RESEARCH ARTICLE OPEN ACCESS

Nano-Size Cement Bypass as Asphalt Modifier in Highway Construction

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Abstract
This work is devoted to potentially use nanomaterials namely cement bypass to improve physical, chemical, and rheological properties of bitumen. The proposed method based on using cement bypass with bitumen to increase the strength and improve the properties of modified nanomaterial-bitumen mixture. In this work, useful application of cement bypass to be used in a mixture with bitumen in asphalt concrete pavement application was developed. This new methodology is based on grinding of cement bypass by ball milling technique to produce nano-sized bypass material with particle size in the range of 10-100 nm. The prepared cement bypass nano-sized materials have a high surface area to volume ratio compared to the conventional materials. The optimum modification level was determined by using spectroscopic techniques such as Transmission electron microscope (TEM) and Scan electron microscope (SEM). Experiments show that 15% of nano-sized cement bypass gives the highest penetration, softening point and compressive strength.
KEYWORDS: Cement bypass, Asphalt Modifier, Nanomaterial, Highway Construction.

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I. Introduction

Unmodified bitumen has limited capacity under wide range of loads and temperature that occur over the life of a pavement [1-3]. Therefore, different modifiers have been added to bitumen to overcome the heavy loads and weather change [4-8]. Weak properties of asphalt concrete mixtures invoke researchers for improving its physical, chemical, and mechanical properties [9]. In Egypt, cement industry discard about 3 million tons per year of cement dust that are collected from exhaust gases of cement kiln and cooling towers. The huge quantity of cement dust creates serious problems for both industry manufacture and environment [10-13].

The cement bypass consists of partially calcinated and unreacted raw feed, clinker dust and ash, enriched with alkali sulfates, halides and other volatiles [14]. Taha *et al* [15] reported that cement bypass could be used as filler in asphalt paving mixtures. The authors found that addition of 5% cement bypass (by weight) to lime produce the same optimum asphalt binder content as the control mixture without negative effect on asphalt concrete properties.

Nanomaterials have been widely used in different applications, in particular, as additives in material science engineering. The high surface to volume ratio and atomic size of the nanoscale materials has attracted the attentions for use to modify physical and mechanical properties of bitumen [16, 17]. For example, nano-SiO_2 increases the physical and mechanical properties of asphalt binders mixtures [16]. Therefore, the use of nano-sized cement bypass material as asphalt modifier in highway construction is not only of significant economic use but also help to reduce the harmful waste materials.

Herein, we are introducing the use of nano-size cement bypass to improve both the physical and chemical properties of bitumen. Different tests have been investigated in order to check the effect of adding cement bypass modifier on bitumen properties such as penetration, softening and compressive tests.

II. Materials and Methods

2.1 Material Characterization

All materials used in this work include aggregate, sand, mineral filler; bituminous material and cement bypass were used without further purifications. The bitumen used in this study was 60/70 penetration grade obtained from Suez Refinery Company. Nano-size bypass material was prepared by heating the raw material in oven at 400 ^{0}C for 48 hours. Then the material was grained in ball milling machine for 10 hours. The cement bypass was supplied by Egyptian Cement Company (Qena) and added to bitumen with different percentages namely, 8%, 10%, 15% and 20% (by the weight of bitumen). The mixing temperature of bitumen with cement bypass was adjusted between 130 °C and 170 °C. Low shear mixer was used to prepare homogenize mixtures. Asphalt concrete mixtures were prepared for modified and unmodified asphalt concrete mixtures using Marshall mix design method. Mixing the unmodified bitumen with 20% bypass produces inhomogeneous mixture. Morphology and structural of the prepared materials were investigated by transmission electron microscopy (TEM, JEOL JEM-1230 with accelerating voltage of 120 kV) with EDX detector unit attached to the system.

III. Results and Discussion

The morphology of grounded cement bypass powder was analyzed using transmission electron microscope (TEM). Figure 1 shows that the bypass has nanorods structure and the diameters of the cement bypass nanorods was in the range of 20 - 30 nm and the length can be as long as 0.5 µm. While bitumen raw material was viscoelastic and homogenize material. The structure morphology of the resulting mixture depends on bitumen/bypass ratio. In details, the addition of 8% of nano-size cement bypass to bitumen results on homogeneous mixture. The resulting mixture shows continuous bitumen phase with dispersed cement bypass nanorod particles (8%), or two interlocked continuous phases (10 and 15%). Interestingly, the mixture forms strong networks and homogenous material at 15% of the cement bypass and disperses rapidly and uniformly throughout the material and forms a reinforcing network structure (Figures 2-4).

3.1 Penetration test and softening point

Penetration test of modified and unmodified bitumen samples were investigated in accordance with ASTMD5-97 specification. The grades are based on penetration units, where one penetration unit equals one tenth of a millimeter penetration. Similarly, softening point was performed according to ASTM D36-95 specifications. The results of penetration and softening tests are shown in Table 1.

