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Hot Mix Asphalt (HMA) Performance as Affected by Limestone Powder Filler Content

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Abstract: The mineral filler is a mineral fine particle with physical size passing the number 200 standard mesh sieve (75 micron) which plays an important role in asphalt mixtures properties. This research represents a laboratory study of the effect of using different contents of limestone powder as mineral filler in hot mix asphalt HMA properties and performance. In this investigation we used limestone powder as mineral filler because it is the most common filler used in Egypt and its good evaluation in improving the HMA performance and properties, three percentages of limestone powder were used in this study (4, 6 and 8% of the total mix). Marshall Tests and indirect tensile test were performed to investigate the difference in behaviors of different samples with different parameters that considered in this study. The control mix used in this study contains crushed gravel, rough aggregate particles with medium gradation of aggregate. The results revealed that Marshall Stability (MS), Marshall Quotient (MQ) and air void (VTM) were decreased with increasing limestone powder content; however flow values and bulk density were increased with increasing limestone powder content. Also, the results indicated that the indirect tensile test (ITS) and stiffness modulus (SM) were decreased with increasing limestone powder content, while strain failure was increased with increasing the content of limestone powder. It can be concluded that using of limestone as mineral filler in the HMA is proposed because it is common in Egypt and reduce the cost but shouldn't exceed 4% of the total hot asphalt mix.

Key words: Limestone powder · Mineral filler content · Hot mix asphalt · Marshall test · Indirect tensile strength

INTRODUCTION

Mineral fillers are finely-ground inert material passing the No.200 sieve (Fig. 1), fills the void space between coarse aggregates particles and pores within the aggregates particles and sometimes called "stabilizers" that added to the asphalt mix for toughening and improving its resistance to cracking because Asphalt alone is not durable enough for use as shingles. Also, high-performance fillers maximize heat-transfer, helping to keep shingles cooler and extend their lifespan. One of the benefits of adding filler to HMA is reducing the cost of manufacturing. Up to 70% of filler may be added, depending on various factors however, too much filler reduces shingle quality. One of the most common fillers (especially in Egypt) is limestone powder. The resistances to compaction of bituminous mixes are affected by filler content and one of the mix variables and he added that higher the resistance of the mix to compaction leads to higher its measured stiffness value and consequently better resistance to permanent deformation performance is expected in the pavement also, higher the percent of fines in the mix leads to higher the measured stiffness of mix at a lower value of resistance to compaction (Fig. 2) [1]. The mineral fillers act as a part of the mineral aggregate by filling the voids between the coarser particles in the asphalt mixtures and thereby strengthen the asphalt mixture, also mineral fillers when mixed with asphalt form mastic, high-consistency binder or matrix that cements lager binder particles together; most likely a major portion of the filler remains suspended in the binder while a smaller portion becomes part of the load bearing framework [2].

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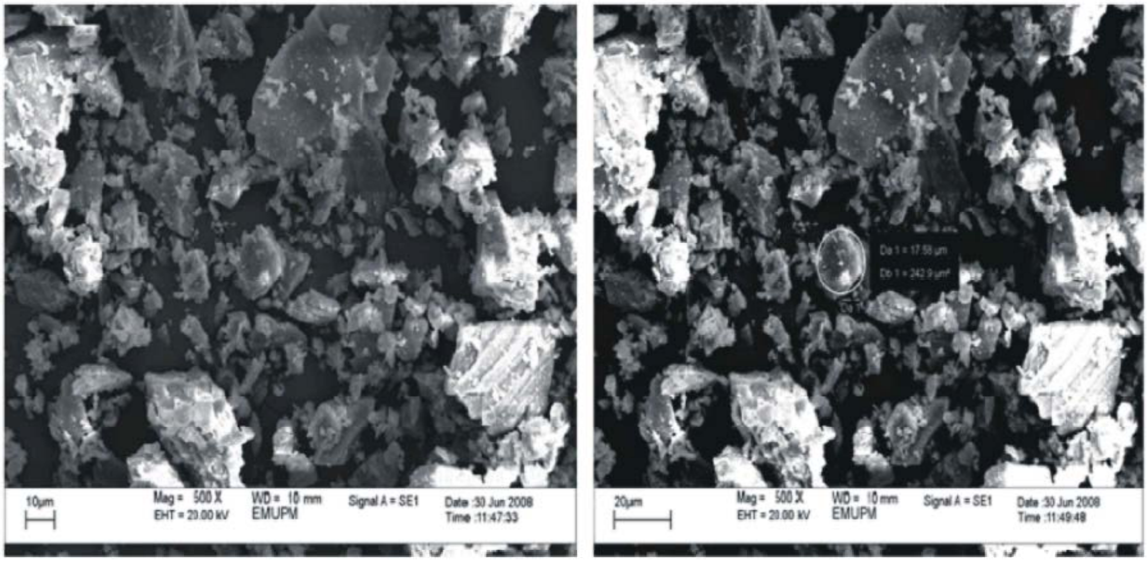

