500-037 THE USE OF DIATOMITE IN THE STONE MASTIC ASPHALT MIXTURE

M. ATASARAL[1], A.G. GÜNGÖR[1], F. ORHAN[1], S. KAŞAK[1], M.K. ÇUBUK[2]
[1]General Directorate of Turkish Highways, 06100 Ankara, TURKEY
[2] Department of Civil Engineering, Gazi University, 06570 Ankara, TURKEY

ABSTRACT

In our country 95 percent of the passenger transportation and approximately 90 percent goods transportation are provided by using the highway transportation system. However on the our highways, increasing high volume of annual average daily traffic (AADT) and over loading and addition of negative effects of climate and construction conditions cause the permanent deformations like that fatigue cracking, rutting and shoving. The most common deterioration type is the rutting due to the heavy vehicles and their overloading.

It can be say that permanent deformation behaviors of SMA (Stone Mastic Asphalt) mixtures are better than the other hot mix types in the all climate conditions and under the heavy traffic loads. In this aspect, the use of SMA mixtures provides significant advantages in improving the performance of pavements. Improving the advanced type of the SMA mixtures and increasing application of SMA mixtures are very important to prolong the pavement life. For this purpose, 3 percent diatomite was used as filler aggregate in the SMA mixtures without adding any fiber.

In this study, it was investigated that the effect of the Diatomite material on the performance of the SMA mixtures. The performance comparison was made between diatomite added and conventional SMA mixtures.

For that purpose, Marshall Designs were prepared for diatomite added and conventional SMA mixtures. For these two types of SMA mixtures; the rutting tests were performed to find out plastic deformation behaviors and the fatigue lifes were determined using four point bending beam fatigue test. And also indirect tensile tests were carried out on the SMA mixtures.

Therefore, the effects of the diatomite on the performance of SMA mixtures were researched, by analysis these tests results. The results indicated that, diatomite addition, increased stiffness and similar test results were found for other properties, only fatigue life of diatomite added SMA little lower than conventional SMA Mixture also, cost analysis were done for two mixtures.

Keywords: Stone Mastic Asphalt, Rutting, Diatomite, Fatigue

1. INTRODUCTION

In Turkey, SMA mixtures have been used since 1998. Generally, high traffic volume roads have been constructed using SMA mixtures as a wearing course.
As it is known, SMA mixtures have a binder rich mastic mortar. An efficient stabilization of the mastic is necessary in order to prevent its segregation from the coarse particles. A small amount of cellulose fiber is generally added to the mixture in order to enable the mix to hold high bitumen content and at the same time, stabilize high bitumen content, creating the mastic.
In this study, diatomite material is added as filler aggregate to stabilize the mastic mortar and to find out the diatomite effect in the SMA mixtures. Also, for comparison the properties of SMA mixtures with fiber have been investigated.

2. MATERIALS AND EXPERIMENTAL WORK

2.1. Properties of Diatomite

Diatomite is an agglomerative rock formed with accumulation of diatoms, a member algae family, exhibiting fossil characteristics. Natural diatomite has very high water absorption ranging from 10-60 %. Its dry unit weight are between 0, 34 – 0, 67 g/cm^3. Table-1 features some important chemical properties of diatomite which was used in this study. Micro-structure of Ankara Diatomite is given in Figure-1

2.2. Properties of Bitumen and Aggregate

The bitumen binder selected for the tests was 50/70 penetration grade bitumen from Kırıkkale refinery. Bitumen tests are performed according to both TS 1081 EN 12591 and superpave performance grade standards. Properties of bitumen are presented in Table-2 and Table-3.

