Investigation of Rheological Behaviours of Dense Bituminous Mixtures under Repeated Creep Testing Utilising Polypropylene Fibers as a Modifier

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Abstract

The heavy vehicles in the composition of traffic, non-foresightable axle loads and tire pressures have motivated the highway engineers to search for new pursuits. Especially in our country, the addition of the overloaded vehicles into traffic stream and the occurrence of rutting, because of the hot climatic conditions, has become one of the most predominant distress parameters. Because of the above mentioned reasons, the modification of physical and chemical properties of the bituminous binders has been assimilated to ensure the desirable performance in the flexible pavements. Starting from the beginning of seventies, because of their engineering importance, much research has been devoted to the permanent deformation phenomenon in flexible pavements. In order to prevent this phenomenon, namely rutting and also fatigue and low-temperature cracking, different types of polymer modifiers have been utilised in different types of projects carried out worldwide. Polypropylene (PP) fibers are one of these modifiers which can be obtained locally. Therefore when compared to other types of modifiers, they provide in real economy for developing countries. These are some of the main reasons why PP fibers are used in all throughout the tests carried out in the study. In the proposed study, first of all, Marshall design is carried out in order to find out the optimum bitumen contents for control and PP fiber modified specimens. These designs were carried out with one type of bitumen and a single gradation. Different types of PP fibers are used in order to determine the optimum bitumen content and the optimum PP amount in the prepared Marshall specimens. Then with these optimum amounts in hand, first of all the bitumen samples have been modified at a standard mixing temperature. With these modified bitumen samples, again, Marshall specimens have been fabricated and tests are carried out with Universal Testing Machine in order to determine the rheological behaviours of dense bituminous mixtures under repeated creep testing. Different load values and loading patterns have been applied to the previously prepared specimens at a predetermined temperature in order to determine the rutting susceptibility of the mixtures. After examining the obtained results, it has been found out that the PP modification of bituminous binders has developed the physical and mechanical properties of the mixture and substantially improved the resistance to permanent deformations. Besides, the polypropylene modification results in 30% economy form bitumen which is very important for the costly asphalt concrete production in recent times.

Keywords: Polypropylene fibers, Marshall design, Bitumen modification, Universal Testing Machine, Repeated creep test, Stability, Service life

Introduction

Viscoelastic materials, such as plastics, exhibit flow in addition to their elastic characteristics. Such behaviour is also common for asphalt concrete. This kind of flow under applied load pattern is called creep. Creep is defined as time dependent deformation characteristic of a viscoelastic material subjected to load. In addition to viscoelastic behaviour, asphalt concrete demonstrates elastoplastic and thermoplastic properties, so deformation characteristics of asphalt concrete depend on temperature. Therefore, creep of asphalt concrete is the combination of elastic, plastic and viscoelastic behaviours, which can be modelled by the combination of basic rheological elements such as springs, dashpots and their various combinations. Maxwell, Kelvin, Burger and more complex rheological models are used to model the behaviour of asphalt concrete as complex viscoelastic, elastoplastic and thermoplastic engineering material.

From the beginning of seventies, because of the engineering importance, much of research has been devoted to the study of permanent deformation (aka rutting) in flexible pavements (Hofstra and Klomp 1972; Uge and Van de Loo 1974; Van de Loo 1974; Hills et al, 1974; De Hilster and Van de Loo 1977; Van de Loo and De Hilster 1978; Van de Loo and De Hilster 1978; Bolk and Van de Loo 1979). Rutting can result in the loss of pavement serviceability in case when cracking follows the formation of ruts and rapid deterioration of pavement due to accumulation of water on the pavement surface. Under normal service conditions, deformations within the bituminous materials occur more frequently during late spring, summer and early fall because of high temperature conditions. During winter, the subgrade soil may be frozen, so it provides firm support for asphalt pavement and thus reduces pavement deformation.

Universal Testing Machine (UTM-5P) can carry out static and repeated creep tests. This system allows asphalt concrete to be tested for its ability to withstand repeated axial loading. The UTM-5P software can replicate varying road conditions through increases in frequency and force of axial loads. Static and dynamic creep tests can be performed using the UTM-5P giving the data for plastic deformation. The UTM-5P comprises of a loading frame, fitted with a closed loop servo-controlled pneumatic actuator assembly, control and data acquisition system (CDAS). The CDAS has eight transducer inputs and houses an additional module that controls a servo-valve. The system can operate and control either force, displacement or strain (using an on-specimen transducer) or a combination of all three (Feeley 1994).

Asphalt concrete under constant stress condition exhibits a typical deformation characteristic which can be explained in four stages as shown in Fig. 1. These are:

a) Instantaneous elastic and/or non-elastic deformation: with the application of load, there is a immediate deformation, which is explained by the behaviour of spring element in the rheological model. Upon the removal of the load through this stage, a portion of the deformation is recovered instantaneously. The amount of recovery is not necessarily equal to the instantaneous deformation that has occurred due to the application of the initial load.

b) Primary creep: if the load on the system is not removed, the material deforms further, but with a decreasing rate, which is explained with the deformation characteristics of the Kelvin body in the system. Observed deformation at this stage has both recoverable and unrecoverable portions.

c) Secondary creep: at this region the slope of deformation is linear, which is represented as the deformation of the dashpot of the Maxwell body in the system. The deformation that exhibits at this stage is unrecoverable.

d) Tertiary creep: this stage represents the complete plastic failure of the material. In this stage deformation has an accelerated increasing rate.

