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Utilization Of Steel Slag Aggregate in Hot Mix Asphalt in Egypt

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Abstract*: Steel slag is a byproduct from either the conversion of iron to steel in a basic oxygen furnace, or the melting of scrap to make steel in an electric arc furnace. This paper presents the influences of the utilization of steel slag as a coarse aggregate replacing the traditional limestone aggregate on the properties of a binder and surface course hot mix asphalt (HMA). Six percentages (0%, 20%, 40%, 60%, 80%, and 100%) of limestone aggregate were replaced by steel slag aggregate (SSA) for both binder and surface course. The effectiveness of SSA in HMA was measured by preparing Marshall Specimens and measure their stability, flow, stiffness, indirect tensile stress, and loss of stability. It was observed that replacing up to 60% of limestone coarse aggregate by SSA improved the mechanical properties of the mixtures and it was the optimal percentage.

***Index Terms*—steel slag aggregate, asphalt mixtures, Marshall, indirect tensile strength.**

I. INTRODUCTION

Steel slag is a byproduct from either the conversion of iron to steel in a basic oxygen furnace, or the melting of scrap to make steel in an electric arc furnace. Approximately 1 ton of steel slag is generated while producing each 3 tons of stainless steel [1]. Around the world fifty million tons of steel slag is produced as a byproduct annually [2].

If not recycled, Steel Slag will end up in landfills costing money and causing environmental problems. Utilization of these waste materials can be seen as a way to minimize the amount the dumped wastes and save the natural resources. Depending on these reasons researchers have established studies to determine the availability of partially substitute the traditional virgin aggregate with Steel Slag Aggregate (SSA) as a road construction material especially in Hot Mix Asphalt (HMA) [3-8].

In HMA the aggregate represents approximately 90% from the total volume of the mixture and have a direct effect on the physical and mechanical properties of the mixture [9].

SSA has a high durability and strength because it has a significant amount of oxidized steel in its chemical composition and has high angular and vesicular shape which makes it an appropriate material for road construction use in different road layers. Also based on high friction and abrasion resistance SSA has gained wide utilization on industrial roads, intersections, and parking areas where high wear resistance is required [10]. Asi, conducted a study showed that asphalt mixtures containing 30% limestone aggregate replaced by SSA will have a higher skid resistance by 10% more than the traditional Marshall mixtures [10]. Asi et al. conducted a study to measure the effectiveness of using SSA in Asphalt mixtures by trying different SSA percentages and determining the resilient modulus, creep modulus, indirect tensile strength, and rutting resistance. They reported that replacing a 75% percentage of limestone coarse aggregate by SSA exhibited better mechanical properties of the asphalt [8].

Using of SSA in asphalt mixtures should be limited to replace either the coarse or the fine aggregate, but not both, because a 100% SSA mixture will be susceptible to a bulking problems and high proportion of voids because of the angular shape of SSA and it will require a high percentage of binder which make using SSA instead of the traditional limestone aggregate not feasible [8].

In Egypt there is a huge amount of steel slag produced annually as a byproduct while producing steel. Some of steel manufactures build mechanical crushers for that slag in order to be able to market it as a road construction material.

This study aims to evaluate the availability of using the SSA produced in Egypt as a coarse aggregate replacing the traditional limestone aggregate in the most used HMA in Egypt (Binder 3-D and Surface 4-C mixtures) in the view of the Egyptian specifications and the Egyptian Code of Practice.

II. MATERIALS AND METHODS

A. Steel Slag

This study was carried out on a primary slag which is a byproduct of the steel industry process at "Ezz- Steel" factory, located in El Dekhala- Alexandria, northen Egypt. The steel is produced by EAF through a direct fusion process. After collecting slag from the furnace it is allowed for aging through a specific process in an open unprotected area and subsequently the material is transported to the mechanical crushers which crush the slag bulks into different sizes approximately the same as crushed limestone sizes.

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SSA is used in this study as a replacement of coarse limestone aggregate fraction, so the used SSA sizes was “0-12” (0-12 mm diameter) and “12-22” (12-22 mm diameter). These different SSA sizes were sieved on a set of sieves and their physical and mechanical properties were determined in order to determine the validity of these materials to be used as a coarse aggregate in asphalt mixtures.

Table 1

Characteristics of Conventional Coarse Aggregate

Test No.	Test		Type of Aggregate	AASHTO Standards	Results
1	Abrasion After 500 Revolution		PIN 1	T - 96	26.60%
			PIN2		26.50%
2	Water absorption		PIN 1	T-85	2.80%
			PIN2		2.50%
3	Specific Gravity	Bulk	PIN 1	T-85	2.59
		Saturated			2.66
		Apparent			2.79
		Bulk	PIN 2	T-85	2.6
		Saturated			2.67
		Apparent			2.78
4	Stripping		PIN1 & PIN 2	T-182	>95%
5	Soundness		PIN 1	T - 104-68	2.07%
			PIN 2		2.03%

Table 2

Characteristics of Steel Slag

Test No.	Test		Type of Aggregate	AASHTO Standards	Results
1	Abrasion After 500 Revolution		0-12 mm	T - 96	18.50%
			12-22 mm		18.10%
2	Water absorption		0-12 mm	T-85	1.10%
			12-22 mm		1.00%
3	Specific Gravity	Bulk	0-12 mm	T-85	3.45
		Saturated			2.5
		Apparent			2.54
		Bulk	12-22 mm	T-85	3.44
		Saturated			2.49
		Apparent			2.53
4	Stripping		0-12 & 12-22	T-182	>95%
5	Soundness		0-12 mm	T - 104-68	1.03%
			12-22 mm		1.01%

Table 3

Characteristics of bitumen

Test no.	Test	AASHTO Designation no.	Results
1	Penetration,0.1mm	T-49	63
2	Softening Point,°c	T-53	45
3	specific gravity at 25°c	T-228-04	1.01

B. Virgin aggregates and Bitumen

Virgin aggregates were crushed limestone (coarse and fine aggregates) and the used binder was the traditional bitumen of grade class 60/70.

