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IMPROVEMENT OF MARSHALL PROPERTIES FOR HOT MIX ASPHALT BY USING CERAMIC FIBER

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ABSTRACT

Many road networks are using hot mix asphalt (HMA) to construct pavement layers. The Marshall method is the common procedure used in the design of the HMA and used at the time of the construction of the roadway to quality control. The present work is using ceramic fiber as a reinforcement to improve the characteristics of the HMA. The Marshall properties are examined by several tests such as Marshall stability test, and the flow test. The group of samples was made by utilizing 0.50, 1.0, 1.5, and 2.0 percentages of ceramic fibers by the total weight of the mixture. The results of the experiment showed the maximum Marshall stability occurred at a value of 1% ceramic fiber; the flow value decreased with increasing of fiber content, and the maximum Marshall quotient occurred at a value of 1% ceramic fiber. Also, the air voids, void filled with asphalt, and the void in mineral aggregate increased with increasing ceramic fiber content.

KEYWORDS: Ceramic Fiber, Hot Mix Asphalt, Marshall Test, Marshall quotient, The Volumetric properties.

1. INTRODUCTION

The road network in every country plays a main role in connecting the regions and cities with economic, cultural development, and socialite. The layer of asphalt plays an essential role in the protection of the road's structure by transferring compressive stresses from the upper layers to a lower one (subgrade). The paramount importance of this layer is efficiently providing safety and comfort for the roads users throughout their service life. Therefore, constructing asphalt pavement with the desired quality and suitable lifetime has been studied by designers (Cai et al., 2018). To distribute the stresses caused by the traffic loads and protect the underlying unrestrained layers from the impacts of water, asphalt paving mixtures are utilized as wearing or base layers in the roads pavement structure. Furthermore, it is known that the asphalt pavement is continually deteriorating under the combined actions of the environment and the traffic loads . The performance of asphalt pavement is defined as the ability of the road to satisfy the demand of the environment and the traffic along with its design life (AASHTO, 1993).

Recently, various types of additives have been used by researchers to improve asphalt mixture performance. These additive types include fly ash, polymers such as SBS, and fibers such as carbon or glass fibers, etc. (Mirhosseini et al., 2016; Khattak et al., 2013). Different types, sizes, and ratios of fibers have been utilized by many researchers to improve the asphalt mixture performance. Over the last decades, in most parts of the world, fibers have been used to reinforce the pavement materials. Through random distribution inside the materials or by applying oriented fibrous materials (Taherkhani, 2016).

Mahrez et al. (2005) found that the using of glass fibers reduced the stability and increased the rate of flow of asphalt mixtures. The fatigue life of the asphalt mixture is improved by increasing the cracking impedance and constant deformation because the fibers can withstand the stresses of structural created by traffic loads.

Salman et al. (2001) have been used four types of fibers included glass fiber, two types of steel fibers, and polypropylene fabric manufactured in local factories. They studied the influence of adding these four kinds of fibers onto the Marshall parameters. Also, they considered the effects of numerous compaction efforts on the properties of Marshall of the fiber-asphalt concrete mixture. They reported that the addition of these types of fibers to the asphalt mixture caused a negative effect on the variability of the test of the Marshall (flow, stability, % air voids, the weight of the unit, and % VMA). They found that the fiber-asphalt mixtures required more compaction effort compared with the control mixture.

The inner friction and coherence reflect the mixture stability where coherence is a measurement of the strength of the bitumen binding, and internal conflict a benchmark of the resistance of interlocking and friction for aggregates. On the other hand, the flow is known as a measure of the deformation of the sample. In General, high flow values indicated a plastic mixture that will undergo permanent deformation beneath traffic. In contrast, lower values may indicate a mix with voids greater than normal and the asphalt insufficient to ensured durability, hence cracking premature might be experienced as the mixture is brittle (Roberts et al., 1996).

Although the utilization of fibers increases the asphalt mixtures viscosity and reduces the workability, high rigidity and strength characteristics have made them one of the better additives for improving the properties of asphalt mixtures. A study conducted by (Arabani et al., 2019) showed that ceramic fibers (CFs) could improve the asphalt mixtures performance, because of their high stability to temperature and chemical changes, flexibility suitable, and appropriate the shock resistance (Arabani et al., 2019).

The aim of this study is to evaluate the impact of using ceramic fiber with different percentages on the volumetric properties and Marshall characteristics of wearing course asphalt mixture.