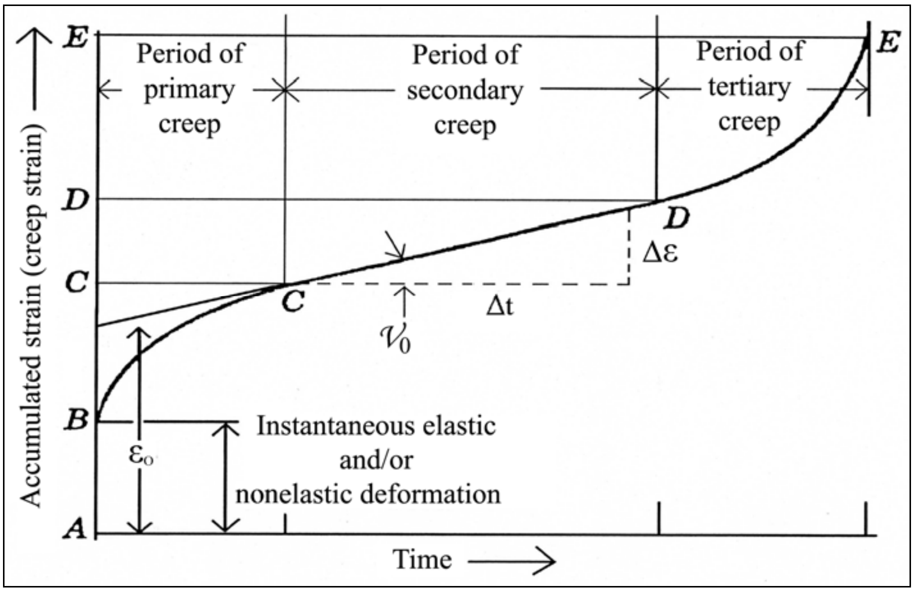

Fig. 1. Typical creep curve for asphalt materials

In a creep test, the specimen, which is supposed to be in a virgin state (undisturbed), is subjected to a load applied as quickly as possible in order to keep the stress at a constant value after application of load. The resulting deformation or strain of the specimen is measured as a function of time elapsed since the load was first applied. This type of testing is known as static creep test. Static creep test represents the conditions common for parking lots where the heavy vehicles with full load park and stay in that position for a long period of time (at least, 24 hours). This period may extend to one week, one month or can be even longer. The accumulated strain or, in other words, the total displacement is dependent of both the load and the material properties. As it is not practical to measure the stresses, strains and displacements on site, different types of testing devices were developed in order to measure these values in the laboratory environment. In fact, creep testing of bituminous mixtures in compression, either uniaxial or triaxial, remains the main source of materials data for pavement design for long-term permanent deformation (Feeley 1994). For example, Universal Testing Machine (UTM-5P) can carry out static and repeated creep tests. This system allows asphalt concrete to be tested for its ability to withstand repeated axial loading. The UTM-5P software can replicate varying road conditions through increases in frequency and force of axial loads. Static and dynamic creep tests can be performed using the UTM-5P giving the data for plastic deformation. The UTM-5P comprises of a loading frame, fitted with a closed loop servo-controlled pneumatic actuator assembly, control and data acquisition system (CDAS). The CDAS has eight transducer inputs and houses an additional module that controls a servo-valve. The system can operate and control either force, displacement or strain (using an on-specimen transducer) or a combination of all three (Feeley 1994).

Repeated creep is also a very important phenomenon for asphalt concrete. In hot summer days, on climbing lanes, heavy vehicles with full load impose a considerable amount of distress to the pavement structure. The repetition of the heavy axle loads become more pronounced with the increased amount of traffic. The combination of hot weather with significant axle loads and slow moving trucks and trailers create a serious problem for the performance life of pavement structure. Pronounced amounts of permanent deformation, in other words, rutting, arise in the above-mentioned climbing lanes for the stated conditions. Also on straight road sections, because of the slow speed and heavy loads of the trucks and trailers, similar problems can be encountered. Traffic lights and bus stops arises also similar problems in the pavement structure. Therefore, visible rutting phenomena can be located frequently on these types of road sections.

UTM-5P is capable of carrying out the repeated creep tests in the laboratory environment as stated above. In present research work, it was planned to study two important properties of asphalt concrete. These are accumulated strain and creep stiffness versus pulse counts of the tested Marshall specimens under constant loading (stress) and temperature conditions. Also accumulated strain slope, resilient modulus, and resilient strain versus pulse counts of the specimens were recorded during the conducted tests. Accumulated strain and creep stiffness characteristics of asphalt concrete are mainly affected by the temperature and frequency of loading. Universal testing machine allows asphalt concrete to be tested for its ability to withstand repeated axial loading at varying temperatures.

4. Experimental Program

Marshall specimens were prepared in the laboratory environment utilizing 50 blows on each face representing medium traffic conditions according to ASTM D1559-76. The standard 50/70 penetration bitumen was modified in the laboratory with PP fibers. Marshall stability and flow tests were done and repeated creep tests were carried out by using Universal Testing Machine (UTM-5P) in order to find the rheological properties of asphalt concrete. These tests were considered to be adequate to clarify the positive effect of PP fibers on asphalt concrete.

4.1. Material Properties

In laboratory test program, continuous aggregate gradation has been used to fit the gradation limits for wearing course Type 2 set by General Directorate of Turkish Highways (2006). The aggregate was calcareous type crushed stone obtained from a local quarry and 50/70 penetration bitumen was obtained from a local refinery were used for preparation of the Marshall specimens. Physical properties of the bitumen samples are given in Table 1. The physical properties of coarse and fine aggregates are given in Tables 2 and 3. The apparent specific gravity of filler is 2790 kg/m^3.

Table 1. Physical properties of the reference bitumen

Property	Test Value	Standard
Penetration at 25°C, 1/10 mm	55.4	ASTM D 5-97
Penetration Index	-1.2	-
Ductility at 25°C, cm	> 100	ASTM D 113-99
Loss on heating, %	0.057	ASTM D 6-80
Specific gravity at 25°C, kg/m^3	1022	ASTM D 70-76
Softening point, °C	48.0	ASTM D 36-95
Flash point, °C	327	ASTM D 92-02
Fire point, °C	376	ASTM D 92-02

Table 2. Physical properties of coarse aggregates

Property	Test Value	Standard
Bulk specific gravity, kg/m^3	2703	ASTM C 127-04
Apparent specific gravity, kg/m^3	2730	ASTM C 127-04
Water absorption, %	0.385	ASTM C 127-04

Table 3. Physical properties of fine aggregates

Property	Test Value	Standard
Bulk specific gravity, kg/m^3	2610	ASTM C 128-04
Apparent specific gravity, kg/m^3	2754	ASTM C 128-04
Water absorption, %	1.994	ASTM C 128-04

Aggregate gradation for the bituminous mixtures tested in the laboratory has been selected as an average of the wearing course type 2 gradation limits given by General Directorate of Highways of Turkey which is stated in the Highway Technical Specifications (2006). The mixture gradation and gradation limits are given in Table 4.

