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THE EFFECT OF USING POLYPROPYLENE FIBER ON DEFORMATION RESISTANCE OF ASPHALT CONCRETE

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Abstract- Asphalt concrete (AC), a mixture of bitumen and aggregates is one of the widely used material in Civil Engineering with an approximate worldwide usage of 102 million tons annually. Since the pavement construction is only expected to increase with time, scientists and engineers have been putting great effort into improvement of the performance of asphalt pavements from both the functional and sustainability perspectives. Binder has been of special focus in this regard and has been modified with the addition of various fibers in one of the recognized techniques to improve the Asphalt Concrete. Fibers modified asphalt is referred to as Fiber-Reinforced Asphalt-Concrete (FRAC). One key fiber that has shown promising outcomes is polypropylene fiber. In this study, we investigated FRAC materials modified by polypropylene fiber inclusion and its effect on the deformation resistance. The Effects of modification were also observed on the mixing procedure. Results showed that the Optimum Binder Content increases 10-11% and the stability of the polypropylene fiber modified asphalt pavement increases up to 14% however, the flow values decrease up to 7-8%. Addition of polypropylene fibers significantly improved the deformation resistance of asphalt. In addition to achieving the asphalt mechanical improvement through polypropylene fibers lead to the concept of a new market to utilize the waste fiber thereby lessening the environmental consequences.

Keywords- Asphalt Concrete, Fiber-reinforced asphalt concrete (FRAC), Polypropylene Fiber.

INTRODUCTION

Intra country transport communication is so vital that it has become one of the integral functions of both economic stability and progress. However, pure, and unmodified asphalts used in Pakistan are prone to temperature cracking due to weather extremities. Other distresses like alligator or fatigue cracking and rutting are also seen on the roads in Pakistan due to improper mix-design and inadequate compaction. A resultant penetration of water is caused by these distresses leading to partial or complete pavement-failure, making it necessary to improve the properties of pavement. Being a viscoelastic material, pavement performance such as rut resistance owes itself greatly to bitumen. In hot weather extremes problem is aggravated due to bitumen's lower stiffness [1].

These limitations call for research and innovation in materials and techniques and innovations in pavement engineering to advance the pavements in terms of durability and resistance to distresses and thereby requiring lesser maintenance [2]. The research to achieve these goals has culminated into development of the techniques that are collectively known as 'modification of asphalt' [3]. They employ various types of fibers and polymers that are applied to the asphalt [4]. Fiber application is very advantageous for increased durability as it improves fatigue and rutting resistance, increases service life, and reduces thermal cracking [2, 5]. In conventional mixes, Fiber-reinforced asphalt concrete materials (FRAC) materials are used for overlays or maintenance of pavements and bridge-deck membranes. They are also used in composite pavements and multi-course flexible pavements [6].Test like Indirect Tensile Test (IDT), Marshall Stability, susceptibility to moisture damage, susceptibility to freeze/thaw, modulus of resilience, and deformation under repeated load performed by Simpson and Kamyar after modifying the mix by adding polyester fibers, polypropylene, and some other polymer sand showed an increased tensile strength and cracking resistance for polypropylene-modified mixtures of polymers. Under repeated load deformation test, rutting potential was observed to reduce only in polypropylene-modified specimens [7].

Polypropylene addition into the asphalt concrete in a dry basis increases Marshall stability values, decreases flow values and increases the fatigue life in a marked way [8]. Stiffness of bitumen also increases with the addition of *polypropylene fibers* resulting in more stiff mixtures with reduced drain-down and increased fatigue life [9]. Another research shows that addition of *polypropylene* into asphalt has shown the decrease in the Marshal Flow (38%), increase in stability values (26.3%) and increase in air voids (67.5%) [10]. As far as the bonding and strengthening of bitumen is concerned, polypropylene fibers depict excellent results [11]. Also, for consistent fiber lengths at lower temperature, higher fiber contents have shown higher strengths and fracture toughness [12]. Earlier, limitations have been showed in the mixing process of polypropylene fibers using dry method [13]. This study use different percentages of polypropylene fiber incorporating small size (i.e. 6mm) to explore the impact of smaller fiber size on dry mixing process [14]. Marshal Stability test was performed for flow and stability values to investigate polypropylene fiber's impact on Optimum Binder Content (OBC) and to find resistances against distresses in asphalt concrete.

