

# Technical-Economic Studies about Polyester Fibers with High Strength on Asphalt Mixtures with Solid Granulation

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**ABSTRACT:** The term of mechanical properties of asphalt mixture by using of proper additives has been searched in recent decade by foreigner engineers. In this article, the technique of using of polyester fibers with high strength in making the asphalt samples and the Marshall test for studying the stability (technical features) of asphalt mixture used and assessed. The results indicate that in the samples in lower percent amounts of fibers, strength is increased while with increasing of the presence percent of fibers in mixture, strength is reduced. Also with increasing of fibers percent, fluidity, total void volume of mixture (VTM), void volume of aggregates (VMA) are increased ascending and on the other hand, special weight and the volume of space filled with bitumen (VFA) of mixture containing fibers with high strength were reduced by increasing of fibers presence. On the other hand, the cost of adding this kind of fibers to the asphalt mixture was estimated 10 percent of asphalt production cost that this amount of cost with regard to the positive effect of additives on asphalt seems proper. By studying and analyzing the diagrams, optimum percent of polyester fibers with high strength in this research was obtained %0.5 which has the best effect on asphalt mixture. By studying the obtained results, it was concluded that asphalt mixture strengthened with polyester fibers with high strength has been more flexible mixture than the base mixture and it can be used in the regions with moderate weather and not so much traffic.

**Keywords:** Polyester Fibers With High Strength, Marshall Stability, Fluidity, VTM, Special Weight

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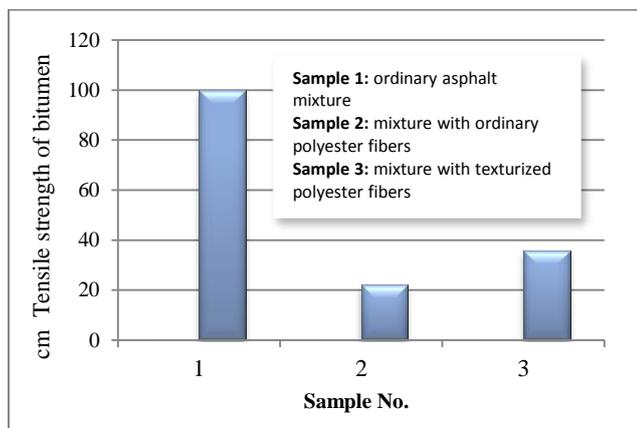
## INTRODUCTION

The term of asphalt mixture properties by using of additives is considered by experts. In order to improve the performance of asphalt mixtures, different additives are added to the bitumen and asphalt mixture that fibers materials can be mentioned as the most important of these materials. In this research, fibers polyester with high strength for arming the asphalt mixture and also asphalt mixture with solid granulation and according to ASTM were used. Also improvement of Marshal test parameters which is one of the main purposes of this research causes the asphalt production with good quality and this issue causes to increase the quality of asphalt mixture. On the other hand, the exerted cost in the research is assessed to calculate the economic effect of these additives on the

mixture. In the following, with reviewing the results of accomplished researches, the issues will be explained. The research results indicated that generally adding the polyester fibers causes to improve the wet tensile strength and the tensile strength ratio (TSR), increasing of the amount of toughness in both dry and wet conditions causes to increase the amounts of void, asphalt amount, unit weight and finally Marshall Stability. Also in this research, it was concluded that fibers with length of 0.635cm (1.4inch) with %0.5 have the most effect on the above results, (Kalia Anurag et al., 2005).

In another research, the effect of different fibers on the tensile property of bitumen was studied. The ordinary and texturized<sup>2</sup> polyester fibers were used in this research. They added the fibers with length of 12mm and the presence of %0.25 to the asphalt mixture in 165°C (Abtahi

Mehdi et al., 2011). The obtained results indicated that adding both kinds of fibers to the bitumen causes to reduce the tensile strength of bitumen compared with ordinary conditions. The research results have been indicated in the Graph 1:



**Graph 1.** The test results of tensile strength

➤ According to the Graph, when polyester fibers become texturized, tensile strength is increased (comparing the sample 2 with 3).