Table 4. Type 2 wearing course gradation (Highway Technical Specifications, 2006)

Sieve size, mm	Gradation limits, %	Passing, %	Retained, %
12.7	100	100	0
9.52	80-100	90	10
4.76	55-72	63.5	26.5
2.00	36-53	44.5	19.0
0.42	16-28	22	22.5
0.177	8-16	12	10.0
0.074	4-10	7	5
Pan	-	-	7

The physical properties of the PP fibers used in the experimental program are given in Table 5 (Tapkın 2008).

Table 5. The physical properties of PP fibers (Tapkın 2008)

Characteristic	Value	Standard
Homogeneity, %	100% Polypropylene	-
Colour	Transparent	-
Length , mm	3 - 50	-
Melting temperature, ^{o}C	160	-
Specific Gravity, kg/m^3	910	ASTM D-792
Fire point, ^{o}C	590	-
Glass transition temperature, ^{o}C	-18	-
Alkali resistance as % of strength retained after treatment in 40% NaOH solution at 20^{o}C for 1000 hours	99.5	-
Water absorption, %	0.01-0.02	ASTM D-570
Moisture retention, at 20^{o}C and 65% relative humidity	< 0.1%	-
Rupture resistance, MPa	31-41	ASTM D-638
Elongation, %	≥ 33	ASTM D-638
Elongation at rupture, %	100-600	ASTM D-638
Tensile strength, MPa	31-37	ASTM D-638
Compressive strength, MPa	37-55	ASTM D-695
Bending strength, MPa	41-55	ASTM D-790
Tensile modulus, MPa	1137-1551	ASTM D-638
Bending modulus, 23 ^{o}C, MPa	1172-1723	ASTM D-790
Hardness, Rockwell	R80-R102	ASTM D-785
Thermal expansion, linear, m/m/ ^{o}C	0.031-0.039	ASTM D-696

4.2 PP modification of bitumen samples

The standard 50/70 penetration bitumen that was used in the experiments was modified by using PP fibers. The mixing temperature was around 165-170 ^{o}C. The fibers were premixed with bitumen using a standard mixer at 500 revolutions per minute. The mixing period was two hours. M-03 type (having fiber length of 3 mm), M-09 type (having fiber length of 9 mm) and waste fibers were utilized in this modification process. For M-03 type fibers, fiber contents of 3‰, 4.5‰ and 6‰ by weight of aggregate were premixed with bitumen and were used for preparation of standard Marshall specimens. For M-09 type and waste fibers only 3‰ fiber content was utilized. According to the workability criteria, M-03 type fibers were found to be the most suitable modifiers and due to the consistency of the Marshall test results, M-03 type fibers with 3‰ fiber content had been determined as the optimal addition amount for standard 50/70 penetration bitumen. The physical properties of the PP modified bitumen samples with 3‰ fiber content are given in Table 6.

Table 6. Physical properties of the PP modified bitumen samples

Property	Test Value	Standard
Penetration at 25°C, 1/10 mm	45.5	ASTM D 5-97
Penetration Index	-0.8	-
Ductility at 25°C, cm	> 100	ASTM D 113-99
Loss on heating, %	0.025	ASTM D 6-80
Specific gravity at 25°C, kg/m^3	1015	ASTM D 70-76
Softening point, °C	52.1	ASTM D 36-95
Flash point, °C	292	ASTM D 92-02
Fire point, °C	345	ASTM D 92-02

When the above Table 6 is examined, it can be clearly seen that the physical properties of the fiber modified bitumen samples were greatly improved vs. reference. For example, penetration, penetration index and softening point values were improved the most. Finally, the addition of 3‰ of M-03 type fibers provides the most significant effect on the properties of bitumen/asphalt mixtures.

4.3 The proportioning of the bituminous mixture

In order to determine the optimum bitumen content, it is required to perform Marshall stability and flow tests. The relevant Marshall test results are summarized in Tables 7 - 13. The values stated in these tables are the average values for three different specimens. Therefore, each table represents the test results of 24 different specimens. Tables 7 and 8 represent the Marshall test results of two sets of specimens prepared with reference bitumen.

Table 7. Marshall test results for specimens prepared with reference bitumen (Set 1)

Bitumen Content	V.M.A. (%)	Air Void (%)	Unit Weight (kg/m^3)	Stability (kg)	Flow (mm)	Marshall Quotient
3.5 %	16.982	8.847	2369	1399	2.38	587.8
4.0 %	16.009	6.653	2408	1525	2.57	593.4
4.5 %	15.339	4.775	2439	1562	2.60	600.8
5.0 %	15.370	3.675	2450	1395	2.83	492.9
5.5 %	15.482	2.671	2458	1158	4.47	259.1
6.0 %	16.402	2.611	2443	981	4.67	210.1
6.5 %	17.338	2.594	2427	845	5.41	156.2
7.0 %	18.209	2.524	2413	719	6.90	104.2

Table 8. Marshall test results for specimens prepared with reference bitumen (Set 2**)**

Bitumen Content	V.M.A. (%)	Air Void (%)	Unit Weight (kg/m^3)	Stability (kg)	Flow (mm)	Marshall Quotient
3.5 %	16.487	8.303	2383	1425	2.12	672.2
4.0 %	15.827	6.451	2413	1530	2.77	552.3
4.5 %	14.828	4.199	2454	1647	2.80	588.2
5.0 %	14.872	3.109	2464	1418	3.42	414.6
5.5 %	15.183	2.326	2467	1196	3.69	324.1
6.0 %	16.020	2.165	2454	1006	4.86	207.0
6.5 %	16.876	2.049	2441	822	5.80	141.7
7.0 %	17.796	2.032	2425	756	7.22	104.7

Tables 9 - 11 present the Marshall test results of specimens with M-03 fiber contents of 3‰, 4.5‰ and 6‰ (by weight of aggregate).

