

# Understanding spectral characteristics of asphalt roads

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## Introduction

The quality standards for transportation infrastructure have evolved considerably over the last three decades. The data accuracy requirements to support related management efforts shrink from tens of meters to a few decimeters with annual update rates. Recent advances in hyperspectral remote sensing technology have shown capabilities to derive physical and chemical material properties on a very detailed level (Clark, 1999). Consequently one would raise the questions: **Are asphalt road surface conditions reflected in the spectral characteristics of these surfaces?** The Santa Barbara asphalt road spectra library was developed to provide generic understanding about the spectral properties of road surfaces in various conditions and with different distresses. The following presentations and interpretations represent a subset of this spectra library and should support remote sensing researchers, transportation scientist and others in their study of road surface conditions.

In general, spectral libraries contain pure spectral samples of surfaces, including a wide range of materials over a continuous wavelength range with high spectral detail, and additional information and documentation about surface characteristics and the quality of the spectra (i.e. metadata). In February 2004, a ground spectra acquisition campaign was conducted in the area of Santa Barbara/Goleta, CA. Ground spectra were acquired with an Analytical Spectral Devices (ASD) Full Range (FR) spectrometer (Analytical Spectral Devices, Boulder, CO, USA). The FR spectrometer samples a spectral range of 350-2400 nm. The instrument uses three detectors spanning the visible and near infrared (VNIR) and shortwave infrared (SWIR1 and SWIR2), with a spectral sampling interval of 1 nm. FR field spectrometer data are widely used and considered to provide accurate and high quality spectral measurements. All acquired targets were documented and integrated into a spectral library that is made available here. The PCI and structure index were derived from Roadware ([www.roadware.com](http://www.roadware.com)) in-situ vehicle inspections in Dec. 2002. The spectra were preprocessed to apparent surface reflectance. No noise removal or any related modifications have been performed and every user of the library should consider that.

## Spectral properties asphalt road surfaces

Asphalt pavements consist of rocky components and asphalt mix (or hot mix or bitumen). The mineral constituents of the crushed stone rocky components can vary depending on the geological region but usual major components in the aggregate are dominated by **SiO<sub>2</sub>, CaO and MgO** (Robl et al., 1991). The asphalt mix consists of oil, asphaltenes, and resins. The oils add viscosity and fluidity, asphaltenes cause strength and stiffness, and

resins are important for interfacial adhesion and ductility in the pavement. This makes bitumen a complex substance that can vary in composition depending on the source of the crude oil and on the refining process. The chemical nature essentially is a mix of hydrocarbons with 50-1000 carbon atoms plus enough hydrogen, oxygen, sulphur and nitrogen substituents to give some of the molecules a polar character. More specifically, the chemical components of asphalt mix are Carbon (80-87%), Hydrogen (9-11%), Oxygen (2-8%), Nitrogen (0-1%), Sulfur (0.5-1%) and some trace metals.

Figure 1 presents three spectral samples of pure road asphalt with no obvious structural damages or cracks. The age of the pavement, the Pavement Condition Index (PCI) and the Structure Index are shown with image examples of the surface. Spectrum 1 reflects a recently paved road. The surface is completely sealed with asphalt mix. The spectral reflectance is generally very low and hydrocarbon constituents determine the absorption processes. The minimum reflectance is near 350 nm with a linear rise towards longer wavelengths. Hydrocarbon compounds exhibit electronic transitions arising from excitations of bonding electrons in the UV and VIS causing this strong absorption. The absorption is broad and there are no individual resolvable absorption bands in this spectral region due to the complex hydrocarbon nature of bitumen. Overlapping electronic processes with their absorption strength decreases towards longer wavelength causes these absorptions. This broad overall reflectance increase toward longer wavelengths is also seen in coals, oil shales and chars (Cloutis, 1989).

