2nd Conference on Sustainability in Civil Engineering (CSCE'20)
Department of Civil Engineering
Capital University of Science and Technology, Islamabad Pakistan

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

[a] Muhammad Fawad Rashid, [b] Naveed Ahmad, [c] Ahtsham Ahmed

a: Department of Civil Engineering, University of engineering and Technology Taxila, fawad04ce2k14@gmail.com
b: Department of Civil Engineering, University of engineering and Technology Taxila, n.ahmad@uettaxila.edu.pk
c: Department of Civil Engineering, University of engineering and Technology Taxila, iamahtsham@gmail.com

Abstract- *Asphalt concrete (AC*), a mixture of bitumen and aggregates is highly temperature sensitive and an equally important material used in civil engineering due to its utility and universal usage and thereby making it one of the highly researched area in the field with a focus on improving the Asphalt concrete. Of the many approaches, modification of the asphalt binder is one that focuses on addition of external agents for improving *Asphalt Concrete*. Nowadays, different materials are used to reinforce asphalt concrete. Fibers have made a reputation for themselves among the other modifiers used mainly due to the promising results that they have shown. Steel fiber modified asphalt is referred to as steel fiber-reinforced asphalt-concrete (SFRAC). This study investigates the usage of steel fiber as a modifier and its results on the deformation resistance of the *Asphalt Concrete*. The whole process was investigated carefully to observe the effects steel fiber on the mixing procedure of Asphalt Concrete during the manufacturing phase, and performance of asphalt concrete was inspected later using several laboratory tests. Results showed that the Optimum Binder Content increases 4-6% however, the stability of the steel fiber modified asphalt pavement decreases up to 20% and hence causes no significant improvement in deformation resistance. This reduction in the stability is mainly due to the insufficient bonding of the steel fiber with asphalt concrete. Whereas, from the sustainability perspective, it leads to concept of the new market to utilize waste fibers.

Keywords- Asphalt Concrete, Asphalt Mechanical Improvement, Fiber-reinforced asphalt concrete (FRAC), Steel Fiber.

INTRODUCTION

Intra-country transport acts as the lifeline for the trade and communication in a country. Different kinds of distresses can develop in hot-mix asphalt (HMA) which affect the structural and functional performance of pavement. In hot summers, bitumen becomes soft and when pavements are subjected to heavy loading of traffic vehicles, bitumen consolidation or lateral movement of materials take place, causing development of stresses. Above scenario necessitates research for new materials and innovations in pavement engineering to make the pavements more durable and more resistant to the distresses leading to a lesser requirement for maintenance [1]. To minimize the drastic effects of weather and traffic, various methodologies and techniques have been invented to make the performance of flexible pavements better, known as 'modification of asphalt' [2]. Various types of fibers and polymers are applied to the asphalt for this purpose [3].

It is imperative to have an idea of other research in this field before discussing the approach of this study. Nowadays, the steel fibers are used to take the stresses at the top layer of pavement which is subjected directly to the effects of loading and wear and tear [4]. Other studies on distribution of steel wool have revealed that a poor distribution is achieved when long and thin fibers are used. On the contrary, short, and thick fibers have shown better dissemination in the mixture. The impact of steel on properties like the porosity and electrical conductivity of dense asphalt concrete has also gained attention of the researchers.With regard to the particle loss resistance and flexural strength of dense asphalt concrete, no relevant improvement has been reported [5]. Recently, futuristic applications of electrically conductive asphalt concrete have been studied with a great zeal. Although it can be achieved using both the steel fiber and graphite, steel fiber has been proven to be more effective in improving the conductivity of asphalt concrete[6]. Steel fiber modified FRAP shows it as a promising material for highway pavement due to its high performance in crack regulation [7]. Cracking in low temperature, bleeding in high temperature and water damage are major contributors towards the deterioration of the pavement. The test results of rutting test, low temperature bending test, freeze-thaw splitting test have been compared with the stability in high temperature, anti-cracking performance in low temperature and the water stability between steel fiber asphalt concrete and the ordinary asphalt concrete. The conclusions drawn from these comparisons suggest that steel fiber addition in the asphalt concrete can effectively contribute towards the performance of the road [8]. Recent researches have opened a way for other promising prospects for fiber modification such as the electrothermal applications by incorporation of conductive fibres (e.g. carbon and steel fibers). Adding electrothermal properties broaden utility scope of asphalt concrete in a more futuristic way. Applications such as de-icing, snow and ice removal, self healing through induction heating, snow and ice removal and energy harvesting are some key areas in this regard [9-13]. The current work focused on increasing the lifetime and enhancing the performance of asphalt concrete roads by using steel fibers as additive material. For this purpose, Marshall test is performed using different fiber percentages and binder contents.