In another research by Hejazi, et al. (2008), the effect of polyester and also tire fibers on the asphalt properties was studied. About polyester fibers, the results indicated that in the fibers ratio of 3%, Marshall stability with length of 6mm were in order more than the fibers with length of 30 and 12mm. Also in the similar length of 12mm, the Marshall stability of mixture at the presence of fibers with the amount of 1.5 percent was in order more than %3 and %6. So the general result indicated that in less percent and length, better result is obtained. In studying the results of tire fibers used in asphalt, in the similar length of 12mm, Marshall Stability of 1.5 percent was in order more than 3% and 6%. In the similar percent of %6, Marshall Stability of 12mm was more than 60mm. So the general result indicates that in less percent and length, the best result is obtained by Abtahi et al. (2011).

Although increasing of Marshall Stability is one of the engineers' purposes for strengthening the asphalt mixture; but reduction of this parameter was seen in the results of some researches. The research results of the wasting polyester fibers effect on the asphalt mixture indicated that Marshall Stability is reduced. About fluidity, in the percent of 0.2, 0.4 and 0.6, increase was observed. Mirzaei et al. (2009) stated that the void percent of asphalt concrete and also the percent of aggregates void were also increased.

In a research done by Serfas et al. (1996), the comparative study was done about the effect of polyester fibers and glass fiber for strengthening the asphalt mixture. The selected length of polyester fibers for using in the project was 8mm. The weight percent used in the project was %0.20 of asphalt. The tests results indicated

that Marshall Stability causes about %13 increase for polyester fibers. The positive effects of using of polyester fibers on ITS, tensile strength, resilient modulus, were obtained.

Guan et al. (2014) in a laboratory work were studied several kinds of fibers for strengthening the asphalt mixture. The length of used fibers was 6mm and the weight percent was %0.25 of asphalt weight. The tests results indicated that adding polyester fibers with high conditions, increases the Marshall stability about %13.

Serfas et al. (1996) reported that from the researches results of domestic and foreigner researchers, it is concluded that the fibers which used in the past works were polyester fibers with low denier (weight of 9000 m of fibers in gram). While in this project, polyester fibers with high stability in filamentous form which are used as tire yarn, were utilized. The effect of polyester fibers with high strength in asphalt and in filamentous form hasn't been still used.

## MATERIAL AND METHODS

### Materials

The needed materials in this research were in order bitumen, aggregates and polyester fibers with high strength that will be explained in the following:

### Bitumen

In order to study the effect of industrial polyester fibers on the mechanical properties of asphalt mixture, asphalt samples were made from standard bitumen of 85-100 refiners in Kermanshah and with the specifications of table 1.

**Table 1.** The specifications of consumed bitumen in the tests

Test kind	Standard No.	Results	Standard amount
Special weight in 25°C	T228	1.012	--
Influence degree in 25°C (100 gram-5 second, in 0.1mm)	T49	98	85-100
Softness point (loop and ball), in centigrade	D36	45	45-52

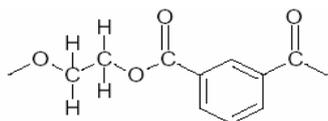
### Consumed fibers

In this project, polyester fibers with high strength which were provided from tire Cord Company in Kermanshah and are applied for strengthening the vehicles rubber, were used. In Iran, this kind of fibers in filamentous form for strengthening the asphalt mixture hasn't been still used. The polyester fibers used in this project were from fibers with scores of 2200 and 1440 which were used in combinative form. Denier amounts of them are in order 1980 and 1300 gram. Since these fibers have been used in asphalt dispersedly; so tonicity is the determining factor. Some of the properties of this kind of

fibers have been mentioned in Table 2. Chemical formula of Polyethyleneterephthalate (PET) polyester fibers is in the following form (Figure 1):

**Table 2.** The properties of polyester fibers used in this project

Melting point (C°)	Tonicity or the breaking stress (cN/tex)	Tonicity or the breaking stress (gr/denier)	Force in the breaking point b.s	denier (gr)
250-260>	75	7	154	1300,1980



**Figure 1.** Chemical formula of PET polyester fibers

### Making the samples

The method of making and designing the asphalt mixture was done according to the standard method of ASTM-D 1559. With regard to this issue that the materials were related to the mixture design of 2014 of Sanandaj municipality, so the optimum bitumen percent (5%) was available; therefore for the percent amounts of 0.5, 1, 1.5 and 3 percent of polyester fibers with high strength, the asphalt sample in this research was made and Marshall Tests were done on it. There are two main methods about the manner of mixing the fibers with asphalt mixture:

A) **Dry method:** in this method, at first the fibers are mixed completely with the aggregates which have been heated in the oven since before and then bitumen is added to it.

