Nanomaterial Compatibility and Effect on Properties of Base Bitumen Binder and Polymer Modified Bitumen

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Abstract: Nanotechnology has been gradually penetrated into the field of bitumen modification. Seemingly magic effect of nanomaterials has now been brought to improve the performance of bitumen. To demonstrate many of the prospective application, research has been conducted through series of positive and effective effort dealing with the preparation of modified bitumen to demonstrate the mechanism of modification and resultant improvement in performance. In this review, various nanoclay used in bitumen modification are initially presented, followed by the method employed for the bitumen with these material and finally the effect of nanomaterials on the performance of base bitumen are presented and the modified mechanism are discussed. Based on the current research result, the influence of preparation process parameter on the compatibility of every phase in modified bitumen and the stability of modified bitumen system are described.

Keywords: nanomaterial; bitumen; modification; composite; properties.

1. INTRODUCTION

Nanomaterial's are the morphological feature on the nanoscale, and especially have special properties stemming from their nanoscale dimension. Nanomaterials have attracted considerable interest in both academic and industries due to unique mechanical, thermal barrier, optical, electrical and magnetic properties. Material science and Technology research focused on materials at macro to micro or nanoscale. Various material states, liquid, semi-solid or solid, bitumen is a black or dark complex matrix containing hydrocarbons of varying molecular weight and non-metallic derivatives. Bitumen is usually employed as an organic binding material for waterproofing, moisture resistance and corrosion resistance. Temperature susceptibility characteristics and the physical properties of asphalt bitumen at high and low field-operating temperatures can affect the final performance of the mixture. To improve the performance of bitumen and asphalt concrete mixtures, addition of modifiers such as polymers have become popular in recent years. As a matter of fact, polymeric nanocomposites are one of the most exciting materials discovered recently and the physical properties are successfully enhanced when a polymer is modified with small amount of nanoclay on a condition that the clay is dispersed properly at nanoscopic level. Nanoclays are naturally occurring minerals and are, thus, subject to natural variation in their constitution. The purity of the clay can affect final nanocomposite properties. Many types of clay are alumina-silicates, which have a sheet-like (layered) structure, and consist of silica SiO_4 (tetrahedron) bonded to alumina AlO_6 (octahedron) in a variety of ways. A 2:1 ratio of the tetrahedron to the octahedron results in mineral clays, the most common of which is montmorillonite (Fig 1). The thickness of the montmorillonite layers (platelets) is 1 nm and aspect ratios are high, typically 100–1500. The degree of expansion of montmorillonite is determined by their ion (e.g., cation) exchange capacities, which can vary widely. A characteristic number of these types of clay are the cation exchange capacity (CEC), which is a number for the amount of cations between the surfaces. The CEC of montmorillonite ranges from 80 to 120 meq/100g (milli-equivalents per 100 grams). The expansion pressure of montmorillonite in which sodium ions constitute the majority of the adsorbed cations (called Na montmorillonite) is very high, leading to the exfoliation and dispersion of the crystal in the manner of fine particles or even single layers. When Ca^{2+}, Mg^{2+}, and ammonium are the dominant exchangeable cations, the dispersion is relatively low and the size of the particle is relatively large. Separation of the clay discs from each other will result in a nanoclay with an enormously large active surface area (it can be as high as 700 to 800 m^2 per gram). This helps develop an intensive interaction between the nanoclay and its environment (bitumen in our case). The process to realize the separation (surface treatment) is dependent on the type of material to mixed [1].

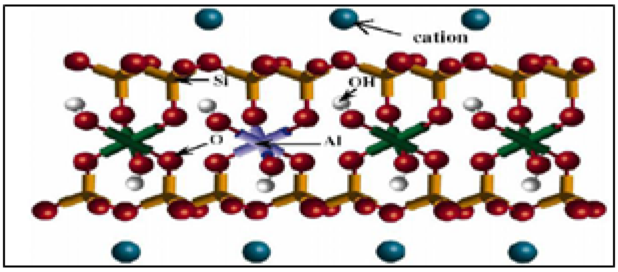

Figure 1: Montmorillonite Structure [1]

