THE DETERMINATION OF PERFORMANCE OF WEARING COURSE MIXTURES USING ADVANCED ASPHALT TESTS

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ABSTRACT

The performance of asphalt mixture, which is used as a wearing course, is very important. In Turkey, modified bitumen and aggregates produced from volcanic rock have been used since 1997 in order to increase the service life and ride comfort of the roads. By increasing the durability and skid resistance of wearing courses volcanic aggregate and PMB are used in surface part of the bituminous mixtures pavement, in heavy traffic roads or hot region and the region which have the maximum and minimum temperature differences are really considerable.

The cost of hot mix asphalt is quite high, so the main aim is, to construct roads which have long life, low maintenance-repair cost and high riding quality. For these reasons to select suitable mixture considering climate conditions and traffic density is important for long life pavement. Beside, the study has been focused on determining the type of functional mixture.

In this study, asphalt concrete (AC) and stone mastic asphalt (SMA) mixture design were prepared with basalt aggregate using both Marshall and Gyratory compactor method. For mixture tests, bitumen 50/70(PG 64-22) and polymer modified bitumen PMB 70-16 were used. For these four types of bituminous mixtures; the rutting tests were performed to find out plastic deformation behaviours and the fatigue life were determined using four point bending beam fatigue test and cycling compression test for determining the resistance of bituminous mixtures to permanent deformation was performed. Moreover, indirect tensile tests and elasticity modulus tests were carried out on these mixtures.

As a conclusions depend on the performance tests results the mixture, which have superior performance, have been determined. It can be said that permanent deformation and fatigue behaviours of SMA mixtures with PMB are better than the other hot mix types in 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. On the other hand, depend on the climate, traffic conditions and economy other mixtures can be evaluated.

Keywords: asphalt concrete, stone mastic asphalt, fatigue test, PMB

1.INTRODUCTION

On the first step of this study aggregate design gradation and bituminous mixture types selections were performed. When aggregate type determining for wearing course it is necessary the use of basalt aggregate which is produced from volcanic rock, is used commonly in Turkey. So in this study basalt aggregate was used. To provide aggregate gradation half of the fine fraction limestone aggregates were added. The properties of both of aggregates and asphalt concrete and stone mastic asphalt specification limits are presented in Table-1.

Table-1 The properties of aggregates

Aggregate Type	Yapracık Basalt	Alacaatlı Limestone	National Specification Limit	
Property			**AC**	**SMA**
Los Angeles Abrasion Test, %	11,0	24,0	max.30	max.25
Soundness (Na_2SO_4) Test, %	2,0	2,0	max.10	max.8
Polished Stone Value,(PSV)	53	42	min. 50	
Water Absorption, %	1,2	0,5	max.2,0	

Aggregate mixture gradation for wearing course was determined considering the National Specification limits and gradations which are used commonly in Turkey. Aggregate mixture gradations and the National Specification limits were presented in Table-2 and Graphic-1.

In this study, two types of bitumen binders were used. First one was 50/70 penetration grade bitumen, second one was polymer modified bitumen produced with %4,5 SBS. Properties of bitumen and PG are presented in Table-3.

Table-2 Aggregate mixture gradation

Sieve Size mm	% Passing			
	AC Wearing Course		**SMA**	
	Design	**Specification Limits**	**Design**	**Specification Limits**
19,1	100	100	100	100
12,7	90,0	83-100	95,2	90-100
9,5	80,0	70-90	62,0	50-75
4,75	45,0	40-55	33,0	25-40
2,00	32,0	25-38	23,7	20-30
0,42	15,0	10-20	15,0	12-22
0,177	8,0	6-15	12,0	9-17
0,075	7,0	4-10	9,0	8-14

