Available online at www.sciencedirect.com
SciVerse ScienceDirect
ELSEVIER
Procedia - Social and Behavioral Sciences 53 (2012) 514 – 523
Procedia Social and Behavioral Sciences

SIIV - 5th International Congress - Sustainability of Road Infrastructures

Spectroradiometric Laboratory Measures on Asphalt Concrete: Preliminary Results

Mei Alessandro[a]*, Fiore Nicola[b], Salvatori Rosamaria[a], D'Andrea Antonio[b], Fontana Maurizio[b]

[a]*CNR- Institute of Atmospheric Pollution Research, Area della Ricerca di Roma1, Via Salaria Km 29,300 Monterotondo (RM) 00015, Italy*
[b]*University of Rome "La Sapienza" –DICEA, Via Eudossiana 18, Rome 00184, Italy*

Abstract

This paper presents the preliminary results of a project concerning the use of spectroradiometric measurements for the characterization of aggregates and asphalts mixtures commonly used for road paving.
Radiometrical measurements, in the wavelength range between 350-2500nm, were performed on selected samples with different compositional characteristics; the relationships between spectral signatures and different bituminous mixtures samples were analyzed.
The results suggest that spectroradiometrics analyses can be used to establish new efficient and fast road classification procedures to support activities of pavement management systems and interpretation of remote sensed images.

Keywords: bituminous mixtures, wearing course, spectral signature, spectroradiometry

* Corresponding author. Tel.: +39-0690675636.
E-mail address: mei@iia.cnr.it

 doi:10.1016/j.sbspro.2012.09.902

1. Introduction

Spectroradiometry can be successfully used in a broad range of applications. The common practice today consists in extensive field observations conducted by experts leading to a definition of a pavement condition index (PCI) and/or a structure index (SI) based on established physical parameters. Other technologies include the application of PMS with semi automated in situ pavement surveys. Nevertheless, such surveys remain expensive and challenging. Previous studies of pavement condition mapping by remote sensing illustrate the procedures for identifying asphalt roads that need maintenance works [7]. Recent advances in imaging spectrometry provide the possibility to detect physical and chemical properties of materials at very detailed level. There is evidence that road properties, such as aging and material composition, can affect spectral characteristics even if it is still an open question to quantify the relationship between reflectance values and specific road surface characteristics.

The use of spectroradiometric data to characterize aggregates and bituminous mixtures can lead to improve remote sensed image analyses. The analysis of the spectral signatures allows to discriminate different types of natural or man-made surfaces like asphalt concrete paved areas. In the wavelengths range between 350and 2500nm, the radiometric response of recent asphalts is dominated by bitumen, which almost completely absorbs the incident solar radiation. The aggregates composition and their dimensions have only a marginal influence on the spectral behavior [9,13].

Due to time and degradation processes, asphalt surfaces loose bitumen and this occurrence generates an increase of reflectance values. In fact, the oxidation processes and the exposure of the lythic components modify the spectral signature of the new asphalt showing the appearance of the iron oxides absorption peaks at 520, 670 and 870 nm, while the loss of the oily compounds determines the disappearance of hydrocarbons characteristic peaks [5].

The absorption of hydrocarbons, particularly evident in “new” asphalt surface, affects at 1750nm and after 2100 nm with significant doublet at 2310 and 2350 nm [3]. In addition, in "old" asphalts, there is a significant slope change in spectral signature between 2100-2200 nm and 2250-2300 nm, respectively due to the influence of silicate minerals outcropping and hydrocarbons [8].

Currently, most of spectroradiometric studies concerning road pavement management, aim to identify relationships between spectral data and paved surfaces quality conditions. In fact, the analyses of multi- and hyper-spectral remotely sensed imagery can allow not only to discriminate road network but also to evaluate weathering alteration of asphalt surfaces [4,10,11,12]. The spectral difference between the wavelengths 830 and 490 nm values, allows to correlate the Pavement Condition Index (PCI) and the spectral data with an R-squared of 0.63. Moreover, spectroradiometrical measurements could be successfully integrated with other analysis methods like ARAN even if it is still not possible to quantify precisely the contribution of aging, erosion, structural damages and compositional characteristics to spectral signatures [7].