2. EXPERIMENTAL WORK

2.1. MATERIALS

2.1.1. Aggregates

The aggregates have been brought from the local quarries. The nominal maximum size of aggregates was (12.5mm); the coarse aggregate size was between the sieve size (19mm) and sieve size (4.75mm). The fine aggregate was free from any impurities; it brought from the same source of coarse aggregate, and its gradation was between sieve size (4.75mm) and sieve size (0.075mm). The properties of aggregates are listed in Table.1.

2.1.2. Filler

The filler used in this study was limestone dust. It is widely available in the local market at a relatively low cost.

2.1.3. Binder

The conventional 40/50 asphalt penetration grade was utilized to prepare specimens. The results of the tests compared to the limits of the State Commission of Roads and Bridge specifications (SCRB, 2003). The characteristics of the asphalt cement used in this study are shown in Table 2.

Table. 1. The Properties of Aggregate.

Test	ASTM Specification	Result	SCRB Specification
Coarse aggregate			
Bulk Specific Gravity (gm/cm^3)	C-127	2.579	----
Apparent Specific Gravity (gm/cm^3)	C-127	2.601	----
Percent Water Absorption,%	C-127	0.54	----
Abrasion wear (Los Angeles)%	C-131	15.79	30 Max
Fine aggregate			
Bulk Specific Gravity (gm/cm^3)	C-128	2.61	----
Apparent Specific Gravity (gm/cm^3)	C-128	2.632	----
Percent Water Absorption,%	C-128	0.952	----

Table. 2. Physical Properties of the used asphalt cement.

Test	Units	Results	SCRB 2003 Specification Limits	ASTM Specification No.
Penetration (25 ° C,100 gm., 5 sec)	1/10 mm	47	40 – 50	D-5
Ductility (25 ° C, 5 cm/min)	cm	135	≥ 100	D-113
Kinematic Viscosity, @ 135° C	cSt	405	—	D-2170
Softening Point (Ring & Ball)	°C	50	—	D-36
Flash Point (Cleveland Open Cup)	°C	270	232 min.	D-92
Specific gravity at 25 °C	—	1.04	—	D-70

2.1.4. Fibers

Ceramic fiber is not commonly used as a reinforcement of asphalt concrete in Iraq. The ceramic fiber was chosen as a reinforcement of the asphalt mixture in this work. It was added in different percentages to the asphalt mixtures.

2.2. Methodology

The methodology of this study includes many stages; firstly preparing the raw materials and conducting the physical properties tests required for them. Secondly manufacturing the asphalt mixtures from the raw material according to the specifications to find the optimum asphalt content (OAC) of mixtures without any additives. Finally, determine the OAC for samples with ceramic fibers based on the Marshall characteristics, then conducting the Marshall test for prepared models; Marshall properties involve the flow, stability, and bulk density.

2.3. Marshall Method

Marshall method is measuring the resistance to plastic flow of cylindrical samples of t asphalt pavement mixtures loaded onto the lateral surface utilizing the Marshall apparatus according to (ASTM D 6927-04). This method involves the preparation of cylindrical samples with diameter (101.6mm) and height (63.5 ±1.27 mm). The compaction hammer, Marshall Mold, and spatula were heated to a temperature of 150 °C on a hot plate. Then, the asphalt mix was put in the preheated mold, and spaded strongly with the heated spatula for 15 times around the circumference and 10 times in the inside. The temperature of the mixture directly before compaction should be between (142 – 146) °C. After that, 75 blows on the upper and bottom of the sample were applied with a compaction hammer of 4.535 kg sliding weight, and a free fall from 457.2 mm distance. The sample in the mould was left to cool for 24 hours at a room temperature and then removed from the mould. The Marshall stability and flow test were conducted for each sample. The cylindrical samples were put in the water bath at 60 °C for (30 – 40) minutes and then tested by compressing on the side surface at a constant rate of 2in./min.(50.8mm/min.) until reached to the extreme load (failure), as shown in Plate (1). The stability value and the corresponding flow value were recorded. For each percentage of the cermaic fibers, three samples were prepared, and the average of the test results are taken. The bulk specific gravity and density (ASTM D-2726-08), theoretical (maximum) specific gravity (ASTM D-2041-03), and the air voids percentage (ASTM D-3203-05) were determined for each sample. The optimum asphalt content is selected with the limits of the (SCRB R/9, 2003).