Contents %	Ankara Diatomite
SiO_2	88,32
Al_2O_3	3,47
Fe_2O_3	0,48
CaO	0,42
MgO	0,26
Na_2O	0,17
K_2O	0,28
TiO_2	0,18
P_2O_5	0,10

Table 1: Chemical properties of processed Ankara Diatomite

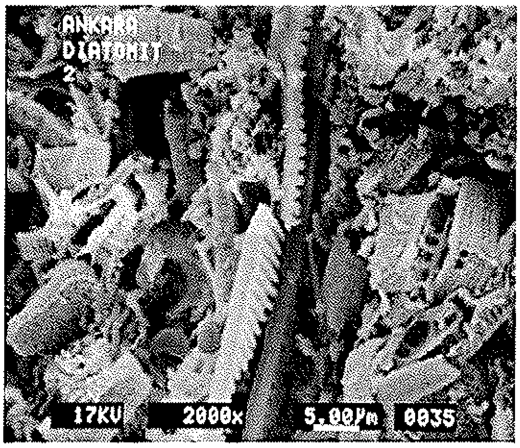

Figure 1: Micro structure of Ankara Diatomite

Test Name	Standard	Test Result
Penetration (25°C)0,1mm	EN 1426	68
Softening Point, (R/B)°C	EN 1427	49
Flash Point , °C	EN 22592	260+
Solubility	EN 12592	99,4
Density	ASTM D70	1,025
Resistance to Hardening	EN 12607-2	
-Mass Loss, %		0,1
-Increase Softening Point, °C -Drop In Softening Point °C	EN 1427	4
-Drop In Penetration, % -Increase Penetration %	EN 1426	16

Table 2: Physical properties of the bitumen

	Properties		Results	
Original Bitumen	Penetration (25°C)0,1mm		68	
	Softening Point, (R/B)°C		49	
	Brookfield Viscosity 135°C,20rpm	Pa.s	0,373	
	DSR (G*/sinδ>1kPa)	Fail Temp.	66,8	
		Grade	64	
RTFOT	Mass Loss	%	0,1	
	DSR (G*/sinδ >2,2 kPa)	Fail Temp.	67,6	
		Grade	64	
PAV	DSR (G*sinδ <5000 kPa)	Fail Temp.	20,3	
		Grade	22	
	BBR		S (MPa)	m-value
	temperature	-12 °C	179	0,302
			136	0,338
	(S≤300MPa m≥0,300)	-18 °C	287	0,278
			272	0,274
PG			64-22	

Table 3: PG (Performance Grade) of the bitumen

In this study, aggregates produced from basalt quarry have been used for design and tests. The properties of aggregates and design gradation are given Table-4 and Table-5. Also, as filler aggregate 5 percent limestone filler is added in the SMA mixtures with fiber and 2 percent limestone filler and 3 percent diatomite filler are added in the SMA mixtures with diatomite.

Test Name	Standard	Test Result
Los Angeles abrasion test, (%)	ASTM C 131	11,7
Soundness test, (%)	AASHTO T 104	2,0
Polished Stone Value (PSV)	EN 1097-8	53
Water absorption, (%)	AASHTO T 85	1,2
Flakiness index, (%)	BS 812	24,5

Table 4: Physical properties of the aggregate

Sieve size		%, Passing	
inch	mm	Design Gradation of SMA Mixture	SMA Type-1 National Specification Limits
¾	19,1	100	100
½	12,7	95,0	90-100
3/8	9,5	62,0	50-75
No.4	4,75	33,0	25-40
No.10	2,00	23,0	20-30
No.40	0,42	15,0	12-22
No.80	0,177	12,0	9-17
No.200	0,075	9,0	8-14

Table 5: Design gradation of SMA mixture and National specification limits

2.3. Laboratory Tests

Initially, for two types of SMA mixtures, Marshall mixture designs have been prepared. First mix design has been prepared adding 0, 45 percent Viatop 66 fiber and for second mix design 3 percent diatomite has been added as a filler without fiber. Also, 5 and 4 percent diatomite filler addition have been studied but the mixture workability was very difficult and optimum bitumen content found very high. So, 3 percent diatomite content was selected, as a suitable amount. Before addition of diatomite, it is first oven dried, crushed and then sieved thought No.200 sieve. National specifications criteria and two mix design results are given Table-6 and 7.

