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Evaluation of potential gaseous emissions of asphalt rubber bituminous mixtures. Proposal of a new laboratory test procedure

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HIGHLIGHTS

- A new laboratory test was proposed for the generation of gaseous emissions from asphalt rubber bituminous mixtures.
- Gaseous emission of bituminous mixtures were sampled in the laboratory and at construction sites.
- Laboratory analyses focused on concentrations of potentially hazardous compounds.
- Experimental data were evaluated in the framework of a risk assessment model.
- The laboratory procedure in most cases yielded conservative values of risk parameters.

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ABSTRACT

When deviating from standard paving solutions, it is necessary to verify that the use of supplementary components or the adoption of different processing conditions do not lead for construction workers to an increase of the risk associated to fume exposure. In the specific case of bituminous materials containing crumb rubber from end-of-life tyres, such an issue was addressed in an investigation in which a new laboratory test procedure for the evaluation of the composition and of the potential hazardous effects of gaseous emissions released during paving operations was developed and validated. Experimental activities were carried out by considering six different asphalt rubber mixtures, the emissions of which were sampled both in the field and in the laboratory. Subsequent analyses were performed by evaluating concentrations of volatile organic compounds and polycyclic aromatic hydrocarbons and by calculating corresponding toxic and carcinogenic risk parameters by means of adequate models. Effects of material-specific and site-specific factors were clearly distinguished and in most cases it was observed that analyses derived from laboratory-generated emissions led to a conservative estimate of risk. In general terms it was therefore concluded that the proposed procedure may be extremely valuable for the assessment of the true emission potential of bituminous mixtures containing crumb rubber and that in the future it may be employed as an evaluation tool during the mix design and field monitoring phases.

1. Introduction

Pavement engineering is continuously evolving as a result of several driving forces which nowadays include the need of taking into account the compatibility of any innovative material or technology with the health and safety of construction workers. In the specific case of bituminous binders and mixtures, such an aspect is mainly related to gaseous emissions generated during production and laying, which should be maintained below acceptable levels in order to limit their potentially harmful effects [1–3]. Thus, when deviating from standard paving solutions, it is necessary to verify that the use of supplementary components (such as additives and recycled materials) or the adoption of different processing conditions (e.g. higher temperatures) do not lead to an increase of the risk associated to fume exposure.

The general approach illustrated above should be adopted for the evaluation of bituminous materials containing crumb rubber from end-of-life tyres, widely diffused worldwide as a result of their enhanced performance-related properties [4–6]. The most common production process of such materials requires premixing of rubber particles with bitumen (according to the so-called "wet" process), with the consequent yield of a binder, also known as

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"asphalt rubber" [ASTM D6114], which can thereafter be employed for the preparation of bituminous mixtures in hot mix asphalt plants. As a result of the high viscosity of asphalt rubber, production and laying operations are usually carried out at temperatures which are significantly higher than those of standard paving materials, thus leading to an increase of gaseous emissions which are characterized by a peculiar odor due to the presence of heated rubber particles.

Although it has been reported that laying of asphalt rubber mixtures may be associated to more frequent irritation symptoms in construction workers [7,8], analysis of available literature reveals that there is a lack of understanding of the true increase of health hazards, if any, caused by the adoption of such a paving technology in substitution of traditional ones [9,10]. Thus, the Authors focused on this topic by performing experimental investigations in which composition of gaseous emissions sampled at paving sites was analyzed and thereafter used as part of a sanitary-environmental risk analysis model employed to quantitatively assess the possible toxic and carcinogenic effects on individuals engaged in construction operations. It was observed that emissions are influenced by material-specific factors (i.e. mixture composition, crumb rubber type and base bitumen type) but are also affected by site-specific conditions which may be described in terms of layer thickness, laying and air temperature, air pressure, relative humidity and wind speed. By adopting a differential approach in which standard paving materials and laying conditions were used as a reference, it was concluded that emissions coming from asphalt rubber materials lead to toxic and carcinogenic risks for construction workers which are comparable to those of standard paving mixtures containing neat bitumen or polymer-modified binders [11,12].

In this paper the Authors provide a further contribution to this area of research by presenting the results obtained in the development and validation of a laboratory test procedure for the evaluation of the composition and of the potential hazardous effects of gaseous emissions released by asphalt rubber mixtures. Such a procedure was deemed necessary in order to base toxic and carcinogenic assessments on data which refer to fumes produced in standard, controlled conditions, and that as a consequence are not affected by the previously mentioned site-specific factors [12].