The aim of our research activities is to investigate the possibility of using spectral measurements to detect asphalt concrete characteristic. The first phase of these activities, presented in this paper, concerns the study of physical characteristics of “new asphalt concrete” (starting materials) by means of spectroradiometric measurement performed in laboratory controlled conditions. In the second phase, still in progress, we will try to characterize asphalt concrete surface by means of field surveys and aerial/satellite image analyses.

The spectral signatures, obtained in laboratory on samples with known characteristics, can play a crucial role in the parameterization of physical and chemical properties of bituminous mixtures. In addition, measurements carried out under controlled environmental conditions can reduce the "failures" due to meteorological conditions.

Finally, in this work is discussed the possibility to discriminate, by radiometric laboratory measurements, the different lithologies of aggregates, to recognize their physical characteristics, also whether they are not conventional [15], and to estimate the percentage of bitumen in asphalt mixtures.

2. Spectroradiometric analysis

Spectral signature of different samples of aggregates and asphalt mixtures were acquired, under controlled laboratory conditions, with the portable spectroradiometer Fieldspec3 of Analytical Spectral Devices (inc. Boulder, CO, USA). The Fieldspec measures the light intensity in wavelengths range between 350 and 2500 nm using an optical fiber bundle that collects the reflected radiation with 25° conical field of view. The instrument uses three detectors spanning the visible, near-infrared (VNIR) and short-wave infrared (SWIR1 and SWIR2) with a spectral sampling interval of 1.4 nm for the VNIR and 2nm for the SWIR detectors. The light is projected from the fibers in an holographic diffraction grating where the components of different wavelengths are separated and subsequently reflected to be collected from three different spectrometers. Between 350 and 1050 nm, corresponding to the visible and first fraction of near infrared wavelength, the light is measured by a photodiode array with 512channels and have a spectral resolution of 3 nm to 700 nm. The medium infrared region is measured by two spectrometers that acquires the ranges 900-1850 nm and 1700-2500 nm, with a spectral resolution of 10-12nm.

All measures were performed in a laboratory designed as dark room; a 50 watt Pro-Lamp was used as a light source. This lamp have a constant light spectrum between 350 and 2500 nm, designed to provide diffuse reflectance measurements in laboratory (Fig.1).

Fig. 1. Acquisition system

The experimental measurement parameters were determined optimizing the system geometry in order to obtain a constant signal and reduce instrument errors. The radiometer, with 25° field of view, was located at a distance of 8cm from the asphalt samples and 20 cm from sample holder containing loose aggregates and bitumen. The radiometer has been set up on reflectance mode and a Spectralon panel, assumed as lambertian surface, was used as white reference. Spectralon is an high-density fluoropolymer and its optical properties ensure a constant spectral response in the range between300-2500nm (99% between 400-1500 and > 95% more than 1500 nm). Each measurement was performed with 50 integration cycles to minimize the light oscillations while, to minimize scattering effect due to sample roughness, 2 spectra were collected rotating the sample each 90°; at last these spectrum were averaged for each sample.

In order to ensure a good analytical data quality, the reference panel spectral signature has been acquired at the beginning and at the end of each measuring session. Finally, for each measured sample, a digital photo was taken (10 Mpixel) paying attention to produce the same lighting condition geometry, performing manual calibration of a white reference to standardize the images and make them comparable [13]. The photographs were collected in order to have a complete ancillary dataset of the analyzed samples.

3. Materials

For this study two basaltic aggregates, and expanded clay granules are used. Basaltic aggregates came from the same leucititic tephrite rock and are characterized by different physical and strength properties as they belong to different levels of the rock mass.