A: Some of Marshall specimens **B:** Test running

Plate 1. Marshall test.

3. RESULTS AND DISCUSSIONS

3.1. Marshall Stability

Marshall test indicated that the stability of mixtures containing ceramic fibre was higher than those of the control mixture, where high stability means a higher stiffness of asphalt mixture. The stability increased by (8.74, 36.47, 20.42, and 12.54) % for ceramic fiber content (0.5, 1, 1.5, and 2) %, respectively, as shown in Fig.1. The stability value increased as the fibre content increase to a certain percentage, then began to decrease. The increment in the fibres percentage in the mixture resulted in low contact points among the aggregates; leading to less stability.

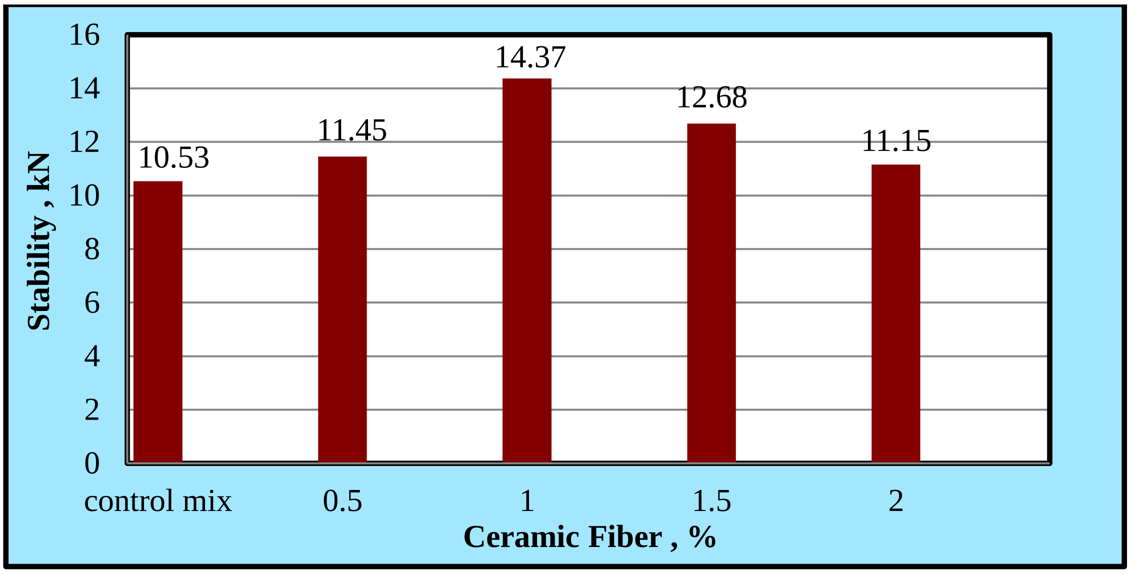

Fig. 1. Effect of Ceramic Fiber on Marshall Stability of Asphalt Mixture.

3.2. Marshall Flow

The asphalt mixture has a lower resistance under the impact of traffic loading, resulted in high flow value. In this work, the flow values of the asphalt mixtures incorporating ceramic fibers were smaller than the control mixture. The flow values decreased with increasing the fiber content, which have reduced by (5.09, 20.06, 12.28, and 4.49) % for ceramic fibres contents (0.5, 1, 1.5, and 2) %, respectively, as shown in Fig. 2.