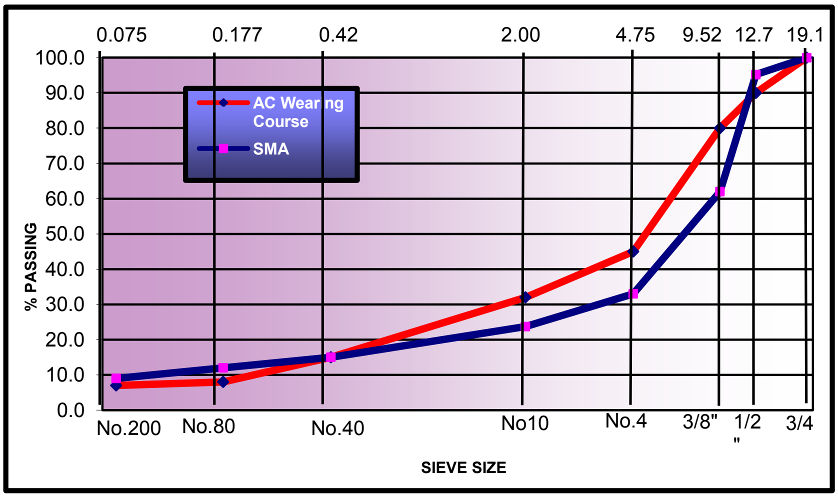

Figure-1 AC wearing course – SMA gradation curves

Table-3 Properties of bitumen 50/70 and polymer modified bitumen

	Bituminous Binders		**B50/70**		**PMB**	
Orijginal Bitumen	Penetration, 0,1mm		63		54	
	Softening Point, °C		48,8		67,0	
	Brookfield Viscosity 135°C,20rpm	cP	373		1255	
	DSR (G*/sinδ>1kPa)	Fail Temp. °C	66,8		71,8	
		Grade	64		70	
RTFOT	Mass Loss	%	0,02		0,2	
	DSR (G*/sinδ >2,2 kPa)	Fail Temp. °C	67,6		74,4	
		Grade	64		70	
PAV	DSR (G*sinδ <5000 kPa)	Fail Temp. °C	20,3		23,9	
		Grade	22		25	
	BBR (Bending Beam Rheometer)		S (MPa)	m-value	S (MPa)	m-value
	Temperature	-6 °C			67,8	0,326
					65,4	0,318
	(S≤300MPa m≥0,300)	-12 °C	179	0,302	223	0,263
			136	0,338	231	0,268
		-18 °C	287	0,278	403	0,213
			272	0,274	405	0,216
PG BITUMEN (AASHTO M320)			**64-22**		**70-16**	

2. MIXTURE DESIGN

Initially, considering selected aggregate gradations bituminous mixture designs were prepared according to Marshall and Superpave Methods. Marshall design was prepared according to Asphalt Institute MS-2 and Superpave mixture design was prepared according to Asphalt Institute SP-2 and AASHTO R35 Superpave Volumetric Design for Hot-Mix Asphalt Standards.

Because of the heavy traffic in Turkey 125 number of gyrations were used as N_{design} and design mixtures were compacted that is essential for ESAL≥30 million. In addition, theoretical maximum density that as N_{max} for 205 numbers of gyrations was controlled that if less than 98 percent.

By the both of two methods, AC wearing course and SMA mixture design were prepared. The properties of these designs were presented in Table-4 and Table-5.

Table- 4 Results of Marshall design

PROPERTIES	AC Wearing Course		SMA	
	Design	Specification Limits	Design	Specification Limits
Opt. Bitumen %	5,25	4-7	6,5	
Bulk Density	2,473		2,458	
Max. Theoretical Density	2,567		2,548	
Air Void, %	3,66	3-5	3,53	2-4
VMA, %	14,6	min.14	16,8	min.16
Percent Voids Filled with Asphalt (VFA), %	75,0	65-75	79,0	
Schellenberger Bitumen Drain Down, %			0,16	max.0,3

Table- 5 Results of Superpave design

PROPERTIES	AC Wearing Course	SMA
Opt.Bitumen %	4,92	6,50
Bulk Density	2,476	2,462
Max. Theoretical Density, (Gmm)	2,579	2,553
Air Void, %	4,0	3,58
VMA, %	14.3	16,6
VFA, %	72,0	78,4
% Gmm @ N_{min}=9	86,8	87,2
% Gmm @ N_{max}=205	97,3	97,5

3. ASPHALT PERFORMANCE TESTS

After the mixture design of AC and SMA, performance tests using two types of bituminous binder (B50/70 and PMB70-16) were performed on the four types of asphalt mixtures. These tests are given below.

