Influence of Mineral Fibers Properties on the Performance of Hot Mix Asphalt for the Surface Layer of Pavement

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Abstract: *Using of fibers is not a new phenomenon; the technique of fiber-reinforced bitumen began as early as 1950. Fiber reinforcement refers to incorporating materials with desired properties within some other materials lacking those properties [1]. The principal function of the fiber is to provide additional tensile strength in the resulting composite. This could increase the amount of strain absorbed during the fatigue and fracture process of the mixture [2]. Fibers are sometimes added to stabilize the binder during mixing and placement. An additional benefit of using fibers is that fibers have been shown to allow increased asphalt binder contents and thus increase film thicknesses thereby increasing durability [5]. Asphalt cement modifiers have been used in pavement technology to enhance pavement performance and reduce different types of pavement distress, of which, rutting, low temperature cracking, fatigue cracking, stripping, and hardening are the most common failure. The present project investigate the usability of mineral fibers in order to resist the stresses occurring at the surface layer of pavement, which are directly subjected to the traffic effects. For this purpose four different types of mineral fibers (steel , aluminium , copper and tin), four different fiber rates (1% , 1.5% , 2% , 2.5%) by total weight of mixture, with varying lengths of mineral fiber (0.5 ,1.0 ,1.5 ,2.0) cm, and four different thickness (0.2 , 0.4 , 0.7 , 0.9) mm were used in this study. All specimens have been tested by Marshall method. The results indicated that adding (1.5%) of the copper fiber by the total weight of mixture, with (0.5 cm) length and (0.4 mm) thickness increase Marshall stability by (34%) as compared with the conventional mix.*

Keywords*: Hot Mix Asphalt, Marshall Properties, Mineral Fiber, Steel Fiber, Aluminium Fiber, Tin Fiber, Copper Fiber, Marshall Stability, Marshall flow.*

I. INTRODUCTION

Many former researches focused on the influence of fiber on the engineering properties of asphalt or asphalt mixture. The idea was based on the general concept that if hot mix asphalt (HMA) is strong in compression and weak in tension, then reinforcement could be used to provide needed resistance to tensile stresses [3]. In recent years, a multitude of fibers and fiber materials are being introduced regularly in the market as new applications such as polyester fiber, asbestos fiber, glass fiber, polypropylene fiber, carbon fiber, cellulose fiber, etc. [4]

Ahmed S.D. AL-Ridha et al (2014) research subjects include the studies focusing on asphalt cement modifiers have been used in pavement technology to enhance pavement performance and reduce different types of pavement distress, of which, rutting, low temperature cracking, fatigue cracking, stripping, and hardening are the most common failure. Fiber is one of the additives used for this purpose. [5]

Zube (1956) studied on the reinforcement of asphalt mixtures. The study evaluated various types of wire mesh placed under an asphalt overlay in an attempt to prevent reflection cracking. The study concluded that all types of wire reinforcement prevented or greatly delayed the formation of longitudinal cracks. Zube suggests that the use of wire reinforcement would allow the thickness of overlays to be decreased while still achieving the same performance. [6]

Jahromi, S.G., (2008) study showed the carbon fiber has the potential to improve structural resistance to distress occurring in road pavement due to traffic loads. Further, addition of fiber improves fatigue life and permanent deformation of bituminous mixtures by improving mix stiffness. [7]

Akbulut, H., (2000) used three types of fibers, i.e., cellulose, mineral and polyester fibers, are mixed with bitumen to stabilize the mastic and reduce binder drainage. They are commonly used in stone matrix asphalt and porous asphalt in Europe, USA and other countries. [8].