Fig. 1: Limestone particles size and shape at 500x magnification

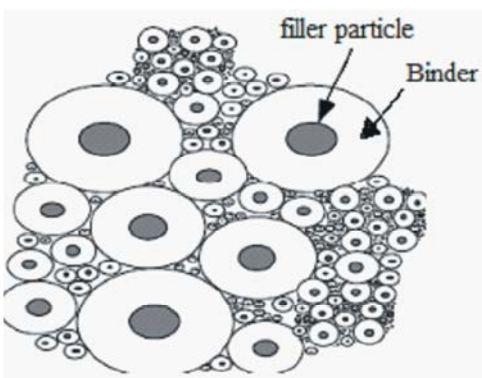

Fig. 2: The interaction of mineral filler with bitumen

The increasing filler content increases the brittleness and tendency to crack in service [3]. Muniandy *et al*. [4] stated that the mineral filler that is finer than the thickness of the asphalt film blends with asphalt cement binder to form a mortar or mastic that improved stiffening of the asphalt mix. Particles larger than the thickness of the asphalt film have as mineral aggregate and hence contribute to the contact points between individual aggregate particles [5]. Furthermore, they affect the workability, moisture sensitivity, stiffness and ageing characteristics of hot mix asphalt [6]. Also, fillers differ in gradation, particle shape, surface area, void content, mineral composition and physico-chemical properties and therefore, their influence on the properties of HMA mixtures also varies. The maximum allowable amount should be different for various types of filler. Also, the filler affects the optimum asphalt content in bituminous mixtures by increasing the surface area of mineral particles and also the surface properties of the filler particles modify significantly the rheological properties of asphalt such as penetration, ductility and also those of the asphalt mixture, such as resistance to rutting [4, 7].

Several studies were conducted to evaluate mineral filler type and content on the performance of HMA. Hafeez and Kamal [8] reported that the filler content increase in asphalt increases the softening point and also, the density improvement tendency of a mix reduces with the increase in the filler to asphalt ratio (Figs. 3 & 4). Asmael [9] observed that the percentage of fillers affects significantly the performance of hot asphalt mix.

The effect of different filler type and contents on the performance of filler-bitumen systems and bituminous paving mixtures had been studied by Al-Qaisi [10], who stated that the range of the filler-asphalt (F/A) ratio is influenced by the type of filler used to reach the wanted good properties. Mahan [11] reported that the advantages that filler offers for the durability of the bituminous mixtures in the case of water action are due to its physical characteristics, reducing the porosity of the granular structure and thereby making the access of water and air difficult. Furthermore, the chemical nature of filler may mean greater affinity with the asphalt binder, improving the resistance to the displacement that the water causes the bitumen. Mehari [12] suggested that mineral filler had mostly increased the mixture stiffness. It was reported that using hydrated limestone filler with different percentages