The results in Table 1 reveals that the penetration for the modified bitumen decreases and softening point increases with the increase of cement bypass ratio [7]. Hence, bitumen modified with 15% cement bypass shows higher improvement for both penetration and softening point. Using cement bypass as asphalt modifier produce hard bitumen, which is useful to resist rutting [18]. The lower the penetration grade, the “harder” the asphalt that is useful in hot climate areas as well as higher softening point indicates lower temperature susceptibility [19]. It is worth to mention that 15 % of nano-size cement bypass addition gives reinforced homogenous mixture (Figure 4) that make bitumen hard and can resist heavy load.

3.2 Compressive Strength

Compressive Strength for modified and unmodified asphalt concrete mixtures were calculated using equation 1:

$$\sigma_c = \frac{4P\max}{\pi D^2} \quad (1)$$

Where σ_c is the unconfined compressive strength, P_{max} is the maximum applied compressive load, and D is the specimen diameter. Table 2 shows that the compressive strength increases with the increase of nano-size cement bypass ratio [20]. A modified mixture with 15% of cement bypass posses the highest value for compressive strength.

These results are in accordance with the decrease in penetration test, i.e., the improvement in compressive Strength is due to using harder bitumen. The results of compressive strength give an indication that the mixtures with high compressive strength have a better resistance to permanent deformations.

IV. Conclusion

This work has shown the potential use of nano-size cement bypass as modifier for bitumen. The results showed significant improvement in both penetration and softening points of all modification level used as compared to the unmodified bitumen with the highest effect at 15% ratio. In addition, using cement bypass notably increases the compressive strength of bitumen as well as increase resistance to rutting. From the results of various test using bypass nano-powder can improve road mechanical properties, including rutting resistance and enhance bitumen performance to resist high traffic loads.

V. Acknowledgements

The authors sincerely thank Misr Cement Company for providing the cement bypass materials and the central Lab., South Valley University, Qena, Egypt for TEM and SEM measurements.

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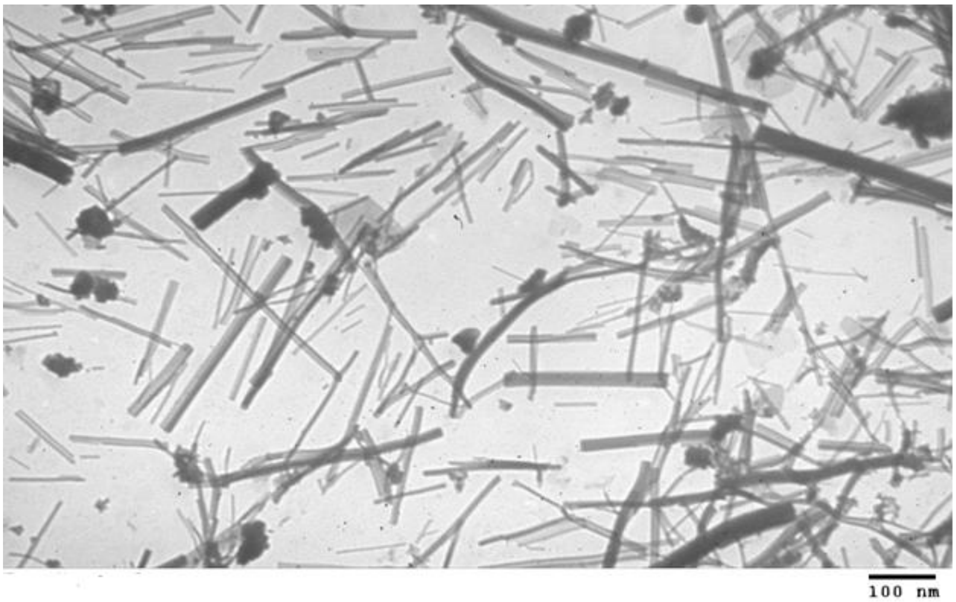

Figure. 1. TEM image of cement bypass powder.

