Available online at www.CivileJournal.org

Civil Engineering Journal

Vol. 2, No. 10, October, 2016

Influence of Polypropylene Length on Stability and Flow of Fiber-reinforced Asphalt Mixtures

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Received 30 July 2016; Accepted 25 October 2016

Abstract

Engineers are constantly trying to improve the performance of the flexible pavements. The main surface distress types which cause maintenance and disruption are rutting and fatigue cracking. For solving these problems, many studies have been carried out until now, ranged from changing gradation to adding polymers and fibers to asphalt mixture. In this study, polypropylene additive was selected as fiber additive because of low costing and having good correlation with asphalt pavement. Three type of polypropylene additive in the length 6, 12 and 19 mm were selected and used at five different percentages in the asphalt concrete mixture. Asphalt specimens were analysed by Marshall Analysis and finally tested by Marshall Stability apparatus. Adding polypropylene increased Marshall Stability (38%), and decreased Flow (39%). These results show that polypropylene can be helpful for increasing pavement life.

Keywords: Polypropylene Fibers; Improvement; Marshall Stability; Flow.

1. Introduction

Scientists and engineers are constantly improving the performance of the flexible pavements. The cost of rehabilitation and maintenance of asphalt concrete pavement is one of the major problems because of improper mix design and/or using improper asphalt either in amount or quality. In order to ensure pavement long-term durability, thus minimizing maintenance cost and conserving resources, proper selection of paving materials together with optimal mix and pavement design are of great importance.

Two important distresses which cause spending for maintenance and rehabilitation are permanent deformation (rutting) and fatigue cracking. In both of them, the aggregate gradation and the percent of asphalt are playing important roles. For solving these problems different efforts have been done like changing gradation to the stone mastic asphalt (SMA) (gap gradation) concluded in higher rutting resistance in SMA compare to dense-graded wearing course mixture [1, 2], increasing coarse aggregate fracture faces showed an increase in rutting resistance, National Cooperative Highway Program 9-35 reports [2]. Changing aggregate gradation to coarser gradation, results in the lower rut problem [3, 14]. Increasing crushed coarse and fine aggregate fractures (instead of rounded aggregate like gravel) increase the shear resistance which result in higher resistance to rutting [5] and also increase Marshall Stability [6, 7]. Using cubical particles can increase internal friction which improves rutting resistance [7, 9, and 10]. Strategic Highway Research Program (SHRP) in summary report on permanent deformation in asphalt concrete indicates that shape of aggregate (rounded to angular) and size (increase in maximum size) will increase rutting resistance [8, 9]. As an utilizing additive for example using hydrated lime in many different studies has been performed like research of Burger & Huege which says that use of hydrated lime contributes to high performance asphalt pavement to mitigate moisture susceptibility, improving rut resistance and reducing fatigue cracking or The National Lime Association has confirmed using hydrated lime in asphalt mixture, make the pavement more resistant to rutting and fatigue cracking [11]. These distresses are common in many countries because of improper mix design and traffic loading and there are

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few investigations in this area to improve roads performance. Performance improvements are normally found with respect to permanent deformation (rutting), fatigue resistance and low temperature cracking, particularly for the modified binders with polypropylene [15]. These improvements are also confirmed in full-scale tests using for example Heavy Vehicle Simulator [15], and field trials, such as test sections in the Long Term Pavement Performance program in North America [16] and airfield runways [17]. A promising cause of toughening may be that the fibres in HMA enhance the shear strength at the interface between the HMA matrix and fibres, and the enhanced property can delay the initiation and propagation of damages [18]. Repeated load creep tests under different loading patterns have also shown that the time to failure of fiber-modified asphalt specimens under repeated creep loading at different loading patterns increased by 5–12 times versus reference specimens, a very significant improvement [19].

The objective of this study is to improve mix design and workability of Hot Mix Asphalt (HMA), by using various lengths of polypropylene (PP) fiber to increase stability of mixture and decrease flow. The reason of using polypropylene is because of economically occasion of this material, which can be obtained from loom factories by reasonable price. Different researches show an improvement in pavement in rutting and fatigue cracking by using this material.

2. Materials and Method

2.1. Optimization Model Design

All the aggregates in this study are 100% crushed. The aggregates are limestone obtained from Jahad-E-Nasr site in Kermanshah, Iran. Figure 1 shows the gradation.