The difference between the two kinds of aggregate consists in a porosity predominance and a lower resistance to fragmentation of the aggregate taken from the top of the cluster. Table 1 summarizes aggregates properties.

Table 1. Aggregates characteristics

	Dense Gravel 5-11	Fine Dense Gravel 2-6.3	Dense Sand 0-5	Porous gravel 5-11	Porous Fine Gravel 2-6.3	Porous Sand 0-5	Expanded Clay 4-8
ID	GRCB	GRCA	SAC	GRPB	GRPA	SAP	EC
Apparent particle density EN 1097-6[Mg/m³]	2.76	2.78	2.78	2.63	2.64	2.76	0.66
Pre-dried particle density EN 1097-6[Mg/m³]	2.63	2.60	2.57	2.42	2.43	2.40	0.57
Saturated surface dried particle density EN 1097-6[Mg/m³]	2.68	2.67	2.65	2.50	2.51	2.53	0.71
Water Absorption EN 1097-6[%]	1.9	2.5	3.0	3.3	3.3	5.4	25.8
Loose bulk density EN 1097-3[Mg/m³]	1.39	1.39	1.41	1.23	1.33	1.41	-
Sand equivalent [%] EN 933-8	-	-	73	-	-	72	-
Flow coefficient EN 933-6	-	-	38	-	-	35	-
Methylene blue EN 933-9	-	-	4.3	-	-	9.5	-
Resistance to fragmentation [%] EN 1097-2	14	-	-	22	-	-	-
Simplified petrographic description EN 932-3	leucititic tephrite	leucititic tephrite	leucititic tephrite	leucititic tephrite	leucititic tephrite	leucititic tephrite	Expanded Clay
Polished stone value (PSV) EN 1097-8	49.8			46.4			76.1
Photos							

These aggregates were mixed in different proportions in order to obtain a total of 3 mixtures according to specifications of ANAS surface course: mixture with compact leucititic tephrite (MIXC), mixture with porous leucititic tephrite (MIXP)and mixture with expanded clay (MIXE) (Table 2).

For each of these compositions 4 different percentages of bitumen (b1, b2, b3, b4) were added in order to obtain 12 asphalt mixtures to be compacted according to the Marshall method (Table 3). The radiometric measurements were carried out both on loose and compacted samples.

Table 2. Aggregates and mixtures grading

Sieve [mm]	SAC 0-5 cm [%]	GRCA 2-6.3 cm [%]	GRCB 5-11cm [%]	Filler	EC 4/8cm [%]	GRPA 2-6.3cm [%]	GRPB 5.6-11cm [%]	SAP 0-4cm [%]	**MIX C [%]**	**MIX P [%]**	**MIX E [%]**
10	100	100	98.9	100	100	100	100	100	**99.7**	**99.8**	**99.7**
8	100	100	69.8	100	91.9	100	98.1	100	**91.0**	**95.1**	**91.3**
6.3	100	100	35.4	100	45.1	100	81.0	100	**80.6**	**86.5**	**75.6**
4	99.9	70.1	3.0	100	0.7	87.8	16.7	99.9	**60.4**	**65.1**	**53.9**
2	72.6	18.8	0.7	100	0.3	5.6	0.4	80.5	**34.4**	**31.6**	**33.3**
1	33.3	8.8	0.6	100	0.2	0.3	0.1	51.0	**20.3**	**22.0**	**19.2**
0.5	19.9	6.4	0.6	99.9	0.2	0.1	0.1	30.6	**15.8**	**16.4**	**14.6**
0.25	12.8	5.2	0.6	99.1	0.1	0.0	0.1	16.5	**13.4**	**12.5**	**12.1**
0.125	8.8	4.1	0.4	94.1	0.1	0.0	0.0	7.8	**11.5**	**9.7**	**10.3**
0.063	6.3	3.1	0.1	78.5	0.1	0.0	0.0	2.5	**9.1**	**7.0**	**8.1**
MIX C	**27**	**35**	**30**	**8**	**-**	**-**	**-**	**-**	**100**	**-**	**-**
MIX P	**-**	**-**	**15**	**8**	**-**	**30**	**20**	**27**	**-**	**100**	**-**
MIX E	**30**	**23**	**25**	**7**	**15**	**-**	**-**	**-**	**-**	**-**	**100**

