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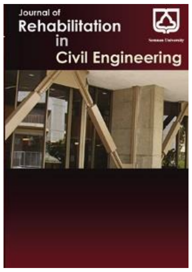

Evaluation the Effect of Different Kind of Waste and Mineral Filler on the Fatigue Life of Asphalt Mixtures with Dissipated Energy Method

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ABSTRACT

In recent decades, with increasing in traffic load, a great portion of repair and maintenance budget is being spent on improving the pavement failure. Asphalt fatigue, which is due to traffic cyclic loading, is one of the most important failure in asphalt pavements, therefore, increasing fatigue life in pavement can lead to a decrease in repair and maintenance budget. As a result, replacing or adding some additives to improve the fatigue behavior of the asphalt mixture, can help to reduce the fatigue cracks and increase the mixture life. In this research, fatigue behavior of asphalt mixture has been analyzed by using four point bending beam test with constant strain method on control and modified specimens with cement, coal waste and lime as filler. Fatigue behavior has been assessed at 2 strain 400 and 600 with replacing cement, coal waste and lime as the filler in the mixture. Results show that using each of 3 fillers at both strain state, leads to an improvement in fatigue life of asphalt mixture. Analyzing the results show that using above fillers could be used as an approach to improve the pavement's function. Quantitatively, the three fillers, cement, coal waste and lime improved the fatigue life compared to the witness specimen by 75%, 55% and 8.2% at strain state of 400 and 107%, 72% and 7.1% at strain state of 600, respectively. Using coal waste can reduce the environmental issues due to coal waste deposits in addition to improving the fatigue life of asphalt mixture.

1. Introduction

In general, fatigue cracks in asphalt mixture are one of the parameters that should be

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concerned in designing flexible pavements. Therefore, extensive researches have been conducted on improving the fatigue behavior of asphalt mixture by extending the fatigue life. Reviewing accomplished researches, it can be found out that, researchers have conducted different tests to discover the effect of different parameters of asphalt mixture and environmental and laboratory conditions on the fatigue life.

One of the current concerns is the existence of millions of tons of mineral and industrial waste material deposited all over the globe along which great issues exists, such as dangerous environmental issues. On the other hand, inevitable utilization of material in hot mix asphalt and its growing expenses and deficiency of proper and sufficient resources is another issue in pavement industries. Utilizing these waste materials as effective additives in hot mix asphalt, not only preserves natural resources and environment, but also has a tremendous effect on saving the building expenses of pavement.

In this research, replacing cement, coal waste and lime as the witness filler has been investigated. The testing apparatus used in this research was the four-point bending apparatus.

2. Literature review

Kim et al. investigated the effect of polymer sulfur on fatigue behavior of asphalt mixtures using four-point bending apparatus at 2 strain levels of 200, 400 and 600 μs according to ASTM D7460 and AASHTOT321. Their research resulted that mixtures containing 30% polymer sulfur and 2% air have the best fatigue behavior among other mixing designs, especially in lower strain levels [1].

Topkin investigated the effect of filler type on the fatigue behavior by using cement, lime, and 3 types of fly ash for the filler of 7%. Among all these fillers, soma fly ash and kangal fly ash had the longest fatigue life [2].

Yilmaz et al. compared the fatigue life of asphalt mixtures with asphaltin and lime stone fillers utilizing UTM apparatus. Their investigations showed that by increasing the proportion of asphaltin, the cycles needed for failure increases which mean that the samples had a better fatigue behavior [3].

Chudhari and Chandra investigated a research on the effect of the amount and type of filler on the fatigue life of asphalt mixture by adding marble, granite, hydrated lime, quartzite and fly ash as filler. This research was conducted under 0.1 second sinus loading at 25^{o}C under four-point bending apparatus. Failure criterion is defined as reaching 50% of initial rigidity. Chudhari and Chandra's results show that samples with 4% hydrated lime as the filler have the longest fatigue life, also, adding more filler results in reducing the fatigue life. But in other mixture with different materials as the filler, 7% of filler responds to the maximum fatigue life [4].