Table 9. Marshall test results for specimens with 3‰ of PP fibers

Bitumen Content	**V.M.A. (%)**	**Air Void (%)**	**Unit Weight (kg/m^3)**	**Stability (kg)**	**Flow (mm)**	**Marshall Quotient**
3.5 %	17.519	9.436	2354	1569	2.65	592.0
4.0 %	16.557	7.263	2393	1858	2.99	621.4
4.5 %	16.217	5.761	2414	1869	3.20	584.0
5.0 %	15.812	4.179	2437	1720	3.70	464.9
5.5 %	15.643	2.856	2454	1408	4.10	343.4
6.0 %	16.257	2.442	2447	1250	4.50	277.8
6.5 %	17.047	2.250	2436	1034	5.55	186.3
7.0 %	17.933	2.195	2421	862	6.85	125.8

Table 10. Marshall test results for specimens with 4.5‰ PP fibers

Bitumen Content	**V.M.A. (%)**	**Air Void (%)**	**Unit Weight (kg/m^3)**	**Stability (kg)**	**Flow (mm)**	**Marshall Quotient**
3.5 %	17.607	9.533	2351	1629	3.60	452.5
4.0 %	17.007	7.762	2380	1882	3.04	619.1
4.5 %	17.097	6.752	2388	1876	3.24	579.0
5.0 %	16.609	5.086	2414	1967	3.24	607.1
5.5 %	16.628	3.991	2425	1467	3.87	379.1
6.0 %	17.250	3.598	2418	1252	3.96	316.2
6.5 %	17.825	3.167	2413	1146	3.84	298.4
7.0 %	18.347	2.688	2409	977	4.59	212.9

Table 11. Marshall test results for specimens with 6‰ of PP fibers

Bitumen Content	**V.M.A. (%)**	**Air Void (%)**	**Unit Weight (kg/m^3)**	**Stability (kg)**	**Flow (mm)**	**Marshall Quotient**
3.5 %	18.436	10.443	2327	1622	2.98	544.3
4.0 %	17.947	8.807	2353	1807	2.68	674.3
4.5 %	18.864	8.739	2338	1717	3.49	492.0
5.0 %	19.072	7.889	2343	1721	4.10	419.8
5.5 %	17.327	4.795	2405	1682	3.24	519.1
6.0 %	18.543	5.104	2381	1428	3.68	388.0
6.5 %	18.441	3.893	2395	1380	3.61	382.3
7.0 %	19.497	4.059	2375	1250	5.04	248.0

Tables 12 and 13 present the Marshall test results of specimens with M-09 type fiber at 3‰ contents and waste PP fibers with fiber content 3‰ (by weight of aggregate).

Table 12. Marshall test results for specimens with 3‰ of PP fibers M-09

Bitumen Content	**V.M.A. (%)**	**Air Void (%)**	**Unit Weight (kg/m^3)**	**Stability (kg)**	**Flow (mm)**	**Marshall Quotient**
3.5 %	17.178	9.062	2363	1881	2.74	686.5
4.0 %	16.133	6.791	2405	2036	3.17	642.3
4.5 %	15.795	5.287	2426	2201	2.83	777.7
5.0 %	15.572	3.905	2444	2041	3.91	522.0
5.5 %	17.969	5.534	2386	1223	3.35	365.1
6.0 %	18.495	5.049	2382	1152	4.92	234.1
6.5 %	18.928	4.466	2380	1096	3.66	299.5
7.0 %	19.301	3.826	2381	1023	4.36	234.6

Table 13. Marshall test results for specimens with 3‰ of waste PP fibers

Bitumen Content	**V.M.A. (%)**	**Air Void (%)**	**Unit Weight (kg/m^3)**	**Stability (kg)**	**Flow (mm)**	**Marshall Quotient**
3.5 %	17.275	9.168	2361	1455	3.44	423.0
4.0 %	17.029	7.787	2379	1394	3.69	377.8
4.5 %	16.463	6.038	2407	1492	4.62	323.0
5.0 %	15.913	4.294	2434	1471	3.61	407.5
5.5 %	15.634	2.845	2454	1273	3.75	339.5
6.0 %	16.114	2.275	2452	973	4.53	241.8
6.5 %	17.105	2.319	2434	829	5.72	144.9
7.0 %	18.109	2.298	2418	725	7.19	100.8

To determine the optimum bitumen content, the bitumen contents corresponding to the mixtures with maximal stability and unit weight, 4% air voids and 70% voids filled with asphalt, were found and averaged according to the limits given by the General Directorate of Highways of Turkey (2006). These optimum bitumen contents are represented in Fig. 2.

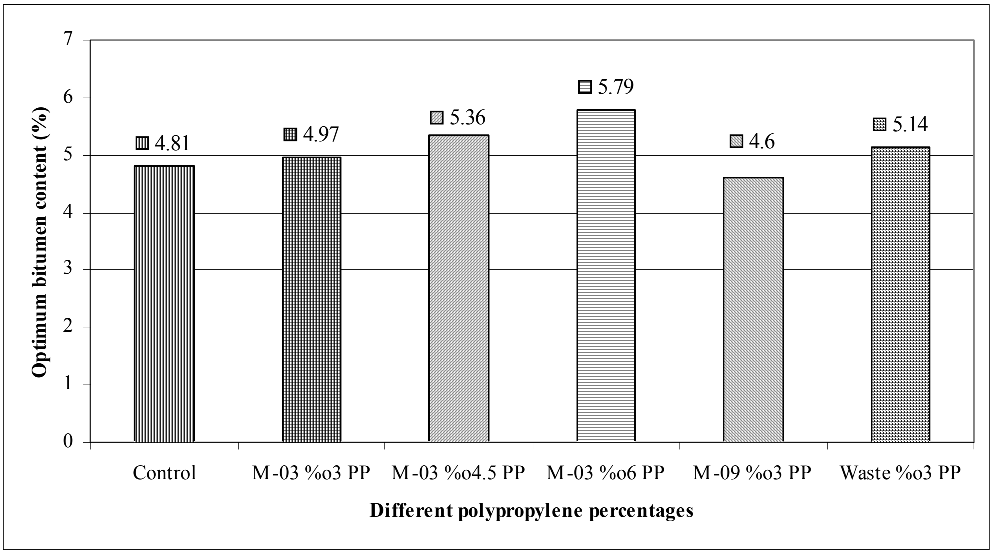

Fig. 2. Optimum bitumen contents for different type and amount of PP fibers

Based on the performed experiment, the optimum bitumen content varies depending on the type and dosage of fibers (Fig. 2). However, in addition to optimum bitumen content, the optimal PP amount and type, the homogeneity in the preparation of the Marshall specimens, the ease in the addition of the PP fibers, the ease in the fabrication of the specimens and the fluctuations of the obtained data are very important. For example, Marshall test results for specimens prepared with more than 3‰ M-03 type fibers and all mixtures made with M-09 and waste fibers resulted in creased values of optimum bitumen contents. M-09 and waste fibers also had very little workability. The addition of these fibers into bitumen is very difficult and the high viscosity of the modified bitumen does not allow fabricating dense Marshall specimens. The fluctuations in the stability and flow values and Marshall Quotients support the above mentioned facts. Based on these results, M-03 PP fibers at dosage of 3‰ by the weight of aggregate were selected as optimal.

