Effect of Type and Percentage of Unconventional Mineral Fillers on the Performance of Hot Mixed Asphalt

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Abstract: ***There were several studies, analysis and research projects concerning the performance, practicability and environmental suitableness of using recycled products in highway construction. There are plenty of local waste materials that might be utilized effectively as mineral filler in hot mix asphalt concrete (HMA) rather than traditional limestone dust. The main objective of this study is to explore through an experiment the effect of amount and quality of appending three different unconventional types of mineral filler include waste glass beads (WGB), local loam redbrick dust (LRD) and coal fly ash (CFA) as proposed alternative materials instead of the traditional limestone powder (LSP). for this purpose, a comprehensive laboratory-testing program was performed to determine the effect of different sorts and amounts of those fillers on the engineering and mechanical properties of HMA, and then verify the consequents on design properties and performance of the surface layer of flexible pavement. Based on this investigational program, it is verified that fillers comprise important influence on the properties of HMA mixtures. In addition, inclusion of theses non-conventional fillers could be utilized efficiently in asphalt-concrete mixture as a replacement in terms of stability, deformation and voids characteristics.***

Index Terms: Mineral Filler, Waste Materials, Hot Mixed Asphalt, Flexible Pavement.

I. INTRODUCTION

Mineral filler is a material consists of mineral particles from the coarse and/or fine aggregates, used in the asphalt mixture or from different sources like stone powder, Portland cement or hydrated lime. It usually improves the rheological, mechanical, and thermal behavior and water sensibility of asphalt mixtures. It has long been perceived the frequent roles of fillers within the hot mix asphalt (HMA) performance. The filler usually filling the voids between fine and coarse aggregates in the mixtures and changes the asphalt binders properties. In the HMA design, the mastic *(which is mixture of fillers, asphalt binder and ai*r) affects the larger aggregates particles lubrication, the compaction characteristics, Voids in mineral aggregate as well as the optimum asphalt content (O.A.C).

In developing countries, cost is the main concern for any type of pavement constructions. Hence, the prime aim of this investigation has been set out to look at the impact of exploitation non-conventional fillers like waste glass beads (WGB), local loam red-brick dust (LRD) and coal fly ash (CFA) on the performance of hot mix asphalt (HMA) and compare the characteristics of asphalt-concrete mixtures thereupon created using traditional limestone powder (LSP) filler according to the test procedure nominative by AASHTO.

II. EFFECT OF MINERAL FILLER ON HMA

Filler, as one of the constituents of asphalt mixture, plays a noteworthy part in determining the properties and behavior of the mixture, particularly its binding and aggregate interlocking consequences.

Generally, mineral fillers serve up a dual function when it added to asphalt mixtures. The percentage of mineral filler, which is finer than the thickness of the asphalt film, mingles with asphalt cement binder to figure a mastic or mortar that contributes to improve mix strengthening. Particles larger than asphalt film thickness act as a mineral aggregate and thus contribute to enhance contact points among individual aggregate particles **[1]**.

The filler in asphalt mixture plays its role through two mechanisms:

a. Filler offers extra contact points between larger aggregates, and can be considered as a continuance of the asphalt-aggregate fraction mix.

b. Filler either increases the mixture stability by increasing the asphalt binder viscosity **[2]**.

Filler offers benefits for the durability of the asphalt mix upon water act due to its physical characteristics that reducing the porosity of the granular formation and hence make the access of water and air is more difficult.

In addition, the chemical nature of filler may mean greater attraction with the asphalt binder, improving the resistance to the displacement that the water causes the bitumen. Filler also offers better resistance to micro-cracks for increasing the fatigue life of asphalt-concrete mixture **[3]**.

III. MATERIAL CHARACTERIZATION

A. Hot Mix Asphalt;

Hot Mix Asphalt generally consists of combination of different sizes of aggregates in the company of mineral filler; they uniformly mixed with bitumen, each of them has its own specified characteristics, which must be suitable to precise construction and design purposes. The following is a brief of the tests, References, and results that carried out on the considered HMA

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of wearing course as per Egyptian code of practice.