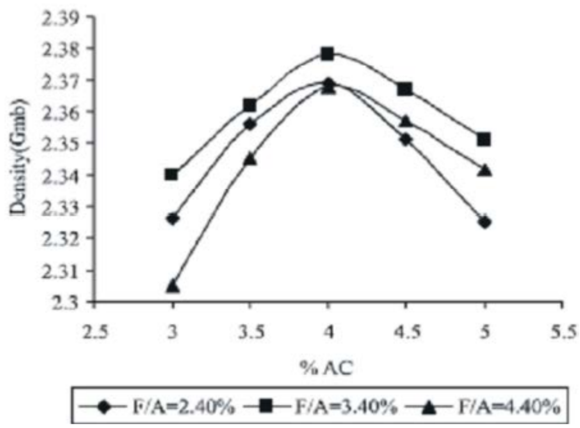

Fig. 3: Influence of filler to asphalt content on density value of HMA [8]

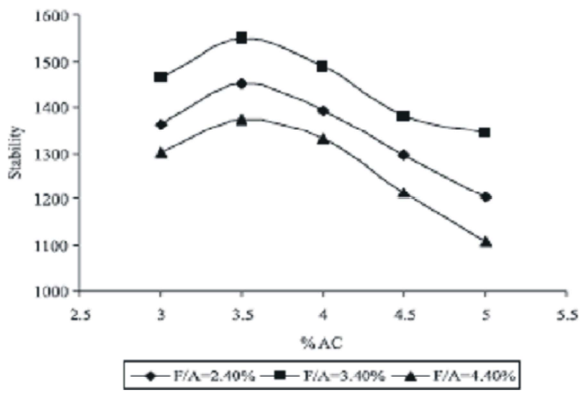

Fig. 4: Influence of filler to asphalt content on stability value of HMA [8]

had a direct effect on Marshall requirements and bulk density and also, had a superior stiffening properties when mixed with the binder compared to all other filler types. Ramzi Taha *et al.* [13] evaluated the effect of adding either limestone or cement bypass dust (CBPD) as a filler in different proportion on binder and Marshal Properties. They concluded that for any filler type (lime or CBPD), penetration and ductility of the filler-binder mortar generally decreased as filler content was increased. However, such decrease was steeper and more pronounced when lime rather than CBPD was used as filler. On the other hand, softening point increased with the filler content where more significant increment was observed when lime rather than CBPD. Also, when considering the Marshal properties, the substitution of 5% CBPD for lime as filler would be the optimum value used in asphalt concrete mixtures. Any percentages higher than 5% CBPD would require more asphalt binder and thus produce an uneconomical mix. Hassan *et al.* [14] studied the effect of using different percentages of waste cement dust as mineral filler on the mechanical properties of hot mix asphalt. They found that each of Marshall Stability, specific gravity, indirect tensile strength and unconfined compressive strength increased as the mineral filler percentage increased. Flow values, void ratio and voids in mineral aggregates decreased as the filler content increased (Figs. 5 & 6). Asphalt Institute [15] reported that increasing filler content in the mixture enhances the Marshall and Hveem stability and this is because increasing filler content from 3% to 5.5% fills the voids among aggregate particles thus producing dense mixes, hence increasing stability, whereas increasing filler content beyond 5.5% reduce the contact among coarse aggregate particles, hence reducing the stability. Al-Saffar [16] studied the effect of using different type of mineral filler and different contents (4, 6 and 8%) on the properties if HMA. Who found that the marshal stability increased gradually from 4% to 6% then decreased in the 8% content.

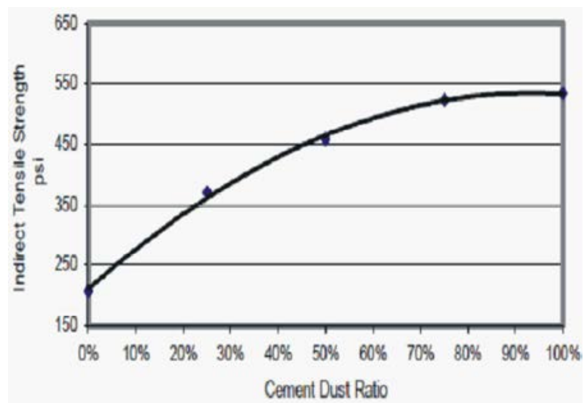

Fig. 5: Indirect Tensile strength of mixtures with different cement dust content [14]