It can be seen that the optimum bitumen contents for reference and specimens with 3‰ of M-03 fibers are 4.81% and 4.97%, respectively (Fig. 2). For the next step of experiments, these two values were taken as 5%

4.4 Experimental setup and repeated creep tests performed

The repeated creep tests have been performed to find out the accumulated strains in the specimen body, or permanent deformation. The creep deformation of standard Marshall specimens was measured as a function of pulse counts or rather time. The load on the specimens was uniaxial and dynamic, which was representing the repeated application of axle loads on the pavement structure. The dimensions of asphalt specimens were approximately the same for nearly all of the specimens. Therefore, a unity in the dimensions was standardized. Prior to testing, the specimens were put into the chamber for 24 hours in order to have the uniform temperature distribution. All of the tests were carried at 50°C. For controlled temperature testing, the specimen's skin and core temperature was estimated by transducers inserted in a dummy specimen and located near the specimen under test. In order to understand the behaviour of the asphalt specimens under different loading patterns, different constant stress values were chosen. These values were 100, 207 and 500 kPa. As PP modification was carried out, utilizing lower stress values like 100 and 207 kPa was not feasible, since under such loading the tertiary creep region could not be observed within the reasonable period of time. Therefore, in order to be able to differentiate between the control and fiber-reinforced samples, a loading level of 500 kPa (approximately 73 psi) was chosen as the standard stress value. This value well represents the tire pressure of a loaded truck. The specimen strain during the pulsed loading stage of the test were measured in the same axis as the applied stress using two linear variable displacement transducers (LVDTs). The applied force was open loop controlled and rectangular in shape.

Load periods were chosen as 500 ms for all of the specimens and the rest periods were 500, 1000, 1500 and 2000 ms, respectively. Four specimens were tested for each loading pattern. The reference specimens were prepared with 5% bitumen content. The fiber-reinforced (M-03 type with dosage of 3‰ by the weight of aggregate) specimens were also prepared with 5% bitumen content.

5. Repeated Creep Test Results

The results of the repeated creep tests are given in Figs. 3 - 10. The first graphs present the accumulated strain versus pulse counts and the second graphs describe the creep stiffness versus pulse. These graphs stand for the average of the four different specimens and, therefore, show the general trend of the specimens under the specified loading and temperature conditions. For uniformity, the constant stress had been taken as 500 KPa and the test temperature was 50°C for all the experiments. The presented graphs well indicate the positive effect of PP fibers on properties of bitumen specimens.

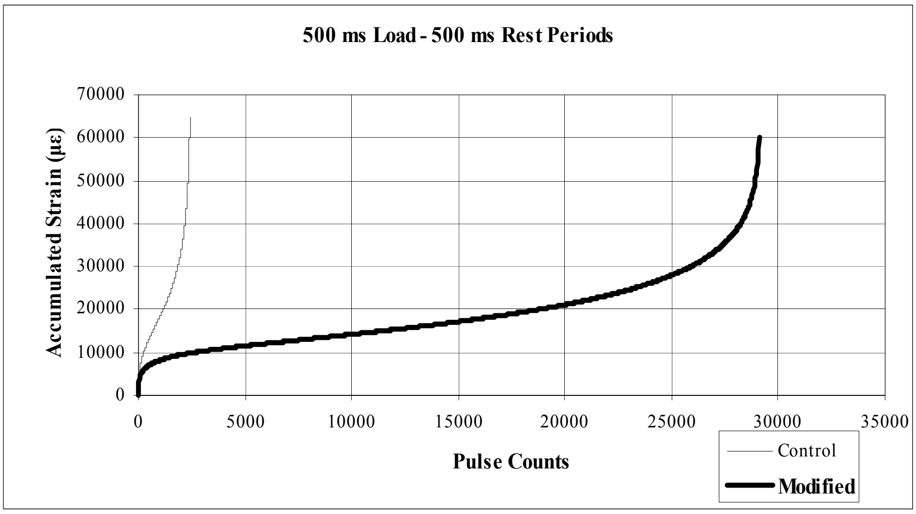

Fig. 3. Accumulated strain vs. pulse counts of specimens with a loading pattern of 500 ms load - 500 ms rest period

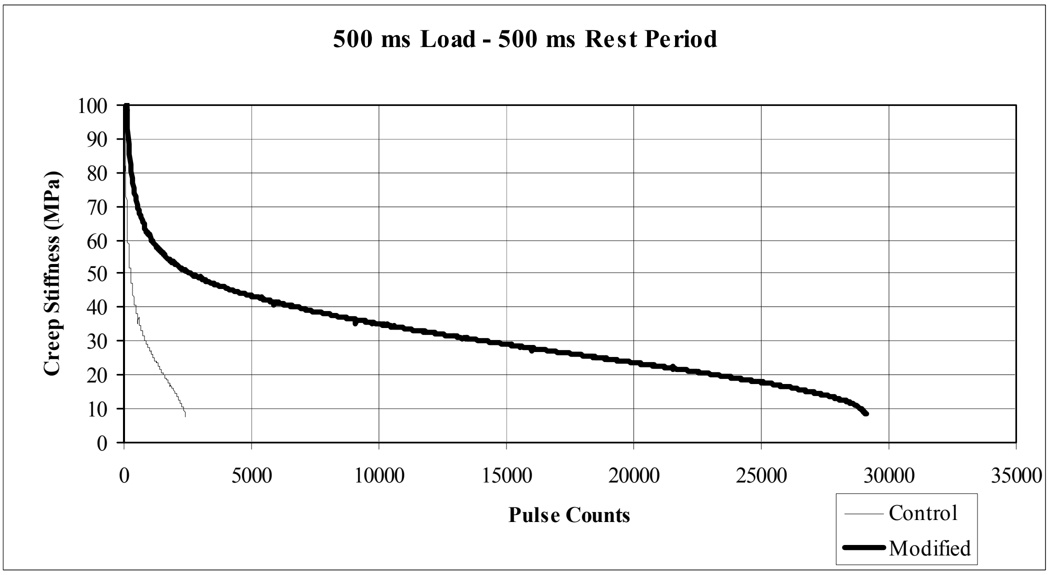

Fig. 4. Creep stiffness vs. pulse count of specimens with a loading pattern of 500 ms load - 500 ms rest period