Maniandi et al. studied the effect of 4 different fillers. These fillers included ceramic waste dust (CWD), coal fly ash (CFA), steel slag dust (SSD) and, as the reference filler, limestone dust (LSD). This research was aimed to investigate the transformation behavior under cyclic loading using UTM apparatus under predefined temperature based on characteristics of asphalt mixture with 4 different waste materials as filler by 7% of aggregate weight. The results of fatigue test on 4 samples show that the longest fatigue life was in respond to

LSD as the filler followed by CWD and CFA, respectively. Using SSD results in the shortest fatigue life among the above 4 fillers [5].

Liao et al. investigated the effect of the amount and type of different fillers, including cement and lime stone, on the fatigue life of mastic asphalt. Their results showed that adding active filler, increased the strength of material against cracking. Their experiment was conducted at different strain levels under cyclic loading with 10 Hz frequency at 20 degrees. The failure criterion was defined as reaching 50 % of initial $G^*\sin\delta$. Their results showed small difference between the amount of $G^*\sin\delta$ for mastic sample with 35% cement and with 35% lime stone [6].

Modarres et al. studied the effect of cement kiln waste as the filler on the fatigue behavior of asphalt mixture. This type of filler is an outcome of high temperature process of cement production at high values. In this research, the effect of this kind of filler has been investigated at low temperature and the lime stone filler has been chosen as the reference filler. This experiment was conducted at 20, 10, 0, -10 and -20^{o}C utilizing four-point bending apparatus. Using 6 different mixture designs, the results show that by reducing the temperature, fatigue life of asphalt mixture shortens, and generally, adding modifying fillers results in an increase in fatigue life [7].

Ziari et al. investigated fatigue behavior of porous asphalt modified with polymer at different strain levels utilizing four-point bending apparatus with dissipated energy approach. This research resulted in an improvement in fatigue life at lower strain levels using polymer, and a logarithmic equation based on fatigue life to calculate fatigue life. With a good correlation, this equation provides a suitable estimation of dissipated energy at particular strain level [8].

Habibnejad et al. studied the fatigue behavior of asphalt mixtures by adding amorphous carbon as modifying filler, utilizing four-point bending beam test. At constant strain condition, adding this filler to bitumen results in increasing fatigue life at low strain levels. Nevertheless, at high strain levels, using AC filler results in a decrease in fatigue life. However, the reduction in fatigue life was very slight and could be neglected when up to 50% AC powder was used [9].

Ruchelany et al. studied the effect of filler type on fatigue behavior of mastic asphalt mixtures using Dolomite, Granodiorite, Limestone and Rhyolite As modifying fillers. Using constant strain method, their research resulted in the best fatigue behavior for Granodiorite, and the least fatigue life for Dolomite as filler [10].

Ameli et al. investigated mastic asphalt mixtures fatigue behavior modified with CWA and RHA at different temperatures. This study utilized linear amplitude strain that resulted in decreasing trend in fatigue life by increasing RHA and increasing fatigue life by increasing CWA. For both fillers (CWA and RHA), an increase in temperature results in a decrease in fatigue life [11].

The tests presented the amount and type of filler and strain level are one of the most important factors in fatigue behavior of asphalt mixtures. But in most researches, the coupled effect of filler and strain level have not been studied, also the effect of cement and CWA has not been under attention as much as other materials which has been investigated here.

According to the research done in this section, it can be understood the importance of fillers in asphalt mixtures and their benefit to improve asphalt mixtures behavior. The summary of other researches show that using waste and mineral additive as a filler could be useful to improve HMA behavior and could help to decrease environment pollution. In this study, a 4-point bending test was performed on three waste and mineral selected fillers.

3. Material and Methods

3.1. Materials

The aggregate material used in this study includes lime stone aggregate type that their gradation size is responding to the Iran Highway Asphalt Paving Code (Code 234) with a maximum nominal aggregate size of 12.5 mm for Topeka layer. Choosing this type of aggregates is due to its better fracture resistance than other aggregate materials [12]. Table 1 contains the aggregate gradation procedure used in this research. The aggregate gradation procedure tests were performed according to AASHTO-T27 standard.

Table1. Aggregate gradation used in this study.

Sieve size (mm)	Gradation limits	Value
19	100	100
12.5	90-100	95.2
4.75	44-74	58.1
2.36	28-58	43
0.3	5-21	13.9
0.075	2-10	6

The used binder in this study is 60/70 penetration grade binder (equal to PG 64-22). Table 2 provides complete specifications of used binder.

