

Economic analysis based on the unit weight of hot mix asphalt**Ali Abdi^a, Mohammad Zarei^{a*}, Mehdi Mehdinazar^a, Farzad Akbarinia^a and Ehsan Nikbakht^b**^aDepartment of civil engineering, Imam Khomeini International University, Iran^bDepartment of civil & Environmental Engineering, Universiti Teknologi PETRONAS, Seri Iskandar, 32610, Malaysia**ARTICLE INFO***Article history:*

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In this paper, economic analysis on the effect of polyester fibers with high strength on the behavior of Hot Mix Asphalt (HMA) is performed. The results indicate that strength is increased by adding fiber to asphalt. Also, unit weight of asphalt mixture was used as a variable parameter in the analyses. The results show that in some certain percentages of fiber, in addition to the enhancement in mechanical properties of HMA mixture the economic benefit value becomes more than the cost and therefore adding polyester fibers with high stability is suggested for the mixture of modified asphalt concrete. Finally, it can be concluded that adding fibers in values of 0.2% to 0.5% has the best result on the asphalt mixture, which because of high resistance and economic aspects makes it more efficient to be used in the highways of warm regions containing traffic.

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1. Introduction

The modification of mechanical properties of asphalt mixture by using additives has been investigated by many researchers (Zarei & Zahedi, 2016; Ameri et al., 2016; Zahedi & Zarei, 2017; Zhao et al., 2014; Zahedi et al., 2017; Mirbaha et al., 2017; Zarei et al., 2019; Aliha, & Ayatollahi, 2008; Aliha, & Saghafi, 2013; Aliha, et al., 2009; Aliha et al. 2016). In order to improve the performance of asphalt mixtures, different additives including natural and synthetic fibers, waste materials, powders and etc. are added to the bitumen and asphalt mixtures (Zahedi et al., 2018; Aliha et al., 2017; Zarei et al., 2019; Barati et al., 2015; Zahedi et al., 2017; Zahedi et al., 2015; Zarei et al., 2015; Barati et al., 2015; Emami et al., 2019). According to the literature review, fibers are the most important additives. For example, the research results of Anurag et al. (2009) indicated that generally adding the polyester fibers corresponds to an increase in the amounts of Marshall Stability, voids in mineral aggregate, asphalt amount and finally unit weight. In another research by Hejazi et al. (2008), the effect of fibers on properties of the asphalt mixture was studied. With regard to polyester fibers, the results indicated that in the fibers ratio of 3%, Marshall Stability with fiber length of 6 mm is higher than the fibers with length of 12 and 30 mm. Also, in length of 12 mm, the Marshall stability of asphalt mixture at the presence of fibers with the amount of 1.5% was more than 3 and 6% fibers. Finally, it was shown that by using lesser amount of fibers and smaller fiber length, better mechanical properties is obtained. In other research by Shukla et al. (2014) a comparative study was done regarding the effect of polyester fibers and glass fiber

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on properties of asphalt mixture. The selected length and the weight percentage of polyester fibers in their research were 8 mm and 0.2% of asphalt weight, respectively. The test results indicated that Marshall Stability increases about 13% and also positive effects of using polyester fibers on indirect tensile strength (ITS), and resilient modulus were observed. In a laboratory work by Guan et al. (2014) several types of fibers for strengthening the asphalt mixture were studied. The length of used fibers was 6 mm and their amount was 0.25% of the asphalt weight. The test results indicated that adding polyester fibers can increase the Marshall stability up to 13%. Zahedi and Zarei (2016) studied the simultaneous effect of black Nano carbon and polyester fiber on the technical properties of asphalt mixture. As a result, it was shown that the stability is increased, special weight is reduced and other Marshall parameters are changed.

In this research, polyester fibers with high strength are added to the asphalt mixture and indirect tensile experiments are carried out on the asphalt mixtures containing superfluous polyester fibers. Furthermore, the economic analysis is performed to evaluate the economic impact of these additives on the asphalt mixture. For this purpose, instead of using constant unit weight, different unit weight obtained from the Marshall test is incorporated.

2. Materials and methods

In this section, the materials investigated with variable parameters such as aggregates, bitumen and polyester fibers with high Denier are explained as follows.