For longer wavelengths, Spectrum A in Figure 1 exhibits some obvious absorption features in the SWIR. Although there are a large number of fundamental organic absorption bands: aromatic C-H stretch, symmetric and asymmetric stretches and bends of CH<sub>3</sub> and CH<sub>2</sub> radicals, carbonyl/carboxyl C-O stretch and the aromatic carbon stretch, and numerous combinations and overtones (Cloutis, 1989). The low overall reflectance suppresses most of the distinct features except the most prominent ones near 1700 nm and from 2200-2500 nm. Various C-H stretching overtones and combination bands dominate the feature in the 1700 nm region. If this feature is well developed it is asymmetric and reflects a doublet with the strongest absorption at 1720 nm and a second less deep one at 1750 nm. The region between 2200 and 2500 nm is affected by numerous overlapping combination and overtone bands (Cloutis, 1989). This causes the strong reflectance decrease beyond 2200 nm. The absorption is strong in the 2300 nm region with a well-developed doublet at 2310 and 2350 nm with the 2310 nm feature usually being the stronger one.

Spectrum C in Figure 1 shows an old, deteriorated road surface. The image of the surfaces shows that the asphalt seal is widely eroded and the remaining asphalt mix has undergone an aging process. The natural aging of asphalt is caused by reaction with atmospheric oxygen, photochemical reactions with solar radiation, and the influence of heat, and results in three major processes (Bell, 1989): the loss of oily components by volatility or absorption, changes of composition by oxidation, and molecular structuring that influences the viscosity of the asphalt mix (steric hardening). The loss of oily components is relatively short-term; the other two are more long-term processes. With

the erosion and aging of the asphalt mix the road surface is less viscous and more prone to structural damages like cracking.

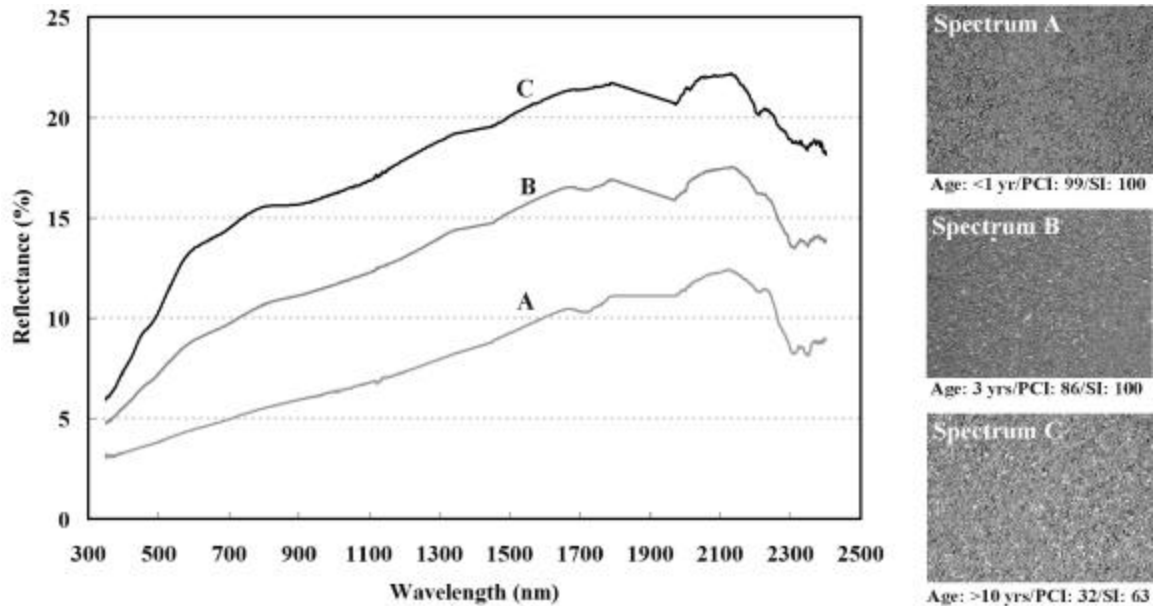


Figure 1: Spectral effects of asphalt aging and deterioration from the ASD ground spectral measurements (the major water vapor absorption bands are interpolated).

