Construction and Building Materials 70 (2014) 379–387

Contents lists available at ScienceDirect

Construction and Building Materials

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

Experimental investigation on the effect of hydrated lime on mechanical properties of SMA

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HIGHLIGHTS

- Partial substitution of the filler with HL significantly improves the resistance indices of SMA.
- There is an optimum amount of hydrated lime in SMA mixture.
- Using HL as additive leads to superior performance comparing with partial substitution of HL.
- The HL modified SMA with 9.5 NMAS is much stronger against rutting compared to the SMA of 12.5 NMAS.

ARTICLE INFO

Article history:
Received 28 October 2013
Received in revised form 10 July 2014
Accepted 23 July 2014
Available online 24 August 2014

Keywords:
Asphalt
SMA
Filler
Hydrated lime
Rutting
Dynamic modulus
Creep

ABSTRACT

One of the most important and costly damages to the pavements, especially in high traffic areas is rutting. An optimal use of lime is significantly important with regard to expensive cost of the lime and its improving properties in stone matrix asphalt (SMA). In this paper, simple performance tests (i.e. dynamic modulus, dynamic creep, and static creep) were used based on NCHRP-465 report. In which the effect of directly added different percentages of hydrated lime filler to the mixture in dry state as a partial substitute of the aggregate materials in comparison with introducing it as an additive to the mixture on performance and mechanical properties of SMA was assessed. For this purpose, the SMA samples with two different aggregate gradation and different hydrated lime contents were prepared as a part of filler. The obtained results indicate that partial substitution of the filler with hydrated lime will cause an improvement in the resistance indices like flow number, flow time as well as rutting and fatigue cracking factors of SMA, while the permanent deformations of the asphalt decrease. Obviously, it indicates existence of an optimum amount of hydrated lime in mixture. The results obtained from this contribution can be used to design and implement asphalt mixtures in accordance with the requirements of the contractors, engineers and researchers.

1. Introduction

The road network is usually described as the essential need of any country, so that this valuable asset consumes a noticeable amount of the national budget every year for development and maintenance. Therefore, taking into consideration the limitations of financial and technological resources, current situation of the roads must be maintained and even improved by spending much less money. Implementation of asphaltic pavements with continuous distribution of grain size would possibly lead to damages like rutting of wheel raceway and bleeding. These damages require maintenance and rehabilitation in a relatively short time after the road comes into service. This will involve spending of a lot of money. Some European countries, as well as US and Canada have decided to use stone matrix asphalt (SMA) in order to meet some special expectations of paving such as resistance against rutting, preventing expansion of reflective cracks. The SMA contains certain ingredients and changing material, mixing method and mix design of each component will alter mechanical properties of the mixture. In asphalt mixture with continuous graded aggregate, using filler, increase the contact points and the loading capacity, improve the compressive and shear strengths, and reduce the deflection. Filler in stone matrix asphalt plays an important role which is increasing stiffness of the mixture [1]. Different types of fillers including crushed stone, cement and lime can be used in the asphalt mixtures. The multifunctional effects of hydrated lime in open graded aggregate need to be evaluated when added as additive or part of filler aggregate in mixture.

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http://dx.doi.org/10.1016/j.conbuildmat.2014.07.084
0950-0618/

2. Objective

Stone matrix asphalts (SMA) need a kind of open grain distribution for production and enhancement of bitumen content and contact between aggregates at the same time. In fact, a direct contact between the aggregates will cause stability. Application and development of the SMA was initially started within 1980s in some of European countries. After 1990 when the first SMA projects were started in Canada and later within some states of America in 1991, application of the SMA mixture became popular in these regions [2].

Different fillers are used in this mixture. Craus et al. showed in 1978 that the physiochemical properties are dependent on intensity of interfacial adsorption between the bitumen and the filler. Thus, an active surface of the filler was expected to create a strong composition between them [3]. Previous studies conducted by Kim in 1990, 1994, 1995 and 1999 as well as an earlier contribution of Bahia in 1999 indicates that the fatigue damage and the restorability depend heavily on the properties of the bitumen, properties of bitumen additives, interaction between bitumen and its additives, and ingredients which affect growth of the micro-cracks in the mastic [4]. According to the results obtained from the performance and volumetric tests, and also by establishing a relationship between the parameters extracted from these tests, finer filler will make the asphalt mixture stiffer and will eventually reduce the rutting phenomenon [5]. The crushed stone is a common filler material. Moreover, the hydrated lime is more effective filler in comparison with other mineral fillers because accumulation of greater micro-cracks in the sample from the initial loading until the final failure will increase fatigue life of the asphalt. The physiochemical interactions between the filler and the bitumen in terms of the fine particles and their surface features affect characteristics of the fatigue failure [6]. It was 2005 that the effect of hydrate lime on dynamic modulus and stiffness of the HMA mixture was reported in some studies [7], while some researches were conducted in 2008 and 2009 on the effect of hydrated lime on stripping and moisture damages due to the bitumen-lime filler interaction [8,9]. Meanwhile, some research works were directed in 2010 using hydrated lime in the HMA asphalt to examine the effect it has on the rutting phenomenon in addition to predict the cracking behavior in asphalt [10,11].