1.1 Steel Fiber:

Steel fibers are filaments of wire, cut to defined length, and used for the preparation of fiber-reinforced concrete, mortar, and other composite materials. Steel fibers generally have 0.3 to 1.1 mm diameter and 15 to 50 mm length. As compared to polypropylene fibers, steel fibers have very high modulus of elasticity making it a superior choice in many applications. Some of the properties of steel fibers are shown in Table 1.

Table 1 - Properties of commonly used steel fibers

Relative density	Diameter, mm (0.0001 in.)	Tensile strength, MPa	Modulus of elasticity, MPa	Strain at failure, %
7.8	100 - 1000	500 - 2600	210000	0.5 - 3.5

Although the work is still being done for developing the mixing methods of fibers with the asphalt concrete, yet the addition of short random fibers in asphalt concrete does not require much additional effort. Along with the improvisation in the mechanical performance of the asphalt pavements, the innovative prospects offered by the Steel fiber reinforced asphalt concrete (SFRAC) make it a candidate for improving sustainability and lifecycle costs.

RESEARCH METHODOLOGY

Initially, aggregate to be used in the project was selected. For aggregate, Margalla stone quarry was selected, and material was brought from there. Then bitumen grade was selected, and it was 60/70. Based on material properties, gradation was selected which was NHA class B which is a fine gradation as compared to NHA class A gradation. Different tests were performed for aggregates and bitumen. Next challenge was to prepare mix and select amount of fibers for Marshal Mix Design. The methodology adopted for this work is shown the figure below:

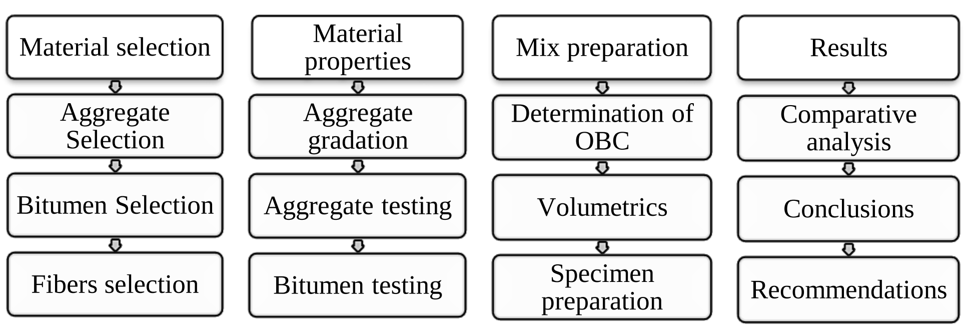

Figure 1: Scope and Methodology of the Work

Literature was reviewed to get the optimum amount of fibers for Marshall Mix Design. After reading different studies, the dosages of 0.5% and 1.0% were selected by weight to determine Optimum Binder Content through Marshal Mix Design. 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% steel modified and 1% steel 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 are listed in Table 2.