1-Resistance to Compacted Hot Mix Asphalt to Moisture-Induced Damage. (AASHTO T 283, EN 12697-12)

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)

4-Bituminous mixtures-Test Methods for Hot Mix Asphalt-Part 25: Cyclic Compression Test (EN 12697-25 method B)

5-Laboratory Determination Of Resilient Modulus For Flexible Pavement Design (NCHRP Project 1-28 A)

3.1 Indirect tensile strength for water sensitivity and resistance to permanent deformation

Tensile strength tests were performed using accelerated water conditioning, with a freeze-thaw cycle of compacted AC and SMA mixtures. Bitumen 50/70 and polymer modified bitumen were used for the design mix. For each one of AC wearing course and SMA mixtures, ten samples total is forty samples were prepared. Indirect tensile strength tests were performed in unconditional and then it was conditioned at -18°C in a fridge. Results of these tests were presented in Figure 2.

The susceptibility of asphalt mixtures to deform is assessed by the rut formed by repeated passes of a loaded wheel at 60^{o}C temperature. The specimens were prepared with bitumen 50/70 and PMB bitumen. For rutting test, large-size device (LCPC rut tester) is used and tests continued until 50000 cycles at 60°C temperature, the tests results are presented in Figure 3.

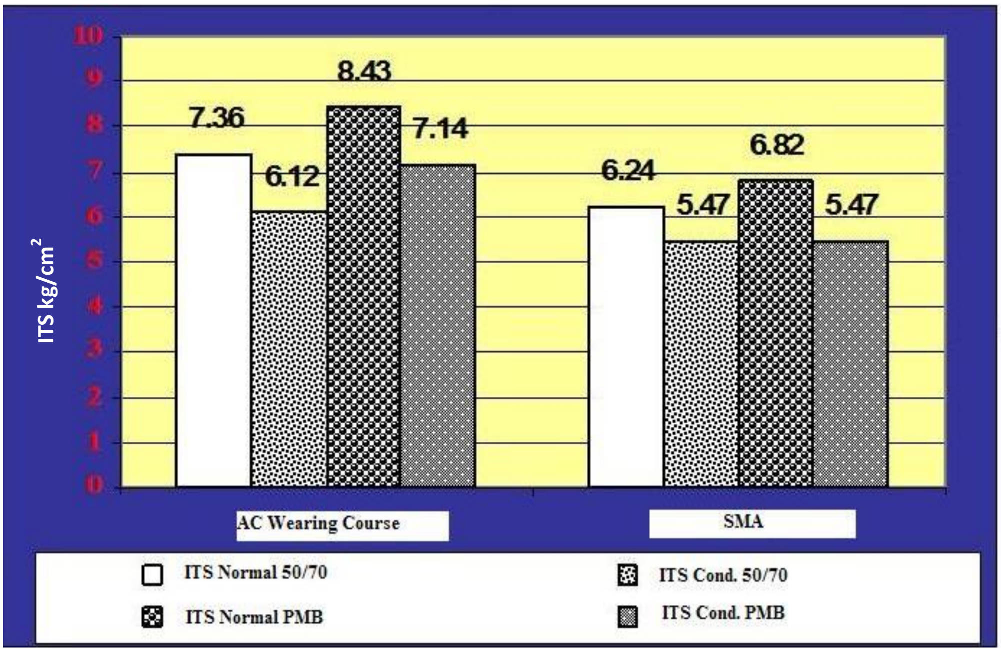

Figure -2 Indirect tensile strength tests results

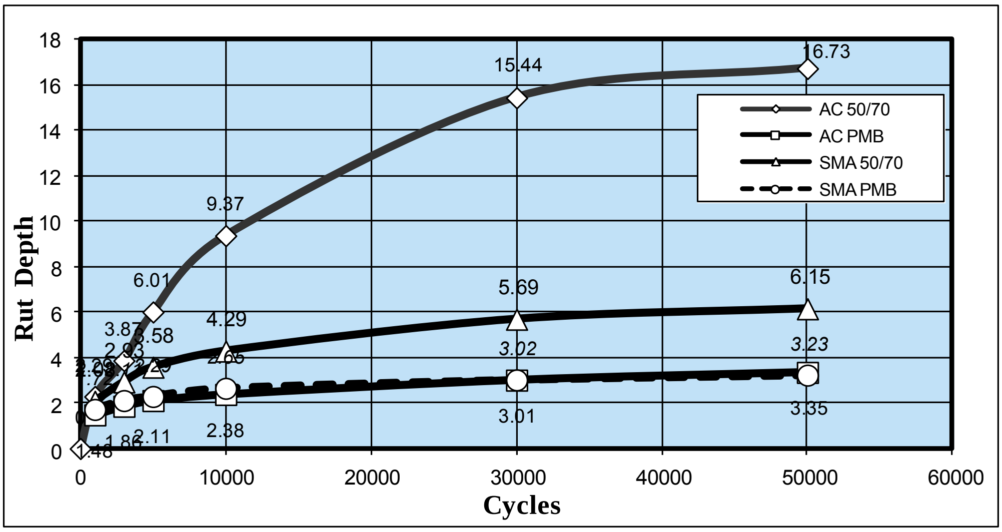

Figure -3 Wheel tracking tests on the four different mixtures

3.2 The fatigue and permanent deformation tests