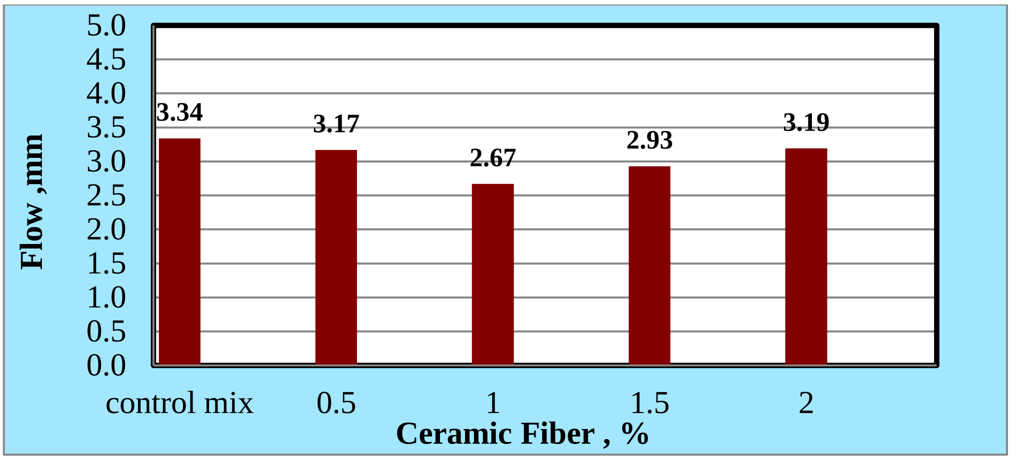

Fig. 2. Effect of Ceramic Fiber on Marshall Flow of Asphalt Mixture.

3.3. Marshall Quotient

The Marshall quotient (MQ) is defined as the proportion of the stability to the flow value of the asphalt mixture, also known as the rigidity ratio (Siswanto et al., 2017). The values of Marshall quotient of the asphalt mixture with various ceramic fiber percentages are presented in Fig. 3. It is found that the MQ value of the ceramic fiber recorded of the mixture including 1 % ceramic fiber content is almost greater than the control mixture. Because of the high stability and high MQ of the mixture, the MQ increment is shown that this asphalt mixture provides the best resistance against permanent deformations, and also signalize refers that this mixture could be used in roads pavement where the stiff bituminous mixture is required.

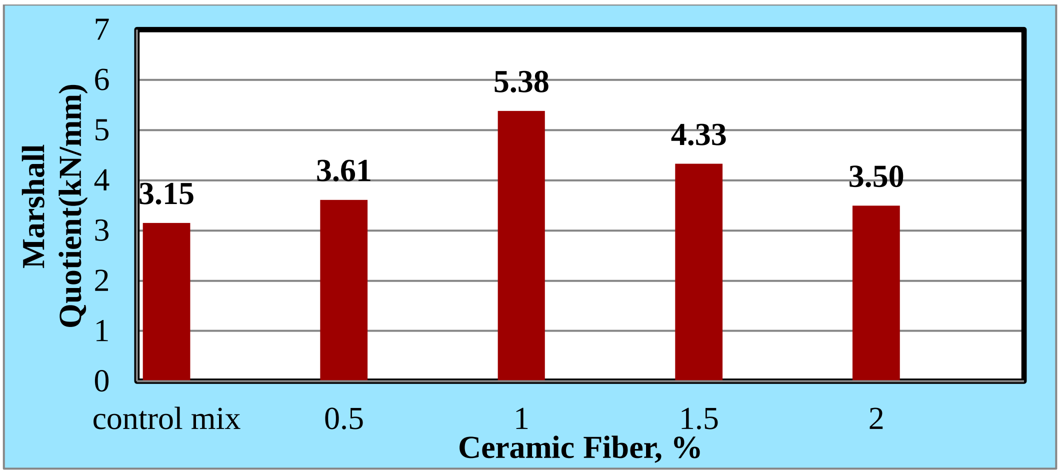

Fig. 3. Variation of Marshall Quotient with different Ceramic Fiber percentages, %.

3.4. Bulk Density

The bulk density value was reduced with an increment of the fiber content The bulk density decreased to values compared to the control mix by about (1.11, 1.24,1.71, and 2) % for ceramic content (0.5, 1, 1.5, and 2) %, respectively, as shown in Fig. 4. The maximum decrement of the bulk density for the mixture occurred at a value of 2% ceramic fiber from weighing of the total mixture .

The increase in the bulk density of the mixture with ceramic fiber was due to the rise of the fibre content which causes the distribution of fiber was less homogeneous when mixed, which increase the formation of fibre blends.