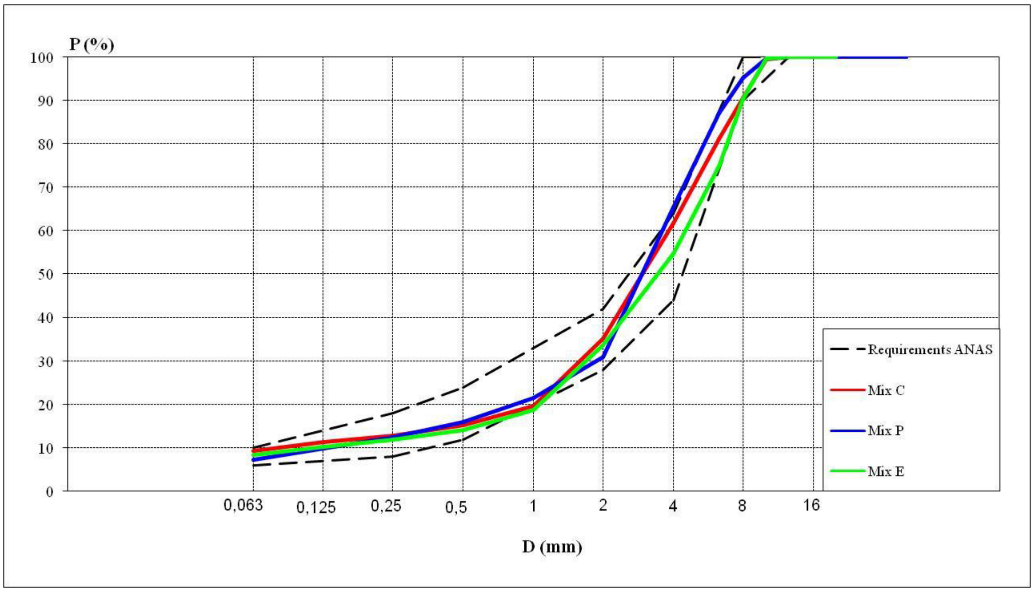
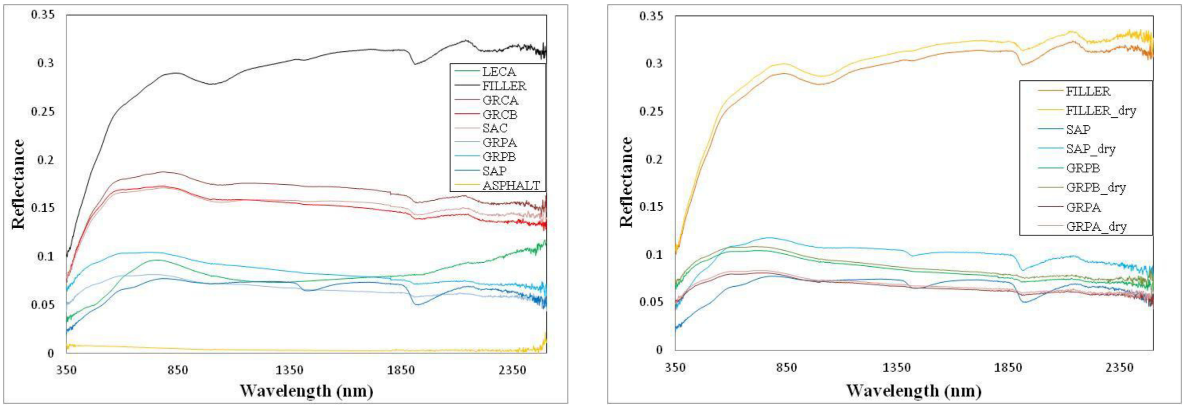


