Gilsonite-Modified Bitumen

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Hot mix asphalt has various benefits such as good workability and durability. It is one of the most general materials used as asphalt mixtures in road pavements. Asphalt mixtures and binders can be improved by modifying them with various additives. Gilsonite is a natural asphalt hydrocarbon which may be used as an additive to hot mix asphalt. It is used as an asphalt binder modifier (wet process) and an asphalt mixture modifier (dry process) to improve the properties of the mix. It provides the option of improved rheological properties, stability, strength rutting resistance and moisture sensitivity.

polymer modified asphalt | asphalt gilsonite | gilsonite in asphalt pavement

1. Introduction

The life cycle of asphalt mixtures (surfacing layer) can be determined by measuring the fatigue and stress characteristics including permanent deformation resulting from traffic loading [1]. Therefore, improving the quality of the asphalt mixture such as rutting resistance and moisture damage will lengthen the pavement service life, thus, accordingly enhancing the sustainability [2]. Hot Mix Asphalt (HMA) is an essential material in the paving industry and offers several advantages including versatility, good durability, and cost-effectiveness [3]. HMA is a combination of two primary ingredients: aggregates and asphalt binder [4]. HMA deteriorations including aging, low temperature, and fatigue cracking, rutting, and moisture-induced damages are mostly due to the mechanical and rheological properties of the binder and asphalt mixtures [5]. The global consumption of asphalt binders has rapidly increased since the 1900s, being used mostly as the binder for asphalt mixtures for road construction and maintenance [6]. Poor asphalt not only reduces the pavement service life but also causes further issues, for example, increased repair, premature failure, increased maintenance costs [7], hazardous conditions for road users, and finally, reduced safety.

Road authorities, the asphalt industry, and related researchers have paid increased attention to modify the asphalt binder with various materials to decrease the life-cycle cost and develop the service performance of roads. Asphalt modification is one of the most popular approaches [8]; modified asphalt has been developed to produce an alternative to traditional HMA. In the process, additives were added to the binder to improve asphalt binder characteristics, such as the adhesion to aggregate, the properties of the final asphalt mixture, and workability [9]. Additives are used to increase the pavement service life and delay deterioration. These additives can be either added to asphalt binders (wet process) or added immediately into the mixture in plants (dry process) [10][11]. Although numerous additives increase the performance of asphalt binder and mixture, the proper performance of an additive must not be the primary principle for selecting it; there are also other aspects including environmental and economic concerns that should be considered when choosing an additive [12]. One of the important additive materials is gilsonite. Gilsonite is a resinous hydrocarbon belonging to the hydro carbonates in the classification of asphalt binder modifiers [12][13], and has been assessed and utilized in numerous industrial aspects [12]. Gilsonite, the scientific name of which is “uintaite”, was discovered in the 1860s, and later referred to as “gilsonite” after Samuel H. Gilson [14]. Gilsonite is also referred to as asphaltum, natural asphalt, mineral asphalt binder, asphalt binder powder mineral tar, or drilling mud [14].

2. Critical Evaluation of Gilsonite as Asphalt Modifier

A wide range of gilsonite has been added to the asphalt binder and asphalt mixtures by wet and dry processes, respectively. Different processes and range of sources may contribute to the different performance properties of the modified asphalt mixtures. For example, Quintana et al. used high purity gilsonite and had a low carbon and sulfur content [15], compared with other studies where the gilsonite had higher carbon and sulfur contents [16].

Compared to the control asphalt mixtures, modified asphalt mixtures in the wet process provide better performance properties [17]. However, the dry process is cost-effective and it is much easier for a manufacturer to produce the asphalt mix as it does not need mixing tanks [17]. A modified wet process was used in most of the research, and the reviewed studies indicated that gilsonite asphalt pavement using the wet process exhibited good performance [18][19][20].

The methodologies have been developed and subjected to numerous research investigations. Several tests were conducted to assess the performance of the resulting products following different standards. Physical properties tests such as penetration, softening point (SP), ductility and viscosity were the common tests considered by most of the reviewed studies to evaluate the rheological properties of modified binders. According to the reviewed studies [18][19][20][21], adding gilsonite mitigated the penetration value and increased the softening point, ductility and viscosity values; based on these test results, modification of the asphalt binder with gilsonite can increase the quality of the asphalt mixture. However, increased viscosity of modified binders led to escalated mixture and compaction temperatures [21]. Therefore, gilsonite modification can lead to binder oxidation and decline of the design life because of reduced flexibility and cracking fatigue [22]. Therefore, adding another additive, such as waxes, to the gilsonite-modified binder was necessary to decrease the viscosity [23].