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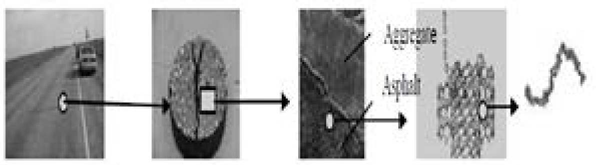
Nanotechnology has gradually been incorporated into the field of modified asphalt with various kinds of nanomaterials being used to modified bitumen. Fig.2 illustrates the length scales evolution of a bitumen concrete material from macro scale to meso, micro, nano and quantum scales [2]. The microstructure is the sole determinant of macro properties, thus nano-modified bitumen offer a significant improvement over a fundamental material properties, which is superior to other bitumen modification method. In August 2006, a National Science foundation workshop entitled 'Nano Modification of Cementious Materials' was held on USA, which focused on using nanotechnology for improvement of bitumen concrete. One of the main conclusions of this workshop was that nano science and nanotechnology could lead to improvement in bitumen concrete technology. In this workshop the field of "Asphalt nanomaterial science" was established. In this review, various preparation method of nanoclay modified bitumen is analyzed, and influence nanomaterial on the base bitumen properties and mechanism are summarized.



Macro Meso Micro Nano Quantum
100 10^{-3} 10^{-6} 10^{-9} 10^{-12}
Length (m)

Fig.2: Illustration of the evolution of different asphalt dimension [2]

2. VARIOUS NANOMATERIAL'S USED IN BITUMEN MODIFICATION

Various polymer modifiers impart different inherent characteristics to composites. Through research and development, several good asphalt modifier such as polyethylene (PE), ethylene vinyl acetate (EVA), rubber and styrene butadiene (SBS) block co-polymer, have been identified. The light weight porous SBS has both the elastic properties of the rubber and thermoplastic properties of resin, which allows for a wide range of application. However some resins such as (PE) are relatively inexpensive, obtainable from recycled plastic and can be mixed directly into base asphalt. Therefore, many researchers are still committed to polymer modified bitumen, working toward avoiding the drawback of this material in order to prolong its use in pavement engineering. One of the major shortcoming of pure polymer modifier is that most of the polymer thermodynamically incompatible with bitumen due to large difference of density, polarity, molecular weight and solubility between polymer and asphalt. This can result in delamination of the composite during thermal storage, which is not readily apparent and adversely affect the material when it is used in construction.

In Egypt, Afaf Abel, Halim Mohmoud [3] in El-Minia University reported the modification base bitumen and polyethylene terephthalate modified bitumen using nanolayered silicate. In Iran, M Arabani, V. Shakeri [4] in University of Guilan reported the modification of base bitumen using nano-ZnO. In China, Hua Yao, Zhanping You et.al.,[5] have investigated the long term ageing and short term ageing of bitumen using nanomer 1.44p, carbon micro fibre and nanoclay.

Saeed Sadeghpour Galooyak et.al, [6] discussed The influence of organophilic montmorillonite (OMMT) nanoclay (Nanofill-948) on the rheological properties and storage stability of SBS modified bitumen. Organophilic montmorillonite is nanoclay having montmorillonite as a base and prepared by mixing 45% nominal content of Distearyldimethylammoniumchloride (having density 1.4g/cc, particle size 36µm) with montmorillonite. In Italy, Filippo Merusi, Felico Gialiani et.al, [7] discussed the influence of organically modified (OMMT) nanoclay (cloisite20A) on the viscoelastic behaviour of SBS modified bitumen. Henglong Zhang, Liang Hu et.al, [8] studied the influence of Limestone powder, Nano-$CaCO_3$, and Montmorillonite (MMT) nanoclay on the oil resistance properties of SBS modified bitumen. In India, Jafrey Danial, Panneerselvam [9] in NIT Trichy reported the modification base bitumen, polypropylene and polypropylene with spheri glass using MMT (cloisite15A). Abolghasem Yazani, Sara Pourjafar [10] discussed the optimization of asphalt binder modified with Polypropylene/SBS/Nanoclay using Taguchi method (QUALITEK-4). Thais F. Pamplona, Bruno De C. Amoni [11] discussed the influence of vermiculite organically MMT on the rheological, ageing effect and storage stability of SBS modified bitumen. Farhad Zafari, Mohammad Rahi et.al, [12] discussed the influence of Nano-silica on the anti-ageing property, rutting performance, and rheological properties of base bitumen.