Table 3. Bitumen content

	Percent of Bitumen by Dry Weight Of Aggregate			
Mixtures	b1 [%]	b2 [%]	b3 [%]	b4 [%]
MIX C	3.9	4.2	4.9	5.3
MIX P	3.9	4.5	5.4	5.8
MIX E	5.1	5.6	6.0	6.5

4. Laboratory measurements

During the first experimental step spectroradiometric measurements were performed on different kinds of aggregates: GRCB, GRCA, SAC (compact leucititic tephrite), SAP, GRPA,GRPB (porous leucititic tephrite), expanded clay (EC), FILLER and bitumen.



(a) (b)

Fig. 2. (a) Bitumen and aggregates spectral signatures at natural humidity; (b) porous aggregates before and after drying.

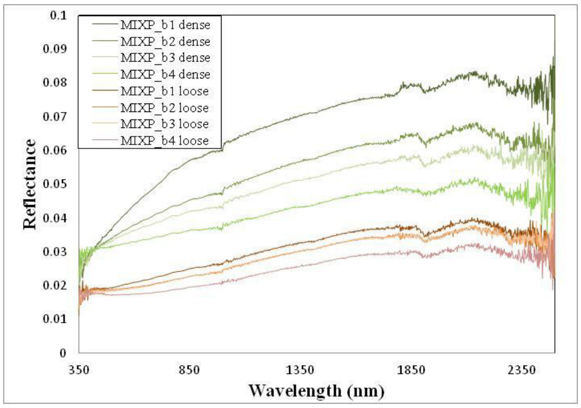


Fig. 3. Spectral signatures of loose and compacted samples (MIX P)

Figure 2 shows all aggregates with natural humidity and bitumen spectra. Figure 2b illustrates the spectra of the porous aggregates obtained under conditions of natural humidity and after drying them in the oven. For each sample 8 spectral signatures were acquired by rotating the sample of 90° every two acquisitions. The mean and standard deviation of each measurements set was calculated to obtain the characteristic signature of the sample. Figure 3 shows the spectra characteristics of the loose and compacted mixtures for samples with different percentage of bitumen.

5. Results

The analysis of spectral signatures (Fig. 2a) shows that reflectance values are very low in the visible wavelength range; reflectance values increase up to 0.008 in the near infrared for leucititic tephrite porous aggregate samples and up to 0.17 for Marshal specimens.

The spectral signature of the filler shows an inflection in visible range but the reflectance values are around 0.3; these reflectance values are mostly due to the fine aggregate which tends to reduce the shadows effects. Particularly in the near infrared the spectral reflectance of this material, which consists almost completely of pyroxene and plagioclase, depends on the grain size; higher is the grain size more is the amount of light absorbed and consequently lower is the reflectance [2].

Finally, the spectral signature of the expanded clay, presents a peculiar behavior due to its mineralogical composition; the presence of prevalent clay minerals, basically different from minerals present in volcanic rocks , makes it possible distinguish it from other lithotypes.

Through the petrography tabs provided with aggregates, it has been observed some analogies between the spectral signatures of these materials and their mineralogical composition. Some absorption peaks at 0.9 nm and 1.9/2 nm, characteristic of the pyroxene and plagioclase [14], are identified. Furthermore, between 0.3 and 0.9 nm spectral behavior is similar to ortho-pyroxenes spectral signature; this mineral, in fact, are prevalent both as well-as shaped crystals and as fine-grained ground-mass in the volcanic rocks [1].

The analysis of measurements performed on the same samples, after drying in the oven, give similar spectral signatures to those developed on the samples at natural conditions, even though presenting higher reflectance values. This is mainly due to the presence of water that absorbs incoming radiation in the 350-2500nm range.