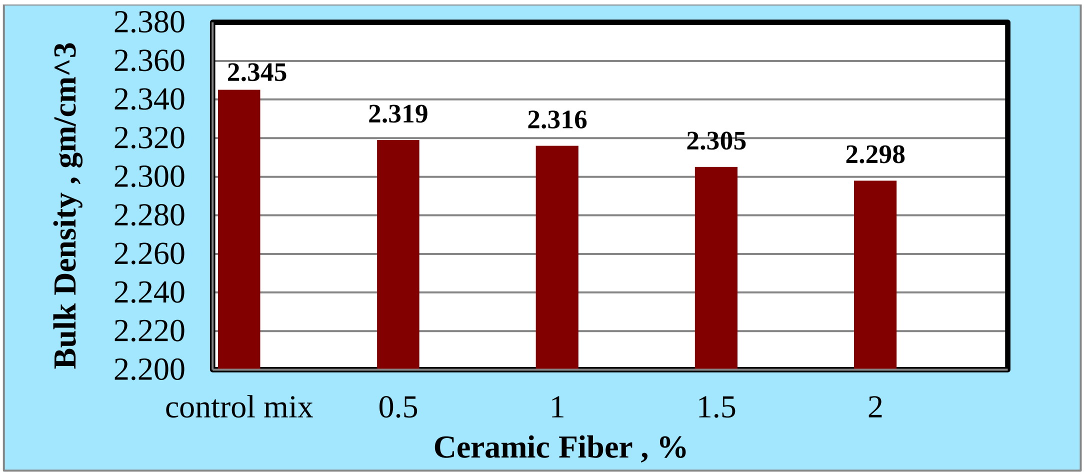

Fig. 4. Effect of Ceramic Fiber on Bulk Density of Asphalt Mixture.

3.5. Air Voids (AV%)

The voids in the total mixture are important parameter that affects the durability of asphalt mixture. The Air Voids of mixtures containing fibers were higher than those of control mixture. The air voids value increased with increasing fibre content by about (2.48, 3.92, 17.62, and 19.85) % for ceramic fibre content (0.5, 1, 1.5, and 2) %, respectively, as shown in Fig. 5.

The increment in the mixture voids could be attributed to the larger surface areas (aggregate and fibers) that needed to be wetted by binder. The results of the air voids values of mixtures showed that by using a certain fibers content may lead to higher performance than the ordinary mixture with the same asphalt content.

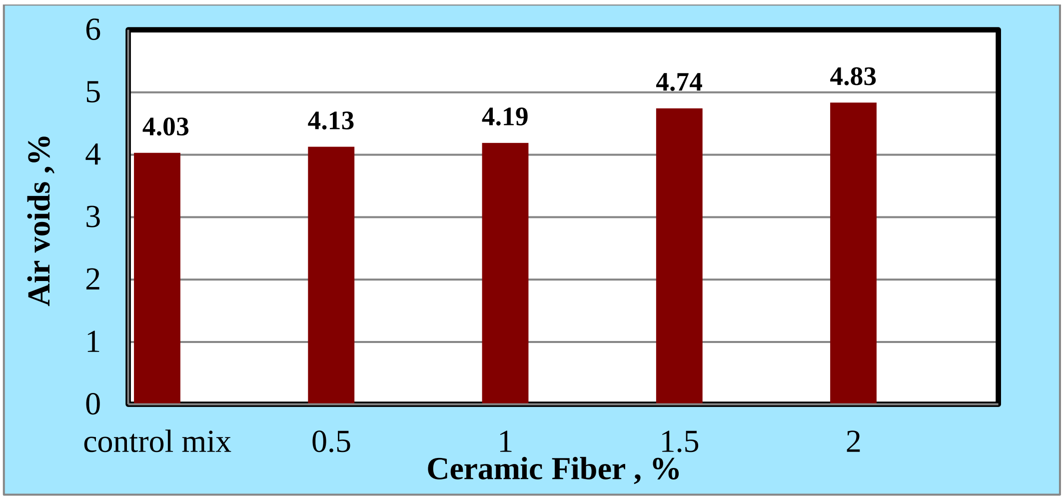

Fig. 5. Effect of Ceramic Fiber on Air Voids of Asphalt Mixture.

3.6. Voids in Mineral Aggregate (VMA%)

The voids among the aggregate particles is named as voids in the mineral aggregate which represents a significant parameter that must be satisfactory to obtain a good coating of aggregates; hence leads to improve the durability of HAM by reducing the loss of adherence between asphalt and aggregates.

In this study, the VMA value increased by about (6.14, 7.39, 9.43, and 24.34)% for fiber content (0.5, 1, 1.5, and 2)%, respectively, as shown in Fig. 6. Fiber soaks up the binder produces mixtures with higher voids. Also, higher air voids content is recognized when increase fiber content.