Properties	National Specification Limits
Blow number	50
Air voids, (%) Air voids on the warm climate areas, (%)	2-4 3-4
Voids in mineral aggregate (VMA), (%) min.,	16
Rut Depth (30 000 cycles, 60°C), (%), max.	6
Fiber Rate, %	0,3 – 1,5
Schellenberger bitumen drain down, (%), max.	0,3

Table 6: SMA Type-1 Design Criteria

	Mixture Types			
Design Values	**Fiber Content % 0,45**	**Diatomite Content % 3**	**Diatomite Content % 4**	**Diatomite Content % 5**
Optimum Bitumen, %	6,55	6,45	7,55	8,20
Practical density, Dp	2,467	2,464	2,433	2,412
Stability, (Kg)	647	620	637	640
Flow value, (mm)	3,20	3,05	3,15	3,10
Theoretical maximum density (Dt),	2,546	2,547	2,508	2,485
Percent voids filled with asphalt (VFA),%	81,2	79,9	83,5	84,7
Air voids (Vh),%	3,11	3,27	3,00	2,95
Voids in mineral aggregate (VMA),%	16,55	16,74	18,1	19,3
Schellenberger bitumen drain down, (%)	0,104	0,279	-	-

Table 7: Results of Marshall Design

In the next step, after the design, performance tests have been performed on the two types of SMA mixture. These tests are given below.

1-Resistance to Compacted Hot Mix Asphalt to Moisture-Induced Damage. (AASHTO T 283)
2-Bituminous mixtures-Test Methods for Hot Mix Asphalt-Part 22: Wheel Tracking. (EN 12697-22)
3-Bituminous mixtures-Test Methods for Hot Mix Asphalt-Part 24: Resistance to Fatigue (EN 12697-24)

Tensile strength tests have been performed using accelerated water conditioning, with a freeze-thaw cycle of compacted SMA mixtures.
The susceptibility of SMA mixtures to deform is assessed by the rut formed by repeated passes of a loaded wheel at 60°C temperature. For rutting test, large-size device (LCPC rut tester) is used and the tests have continued until 50 000 cycles.
To characterize the fatigue of two types SMA mixtures, four-point-bending tests have been performed using prismatic beams. Fatigue tests are undertaken for three strain levels at 20°C temperature.

3. RESULTS AND DISCUSSION

The purpose of our research study are both recognizing the effect of diatomite in SMA mixtures and determining the laboratory performance of diatomite added SMA mixtures. When looking for comparison between the diatomite added and fiber added SMA mixtures, the following evaluations can be done.

-For two types of SMA mixture, optimum bitumen contents and air voids are approximately same (Table-7).

-It was seen that, the diatomite content influenced the optimum bitumen content. If the diatomite contents are high the optimum bitumen contents increase (Figure-2).

-Tensile strength of conditioned and unconditioned samples and Tensile Strength Ratio values have been found similar (Table-8).

-Rutting behaviour of the two SMA mixtures, do not differ from each other. The rut depth for two mixtures after 30 000 cycles are 5, 69 and 5, 55 %, it can be said that these values are acceptable level (Table-9 and Figure-3).

-Fatigue tests have been performed at 200, 300 and 500 x 10^{-6} strain levels, for both SMA mixtures. The fatigue tests results are presented in Table-10. For depending the results of fatigue tests; SMA mixtures with fiber have longer fatigue life, number of cycles, than the mixture with diatomite (Figure-4, 5). As it is known, the fatigue test continues until the calculated stiffness has dropped to half its initial value or until the specimen breaks or until 2 x 10^6 cycles. Diatomite added SMA mixtures tend to have a better resistance to fatigue in terms of number of cycles at failure under all strain levels (Figure-5). It can also be observed that, fiber added SMA dissipates much energy (Figure-8). Diatomite added mixtures have short fatigue life however; their initial stiffnesses are slightly higher (Figure-6, 7).