The fatigue and permanent deformation tests by cyclic pressure method were performed for four type mixtures. In addition resilient modulus of mixtures were determined. According to TS EN 12697-24 fatigue tests were performed for prismatic samples by the four point bending method. Hot mixtures were prepared with desired properties, were compacted by the plate compactor in a mold is 300x400x50mm. After the mixture cooled, specimens were divided to 400x50x50mm beam test sample for the fatigue tests. The tests were performed at the defined conditions in the standard and they were performed in climate chamber at 20°C temperature. Fatigue tests were undertaken three strain levels 200.10^{-6}, 300.10^{-6}, 500.10^{-6} and the levels were selected 10^4- 2.10^6 cycles for fatigue life. 75 tests were conducted and results were evaluated by eliminating some tests.

The results of fatigue tests were presented in Table-6. Fatigue test results of the mix types were presented in Graphic 4, 5, 6.

Table- 6 Four point fatigue tests results

Mix Types	Applied Strain	Initial Stiffness (Mpa)	Final Stiffness (Mpa)	% Initial Stiffness	Dissipated Energy (MJ/m^3)	Cycles
AC 50/70 Bitumen	500	4227	2116	50,0	20,3	**65.174**
	300	4909	2454	50,0	26,6	**265.995**
	200	5258	2989	56,7	78,8	**1.714.456**
AC PMB	500	5373	2689	50,0	23,0	**99.536**
	300	5810	2904	50,0	53,7	**546.374**
	200	6097	4053	68,0	76,0	**1.883.482**
SMA 50/70 Bitumen	500	3668	1832	50,0	11,8	**42.170**
	300	4182	2081	50,0	47,9	**471.097**
	200	4139	2412	60,0	84,4	**1.919.253**
SMA PMB	500	3683	1840	50,0	21,2	**90.162**
	300	4123	2178	52,8	110,1	**1.133.696**
	200	4174	2989	71,6	85,1	**2.000.000**