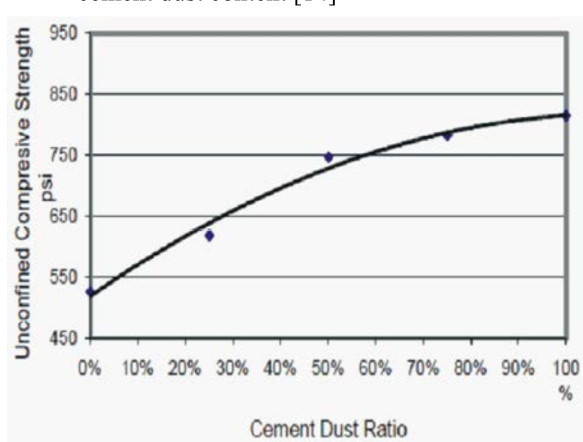

Fig. 6: Unconfined Compressive strength of mixtures with different cement dust content [14]

Therefore, the objective of this study was to investigate the effect of using different contents of limestone powder as mineral filler on the performance of hot mix asphalt (HMA) and give a recommended content of filler.

RAW Materials: Limestone powder was used as mineral filler in this study because it is the most common filler used in Egypt and its good evaluation in improving the HMA performance and properties. The bulk specific gravity of limestone powder was 2.652. Specific Surface of limestone powder is 2800-3500 (cm^2/g). The asphalt cement used was AC 60/70. This asphalt material, supplied by El-Suez is the usual asphalt grade used for asphalt pavement construction in Egypt. The specific gravity of asphalt cement used was 1.035.

Experimental Work: The coarse aggregate, fine aggregate, mineral filler and asphalt cement were used to prepare the Marshall Test specimens with 65 mm height and 101.6 mm diameter. The tested asphaltic concrete mixes for control mix were composed of 60% coarse aggregate, 36% fine aggregate and asphalt cement. Three samples were made for each asphalt content. We studied in this paper different mineral filler content (4, 6 and 8% of the total mix). The following tests were used in this investigation:

Marshall Test: In Marshall Method, the resistance to plastic deformation of compacted cylindrical specimen of asphalts mixture is measured when the specimen is loaded diametrically at a deformation rate of (50) mm per minute. The Marshall Stability of the mix is defined as the maximum load carried by the test specimen at a standard test temperature of 60°C (Fig. 6). The flow value was the deformation that the test specimen undergoes during loading up to the maximum load. Flow was measured in (0.25) mm units with rate of loading 0.05 in /min. Marshall Test, Stability, flow, bulk density, void ratio and Marshall Quotient (MQ) were determined.

The Marshall Quotient (MQ) was determined using the following equation:

$$MQ = \frac{Stability}{Flow} \tag{1}$$

Indirect Tensile Test (ITS), Stiffness Modulus and Strain Failure: The stiffness modulus and the indirect tensile strength of HMA are used often to evaluate the relative quality of materials. The load was applied vertically in the vertical diameter plane of a cylindrical specimen of asphalt concrete. The indirect tensile strength is the maximum stress developed at the center of the specimen in the radial direction during loading. The specimen failed by splitting along the vertical diameter as shown in Figs. 7 and 8. Indirect Tensile Strength (ITS), strain at failure (ξ_f) and Stiffness Modulus (S_M) values were determined using the following equations:

Fig. 7: Marshall Stability test

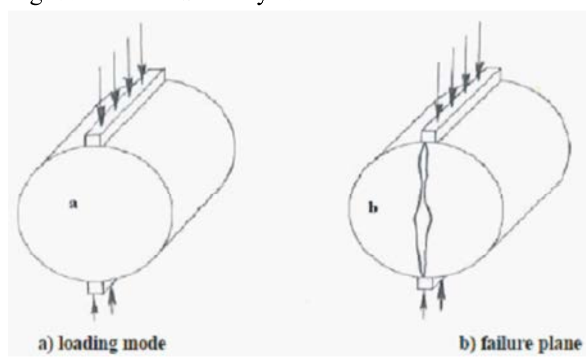

Fig. 8: Laboratory test setup for the ITS test

$$ITS = \frac{2P}{\pi \times h \times d} \tag{2}$$

$$\zeta_f = \frac{6.63U}{\pi d}\% \tag{3}$$

$$S_M = \frac{0.573P}{h \times U} \tag{4}$$

RESULT AND DISCUSSION

The results are presented and discussed as follows:

Effect of Mineral Filler content on Marshall Test Results and Analysis

Marshall Stability: Fig. 10 shows the results of the stability test of different limestone content (4%, 6% and 8%). The results revealed that the stability values were decreased linearly with increasing mineral filler content.

Fig. 9: The Indirect Tensile Strength Test Apparatus

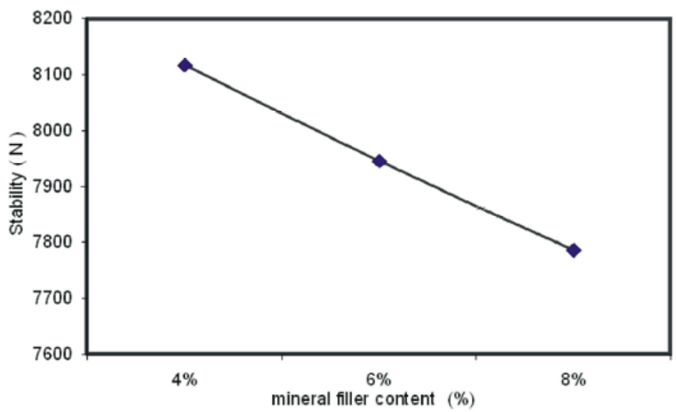

Fig. 10: Effect of different mineral filler content on Marshall Stability

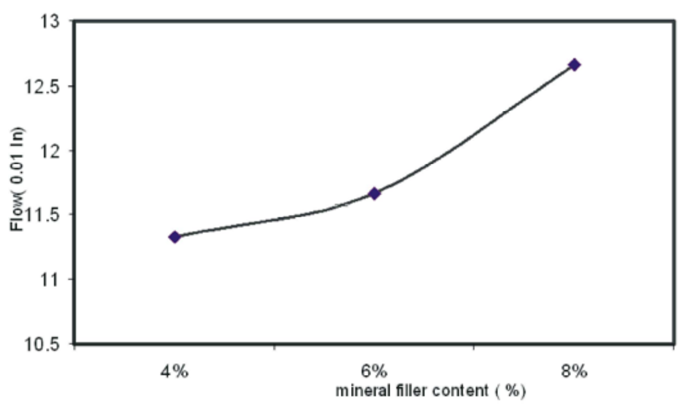

Fig. 11: Effect of different mineral filler content on flow

This result may be explained by that the increase of limestone mineral filler content made the mix flexible so it becomes weak to resist loads.

Flow Values: The results of flow values test for different limestone filler contents are presented in Fig. 11. The flow value was increased with increasing mineral filler content and this result was suspected because decreased stability with increasing of filler content which resulted in increasing flexibility of the mix so it becomes not able to resist loads.

Bulk Density: The relationships between different mineral filler contents and bulk density are illustrated in Fig. 12. The same trend of the results of flow values were observed in the bulk density values witch increased with