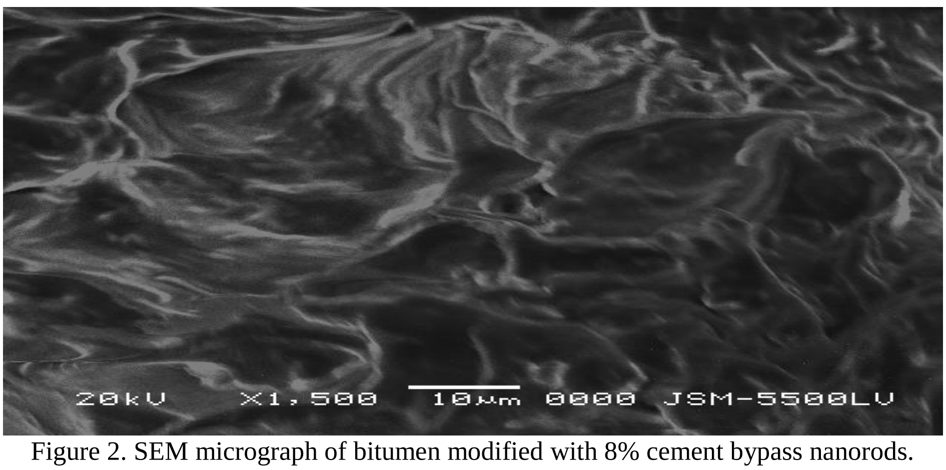

Figure 2. SEM micrograph of bitumen modified with 8% cement bypass nanorods.

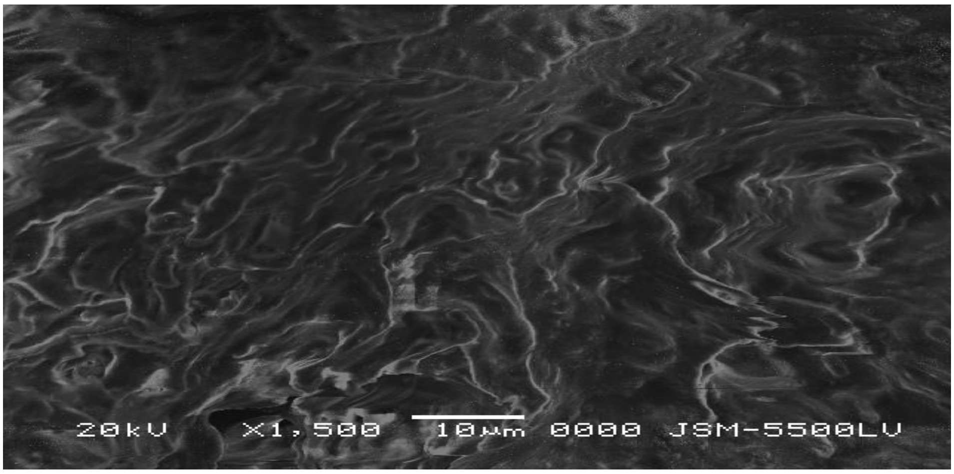

Figure 3. SEM micrograph of bitumen modified with 10% cement bypass nanorods.

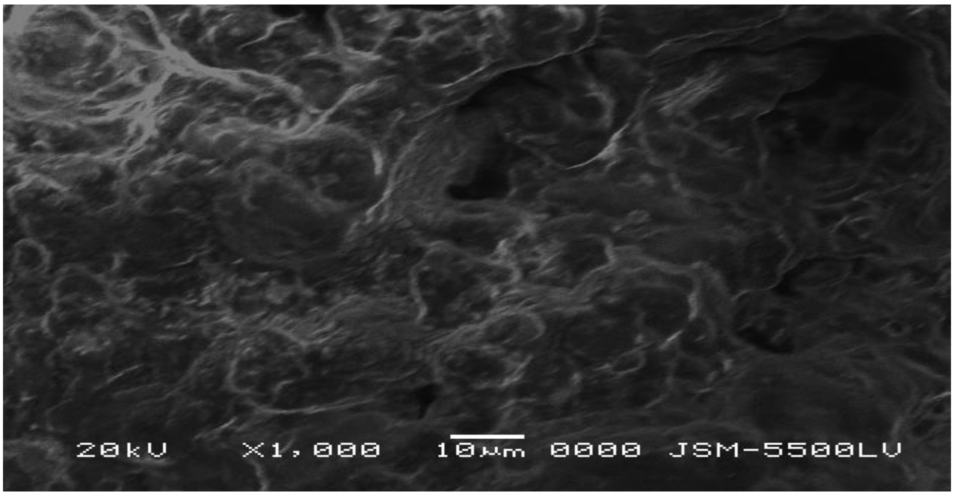

Figure 4. SEM micrograph of bitumen modified with 15% cement bypass nanorods.

Table 1: Penetration test and softening test results

Bitumen Type / Test	**Penetration @ 25 ° C**	**Softening Point ° C**
Unmodified bitumen	68	45
Modified bitumen with 8% Cement Bypass	65	47
Modified bitumen with 12% Cement Bypass	62	48
Modified bitumen with 15% Cement Bypass	51	50

Table 2: Compressive strength test results

Bitumen Type / Test	**Compressive Strength MPa**
Unmodified bitumen	2.61
Modified bitumen with 8% Cement Bypass	2.84
Modified bitumen with 12% Cement Bypass	2.95
Modified bitumen with 15% Cement Bypass	3.32