1.1 Polypropylene Fiber

Polypropylene is a 100 percent synthetic fiber formed of 85 percent of monomer 'propylene (C_3H_6)' which is a hydrocarbon. Having high molecular weight and mode, the propylene polymerizes to produce polypropylene fibers with very useful properties like lowest density, less moisture absorption, excellent resistant to chemicals, acids and alkalis, and lower conductivity in comparison to other synthetic fibers. Different types of polypropylene fibers classified based on length, diameter, density, and strength (Modulus of elasticity) are shown in Table 1.

Table 1 - Different types of polypropylene fiber **[15]**

Fiber type	Length (mm)	Diameter (mm)	Tensile strength (MPa)	Elastic modulus (GPa)	Specific surface area (m^2/kg)	Density (kg/cm^3)
Mono-filament	30 - 50	0.30 - 0.35	547 - 658	3.50 - 7.50	91	0.90
Micro-filament	12 - 20	0.05 - 0.20	330 - 414	3.70 - 5.50	225	0.91
Fibrillated	19 - 40	0.20 - 0.30	500 - 750	5.00 - 10.00	58	0.95

Asphalt modification with addition of polypropylene fiber shows higher performance grade for rutting resistance at increased temperature. Also, this modification reduces the susceptibility of asphalt to changes in temperature. Additionally, benefits like drain down prevention and improved fatigue performance by enhancing crack resistance of asphalt material are also achieved.

RESEARCH METHODOLOGY

Initially, aggregate to be used for the project was selected and brought from Margalla stone quarry. Then the bitumen grade of 60/70 was selected. Based on material properties, a fine gradation of NHA class B was preferred over the NHA class A gradation. After having performed the requisite testing on the materials, the challenge to prepare mix and to select percentage of fibers for Marshal Mix Design was overcame by reviewing the literature. The dosages of 0.5% and 1.0% were selected by weight to determine Optimum Binder Content through Marshal Mix Design, after studying various studies. After OBC determination, sample of slab was prepared for indirect tensile test separately for control mix and reinforced fiber mix for performance analysis. Dry method was used to mix the fibers with aggregate and bitumen. In the end, a comparison was drawn for different results obtained from unmodified, 0.5% polypropylene modified and 1% polypropylene modified asphalt concrete. A conclusion was drawn through experimental results.

EXPERIMENTAL DETAILS

Various type of tests performed on the aggregate, bitumen and asphalt concrete mixtures have been discussed. For this study, Class B aggregate of NHA Specification was used because it is easy to make a comparison of the test results in case of fine classifications. The physical properties of the aggregate and bitumen used in this study are listed in Table 2. Dry method has been used in this study to add the polypropylene fibers into the asphalt concrete mixture as this method has been well established among the researcher for the successful addition of polypropylene fibers into the asphalt mixture [2, 10, 16]. In dry method, fibers are added to the pre-heated aggregate in accordance with ASTM-D1559 standard. After this, bitumen is added to the aggregate & fiber mixture gradually and Marshall Mix design test is performed on unmodified and polypropylene modified asphalt concrete samples to select suitable type of aggregate and corresponding economical asphalt binder content. This recommended mixture is known as job-mix formula (JMF).

1.2 Sample Preparation.

Minimum requirement of NHA is of 3.5 percent of asphalt content by weight of the total mixture for Class A and Class B. Normally, bitumen in 3 to 6 percent by total weight of mixture is added for the OBC determination. Mixture for fiber-modified and unmodified mixtures was prepared for 3.5, 4.0, 4.5, 5.0, and 5.5% asphalt. Three samples, two compacted and one loose one with a total weight of each sample 1200g are prepared. 0.5% (6g) and 1.0% (12g) fiber by weight of the total sample were added. Compacted samples were prepared at first by the dry method and after being placed in testing mould, 75 blows on each side were subjected using hammer of 4.5 kg. Resultant sample was cylinder with 4-inches inner diameter and 2.5 inches height. Mixture was then prepared for the loose sample with no compaction effort (Blows). Calculation of values different parameters was the performed using the formulae listed in Table 3.

