Analysis of the use of coal tar as a binder in bituminous mixtures, using Marshall and Ramcodes methodologies

R Ochoa-Díaz

Universidad Pedagógica y Tecnológica de Colombia - UPTC, Tunja, Colombia.

E-mail: ricardo.ochoa@uptc.edu.co

Abstract. This paper presents an alternative use of coal tar, a by-product of the steel industry, given the problems of accumulation and negative environmental impact. Therefore, it is necessary to analyze the incorporation of coal tar as a binder in paving mixtures. First, this paper presents the origin, description of the main characteristics, and properties of tar. Then, this paper evaluates the mix of coal tar by means of the RAMCODES and Marshall methodologies to determine its resistance. The results of the tests explain the physical and mechanical properties of the mix. Taking into account the results of both methods, this paper makes a comparison to determine the suitability of the RAMCODES methodology in the mix design. Finally, it analyzes the alternatives to coal tar that can be used as binders in bituminous mixes for pavement and the advantages of their uses under some specific conditions.

1. Introduction

Since ancient times, man has continually developed activities that allow him to subsist and evolve. At the beginning, these activities were limited to consuming the animals and plants that nature offered, without producing any alterations in nature since the residues generated by these activities were mainly organic. With the development of industrial activities, however, mankind has produced an increasing number of inorganic residues that are not biodegradable. Governments and institutions are dedicating resources to the development and promotion of technologies that allow these inorganic residues and materials to be used constructively, thereby reducing the environmental and economic consequences that they cause [1].

The construction of highways is an activity that is generally considered to be an important use of natural resources in which, specifically, the creation of bituminous mixtures used in the construction of wearing courses requires the use of large quantities of stone aggregates [2].

In order to promote environmentally sustainable practices, this study aims to contribute to the development of technologies that utilize the residues and byproducts of the steel industry in order to improve the environmental conditions in the areas of influence of these companies. The objective is to analyze and evaluate the possibility of substituting part of the natural aggregates and the asphalt that are traditionally used in the manufacturing of bituminous mixtures for residues from the steel industry like granulated slag and coal tar.

2. Materials

2.1. Coal tar as a binder

Tar is a semisolid bituminous product or liquid that is obtained as a residue of the distillation, in the absence of air, of organic substances that posses volatile materials, like carbon or wood. It is a binder
in the cold, water resistant, insoluble in lubricating oils and petroleum derived combustibles, soluble in ether, benzene, carbon disulfide, chloroform, and quinoline. Tar is formed from aliphatic and naphthalene compounds that contain hydrogen, oxygen, nitrogen, and sulphur.

2.2. Aggregates
Crushed gravel was used as a thick aggregate, which was subjected to the following tests: Los Angeles abrasion coefficient, percent of fractured face, elongation index and flattening index. Sand was used as a fine aggregate. Portland cement and fine sand that passed through a #200 sieve were used as mineral filler, both of which were tested to determine their specific gravity. All of the tests were conducted according to the INVÍAS testing guidelines for road materials [3].

2.3. Granulated slag as a fine aggregate
Granulated slag is a residue that comes from the blast furnace in the manufacturing of iron in integrated steel plants. The blast furnace is a tall, vertical oven whose main function is to produce pig iron of a chemical constant composition. The elements that are released from a blast furnace are: blast furnace gas, blast furnace flue dust, liquid slag and pig iron. The slag is released from the blast furnace in liquid form at 1400 °C and is pushed forward with a high pressure water jet and disintegrated into small particles to form granulated slag [4, 5].

3. Methodology
The methodology utilized in this investigation can be divided into three stages. First, tests were conducted to study the characteristics of the materials to be used in the design of the bituminous mixtures. Second, tests were conducted to obtain the working formula of the bituminous mixture using the RAMCODES and Marshall methodologies [6-8]. Third, the results obtained using these two different methodologies were compared as well as the benefits of utilizing tar through the obtainment of the dynamic module of the mix that offers the best mechanical characteristics.

4. Experimental design
This study attempted to implement the mix for wearing courses and the mix chosen for the development of this study is a type 2 heat-dense mixture (MDC-2), article 450-07 INVIAS [9]. With the idea of conducting a detailed analysis of the behavior of the slag and the coal tar in the mix, fifteen types of mixes were designed with the following variables: the fine aggregates (slag (E) and sand (A)) and mineral filler (cement (C) and fine sand (A)). The grain sizes of these materials were adjusted inside the granulometric band of the MDC-2 mix; they were placed in the center, on the fine side and on the thick side of the granulometric band. These were adjusted with the objective of evaluating the incidence of the grain size in the behavior of the mix.