In this study, Marshall Method *(Asphalt Institute, 2003)* of Mix Design was adopted for preparation of mixes. The method is intentional for laboratory design of asphalt hot mix for paving.

Asphalt Cement: one type of asphalt cement of (60-70) grade of penetration was employed; it was obtained from Suez Petroleum Refinery. This grade is commonly used for heavy traffic and hot weather conditions in Egypt. Table-1 shows tests carried out on asphalt cement, and their average results.

Aggregates: in this study, crushed dolomite aggregate as it is the most widely sort used in asphalt mixes in Egypt. Table-2 point up the tests carried out on the aggregate beside their average results.

Table-1: Laboratory Test Results of Bitumen used in HMA

Test	Unit	Specification	Averag
Specific Gravity	gm/cm^3	ASTM – D70	1.02
Penetration	0.01mm	ASTM – D05	66
Flash Point	^oC	ASTM – D92	307

Table-2: Test Results of Aggregate used in Asphalt mix.

	Test	Unit	Specification	Test Results			Average	Specs. Required
				Test-1	Test-2	Test 3		
1	Specific Gravity *(coarse)*	----	ASTM – C127	2.731	2.733	2.733	2.732	N.S.
2	Specific Gravity *(Fine)*		ASTM – C128	2.755	2.753	2.754	2.754	N.S.
3	Specific Gravity *(Filler)*		ASTM – C120	2.780	2.790	2.793	2.788	N.S.
4	Abrasion *(Los Angeles)*	%	ASTM – C131	25	26	26	26	40 Max.
5	Soundness *(MgSo$_4$)*	%	ASTM – C088	9.2	8.9	9.1	9.0	12 Max.

Asphalt Mix: A wearing course 4-C type was considered in this study, as it is the most extensive asphalt mix types used in Egypt for wearing course. The lower and upper limits of this course gradation are as per the ECP-2010 specification.

The Marshall Mix Design procedure (ASTM D-1559) was followed in performing the mix designs where locally available materials that met the normal ECP-2010 specifications were used to produce the reference mix.

The mixing and compaction temperature was consigned to be 160°C and 140°C respectively for efficient asphalt. OAC was calculated as per the Asphalt Institute MS-2 series by taking the average asphalt content corresponding to 4% air voids, maximum stability, and maximum bulk density, and was checked-out against other parameters. The air voids in the design were kept at 3.5% as per the requirements of specifications. Tables 3 and 4 show the design of blending mix as well as the attained Job Mix limits and its compliance to the specifications employed by ECP-2010 as adopted in this research.

Table-3: HMA Blending Test Result of Wearing Course (type4-C)

Sieve open / Material	1"	3/4"	3/8"	# 4	# 8	# 30	# 50	# 100	# 200
Agg.-2	100	71.1	1.2	0.9	0.0	0.0	0.0	0.0	0.0
Agg.-1	100	99.9	58.6	1.8	0.9	0.6	0.0	0.0	0.0
Sand	100	100	99.7	99.2	97.8	49.1	3.7	0.9	0.0
Filler	100	100	100	100	100	100	100	98	96
Mix	100	97.3	74.3	50.7	49.8	28.3	13.6	7.7	6.2
JMF	100	92.3-100	69.3-79.5	48.0-54.7	45.8-50.0	24.3-32.0	13.0-17.6	7.0-11.7	6.1-8.0
Specs.	100	80-100	60-80	48-65	35-50	19-36	13-23	7-15	3-8

Table-4: HMA Mechanical Properties Test Result (Type4-C)

Criteria	Bitumen (%)	Stability (Kg)	Flow (mm)	Density (kg/cm^3)	Air voids (%)	VMA (%)	VFB (%)	Stiffnes (kg/mm)
4-C Mix	5.10	1060	2.15	2.411	3.50	15.9	95.2	494
Specs.	4.0 – 7.5	Min 900	2 – 4	-----	3.0 – 5.0	Min. 15.0	-----	-----

B. Mineral Fillers;

Three unconventional filler types, namely **(WGB), (LRD)** and **(CFA)** along with the traditional **(LSD)**, all with particle sizes passing #75µm sieve were laboratory characterized.