Other tests used in assessing the performance of the gilsonite-modified binder at high temperatures and at low temperatures were DSR and BBR, respectively. Based on the available literature, the gilsonite improved the performance of the asphalt binder in high temperatures through increased shear strength of the modified binder [12][24][18][25][26][27][28]. However, the reviewed studies confirmed the weakness of gilsonite as a modifier for asphalt binder in terms of its properties at low temperature, due to the stiffness values of gilsonite-modified asphalts increasing with increasing gilsonite concentration [24][29][27]. It is suggested that gilsonite can be used in regions with a tropical environment to improve the asphalt binder performance. At the same time, it is recommended to avoid the use of gilsonite-modified binders in cold regions due to the brittleness of the asphalt binder resulting in pavement cracking.

The Marshall tests are considered the basic unit and the universally acceptable measurement to identify the quality of asphalt mixtures as indicated by common standards. Regarding Marshall tests, the use of gilsonite in asphalt mixtures can improve the Marshall properties of mixtures by increasing Marshall stability [19][30][20][29][31]. Moreover, the stability value continued to increase when the rate of gilsonite increased up to 10% [32][30], enhancing the resistance against deformation of the asphalt mixture [19].

Other tests were also used to assess the performance of the asphalt mixtures. For example, the indirect tensile strength (ITS) test was carried out for most of the resulting asphalt mixtures, as this test indicates the mechanical properties and moisture sensitivity of asphalt mixtures. According to the reviewed studies [16][33][20][34][29][31], mixtures with gilsonite have a greater ITS value compared to mixtures without gilsonite. This is due to the improved adhesion of aggregates to the binder as a result of the better adhesion of the gilsonite-modified asphalt binder to aggregate [19]. Moreover, based on the TSR index, adding gilsonite to asphalt binder enhanced the moisture sensitivity to asphalt mixtures [19][30][20][29][31]. However, the gilsonite content of more than 5% in asphalt binder did not have a significant effect on TSR index; thus, there is no effect on moisture sensitivity [16][15]. At the same time, adding more than 5% gilsonite reduced the TSR index, which had a negative impact on moisture damage due to the increase in the mixture brittleness [31]. Generally, adding up to 5% gilsonite improved the resistant moisture damage; therefore, using gilsonite to modify asphalt binder is recommended in humid regions.

The main important outcome obtained from the creep test is to show the permanent deformation which somewhat relies on the rutting resistance of the asphalt mixture [30][35]. The findings from the DCT, MSCR, and WTT tests showed that the asphalt mixtures prepared by binder modified with gilsonite improved the rutting resistance [18][19][30][25][36][21]. This improvement is suggested to be due to the high content of asphaltenes in gilsonite [14], which increased the rutting resistance of the asphalt-modified mixtures. Likewise, adding gilsonite improved the stiffness [18][15] and decreased the elasticity of asphalt-modified mixtures at low temperatures, which increased the rutting resistance. Interestingly, based on the literature reviewed, it should be noted that results from dynamic tests on asphalt mixtures and rheological tests on asphalt binders are consistent and verified similar trends seen in rutting resistance as gilsonite content increases.

According to the reviewed studies, the resilient modulus test was considered by many of the researchers [19][15][30][20][37][31] to evaluate the asphalt-modified mixtures in terms of resilient deformation. The results showed that the resilient modulus parameter increased as the content of gilsonite in the asphalt mixtures increased. This reflects the positive influence of gilsonite on asphalt binder. However, resilient modulus test findings showed a significant drop in the flexibility property of asphalt mixtures made of binder modified with gilsonite [30]. Considerably, an overdose of gilsonite in asphalt binder led to excessive resilient modulus values, which resulted in brittle asphalt mixtures.

Since gilsonite is recognized as an additive material that contributes towards to modification of the asphalt binder and consequently improves the asphalt mixture properties, some of the research projects [26][29][27][28][31] have carried out further investigations combining other additives alongside gilsonite to develop the asphalt binder. Most of these investigations have decided to select SBS as an extra additive with gilsonite, due to SBS improving the

HMA performance properties, and also used gilsonite to replace SBS due to SBS being an expensive additive [26][29][28]. Based on the rheological evaluation of the modified binders, using gilsonite with SBS in the same mixture decrease the viscosity of the binder [26][29], which helps to increase the workability of the asphalt mixture by decreasing the mixing and compaction temperatures. Based on the reviewed studies, modification of the asphalt binder with gilsonite and SBS improved stability, ITS, moisture sensitivity and fatigue life [26][29][28]. It also improved the storage stability of asphalt-modified binder [28], thus, extending the service lives of HMA.

However, the gilsonite has a negative effect on asphalt binder at low temperatures [24][33][34][29][27]. Here, in order to improve the low-temperature performance, SBR was selected as an additive to asphalt binder modified with gilsonite [27]. Based on the DSR test results obtained, the rheological properties of asphalt binder modified with gilsonite improved with the addition of SBR [27]. Significantly, the addition of SBR improved the fatigue resistance performance of the asphalt binder modified with gilsonite [27]. Furthermore, the results indicated that the addition of SBR increased the penetration, SP, and ductility values of the asphalt binder modified with gilsonite [27]. Hence, SBR enhanced asphalt binder modified with gilsonite, making it more flexible and cracking resistant which improved its low-temperature properties. However, there is a negative effect that needs to be considered; the SBR increased the temperature sensitivity for gilsonite-modified asphalt binder [27]. However, it is interesting to note that adding wax improved the temperature sensitivity of the asphalt binder [38][39][40] and can overcome this problem.