2.1 Bitumen

In order to study the effect of polyester fibers on the behavior of asphalt mixture, the bitumen samples were fabricated according to standard bitumen of 85/100 supplied from Kermanshah refinery (west of Iran) and with the specifications listed in Table 1:

Table 1. Specifications of consumed bitumen in the tests

| Test | Standard | Results | Standard |
|---|----------|---------|----------|
| Special weight (25°C) | T228 | 1.011 | - |
| Penetration Grade in 25°C (100 gram-5 second, in 0.1mm) | T49 | 97 | 85-100 |
| Softening point (loop and ball), in °C | D36 | 48 | 45-52 |

2.2 Aggregates

The curve of granulation and sieve size of the aggregates has been drawn in Fig.1.

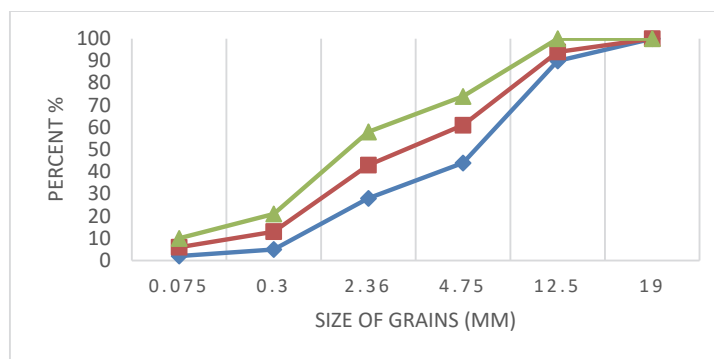


Fig. 1. Granulation of aggregates in asphalt mixture of Topeka layer, 0-19mm

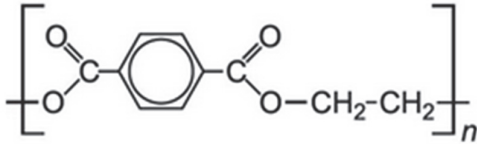
2.3 Consumed fibers

In this study, PET polyester fibers with the strength specification manufactured by tire Cord Company in Kermanshah with high strength (denier) were utilized as additive. Some of the properties of this kind of fibers have been mentioned in Table 2.

Table 2. Properties of polyester fibers used in this project

| Melting point (° C) | Yield strength (MPa) | Ultimate tensile strength (MPa) | Denier (gr) |
|------------------------|-------------------------|------------------------------------|----------------|
| 250-260< | 75 | 154 | 1980 |

Chemical formula of PET polyester fibers is shown in Fig. 2.

**Fig. 2.** Chemical formula of polyester fibers**Fig. 3.** Mixture of the fibers and aggregates prepared using dry method

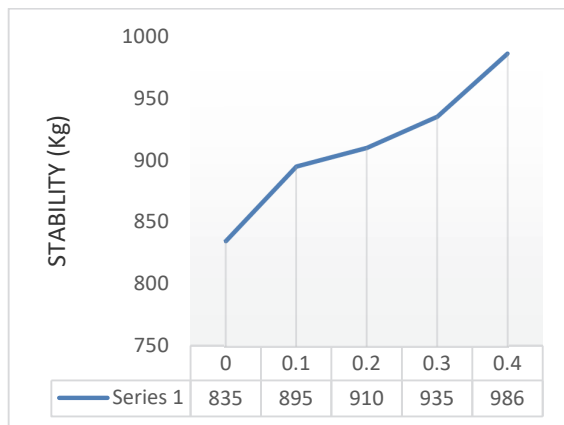
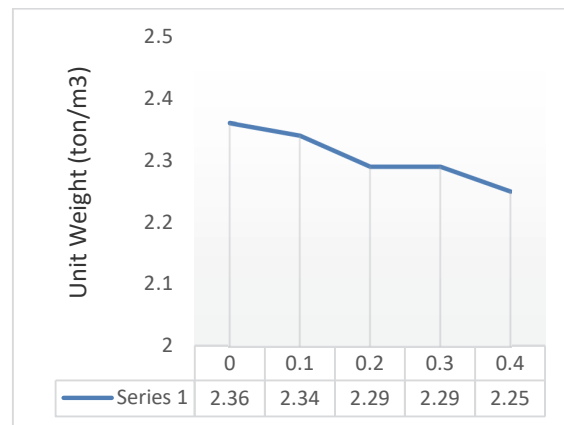
3. Experimental Samples

The asphalt mixtures in this study are prepared and designed according to ASTM-D 1559 (Asphalt Institute, 1984). The optimum bitumen percent was obtained equal to 5% and for the amounts of 0.1, 0.2, 0.3 and 0.4% of high strength polyester fibers, the asphalt samples were made and Marshall Tests were conducted. As displayed in Fig. 3, dry method was used for the preparation of samples.