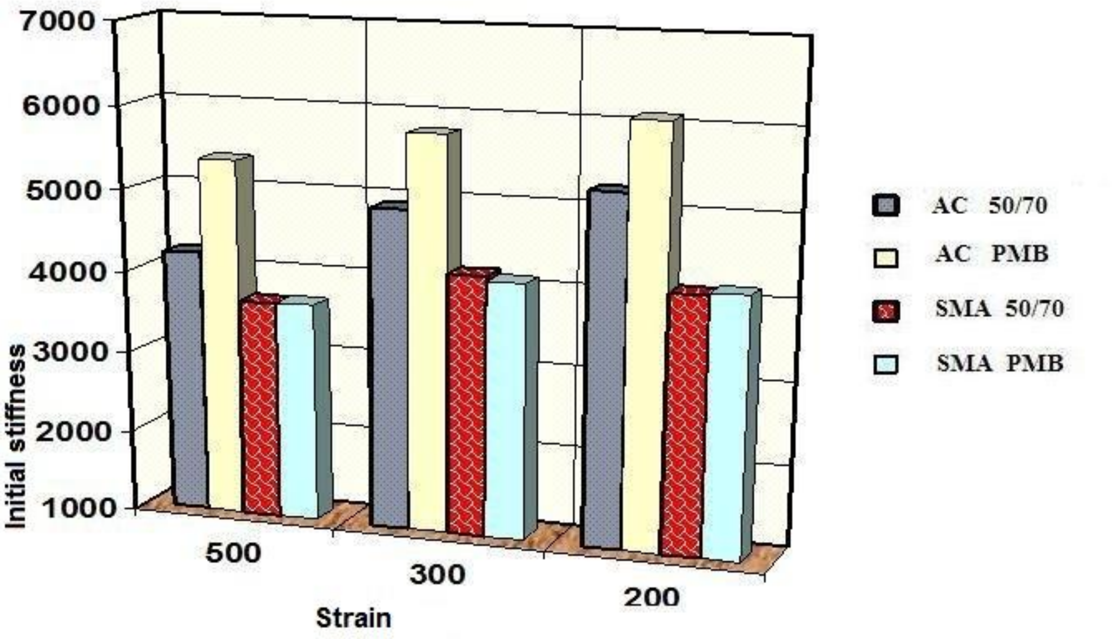

Figure -4 Initial stiffness values of mixtures

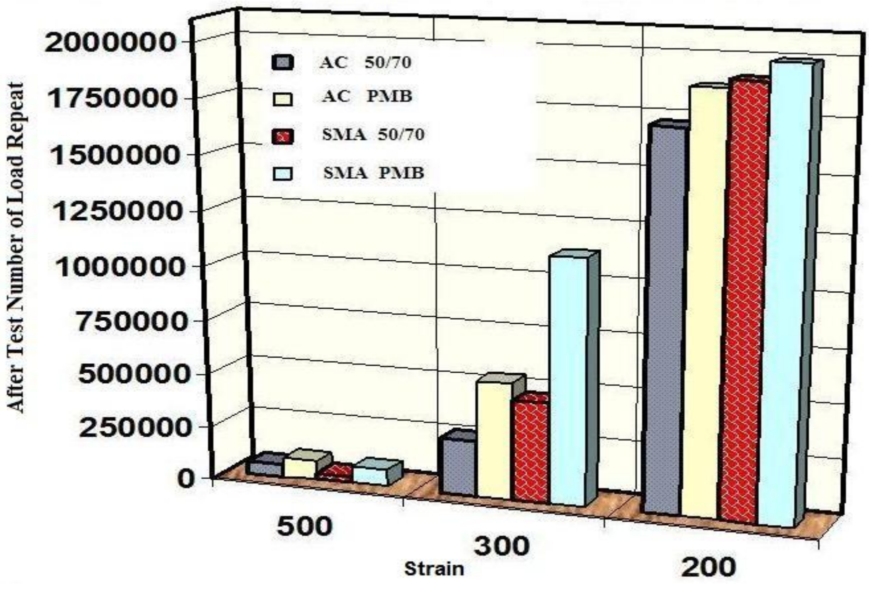

Figure -5 Fatigue life depend on strains of mixtures

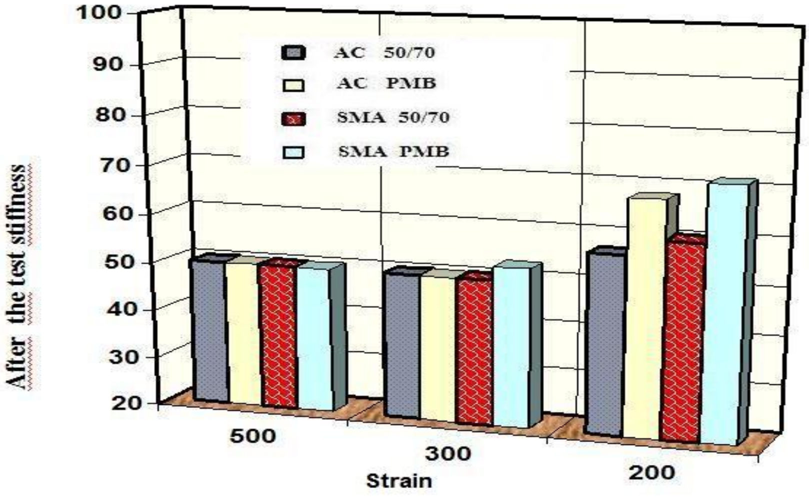

Figure -6 Final stiffness values of mixtures after the test

Cyclic compression test was performed by TS EN 12697-25 standard method B, according to Triaxial Cyclic Compression Method. UTM 100KN test machine was used for the tests. The test is called that repeated load permanent deformation test in literature. The test is applied as that: for determining the permanent deformation characteristics of hot mix repeated dynamic load is applied thousands times and cumulative permanent deformation is recorded as the function of number of cycles. This approach was found out the first time at the middle of 1970's. In the Strategic Highway Research Program equipment was developed that was able to perform the repeated load permanent deformation tests for hot mix. There is a relationship between cumulative deformations with load cycle number. It is explained that three zones (first, second, third) usually occurred in the cumulative permanent deformation curve. In the first zone permanent deformation occurs too quickly and then increasing of permanent deformation reduces, in the second zone it reaches to stabile level. At the end, increasing of permanent deformation occurs quickly.

For the test, specimens were compacted with a 100mm diameter mould using gyratory compactor, tops and bottoms of the specimens were cut. The specimen which was placed in the triaxial cell, confining pressure 150kPa was applied under 300 kPa cyclic axial pressure at 50°C temperature in the climatic chamber. The axial haversinusoidal loading was applied. The test was continued until 15000 cycles.

At least 4 samples results for each different mix were evaluated. According to results of the tests total permanent strain (%) depend on number of loading cycle, deformation (mm), minimum strain rate (με/cycle), percent strain at min. strain and cycle at minimum strain rate were calculated. Results of the tests are presented in Table 7 and Figure 7-8.

Table-7 The averages of cyclic compression tests results

Mix Types	Number of load repeat (cycles)	Total permanent strain, %	Permanent deformation mm	Min. strain rate με/cycle	Strain @ min. strain %	cycles @ min. strain rate
AC 50/70 bitumen	15000	0,869	1,209	0,100	0,820	11120
AC PMB	15000	0,550	0,767	0,024	0,533	9728
SMA 50/70 bitumen	15000	1,7775	2,658	0,165	1,637	11402
SMA PMB	15000	1,309	1,937	0,122	1,297	13910