The spectral effects represent a mixture of both the exposition of rocky components and the asphalt aging. The vanishing of the complex hydrocarbon components cause a general increase in reflectance in all parts of the spectrum. This difference is highest in the NIR and SWIR with more than 10% reflectance. The electronic absorption processes in the VIS-region reflect the dominance of minerals and result in a concave shape with distinct iron oxide absorption features. They appear for 520, 670 and 870 nm. The typical SWIR hydrocarbon absorption features in 1700 and 2300 nm region vanish for older road surfaces and are replaced by mineral absorptions. For example there is significant change in slope in the transition from hydrocarbon to mineral absorption. For older road surfaces the slope increases between 2120-2200 nm as the 2200 nm silicate absorption gets more prominent. The slope is higher for new pavement materials 2250-2300 nm, which correlates with the intensity of 2300 nm hydrocarbon feature.

Spectrum B in Figure 1 represents a road pavement of intermediate age and condition. The surface exhibits both the asphalt mix and exposed minerals. The spectral characteristics reflect this intermediate stage by showing absorption features from hydrocarbons and minerals. The intensity and characteristics of the features is less distinct than for “pure” very new and very old road surfaces. This shows that the aging and deterioration process is gradual and there is strong spectral evidence that this transition in surface material properties can be described in hyperspectral datasets. It should be noted that a road aging from 1 to 3 years, a change in PCI of 100 to 86, and a constant structure index of 100 has about the same spectral impact than from 3 to more than 10 years, a PCI decrease from 86 to 32 and a structure index decrease from 100-63. This suggests that the spectral signal is very sensitive to early stages of aging and

deterioration and later, more severe road damages have a lower spectral impact.

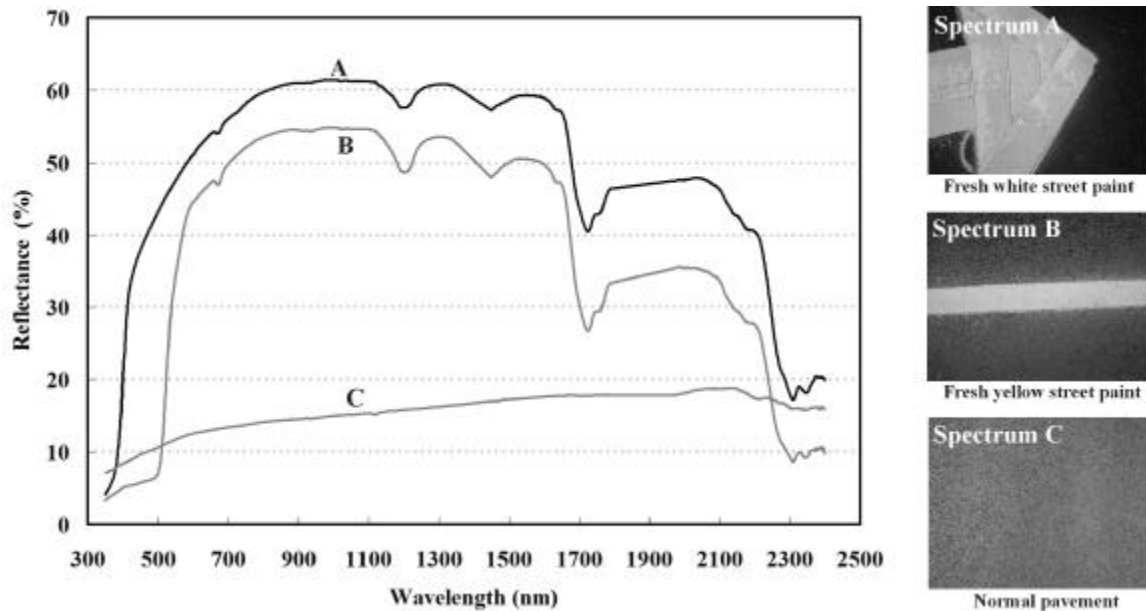


Figure 2: Spectral characteristics of street paint in different color versus asphalt pavement from the ASD ground spectral measurements (the major water vapor absorption bands are interpolated).