4. Results and discussion

4.1. Analysis of Marshall Stability Results

As shown in Fig. 4, the results indicates that by adding fiber to mixture, strength or Marshal stability is increased; in a manner that the sample containing 0.4% of polyester fibers has higher strength by 20% compared to the sample without fibers.

**Fig. 4.** Marshall Stability results**Fig. 5.** Unit weight results

4.2. Analysis of the Unit Weight Results

As can be seen from Fig. 5, with increasing the fiber content to the mixture, unit weight is reduced. This result is associated with the low amount of unit weight of polyester fibers. According to Fig. 5, the

unit weight of the sample containing 0.4% fibers is approximately 4.5% less than the sample without fibers. Unlike the previous studies (Mirbaha et al., 2017; Zarei et al., 2019) which a constant unit weight was used, in this research, for economic analysis, the unit weight with specifications displayed in Fig. 5 is used.

4.3. Analysis of Voids in Total Mix (VTM) Results

According to Fig. 6, by increasing the fiber percentage in the mixture, the total void volume of mixture is increased and as a result, it reduces the bleeding which makes it more appropriate for using in tropical regions.

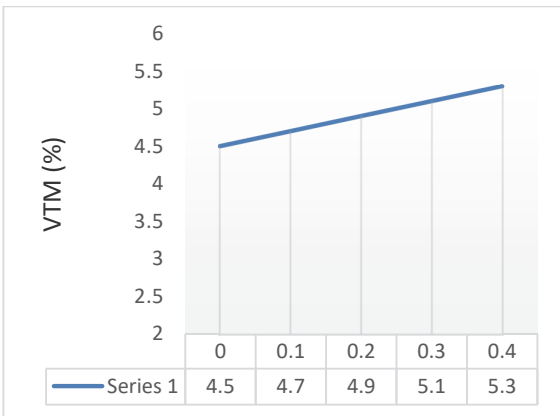


Fig. 6. VTM results

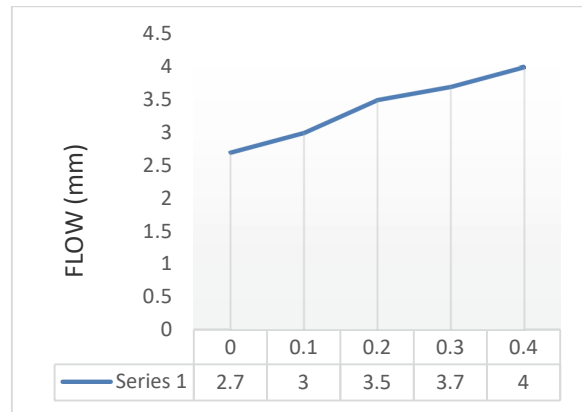


Fig. 7. Marshall Flow results

4.4. The analysis of Marshall Flow results

By adding fibers to the aggregates, Marshall Flow will also be changed. According to Fig. 7, the sample containing 0.4% fiber shows 48% more flow than the base sample.

4.5. The Analysis of Voids in mineral aggregate (VMA) Results

According to Fig. 8, the amount of VMA increased by about 0.5 percent by adding polyester fibers to the asphalt mixture.