Table 2. Specifications of the used binder in this study.

Property	ASTM Standard	Value
Specific gravity at 25 ˚C (g/cm^3)	D70	1013
Flash point (^{o}C)	D99	304
Penetration at 25 ^{o}C (0.1 mm)	D5	68
Ductility at 25 ^{o}C (cm)	D113	102
Softening point (^{o}C)	D36	47
Loss of weight	–	0.2
Degree of purity		99.6

The modifying fillers used in this study are: type 2 Portland cement, coal waste ash and lime. The most important advantage of these three fillers is their lower cost than other modifying additive [13]. Table 3 shows the used fillers properties in this study.

3.2. Mix design

Prior to designing the mixture, it is important to determine the proportion of filler and bitumen in the mixture. Firstly, aggregate materials were heated to 177˚C to 199˚C and then the filler was added to them. After mixing aggregate and filler, preheated bitumen at 121˚C to 138˚C was added to the mixture. The Marshall method is used in this study to determine the optimum bitumen according to ASTM D1559 [14].

The marshall parameters found to be independent of the amount and type of filler. The optimum bitumen in both witness and modifying fillers found to be equal to 4.5%. after mixing the aggregate and filler and adding bitumen, in order to make the specimens, the mixture will be put in molds with 38*5*6.3 cm diminutions [15].

3.3. 4-point bending beam test

The 4point bending beam test is one of the best and most reliable tests to perform fatigue behavior of asphalt mixtures. The principal aim of performing this test is to illustrate a model to estimate the fatigue life of asphalt mixture which is done by loading on the standard samples in the shape of beam. This apparatus is able to simulate the bending loading due to cyclic traffic loads. Fatigue test is performed by placing the asphalt beam under four-point cyclic loading at predefined strain state. This test is performed in constant-strain situation. To keep a constant strain state, applied stress is reduced at each stage, in this situation; actual failure in the beam is never reached. Therefore, in constant-strain situation, failure occurs at the point in which the strength reaches a predefined value. In this study, this point is the point in which strength reaches 50% of its initial value. In four-point beam test, two points are supports and the other two are loading points which are applied to the specimen at 1/3 of span through internal points. This mechanism is illustrated in fig. 1.

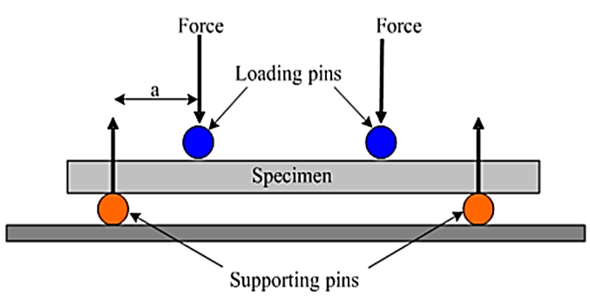

Fig. 1. The mechanism of loading method in4PB test.

3.4. Dissipated energy

One of the novel interpretations in fatigue mechanism is to consider dissipated energy along the loading period. During applying dynamic loading, some energy is transported into the material, a part of this energy is stored in the material and the rest will be dissipated. It can be assumed that fatigue corresponds to the dissipated energy [16]. When a material is subjected to loading and unloading in plastic region, residual loops are created in stress-strain curve, illustrated in fig. 2. These lops show that in each loading and unloading cycle, energy dissipates by a particular amount that emerges as thermal energy due to internal friction [17].

Therefore, dissipated energy can be expressed as the difference between consumed energy (the area under loading cycle) and improved energy (the area under unloading cycle), in summary, the dissipated energy is equal to the area inside the loop [18].

Eq.1 is developed to calculate the dissipated energy, for viscoelastic material, in each cycle [16]:

$$w_i = \pi.\sigma_i.\varepsilon_i.\sin\Phi_i \tag{1}$$

In this equation:

w_i : dissipated energy in ith cycle

σ_i : stress in ith cycle

ε_i : strain in ith cycle

Φ_i : phase angle ith cycle

Also, the total dissipated energy can be derived by summation of dissipated energy in previous cycles, according to Eq.2:

$$W_{total} = \Sigma w_i \tag{2}$$

Table 3. The properties of used fillers in this study.