The traditional **LSP** filler was obtained from a local asphalt mix station at Mansoura city. The waste glass beads **(WGB)** used in this study was obtained through laboratory crushing by los-Angeles test machine and sieved on a #200 sieve. The local loam redbrick dust **(LRD)** was brought from the waste of a local redbrick factory sited at Mitghamr town, while the coal fly ash (**CFA)** is prepared in the laboratory by heating and combusting a virgin coal to 700°C in a furnace and then lifts for 24 hours to be cooled to room temperature and sieved on #200 sieve. All samples were collected and quartered into smaller representative portions before laboratory testing. The test results applied on the said filler materials were as shown in table-5.

Table 5: Proposed Mineral Fillers Physical Properties

Filler Type	Specific Gravity	% Passing #200	Plasticity
LSP *(lime stone powder)*	2.71	95.4	N.P.
WGB *(waste glass beads)*	2.36	90.2	N.P.
LRD *(loam Red-brick dust)*	2.33	86.7	N.P.
CFA *(coal fly Ash)*	2.63	93.9	N.P.

IV. TESTING AND INVESTIGATION

60 specimens of marshal test were prepared in which 12 specimens with 4 different percentages of each three unconventional materials besides 12 for traditional lime stone powder as a reference.

The *Stiffness index* assigned in this study is an empirical relationship represented by the ratio between Marshall Stability and corresponding flow value at optimum asphalt content. It is perceived that the stiffness is a determinant of the material’s resistance to shear stresses, permanent deformation, and hence rutting. The high stiffness values indicate a high stiffness mix and resistance to creep deformation

Retained strength (RS) in this research is assigned through the Retained Marshall Stability test by determining retained stability for Marshall Compacted specimens after curing for twenty-four hours in a water-bath at 60°c in accordance to ASTM D1075 method.

The specimens were divided into two groups; the first, (*unconditioned*) which were immersed in water bath at 60°Cfor 30 min, and then loaded to failure by using curved steel loading plated along with specimen diameter at a constant compression rate of 51mm/min. The second group (*conditioned*) was also placed in water bath at 60°C but for 24hr then tested. Founded on the maximum load that specimen carried at failure,

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The retained stability (RS) was then calculated according to the following equation,

$$RMS = \frac{MS_{cond}}{MS_{uncond}} \times 100\%.$$

Where:

RMS = Retained Marshall Stability,

MS_{cond} = Marshall Stability for conditioned samples.

MS_{uncond} = Marshall Stability for unconditioned samples.

Cylindrical specimens of 101.6 x 63.4 mm were prepared with Optimum Asphalt Content with mineral filler contents ranging from 3 to 9% with an increment of 2%.

Three samples were prepared for each filler content. Forty-eight mix designs were prepared namely, **LSP5**, **LSP7**, **LSP9 LSP11, WGB5**, **WGB7, WGB9, WGB11, LRD5 LRD7, LRD9, LRD11 and CFA5 CFA7 CFA9 CFA11** representing the four sorts of fillers with four different ratios. These designs were setup with the same mix of fine and coarse aggregates to remain aggregate mineralogical characteristics and angularities constant. The only variable in the mixtures was the filler proportion of 3, 5, 7 and 9% (passing #200sieve). Sixteen Marshall Mix designs were made to determine mixtures physical characteristics.

Laboratory experimental specimens were prepared via 75 blows of the Marshall hammer on each one side. The temperature for mixing was designed at160°C while for the compaction was at 140°C.

Results of Marshall Test on the specimens prepared at various filler contents for the three types of proposed fillers as well as the traditional lime stone powder are illustrated in figure-1 to figure-5 and summarized in table-5. All specimens at the Optimum Asphalt Content assigned earlier beside calculated stiffness and retained strength.