Yi and Mc Daniel (1993) used polypropylene fibers in an attempt to reduce reflection cracking in an asphalt overlay. Although crack intensities were less on the fiber modified overlay sections, no reduction or delay in reflection cracking was observed. Sections in which the pavement had been cracked and set before the overlay were found to have less reflection cracking when fibers were used in either the base or binder layers. [9]

Huang et al. (2006) evaluated electrical conductivity of conductive HMA containing micron-scale steel fiber, aluminium chips, and graphite as conductive fillers. They also investigated the applicability of relating the electrical properties to the laboratory mechanical properties of HMA mixtures. Among the conductive additives evaluated of mineral fibers, steel and carbon fibers generally retained or improved the laboratory performance of HMA mixtures, whereas graphite, due to the need for higher content, significantly altered the performance of HMA mixture and especially compromised the cracking resistance. [10]

Sercan Serin (2012) used different rates of steel fiber (0%, 0.25%, 0.50%, 0.75%, 1.0%, 1.5%, 2.0%, 2.5%) were prepared and the optimum value for fiber rate that results in the best stability value was determined as 0.75%.The result of study showed, steel fiber additions can be used in binder course of flexible pavement because of its positive stability impact. [11]

Hassan HF, Oraimi SA, Taha R. (2005) experimental results showed that fibers have better performance than polymers in reducing draindown of asphalt concrete mixtures, and this is the reason why fibers are widely used in stone matrix asphalt and open-graded friction course. [12]

Shuaib H., Ahmad. ,Charles H.,(1999) For fibres with constant section, pull-out resistance increases with an increase in fibre length; up to the transfer length is attained, the longer fibre the greater effect in improving the properties of the composite. Also, since pull-out resistance is proportional to interfacial surface area, non-round fibre cross sections and smaller diameter round fibres offer more pull-out resistance per unit volume than larger diameter round fibres because of the higher surface area per unit volume. Therefore, for a given fibre length, a high ratio of length to diameter (L/d, aspect ratio) is associated with high fibre efficiency in terms of bond. On this basis, it would appear that the fibres should have an aspect ratio high enough to insure that their tensile strength is approached as the composite fails. [13]

Chen H S,el al.(2008) investigated cellulose, rock wool and polyester fiber on the engineering properties of bitumen-reinforcing effect increased with increasing fibers up to a critical fraction, and the tensile strength of bitumen- fiber mastic was increased [14] .Unfortunately, only few researches were interested in the rheological properties of fiber reinforced asphalt binders and its mixtures.

Wu S P, el al. (2007) described the rheological properties of asphalt could be improved by the addition of various fiber modifiers, and the rutting-resistance property of asphalt mixtures with fibers could be improved to a large extent [15] . While these fibers have some advantages, they also exhibit some disadvantages. Asbestos was used but it was reported to be degradable and unsuitable as a long-term reinforcement and a health hazard [16] , whereas the adding of steel fibers to surface layer of flexible pavement may cause discomfort for drivers and reduces safety on the road, which may be caused by a tire puncture, therefore, it is recommended to use it in the layers that under the surface layer such as the binder course or use it in leveling course if the wearing course is exist [5]

II. Material Characterization

The materials used in this study are locally available and currently used in road construction in Iraq except the mineral fibers that are available in local market in northern Iraq but they are not used in the asphalt constructions at this time.

A. *Aggregates*

The coarse and fine aggregate used in this investigation was brought from Freba hot mix plant, and these were originally brought from Darbande Zeoi quarry near Sulaimanyah city in Iraq and crushed at the asphalt plant by mechanical crusher. The mid limit of the (19mm) maximum size dense gradation has been selected according to State Corporation of Roads and Bridges (SORB, 2007) [17], as shown in Table (I)

Table (I): Selected Combined Gradation of Aggregate and Filler According to SORB Specifications

Sieve Size	Specification Range	Selected Gradation
3/4"	100	100
1/2"	90-100	95
3/8"	76-90	83
No.4	44-74	59
No.8	28-58	43
No.50	5-21	13
No.200	4-10	7

B. *Asphalt Cement*

The asphalt cement of grade (40-50) was used in this work from Baiji refinery. The physical properties of this grade of asphalt cement are presented in Table (II).