B) **Wet method:** in this method, at first the fibers are mixed with bitumen and then aggregates will be added to it. It is necessary to be said that in this research for prevention from necking phenomenon (sticking the fibers to each other), dry method was used.

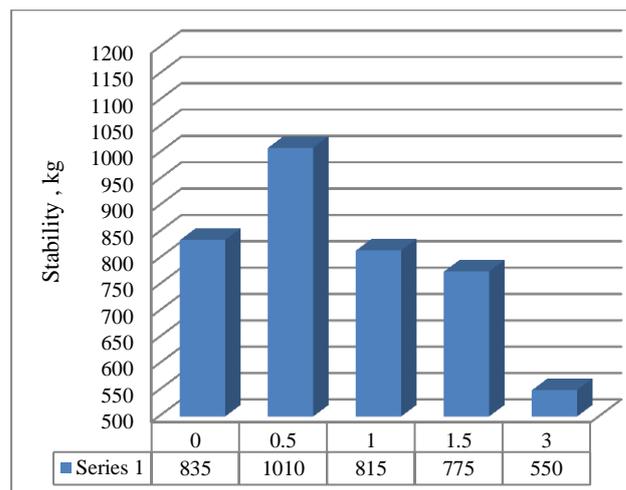
## RESULTS AND DISCUSSION

### Analysis of Marshall Stability results

With regard to arm the asphalt mixture with fibers and also using of it in materials that cause its homogenous absorption in the mixture; polyester fibers have caused to increase the strength of mixture. According to the Graph 2, the test results indicated that in the low percent of fibers, strength is increased; in a manner that the sample containing %0.5 of polyester fibers has more strength than the sample without fibers about 21%. The cause of this result can be this issue that in less percent, the fibers have the arming role and they increase the lock and fastening of aggregates and strength is increased; while in higher percent amounts, increasing of the fibers amount causes to place the fibers between the granulations and reduces the friction between the materials and leads to reduce the strength. Increasing of strength in low percent amounts has been seen in the Shaklav and Guan results. This

amount of increase in strength in comparison with the past researches results can be related to the extra high strength of fibers.

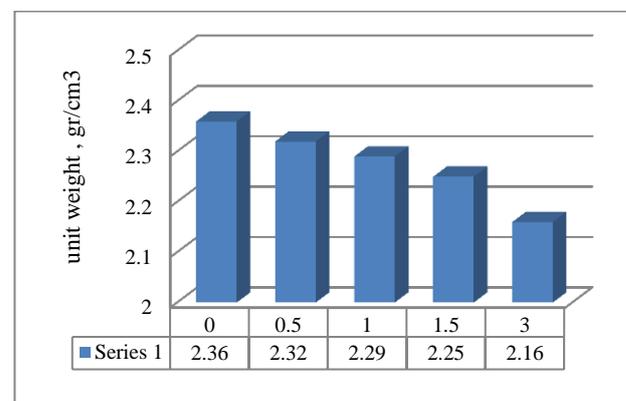
Also the tests were done in a manner that with increasing of the fibers percent, at first increasing of strength and then reduction of strength are seen which indicate the best mixture and the maximum Marshall stability is seen in the parabola head. But what is indisputable is this issue that this kind of fibers already has the highest effect on the Marshall stability that this result will be related to very high strength of these fibers.



**Graph 2.** The effect of different percent amounts of polyester fibers on Marshall stability

### Analysis of the special weight results

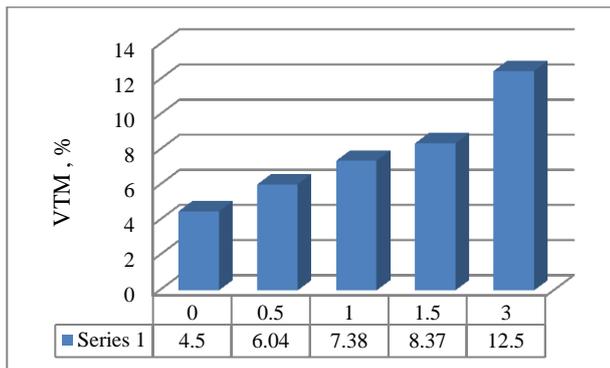
With increasing of the fibers percent in the mixture, special weight is reduced that this result can be related to the low amount of special weight of polyester fibers and replacement of it with materials. According to the Graph 3 and with regard to the diagram, the special weight of sample containing 3% fibers is about 8.5% less than the sample without fibers. On the other hand, reduction of the special weight cannot be desirable, due to it, using of low percent is recommended for less drop of special weight that in these conditions, maximum strength is also confirmed.



