Construction and Building Materials 169 (2018) 396–402

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Application research on the performances of pavement structure with foamed asphalt cold recycling mixture

Zhiqing Zhang [a,*], Chengdong Cong [b], WenBo Xi [c], Shiyun Li [a]

[a] Beijing University of Technology, Beijing 100124, China
[b] Beijing Road Political Bureau Road Engineering Quality Supervision Station, Beijing 100070, China
[c] Beijing Municipal commission of Transport, Beijing 100073, China

HIGHLIGHTS

- Putting forward the primary factors effecting the performance of FACRM pavement.
- Describing FACRM's engineering properties and suggesting a suitable layer structure.
- Suggest optimum pavement structure combinations for different traffic conditions.

ARTICLE INFO

Article history:
Received 12 July 2017
Received in revised form 24 January 2018
Accepted 20 February 2018

Keywords:
Foamed asphalt
Cold recycling mixture
Pavement structure design
Pavement performances
Traffic conditions

ABSTRACT

The properties of foamed asphalt cold recycling mixture (FACRM) will seriously affect the application performances of pavement structure made from FACRM. The results from this study suggest that FACRM has a high modulus and small temperature shrinkage stress, reducing early damage caused by pavement cracks. FACRM has good water stability but poor stability at high temperatures. The strength of the old subgrade, thickness of the FACRM and environmental temperature have significant effects on the performance of pavement structure. FACRM is ideally used as pavement material for light traffic, but not suitable for use as a surface layer for heavy traffic.

1. Introduction

With the pollution of the environment, lack of raw materials, and annual escalation of energy consumption, asphalt pavement recycling technology has obtained greater attention [1–3]. In the late nineties, foamed asphalt cold recycling technology had to be used widely in the United States, Canada, Australia, South Africa and European countries [4–11]. After more than 20 years of the application of this technology, it was found that the properties of the foamed asphalt cold recycling mixture (FACRM) are very unstable due to the diversity of recycled asphalt pavements (RAP) [12]. If the combination of pavement structure is inappropriate, a weak interlayer can be produced, and the structural-load-carrying capacity is reduced, creating potential safety issues and effecting road performance significantly [13].

The asphalt regeneration process using old asphalt is not a physical process, but a chemical reaction [14]. The literature proposes an interaction coefficient to develop a model which estimates the regenerant consumption [14,15]. Jones et al. studied the fatigue characteristics and dynamic creep of cold recycled mixtures formed using different types of RAP and found that a cold recycled mixture of RAP with increased amounts of residual bitumen has better resistance to rutting, and a cold recycled mixture of RAP with decreased amounts of residual bitumen has greater resistance to fatigue [16].

A Chinese study proposed that temperature, air pressure and the addition of water have significant effects on the foaming properties of asphalt [17]. The optimum foaming conditions of bitumen are achieved at 150 °C (asphalt temperature) and approximately 1.5% of water consumption. Cao and He et al. proposed an equation describing the decay of the foaming performance of two types of bitumen, which was used to analysed and propose a foaming

Abbreviations: FACRM, Foamed Asphalt Cold Recycling Mixture; RAP, Recycled Asphalt Pavements.

* Corresponding author.
E-mail address: zhangzhiqing@bjut.edu.cn (Z. Zhang).

https://doi.org/10.1016/j.conbuildmat.2018.02.134
0950-0618/

mechanism of the bitumen [18]. The modulus of FACRM, tested by Li, Zhang and Shi, was found to be 800–1200 Mpa [19]. Optimum foaming temperature, water consumption, water temperature, and other influencing factors, play important roles in the widespread use of cold recycling technology of foamed asphalt [20]. In 2010, the cold recycling technology of foamed asphalt was used to overhaul the Beijing, Hong Kong and Macao freeway, with good results [21]. However, there is still no general consensus on the application performance of FACRM.

The study of foaming mechanism is widely reported in the literature. However, there are few reports on the optimization of road performance of FACRM under different traffic conditions, and even fewer reports on the combination design of pavement structure using FACRM. In this study, the application performance of pavement structure using FACRM on the Luqiu road overhaul project in Beijing is described.