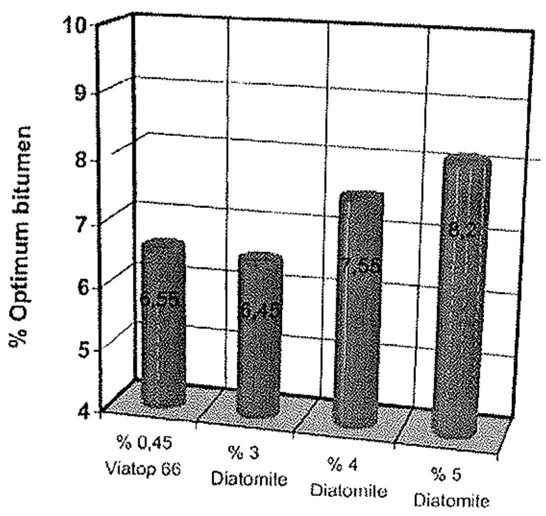

Figure 2: Relationship between mixture types and optimum bitumen content

Mixture Type	Diatomite Content % 3	Fiber Content % 0,45
Average Indirect Tensile Strength of Conditioned Subset, (kg/cm^2)	5,01	5,48
Average Indirect Tensile Strength of Unconditioned Subset, (kg/cm^2)	5,80	6,19
Tensile Strength Ratio (TSR)	0,86	0,89
ITS of conditioned subset with Diatomite / ITS of conditioned subset with Fiber		5,01 / 5,48= 0,91
ITS of unconditioned subset with Diatomite / ITS of unconditioned subset with Fiber		5,80 / 6,19= 0,94

Table 8: Indirect Tensile Strength Test Results

Mixture Type		Diatomite Content % 3	Fiber Content % 0,45
Optimum Bitumen, %		6,45	6,55
Dp design		2,464	2,467
Dp sample		2,400	2,392
%, RUT DEPTH	Number of Cycles	RUTTING	RUTTING
	1 000	1,75	2,08
	3 000	2,63	2,93
	5 000	3,17	3,58
	10 000	4,03	4,29
	30 000	5,55	5,69
	50 000	6,29	6,15

Table 9: Rutting Test Results

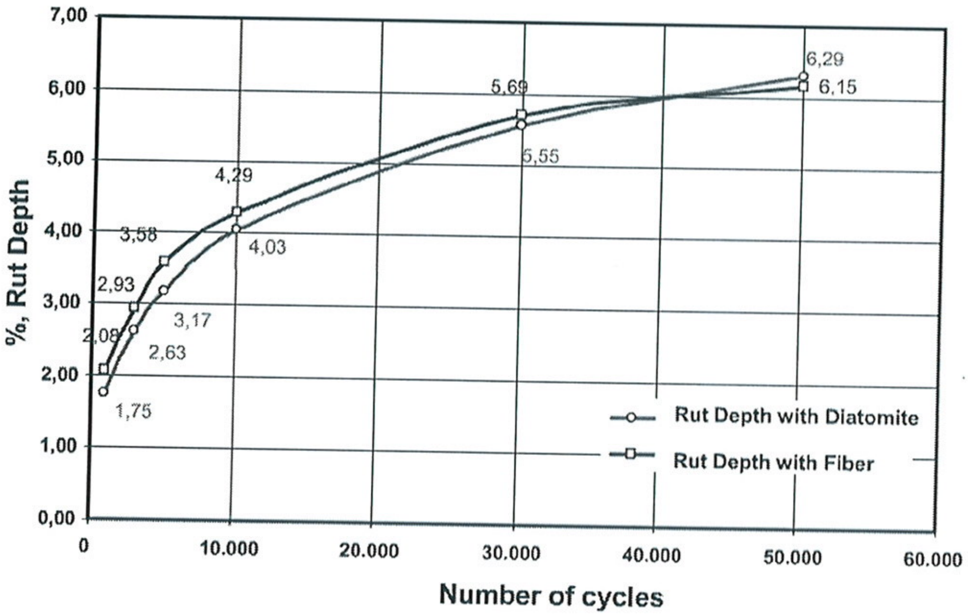

Figure 3: Rutting test results of mixtures with diatomite and fiber

SMA mixture with Diatomite	Strain	Stiffness (Mpa)	Stiffness after the test (Mpa)	% Initial Stiffness	Cumulative Dissipated Energy (MJ/m^3)	Total number of cycles
No:1	500	3103	1547	50	8,74	28 468
No:4	500	2892	1442	50	6,50	24 306
Average	500	2998	1495	50	7,62	26 387
No:2	300	4689	2377	50	48,11	367 040
No:5	300	4110	2030	50	45,04	386 033
Average	300	4400	2204	50	46,58	376 537
No:3	200	3939	1957	50	80,36	1 600 903
No:6	200	4193	1964	50	74,42	1 625 896
Average	200	4066	1961	50	77,39	1 613 400
SMA mixture with Fiber	**Strain**	**Stiffness (Mpa)**	**Stiffness after the test (Mpa)**	**% Initial Stiffness**	**Cumulative Dissipated Energy (MJ/m^3)**	**Total number of cycles**
No:1	500	3521	1763	50	14,36	41 856
No:4	500	3649	1816	50	18,72	54 526
Average	500	3585	1790	50	16,54	48 191
No:2	300	3685	1825	50	65,05	599 533
No:5	300	3754	1850	50	53,02	458 914
Average	300	3720	1838	50	59,04	529 224
No:3	200	3843	2598	**68,0**	110,43	2 000 000
No:6	200	3131	2233	**71,3**	98,65	2 000 000
Average	200	3487	2416	**69,7**	104,54	2 000 000