Finally, the bitumen signatures present, as expected, reflectance values about zero in the investigated wavelengths. The analysis made on 12 bituminous mixtures, show low standard deviation values and a good reliability of radiometric measurements. In particular the average standard deviation of Marshall samples of MIXC (4 bitumen percentages), calculated over the whole spectrum is 0.0031, for MIXP is 0.0030, for MIXE is 0.0028 while loose samples have slightly lower values (0.0012 for MIXC, 0.0011 for MIXP and of 0.0017 for MIXE).

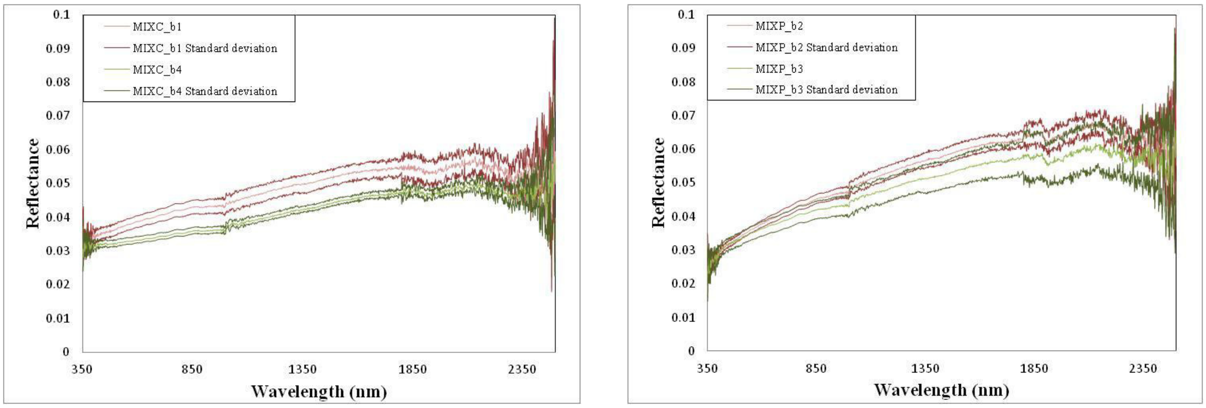
Table 4. Difference of asphalt content between mixtures

	Delta of Bitumen Percent (Δ)			
Mixtures	Δb_{12}	Δb_{23}	Δb_{34}	Δb_{14}
MIX C	0.29	0.65	0.44	1.38
MIX P	0.62	0.87	0.45	1.94
MIX E	0.49	0.49	0.48	1.46

Results obtained with compacted and loose samples show that reflectance values decrease with the increase of the bitumen content. In order to estimate bitumen percentage variations the standard deviation of spectral signatures were analyzed.

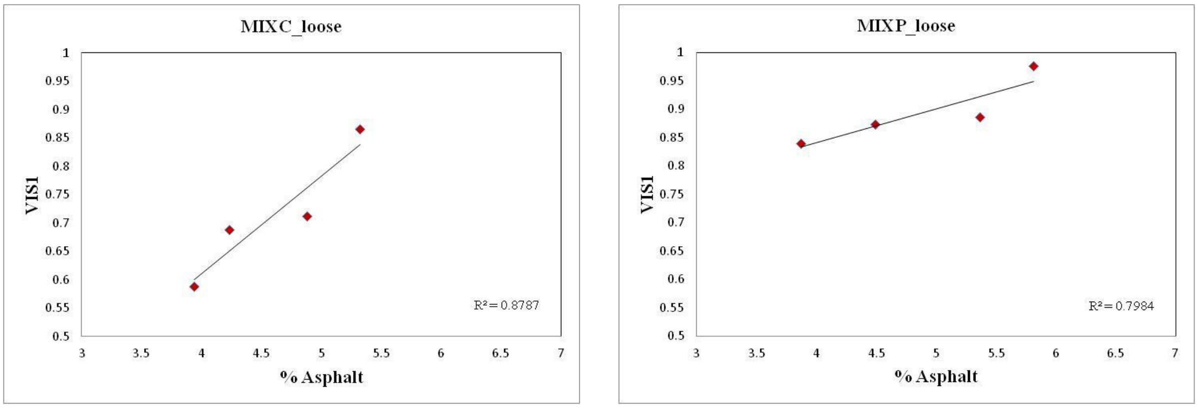
We notice that these values tend to overlap for smallest bitumen content variations (0.87% for MIXP in Fig. 4), but the values remain well distinct if mixtures with major difference in bitumen content are compared; this observation suggests that, in the considered range of electromagnetic spectrum, it is possible to discriminate the samples when their bitumen content difference is higher than about 1% (Fig. 4).