**Graph 3.** The effect of different percent amounts of polyester fibers on special weight

### Analysis of VTM results

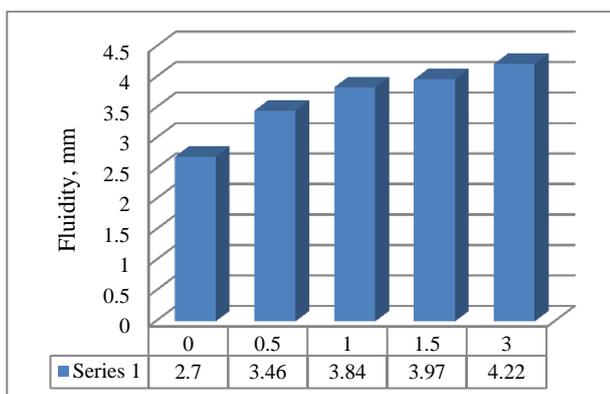
According to the Graph 4, with increasing of the fibers percent in the mixture, the total void volume of mixture is increased that this increase in 3% of fibers is the highest amount; so that in this ratio (namely 3%), 17.8% of total void volume of mixture is increased. It seems the cause of this issue is the absorption of bitumen to the added polyester fibers (which has high level) and reduction of bitumen influence inside the aggregates. This result can cause to reduce the bitumini-zation especially in tropical regions. This increase was also observed in the results of Mirzaei et al. (2009).



**Graph 4.** The effect of different percent amounts of polyester fibers on VTM

### The analysis of Marshall Fluidity results

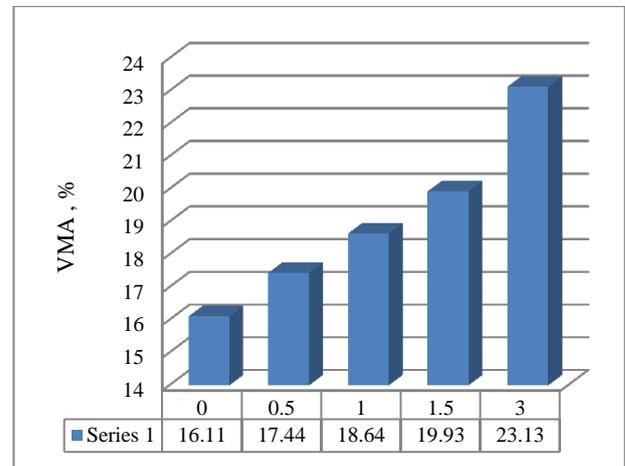
With change of the fibers percent added to the aggregates, fluidity will be also changed. According to the Graph 5 and as it was expected, Marshall test results indicate that with increasing of fibers percent, fluidity is increased so that sample containing 3% of fibers has about 56% more fluidity than base sample. The cause of this increase can refer to the high tensile strength of fibers. Increasing of the fluidity amount was confirmed by comparing the results of this research with the researches results of Mirzaei et al. (2009) and Hejazi et al. (2008). This point must be considered that increasing of fibers percent, reduces Marshall stability and this issue is not desirable; but with regard to the other results, adding fibers in less percent amounts causes to create better results.



**Graph 5.** The effect of different percent amounts of polyester fibers on fluidity

### The analysis of VMA results

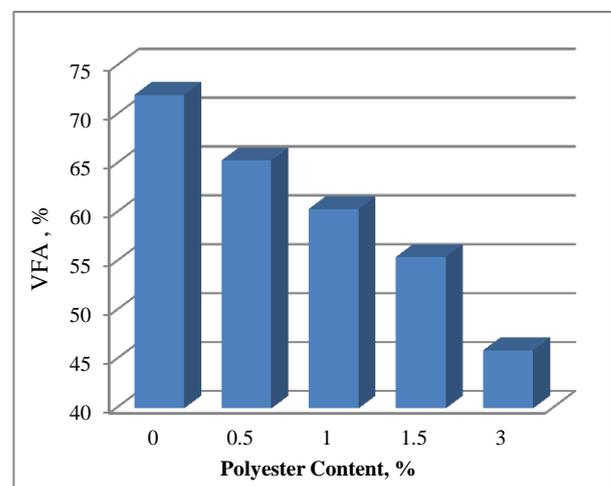
According to the obtained results and with regard to the Graph 6, the void volume of aggregates with existence of fibers is increased, in a manner that in 3% of fibers, about 44% of aggregates void is increased. The cause of this issue can be related to the absorption of bitumen to the fibers existing in the mixture.