Fillers	CaO(%)	SiO_2(%)	Al_2O_3(%)	Na_2O(%)	K_2O(%)	MgO(%)	ZnO(%)	LOI(%)
CWA	1.23	54.04	30.18	0.66	1.47	4.02	0.31	1.98
Cement	63.32	22.90	6.36	0.36	1.06	1.15	2.45	2.40
LS	44.90	18.97	0.46	0.08	0.10	4.64	0.9	29.95

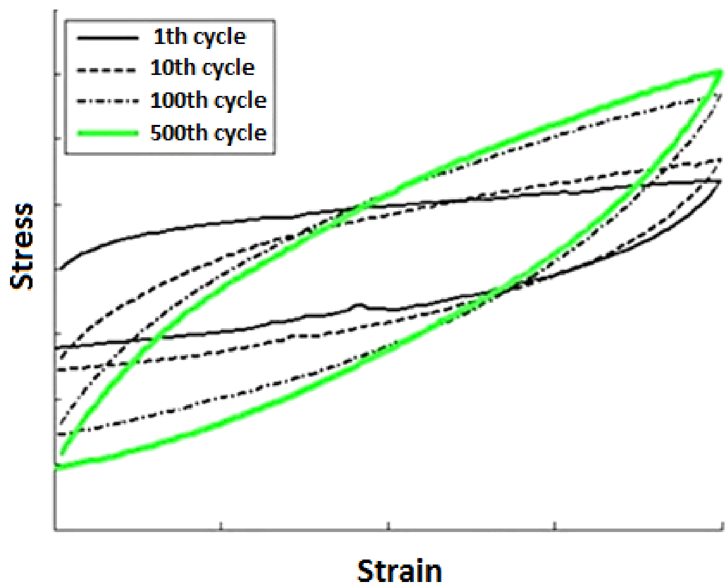

Fig. 2. Stress and strain changes in each loading cycle.

4. Results and discussions

As mentioned before, this research studies the fatigue behavior of asphalt mixtures with four-point bending beam test. Among 8 samples, two samples contained silica as the witness filler, and the other 6 contained CWA, cement and lime, as modifying fillers. The tests were performed at constant strain condition at 400 and 600 µs as the strain level. Temperature and cyclic loading frequency were chosen according to AASHTO T321, equal to 20°C and 10 Hz, respectively. In this research, the fatigue behavior is analyzed using four different approaches: classical, flexural stiffness and summation of dissipated energy.

4.1. Analyzing the fatigue behavior using classical approach

Classical approach, based on the number of loading cycles, is one the most reliable approaches to analyze the fatigue behavior. According to this approach as shown in figures 3 and 4, the longest fatigue life belongs to the cement samples. Samples containing cement and CWA have longer fatigue lives than lime and silica due to their pozzolan properties. Samples containing lime fillers showed a longer fatigue life than silica, but a shorter one than CWA and cement. Quantitively speaking, 3 fillers of cement, CWA and lime improved the fatigue life of the mixture by 75% , 55% and 8.2% at strain level of 400µs by 107% ,72% and 7.1% at strain level of 600 µs respectively.

4.2. Analyzing the fatigue behavior using flexural stiffness trend

According to previous researches, after cyclic loading, asphalt flexural stiffness has a descending trend. Generally, a material with a homogenous texture has a higher flexural stiffness, therefore, the specimen has a better response to cyclic loading and fatigue cracks. Illustrated in figures 5 and 6, samples have a higher flexural stiffness at 400µs for strain level in comparison with 600µs, regardless of filler type. This trend confirms the predicted results of constant strain tests. In other words, at 600µs, samples are subjected to higher stresses, which results in more degradation in stiffness. In average, samples with CWA fillers have the greatest stiffness than others, regardless of strain level, which is assumed to be a result of internal friction and self-healing behavior of these samples. At both strain levels, samples containing lime filler, responded in decreasing stiffness, in comparison with witness samples, which can be assumed to be a result of lime's sensitivity to brittleness. The changes in stiffness trend at two strain levels of 400 and 600µs is discussed below:

50% reduction for silica sample at both strain levels.

50% and 65% reduction for lime sample at strain level of 400 and 600 respectively.

50% reduction for CWA samples at both strain levels.

50% reduction for cement samples at both strain levels.