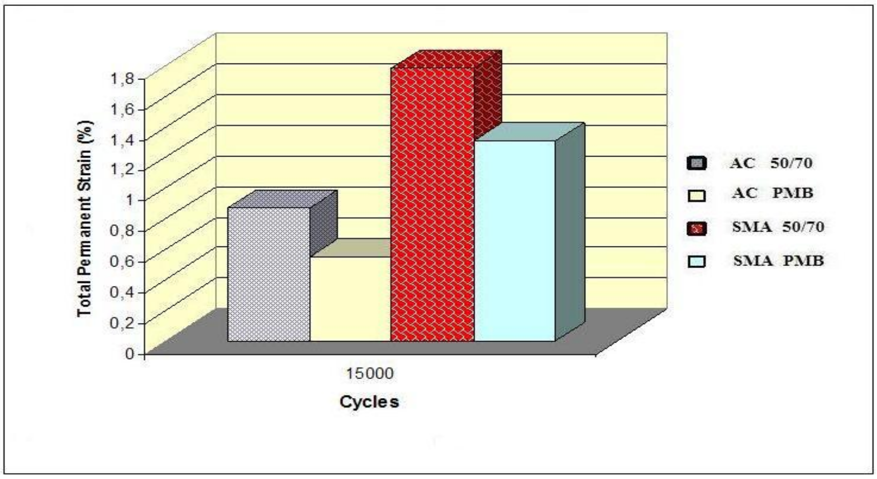

Figure – 7 Total permanent strain values after cyclic compression tests

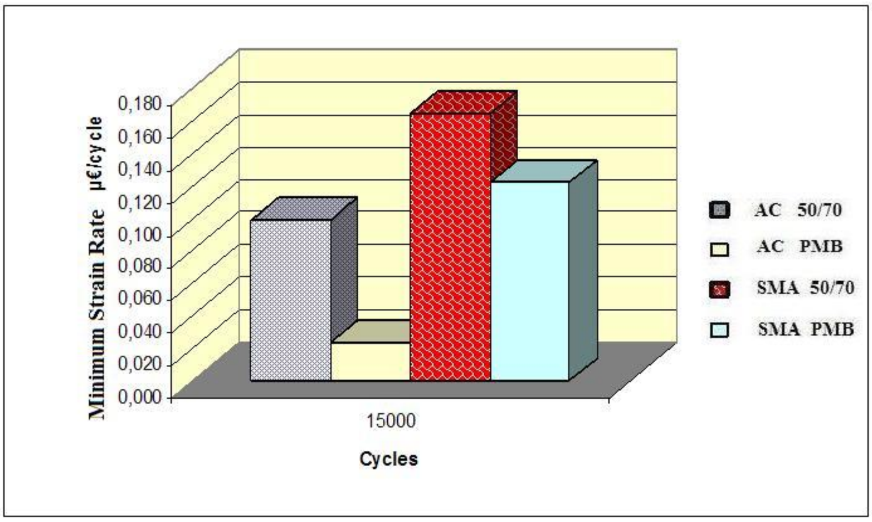

Figure – 8 Minimum strain rate of mixtures after cyclic compression tests

The elasticity modulus of prepared four different mixtures were determined by NCHRP Project 1-28 A method. The samples were prepared as 15 cm diameter with the gyratory compactor. By measuring vertical and horizontal deformation of the sample undertaken lateral loading, elasticity modulus were calculated. The elasticity modulus were presented in Figure 9.