As can be seen from Figs. 3 and 4, the service life of fiber-reinforced specimens (5% optimum bitumen content, 3‰ of M-03 type fibers) are approximately 12 times longer than the control specimens under the same testing conditions. This is a very significant difference showing the positive effect of PP fibers. As can be seen from Fig.3, the control specimens are entering to the tertiary stage of creep only at around 2000 pulse counts; this loading rate corresponds to the primary creep stage for the PP fiber modified specimens. Fiber modified specimens reach the tertiary creep stage only at the pulse counts of 20000. Importantly, at the end of the repeated creep tests, the control specimens have a total collapse, while the modified specimens did not show any sign of failure (so, the fiber modified specimens would have had even a longer service life).

Creep stiffness values drop a certain level (which is taken as 10 MPa for this study) and this can be accepted as the termination of the test. For both specimen types, the termination stiffness values are the same, but the pattern of the decrease in these values show a great difference. When the control specimens fail, the creep stiffness of the fiber modified specimens have only dropped to their 50% values showing that the time required to fail for these specimens is much longer. In addition, the initial creep stiffness values of the fiber modified specimens are correspondingly higher than the control specimens, but because of the operating conditions of the UTM-5P system, it is not possible to give an exact figure.

The corresponding graphs of the control and fiber modified specimens for the 500 ms load – 1000 ms rest periods are given in Figs. 5-6.

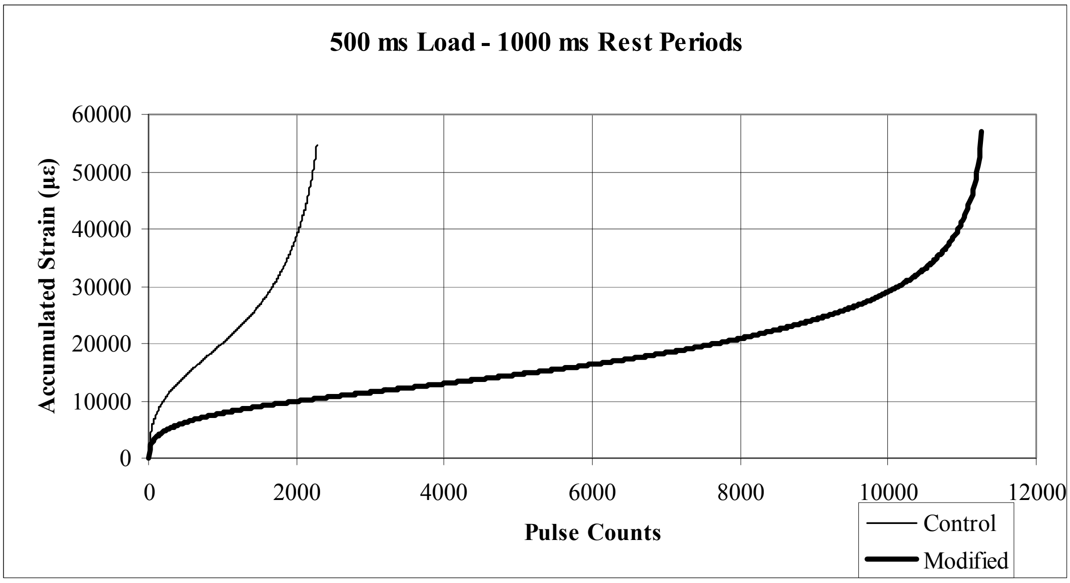

Fig. 5. Accumulated strain vs. pulse counts of specimens with a loading pattern of 500 ms load – 1000 ms rest period

In the above graph, it can be seen that the service life of the modified specimens is approximately five times longer than the control specimens. 500 ms load – 500 ms rest periods loading pattern has a service life approximately 2.5 times longer than the 500 ms load – 1000 ms rest periods loading pattern. This is because of the detrimental effect of 500 ms – 1000 ms rest period on the asphalt concrete specimens. The stresses are pronounced more deeply in the fiber modified specimens in the above loading case. The control specimens are not affected so much from this second type of loading pattern as their service lives are comparatively much shorter than the fiber modified specimens. Therefore, the difference between the service lives of two sets of control specimens is not very distinguishable.

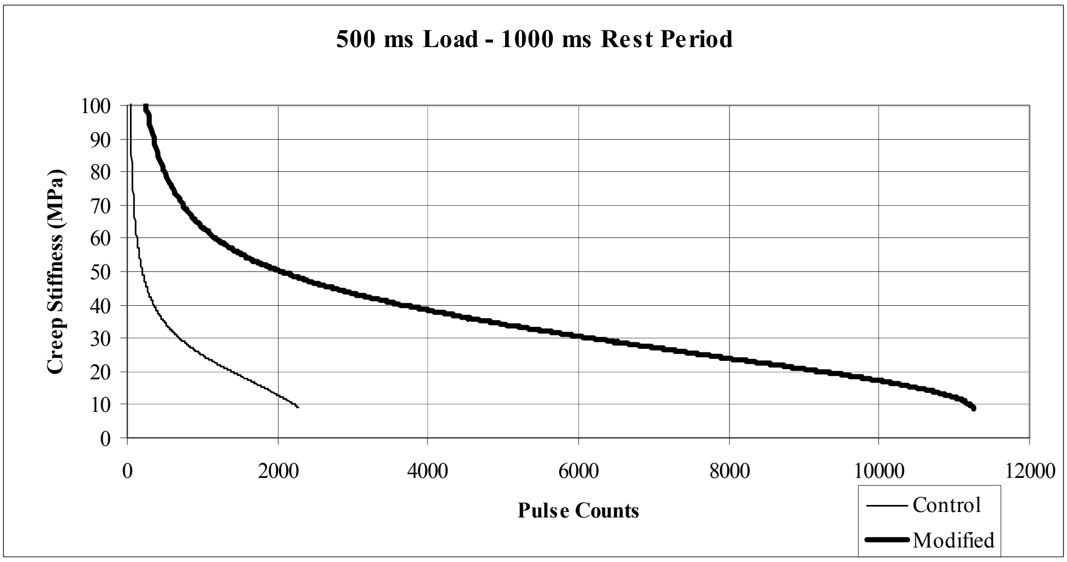

Fig. 6. Creep stiffness vs. pulse count of specimens with a loading pattern of 500 ms load - 1000 ms rest period