5. Results

5.1. Physical and mechanical properties
The results obtained provide evidence for the possibility of creating bituminous mixtures utilizing coal tar as a binder. The best results were obtained when cement was used as filler in the mixture. There was no significant difference detected between mixes that used slag and mixes that used sand as fine aggregates, but in the mixtures with slag it was necessary to use a higher percentage of binder.

The prepared mixture that presented the best characteristics and that fit the standards demanded by the specifications for transit level NT-2 is the M-GAC-14 mix, which is presented below in table 1. This mix was tested to obtain the characteristic dynamic.

5.2. Dynamic properties
This test was performed with the N.A.T. (Nottingham Asphalt Tester) following the guidelines prEN 12697-26 Method IT-CY to an uncertainty of ±1.146% for a level of confidence of 95%.
The dynamic modules were made at a frequency of 10 Hz and at three different temperatures: 5°C, 25°C and 40°C. The results are displayed in figure 1.

Table 1. Results mix m-gac-14.

| Characteristic                | Specification | Results test |
|------------------------------|---------------|--------------|
| Minimum stability (Kg)       | 750           | 792.0        | 755.0        |
| Flow (mm)                    | 2 – 4         | 3.9          | 4.1          |
| Air voids in the mix (Va) %  | 3 – 5         | 4.0          | 3.9          |
| Voids in aggregate (VMA) %   | 15            | 15.2         | 15.8         |
| Voids filled with binder (VFA) % | 65 – 78      | 73.9         | 75.4         |

Figure 1. Dynamic module mix M-GAC-14.

6. Conclusions

This study aims to open an investigation to evaluate the behavior of bituminous mixtures for pavement using different types of binders other than asphalt.

This study does not aim to replace asphalt in pavement mixtures; the intention is to look for alternatives that allow manufacturers to select the product that is best suited to each individual project.

RAMCODES is a useful methodology for the design, production, and quality control of bituminous mixtures because it guarantees the completion of the volumetric parameters demanded by the specifications. This methodology also saves time, resources, and money, since it only requires three briquettes in comparison with the 15 briquettes required by the Marshall test.

The incorporation of the cement as a filler played an important role in the behavior of the mixture because it improved the properties of the binder and improved the adhesion of the aggregates, which permitted better stability and flow responses.

Keeping the thermal susceptibility of coal tar and consequently bituminous mixtures in mind, it was determined that these types of mixtures can be used in cold and temperate climates. Below these conditions, the behavior of the mixture will be acceptable according to the action of the load imposed by transit.
If some mixes did not meet the requirements demanded by INVIAS for wearing courses, they could be used as base or sub-base layers improvers.

References
[1] Belmonte Sánchez A 2009 Análisis de la Reutilización de Residuos Procedentes de la Industria de Silestone en la Fabricación de Mezclas Bituminosas (España: Universidad de Granada)
[2] Carmen R, Germán M, Luis B, Fernando M 2012 Warm mix Asphalt: an Overview Journal of Cleaner Production 22 206
[3] Instituto Nacional de Vías 2007 Normas de Ensayos de Materiales para Carreteras 1 y 2 (Bogotá: INVIAS)
[4] Alfonso G 2002 Proceso Siderúrgico Planta Belencito (Colombia: Acerías Paz del Río S.A.)
[5] Pérez S 2008 Evaluación de la Escoria de Horno como Agregado en Mezclas Asfálticas (Guatemala: Universidad de San Carlos de Guatemala)
[6] Sánchez F 2002 Metodología Racional para el Análisis de Densificación y Resistencia de Geomateriales Compactados (México: Publicación Técnica 200 ed. Sanfandila, Querétaro)
[7] Delgado H 2006 Influencia de la Granulometría en las Propiedades Volumétricas de la Mezcla Asfáltica (México: Publicación Técnica 299 ed. Sanfandila, Querétaro)
[8] Sánchez F 2008 Manual de Aplicación Ramcodes (Venezuela: Solestudios C.A.)
[9] Instituto Nacional de Vías 2007 Especificaciones Generales de Construcción de Carreteras (Bogotá: INVIAS)