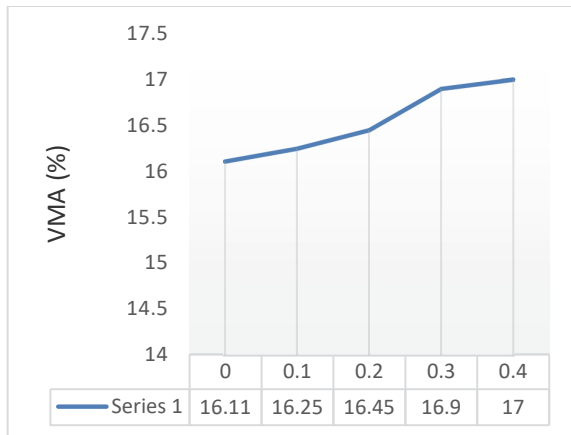


Fig. 8. VMA results

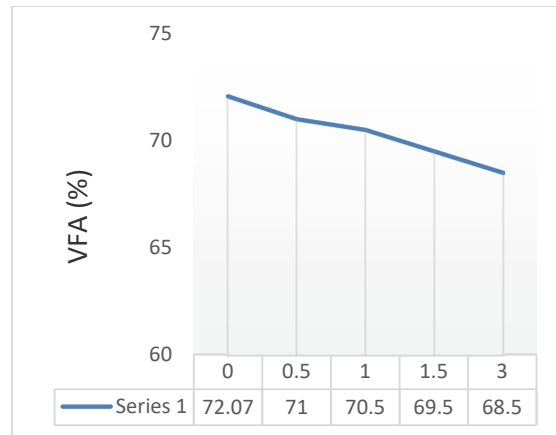


Fig. 9. VFA results

4.6. The Analysis of Voids filled with asphalt (VFA) Results

As can be seen from Fig. 9, by adding polyester fibers, the percentage of the space filled by bitumen is reduced so that in the sample containing 0.4% fiber, a 0.5% reduction in the VFA parameter is seen compared to the neat mixture.

5. Economic Analysis

5.1. Adding Polyester Fiber to Asphalt

Based on Figs. 4 to 9, the addition of polyester fibers improves the technical properties of the asphalt mix. Mirbaha et al. (2017) concluded that using 0.4% polyester fibers and 20% nano-carbon black results in the best strength properties. However, they concluded that using both types of additives would make the design uneconomical. Therefore, the present study was conducted for two purposes. First, the effect of polyester fibers on asphalt mixture and second the economic effect of fiber on an overlay and paving project with a length of 1 km. The results of the Marshall test were converted from kilograms to pounds to be used in subsequent calculations (as shown in Fig. 10).

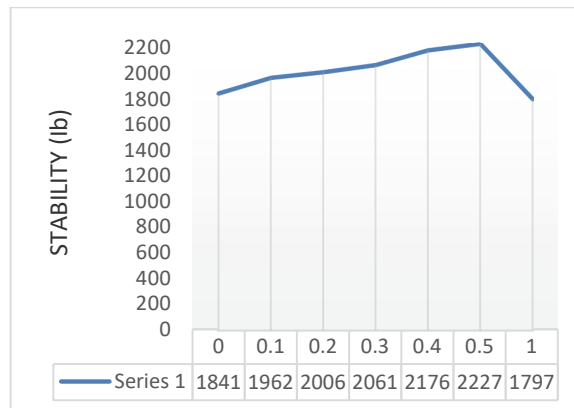


Fig. 10. New samples of Marshall Stability used in the economic analysis

5.2. Asphalt Mixture Design

In order to examine the economic aspect of the use of fibers in asphalt mix, a case study presented in Huang (2004) was used (Huang, 2004). For this purpose, Eq. (1) was used for calculations. The value of SN_0 is obtained equal to 1.97 for asphaltic layer that according to value of SN_0 that depends on underneath layers of asphaltic layer, this parameter is consonant during this research (with different resistance and additive values). Hence, the value of D_1 is obtained from Eq. (1):

$$D_i = \frac{SN_i}{a_1} \quad (1)$$

where, SN_i is structural number (ith layer); a_1 is structural layer coefficient; D_i is ith layer thickness. In order to find the value of a_1 we follow the scales proposed by Huang (2004). It is worth noting that the intended D_1 cannot be reached by using above graph due to resistance increased by fibers. Hence, AASHTO standard limits the coefficient of a_1 to 0.44 to account for this discrepancy. However, Timm and Priest (2006) showed that extrapolation can be used in order to determine the value of a_1 (Timm and Priest, 2006). Table 3 shows the values of these coefficients for different percentages of additives.