**Graph 6.** The effect of different percent amounts of polyester fibers on VMA strength

### The analysis of VFA results

With regard to the results and Graph 8, with adding polyester fibers, the percent of the space filled with bitumen is reduced that in 3% of fibers, it will have a reduction equal to 36% in comparison with base sample.



**Graph 7.** The effect of different percent amounts of polyester fibers on VFA

### Cost

In this research, the economic effect of adding fibers to the asphalt mixture was also studied. As it was mentioned in the previous parts, polyester fibers with high strength were provided and used from tire Cord Company in Kermanshah which is the only producer of this kind of fibers in Middle East. It is necessary to be said that in

order to increase the economic efficiency, the wasting fibers of factory were used.

### **The fibers cost in the mixture**

According to the results of part 4, among the percent amounts of fibers added to the mixture, adding 0.5% fibers to the mixture gives the best result. With regard to this issue that the samples mass in the laboratory was 1.2 Kg, the fibers amount in this research is 6 gram that for each ton asphalt, the obtained amount is 5 Kg. On the other hand, the cost of each kilogram polyester fibers with high strength (wasting) is Limited 1\$ that for 5 kilogram, this amount is 5 USD.

If the cost of producing each ton asphalt is considered about 60 USD; about 8% will be added to the cost of asphalt production that with regard to the positive effect of polyester fibers on mixture, this amount of increase is acceptable.

### **CONCLUSIONS**

In this research for the first time, polyester fibers with high stability and in filamentous form were used. This kind of fibers with regard to high strength and also arming property causes to change on Marshall Results. In the following, the results have been mentioned separately.

-For mixing, dry method was used namely at first aggregates were heated and the fibers were mixed with high accuracy and then the heated bitumen was added to it.

-Polyester fibers with regard to the arming property cause to increase the strength. According to the results, the sample containing %0.5 polyester fibers have about 21% more strength than the base sample that this increase in comparison with the previous researches results is related to the high strength of consumed fibers.

-Existence of fibers in the mixture reduces the special weight so that this reduction was observed as much as 8.5%.

-Increasing of fibers percent in the mixture has direct ratio with the total void volume and in 3% of fibers, 178% of total void volume of mixture is increased.

-The results of Marshall Test indicated that increasing of fibers percent has direct ratio with fluidity; so that adding the sample containing the highest percent of fibers (3%) has about 56% more fluidity than the base sample.

-With increasing of fibers percent in asphalt mixture, the void volume of aggregates was increased, in a manner that in 3% of fibers, 44% of the void volume was increased.

-With adding polyester fibers, the percent of space filled with bitumen is reduced that in 3% of fibers, it will have a reduction equal to 36% in comparison with the base sample.

-With comparing the results of this research with past researches, polyester fibers with high stability have had more effect on Marshall Stability and also other Marshall parameters in comparison with ordinary and even texturized polyester fibers.

This additive caused to improve the mechanical and physical properties of asphalt mixture with solid granulation and with regard to the considerable effects in Marshall Results, using of it in increasing the load-carrying of asphalt is recommended. On the other hand, with regard to this issue that Iran is one of the producers of this product, economically using of these fibers in the asphalt mixture is recommended. With regard to the results, adding fibers as much as 0.5% has the best result on mixture so that the obtained mixture can be used in moderate regions due to more fluidity and it can be used in the region with much traffic due to higher strength. What is indisputable, for obtaining the best results, doing different researches and tests is recommended as follows:

--Using of combination of other fibers in asphalt mixture

--Studying the effects of industrial polyester fibers on tests like resilient modulus, indirect tension, etc.

--Using of different percent amounts of fibers for combination of this additive in asphalt mix.

--Using of fibers with different lengths in asphalt mixture.

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### **Competing interests**

The authors declare that they have no competing interests.

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