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Assessment of gaseous emissions produced on site by bituminous mixtures containing crumb rubber

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HIGHLIGHTS

- Gaseous emission of bituminous mixtures were sampled at several construction sites.
- Laboratory analyses were carried out for the evaluation of the contents of potentially hazardous compounds.
- Experimental data were evaluated in differential terms in the framework of a sanitary-environmental risk analysis model.
- Possible toxicological and carcinogenic effects on workers were assessed.

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ABSTRACT

Crumb rubber (CR) derived from the grinding of end-of-life tires (ELTs) can be employed, either by means of the "wet" or of the "dry" process, in the production of high-performance bituminous mixtures for road paving applications. Nevertheless, when Administrations consider possible implementation of such technologies in pavement construction and rehabilitation, they are often concerned with the potential impact that the use of CR may have on environment and on workers operating at laying sites. This paper provides a specific contribution to this area of technical knowledge, focusing on the assessment of gaseous emissions which workers may be potentially exposed to in the framework of a sanitary-environmental risk analysis model which considers possible toxicological and carcinogenic effects.

1. Introduction

Based on several years of experience worldwide, it has been proven that crumb rubber (CR) obtained from the grinding of end-of-life tires (ELTs) can be employed in the production of high-performance bituminous mixtures for road paving applications [1]. Available technologies are known as the "wet" and "dry" processes. In the "wet" process, CR is preliminarily mixed with bitumen, thus obtaining a very ductile and elastic modified binder, also known as "asphalt rubber" (AR) [ASTM D6114-09], that is then combined with aggregates in the hot mix plant. In the "dry" method, CR is introduced in the production flow of bituminous mixtures as a supplementary component, substituting part of the aggregates and providing enhanced elastic response under loading [2,3].

Research has focused on a number of performance-related issues of bituminous mixtures containing CR, including the assessment of resistance to permanent deformation, fatigue cracking, oxidative ageing and water damage [4]. Moreover, several aspects to be taken into account during mix design and quality control operations have been addressed, with the consequent definition of reliable technical specifications [5,6]. Nevertheless, the effects of the use of CR on gaseous emissions produced during laying operations have not been subjected to extensive investigations, with a limited number of experimental studies which have not yielded quantitative information on the potential health risks which workers are exposed to on site [7–9].

The study carried out in the United States by the National Institute for Occupational Safety and Health (NIOSH) in cooperation with the Federal Highway Administration (FHWA) was based on data gathered at several pavement construction sites, where occupational exposures among asphalt workers were evaluated by comparing conventional and AR bituminous mixtures [7]. Workers' medical data were related to results of chemical analyses carried out on fumes sampled at paving sites in different positions. In

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particular, tests focused on the assessment of potentially harmful substances such as total particulate, benzene soluble particulate, polycyclic aromatic hydrocarbons (PAHs), organic sulphur-containing compounds and benzothiazole. It was found that the highest exposures were from jobs near the paver or asphalt delivery trucks and it was concluded that exposure to emissions of bituminous mixtures containing CR may be potentially more hazardous than that associated to conventional paving materials.

In the personal exposure monitoring study carried out by Watts et al. [8], gaseous emissions of bituminous mixtures containing CR and of the standard type were analysed by considering fine respirable particles (<2.5 μm) and PAHs. Even though experimental results highlighted a greater potential carcinogenic PAH exposure of road workers in the case of AR mixtures, from a statistical point of view no significant differences were found with respect to standard mixtures.

Evaluation of stack emissions at production plants was the subject of the investigations reported by Stout and Carlson [9], who reviewed the results of analyses carried out in the case of bituminous mixtures prepared with and without CR. The studies were performed with different approaches and methods, but in all cases the effects of CR, if any, were reported to be relatively small.

With the goal of filling a significant gap in technical knowledge, the issue of health risk assessment was given a prominent role in two research projects which were recently launched in Italy on the use of CR in bituminous mixtures (‘‘wet" and ‘‘dry" technologies): POLIPNEUS (2012-16), funded by Ecopneus, a non-profit company which has the mission of managing the entire flow of ELTs in Italy, and TYREC4LIFE (2011-14), supported by the European Commission as part of the LIFE + funding program [10,11]. The work presented in this paper is based on monitoring activities which were carried out within these projects on several construction sites in which bituminous mixtures were laid for the formation of wearing and binder courses both of the standard type and containing CR (‘‘wet" and ‘‘dry" mixtures). The main goal of the investigation was to assess the potential health impact on workers of gaseous emissions produced during paving operations. For such a purpose, fumes were sampled at the paver and were then subjected to laboratory analyses for the determination of the concentration of Volatile Organic Compounds (VOCs) and Polycyclic Aromatic Hydrocarbons (PAHs). Results were used within a procedure for the assessment of health risks which workers are exposed to. In such a context, the influence of CR was highlighted in differential terms, comparing calculated risks associated to the laying of mixtures with and without CR.