Also the hydrated lime is added by different techniques to the hot mix asphalt. The commonest methods for adding the lime to the mixture include dry, wet and slurry method [12]. Lime can be proportioned and mixed in HMA in both batch and drum mixers in the plant. Dry lime can be added to dry aggregate and to wet aggregate. Moisture levels in wet aggregate are typically about two to three percent above the saturated surface dried condition of the aggregate. Lime slurries made from hydrated lime or quicklime have also been used. Lime-slurried aggregates are conveyed directly to the drying and mixing portion of the HMA facility or placed into stockpiles for marination. Adding dry lime to the asphalt binder and storing the lime-modified binder prior to mixing with the aggregate has not been practiced widely in the field [13]. The effect of hydrated lime and mixing approach on performance properties of the HMA was evaluated in the same year [14–16]. One other study investigated the effect of optimal content of hydrated lime on aging and workability at high temperatures [17]. In 2011, Lee et al. employed modern experimental techniques and new models to study the effect of modified HMA with hydrated lime on rutting and fatigues cracks [11].

The hydrated lime will reduce the cracking as a result of aging, fatigues or low temperature. The cracking usually occurs after formation of micro-cracks. Fine particles of the hydrated lime are expected to prevent formation of these micro-cracks [7]. The hydrated lime as filler improves stiffness and reduces rutting. Moreover, adding the hydrated lime will not allow the asphalt to stiffen at low temperatures because the lime will act as inactive mineral filler at these low temperatures. The hydrated lime will also reduce the oxidation and ageing effects [8]. As the HMA ages due to oxidation, hydrated lime reduces not only the rate of oxidation but also the harm created by the products of oxidation. This effect keeps the asphalt from hardening excessively and from becoming highly susceptible to cracking (through fatigue and low temperature (thermal) cracking). Synergistically, the filler effect of the hydrated lime dispersed in the asphalt improves fracture resistance and further improves cracking resistance [13]. There are many observations which show the hydrated lime modified HMA has better performance of mixture against rutting, fatigue and thermal cracking [18]. In 1987, Petersen et al. evaluated two asphalt binders modified with limestone and hydrated lime at 20% by weight of binder. The results of this research indicate that lime treatment would improve the resistance of the aged pavement to thermal cracking through the reduced aging index. Since the behavior of HMA mixtures at low temperatures is mainly controlled by the properties of the aged binder, lime treatment would produce HMA pavements that are highly resistant to thermal cracking [19]. The lime-modified bitumen demonstrates a greater potential for dissipating energy through deformation (at low temperature) than the unmodified bitumen. This is a positive effect at low temperatures because it reduces fracture potential. Although the filler effect increases low temperature stiffness, fracture toughness is substantially increased. Fracture toughness is the energy expended in fracturing a material [20]. Nevertheless, base on some studies, the influence of filler on low temperature cracking was hypothesized to be independent of filler type. Unlike rutting and fatigue cracking, adding different amount of hydrated lime as filler in mixture is not so effective on the thermal cracking [21,22].

Some studies have been conducted recently in 2013 toward failure mechanics and advanced suggested models, the effect of hydrated lime on failure performance, and the mechanical properties of mixtures [23,24].

Permanent deformation is one of the most critical parameters for pavement design, which is believed to increase with traffic and tiers pressure. Most of the permanent deformations occur at the upper layers rather than the subgrade. There are different approaches to determine the plastic deformation, out of which repeated load test is used more than the others [1]. In this study simple performance tests were used in order to evaluate performance of asphalt mixtures. Based on NCHRP-465 report, simple performance test (SPT) method(s) accurately and reliably measures a mixture response characteristic or parameter that is highly correlated to the occurrence of pavement distress (e.g., cracking and rutting) over a diverse range of traffic and climatic conditions. Numerous techniques have been suggested to assess pavement performance and distresses. One of the best available solutions for this purpose is to perform three simple performance tests, namely complex modulus (E^*), dynamic creep – flow number test (F_n), and static creep – flow time test (F_t). They yield the best relationship between the experimental results and the field performance [25].

The complex modulus is a way of addressing the relationship between stress and strain of the viscoelastic material. The complex modulus test is often conducted on the cylindrical samples which are exposed to a haversine compressive loading [26]. The complex modules changes by variation in the loading frequency. A Loading capacity which models the traffic load much closer than the other frequencies must be chosen for this test. The dynamic modulus obtained in this regard is equivalent to resilient modulus which is used for design purposes [27].