In spite of the same trend for all fillers except lime at strain level of 600, but the two samples containing CWA and cement showed a better stiffness change regarding to their loading cycles.

4.3. Analyzing the fatigue behavior using dissipated energy summation

Figures 7 and 8 represent positive effect of CWA and cement on dissipated energy in comparison with witness samples. Samples containing lime dissipate energy less than the witness samples. The difference can be ignored.

4.4. Environmental effects of CWA

As mentioned above, there is a huge amount of CWA deposited in a mining workshop in northern regions of I.R. Iran. According to rahmanzade et. al [19], CWA has a proportion of Pb and Cr more than the required amounts in standards. Therefore, if this deposited CWA reaches the underground water, it can be dangerous. In this study, using CWA shows improvement in the fatigue behavior of asphalt. Thus, using CWA can improve the fatigue life and prevent possible environmental issues.

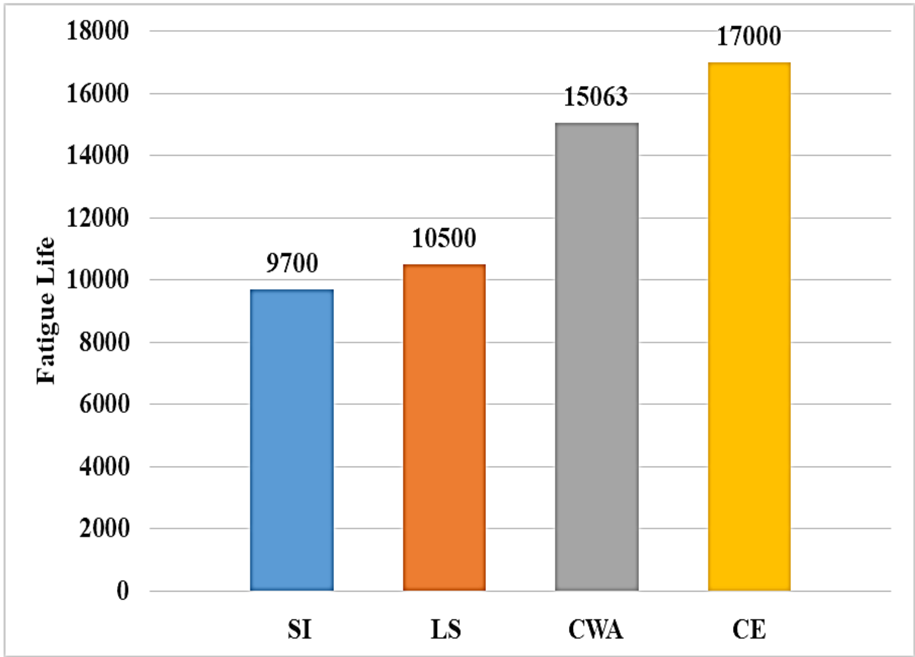

Fig. 3. Fatigue life of asphalt mixtures modified with different fillers in strain level 400 µs.

