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An extensive laboratory investigation of the use of bio-oil modified bitumen in road construction

Alvaro Guarin [a,*], Abdullah Khan [a], Ali Azhar Butt [a,1], Björn Birgisson [a,b], Nicole Kringos [a]

[a] Civil and Architectural Engineering, KTH Royal Institute of Technology, Brinellvägen 23, 10044 Stockholm, Sweden
[b] Aston University School of Engineering and Applied Science, Aston Triangle, Birmingham B4 7ET, UK

HIGHLIGHTS

- Forensic investigation on binder bleeding in bio-oil modified surface dressings.
- Bio-oils had solubility issues with bitumen; low bonding between binder and stones.
- Modified binders showed high mass loss but kept rheological behavior after aging.
- Fish oil modified bitumen worked a little better than rapeseed oil modified binder.

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ABSTRACT

Several roads in Iceland with bio-oil modified surface dressings exhibited severe distresses such as bleeding, binder drain down, and eventually as surface dressing sticking to tires. Samples from six road sections were evaluated in the laboratory to determine the causes of the failure. Binders with and without bio-oil, rapeseed oil and fish oil, were evaluated through a comprehensive rheological and chemical characterization. Both oils, exhibited solubility issues with the bitumen; consequently, the oils covered the aggregates, preventing bonding between binder and stones. It appears that fish oil worked a little better than rapeseed oil for binder modification.

1. Introduction

The use of bio-oils for road construction has been extensively evaluated by many researchers due to diverse reasons such as limited resources of crude oil, price challenges, and environmental concerns [1–11]. Over 30 years, the Icelandic Road Administration has used surface dressings in low traffic roads; they recommend surface dressings for roads constructed for a maximum annual average daily traffic (AADT) of 3000, with around 10% of the heavy trucks (>3.5 tons). Since a significant part of the Icelandic road network has low traffic, surface dressings are commonly used.

In Iceland, the main purposes of the binder modification were to reduce binder viscosity/spray temperature and to protect the environment. At the beginning white spirit was used, but bleeding and harmful environmental effects, precluded its use. In 2006, Icelandic Road Administration begun to promote and use bio-oils such as fatty acid methyl ester from rapeseed oil and ethyl ester from fish oil for binder modification [12]. In contrast to white spirit, bio-oils do not evaporate or degrade with time; instead, they become a permanent part of the binder. Bio-oil modification of bitumen is not very common and, to the knowledge of the authors, the modification processes in Iceland do not follow any stablished standards or bench marked procedures/methods.

During the winter 2012, several road sections in Iceland exhibited extensive damage in their surface dressings; the air temperature for the affected roads varied between 4 °C and 10 °C in summer and between −2 °C and 4 °C in winter. In some cases, the bitumen at the bottom of the surface dressing became loose like an emulsion and was pumped up by the traffic load through

* Corresponding author.
E-mail addresses: alvaro.guarin@abe.kth.se (A. Guarin), abdkha@kth.se (A. Khan), aabutt@ucdavis.edu (A.A. Butt), bjorn.birgisson@aston.ac.uk (B. Birgisson), niki.kringos@abe.kth.se (N. Kringos).
[1] Address: Department of Civil & Environmental Engineering, 2001 Ghausi Hall, University of California, 1 Shields Avenue, Davis, CA 95616, USA.

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Fig. 1. Extensive surface dressing damage.

pores in the surface layer, sticking to the tires of vehicles passing over the area (Fig. 1). Preliminary studies indicated that the worst bleeding was detected in the old rapeseed oil modified bitumen pavement sections; however, sections with ethyl ester from fish oil were also affected.

As part of a detailed forensic investigation to determine the causes of the surface dressing failure, the Icelandic Road Administration retrieved pavement samples from six different road sections and delivered them to the Highway and Railway Engineering laboratory at KTH Royal Institute of Technology (Sweden) for a comprehensive evaluation. The different types of bituminous binders used for the surface dressings are:

- N: Reference bitumen: Binder with penetration grade 160/220.
- K8: Bitumen Penetration Grade 160/220 + Ethyl Ester from fish oil.
- K9: Bitumen Penetration Grade 160/220 + Fatty Acid Methyl Esters (FAME) from rapeseed oil.

Aggregates were mostly extracted from two main rock quarries: Neðri-Mýrar and Uppsala; however some material was taken from other sources such as Víðidalstungumelar and Syðra-Vallholt.

- Neðri-Mýrarnáma: 100% solid basalt rock.
- Uppsalanáma: Variable quality basalt rock.
- Víðdalstungumelar: Variable quality gravel deposits.
- Syðra-Vallholt: Variable quality gravel deposits.

Table 1 summarizes general information about the road sections (materials and thicknesses), construction year, binder type of the surface layers, and pavement status by May 2013, according to the Icelandic Road Administration.

Surface dressings are paved by spraying the binder first, followed by the aggregates distribution and compaction; in Iceland, it is a common practice to place a second layer of surface dressing after about two years. Generally, the roads have several overlays of surface dressing and during rehabilitation; these layers are recycled and mixed with either new bitumen or cement. The gradation of the aggregates is essential to achieve a proper performance of surface dressings; usually uniform gradations are recommended to attain better performance [13]. Larger aggregates provide greater ability to seal, long-term aggregate adhesion, higher surface friction and better waterproofing characteristics because of the higher volume of binder required to hold the aggregate particles in place; more binder is needed since uniform gradations create bigger air voids. This could also promote longer life expectancy depending on the traffic volume. It should be also noted that larger aggregates for uniform gradations may increase the chances for vehicle damage, noise, and roughness. The Icelandic Road Administration provided granulometric analysis data for each surface dressing and all the materials appeared to meet the respective requirements.

2. Experimental investigation

The Icelandic Road Administration extracted square samples from the pavement, since it was difficult to obtain standard cores from the surface dressings. 24 samples were obtained including four samples from each of the six pavements sections (Table 1). It should be noticed that the surface samples may have been broken during the extraction from the road. A comprehensive laboratory work plan was conceived to achieve the following objectives in order to determine the main causes for the low quality of the surface dressings:

- Complete a detailed visual inspection of the surface dressing to identify key problems.
- Verify the penetration grade of the binders, reference and recovered bitumen.
- Determine the Superpave binder grading for reference and modified bitumen.
- Perform a comprehensive chemical characterization of the three binder types.

Accordingly, the following detailed laboratory-testing program was conceived and performed to fully characterize the surface dressings: