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Characteristics of using layered double hydroxides to reduce the VOCs from bituminous materials

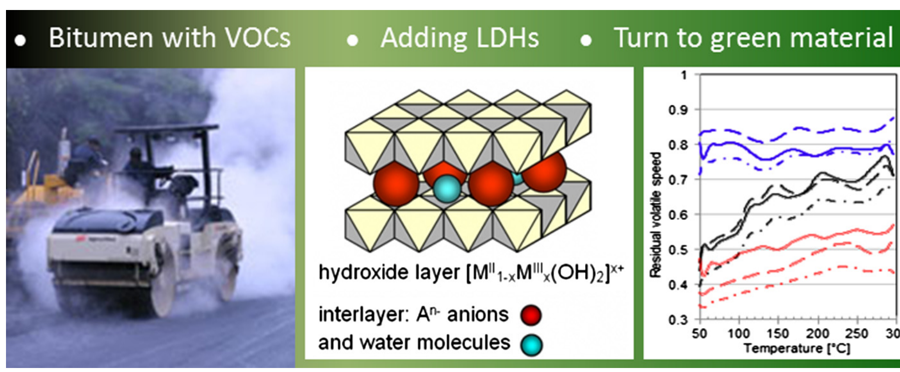
P.Q. Cui [a,b], H.G. Zhou [b], C. Li [a], S.P. Wu [a], Y. Xiao [a,*]

[a] State Key Laboratory of Silicate Materials for Architectures, Wuhan University of Technology, Wuhan 430070, China
[b] China Ge Zhou Ba group Co., Ltd., Wuhan 430030, China

HIGHLIGHTS

- The VOCs emission speed and amount can be characterized by ion current intensity.
- Temperature only has significant influence on the emission of smaller VOC molecules.
- 4 wt% of LDH has the best emission reduction effect of VOCs from bitumen.
- A decrease of 40–60% in VOC emissions can be achieved when LDHs was properly added.

GRAPHICAL ABSTRACT



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ABSTRACT

Various types of molecules in the volatile organic compounds (VOCs) from bituminous materials were detected and analyzed by means of thermogravimetric-mass spectrometry (TG-MS) analysis. The effect of layered double hydroxides (LDHs) additives as VOCs inhibitor was also studied. The ion histogram of volatile components from bituminous binder was obtained through TG-MS analysis. Analysis results show that the environmental temperature has significant influence only on the volatile characteristics of smaller molecules in the pure bituminous binder. The effect of environmental temperature has been found marginal for the volatile speed of bigger molecules and LDHs modified bitumen binder.

The obtained results regarding the pure bitumen and LDHs-modified bitumen demonstrate that LDHs modifiers have the potential to reduce VOC emissions. The reduction effect on different molecules or components varies. For smaller molecules, this effect on volatile speed is significant. LDHs affect the volatile speed of more carcinogenic volatile components to reduce more significantly for dichloroethane and naphthalene, compared with normal octane. The study findings indicate that a LDH percentage of 4% is an optimum for achieving the best emission reduction effect of VOCs for the selected binder, which is 40–60% percent reduction in VOCs.

1. Introduction

Bituminous materials contain organic compounds and hydro carbons of various molecular weights. Researches have shown that these materials release VOCs which are harmful to the environment and construction workers. VOCs released from bituminous

* Corresponding author.
E-mail address: xiaoy@whut.edu.cn (Y. Xiao).

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Table 1
Basic properties of PJ90 bituminous binder.

Properties	PJ90	PJ90 + 3% LDHs	PJ90 + 4% LDHs	PJ90 + 5% LDHs
Penetration at 25 °C, [0.1 mm]	82.1	68.2	66.3	65.1
Softening point [°C]	47.3	51.8	52.5	53
Ductility at 10 °C, [cm]	128.5	72.6	70.7	70.3
Viscosity at 135 °C, [Pa·s]	0.365	0.624	0.694	0.786
Flash point [°C]	345	352	358	362

materials exist not only in the construction process but also during the service period [1,2]. The wide use of such materials in road construction and roof sealant worldwide implies that the associated VOC emissions, which are very toxic to humans and aquatic organisms, can also lead to significant environmental pollution [3,4]. As proved in a case study performed by Gamble [5] and Karakaya [6], workers with weekly exposure to bitumen fume have more symptoms of health issues, such as eye irritation and abnormal fatigue. In order to quantify the effects and propose viable solutions, it is first crucial to characterize the main chemical components in VOCs.

The main component groups in the VOCs from bituminous materials include halohydrocarbons, nitrogen-hydrocarbons, oxygen-containing hydrocarbons, and polycyclic aromatic hydrocarbons (PAHs) [7–9]. These components have the characteristics of low concentration, strong activity and serious harm to humans and the environment. Some of them have the potential of undergoing chemical reaction with abundant matters in the atmosphere and hence producing a second chemical product, resulting in serious pollution to the environment. A literature review shows that studies on VOCs from bituminous materials mainly focus on its direct effect on the construction workers and the surrounding environmental conditions [10,11]. These approaches are partly empirical. As such, they cannot be utilized for effective qualitative and quantitative analyses on the chemical components in bituminous VOCs, and their direct impact on the environment and health of construction workers. Currently, the analysis and detection method for the bituminous VOCs is mainly based on the gas

Table 2
Characteristics of LDHs.