Table 2 - Physical properties of aggregate and bitumen

Aggregate			**Bitumen**		
Source		Margalla stone quarry	**Test name**	**Value**	**Standard**
Type		100 % crushed	Penetration (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 %			

Dry method has been used in this study to add the steel fibers into the asphalt concrete mixture. Reason to use the dry method is that various researchers have used this method for addition of fibers into the asphalt mixture [1, 14]. Aggregates and bitumen were pre-heated in accordance with ASTM-D1559. Steel fibers were then added gradually into the mixture. Now Marshall mix design test is performed on unmodified and steel modified asphalt concrete samples. Main objective to perform the Marshall mix design test is to select as suitable type of aggregate and corresponding economical asphalt binder content. This recommended mixture is known as job-mix formula (JMF).

1.2 Sample Preparation.

NHA requires minimum 3.5% of asphalt content by weight of the total mixture for Class A and Class B. Normally, bitumen in 3 to 6% by total weight of sample 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 are prepared. Two compacted samples, and one loose sample. Total weight of each sample is 1200 g. 0.5% (6g) and 1.0% (12g) fiber by weight of the total mixture were added. First, compacted samples were prepared. For this, mixture was prepared by the dry method and then it was placed in the testing mould. Hammer of 4.5 kg was used for compaction dropped from a height of 18in. 75 blows are applied on both sides of the specimen. Resulted compacted sample was cylinder having 4-inches inner diameter and 2.5 inches height. Mixture was prepared for the loose sample, and no compaction effort (Blows) was applied on it. Now calculate values of different parameters by formulas listed in Table 3.

Table 3 – Different Parameters for Marshall 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	$VFA = 100 \times \frac{VMA - V_a}{VMA}$

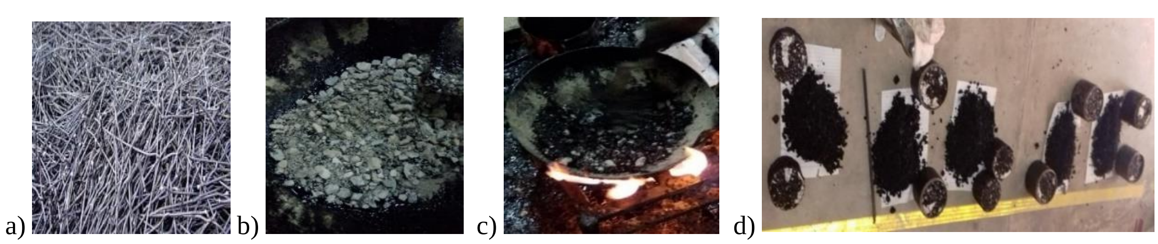

Figure 2: a. Steel fibers used. b. Steel fibers after addition. c. Steel-fiber modified sample being prepared. d. Compacted and loose samples ready for Marshall Stability test

RESULTS

The results that were obtained from various tests performed on the asphalt concrete mixtures and their analysis, have been discussed. Results of three kind of asphalt concrete mixtures were tabulated in Table 4. Graphs between unit weight, VMA, VFA, V_a, stability and flow against asphalt content have been plotted. The results showed that with the addition of steel fibers, volume of air voids (V_a) and voids in mineral aggregates (VMA) increase with a decrease in the VFA values and unit weight of the modified mixtures in comparison to control samples.

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

Criteria	Unmodified		Steel Fiber Modified			
			Fiber percent		OBC	
		OBC	0.5	1	0.5	1
Bitumen-content against maximum stability	4.5	4.57	4.25	4.15	4.75	4.85
Bitumen-content against maximum unit-weight	4.7		5.5	5.5		
Bitumen-content against 4% air voids	4.5		4.5	4.5		

Graphs between asphalt content and various parameters of Marshall test for unmodified and steel fiber modified asphalt mixtures have been plotted. It is also evident from the Figure 3 to Figure 5 that steel modification has negative impact on the performance of asphalt concrete. The reason is that the stability values of steel modified samples are less as compare to those of unmodified samples and flow is more than that of unmodified samples.