Due to complex preparation method nanoscale organic materials are difficult to obtain by using conventional techniques. So commonly used polymer modifier are readily and convenient to be used as a base bitumen additive, forming a promising method for modifying bitumen. However, high initial cost and characteristic of metal oxide have limited their appearance in asphalt modification in both research and application. Theoretically, the vast majority of inorganic metal oxide material can be prepared as nanoscale which can then be used to form nanocomposite with base bitumen. But the key to success accomplishing this is to find dispersing surfactant that is compatible with nano additive and base bitumen. As previously, reported certain metal oxide nanomaterial has occupied dominating position in bitumen modification, among which the most widely used has been the layered clay nanomaterial, primarily MMT and organic OMMT. Base bitumen nanosized modification technology is currently a popular area of research in the field of material science and application and also a driving force in economic growth of transportation development.

3. PREPARATION PROCESS OF POLYMER MODIFIED BITUMEN

Generally speaking, there are currently two main methods used for bitumen modification. One is high speed shearing, the most widely used and mature technology, by which the polymer modifier can be evenly dispersed in bitumen using a shear device. The second technique is “mother liquor melting” and entail dissolved the polymer modifier in organic solvent to prepare a high concentrated solution followed by incorporation of mother liquor into the bitumen by mixing. The final step involves heating the mixture to distil and recover the solvent under high temperature condition. The compatibility between the bitumen and modifier is the key to improve the bitumen modification effect. The compatibility depends on the component of base bitumen as well as the polarity, particle size and molecular structure of polymer modified bitumen and interfacial of interaction between bitumen and polymer modifier. The type of modifying agent, preparation temperature and modification process also effect the performance of modified bitumen.

3.1 Limitation of Polymer Modified Bitumen

Juan Canilo Munera [14] reported that the polymer swell during mixing through absorption of light component of bitumen and thus the properties of base bitumen are altered. As a result, the swelled polymer particle in the bitumen will also affect the compatibility of two phases over a certain temperature range, thus influencing the modifying effect of the base bitumen.

4. PREPARATION PROCESS OF WASTE PLASTIC AND E-WASTE MODIFIED BITUMEN

There are three process to mix waste plastic and E-waste into modified bitumen.

1 Wet process

2 Dry process

3 Semi wet process

In wet process, waste plastic along with other additives is melted and stirred in hot bitumen around 150^0C using a high shear mixer to produce waste plastic modified bitumen (WPMB) which is then added to hot aggregates to produce modified bituminous mixes. In dry process, waste plastic is added to hot aggregates to get Plastic Coated Aggregates (PCA). Optimum quantity of bitumen is then added to produce WPMB- mix. In semi wet process, waste plastic is miscible in bituminous phase in hot melt condition and get separated from bituminous phase on cooling WPMB to ambient temperature. But, some of the plastics in the mixed waste stream do not melt completely and remains disperse in spite of adding additives. Partially modified bitumen containing waste plastic particles is then used to coat the hot aggregates to produce waste plastic modified bituminous mixes. The undissolved plastic acts as a cushion aggregate in modified mixes at ambient temperature to service temperature as during recycling process plastics are toughened with colorants dyes and other fillers, chemical and inert additives, as a result improving their softening, melting and glass transition temperatures. This process is preferred over wet process to have the dual benefit of plastic waste i.e. as a modifier to bitumen and as a cushion aggregate for better inter locking of aggregates. This process is also under validation.

5. PREPARATION PROCESS OF NANOCLAY-POLYMER/RUBBER MODIFIED BITUMEN BINDERS

Majtaba Ghasemi [13] prepared SBS/SiO_2 composite modified bitumen through the previously reported methods. It was found that mother liquor melting is more conductive to the uniform dispersion of the polymer modified and subsequent stable storage of the modified bitumen system. However, this preparation process is relatively complicated and it was found that the solvent might influence other properties of the bitumen. Consequently, in this paper only high-speed shearing bitumen modification method which is commonly used in laboratories and in the field summarized.