Table 2 - Physical properties of the aggregates and bitumen

Aggregates			**Bitumen**		
Source		Margalla stone quarry	**Test Name**	**Value**	**ASTM Standard**
Type		100 % crushed	Penetration Test (25°C)	60 - 70	ASTM D5
Los-Angeles Abrasion Value		24.92 %	Flash point	146°C	ASTM D92
Soundness	Coarse aggregate	3.10 %	Softening point	48°C	ASTM D36
	Fine aggregate	4.60 %	Ductility (5cm / min)	> 100 cm	ASTM D113
Elongation Index		2.90 %	Specific gravity	1.034	ASTM D70
Flakiness Index		5.80 %			
Sand Equivalent		72 %			

Table 3 – Different parameters for Marshal Stability Test

Bulk specific gravity of aggregates, $\boldsymbol{G_{sb}}$	$G_{sb} = \frac{P_1 + P_2 + \cdots\cdots + P_N}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \cdots\cdots + \frac{P_N}{G_N}}$	Voids in Mineral Aggregates, VMA	$VMA = 100 - \frac{G_{mb} \times P_s}{G_{sb}}$
Effective specific gravity of aggregate, $\boldsymbol{G_{se}}$	$G_{se} = \frac{P_{mm} - P_b}{\frac{P_{mm}}{G_{mm}} - \frac{P_b}{G_b}}$	Air voids, $\boldsymbol{V_a}$	$V_a = 100 \times \frac{G_{mm} - G_{mb}}{G_{mm}}$
Effective Asphalt Content, $\boldsymbol{P_{be}}$	$P_{be} = P_b - \frac{P_{ba}}{100} \times P_s$	Voids filled with asphalt, VFA	$VFA = 100 \times \frac{VMA - V_a}{VMA}$

1.3 Determination of stability using Marshall Stability and Flow Test.

Stability maybe defined as the maximum load resistance of the sample and flow is defined as the deformation corresponding to maximum load (Stability) at standard temperature of 60°C. For determining stability, compacted Marshall samples are kept in the water bath at 60°C ±1°C temperature for 30 to 40 minutes and then tested in Marshall Stability tester. Loading is applied on the specimen at constant rate of 51 millimeters per minute, until sample fails. Total number of Newton (lbs.) or kgs force at which sample fails is recorded as Marshall Stability value. Deformation corresponding to this force is recorded as flow and expressed in units' of 1/100 inches.

a) b) c) d)

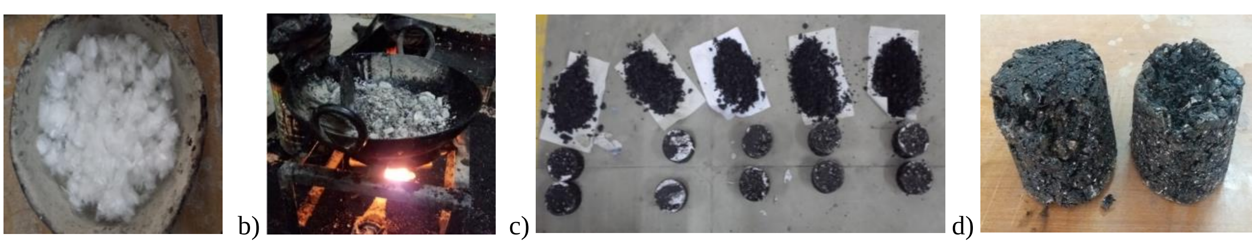

Figure 1: a. Polypropylene fibers before addition. b. Polypropylene-fiber modified sample being prepared. c. Compacted and loose samples ready for Marshall stability test. d. Polypropylene-fiber modified samples after Stability test

1.4 Calculation of Optimum Binder Content.

After calculations six graphs are plotted between asphalt content on x-axis and unit weight, VMA, VFA, V_a, flow, and stability on y-axis. Of the various methods used worldwide to find out Optimum Binder Content are used worldwide, one is to use following three graphs against mentioned criteria for the calculation of optimum asphalt content (a) Bitumen-content against maximum stability (b) Bitumen-content against maximum unit-weight (c) Bitumen-content against 4% air voids. Average of all three asphalt contents obtained from above three graphs is reported as optimum asphalt content (OAC) or optimum bitumen content (OBC).

RESULTS

The results of various tests performed on the asphalt concrete mixtures and their analysis, have been discussed. Results of three kind of asphalt concrete mixtures were tabulated. Graphs between unit weight, VMA, VFA, V_a, stability and flow against asphalt content have been plotted. For modified mixture, results showed in Table 4 reveal that the optimum binder content's value increases by adding polypropylene fiber. Also, stability of the mixture increases, and flow decreases as compared to unmodified samples.