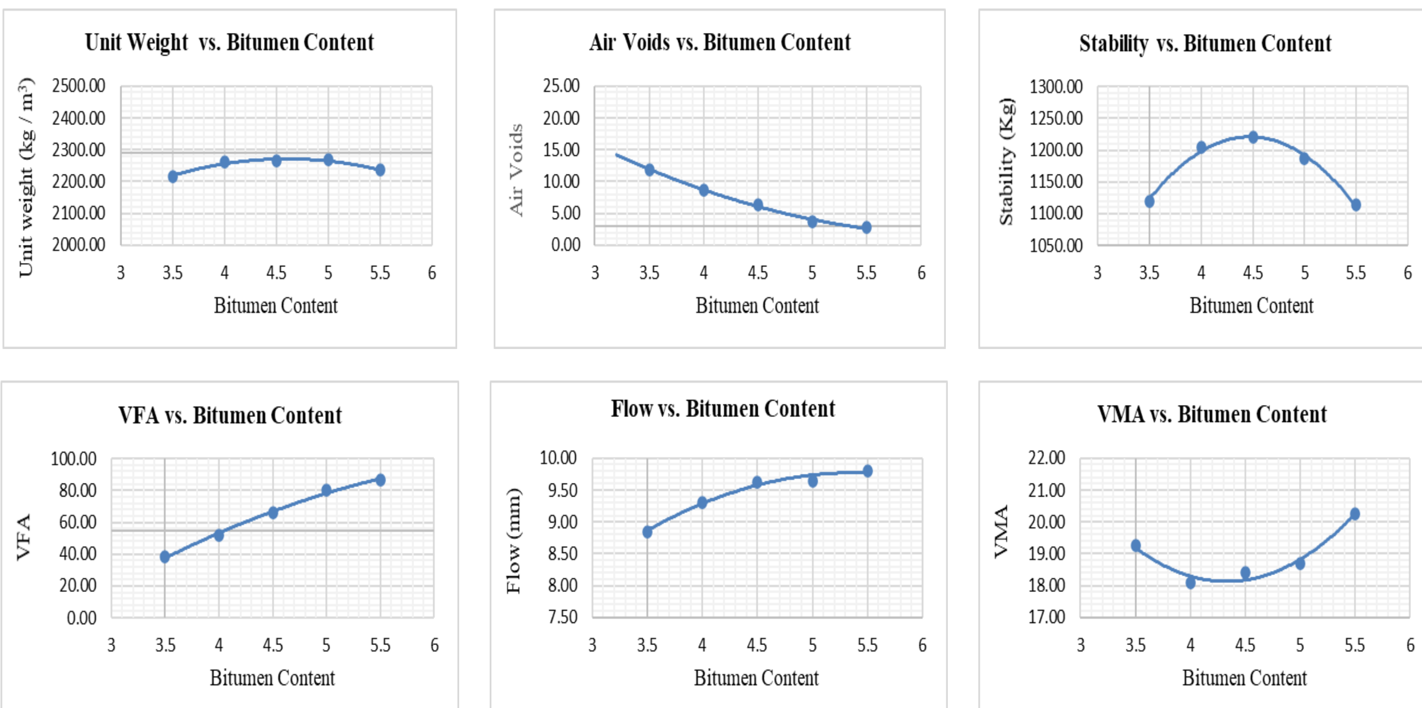

Figure 3 – Graphs for unmodified mixture

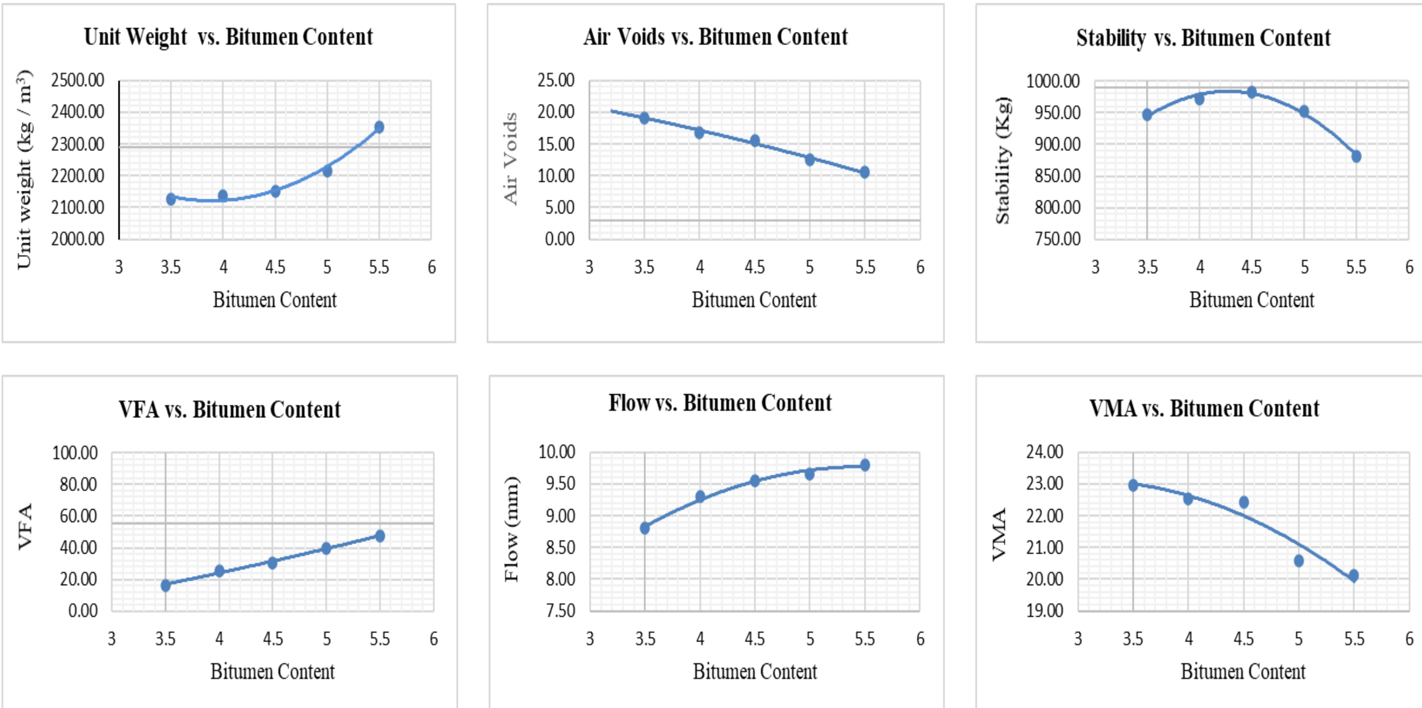

Figure 0 – Graphs for 0.5% steel modified mixture

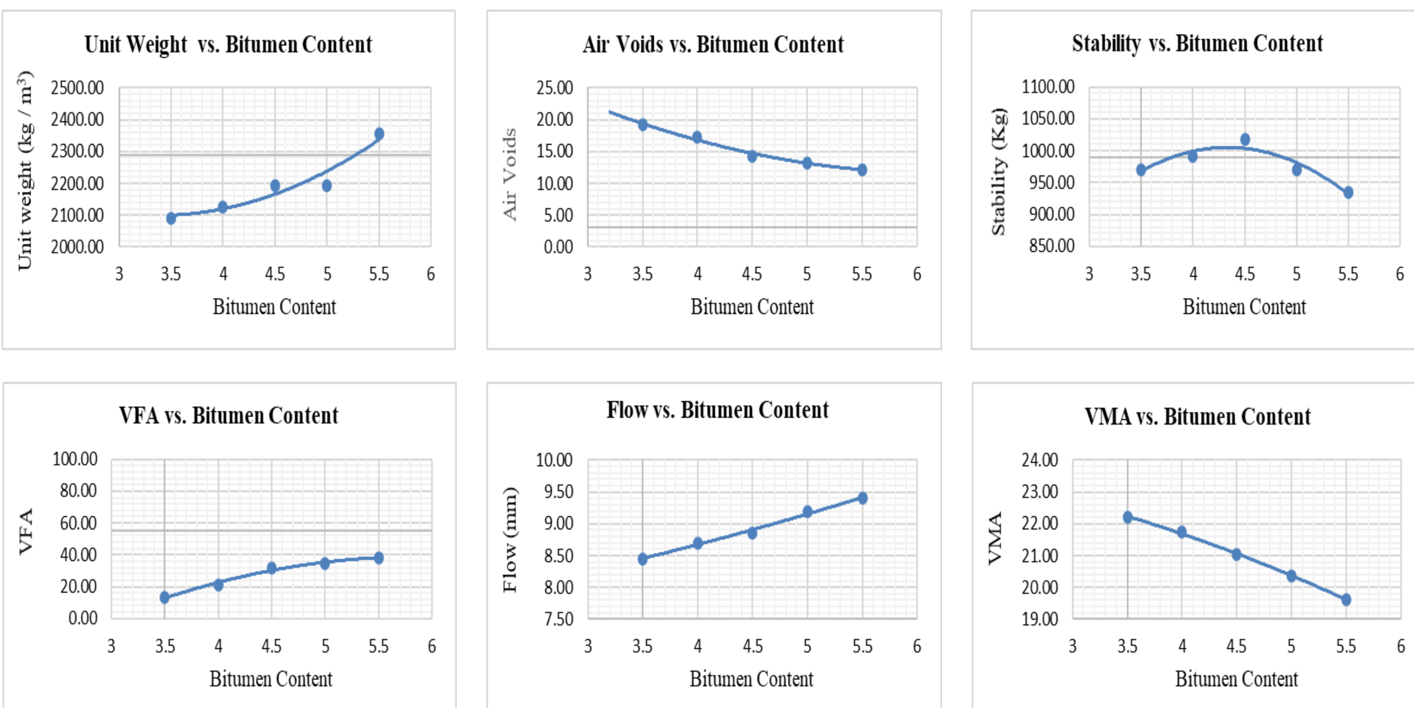

Figure 5 – Graphs for 1.0% steel modified mixture