2. Testing and analysis of foaming asphalt and FACRM

2.1. Foaming asphalt

2.1.1. Asphalt foaming test

An A-grade 90# asphalt and German Wirtgen WLB10 foaming machine were selected for the study. The foam test was performed as described in the Wirtgen Operation Manual, under the guidance of Wirtgen Manufacturers.

Three groups of foamed asphalts were set at foaming temperatures of 155 °C, 160 °C, and 165 °C, and the foaming water consumptions were 1.5%, 2.0%, 2.5%, and 3.0% by the relative amount of asphalt, respectively. The half-life and expansion rate were measured. The test procedure included:

1) Water was injected into the foaming machine tank under no pressure, and the water quantity controlled (1.5%, 2.0%, 2.5%, 3.0%) using a water level indicator. An air compressor was connected and air inflated the air trough. The water pressure was maintained at 6 bars and air pressure maintained at 5 bars using a pressure table.
2) The asphalt was injected into the asphalt tank, and heated to a temperature of 155 °C, 160 °C and 165 °C for approximately 5 min, respectively. The foamed asphalt at different foaming temperatures was made by injecting the asphalt into a special measuring barrel.

2.1.2. Analysis of test results

After the foamed asphalt was prepared as described in Section 2.1.1, the half-life and expansion rate were measured using the special test barrel. The test results are shown in Table 1.

The increase of foaming water consumption, increases the expansion rate rapidly, however the half-life decreases significantly. The longer the half-life of foamed asphalt, the longer the contact time between the foamed asphalt and aggregate; The higher the expansion rate, the more uniform the foamed asphalt mixture and a better quality mixture. Considering half-life and expansion rate, the optimum foaming temperature was 160 °C, and the foaming water consumption was 2.4%.

2.2. Stability analysis of the FACRM

The FACRM is composed of aggregate from old road milling material, with the addition of new material (mainly fine aggregate). Foamed asphalt and cement are used as binders and appropriate amounts of water added.

2.2.1. Milling material (RAP) technical index

Milling material (RAP) is the most important raw material for foamed asphalt cold recycling technology. The RAP material results are shown in Table 2, according to the reference specifications [22].

The asphalt in RAP is effected by environmental factors resulting in a degree of aging, which produce agglomeration with aggregate particles. Theoretically, this has adverse effects on the cold regeneration mixture. Therefore, the material is initially air-dried at room temperature for three to four days. Then, it is crushed and screened to determine the gradation of the milling material. Finally, the proposed gradation is compared to the design specification, to determine the proportion of stone chips and mineral powder required.

2.2.2. Optimum mixture ratio of FACRM

The optimum asphalt content is determined according to the maximum residual stability ratio, in accordance with the Standards [22] and the design method based on Marshall. In this study, the ratio of FACRM mix was optimised by selecting dry and wet splitting strengths and the wet and dry splitting strength ratios.

First, a screening test of the old asphalt pavement milling material was performed and the gradation composition of the milling material was determined, as shown in Table 3.

The pass rate of the milling material in the screening test using a sieve of maximum size of 2.36 mm is low. Fine aggregate (stone chips) and cement was added to adjust the gradation, and both stone chips and cement met the specified requirements.

The mix of materials is consistent with the range of grades in the design documents and the gradation was adjusted to smooth the synthetic gradation curve, within the scope of the requirements described in the design documents. The ratio of milling materials: stonechips: cement was 73.5%: 25.0%:1.5%, respectively, as shown in Fig. 2.

Initially, the amount of foamed asphalt was set at 3%. Heavy compaction tests were carried out by mixing foamed asphalt with selected mineral aggregates. Finally, two parallel tests were conducted, to determine the average maximum dry density and optimum water content, which were 2.142 g/cm^3, and t 6.3%, respectively.

The aggregate was mixed using the synthetic gradation described above. The water consumption of the mixture was 70% of the optimum water content. Five groups were set with asphalt

Table 1
Asphalt foaming performance test.

Foaming water Consumption/%	Foaming temperature					
	155 °C		160 °C		165 °C	
	Expansion rate/times	Half-life/s	Expansion rate/times	Half-life/s	Expansion rate/times	Half-life/s
1.5	14	11	18	12	14	10
2.0	20	10	22	11	20	9
2.5	24	9	26	10	26	8
3.0	28	8	32	9	32	7

The relationships between the foaming water consumption and expansion rate and half-life is shown in Fig. 1.