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Grey System Theoretical Analysis on the Influence of Volatile Organic Compounds Emission from Asphalt on its performance

Honghua Zhang[1,a], Shaopeng Wu[1,b], Ling Pang [1,c], Kim Jenkins[2,d],Man Yu [1,e] , Peiqiang Cui [1,f]

[1]State Key laboratory of Silicate Materials for Architectures, Wuhan University of Technology, Wuhan 430070, China

[2]University of Stellenbosch, Moderator, South Africa

[a]huahongzhang@126.com, [b]wusp@whut.edu.cn, [c]lingpang@whut.edu.cn, [d]yuman@whut.edu.cn, [e]cuipeiqiang2006@126.com, [f]kjenkins@sun.ac.za

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Abstract: Light components in the asphalt can volatilize under the circumstances of high temperature or long-term service process, leading to the deteriorating of the asphalt pavement. This paper tried to discuss the influences of volatile organic compounds (VOC) emission from the asphalt on physical properties in the high temperature (at 180) by grey system theory. Both Heat and Vacuum environment were monitored as the emission conditions and the emission temperature was 180˚C, physical properties of asphalt, released and unreleased were analyzed. Basic tests, including mass change, chemical compositions, penetration and soften point, were used to compare the influences of VOC emission on the asphalts' performances. Meanwhile, grey system theory was used to investigate the sequent performances influenced by VOC emission. Results show that physical properties and four generic components of the asphalts are affected obviously in these two emission conditions, and the oxygen may promote VOC emission from the asphalt. In additional, the greatest factor associating with VOC emission is light components in the asphalt.

Introduction

Asphalt can produce volatile organic compounds in the ambient temperature during the long-term service process, especially in the high temperature atmosphere, leading to the deterioration of its performances and reducing the life expectancy. VOC emission from the asphalt is always accompanied with its aging process. During the VOC emission process, some light components in the asphalt can volatilize into the atmosphere and the others may be combined with the oxygen into large molecular structures. Meanwhile, the four-component and physical properties changed obviously after the releasing, and released asphalts expressed less saturates and less aromatics, as well as more asphaltenes and more soft point, while a complex change of resins in the asphalts [3].However, there is little research about the relationship between VOC emission and asphalt performance, as the gray system theory can easily solve such problems as multifactor and nonlinear analysis by normal statistical regression and can be used as the analysis of the quantification comparison. This paper carried out grey correlation analyses to determine the sequent performances which were influenced by VOC emission from the asphalt. The different asphalts' volatile capacities in different conditions were also compared in this paper.

Experiment

Four fresh asphalts were selected and denoted as PJ-90, HC90, KL90, SK70. The experimental conditions were exhibited in Table 1. This research analyzed the changes of four asphalt mass under the Heat-180˚C. Considering the influence of the oxygen in the air to the asphalt mass loss, this research analysed the decrement of asphalt mass under the Vacuum-180˚C to compare. After the VOC emission in these two conditions, properties of the asphalts released or unreleased were investigated, including the mass change, components analysis, penetration index and the increment of soften point.

Table1 Experimental conditions

Emission Condition	Temperature/˚C	Specimen Thickness/μm	Emission length/h
Heat(H) Vacuum(Va)	180	1250	96

Analytical balance was used in this experiment to weight mass of all the specimens and mass accuracy was 0.001g. Four components (saturates, aromatics, resins and asphaltenes) of the asphalt was measured by Thin-layer chromatography with flame ionization detection (TLC-FID). Due to the number of current intensity is proportional to organic material, these ion currents is detected by the hydrogen flame ionization detector which it can achieve quantitative detection. PI value regressed based on the penetration results with four different temperatures (5˚C, 15˚C, 25˚C, 30˚C). And the penetration and softening point are also used to calculate asphalt penetration index formula shown as Eq.1:

$$PI = \frac{30}{1+50\dfrac{\lg 800 - \lg P_{(25℃,100g,5s)}}{T_{R\&B} - 25}} - 10 \tag{1}$$

$P_{(25˚C,100g,5s)}$ is measured in 25˚C penetration under standard conditions, $T_{R\&B}$ is softening point.