Table 3

Design Results

| Additive % | Marshall Stability (Pound) | Resilient coefficient $*(10^5 - psi)$ | γ' | a_1 | D_i |
|------------|----------------------------|---------------------------------------|-----------|-------|-----------|
| 0 | 1841 | 4 | 2.36 | 0.41 | $D_0=4.8$ |
| 0.1 | 1869 | 4.2 | 2.36 | 0.41 | 4.8 |
| 0.2 | 2656 | 4.3 | 2.35 | 0.49 | 4.02 |
| 0.3 | 3146 | 4.4 | 2.33 | 0.53 | 3.71 |
| 0.4 | 3016 | 4.7 | 2.32 | 0.52 | 3.79 |
| 0.5 | 2875 | 4.9 | 2.32 | 0.51 | 3.86 |

5.3. Economic Analysis

In this section, costs and saving (benefits from adding fiber) are calculated. For this purpose, a 6-line way (each direction 3 lines) with the length of 1 km was considered. It should be noted that the unit weight of asphalt was considered in section 4.2. Also, the price of each ton of asphalt and cost of each kilogram of polyester fiber were respectively considered about 1.5\$ and 43\$. Value of benefit and cost from adding this additive is obtained according to Eqs. 2 and 3 (Mirbaha et al., 2017; Zarei et al., 2019; Zarei et al., 2020a, 2020b):

$$\text{Benefit} = 1000 \times 6 \times 3.65 \times \frac{D_i \times 2.54}{100} \times \gamma' \times \text{asphalt price} - 1000 \times 6 \times 3.65 \times \frac{D_0 \times 2.54}{100} \times \gamma' \times \text{asphalt price} \quad (2)$$

$$\text{Cost} = 1000 \times 6 \times 3.65 \times \frac{D_i \times 2.54}{100} \times \gamma' \times 1000 \times \frac{63}{1000} \times \text{additive percent} \times \text{polyester fiber price} \quad (3)$$

γ' = unit weight of asphalt according to section 4.2

5.4. Result of Analysis

Table 4 expresses the results of benefit and cost determined for the influence of adding the fiber in the mixture of asphalt concrete.

Table 4. Results of the economic analysis of the effect polyester fiber to the mix

| Additive % | Benefit (\$) | Cost (\$) | Benefit-Cost (\$) | $\left(\frac{\text{Benefit}}{\text{Cost}}\right)$ (\$) | Results |
|------------|--------------|-----------|-------------------|--|-------------------|
| 0.1 | 7238 | 8571 | -1333 | 0.84 | Uneconomical |
| 0.2 | 21055 | 16286 | +4769 | 1.29 | Economical |
| 0.3 | 27635 | 24000 | +3635 | 1.15 | Economical |
| 0.4 | 34215 | 31143 | +3072 | 1.10 | Economical |
| 0.5 | 40137 | 38286 | +1851 | 1.05 | Economical |

As can be seen from this Table, unlike the previous researches, economic result can be obtained by combining all related factors including the type of additive and unit weight. Zarei et al. (2020a) studied the economic effect of carbon fiber and rubber powder on asphalt mix. The results showed that despite the technical improvement of the asphalt mix, it was not economically justifiable. In addition, Zarei et al. (2020b) evaluated the effect of lignin on asphalt mix. The results showed that the modified mixture was economic for real paving projects. According to Table 4, adding 0.1 percent polyester fibers to the asphalt mix leads to uneconomical design. This is due to the low strength of the mixture and its direct relationship to the coefficients of D_i . However, as the percentage of polyester fibers in the mixture increases to 0.2%, the stability of asphalt mix increases, and this increases the D_i ; hence, the project becomes economical. Comparing the results of this study with the results of research by Mirbaha et al. (2017), it is concluded that the addition of polyester fibers is preferred. Finally, the results of the analysis showed that adding industrial polyester fiber is suggested according to technical and economic discussions. It was resulted that mixture containing 0.2-0.5% polyester fibers can be used in medium temperature regions due to less flow and with high traffic because of high resistance and in limited form for economic issues in projects.

6. Conclusion

In this paper by adding polyester fiber to asphalt mixture, the economic analysis performed. The unit weight of asphalt was used as a variable parameter. The conclusions of this study can be made as the following:

The results show that increase in the percentage of polyester fibers to maximum point of resistance

(means 0.2%) will not be necessarily economical. Specifically, addition of 0.1% of polyester fibers with high resistance to the mixture, is not economical and hence it is not suggested. This indicates that applying appropriate amount of additive material to asphalt is extremely important in order to achieve the economic efficiency. It was shown that this additive leads to improvement of mechanical properties of asphalt mixture. Finally, adding fibers in amounts of 0.2% to 0.5% has the best result on the asphalt mixture, which because of high resistance and economic aspects makes it more efficient to be used in high temperate regions where there are higher flow and traffic.

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