Table-5: HMA Mechanical Properties Test Result (type4-C)

Criterion	Opt. Asph. Cont.	Filler Type	% Filler Content 3	5	7	9
Stability (kg)	5.10%	LSP	733	1060	965	670
		WGB	790	1150	970	665
		LRD	725	875	1050	715
		CFA	990	890	690	590
Flow (mm)		LSP	2.20	2.35	2.55	3.30
		WGB	2.80	2.40	2.25	2.10
		LRD	2.85	2.65	2.60	2.95
		CFA	2.60	2.50	2.70	2.40
Stiffness (kg/mm)		LSP	333	451	381	230
		WGB	282	487	433	324
		LRD	254	330	404	242
		CFA	381	356	256	174
Air voids (%)		LSP	5.65	4.02	3.61	3.01
		WGB	3.81	4.20	4.66	5.55
		LRD	4.25	3.65	3.45	2.81
		CFA	4.65	3.71	2.90	2.30
Retained Strength (%)		LSP	96.5	95.9	92.1	89.2
		WGB	86.6	88.9	95.1	85.3
		LRD	93.5	87.2	83.9	77.5
		CFA	92.1	83.6	75.4	72.3

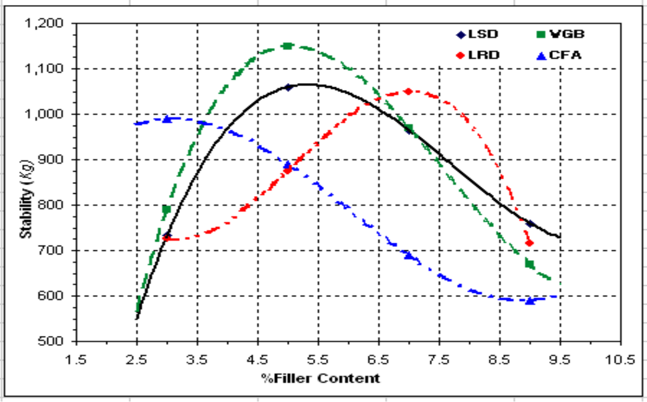

Figure-1: Stability of HMA versus %age of Filler Content

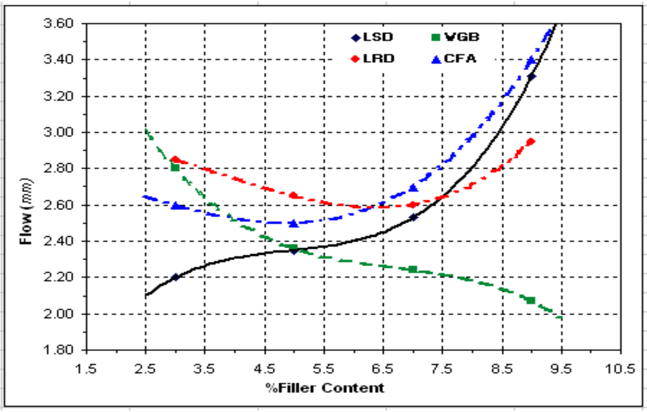

Figure-2: Flow of HMA versus %age of Filler Content

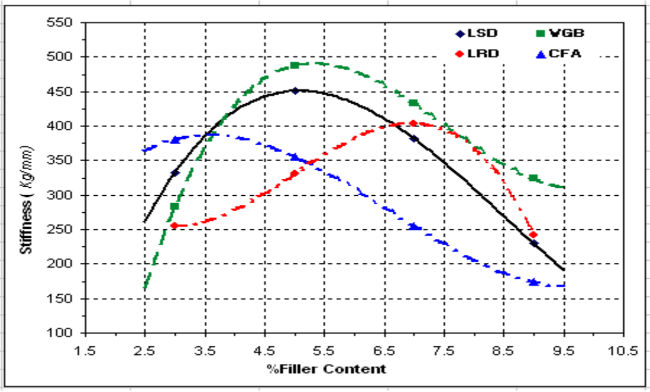

Figure-3: Stiffness of HMA versus %age of Filler Content

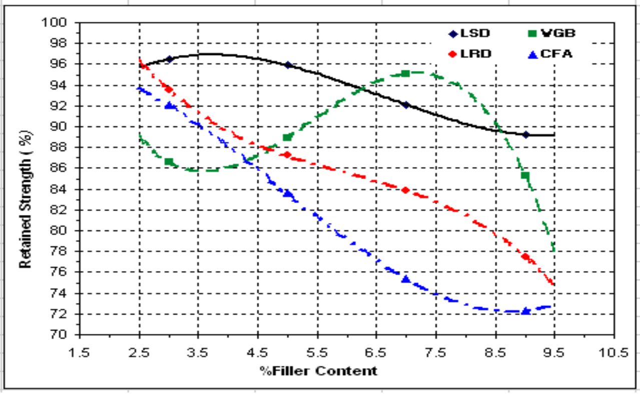

Fig 4: Retained Strength of HMA vers. %age of Filler Content

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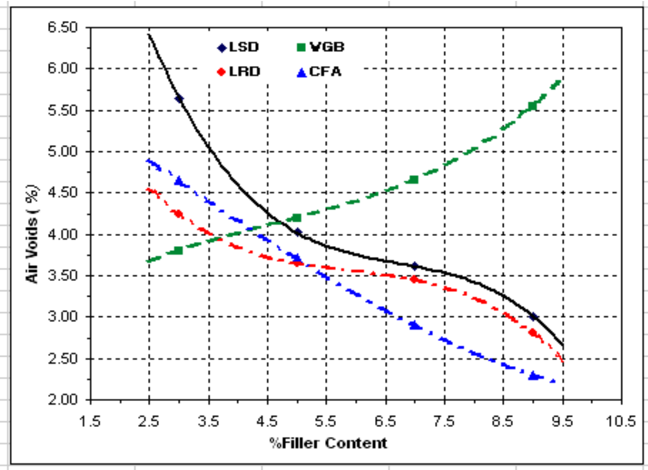

Figure-5: Air Voids of HMA versus %age of Filler Content

V. ANALYSIS AND DISCUSSION

The test results obtained in this research are discussed below;

a. Effect on Marshal Stability: Figure-1 demonstrates the effect of filler types and their contents on Marshal Stability. All considered fillers have the same trend on their effect on stability by content, i.e., as filler content in the mixes increase, Marshal Stability also increases up to