Properties	Values
Chemical composition	Mg-Al double layer structure
Appearance	White powder
Density, [g/cm^3]	1.7
Grain size [μm]	$D_{90} = 0.4$
Moisture content [%]	⩽3
Purity [%]	99.5

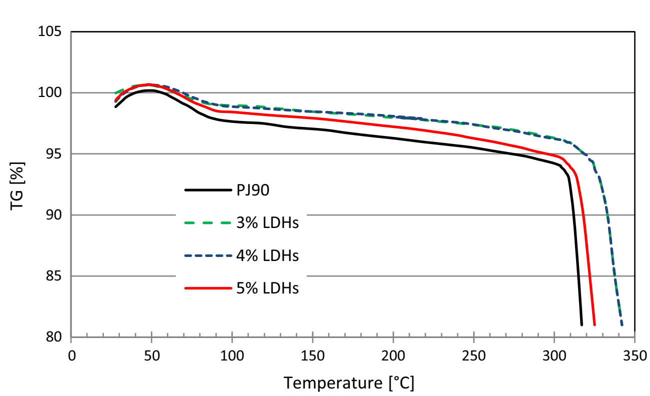

Fig. 1. TG curves of the analyzed bituminous binders.

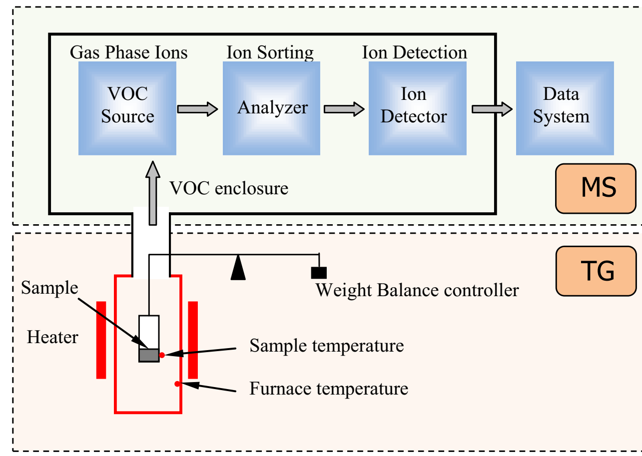

Fig. 2. Principal of TG-MS test and analysis program [16].

chromatography–mass spectrometer (GC–MS) [12,13]. Different kinds of detectors are required depending on the different types of VOC components [13]. There are dozens of chemical components in the VOC emissions from bituminous materials, which implies dozens of detectors are needed. In a slightly different approach, some other detection methods, such as fluorophotometer and ultraviolet spectrometer, were also applied to analyze the VOC emissions [14]. However, these methods were found to be not sensitive enough to detect the VOCs from bituminous materials, which were attributed to the relatively small amount of bitumen sample used in the investigation.

Other detection methods include thermogravimetry (TG). Although it can be utilized to study the weight changes of a sample placed in a controlled temperature program [15], it is only a quantitative thermal technique that gives no direct chemical information [16]. Nevertheless, when it is combined with the amount detection of molecules, a mass spectrum covering the masses of all the molecules can be produced [17]. That is to say, these two techniques can be combined together to perform both qualitative and quantitative studies on VOC emission. In the previous study [16], mass spectrum results achieved through TG-MS were successfully utilized to illustrate the masses, and distinguish the structure and chemical properties of different molecules. Consequently, TG-MS was also employed in this research to characterize VOC emissions from bituminous materials and analyze the effect of VOC inhibitor.

To provide solutions to VOC emission problems for minimizing environmental and health impacts, research efforts have been made. In this regard, the research on the decrease in the speed and amount of VOC emission is a vital subject. Additives were proposed to reduce the VOC amount [16,18,19]. With their special synthesized Mg-Al double layer structures, LDHs were reported as an effective UV resistant additive to modify bituminous materials [20–22]. Their effect on UV resistance is twofold. On the one hand, the inorganic layer sheets are physically UV resistant. On the other hand, the metal elements of layer sheets and negative ions between two layer sheets will chemically absorb UV light [20,23]. These special layer sheet structures of LDHs not only stop UV from outside, preventing the bituminous materials from ageing, but also have the potential to prevent VOC components in the bituminous material itself from volatilizing. Therefore, LDHs were proposed as efficient additives to reduce the VOC emission from bituminous materials. The influence on the VOC emission was characterized by analyzing the volatile amount of molecules.

Briefly, this paper presents the results of a research carried out to characterize the VOC missions from bituminous materials. The effects of LDHs additives in minimizing VOC emissions from