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# Assessment of nanoparticles dispersion in asphalt during bubble escaping and bursting: Nano hydrated lime modified foamed asphalt

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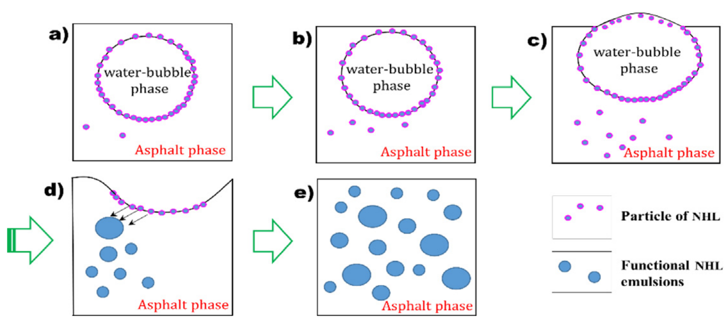
## HIGHLIGHTS

- The NHL particles were dispersed into the water-foamed asphalt by using escaping and bursting bubbles.
- The microstructure of water-foamed asphalt was enhanced by the process of intercalation of asphalt into NHL layers.
- NMFA exhibited better physical performance compared to the original asphalt.
- The addition of 5.0% NHL is the recommended additive content to improve high temperature physical performance of NMFAs.

## GRAPHICAL ABSTRACT

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## ABSTRACT

Saving mixing energy by using escaping and bursting bubbles during the production process of nanomaterial-modified water-foamed asphalt is a novel preparation idea, which can be taken as one type of cleaner physical warm-mix asphalt technology. The objective of this study is to assess the dispersal of nano hydrated lime (NHL) particles in the asphalt using a scanning electron microscopy (SEM) test, and to evaluate the physical properties of NHL modified water-foamed asphalt (NMFA). In this study, the NHL and sodium dodecylbenzene sulfonate ($C_{12}H_{25}C_6H_4SO_3Na$) were added to the water to form suspensions, and the suspensions were mixed with asphalt to form NMFA. The X-ray diffraction (XRD) test was used in order to understand the NMFA's microstructure and dispersal of NHL in water-foamed asphalt. The dynamic shear rheometer (DSR) and the asphalt binder cracking device (ABCD) were also used to evaluate the high temperature and low temperature performance of NMFAs, respectively. The SEM images show that the NHL particles were well dispersed in the water-foamed asphalt while the XRD test results confirmed it and demonstrated that the NMFAs may form an intercalated microstructure. In addition, the presence of NHL reinforcement in the water-foamed asphalt stiffens the asphalt, consequently decreasing the rutting potential. The addition of NHL also increased the low temperature cracking resistance of NMFAs, i.e. decreased the cracking temperature and increased the fracture stress.



## 1. Introduction

In general, warm-mix asphalt (WMA) technology can produce asphalt mixtures at lower temperatures, and it has been used for many years to dramatically reduce energy consumption and decrease greenhouse gases during the construction as an environmentally friendly technology [1–6]. These technologies allow for the production of asphalt mixtures at temperatures 20 °C–55 °C

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lower than those in the production of hot-mix asphalt (HMA) [7]. Additionally, the engineering benefits of WMA technology include better mixture compaction, the ability to carry pavement materials for longer distances and extending the construction season [8]. Normally, the traditional WMA technologies divides into three categories: i) chemical additives (such as polymers and emulsification agents), ii) organic additives (i.e. fatty acid amides, Fischer-Tropsch synthesis wax and Montan wax), and foaming processes (subdivided into water-based and water-containing processes) [1,9–12]. The foaming processes is a physical mixing technology, which does not require the costly chemical additives and allows the production of water-foamed warm mixes with the standard asphalt grade [1,13–15]. This technology mainly entails the addition of small amounts of water, either injected into the hot asphalt binder or into the mixing chamber [1]. The water-containing technologies usually use synthetic zeolite to produce the foaming processes, the crystallization is approximately 20% water, and which will be released from the zeolite structure as the temperature rises [16,17]. In addition, the water-based technologies use water in a more direct way – the water needed to produce the foaming effect is injected into the hot asphalt binder flow with the special nozzles [1]. Obviously, the water-based technology is a more energy-saving and environmentally friendly method, thus, the water-based technology will be studied in this paper. Foaming processes work in two ways to promote mixing at lower temperatures: it reduces the apparent viscosity of asphalt by shear thinning, and it increases the volume of the asphalt (easier to coat particles) [18]. However, some study results showed that the combined effect of decreased mixing temperature and increased water content, as a result of the foaming processes, could reduce the performance of WMA as compared with the traditional HMA mixtures [13,19–22]. Therefore, it is very important to choose an appropriate additive to improve the performance of WMA.