Considering the cost and nanomaterials dispersion in bitumen the content of nanomaterials in the composite should be small. In addition, the viscosity of bitumen is very large and the components are complex, which further increase the difficulties of the nanoparticles dispersion and diffusion into the matrix. To reduce the viscosity in preparing the modified bitumen it is necessary to raise the temperature to facilitate nanoparticles diffusion. Since asphalt is easily aged with oxygen during the composite preparation, the temperature of the mixture should not be too high and the shearing time should not be too high, which present a paradox. Therefore, balancing the uniform dispersion of nanoparticle in bitumen and reducing the aging of bitumen as much as possible will be a key consideration for future research. Moreover, the particle size of polymer in the asphalt is influenced by the shearing rate and shearing time.

In the preparation nanoclay (OMMT)/SBS modified asphalt by Filippo Merusi et.al. [7] SBS and cloisite 20A with different mixing procedures. The two mixing procedure refer to different mixing sequences. The first mixing procedure adopts the following sequence: bitumen is initially mixed with the cloisite 20A, and then the polymer is added to the mix. The second mixing procedure has an inverted sequence, here the polymer mixed with cloisite 20A, thereby forming a polymer nanocomposite, then nanocomposite is added to base bitumen. In second case, the polymer/20A blend was prepared by melt compounding in the Brabender plasticorder static mixer of 50ml capacity, preheated to 190 ^{0}C. The speed was maintained at 30 rpm for about 2.5 min and then it was gradually increased to 60 rpm. The organoclay was added into the molten polymer matrix before increasing the motor speed. The overall blending time was 13 min.

With regard to addition of polymer, clay to the base bitumen, the typical mixing procedure was as follow: aluminium cans of approximately 500 ml were filled with 250-260g of asphalt and put in thermoelectric heater. When the bitumen reached 180^0C, a high shear mixer was dipped into the can and set speed 4000rpm. The polymer and clay were added gradually (5 g/min), while keeping the temperature within the range of 180 ± 1^0C during the addition and subsequent 1.0 h of mixing. The sample was stored in the freezer at -20^0C. Saeed Sodeghpour Galooyak et.al.,[6] used the following process of preparation of SBS/organic MMT (Nanofil 948), there are three method for preparing triple composite of nanoclay/polymer/bitumen

1. In-situ polymerization method
2. Dissolving in an organic solvent
3. Melt intercalated method

In this study, melt intercalated method was chosen because of its efficiency and simplicity. Order of mixing effect was investigated and results indicated that it has no appreciable effect on the characteristics of final samples. So OMMT was added into SBS modified bitumen at 180^0C and the mixtures were blended at the fixed speed of 4000 rpm for 30 min. For all samples, the mixing temperature should not exceed 200^0C, and the mixing time should be as short as possible to prevent degradation of polymer and oxidation of bitumen. The properties of nanocomposites were compared with PMB and original binders. Abolghasem Yazdani et.al.,[10] used the following process of preparation of PP/SBS/Nanoclay. The PP/Nanoclay master batches were prepared using Haake Torque Rheometer (Rheomix 600P) fitted with roller rotors (net chamber volume 69 cm^3). The batch weight was optimized to 43g and mixing was carried out at 200^0C and 20rpm. The Nanocomposites of PP/SBS/Nanoclay were prepared Haake twin screw extruder. The high tendency for decreasing of viscosity and reaching to a fine mixture in one hand, and the enhancement of polymer destruction in high temperatures in other hand, made the mixing temperature ranged from 180^0C to 200^0C. Mixing the obtained Nanocomposite with bitumen was done using Industrial high shear mixture, Silverson, model L4R, Italy. Bitumen (4.5%wt) was preheated till 150^0C. In initial mixing, the Nanocomposite was mixed with bitumen with low rate (200rpm) for 10min. According to this; the polymer structure doesn't deteriorate during the second phase of mixing. In the second phase, the total mixture was mixed with high rate (3000 rpm) for 30 min. Henglong Zhang et.al.,[8] used the following process of preparation of Nano-$CaCO_3$ / SBS /limestone, the SBS modified bitumen with different mineral material was prepared using high shear mixer. SBS modified bitumen was first heated until fully liquid at around 175^0C in the mixer, and then MMT, limestone power or nano-$CaCO_3$ was added into SBS modified bitumen, respectively. The mixture was blended at 3000 rev/min rotation speed for about 30 minutes to ensure a through dispersion of mineral materials.