Following preliminary findings described in a previously published work [13], experimental activities were carried out by considering six different asphalt rubber mixtures, the emissions of which were sampled both in the field and in the laboratory. Subsequent analyses were performed by evaluating concentrations of volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) and by calculating corresponding risk parameters by means of adequate models. Effects of material-specific and site-specific factors were clearly distinguished and in most cases it was observed that analyses derived from laboratory-generated emissions led to a conservative risk estimate. In general terms it was therefore concluded that the proposed procedure may be extremely valuable for the assessment of the true emission potential of bituminous mixtures containing crumb rubber and that in the future it may be employed as an evaluation tool during the mix design and field monitoring phases.

2. Materials

Bituminous mixtures containing crumb rubber which were considered in the investigation were those employed in six different construction or rehabilitation paving projects on provincial and urban roads in Italy [11,12,14]. In the following they are indicated with codes (of the XY-Z type) composed by the abbreviation of site location (e.g. "FI" for Florence, "CE" for Caserta) and by the identification letter of mixture type ("G" for gap-graded, "D" for dense-graded).

Asphalt rubber binders employed in the bituminous mixtures were all provided by the same supplier which operates a "wet" technology production plant. Origin of base components was variable from case to case, but plant-mixing was always carried out with a target crumb rubber content equal to 18% (by weight of total binder) and by adopting an initial curing treatment of 45 min at 190 °C. After completion of this preliminary phase, the resulting asphalt rubber binder was either directly employed for the production of bituminous mixtures (ZA-G and FI-G), or it was transferred to a mobile tank equipped with a heater and an internal agitation system, left to cool down and thereafter transported to the hot mix asphalt plant (mixtures BV-G, CE-D, CB-G and MP-G). In these cases, once it reached destination the binder was reheated up to a temperature of approximately 175 °C and subjected to mechanical mixing until readings obtained from a hand-held viscometer showed viscosity values comprised between 1500 and 5000 cP. The binder was then considered ready for use and thereafter employed with its target dosage for the production of the desired bituminous mixture. The only deviation from this procedure occurred in the case of mixture CE-D, for which the asphalt rubber binder was diluted with neat bitumen in one of the plant tanks, thus leading to formation of a hybrid binder characterized by a lower than usual crumb rubber content (of the order of 5%).

Aggregates employed for production of bituminous mixtures were different from site to site depending on local availability. In each case, percentages of size fractions to be adopted as part of the job-mix formula were defined with the goal of satisfying gradation requirements set in technical specifications either for gap-graded [15,16] or for dense-graded [17] mixtures. Target binder content was also identified by referring to such specifications [15–17] and by taking into account the outcomes of previous similar paving works.

Design thickness (t) of wearing courses laid on site was equal either to 3 cm (mixtures BV-G, ZA-G, CE-D and FI-G) or to 4 cm (CB-G and MP-G).

3. Methods

3.1. Characterization of asphalt rubber binders and mixtures

Asphalt rubber binders sampled at hot mix asphalt plants were subjected to viscosity tests carried out in a wide temperature range (125–190 °C), which includes typical mixing and compaction conditions, by means of a Brookfield viscometer (DVIII-Ultra). Measurements were performed in accordance with EN 13302 by employing a SC4-27 spindle at an imposed shear rate equal to 6.8 s^{-1} (corresponding to 20 rpm).

Samples of bituminous mixtures retrieved from paving sites were employed for the determination of binder content according to 12697-39 (ignition method) and of size distribution of extracted aggregates as indicated by EN 933 (wet method).

3.2. Monitoring of paving sites

During construction works, laying conditions were monitored by employing a hand-held probe for the measurement of air temperature (T_a), air pressure (p_a), relative humidity (ϕ_a) and wind speed (v_w). Moreover, laying temperature (T_m) was recorded by means of an immersion thermometer which was inserted in the loose mixtures immediately behind the paver.

In each paving site gaseous emissions were monitored at the driver's seat of the paver and at the screed by means of a portable pump which for each measurement point was operated for 5 min with a flow rate of 0.5 l/min [8,11,12,14]. With such a system, fumes were adsorbed on active granular carbon cartridges which were then transferred to the laboratory for chemical analyses. Sampling was performed in the most severe exposure conditions for workers, which correspond to mixture discharge from delivery trucks in the case of the driver's seat, and to initial tamping of the hot mixture, before any compaction, at the screed.

3.3. Laboratory generation of gaseous emissions

Gaseous emissions from the bituminous mixtures containing crumb rubber were generated in standard, controlled conditions in the laboratory by means of a purposely-devised test procedure which is based on the use of a high-capacity (80 kg) temperature-controlled mixer equipped with a vertical-axis screw mixing tool [13]. Although the device is the same employed for similar purposes by the research group of the Laboratoire Central