Street paint also represents hydrocarbons with highly reflective properties (Figure 3). Spectra A and B of Figure 2 show reflectance values up to 60 % in the VIS/NIR region. The difference between spectrum A and B in the visible region is due to color since spectrum B represents yellow street paint and blue wavelengths are absorbed. The street paint graphs highlight a typical asymmetric hydrocarbon doublet with the strongest absorption at 1720 nm and a second less deep one at 1750 nm (Cloutis, 1989). Numerous overlapping combinations and overtone bands cause the strong reflectance decrease beyond 2200 nm including a well-developed doublet at 2310 and 2350 nm with the 2310 nm feature being slightly stronger. These features nicely compare to characteristics of newly paved road surfaces (Figure 1), hence with different absorption intensity. From a remote sensing perspective the presence of street paint will increase brightness of a road surface especially in the VIS/NIR and emphasize the hydrocarbon absorptions in the SWIR.

### Spectral properties of typical asphalt road distresses

The most common road distress and indicator of pavement quality is cracking. Cracks, especially with Alligator pattern, indicate structural failure of the road surface due to traffic loads. Cracks allow moisture to infiltrate, increase road surface roughness and may further deteriorate to potholes.

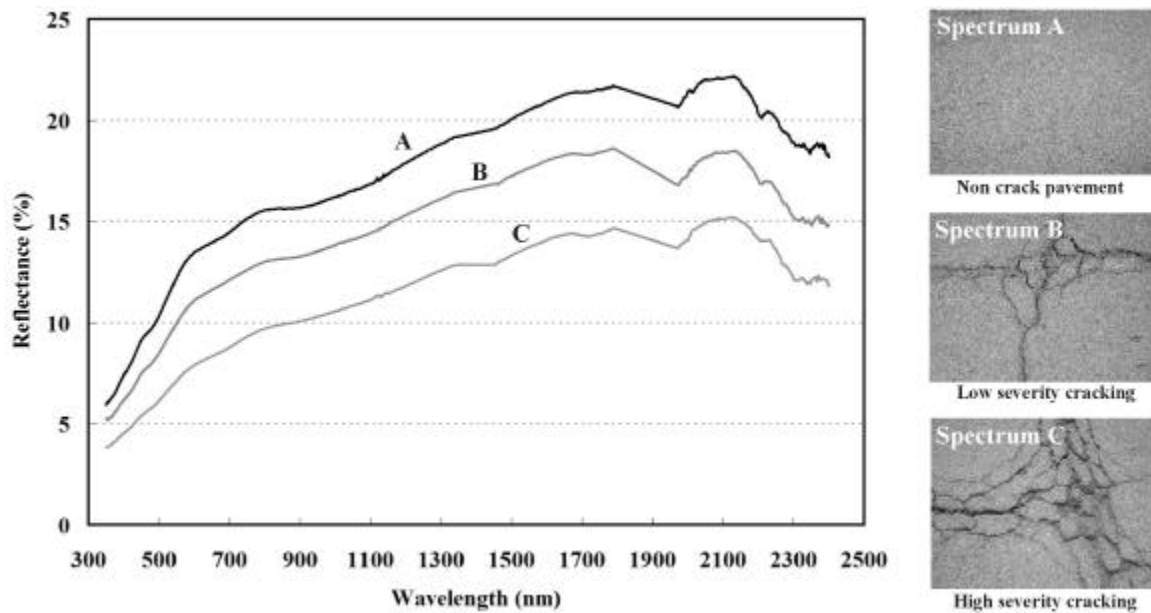


Figure 3: Spectral effects of severity of structural road damages from the ASD ground spectral measurements (the major water vapor absorption bands are interpolated).