Table (II): Physical Properties of Asphalt Cement

Properties	Unit	ASTM	Value
Penetration at (25ºC, 100g, 5 s)	0.1 mm	D5	46
Specific gravity at 25ºC	----	D70	1.03
Absolute viscosity at 60ºC	poise	D2171	2950
Kinematic viscosity at 135ºC	Cst	D2170	360
Softening point (Ring and Ball)	°C	D36	55.6
Ductility (25ºC, 5 cm/min)	cm	D113	103
Flash point	°C	D92	285
Fire point	°C	D92	312

C. *Filler*

The filler used was Portland cement which was brought from Al-Mas cement factory. Its physical properties are presented in Table (III).

Table (III): Physical Properties of Portland Cement Filler

Properties	Unit	Value
Specific Gravity	----	3.151
Unit Weight	gm/cm^3	1.165
Passing Sieve No. 200	%	99

D. *Mineral Fibers*

Four different types of mineral fibers used in this research (Steel , Aluminium , Copper and Tin), four different lengths of fiber (0.5 , 1.0 ,1.5 , 2.0) cm, four different thicknesses (0.2, 0.4, 0.7, 0.9) mm were used , and added by four different contents (1% , 1.5% , 2% , 2.5%) by total weight of mixture.

III. Asphalt Concrete Test

The following tests were performed on the prepared laboratory samples to evaluate the performance of asphalt concrete mixture:

1) Resistance to Plastic Flow (ASTM D 1559).
2) Percent of Air Voids (ASTM D 2041).
3) Bulk specific gravity test (ASTM D 2726).

IV. Testing Program

To achieve the objectives of this study; one type of bitumen grade (40-50) was used to prepare the specimens, from selected grade of aggregate, asphalt content ,mineral filler and mineral fiber. The effects of the following parameters of mineral fiber have been considered in this study:-

1) Type: by adding four different types of mineral fibers (Steel, Aluminium, Copper, and Tin).
2) Length: by adding the mineral fiber with four different lengths (0.5 , 1.0 ,1.5 , 2.0) cm
3) Thickness: by adding the mineral fiber with four different thicknesses of fiber (0.2 , 0.4 , 0.7 , 0.9) mm
4) Content: adding mineral fibers by four different percentages (0.5, 1.0 , 1.5 , 2.0) % by total weight of mixture