Considering the different kind of base bitumen, polymer and nanomaterials, the preparation process of modified bitumen can vary dramatically. In addition to these factors control of preparation process parameter such as shearing speed, temperature and time to prepare the modified bitumen with good compatibility and thermal storage are also area of work for future research in nanomaterial/ polymer multi modified bitumen.

6. EFFECT ON NANOMATERIAL ON BASE BITUMEN OR MODIFIED BITUMEN AND THEIR MECHANISM

6.1 Compatibility and Stability

Compatibility of material is the major factor and necessary condition for even dispersion and composite stability. Consequently, researchers are working diligently and using appropriate technical to prepare uniform nanomaterial and stably disperse there in asphalt. Unfortunately, nanomaterials can easily aggregate together which cause spot segregation. This results in the uneven microstructure of composite leading to the force field distortion and finally affecting the positive aspect of the nanomaterial sometimes resulting negative property effects. Lack of dispersion of the added nanomaterials in the uniform state for extended period will cause microstructure of the composite to gradually change either during transportation and storage or in the application on a pavement. This condition is unacceptable.

In order to promote the dispersion organic clay MMT nanoparticle in polymer modified bitumen, Filippo Merusi [7] prepared clay has not simple filler like effect, being its presence related with quite important variation in crossover frequency and glass transition. It was consequently supposed that clay nanometric size can interact with the maltenic liquid phase of bitumen thereby extending its effect on the transition phenomenon. The presence of clay and the mixing sequences are the main factor that controls the final properties of the blend. In case of P-type mixing a certain improvement in the mechanical properties was recorded but the general rheological behaviour resembles that of the bitumen/SBS binary blend (conventional PMB). With N- type mixing, clay has an effective and fundamental impact on bitumen internal structure and rheology. In this case, the presence of clay deeply alters the equilibrium between the polymer rich phase and asphalt rich phase, thus enhancing compatibility between two phases.

In order to promote the dispersive organic clay MMT (Nanofil-948) nanoparticle in polymer modified bitumen (Saeed Sodeghpour Galooyak et.al. [6]) when the SBS/OMMT content in the triple nanocomposite was 100/50; the storage stability of the compound was improved significantly. By increasing nanoclay, the difference in softening point between top and bottom of aluminum tube becomes lower but because of the precipitation of non-exfoliated OMMT particles the difference in softening point becomes negative with the increasing SBS/OMMT content to 100/65 and higher. In the proportions higher than SBS/OMMT = 100/50, precipitated nano-particles are aggregated at the bottom section of tube, so softening point of bottom section increased. So it can be concluded that SBS/OMMT ratio is critical parameter to obtain the high temperature storage stability of SBS-modified asphalts. Therefore, saturation proportion of SBS/OMMT is equal to 100/50 and higher content is not appropriate. In nanometric scale Brownian forces and molecular interaction are dominant forces. By using nano-particles in PMB, the mean free path of polymer in PMB can be limited. Fig. 3 shows intercalation and exfoliation of polymer with nanoclay.