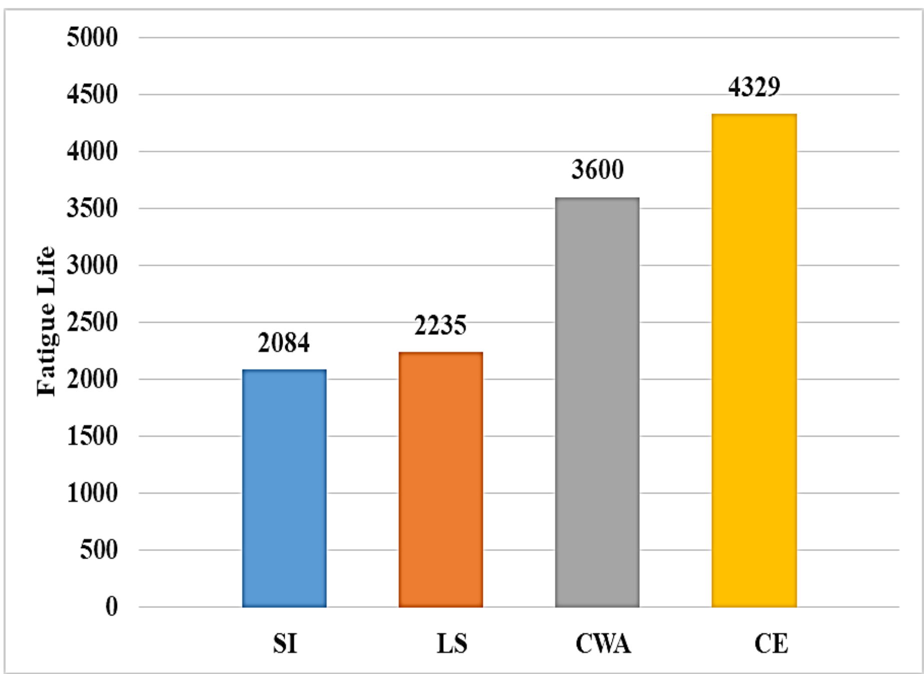

Fig. 4. Fatigue life of asphalt mixtures modified with different fillers in strain level 600 µs.

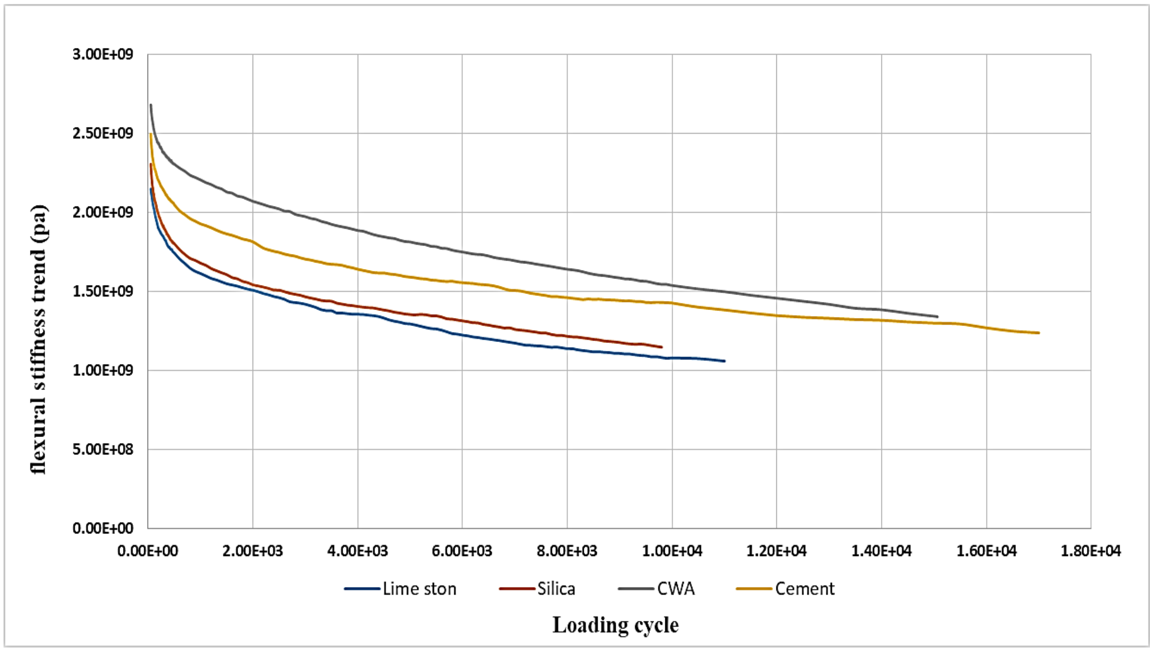

Fig. 5. Flexural stiffness of asphalt mixtures modified with different fillers vs. loading cycle in strain level 400 µs.