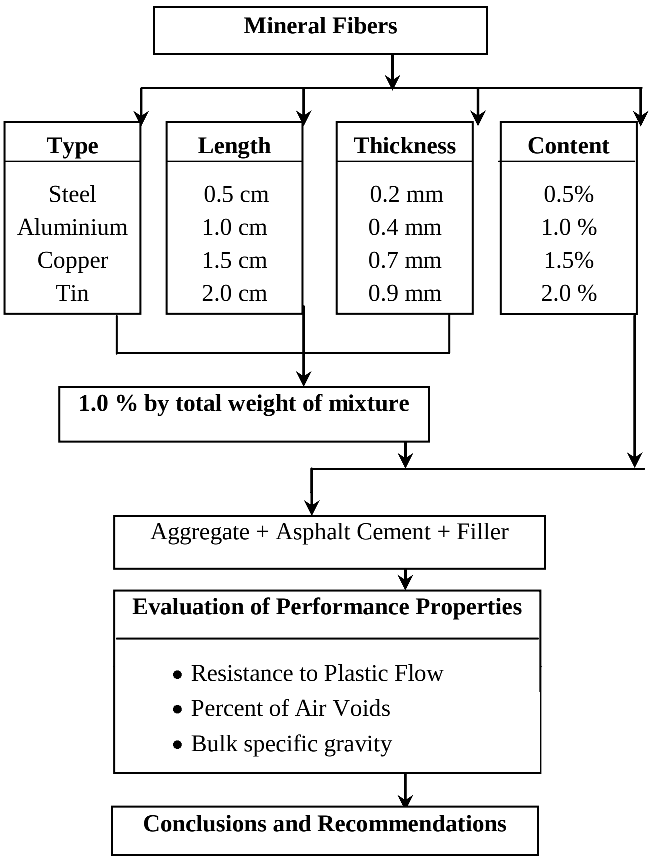

Fig.1 Shows the flow chart of the study

V. Results and Discussions

A. Optimum Asphalt Content

Marshall molds were prepared for different percentages of asphalt cement grade (40 – 50) by varying the asphalt cement percentage from (4% - 6%) mixed with aggregate, and Portland cement filler. Marshall stability test was conducted and the properties of asphalt mixtures such as flow value, bulk density, percentage air voids, voids filled with Asphalt (VFA) and voids filled with mineral aggregates (VMA) were determined. The results showed that optimum asphalt content equal to (5%) by using the limitations of above properties.

B. Effect of Mineral Fiber Type

Four different types of mineral fiber were used with a length of (1.0) cm and added by (1.5%) by total weight of mixture, mixed with the optimum asphalt content (5%) to prepare each specimen.

Fig.2. Different types of mineral fibers

The results of Marshall test are shown in Table (IV) and represented in Fig. (3 to 6). According to results, the copper and tin fibers improved the Marshall properties as compared with conventional mixture , whereas the steel and aluminium fibers increased the Marshall stability but gave undesirable values for the Marshall flow and air voids.

Table (IV): Effect of Mineral Fiber Type on Marshall Test Properties

Mineral Fiber Types	Marshall Test Results			
	Stability (KN)	Flow (mm)	Bulk Density (gm/cm^3)	Air Voids (%)
Without Fibers	14.201	3.592	2.296	3.869
Steel	14.567	5.858	2.288	7.461
Aluminium	18.378	4.475	2.210	6.486
Copper	16.117	2.423	2.254	4.162
Tin	14.940	2.945	2.244	4.278