Figure 3 shows the spectral effects of structural damages or Alligator cracks with different severity on the spectral signal. The general road surface reflectance of the pavement is similar to spectrum C in Figure 1 with the spectrum is dominated by mineral absorption processes. The main spectral impact of cracking is on object brightness in all parts of the spectrum. The increasing surface roughness and shadows cause reflectance differences of up to 7-8 % in the NIR and SWIR between the actual pavement and high severity cracks. The concave shape in the VIS/NIR is more obvious for brighter, non-cracked road pavements. There also is indication that the cracked surfaces have more intense hydrocarbon absorption features in 1700 nm and 2300 nm region. The asphalt mix erosion and oxidations happens on road surface. Cracking exposes deeper layers of the pavement with higher contents of the original asphalt mix that is then manifested in increased hydrocarbon absorption features. This fact highlights the contrary spectral signal between road deterioration of the pavement itself (Figure 1) and the severity of structural damages (Figure 3). An aging road surface gets brighter with decreasing hydrocarbon absorptions, structural distresses cause less reflectance with increasing hydrocarbon features. Although the reflectance difference and intensity of the hydrocarbon absorptions is less for cracks than for new asphalt surfaces, this fact indicates certain limitations in hyperspectral remote sensing of road conditions.

A second common road distress is raveling. The process of raveling describes the progressive dislodgement of pavement aggregate particles. This is mainly caused by increasing loss of bond between aggregate particles and the asphalt binder. Effects are the accumulation of loose aggregate debris on the road surface and less friction of vehicles,

increasing surface roughness, and collecting water in the raveled locations causing vehicle hydroplaning.

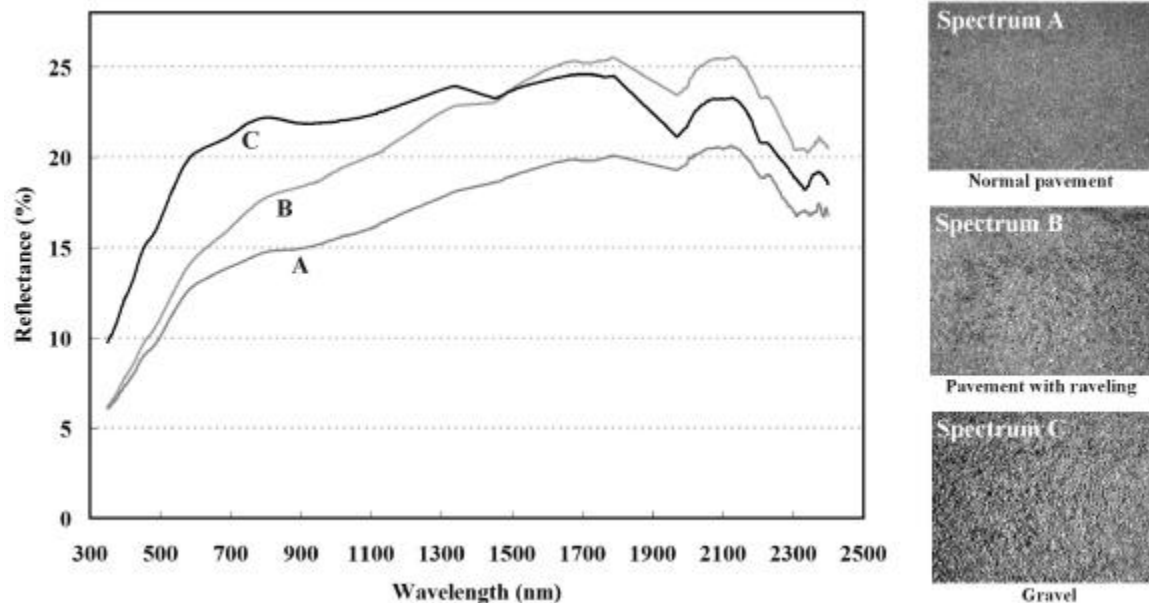


Figure 4: Spectral effects of raveling from the ASD ground spectral measurements (the major water vapor absorption bands are interpolated).

