.42	0.95	-19

Initially the materials analyzed show higher dispersion in their SRI values, clearly identified with a cut line in SRI=70%. This means that 58% of the evaluated materials present an initial SRI in the 70-100% range, whereas the remaining 42% presents values between 69 and 50% (Fig. 1).

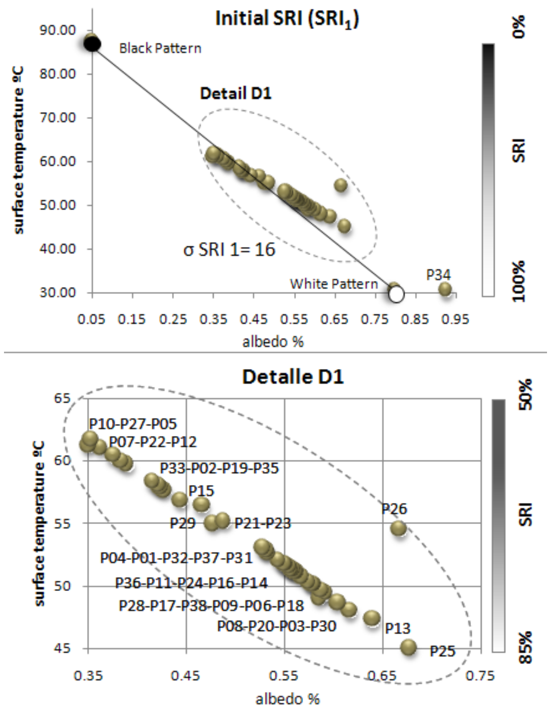

Fig. 1. Initial Solar reflectance index (SRI_1) according to surface temperature (ºC) and albedo.

For aged materials *(SRI_2)* the cut line disappears and all materials are grouped in a 66-48% *SRI* range, which indicates that over 58% of the materials initially evaluated were efficient in their thermal response, and their performance worsened in just one year by 24%. Besides, it is clearly observable that the variable most affected by aging is albedo. Likewise, due to aging, surface temperatures in the studied cases had an approximate 7 to 11ºC temperature increment. (Fig. 2 and Table III)

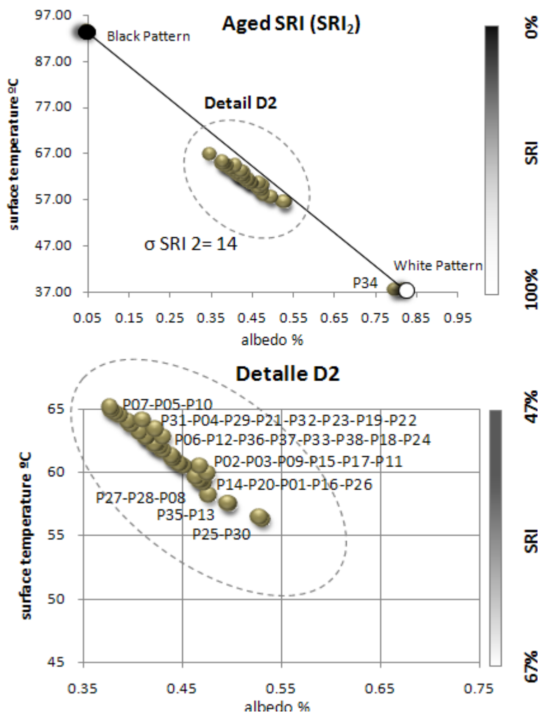

Fig. 2. Aged Solar Reflectance Index (SRI_2), according to surface temperature (ºC) and albedo.

A. Solar Reflectivity Index Aging according to its Composition

After submitting the pavements to exterior weather conditions (aging), the *SRI* level differences were calculated for monolayer and bilayer materials. 70% of the monolayer materials and 78% of the bilayer decreased their thermal efficiency.

Within the stable materials there was 25% of monolayer and 11% of bilayer. Improvements of *SRI* higher to 15% were registered from which 5% correspond to monolayer and 10% to bilayer. (Fig. 3. and Table III).