In order to promote the dispersion of two different type of organic nanoclay (cloisite 6A and cloisite 25A) nanoparticle in Polymethylpentene (PMP) (Santosh D. Wanjale et.al.,[15]) nanocomposites of PMP and clay were successfully prepared using a melt intercalation technique. Two organophilic clays were used to facilitate intercalation of the polymer. From the X-Ray Diffraction (XRD) results, one can conclude that, for both types of clays, the structures of the nanocomposites formed are intercalated, disordered and partially exfoliated. Dynamic mechanical analysis (DMA) illustrates the reinforcing effect of clay, as evidenced by the improved storage modulus over a range of temperatures studied. The effect of clay treatment on nanocomposite is discernible in the dynamic response of the nanocomposites. The extent of increase in storage modulus is significantly higher for nanocomposites prepared using 25A clay and compatibilizer than that of 6A clay based nanocomposite. In the present case, 6A clay has larger d-spacing and is more hydrophobic than 25A; nevertheless; the results show that the nanocomposites with 25A clay exhibit better properties. The addition of compatibilizer results in increased d-spacing and improved thermal stability but does not bring about much improvement in the dynamic storage modulus at higher temperatures (due to the low melting point of the compatibilizer). From this observation, it can be concluded that, by choosing a compatibilizer with a high softening/melting point, a good combination of properties with respect to the pristine polymer can be achieved. Magdy Abdelrahman [16] prepared Nano-SiO_2 with base bitumen. Fourier Transform Infrared (FTIR) testing was conducted to evaluate the nature of the interactions between nanoclay and asphalt. Increasing nanoclay concentration in asphalt enhances temperature susceptibility of asphalt, as well as increasing the complex modulus in addition to decreasing phase angle. FTIR experiments indicate a significant change in Si-O vibration from nanoclay, indicating strong nonbonded interactions of Si-O tetrahedra with asphalt. These changes in Si-O vibrations suggest both distortion in Si-O tetrahedra as well as stronger interactions between asphalt and NC. Further, X-ray diffraction (XRD) testing results show intercalation of asphalt in clay galleries indicated by an enlarged d-spacing of up to 43.17 $Å^0$. The d-spacing decreases with NC content. These experiments suggest that the addition of engineered nanoclays to asphalt has tremendous potential in tailoring the properties of asphalt based on type of application.

6.2 Aging Resistance

When bitumen is aged, it hardens and become brittle and thus a bitumen roadway will appear to be prematurely damaged. Bitumen aging is the one of the reason for distraction which can be divided into two stages: short term aging and long term aging. Short term aging is case by heating of asphalt in pavement paving and long term aging is generated by the combined action of thermal oxidation, illustration, precipitation and traffic load in the service life of bitumen pavement. The aging of some modified bitumen includes not only the effect of bitumen, but also the degradation of polymer. The excellent aging resistance of modified bitumen derived from its good compatibility and solubility. So the compatibility and stability are the premise of anti-aging properties of modified bitumen. In addition, the distribution pattern of nanolayered in modified bitumen also improves the aging resistance. The effect of adding OMMT on PMB aging was investigated by Saeed Sadeghpour Galooyat et.al.,[6]. Nanoclay can prevent aging of PMB. A lower retained penetration value and higher increment in softening point reflect more aging of the binder. The difference between softening point after and before aging is decreased by adding OMMT. Also, with this retained penetration increased. The incorporation of impermeable anisometric particles into the PMB matrix forces the permeating molecules to wiggle around them in a random walk, hence diffusing through a tortuous pathway (Fig.4). The permeation of oxygen molecules through composite materials has been predicted to be a function of the aspect ratio of the inclusions, their volume fraction and orientation. Also, barrier properties of OMMT are induced to PMB. By increasing content of SBS/OMMT from 100/50 to 100/65, non-exfoliated particles accumulated in the bottom of the container and adhered to it; as a result softening point difference for this sample became negative. Oxidation of bitumen always yields a worse performance of bitumen at low temperature. So, improving aging properties of PMB by adding OMMT, led to proper performance in low temperatures and lower thermal cracking.