When the creep stiffness values of the control and fiber modified specimens are compared, it can be seen that while the control specimens fail, the fiber modified specimen’s creep stiffness values have only dropped by 50% of the original values. This is in conformity with the 500 ms load – 500 ms rest period graphs. In addition, as can be seen from Figs. 4 and 6, the creep stiffness values are changing between 0-100 MPa. The reason for specifying a range between 0 and 100 MPa is to have unity between the appearances of all of the graphs.

The corresponding graphs of the control and modified specimens for the 500 ms load – 1500 ms rest periods are given in Figs. 7-8.

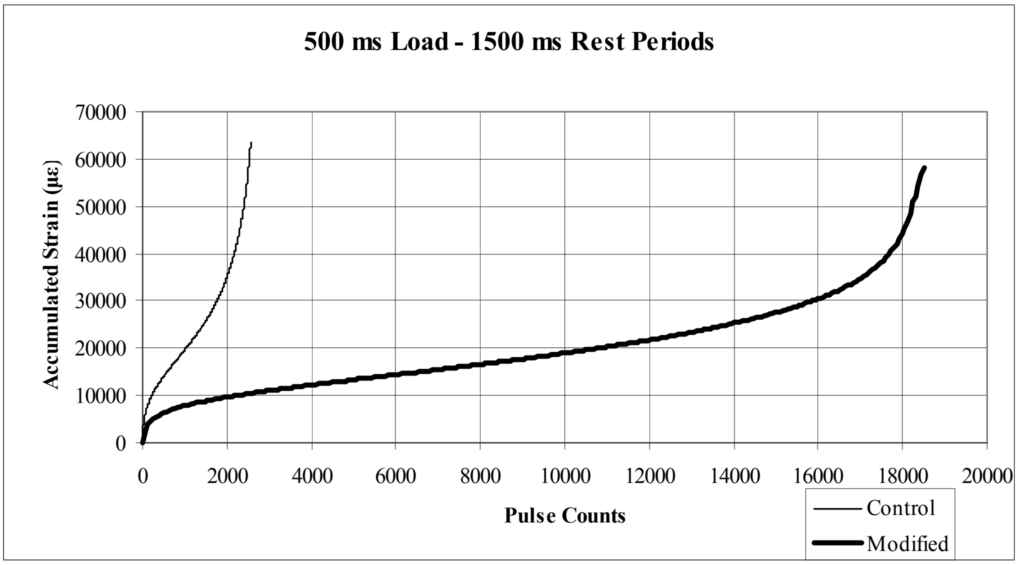

Fig. 7. Accumulated strain vs. pulse counts of specimens with a loading pattern of 500 ms load – 1500 ms rest period

The service lives of fiber modified specimens are approximately 7.5 times higher than the service lives of the control specimens in Fig.7. Similarly to the previous loading patterns, when the control specimens reach their tertiary creep stage, the fiber modified specimens are in their primary creep stage. Therefore, it can be concluded that the stiffness of the fiber modified specimens is significantly enhanced vs. the stiffness of the control specimens. The creep behaviour of the asphalt specimens can be better observed using fiber modified specimen graphs. It can be concluded that the accumulated strain versus pulse counts of fiber modified specimens conform very well to the typical creep curve of a viscoleastic, elasto-plastic and thermoplastic material such as asphalt concrete (Fig.1).

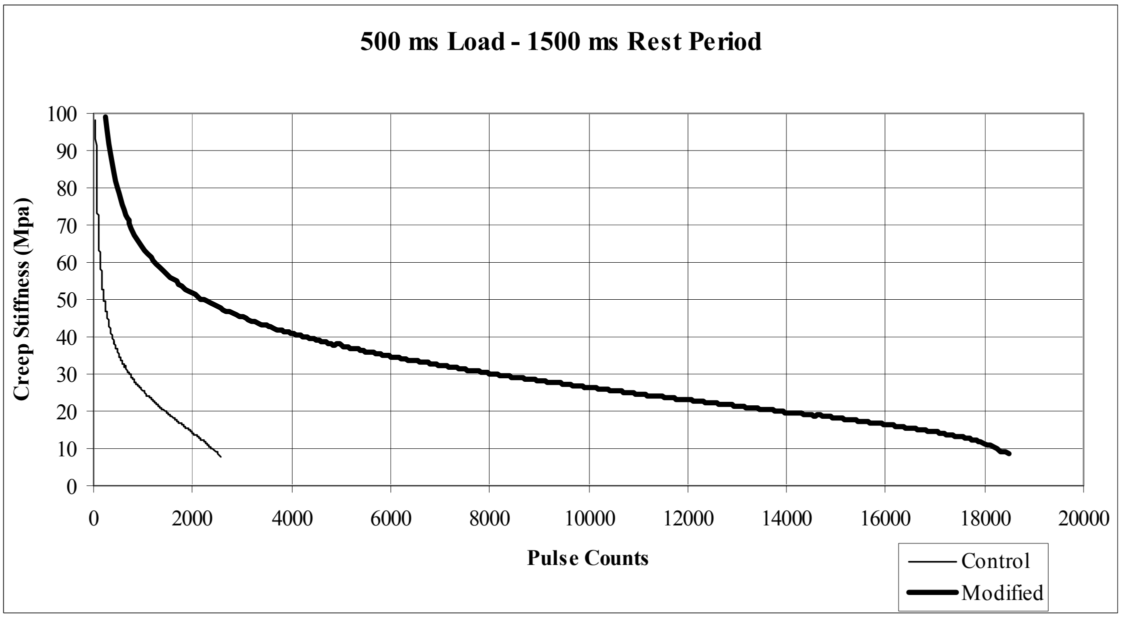

Fig. 8. Creep stiffness vs. pulse count of specimens with a loading pattern of 500 ms load - 1500 ms rest period

The accumulated strain versus pulse counts and the creep stiffness versus pulse counts of the control and modified specimens for the 500 ms load – 2000 ms rest periods are given in Figs. 9-10. The main difference of this loading pattern is related to considerably long rest period. 2000 ms is really a long rest period and can help to model the traffic pattern where the repetition of the axle loads is not as destructive as 500 ms load – 500 ms rest periods (i.e. resulting in 12 times longer service lives than the control specimens).