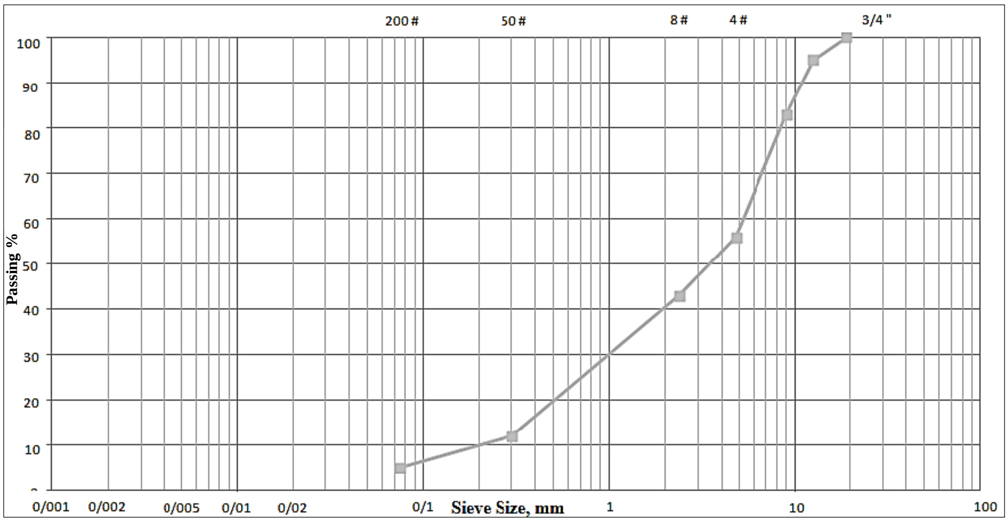

Figure 1. Gradation of the aggregates

2.1.1. Genetic Algorithm

The coarse aggregates are tested according to ASTM C127-07, Standard Test Method for Density, relative Density (Specific Gravity), and Absorption of Coarse Aggregate. According to the standard, test sample with minimum 3 Kg (mass of test sample is depend on the nominal maximum size of the aggregate gradation) should be dried in the oven to constant mass at a temperature of 110 ± 5 °C. When it gets dried, it is cooled in air temperature for 1 to 3 h till can be handled easily. Subsequently immersed in water at room temperature for 24 ± 4 h, and then the test sample is removed from water to be dried by the cloth to Saturated Surface-Dry (SSD) condition. The mass of the test sample in SSD condition is determined to the nearest 0.5 g or 0.05% of the sample mass whichever is greater. In Table 1, the result of specific gravity and absorption of coarse aggregate is illustrated.

Table 1. Specific gravity and absorption of the coarse aggregate

Item	Size		
	4.75 mm	12 mm	19 mm
Wight of oven dried sample in air (g)	562.4	563.8	566.1
Weight of SSD sample in air (g)	564.2	565.3	567.5
Weight of sample in water (g)	365.8	363.7	363.4
Bulk Specific Gravity (Dry)	2.80	2.79	2.76
Bulk specific gravity (SSD)	2.84	2.80	2.83
Apparent Specific gravity	2.86	2.79	2.81
Absorption	0.73	0.59	0.57

2.1.2. Specific Gravity of the Coarse Aggregate

The specific gravity and absorption of fine aggregate is tested according to ASTM C128-07, Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of fine Aggregate. According to the test approximately 800 g of fine aggregate should be placed in a pan with water cover it for 24 h. Then, the sample spread on a flat surface exposed to a warm air and stirred to get to the Saturated Surface-dry (SSD) condition. SSD dry sample shall be divided into two equal sections; one of them is weighted and dried to constant weight at a temperature 100 –110 °C, then it should be cooled in air and weighted. The other section is introduced into the flask which is filled almost to 1000 ml. After one hour in a constant temperature at 20 °C, flask is weighted. In Table 2, the result of specific gravity and absorption of fine aggregate is illustrated.

Table 2. Specific gravity and absorption of fine aggregate

Item	Result
Wight of oven dried sample in air (g)	390.7
Weight of SSD sample in air (g)	403.4
Weight of Pycnometer with sample and water (g)	1608.5
Weight of Pycnometer with water (g)	1351.9
Bulk Specific Gravity (Dry)	2.69
Bulk specific gravity (SSD)	2.73
Apparent Specific gravity	2.89
Absorption	1.47

2.1.3. Los Angeles Abrasion Test

ASTM C131–06 Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine, is carried out to satisfy the hardness and toughness of the crushing aggregate specification. According to the standard aggregate should be washed and placed in the oven at 110 ± 5 °C (230 ± 9 °C) to substantially constant mass. Then sample is placed in the Los Angles testing machine. After 500 revolutions at a speed of 30 to 33 r/min aggregates are taken out from machine and the aggregates coarser than 1.70–mm (No. 12) are oven dried at 110 ± 5 °C (230 ± 9 °F) to substantially constant mass and weighted to the nearest 1 g. At the end the percent loss of aggregates is calculated, according to the code for nominal 19.0 mm (3/4 – in) the percent loss of aggregate should be in the range of 10 to 45% [13], as presented in Table 3.