2. Experimental

2.1. Construction sites

Experimental investigations were carried out on several construction sites which involved the laying of a wide range of bituminous mixtures, including standard ones and several types of ‘‘wet" and ‘‘dry" mixtures containing CR. A synthetic description of considered sites and mixtures is given in Tables 1 and 2.

Standard mixtures (identified with ‘‘S" as final letter in code names) were designed according to available technical specifications for binder courses [12]. They contained aggregates of different origin and, as shown in Table 1, were prepared by employing both neat and polymer-modified bitumen. Mixture QU-S also incorporated 13% (b.w. on dry aggregates) of Reclaimed Asphalt Pavement (RAP) material.

Table 1
Construction sites considered in the investigation – standard bituminous mixtures.

Mixture code	Binder type	Site type	Layer thickness (cm)
QU-S	Neat bitumen	Urban road	7
BR-S	Polymer-modified	Trial section	9
AL-S	Neat bitumen	Provincial road	4

Table 2
Construction sites considered in the investigation – bituminous mixtures containing CR.

Mixture code	Mixture type	Site type	Layer thickness (cm)
BV-W	Gap-graded	Provincial road	3
SF-W	Gap-graded	Urban road	5
AO-W	Dense graded	Motorway	4
AL-D	Dense graded	Provincial road	4

Mixtures containing CR were both of the gap-graded and dense-graded type. Those containing asphalt rubber (identified with ‘‘W" as final letter in code names) were conceived for the formation of wearing courses and were produced in three different hot-mix plants by employing binders which were prepared by the same Company according to an undisclosed recipe. No information was available on component materials (base bitumens and CRs) employed for each production batch. Mixture AL-D was of the ‘‘dry" type and was used as a binder course material. Its job-mix formula was obtained from that of a standard reference mixture (AL-S), also included in the investigation, by simply adding 1% CR (b.w. of aggregates) and by slightly increasing target bitumen content to take into account additional adsorption effects due to CR.

Mixtures SF-W and QU-S were produced in the same day and in the same plant by employing a common base bitumen. Mixtures AL-D and AL-S shared these same common aspects (day and plant of production, employed bitumen) and were also laid in the same site.

During pavement construction operations, temperature of the mixtures was continuously monitored behind the paver's screed by means of hand-held immersion thermometers. Site-specific conditions were also recorded by measuring air temperature.

Samples of bituminous mixtures taken at the construction sites were subjected to laboratory tests for the determination of binder content and aggregate size distribution. Binder content was determined by means of ignition tests carried out according to EN 12697-39. Size distribution of aggregates recovered from ignition tests was evaluated in wet conditions by employing the standard set of sieves indicated in technical specifications.

A synthesis of mixture composition data is provided in Tables 3 and 4. Binder content (%B) is expressed as a percentage b.w. of dry aggregates. Aggregate size distributions are described by referring to maximum diameter (D_{max}, corresponding to 100% passing), percentage of fine aggregates (%P_2, passing the 2 mm sieve) and of filler (%$P_{0.075}$, passing the 0.075 mm sieve). Both tables also contain average air (T_A) and mixture (T_M) temperature values recorded on site during laying operations.

2.2. Test methods

Fume samples were taken at the driver's seat of the paver, in the most severe exposure conditions during mixture discharge operations from trucks, and at the screed, immediately after discharge of the hot mixture and during the forward movement of the paver along the construction site. Sampling was carried out by employing a pump (0.5 l/min flow rate, 5 min total sampling time) by means of which fumes were adsorbed on active granular carbon cartridges which were then stored at freezing temperature until analysis. These matrixes were subjected to solvent extraction (with methylene chloride, Fluka, HPLC grade) in an ultrasound bath for 60 min [EN 13649, 13] and were then analysed with an Agilent 7890/5975 gas chromatograph, equipped with a HP5-MS capillary column (30 m × 0.25 mm × 0.25 μm), for the determination of the concentration of Volatile Organic Compounds (VOCs) and Polycyclic Aromatic Hydrocarbons (PAHs) [2,14].

3. Results and discussion

Results of analyses performed on gaseous emissions sampled at the test sections are given in Tables 5–8 (mean values derived from two independent replicates). Listed compounds are those which are considered toxic or carcinogenic among all substances potentially detectable by means of gas-chromatographic techniques. These are also the compounds which were considered within the sanitary-environmental risk analysis procedure described in Section 4.

Table 3
Mixture composition and laying conditions – standard bituminous mixtures.

Site code	%B (%)	D_{max} (mm)	%P_2 (mm)	%$P_{0.075}$ (%)	T_L (°C)	T_A (°C)
QU-S	4.8	25	29.0	6.3	165	28
BR-S	5.5	20	31.5	6.1	165	28
AL-S	4.7	20	35.5	5.4	170	15