Table 4 - Optimum binder content of unmodified and Polypropylene modified mixtures

Criteria	Unmodified		Polypropylene Modified			
			Fiber percent		OBC	
		OBC	0.5	1.0	0.5	1.0
Bitumen-content against maximum stability	4.5	4.57	4.5	4.45	5.08	5.05
Bitumen-content against maximum unit-weight	4.7		5.5	5.5		
Bitumen-content against 4% air voids	4.5		5.25	5.2		

Figure 2 to Figure 4 show graphical plot between asphalt content and various parameters of Marshall test for unmodified and fiber modified asphalt mixtures. Stability of the polypropylene fibers samples is more when compared to the unmodified or control samples with 0.5% PP-fiber modification being more stable than 1.0% PP-fiber modified asphalt mixture, meaning that low polypropylene fiber content can achieve greater stability as compared to higher one. Flow values of polypropylene modified samples are less than those of control samples which means modified samples are more stable against the traffic loads.

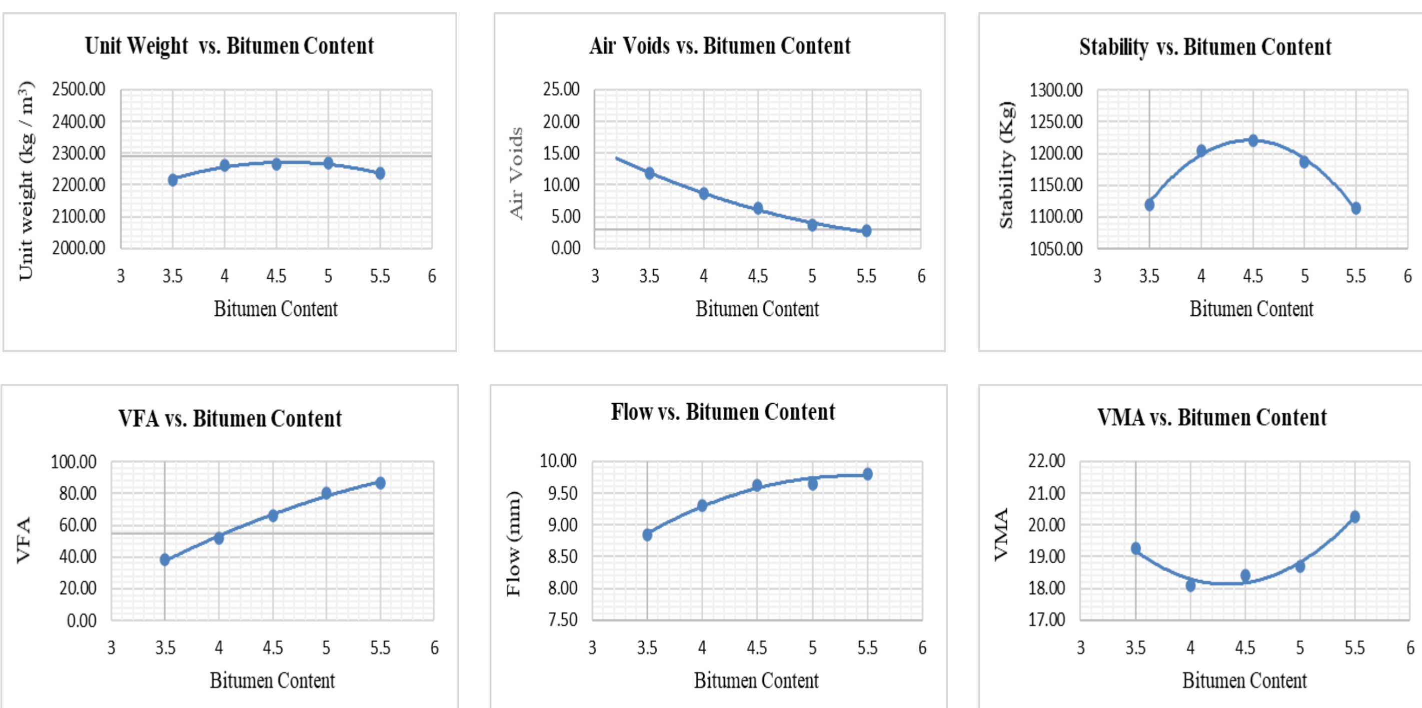

Figure 2 – Graphs for unmodified mixture

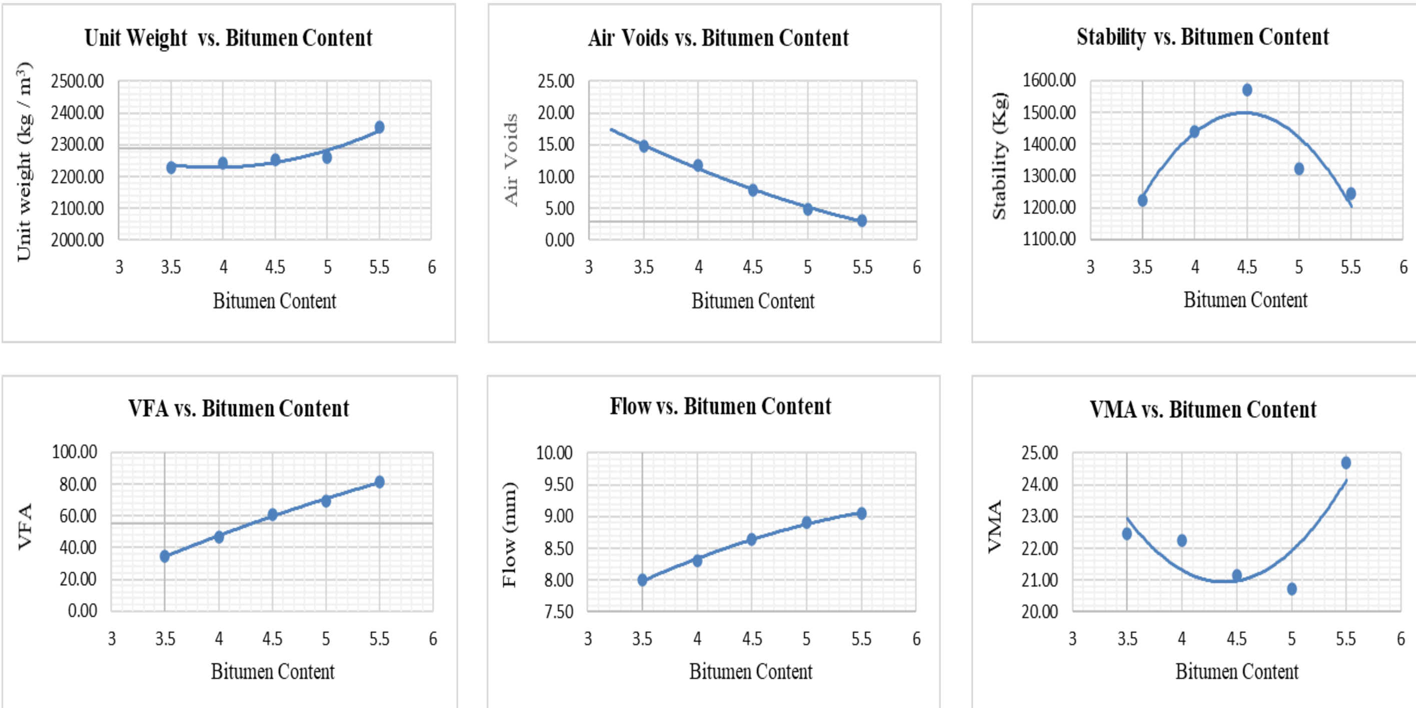

Figure 3 – Graphs for 0.5% polypropylene modified mixture

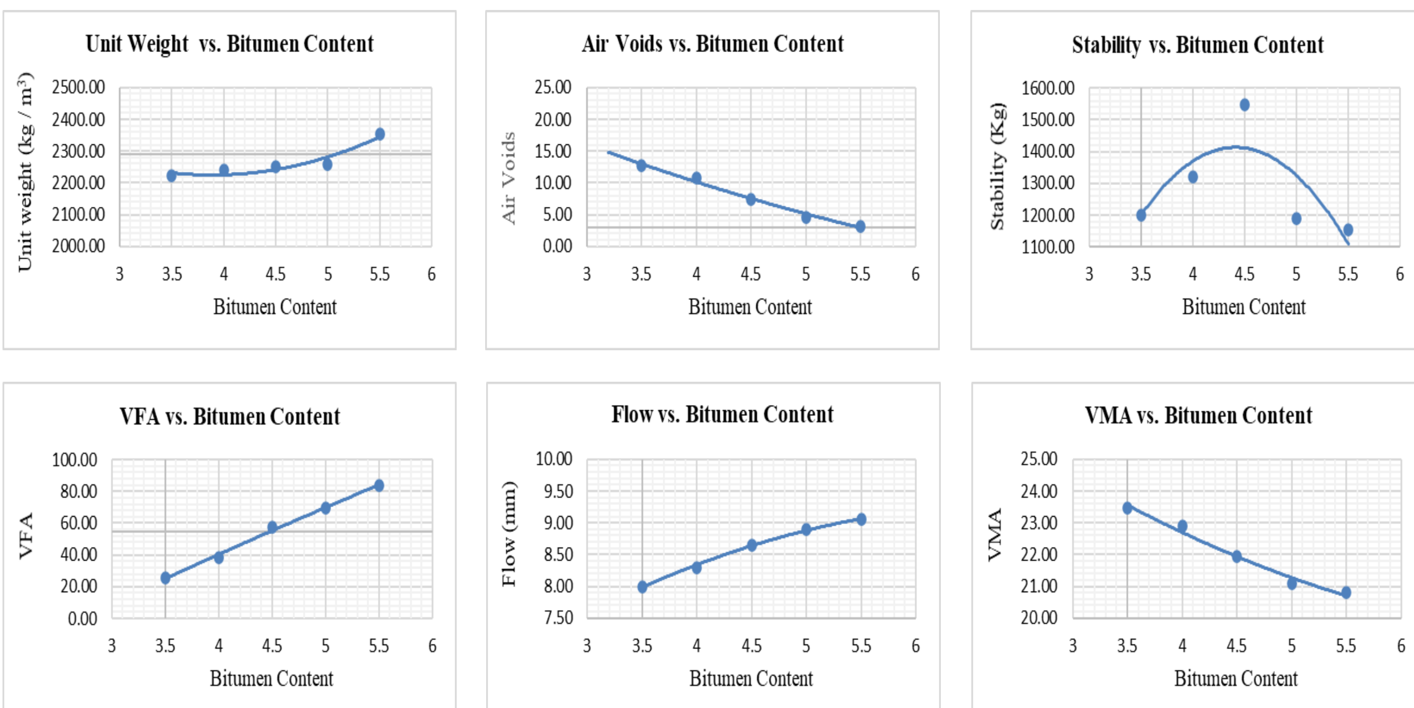

Figure 0 – Graphs for 1.0% polypropylene modified mixture

Figure 5a reveals the stability of 0.5% polypropylene fiber modified sample is highest among all other samples at OBC while Figure 5b shows minimum flow at optimum asphalt content in case of 0.5% PP-modified samples as compared to other samples. Also, mix-design criteria at optimum binder content is also verified for control and PP-modified samples.

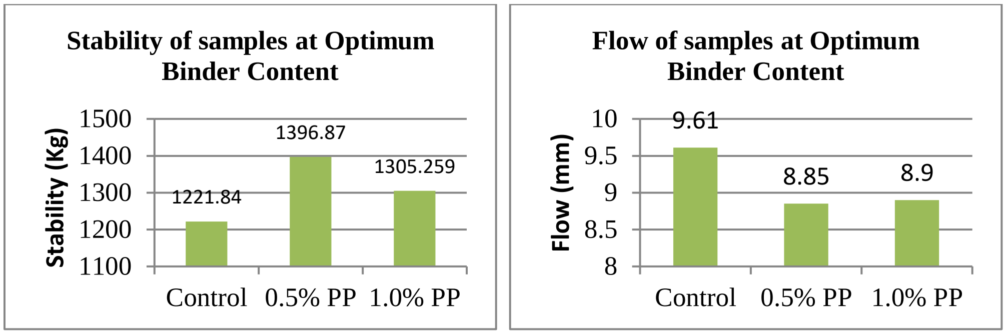

Figure 5 – a. Stability of the control & modified samples at OBC. b. Flow of the control & modified samples at OBC

CONCLUSION

In this study, polypropylene fibers were used as modification in asphalt concrete. Main purpose of this research was to study the effect of the fiber addition in dry method in the asphalt mixture and the performance of hot mix asphalt. 0.5% and 1.0% by weight polypropylene fiber was added to asphalt mixture for the analysis. It is concluded from the results that polypropylene fibers modification has improved various properties of the HMA. For example, polypropylene addition significantly improved the stability of the asphalt mixture up to 14% and Optimum Binder Content up to 10-11%. With polypropylene fiber addition, VFA, overall unit weight, air voids and flow decreased in comparison to unmodified asphalt mixture. Modified mixture gave best performance at 0.5% polypropylene fiber.

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