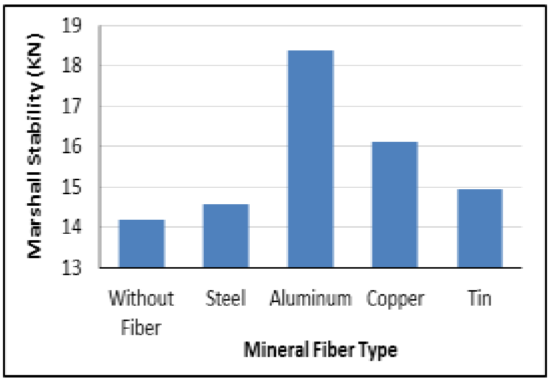

Fig.3 Effect of mineral fiber type on Marshall stability

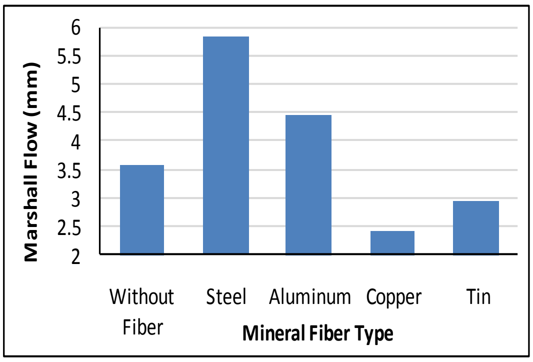

Fig.4 Effect of mineral fiber type on Marshall flow

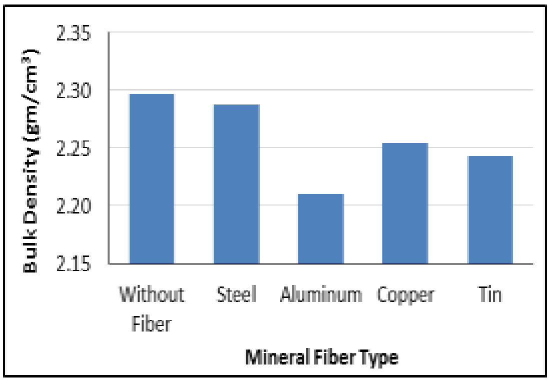

Fig.5 Effect of mineral fiber type on bulk density

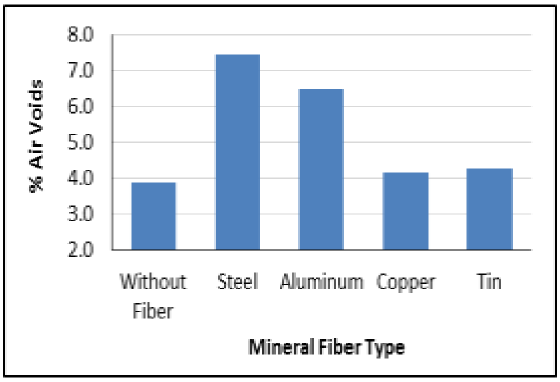

Fig.6 Effect of mineral fiber type on air voids

C. *Effect of Mineral Fiber Length*

Four different lengths of mineral fibers particles (0.5, 1.0, 1.5, and 2.0) cm were used in this study to determine the optimum length of mineral fibers particles which provide the best performance of hot mix asphalt for the surface layer of pavement. Table (V) and Figures (7 to 10) show the effect of mineral fibers length on Marshall Properties. The results indicate to decrease in Marshall stability and bulk density with increase length of mineral fibers particles , while the Marshall flow and air voids decrease ; therefore (0.5) cm length of mineral fibers reflect the best performance of Marshall properties.

TABLE (V): EFFECT OF MINERAL FIBER LENGTH ON MARSHALL TEST PROPERTIES

Mineral Fiber Length (cm)	Marshall Test Results			
	Stability (KN)	Flow (mm)	Bulk Density (gm/cm^3)	Air Voids (%)
0.5	16.416	2.298	2.305	3.758
1.0	16.117	2.423	2.264	3.737
1.5	15.918	3.12	2.259	4.442
2.0	14.311	3.322	2.240	4.762