Traditionally, regular hydrated lime has been used extensively in HMA or WMA as a quality filler and/or additive, but the nano hydrated lime (NHL) has not been used in road construction industries [23–25]. The nanomaterials have recently been brought into the spotlight because of their unique characteristics. Nanomaterials are defined as materials that have at least one dimension fall into nanometer scale (1 nm–100 nm). The nano materials have physicochemical properties different from those in typical macroscopic form [19,26,27]. Different nanomaterials such as nanoclay, nanosilica and nano hydrated lime have been used to improve the performance of asphalt [28]. There are two major distresses existing in the current asphalt pavement which are rutting and thermal cracking. Rutting (permanent deformation) occurs in the asphalt pavement when accumulation of permanent deformation results from the drop of the complex shear modulus as the pavement temperature increases or repeating impact of vehicular load [29–31]. Meanwhile, thermal cracking (thermal shrinkage) occurs in asphalt pavement when the thermal tensile stress that results from temperature drop within the asphalt pavement exceeds its strength at that temperature. The nano hydrated lime (NHL) could be used to improve the dynamic modulus and rutting susceptibility of modified asphalt [32–34]. Based on the literature reviews [35,36], the asphalt may be intercalated into the space of NHL layers and the NHL modified water-foamed asphalt (NMFA) is also an intercalated structure. These changes in the microstructure of NMFA may have some effects on the high and/or low temperature performance of NMFA.

In addition, the traditional mechanical mixing method makes it difficult to well disperse the NHL particles into asphalt due to: 1) the high viscosity of asphalt, 2) the NHL particles are hydrophilic but the asphalt are hydrophobic [37], 3) the NHL particle's small size, high reactivity, and large surface area to volume and corresponding agglomeration [38]. The compatibility of nano materials with asphalt and the dispersion of nano particles in the asphalt is the key to improve performance of modified asphalt. The traditional mechanical mixing method also takes so much mixing energy to disperse the NHL particles into asphalt. Therefore, it is very important to develop a way to well disperse the NHL particles into asphalts with less mixing energy.

In this study, the NHL and sodium dodecylbenzene sulfonate ($C_{12}H_{25}C_6H_4SO_3Na$) will be added to the water to form suspensions, and the suspensions will mix with asphalt to form NMFA. The main objective of this study is to evaluate this modified warm-mixing technology from the following two aspects: (1) the assessment of NHL particles dispersion in asphalt during bubble escaping and bursting, and (2) the investigation of the physical performance of NMFAs.

## 2. Materials and experimental program

### 2.1. Basic materials and fabrication of NMFA

Original asphalt, *PG58-28*, was used in this study. This asphalt binder was obtained from Gladstone (Michigan, U.S.A) without further treatment. The viscosity at 135 °C was 312.5 mPa*s, and the $G^*/\sin(\delta)$ at 58 °C was 1.86 kPa. Hydrated lime is an inorganic compound with over 90% $Ca(OH)_2$, 1.2% CaO, 1.5% $SiO_2$, 1.5% $CO_2$ and 3% $CaCO_3$, all by weight, and the hydrated lime is presented in the form of quartz and cubic polymorph. The relative density and pH value of NHL are 2.24 g/cm$^3$ and 12.4, respectively [39]. Hydrated lime is an abundant compound worldwide that is largely employed in hot mix asphalt (HMA) to improve the stripping potential and moisture susceptibility characteristics of HMA [40]. Nano-sized hydrated lime is used in this study because of its huge surface area, good dispersal, good absorption and stability, and high chemical purity [41].

Distilled water and nano hydrated lime (NHL) were selected as a foaming agent and modifying agent for the production of NHL modified water-foamed asphalts (NMFAs), respectively. The standard size of NHL used in this study is 100 nm. A LitesizerTM100-AntonPaar instrument was used to check the size distribution of NHL. The size distribution of NHL (Fig. 1) showed a polydispersity index of 32.39% and a peak size at 855.4 nm, which is much larger than 100 nm. It is quite clear that the agglomeration occurs in NHL material. Sodium dodecylbenzene sulfonate ($C_{12}H_{25}C_6H_4SO_3Na$) is one type of surfactant used to prevent or mitigate agglomeration

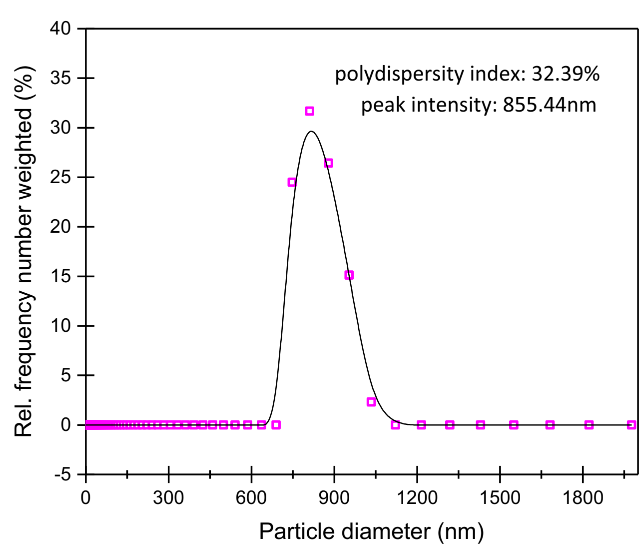


**Fig. 1.** Particle size distribution of NHL used in this study.