Table 10: Results of four point bending beam fatigue test

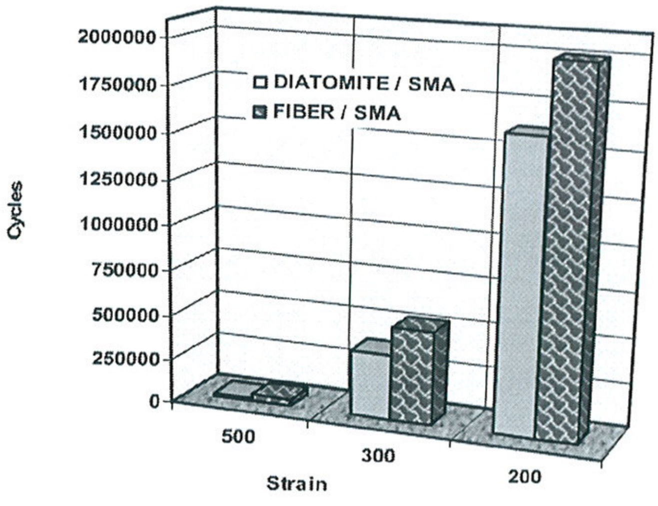

Figure 4: Strain versus number of cycles for SMA mixtures

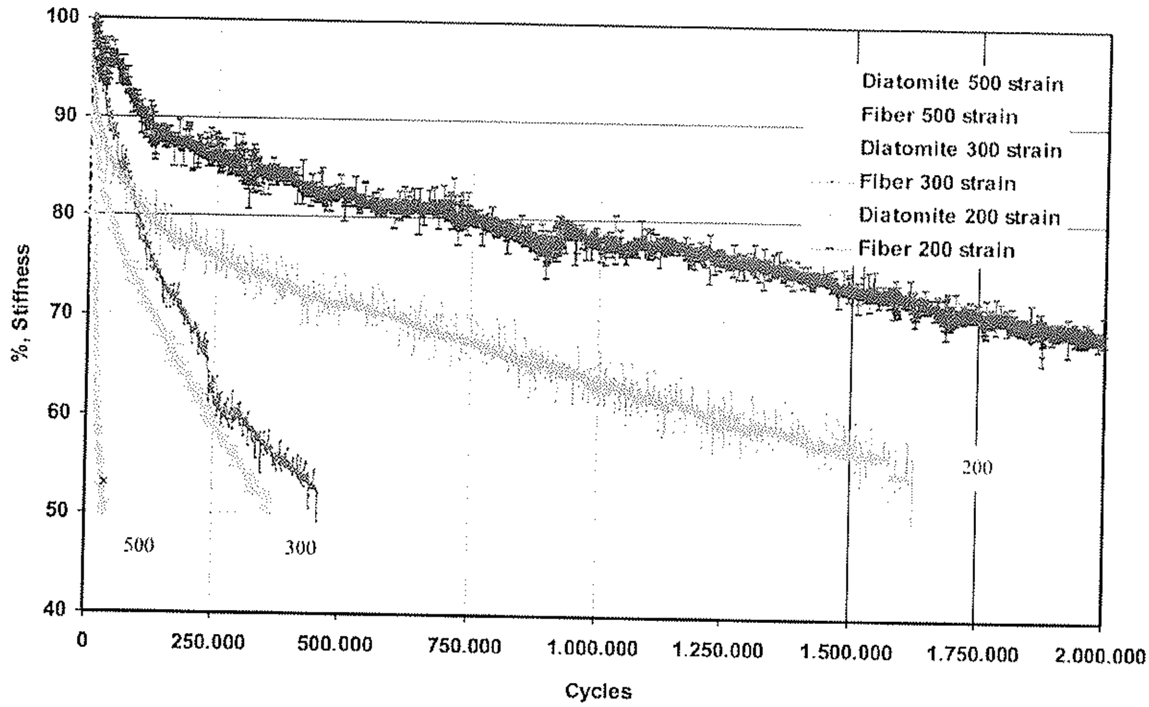

Figure 5: Strain versus number of cycles for all strain levels

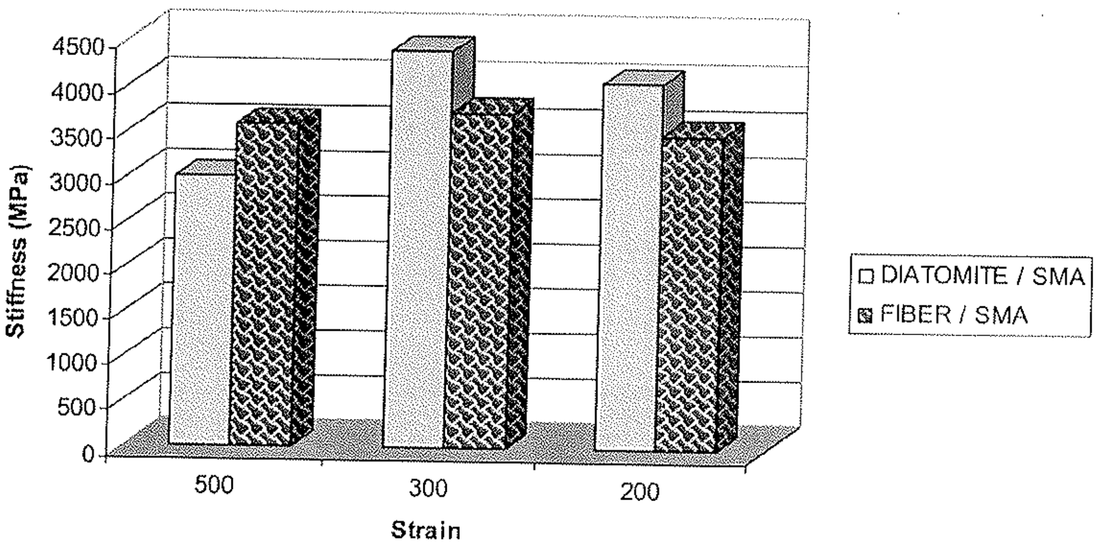

Figure 6: Initial stiffness values of strain levels

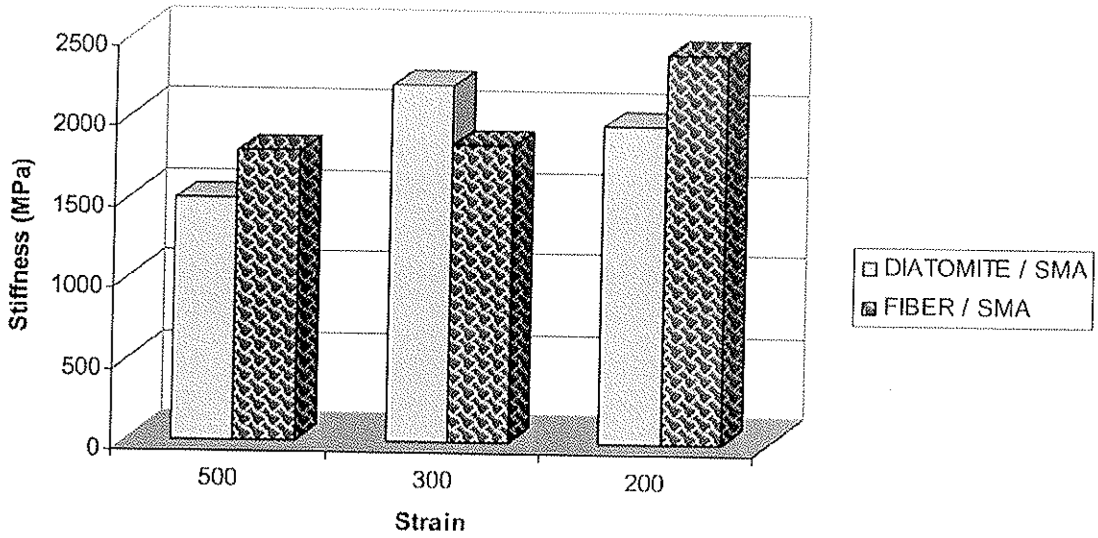

Figure 7: Final stiffness of SMA mixtures

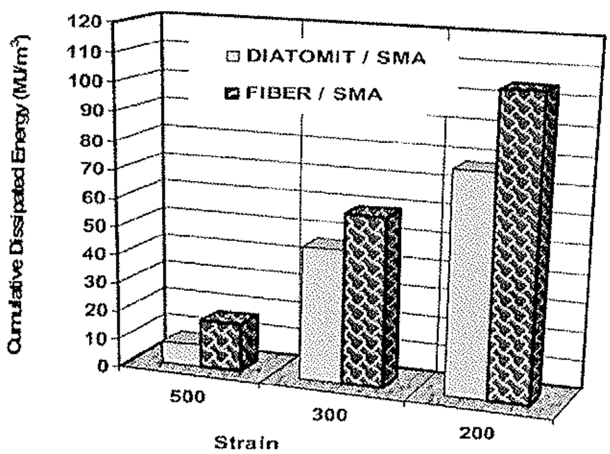

Figure 8: Strain versus number of cumulative dissipated energy

4. CONCLUSIONS

It can be concluded that, the two types of SMA mixtures show approximately similar behaviours to the water damages, in term of tensile strength and to the rutting resistance. The fiber added SMA has best performance under fatigue. Especially, at 200 x 10^{-6} strain level, fiber added SMA mixture kept 70 % of its initial stiffness up to 2 x 10^{6} cycles. To improve the fatigue behaviour of diatomite added SMA, lower content of diatomite should be investigated.