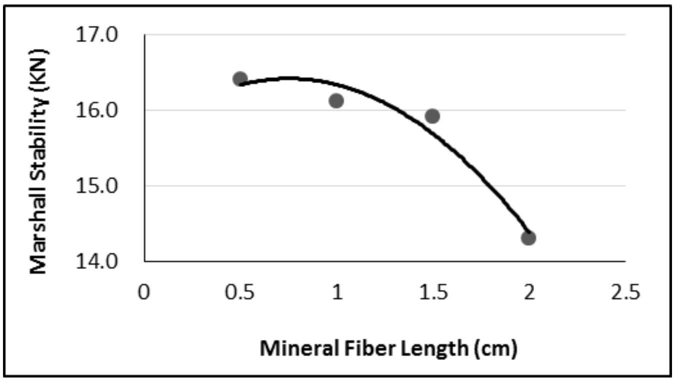

Fig.7 Effect of mineral fiber length on Marshall stability

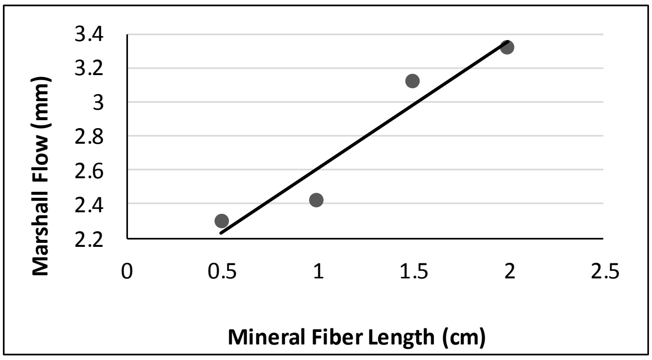

Fig.8 Effect of mineral fiber length on Marshall flow

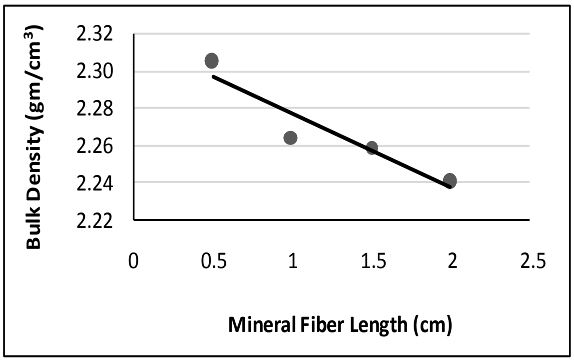

Fig.9 Effect of mineral fiber length on bulk density

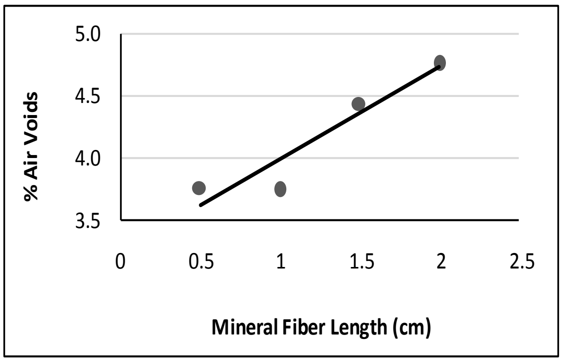

Fig.10 Effect of mineral fiber length on air voids

D. Effect of Mineral Fiber Thickness

Four different thicknesses of mineral fiber (0.2, 0.4, 0.7 and 0.9) mm were used in this study to determine the optimum thickness of mineral fibers particles.

The results shown in Table (VI) and represented in Fig. (11 to 14) indicate to increase in the Marshall stability , Marshall flow , and air voids with increase the thickness of mineral fibers until the maximum value then tend to decrease. Whereas the bulk specific gravity increase.

TABLE (VI): EFFECT OF MINERAL FIBER THICKNESS ON MARSHALL TEST PROPERTIES

Mineral Fiber Thickness (mm)	Marshall Test Results			
	Stability (KN)	Flow (mm)	Bulk Density (gm/cm^3)	Air Voids (%)
0.2	16.117	2.423	2.264	3.737
0.4	18.957	2.416	2.311	3.717
0.7	17.22	2.421	2.32	3.71
0.9	15.732	2.033	2.31	3.67