Grey System Theory

Grey correlation analysis provides quantitative comparisons between factors in a system. Let X_0 be the reference array, $X_0=\{X_0(1),X_0(2),\ldots,X_0(n)\}$, and X_i be the comparison array, $X_i=\{X_i(1),X_i(2),\ldots, X_i(n)\}$, where i= 1,2,3,…,m. Thus, a new reference array denoted as $Y_0= \{Y_0(1), Y_0(2),\ldots, Y_0(n)\}$, and a new comparison array denoted [5] .

$$Y_0=\left\{\frac{x_0(1)}{\bar{x}_0},\frac{x_0(2)}{\bar{x}_0},\ldots,\frac{x_0(1)}{\bar{x}_0}\right\} \tag{2}$$

Where $\bar{x}_0=\frac{\sum_{k=1}^{n}x_0(k)}{N}$ and $Y_i=\{\frac{x_i(1)}{\bar{x}_i},\frac{x_i(2)}{\bar{x}_i},\ldots,\frac{x_i(n)}{\bar{x}_i}\}$ Where $\bar{x}_i=\frac{\sum_{k=1}^{n}x_0(k)}{N}$ (i=1, 2, 3,…, m).

The correlation coefficient, $\xi_i(k)$ between the comparison curve and the reference curve at the moment k is calculated with the following Eq.3 [5]

$$\xi_i(X_0^{(K)},X_i^{(K)})=\frac{\min\limits_{i=1,n}\min\limits_{k=1,n}\Delta_i k+\rho\max\limits_{i=1,n}\max\limits_{k=1,n}\Delta_i(k)}{\Delta_i k+\rho\max\limits_{i=1,n}\max\limits_{k=1,n}\Delta_i(k)} \tag{3}$$

where $\Delta_i k =|(Y_0^{(k)}- Y_i^{(k)}|$, and ρ is the distinguishing coefficient, typically between zero and one and chose as 0.5 in this study. Referring to the first expression in the numerator Of Eq3, $\min\limits_{i=1,n}\min\limits_{k=1,n}\Delta_i k$ is the minimum value in two levels. Similarly, $\max_{i=1,n}\max_{k=1,n}\Delta_i(k)$ is the maximum value in two levels and corresponds to the maximum values in the sets. The correlation level, γ_i between comparison curve and reference curve is calculated using the following Eq.4 [9].

$$\gamma_{\mathrm{i}}=\frac{1}{N}\sum_{i=1}^{n}\xi_i(k) \tag{4}$$

Experimental and Results

This work studied the change of asphalt mass change(y_1), softening point(y_2) and asphalts compositions. The total contents of asphaltenes and resins replaced by y_5 value, the total contents of aromatics and saturates replaced by y4 value and the ratio of y_4 value and y_5 value (y_6) was also analyzed in this research. Table 2 shows asphalt properties and composition changes under different heating conditions.

Table 2 Asphalt properties and composition changes

Asphalt	y1	y2	y3	y4	y5	y6
SK70	0	52	54.4	61.00	39.00	1.56
SK70-H	0.67%	90	9.6	55.79	44.21	1.26
SK70-Va	0.21%	73	10.7	55.08	44.92	1.23
HC90	0	46	87.2	57.28	42.72	1.34
HC90-H	8.33%	100	10.5	52.23	47.77	1.09
HC90-Va	9.05%	100	15.2	53.80	46.20	1.16
KL90	0	46	77.6	57.70	42.30	1.36
KL90-H	4.92%	100	5.8	46.93	53.07	0.88
KL90-Va	4.39%	70	8	54.37	45.63	1.19
PJ90	0	49	60.5	61.56	38.44	1.60
PJ90-H	2.35%	92	9.3	49.31	50.68	0.97
PJ90-Va	1.1%	79	9.8	51.89	48.11	1.08

As shown in Table2, the results indicated some obvious differences on asphalt performances, such as the penetration got smaller, soften point raised, heated asphalts compositions presented less saturates and less aromatics,more resins and more asphaltenes in compare with the fresh asphalt. The reduction of the specimen's mass can be directly representative of the volatilization of the asphalt. The volatile capacity of asphalt from different sources is not the same even in the same emission, the loss sequencing of asphalt mass from big to small is: HC90, KL90, PJ90, SK70. Therefore, the volatile capacity of asphalt in high-temperature is: HC90> KL90> PJ90 >SK70. All the four generic components and asphalt properties are affected obviously by different heating conditions. However, the sequent of asphalt mass loss in Heat-180˚C is higher than that in Vacuum-180˚C for four asphalts. So the oxygen may promote the emission of VOC under the high temperature.