In the examination of spectral signatures in the visible region there is evidence of a slope change corresponding with a variation of bitumen content. In fact when the bitumen percentage increases the slope of signatures decreases. Particularly the signatures of loose material show also a change in the shape of the spectral signature that switches from concave to convex with a decreasing of bitumen percentage (Fig. 3). This variation in shape has been already pointed out by previous studies and correlated with the early stages of alteration [12,13].



(a) (b)

Fig. 4. Variation of samples average spectral signature with the higher (a) and lower (b) Delta bitumen content.



(a) (b)

Fig. 5. Relationship between the VIS1 index and the bitumen percentage of loose asphalt in MIXC (a) and MIXP (b)

To explain the relationship between the change of slope with some existing parameters such as the percentage of bitumen, it was calculated a spectral index, VIS1, using the ratio between the bands corresponding to 400 and 700 nm. Similar bands (490-830nm) have been used in the literature [6] to assess the road surface status from remote sensing data. In this range the noise of the signal is extremely low and does not affect the calculation of the slope.

The relationship between this index and the bitumen percentage provides very high correlation values. For example, for the measurements of loose material, MIX P and C return values of R2 respectively of 0.80 and 0.88. In fact, the spectral signatures of the loose material, compared to compacted samples, tend to have different slopes in the visible as a function of bitumen percentage. The indexVIS1emphasizes this trend (Fig. 5).

Finally, the very low bitumen percentages variations are not spectrally appreciable and the signatures tend to overlap giving an R^2 close to zero.

The observations on loose material do not always apply to the Marshall samples because of the fragmentation of surface grains due to impact compaction.

6. Conclusions

In this study we combined spectrometry and physical laboratory analysis to improve a spectral understanding of asphalt concrete composition. Currently the analysis on the asphalt for the determination of the composition and physical properties are carried out mainly through the use of laboratory techniques often expensive and time consuming.

This preliminary study shows that it is possible to apply spectoradiometric analysis to aggregates used for asphalt concrete in order to evaluate some physical characteristics like lithology, porosity and water content. Moreover, the results confirm that radiometric surveys can be successfully used to check the composition of bituminous mixes and aggregates.

The small variations of reflectance with small changes of the bitumen content, do not allow to establish the exact bitumen amount, however these values allow to appreciate changes in bitumen content in the range of 1%. Future analysis will improve this dataset and will allow to establish the minimal percentage of bitumen content detectable with spectroradiometric analysis.

The analysis of spectral signatures obtained from laboratory samples have demonstrated the potential of the spectroradiometer as innovative and non-destructive analytical method in road engineering investigations. Based on these considerations the field radiometric survey may be considered an effective tool for discriminating surfaces that need maintenance works. In this context the construction of laboratory and field spectral libraries would constitute a useful tool also for chemometric analysis that can be able to discriminate and quantify single asphalt concrete components.

In conclusion, these preliminary results suggest that spectroradiometrics analyses can be used to establish new efficient and fast road classification procedure, providing, for example the location of the asphalt pavements to be checked.