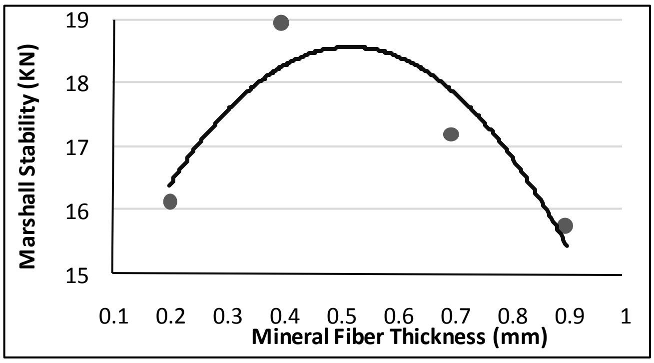

Fig.11 Effect of mineral fiber thickness on Marshall stability

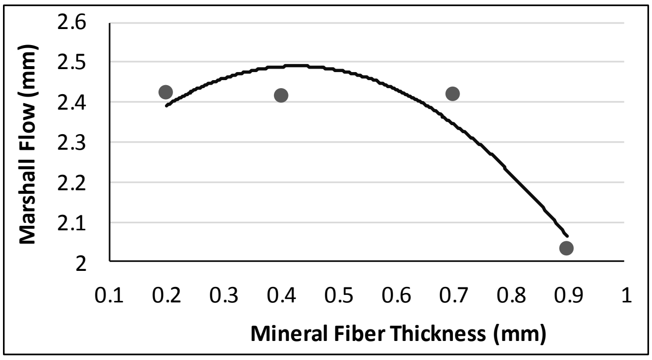

Fig.12 Effect of mineral fiber thickness on Marshall flow

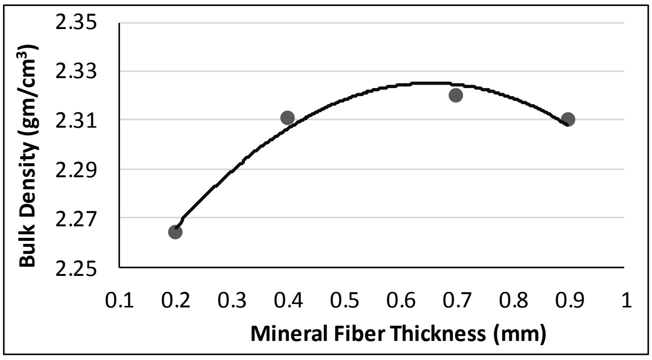

Fig.13 Effect of mineral fiber thickness on bulk density

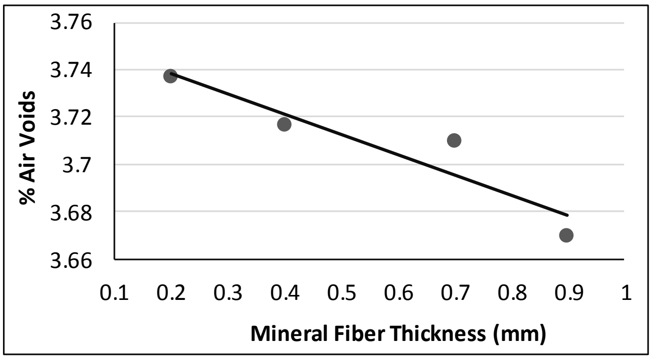

Fig.14 Effect of mineral fiber thickness on air voids

E. Effect of Mineral Fiber Content

To investigate the effect of mineral fibers content on hot mix asphalt performance, four different percentages of the copper fibers were used in this study (1%, 1.5%, 2%, and 2.5%) by the total weight of mixture, mixed with the optimum asphalt content (5%) to prepare each specimen. The relations between Marshall Properties and mineral fibers contents are shown in Table (VII) and represented in Fig. (15 to 18). Figures indicate the increase in the mineral fibers content, lead to increase the value of Marshall stability until maximum value then tends to decrease, whereas the Marshall flow and air voids increase.

TABLE (VII): EFFECT OF MINERAL FIBER CONTENT ON MARSHALL TEST PROPERTIES

Mineral Fiber Content (%)	Marshall Test Results			
	Stability (KN)	Flow (mm)	Bulk Density (gm/cm^3)	Air Voids (%)
1.0	14.511	2.386	2.235	4.205
1.5	16.117	2.423	2.254	4.162
2.0	15.970	2.50	2.267	5.025
2.5	15.925	2.887	2.271	5.619