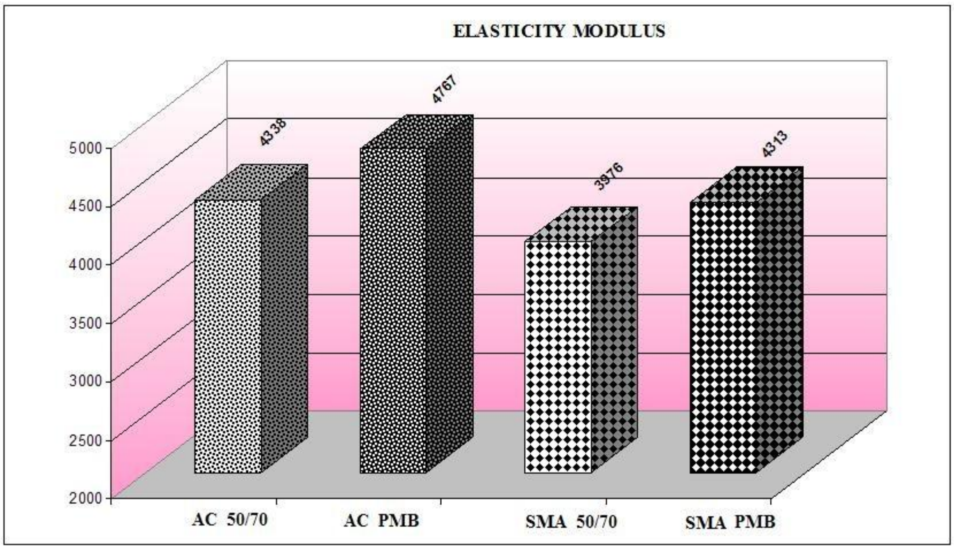

Figure – 9 The elasticity modulus of mixtures

4. CONCLUSION

Results of the studies were explained that: for the same air void ratio when Marshall and Superpave mix design are compared it can be said that: optimum bitumen content which was determined by the Superpave Method was lower than by the Marshall Method.

Indirect tensile strength is indicator of durability of mixtures to deterioration due to water. Indirect tensile strength ratio was calculated by the test and it was seen that all of mixtures ratios are over percent 80. But the ratios of AC mixtures are higher than SMA mixtures.

The rutting test is a good indicator for resistance to plastic deformation. According to the rutting test can be said that polymer bitumen mixture is better than normal bitumen mixture. But it was seen that the AC with normal bitumen are too higher rut depth than SMA mixture values.

Fatigue test is used to define resistance to fatigue of mix and supplies some data for estimate of mixture structural behavior. According to the fatigue test results, SMA with PMB can resistance to more repeated load than the other mixtures. Wearing course mixture loses 50 percent of initial stiffness shorter time than SMA mixture. In the other hand it was seen that stiffness values of AC wearing course mixtures are a bit higher than SMA mixtures. If the energy amount was absorbed by SMA and AC mixtures were compared for different strain groups it was seen that SMA mixtures can be absorbed much more energy. In the other words SMA mixtures lose 50 percent of initial stiffness by absorbing much more energy than wearing course mixtures.

According to cyclic compression test results permanent deformation and creep ratios of SMA mixtures are more than AC wearing course mixtures. But as known all performance tests are not able to reflect real behavior of all type mixtures. For example Marshall Stability values of SMA mixtures are low, on the other hand it is not occurred any problem about low stability on road and there is not stability criteria for SMA in the Europe Standards. Similarly in the EN 13108-1 asphalt concrete specifications permanent deformation is placed according to EN 12697-25 but is not placed in EN 13108-5 Stone Mastic Asphalt Specifications. In this research, it was seen that the most durable to permanent deformation mix type is AC wearing mix with modified bitumen.

Research tests of four types mixtures were done and now these mixtures are used in Turkey. According to basically traffic and then climate conditions of region in that the road will be constructed, type of the mix and the bitumen type are chosen. SMA with PMB is the most suitable mix using for hot regions and regions in where temperature differences are high and regions in where heavy vehicle traffic is high. SMA with normal bitumen is the most suitable mix using for regions in where summer temperatures are too high and winter temperatures are not too low. AC wearing with PMB is the most suitable mix using for regions in where there is low traffic and summer-winter temperature differences are high. AC wearing course with normal bitumen is the most suitable mix using for regions in where summer-winter temperatures are not too high and there is low traffic.

In terms of life cycle cost analysis of wearing course, it can be said that, using suitable mixture, the life of wearing course will be prolonged. If the life of wearing course prolongs about 2 or 3 years, construction cost of wearing course will decrease approximately 33 percent for Turkey economic condition. In addition if vehicle operating costs are added, decreasing cost will be much more.

5. ACKNOWLEDGEMENTS

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