We can see in Figure 6a that, Steel fiber modified samples have shown lowest stability at the optimum binder content. It is evident from the Figure 6b that, at optimum asphalt content, flow values in steel modified samples are comparatively highest. Also, mix-design criteria at optimum binder content is not satisfied for steel-modified samples.

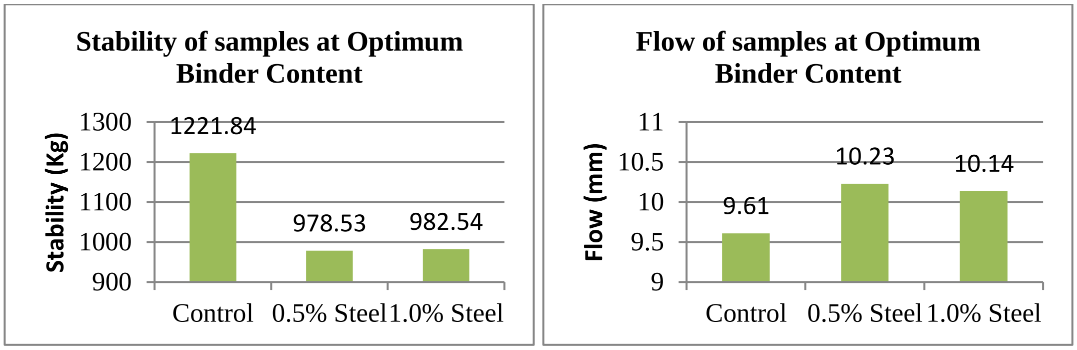

Figure 6 – a. Stability of the control & modified samples at OBC. b. Flow of the control & modified samples at OBC