Acknowledgements

We thank Armando Di Curzio, road laboratory technician of the University La Sapienza, for the cooperation given preparing samples for radiometric analysis of this work.

References

[1] Clark, R.N., Swayze, G.A., Gallagher, A., King, T.V.V. , & Calvin W.M. (1993). The U. S. Geological Survey, Digital Spectral Library: Version 1: 0.2 to 3.0 microns. U.S. Geological Survey. Open File Report 93-592, http://speclab.cr.usgs.gov (accessed April 2012).
[2] Clark, R.N (1999). Spectroscopy of rocks and minerals and principles of spectroscopy. Manual of Remote Sensing, Volume 3: Remote Sensing for the Earth Sciences, Rencz A.N. Eds.; John Wiley & Sons Inc.; pp 3-58.
[3] Cloutis, A.E. (1989). Spectral reflectance properties of hydrocarbons: remote-sensing implications, Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects. Science 4914, 165–168. FHWA 1996.
[4] Gomez, R. B., (2002). Hyperspectral imaging: a useful technology for transportation analysis. Opt. Eng.,41, 9, 2137-2143.
[5] Herold, M., Roberts, D. A., Gardner, M. E., & Dennison, P. E. (2004). Spectrometry for urban area remote sensing-Development and analysis of a spectral library from 350 to 2400 nm. Remote Sensing of Environment, 91, 304−319.
[6] Herold, M., & Roberts, D. A. (2005). Spectral characteristics of asphalt road aging and deterioration: Implications for remote-sensing applications. Applied Optics, 44(20), 4327−4334.
[7] Herold, M., Roberts, D., Noronha, V. , & Smadi, O., (2008). Imaging spectrometry and asphalt road surveys. Transportation Research, Part C: Emerging Technologies 16, 153–166.
[8] Levinson, R., Berdahla, P., Akbaria, H., Millerb, W., Joedickec, I., Reillyd, J., Suzukie, Y. , & Vondranf, M. (2007). Methods of creating solar-reflective non white surfaces and their application to residential roofing materials. Solar Energy Materials & Solar Cells, 91 304–314.
[9] Mei, A., Salvatori, R., & Allegrini, A., (2011a). Analisi delle superfici asfaltate tramite dati di campo e immagini iperspettrali MIVIS. Italian Journal of Remote Sensing, Vol. 43: 147 – 159.
[10] Mei, A., Salvatori, R., Cipolletti, F., & Allegrini, A., (2011b). Analisi di immagini Quickbird per l'identificazione e la classificazione delle superfici asfaltate. Proceedings of 15th National ConferenceASITA, 15 – 18 november 2011, Reggia di Colorno – Parma (IT).
[11] Mori, M., Iwata, T., Minami, Y., Kato, S. , & Akamatsu, Y. (2008). Spectral analysis of building materials used in Japan. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII Part B8, Beijing 2008
[12] Noronha, V., Herold, M., Gardner, M. , & Roberts, D.A. (2002). Spectrometry and imaging spectrometry for road centerline extraction and evaluation of pavement condition. Proceedings of the Pecora Conference, Denver, CO.
[13] Salvatori, R, Mei, A. , & Salzano, R. (2009). Caratterizzazione spettrale di superfici asfaltate e realizzazione di una libreria di firme spettrali. Proceedings of 13th National Conference ASITA, 01-04 December, Bari (IT).
[14] Rencz A. N. (1999). Remote sensing for the Earth sciences. Manual of Remote Sensing, Third Edition, Volume 3, American Society for Photogrammetry and Remote Sensing.
[15] D'Andrea, A., Bonora, V., & Drago, D. (2004). Asphalt concrete with bottom ash: Environmental aspects. Paper presented at the Proceedings of the International Conference on Restoration, Recycling and Rejuvenation Technology for Engineering and Architecture Application, 56-63. Retrieved from www.scopus.com.