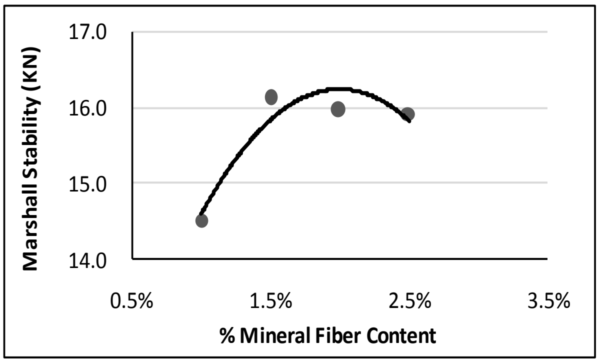

Fig.15 Effect of mineral fiber content on Marshall stability

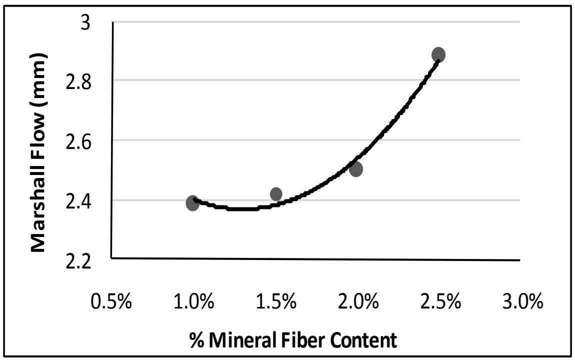

Fig.16 Effect of mineral fiber content on Marshall flow

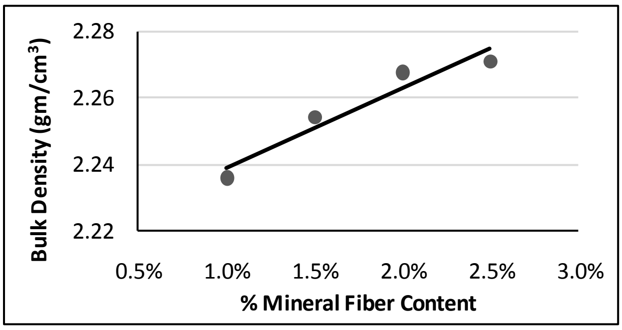

Fig.17 Effect of mineral fiber content on bulk density

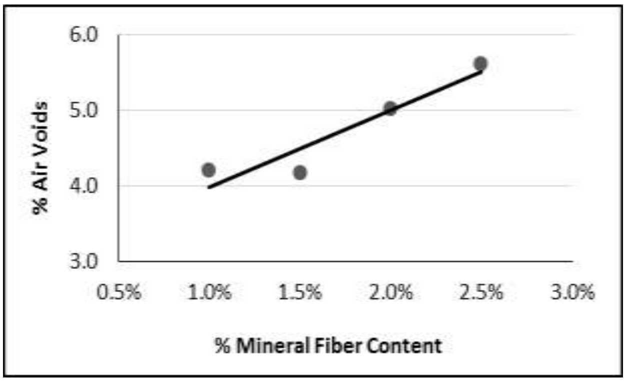

Fig.18 Effect of mineral fiber content on air voids

VI. CONCLUSIONS

Based on the analysis performed on the experimental data of hot mix asphalt by focusing on Marshall test to obtain the optimum properties of asphalt in this study the following conclusions can be shown:

1) After adding four different types of mineral fibers to conventional mixture, the results showed that the copper fiber is the best type of mineral fibers in which the Marshall stability increased by 14 %. Although adding the aluminum fibers reflect increase Marshall stability by (29%), but Marshall flow and air voids values still out of the range according to (SORB) specifications.
2) The results indicate that the optimum content of the mineral fibers is 1.5% by the total weight of the mixture in which the Marshall stability increased by (14 %), and Marshall flow and air voids still in the ranges according to (SORB) specifications.
3) The results of using different lengths of mineral fibers particles added to the mixture indicate that optimum length is 0.5 cm in which the Marshall stability increased by (16 %) as compared with the conventional mix.
4) The results of using different thicknesses of mineral fibers particles added to the mixture indicate that the optimum thickness is 0.4 cm in which the Marshall stability increased by (34 %) as compared with conventional mixture, and the Marshall flow is (2.416) mm.

Finally, the conclusion of this study, adding (1.5 %) by the total weight of mixture of copper fiber to the asphalt mixture, with (0.5) cm length, and (0.4) mm thickness increases Marshall stability by (34%) and decreases Marshall flow by (32.7%) as compared with the conventional mix.

VII. RECOMMENDATIONS

1) Further work is required to investigate the effect of physical properties of mineral fibers such as (Density, modulus of elasticity, melting point … etc) on the performance of hot-mix asphalt.
2) Additional research is needed to study the effect of mineral fibers properties on the resistance of mixture to moisture damage, low temperature cracking, rutting, and fatigue.

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