CONCLUSION

In this study, steel fibers were used as modification in asphalt concrete. Main purpose of this research was to study the effect of the fiber addition using dry method in the asphalt mixture and the performance of hot mix asphalt. 0.5% and 1.0% by weight steel fiber was added to asphalt mixture for the analysis. It is concluded from the results that steel modified asphalt mixtures did not show good performance as the stability decreases up to 20%. Possible reason for this was the incompatibility of the steel fiber with the asphalt mixture as adequate bonding could not take place, due to which stability values of such mixture were found to be less than control samples. However, steel fiber is good for increasing electrical conductivity of the pavement and applications related to it are prodigiously revolutionary.

ACKNOWLEDGMENT

The authors would like to thank Muhammad Asad Hayat and Muhammad Farhan Ahsan who helped thorough out the experimental work, particularly TITE department, UET Taxila for providing laboratory assistance.

REFERENCES

[1] A. Qadir, "Rutting performance of polypropylene modified asphalt concrete," *International Journal of Civil Engineering*, vol. 12, pp. 304-312, 2014.

[2] S. Tapkın, Ü. Uşar, A. Tuncan, and M. Tuncan, "Repeated creep behavior of polypropylene fiber-reinforced bituminous mixtures," *Journal of Transportation Engineering*, vol. 135, pp. 240-249, 2009.

[3] Y. R. Kim, *Modeling of asphalt concrete*, 2008.

[4] S. Serin, N. Morova, M. Saltan, and S. Terzi, "Investigation of usability of steel fibers in asphalt concrete mixtures," *Construction and Building Materials*, vol. 36, pp. 238-244, 2012.

[5] A. García, J. Norambuena-Contreras, M. N. Partl, and P. Schuetz, "Uniformity and mechanical properties of dense asphalt concrete with steel wool fibers," *Construction and building materials*, vol. 43, pp. 107-117, 2013.

[6] H. Wang, J. Yang, H. Liao, and X. Chen, "Electrical and mechanical properties of asphalt concrete containing conductive fibers and fillers," *Construction and Building Materials*, vol. 122, pp. 184-190, 2016.

[7] Y. Paluri, S. Mogili, H. Mudavath, and R. K. Pancharathi, "A study on the influence of steel fibers on the performance of Fine Reclaimed Asphalt Pavement (FRAP) in pavement quality concrete," *Materials Today: Proceedings*, 2020.

[8] J. F. Guo, "The Effect of Steel Fiber on the Road Performence of Asphalt Concrete," in *Applied mechanics and materials*, 2014, pp. 1342-1345.

[9] S. Wu, P. Pan, M. Chen, and Y. Zhang, "Analysis of characteristics of electrically conductive asphalt concrete prepared by multiplex conductive materials," *Journal of materials in civil engineering*, vol. 25, pp. 871-879, 2013.

[10] Q. Liu, E. Schlangen, and M. Van De Ven, "Induction healing of porous asphalt," *Transportation research record*, vol. 2305, pp. 95-101, 2012.

[11] A. García, M. Bueno, J. Norambuena-Contreras, and M. N. Partl, "Induction healing of dense asphalt concrete," *Construction and Building Materials*, vol. 49, pp. 1-7, 2013.

[12] A. Menozzi, A. Garcia, M. N. Partl, G. Tebaldi, and P. Schuetz, "Induction healing of fatigue damage in asphalt test samples," *Construction and Building Materials*, vol. 74, pp. 162-168, 2015.

[13] R. B. Mallick, B.-L. Chen, S. Bhowmick, and M. Hulen, "Capturing solar energy from asphalt pavements," in *International symposium on asphalt pavements and environment, international society for asphalt pavements, Zurich, Switzerland*, 2008, pp. 161-172.

[14] S. Esfandiarpour, "Hybrid Reinforcement of Asphalt-Concrete Mixtures Using Glass and Polypropylene Fibers," Eastern Mediterranean University (EMU), 2010.