Table 3. Los Angeles abrasion value

NO.	Original Mass	Final Mass	Percent Loss (%)
1	4996.2	3315.5	33.65
2	5006.3	3324.7	33.59
3	5003.9	3316.6	33.72

2.2. Bitumen

The type of asphalt in this study is 60-70 penetration which is obtained from Isfahan Mineral Oil Refinery, Isfahan, Iran.

2.2.1. Penetration

According to the ASTM D5–06, Standard Test Method for Penetration of Bituminous Materials, a container of asphalt cement is brought to the standard test temperature, 25 °C in a thermostatically controlled water bath, and then the sample is placed under the standard needle with 100 g weight, which is allowed to penetrate the asphalt cement sample for 5 seconds. At least three determinations at points on the surface of the asphalt sample not less than 10 mm from the side of the container and not less than 10 mm apart are conducted as shown in Table 12. Penetration test can be performed at different temperature 0, 4, 45, 46.1 °C. The difference in performance among these temperatures is weight of needle and time of penetrating. The depth of penetration is measured in units of tenth (0.1) of millimetre and reports as penetration units.

Table 4. Penetration test results

NO.	Penetration (0.1 mm)
1	95
2	83
3	89
Average	89

2.2.2. Softening Point

According to ASTM D36–06 Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus), the softening point is the temperature at which asphalt can't support the weight of steel ball and starts flowing. Test is performed by immersing ring–and–ball apparatus in the distilled water (30 to 80 °C), USP glycerine (80 to 157 °C) or ethylene glycol (30 to 110 °C). Steel ball has 9.5 mm (3/8 inch) diameter and 3.50 ± 0.05 g weight. This test was conducted in distilled water and results are shown in Table 5.

Table 5. Softening point test result

NO.	Temperature
1	48.6
2	47.3
3	44.5
Average	46.8

2.2.3. Ductility

The ductility test is conducted according to ASTM D113–07, Standard Test Method for Ductility of Bitumen Materials. The aim of ductility test is to measure the distance asphalt that can stretch before breaking. Test is made at a temperature of 25 ± 5 °C and with a speed of 5 cm/min. Test specimen is placed in the water at a specified temperature for 90 ± 5 min to be brought to the test temperature. Table 6 presents the results.

Table 6. Ductility test result

NO.	Ductility, cm
1	+100
2	+100

2.3. Polypropylene

The physical properties of polypropylene fibers used in this study are summarized in Table 7.

Table 7. Physical properties of polypropylene fiber

Properties	Specification data
Type	Polypropylene, 100%
Cross Section	Round
Specific Gravity	0.91 gr/cm3
Diameter	19 Microns
Melting Point	160-165 ºC
Softening Point	140-165 ºC

Tensile Strength	400 MPa
Fiber Length	6 mm, 12 mm, 19 mm
Modulus of Elasticity	4.1 GPa
Acid and Salt Resistance	High

2.4. Mix Design Method

In this study, Compound basis approach was selected. In this method, first bitumen and aggregate are mixed together for appropriate time (about 30 sec), and then they are introduced to polypropylene fiber. Polypropylene is applied in three lengths 6, 12 and 19 mm. The polypropylene was added in 0.1, 0.2, 0.3, 0.4 and 0.5% of the total mix weight. The optimum bitumen was found to be 5%.

Asphalt mixing method is implemented based on ASTM-D1559. The Marshall test is an empirical test in which cylindrical compacted specimens (Figure 2), 100 mm in diameter by approximately 63.5 mm in height, are immersed into the water at 60°C for 30–40 min. Then, they are loaded to failure using the curved steel loading plates along a diameter at a constant compression rate of 51 mm/min. The Marshall stability value is the maximum force recorded during the compression while the flow is the deformation recorded at maximum force. Other regarding quantities are computing relations of mixing design is specified by Marshall method.

Figure 2. Compacting the samples

Figure 3. Fiber-reinforced specimens

3. Results

As it can be seen in Figure 4 by increasing percentage of polypropylene, Marshall Stability goes high and also providing higher stability with longer polypropylene is observed. Flow is also developed got lower by adding higher percentage of polypropylene in percentage and length (Figure 5). Results for modified asphalt with 0.1% of 6 mm long polypropylene additive by weight of total mix are: Marshall Stability 901 kg and Flow 4.7 mm.

For 0.5% of 19 mm long polypropylene by weight of total mix, in this percent of polypropylene Marshall Stability jumped up to 1248 Kg which improved Stability for about 38%, Flow was 3.4mm which decreased for 39%.