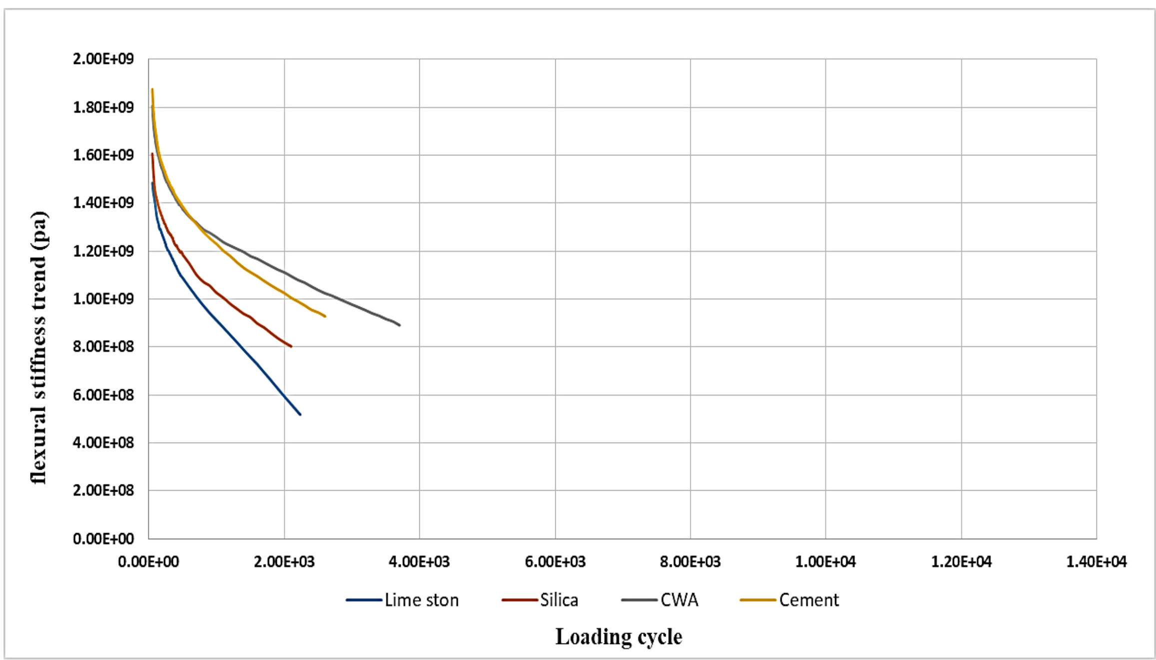

Fig. 6. Flexural stiffness of asphalt mixtures modified with different fillers vs. loading cycle in strain level 600 µs.

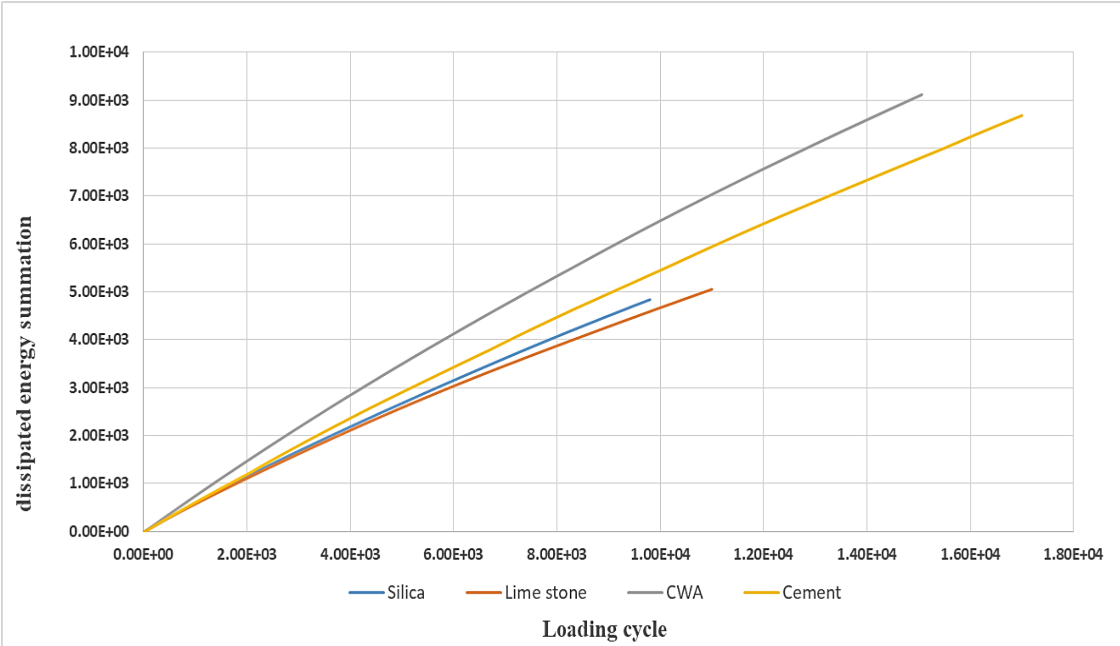

Fig. 7. Dissipated energy of asphalt mixtures modified with different fillers vs. loading cycle in strain level 400 μs.