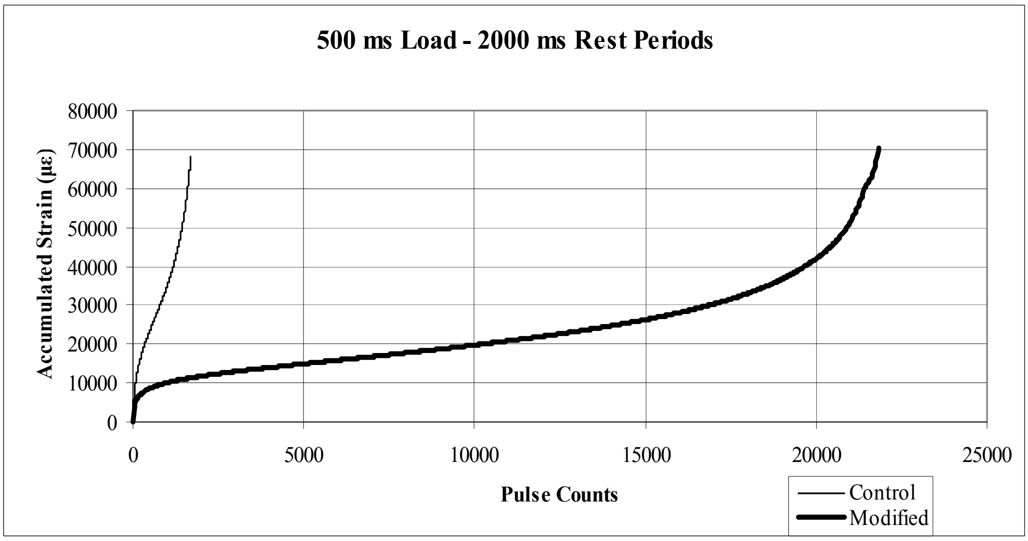

Fig. 9. Accumulated strain vs. pulse counts of specimens with a loading pattern of 500 ms load – 2000 rest period

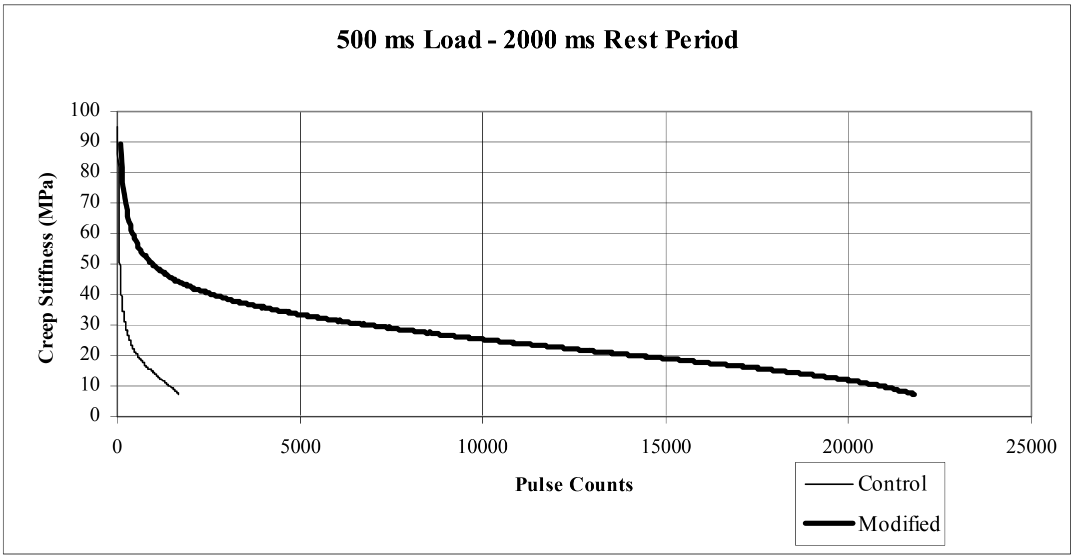

Fig. 10. Creep stiffness vs. pulse count of specimens with a loading pattern of 500 ms load - 2000 ms rest period

When the control specimens fail, the creep stiffness of the modified specimens have dropped only to 44% of their original value. This well conforms to behaviour under previous loading patterns. It can be concluded that the repeated creep behaviour of the asphalt specimens can be tested very accurately using the UTM-5P testing system.

6. Conclusions and Recommendations

Based on the Marshall tests with fiber reinforced specimens, the optimum bitumen content was found to be 5.0%, the same as for the control specimens. The most suitable PP fiber, M-03 type, can be used at a dosage of 3‰ by the weight of the aggregates. The addition of the PP fibers into the asphalt mixture increased the Marshall stability values by 20%.

The stiffness of the Marshall specimens has increased in a considerable manner, which is also supported by the visible increase in the Marshall Quotient values. The conclusion can be made that the lives of the fiber modified asphalt specimens under repeated creep loading at different loading patterns increased by 5-12 times vs. control specimens. This is a very significant improvement. The repeated creep tests resulted in primary creep stage in case of the modified specimens, while the control specimens reached their tertiary creep stages. This fact is also well supported by the creep stiffness values. While the control specimens are failing, the creep stiffness values in the fiber reinforced specimens have dropped only to 50% of their original values. The results from the analysis of the tested specimens show that the addition of PP fibers improves the behaviour of the specimens by increasing the life of samples under repeated creep testing. This is an important step in the generation of high performance asphalt paving products. Also the lighter asphalt products can lead to an important remedy for flushing and bleeding problems.

The static creep tests can be carried out on the PP fiber modified specimens at various loading and temperature patterns. Also, PP fiber reinforcement of the bitumen can be examined by the aid of optical and scanning electron microscopy. A further study will focus on the behaviour of the asphalt specimens at lower temperatures.

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