Analysis of Grey system theory

In this paper, all of y_1, y_2, y_3, y_4, y_5, y_6 are the comparison arrays, exhibiting the contents of the rate of mass change, soften point, penetration index, light components, resins and asphaltenes, the ratio of light components and resins and asphaltenes, respectively. The r_1 represents the correlation level between asphalt (aged in vacuum) and different asphalt properties. The r_2 represent the correlation level between the asphalt (aged in heat with oxygen) and different asphalt properties.

Table 3 Results of correlation analysis of SK70 asphalt

	SK70-Va	SK70-H	ξ	r_1	r_2
y1	0.715909	2.284091	0.514612	0.788153	0.651382
y2	1.018605	1.255814	0.841088	0.920031	0.880560
y3	0.278517	3.595046	0.346897	0.686638	0.516767
y4	0.961478	0.973804	1.000000	0.994727	0.997364
y5	1.051667	1.035136	0.986833	0.979958	0.983396
y6	0.907912	0.934236	0.946011	0.935987	0.940999

Table 4 Results of correlation analysis of HC90 asphalt

	HC90-Va	HC90-H	ξ	r_1	r_2
y1	1.414608	1.585392	0.360624	0.380822	0.370723
y2	0.972222	1.388889	0.586978	0.586978	0.586978
y3	4.444974	15.23499	0.379147	0.440770	0.409958
y4	1.025806	0.885513	1.000000	0.967115	0.983557
y5	0.970901	1.129097	0.985485	0.947552	0.966518
y6	1.039074	0.771293	0.910497	0.856003	0.883250

Table 5 Results of correlation analysis of KL90 asphalt

	KL90-Va	KL90-H	ξ	r_1	r_2
y1	1.414608	1.585392	0.736868	0.713159	0.725014
y2	0.972222	1.388889	0.933316	0.846366	0.889841
y3	4.444974	15.23499	0.535599	0.338964	0.437281
y4	1.025806	0.885513	1.000000	0.964262	0.982131
y5	0.970901	1.129097	0.997885	0.957936	0.977910
y6	1.039074	0.771293	0.977360	0.914156	0.945758

Table6 Results of correlation analysis of PJ90 asphalt

	PJ90-Va	PJ90-H	ξ	r_1	r_2
y1	0.956222	2.043478	0.606573	0.391476	0.499024
y2	1.077273	1.254545	0.838645	0.746195	0.792420
y3	1.185858	3.254696	0.940086	0.423134	0.681610
y4	0.956422	0.908936	1.000000	0.961933	0.980967
y5	1.051687	1.108009	0.973106	0.930601	0.951854
y6	0.885788	0.799019	0.826906	0.780251	0.803578

According to the similar or different levels of the development trends, grey correlation analysis can measure the extent of the similar factors, extracting the main factor, the main features and the difference between the factors. Larger r_i shows that the heating conditions have a greater effect on the asphalt properties. From the above result, according to the values of the correlation level which represents the correlations between asphalt conditions and different asphalt properties. It can be seen, four test asphalt have the same tendency: $y_4 > y_5 > y_6 > y_2$, So Light components has the biggest contribution to the heating conditions followed by the ratio of light components and resins and asphaltenes, whereas the mass change has the smallest effect on the heating conditions, which indicates that the influences of heating conditions can be examined by y_4 firstly.

Conclusions

According to grey correlation analysis, the conclusions are as follows:

(1) According to the experiment results, the mass decrement of Vacuum (Va) was smaller than that of Heat (H) in the same temperature, which can also demonstrate that the oxygen may promote VOC emission and indicate that the volatile capacity of asphalt in high-temperature is HC90>KL90>PJ90>SK70. And the oxygen may promote the emission of VOC under the high temperature.

(2) The greatest factor influenced by asphalt's VOC emission is not the ratio of the total contents of asphaltenes and resins and the total contents of aromatics and saturates, but light components in the high temperature.

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