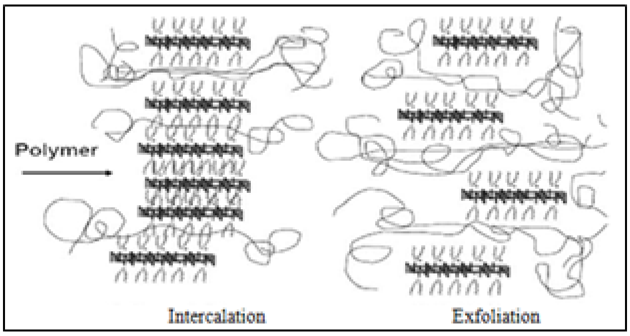


Figure 3: Schematic Diagram of OMMT/SBS Modified Bitumen [6]

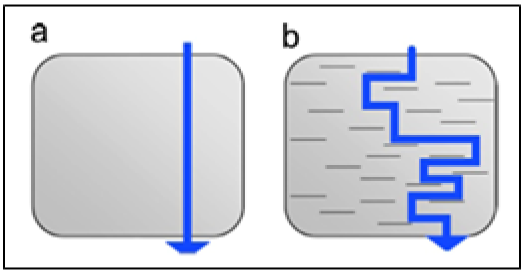


Figure 4: Model of oxygen diffusion to triple nanocomposite (a) SBS/Bitumen blend; (b) OMMT/SBS/Bitumen blend composite [6]

6.3 Miscellaneous Properties

Other properties of modified bitumen such as rheology and pavement performance also depend foremost on the compatibility and stability of modified bitumen. Therefore the entire factors which affect the compatibility and stability will also influence the other material properties. We prepared PET polymer of 13% and nanoclay content in modified bitumen sample were O%, 3%, 6% and 9% respectively. The physical properties such as penetration value and softening value are enhanced with the increase of nanoclay concentration.

Mohammed Sadeque [17] reported that Bitumen mixtures were prepared with various amount of nanoclay. Based on the experimental results, it was found that the addition of nanoclay improves the rheological properties of bitumen. The penetration decreases as the softening point increases with addition of nanoclay in bitumen. Asphalt concrete prepared from nanoclay modified bitumen shows significant improvement in the Marshall Stability.

Henglong Zhang [8] reported that SBS modified bitumen mixture were prepared with montmorillonite (MMT), nano-$CaCO_3$ and limestone powder (LSP). Based on the experimental results, it was found that both MMT and nano-$CaCO_3$ enhanced the diesel resistance to SBS modified bitumen, while LSP decrease the diesel resistance to SBS modified bitumen. The engine oil resistance to MMT/SBS modified bitumen is also investigated. Both SBS modified bitumen and MMT/SBS modified bitumen show swelling phenomenon in engine oil. However, due to barrier properties of intercalated structure in MMT/SBS modified bitumen, MMT can reduce the swelling of SBS modified bitumen in engine oil.

7. CONCLUSIONS AND PERSPECTIVE

Throughout the field of modified bitumen with nanomaterials, different nanomaterial appears to play a positive role in improving the properties of bitumen. Mechanism of using nanomaterial together with base and polymer modified bitumen and polymer/nano/bitumen system various perspectives have been summarized and analyzed. As more investigators pay attention to the nanomaterial applied in bitumen modification, nanoscience and nanotechnology will help make progress in bitumen modification. In the preparation of modified bitumen, conventional polymer modified bitumen preparation method have been used but the influence of various preparation process parameters, such as temperature, shearing and time on the modified bitumen product has not been investigated. It is believed that the modification of nanomaterial on base bitumen and modified bitumen is a chemical reaction process. Method of reasonable dose of nanoparticle into the bitumen to achieve nanoscale dispersion and improvement the compatibility of every phase and the comprehensive properties of modified bitumen material will be the focus of research work in the field. Simultaneously, further research on mechanism of nanomaterial modified bitumen and its microstructure will be significant in guiding the engineering practices.

8. FUTURE SCOPE IN ROAD CONSTRUCTION AND MAINTENANCE

Varieties of polymers, waste tyre rubber, plastic waste, E-waste, paint sludge and polymeric waste from many other streams in day to day life have been candidates for the development of Modified Binders. Some of the modified binders met the specified criteria with respect to their performance and have been commercialized whereas others have failed to meet the basic criteria specially phase separation, elastic recovery and so on. Nano materials are needed to be investigated in combination with such modifiers including e-waste. A tailor-made formulation is needed to be developed through laboratory design of experiments making use of nano materials and different modifiers.

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