maximum then decreases except for mixtures with **CFA**. This is because of the fact that voids at lower filler content is excessively high and the aggregate tend to be finer as filler content increases, hence both effects have a tendency to reduce the stability values. Moreover, anything increases the asphalt cement viscosity is directly increase the Marshal stability. Thus, a little addition of fine material like a filler to the mixture may lead to make the asphalt cement and dust mixture act as an extra viscous binder thus increase Marshal stability. However, if the dust is exceedingly fine, it could expand the asphalt cement, making act like higher asphalt content, and lower the stability, depending on Marshal Stability shape against asphalt content curve [**7**]. Figure also indicates that the **WGB** filler had the highest stability while **CFA** was the lowest although it was within the permissible limit of 900kg as per ECP-2010.

b. Effect on Marshal Flow: As it is plainly illustrated in Figure-2, the values of Marshal Flow that obtained from the experimental prepared mixes using all types of fillers, meet the Marshal criteria (2-4mm). For mixes prepared using 3%, 5%, 7%, and 9%, the flow values obtained are ranging from 2.2 to 2.6mm at the 6.2% filler content. Higher values of flow were obtained for lower filler contents using 3% **WGB**. At higher filler content, higher values of flow were also obtained using 9% **CFA** featured to **LSD** filler. Lower flow values were obtained at higher value of **WGB** filler due to self-stiffness which solidifies the mixture more than other types of fillers.