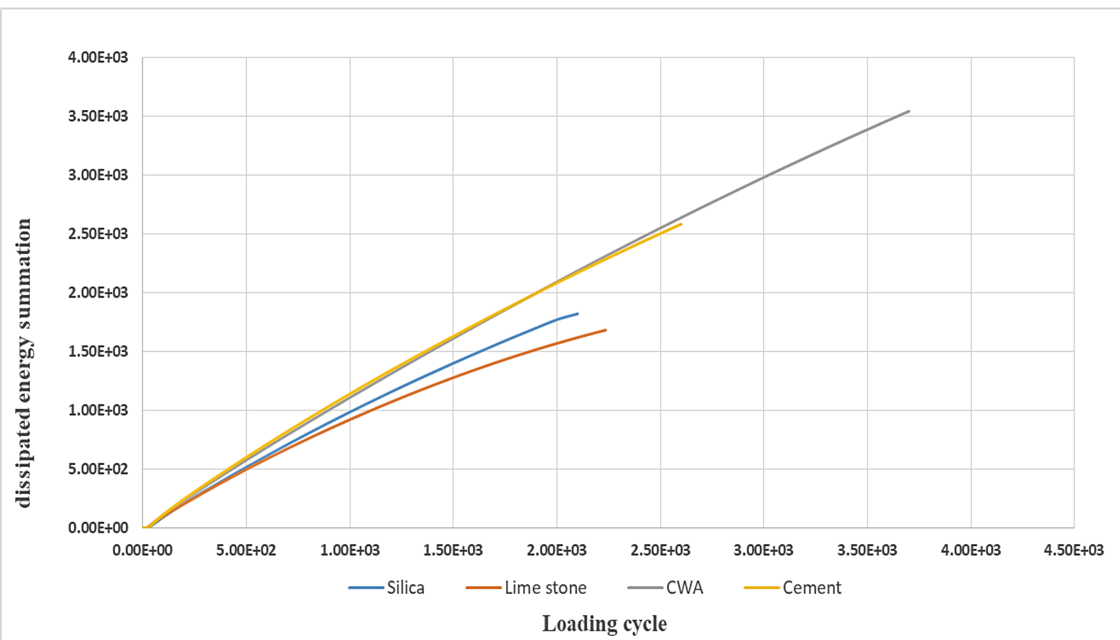

Fig. 8. Dissipated energy of asphalt mixtures modified with different fillers vs. loading cycle in strain level 600 μs.

5. Conclusion

Considering the ascending rate of road transportation and damages due to this load, recognizing and preventing these damages is an essential issue. Fatigue cracks are one the most important and common damages in asphalt. In this study, the fatigue life of asphalt was investigated with CWA, cement and lime as modifying fillers under two strain levels of 400 and 600 μs.

- In experiments conducted by replacing 3 fillers to the asphalt mixture, it was observed that the maximum fatigue life of the modified asphalt mixtures belongs to the cement the next belongs to the CWA, the next to the lime and the least to the silica filler. Quantitively speaking, fillers of cement, CWA and lime stone at strain level of 400 modified the fatigue life of witness sample by 75%, 55% and 8.2%, and at the strain level of 600, by 107%, 72% and 7.1% respectively.
- Using 3 fillers of CWA, cement and lime, resulted in the most cycles of loading for CWA and the least for lime
- In comparison between two strain levels of 400 and 600 µs, the samples had a better fatigue behavior at strain level of 400 µs, which is assumed to be a result of greater stress level.
- CWA and cement had a better fatigue behavior than lime and silica, showing the greater strength of samples containing these two as filler.
- It can be claimed that the greatest flexural stiffness belongs to CWA regardless of strain level.
- Flexural stiffness trend is similar to dissipated energy. In Flexural stiffness trend, increasing number of loading cycles in constant strain condition, results in a descending curve with a particular slope until failure. Important point in using modifying fillers is that these fillers tend to decrease the curve slope which results in a longer fatigue life and less damage.

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