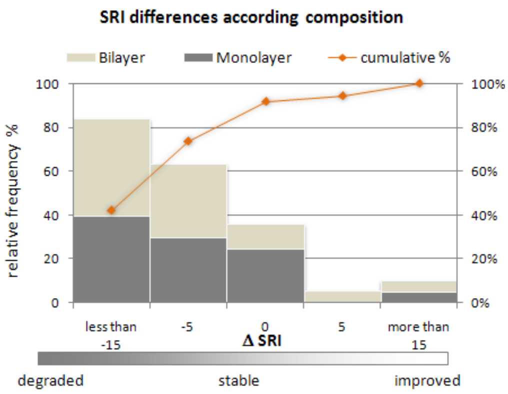

Fig. 3. Relative frequencies distribution (%) of *SRI* differences (*Δ SRI*) in pedestrian pavements according to composition.

B. Solar Reflectivity Index Aging According to its Shape

By analyzing the materials in isolation and according to their shape, it was observed that the most thermally inefficient is the flat one. That means 90% of the materials with this configuration have decreased their *SRI* between 7 and 18%.

The shapes that maintained their *SRI* stable to the passing of time, weather and dirt are the straight and circular, with a relative frequency of 21% in each case. 14% of straight pavements increased their SRI in a 5 to 15% range, improving their thermal conditions. (Fig. 4 and Table III).

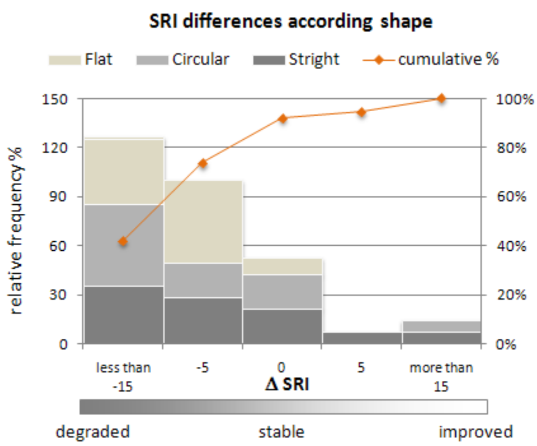

Fig. 4. Relative frequencies distribution (%) of *SRI* differences (*Δ SRI*) in pedestrian pavements according to shape.

C. Solar Reflectivity Index Aging according to its Colors

By separately analyzing the color variable for both compositions, we detected that 100% of the materials in gray, yellow, gray multicolor, travertine, red and black multicolor, and bordeau decreased their SRI by 5 to 20%.

Within the colors that maintained a constant *SRI* through time are, firstly, the black and black-white pavements, since half (50%) the samples did not suffer wearing from open air exposure. Colors which increased the *SRI* were black (27%) and black-white (25%) by 6 to 15%. (Fig. 5 and Table III).

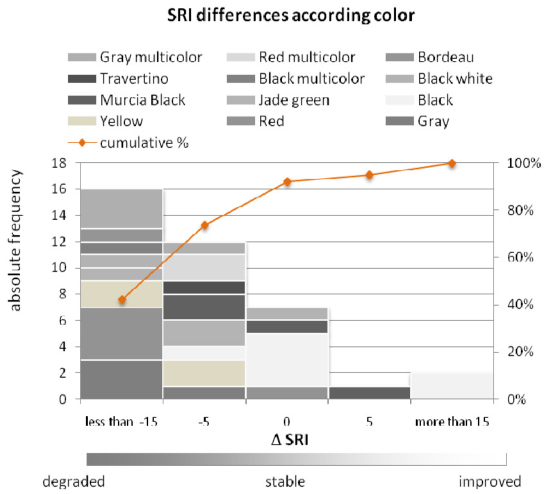

Fig. 5. Relative frequencies distribution (%) of *SRI* differences (*Δ SRI*) in pedestrian pavements according to color.

IV. Conclusion

Results show that the SRI is a useful indicator for categorizing the thermal behavior of a group of pedestrian pavement samples. 74% of the pedestrian pavements tend to decrease their SRI with time as a consequence of the wearing away produced by exterior conditions and dirt accumulation.

The most affected optical property was albedo. However, a group of materials showed an improvement according to their classification: monolayer composition, straight shape and black and black-white color.

Finally, most of the evaluated pavements decreased their SRI by 23% in just a year in response to aging. Therefore it is necessary to quantify the indicator variation through time so as to achieve a rigorous characterization of the evaluated material's thermal behavior.

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