c. Effect on Marshal Stiffness: As illustrated in figure-3, the stiffness for all filler types has the same attitude in which **WGB** and **LRD** fillers were the highest and little bit less stiff than reference filler (at 6.2%filler content) but still within permissible rang. This result may come up because these two fillers had high interlock and internal friction between aggregate particles which give the mix good internal resistance against external loads as it noted from its high value of Marshal Stability. On the other hand, the stiffness values of **CFA** was the lowest at the reference filler content but also it provides the stiffness value almost closed to the highest of **WGB** at lower filler content of 3.5%.

d. Effect on Marshal Retained Strength: retained Marshall Stability index (RMS) can be used to assess the water effect damages on the Marshall stability for the asphalt concrete mixtures that exposed to water conditions. From the marshal immersion test, which performed on mixtures prepared at optimum asphalt content, the values of retained stability are attained as a ratio of conditioned stability to controlled stability. Mixtures prepared at 3%, 5%, 7% and 9% were evaluated to indicate the effect of mineral filler types used in the mixes. The test results are tabulated and plotted as shown in Table 5 and Figure 4 respectively. The figure indicates that mixes prepared using 4% and 7% **LSD** and **WGB** fillers respectively provide highest retained stability as compared to mixes prepared with **LRD** and **CFA** fillers. It indicates also that mixes prepared using **WGB** filler provide the same resistance to moisture effects for the sample test as LSD at the design filler content (6.2%). On the other hand, decreased retained stability values were obtained from mixes with **LRD** higher filler content, and the lowest was using **CFA** filler but still fulfill the lowest desired value as per ECP-2010 (75%) at design filler content.

Effect on Marshal Air Void's ratio: The effect of different fillers on air voids in HMA was also evaluated and the results are shown in Figure-5. It is a common trend that, as filler content in the mixes increase, the voids in HMA decreases except in WGB, the **A.V.** increased as the glass powder percentage increased. In terms of void ratio, filler content effect is found to be more substantial than that of filler type effect. When we see the impact pattern of filler content on air voids esteems, it appears that there would be an ideal filler content that would enhance the bituminous mixture performance. As can be seen from Figure-5, mixtures using both **CFA** and **LRD** filler types exhibit same manner, but mixtures made using **WGB**, the voids in mix keeps increasing as the content of the filler in the mixture increases. Higher air voids in HMA were obtained from mixes prepared by **WGB** of 9%, and LSD of 3% filler content respectively. This attributes to the fact that **WGB** is coarser than **LSD** filler type.

VI. CONCLUSIONS

From the investigations conducted in this study using diverse sorts of fillers, the following can be concluded:

1. Type of filler and size of particles affect directly the technical properties of the asphalt mixtures. More over, assigning filler content for mix design purpose should be established based on the

Overall performance of **HMA** mixtures.

2. Besides filling the voids, the components of fillers are interacting with the binder present in the mix, potentially making it firm and brittle. The alteration in mix properties is stoutly related to the filler properties.
3. The major finding of this study is that **WGB** and **LRD** used as filler were found to be effective in improving the Marshall stability, Flow, and Marshall Stiffness index, as compared to conventional **LSD** filler. **CFA** had the lowest effect. It did little to enhance the Marshall Stability or strength value as compared with reference filler.
4. Adding **WGB** of 6.2% by total weight of aggregates on the hot asphalt concrete mixtures leading to increase the Marshall Stability by 5.5%, while decreases Flow by 4.5 %.
5. Adding 7% of **LRD** by total weight of aggregates on the hot asphalt concrete mixtures give the same stability of the design filler content of traditional LSD but increases Flow by 4. %.
6. The results of the laboratory tests show that **WGB** and **LRD** fillers improve the overall mixture properties of asphalt. Using these particular industrial wastes and byproducts as fillers, improves pavement engineering properties and performance, hence decreasing the maintenance and rehabilitation costs of the pavement
7. From economic point of view, future studying should be taken on more various local waste materials that might be used as mineral fillers for asphalt mixtures, such as steel fibers, iron filing , polymers etc.,

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