As a conclusions, the use of diatomite as mineral filler in the SMA mixture can be tried to observe the situ performance. The road section should be constructed using this SMA mixture as a wearing course. Diatomite added SMA mixture have lower cost than fiber added SMA for our country, but life cycle cost analysis should be made for future applications.

REFERENCES

[1] Kaşak S. -Experimental Investigations on the Usage of the Diatomite Instead Of Fiber in the Stone Mastic Asphalt Mixture (M.Sc. Thesis), Gazi University Institute Of Science And Technology, Ankara, 2007

[2] Çubuk, K., M., - Effects Of Diatomite On Physical Properties Of Asphalt Cement And Stability And Modulus Of Elasticity Of Hot-Mix Bituminous Laboratory Specimens, 3 rd Euroaphalt&Eurobitume Congress Vienna 2004-Paper 181

[3] Karayolları Teknik Şartnamesi, Bayındırlık ve İskan Bakanlığı, Karayolları Genel Müdürlüğü, Yayın No: 267, Ankara, 2006.

[4] Çubuk, K., M., "Katkı Maddesi Olarak Diatomit'in, Bitümlü Sıcak Karışımların Davranışları Üzerine Etkileri", Ph. D.Thesis, Gazi University Institute Of Science And Technology, Ankara, 1998

[5] "Heavy Duty Surfaces, The Arguments For SMA", EAPA, The Netherlands, 1998

[6] Bates, R. L., "Geology of the Industrial Rocks and Minerals", Dover Publications INC., New York, 1969

[7] Deacon, J.A., "Fatigue of Asphalt Concrete, Graduate Report", the Institute of Transportation and Traffic Engineering, University of California, Berkeley, 1965

[8] Heukelom, W., Klomp, A. J. G., "The Behavior of Asphalt Pavements under Variable Repeated Loads", University of Michigan Ann Arbor, 1967

[9] Aruntaş, Y. H., Albayrak, M., Saka, A. H., Tokyay, M., "Ankara-Kızılcahamam Ve Çankırı-Çerkeş Yöresi Diatomitlerinin Özelliklerinin Araştırılması", Tr.J.of Engineering and Environmental Science 22, Ankara, 1998