The spectra A and B in Figure 4 compare a normal pavement with a raveled road surface. The raveling exhibits larger amounts of rocky components and raveling debris (gravel) on the surface. This generally increases the brightness of the surface due to increasing mineral reflectance and less prominent hydrocarbon absorptions. The raveling spectrum shows characteristics from both the normal pavement and spectrum C. Spectrum C reflects a gravel parking lot surface. In comparison with the pavements, this surface has higher reflectance in the visible and photographic near infrared due to the missing hydrocarbon absorptions. The mineral composition is reflected in more prominent features from iron oxide and other minerals like a calcite feature near 2320 nm.

### Spectral properties of road surface maintenance

Besides rehabilitation treatments there are several maintenance methods to improve and maintain the quality of a road surfaces. Their spectral characteristics are compared to a common asphalt road surface (Figure 5). Spectrum A shows a slurry crack seal that help to prevent water or other non-compressible substances such as sand, dirt, rocks or weeds entering the crack. Slurry seal crack fillings are mixtures of emulsified asphalt or rubberized asphalt spread with a machine onto the asphalt surface. This treatment material has a constant low reflectance on the order of 5 % reflectance. Only very minor hydrocarbon absorption features are represented, similar to the ones found for parking lot surfaces (Herold et al., 2004).



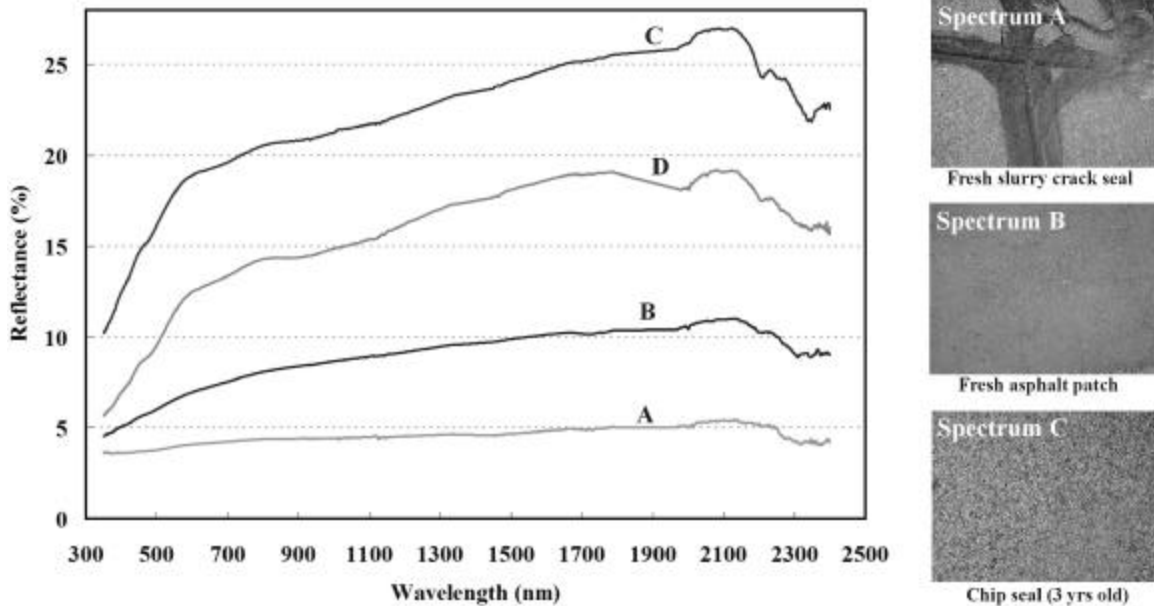


Figure 5: Spectral effects of different road surface treatments from the ASD ground spectral measurements. Spectrum D is an untreated road surface corresponding to spectrum C in Figure 2 (the major water vapor absorption bands are interpolated).