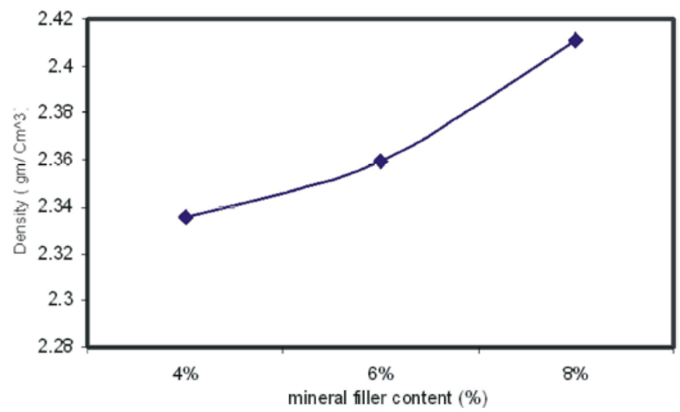

Fig. 12: Effect of different mineral filler content on density

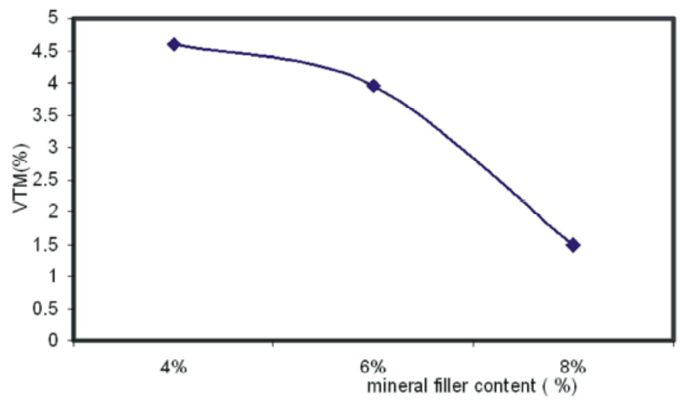

Fig. 13: Effect of different mineral filler content on VTM

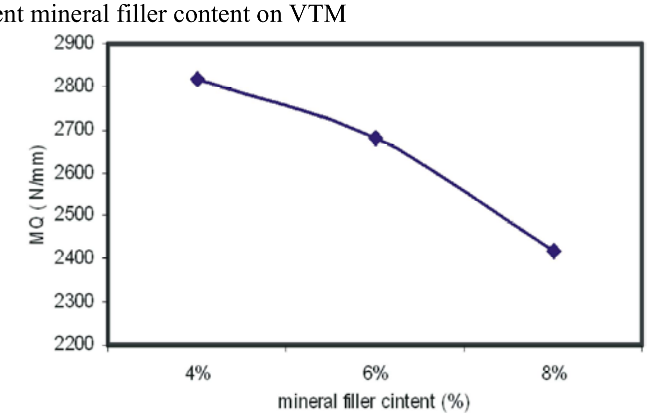

Fig. 14: Effect of different mineral filler content on MQ

the increasing limestone filler content percentage and this result may come up because as mineral filler content increases, the voids in HMA decreases and this leads to increase the values of density of the mixture.

Air Voids: The results of air voids filled with Asphalt (VFA) of different used mineral filler contents (Fig. 13). It reveals that the air voids values were decreased with increasing mineral filler content which may be explained by the resulted good compaction with increasing mineral filler as shown from its high bulk density.

Marshall Quotient: The relationship between different limestone filler contents and Marshall Quotient (MQ) is presented in Fig. 14. It is clear that the values of MQ were decreased linearly with increasing mineral filler content percentage. This may be due to the decrease of stability with the increase of mineral filler content which associated with increasing flow values.