Once the amount of gilsonite that increased the mixing temperature and compaction temperature had been determined [21] (thus, avoiding this negative impact of gilsonite), Sasobit was nominated to modify the asphalt binder accompanied by gilsonite [31]. Sasobit has been used in practice mostly to decrease the construction temperatures (mixing and compaction temperatures) of asphalt-modified mixture [38][39][40]. However, Sasobit has a negative effect on the moisture sensitivity of asphalt mixtures [31]. According to laboratory binder tests [31], it is clear that Sasobit content has a positive effect on the performance and rheological properties of WMA modified by gilsonite. It has improved the performance properties of WMA, including Marshall stability, resilient modulus, DCT, and permanent deformation. Significantly, Sasobit decreased the high construction temperatures related to the use of gilsonite, whereas gilsonite increased the resistance to moisture damage compared to using Sasobit alone [31]. Considering the reviewed studies, results indicate that the application of a combination of gilsonite and other additives such as SBS, SBR or Sasobit provides more benefits than using gilsonite alone.

Most of the reviewed studies [19][30][20][29][31] focused on the Marshal mix design specifications, while few studies [12][33] were relying on the Superpave specifications test. The outcomes for both procedures indicated that modifying asphalt binder with gilsonite improved the rutting resistance of asphalt mixtures; however, it reduced fatigue life and cracking resistance at low temperatures. As a suggestion, another mix design method, “European mix design”, can be implemented. Most studies in the field of modified asphalt gilsonite have only focused on the wet process, despite the dry process being exceedingly cost-effective. According to reviewed papers, the studies focus on FTIR and TLC–FID techniques, while the XRD and SEM will be more useful for understanding the chemical structure after modification due to the SEM images indicating the dispersion of asphalt-modified binder [41]. As a result, it can certainly support understanding the physiochemical behavior of the asphalt-modified binder. Many laboratory-based experiments have been accomplished to appraise the performance of the gilsonite on asphalt binder and mixture, and essentially improve the service life of asphalt pavements. However, the applications of the modified binder on the site need additional study. Although most of the available literature aimed to improve the rheological and mechanical properties, and the durability of asphalt binder and mixtures by modifying it with gilsonite, only a few research studies [30][31] mentioned the economic and environmental benefits of using gilsonite.

3. Economic and Environment Assessment

The criteria considered in this study for the assessment of economic and environmental aspects are the use of gilsonite alone and in combination with other additives in the asphalt industry.

From the economic perspective, the better quality and longer life of pavements satisfy both safety and economical aspects [42]. The use of gilsonite improves asphalt mixture resistance against tensile stresses, resulting in an increase in the service life of the pavement and a reduction in repair and maintenance costs [30]. Likewise, gilsonite is an appropriate alternative and economical choice for enhancing the properties of the binders [36]; for example, gilsonite is less expensive compared with other modifiers such as SBS or EVA (Ethylene-Vinyl-Acetate) [30]. According to the resilient modulus results, gilsonite demonstrated higher performance compared to asphalt mixtures made with pure asphalt binder [19][15][30][20][37][31]. This outcome could have a significant influence on the economic design of roads because of the need in asphalt pavements to have resilient modulus [30]. Moreover, the increased resilient modulus of the mixtures containing gilsonite may reduce the asphalt layer thickness, resulting in improved resistance to heavy traffic loads, and extended service life of the pavement.

From an environmental perspective, the asphalt industry process plays an important role in contributing to the causes associated with global greenhouse gas emissions [43]. Therefore, asphalt industries are actively searching for alternative materials and techniques in order to move towards sustainable development. Considering the amount of recycled material included in the asphalt mixture, gilsonite increases the performance of the porous HMA when using 100% recycled concrete as aggregate [32]; therefore, it is a potential material for sustainable pavement systems. However, adding gilsonite to the asphalt binder decreases the penetration value and increases the SP and viscosity [18][19][20][21]. This leads to increased mixing and compaction temperatures [21][31], resulting in increased energy consumption and associated CO_2 emissions. This can be prevented by using gilsonite with an asphalt binder modified with Sasobit [31]. Furthermore, the DSR test indicated that the use of gilsonite resulted in lower viscosity than SBS, and thus gilsonite offers energy consumption advantages [29]. Ultimately, the evaluation of the environmental impacts and economic feasibility of asphalt mixtures containing gilsonite indicates that adding gilsonite in combination with other selective additives provides more economic and environmental advantages. However, more research is needed to consider the economic and environmental perspectives fully; the cost-effectiveness and carbon footprint of using gilsonite as an asphalt modifier needs further investigation since only a few publications considered this aspect.

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