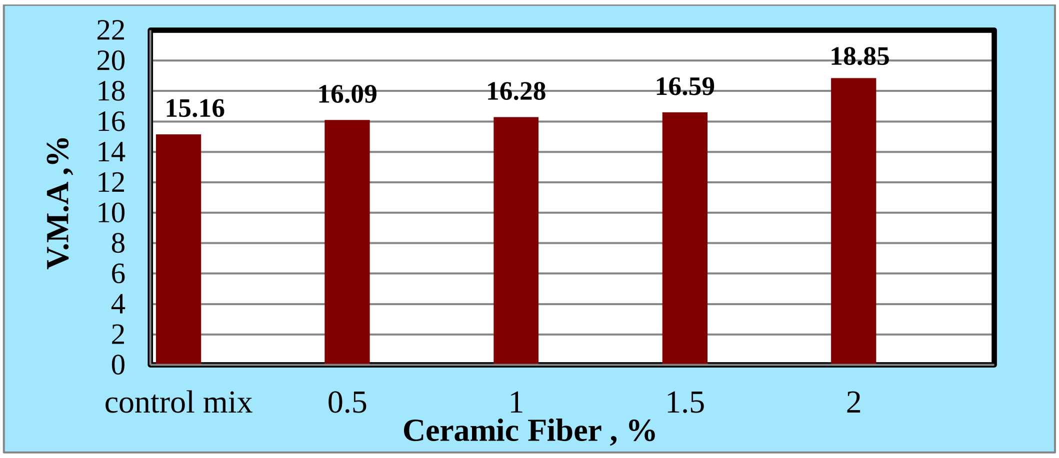

Fig. 6. Effect of Ceramic Fiber on V.M.A of Asphalt Mixture.

3.7. Voids Filled with Asphalt (VFA%)

The VFA is part of the VMA that containing asphalt binder. Also, it may be described as the percentage of the VMA volume filled with asphalt cement. The results showed that the VFA values increased by about (1.25, 1.14, 0.98, and 0.56) % for ceramic fiber content (0.5, 1, 1.5, and 2) %, respectively, as shown in Fig. 7.

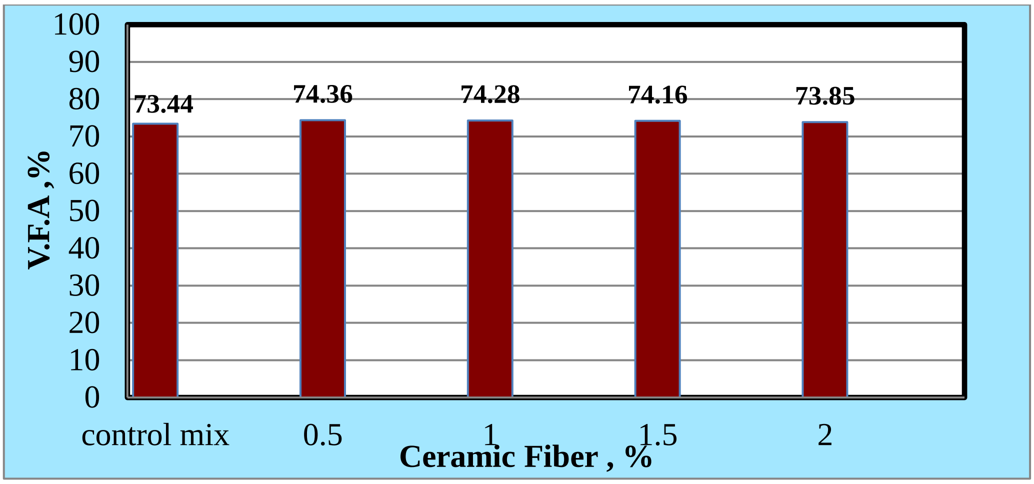

Fig. 7. Effect of Ceramic Fiber on V.F.A of Asphalt Mixture.

4. CONCLUSIONS

According to the specification of substances and test result utilized in that study, the following points are concluded:

- The mixtures containing fibers showed an increment in the Marshall stability values compared to the control mixture. The maximum increment in the stability occurred at 1% ceramic fiber by weight of the total mix, then it decreased with increasing fiber content.
- The mixtures containing fibers showed a reduction in the flow values with an increase of fiber content.
- The mixtures containing fibers appeared an increase in the Marshall quotient values compared to the control mix. The maximum increase in the MQ was occurred at 1 % ceramic fiber content.
- The AV, VMA, and VFA increased with increasing the fiber content, while bulk specific gravity decreased when increasing fiber content in the asphalt mixture.
- From the results that obtained, the importance of adding the ceramic fiber in this work to improve the Marshall properties for the mixture.

5. ACKNOWLEDGMENTS

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