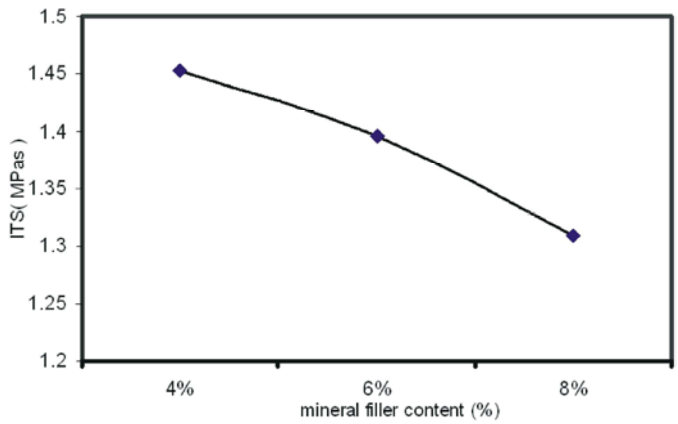

Fig. 15: Effect of different mineral filer content on ITS

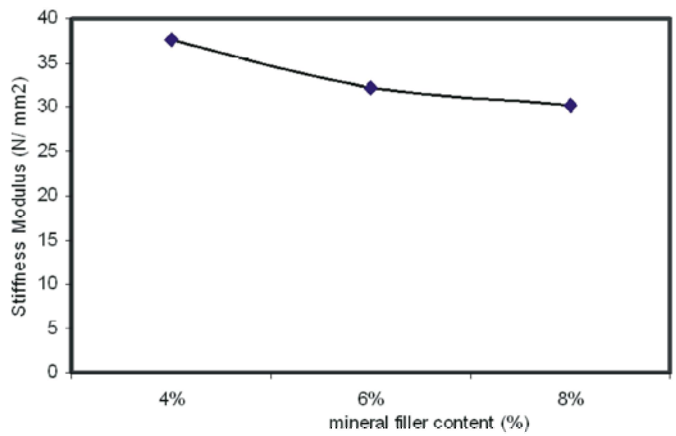

Fig. 16: Effect of different mineral filler content on Stiffness Modulus

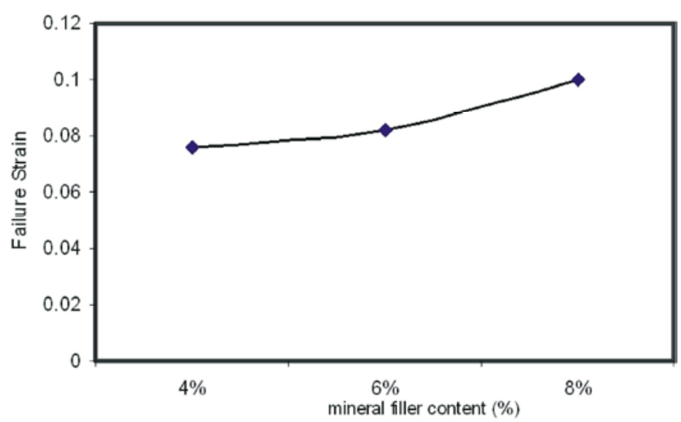

Fig. 17: Effect of different mineral filler content on failure strain

Effect of Mineral Filler Content on Indirect Tensile Strength: Fig. 15 shows the test results of indirect tensile strength (ITS) for all limestone powder contents (4%, 6% and 8% content). It reveals that the indirect tensile strength value was decreased linearly with increasing mineral filler content. This result may come up because as mineral filler content increase, low interlock and internal friction between aggregate particles which lead the mix had poor internal resistance against external loads as it is noted from its low value of Marshall Stability.

Effect of Mineral Filler Content on Stiffness Modulus: Results of stiffness modulus (SM) test for different limestone powder contents (4%, 6% and 8%) are presented in Fig. 16. It reveals that the stiffness modulus value was decreased with increasing mineral filler content percent and this may referred to the low interlock and internal friction between aggregate particles obtained with increasing limestone filler content which weakened the internal resistance of the mix against external loads and horizontal deformation and it is evidenced also, by the low value of ITS and high value of failure strain.

Effect of Mineral Filler Content on Failure Strain: Results of failure strain test for different limestone powder contents (4%, 6% and 8%) are presented in Fig. 17, the results shows the failure strain value was increased with increasing mineral filler content and this results were expected because as mineral filler content increase, low internal resistance against horizontal deformation obtained as it noted from its high value of Marshall Flow.

CONCLUSIONS AND RECOMMENDATIONS

- Using limestone powder as mineral filler in hot asphalt mix shouldn't exceed 4%of the total mix because this percentage had higher values of MS and MQ and consequently had higher HMA performance and properties.
- Bulk density and flow values increased with the increase of limestone powder content in HMA.
- Indirect tensile test (ITS) and stiffness modulus (SM) decreased with the increase of limestone powder content while, strain failure increases with the increase of the content of limestone powder.
- Limestone powder is a common and cheap source of mineral fillers used in Egypt.
- Further studies must be developed to get different sources of mineral fillers with proper contents used in asphalt mixtures to improve its performance and workability and at the same time be economical.

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