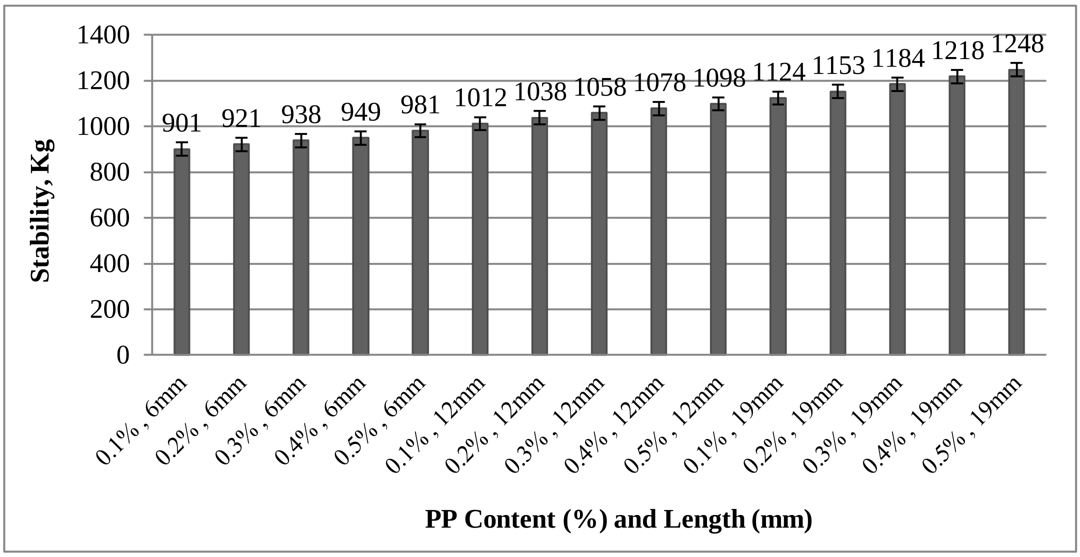

Figure 4. Marshall Stability results at various contents

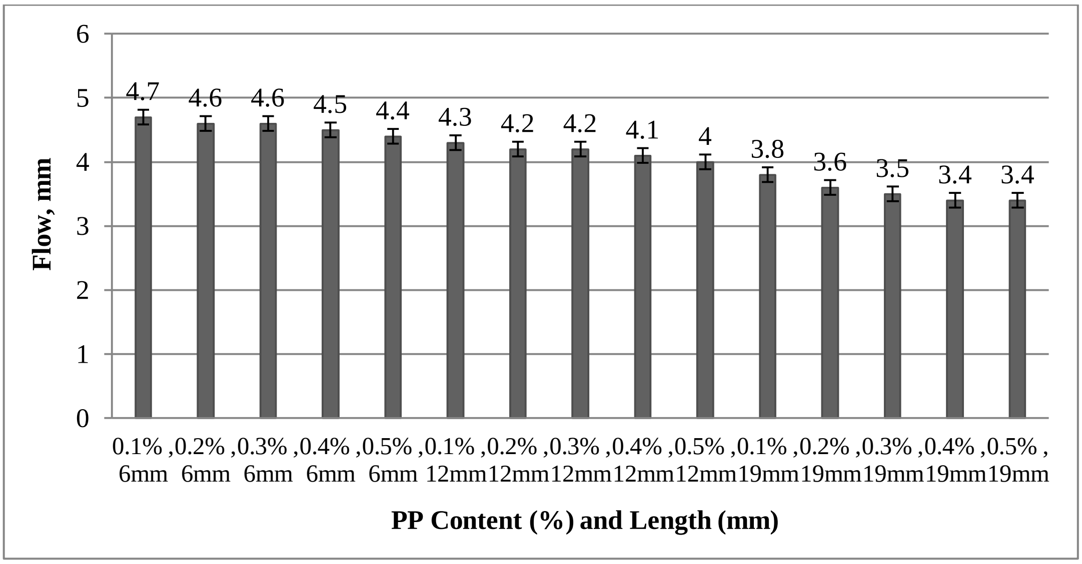

Figure 5. Flow Results at Various Contents

Figure 6. Marshall test

As the results show 0.5% PP with length of 19mm is better than the rest of percentages. Also, it is clear that polypropylene can be helpful for increasing pavements life as other studies are also show this improvement.

4. Conclusion

Asphalt concrete pavements are being preferred over Portland cement concrete pavements because of their low initial cost. This advantage can be minimized if the mix design is not suitable for the road class and traffic composition. In addition to extra cost of these repairs, the traffic disruptions take also place. The base reason of this study was on increasing flexible pavement life by improving HMA characteristics. To solve this problem, Polypropylene (PP) additive was selected because of locally available situation, being as a low-cost additive and having good correlation with HMA according to previous studies. Different percentages (0.1%, 0.2%, 0.3%, 0.4% and .5%) of 6, 12 and 19 mm long PP were added to asphalt mixture with optimum percent of asphalt (5% by weight of total mix), to investigate the difference in asphalt characteristics. It was concluded that 0.5% of 198 mm polypropylene is better than the other percentages and lengths as proved by the results of Stability and Flow.

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