Patches are used to treat an area of localized road distress. The material is similar to usual pavement and spectrum B has similarity to a newly paved road (see Figure 1). **Chip seal treatments include spraying an asphalt binder on the pavement, then immediately covered by a single layer of uniformly sized chips.** The new surface treatment is then rolled to seat the aggregate, and broomed to remove any loose chips. The chip seal spectrum C has significantly higher reflectance than a usual asphalt road surface with more prominent mineral absorption features, similar to a paved road surface (Figure 4).

### Other road surface features

Road surface contains a variety of other features. Their spectral effects are presented in Figure 6. Spectrum A shows an older crack containing green vegetation. This has a strong impact on the spectral response exposing spectral features from chlorophyll, water content and ligno-cellulose typical for vegetation (Herold et al., 2004). The accumulation of oil on the pavement decreases the overall reflectance with more prominent hydrocarbon absorption characteristics (Spectrum B). **The metal manhole in spectrum C also indicates a decreasing reflectance compared to usual pavement along with stronger iron oxide signal at the absorption bands at 520, 670 and 870 nm.**

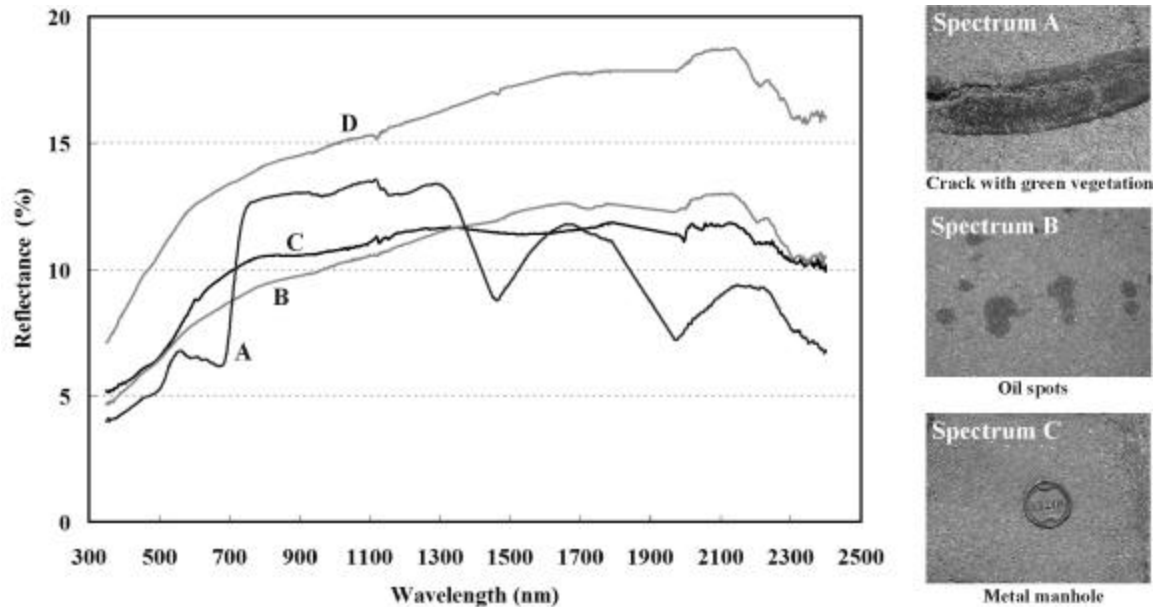


Figure 6: Spectral effects of different road surface features from the ASD ground spectral measurements. Spectrum D is an untreated road surface corresponding to spectrum C in Figure 2 (the major water vapor absorption bands are interpolated).

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