C. Bituminous mixtures

Two main types of bituminous mixtures were investigated in this study; the first type is for the wearing surface which is designated as 4-C and the second type is for the binder course which is designated as 3-D. Six different mixtures were prepared for each type containing 0%, 20%, 40%, 60%, 80%, and 100% of SSA replacing the coarse aggregate fraction in the paving mixture.

III. EXPERIMENTAL DESIGN

The experimental work involved testing both the conventional aggregate and the SSA to determine their physical and mechanical properties. The properties of both conventional aggregate and SSA are shown in Table 1 and Table 2 respectively. Bitumen binder is also tested to determine its properties. Characteristics of the used bitumen are shown in Table 3.For both mixture types the optimum asphalt content (OAC) is obtained for the control mix. (0% SSA) and the 100%SSA mix. using Marshall method. It was observed that increasing the amount of the SSA will increase the OAC because of the high porosity and angularity of the SSA. As a result of the previous observation the other mixes (20%, 40%, 60%, and 80% SSA) where prepared and tested using the OAC for the control mix (0% SSA) because it was found that it will not be feasible to increase the amount of binder above its traditional ranges because of the high binder cost.

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A. Marshall Stability, flow and Marshall quotient tests

Marshall test was carried on both mixture types "4-C" and "3-D" of percentages 0% SSA and 100% SSA to determine the OAC for each mixture. The asphalt cement contents corresponding to maximum bulk specific gravity, maximum stability, 4% air voids in the total mixture, and 80% voids in the aggregate filled with asphalt are used to determine the optimum asphalt cement content [11]. After determining the OAC for 0% SSA mixture this asphalt content was used for the other mixtures (20%, 40%, 60%, and 80% SSA) except for the 100% SSA mixture.

The Marshall quotient (MQ) (Kg/mm) is also calculated as the ratio of stability (Kg) to flow (mm). MQ can be used as a measure of material's stiffness (resistance to permanent deformation) a higher MQ value indicates stiffer materials [12].

B. Indirect tensile strength (ITS) test

The ITS test is performed to determine the tensile properties of the asphalt mixture which is directly related to the cracking properties of the pavement. The ITS test is performed using Marshall apparatus (the ITS mode) at 25°C. The failure load for each specimen was recorded and then the ITS was calculated for each specimen as follows:

$$ITS = \frac{2P}{\pi t d} \quad [1]$$

Where ITS is the indirect tensile strength (KPa); P is the failure load (KN); t is the sample thickness (m); and d is the sample diameter (m).

C. Loss of stability test

Loss of Stability (LOS) is a test measuring the resistance of the mixture to moisture it is a simplified version of AASHTO T165 test, in which the LOS is measured for a three Marshall samples soaked in a water path of 60°C for 24 hours.

IV. RESULTS AND DISCUSSION

A. Marshall Stability, flow and Marshall quotient

For mixtures "4-C" and "3-D" with percentage of SSA of 0% and 100% the OAC is determined using Marshall test procedure. The results are shown in Table 4.

Table 4
Marshall design results

Property	Mixture type			
	0%SSA		100%SSA	
	4-C	3-D	4-C	3-D
Optimum asphalt content (%)	5.30%	4.60%	5.40%	4.75%
Mix bulk specific gravity (g/cm^3)	2.38	2.37	2.68	2.74
Air void (%)	3.27%	3.29	3.33%	5.00%
Voids in mineral aggregate (%)	15%	13%	15.40%	17.00%
Marshall stability (Kg)	1050	895	1150	1010
Flow (mm)	2.3	2.07	2.35	2.2
MQ (Kg/mm)	456.5	432.3	489.3	459

As shown in table 4 the OAC is directly proportional to the percentage of the SSA which may reduce the feasibility of using SSA as a replacement of the traditional limestone aggregate. Based on these reasons the other asphalt mixtures were prepared and tested using the OAC for the control mix (0% SSA) and their Marshall properties are shown in Table 5 and Table 6.

Table 5
Marshall design results

Property	Mixture type			
	20%SSA		40%SSA	
	4-C	3-D	4-C	3-D
Optimum asphalt content (%)	5.30%	4.60%	5.30%	4.60%
Mix bulk specific gravity (g/cm^3)	2.4	2.38	2.52	2.5
Air void (%)	3.40%	4.00%	4.00%	4.40%
Voids in mineral aggregate (%)	16%	14.00%	13.00%	13.50%
Marshall stability (Kg)	950	820	1320	1000
Flow (mm)	2.25	2	2.25	2.125
MQ (Kg/mm)	422	410	586.67	470.58

Table 6
Marshall design results

Property	Mixture type			
	60%SSA		80%SSA	
	4-C	3-D	4-C	3-D
Optimum asphalt content (%)	5.30%	4.60%	5.30%	4.60%
Mix bulk specific gravity (g/cm^3)	2.56	2.58	2.66	2.7
Air void (%)	3.90%	3.95%	3.50%	5.00%
Voids in mineral aggregate (%)	14.00%	14.00%	15.50%	19.00%
Marshall stability (Kg)	1450	1070	1120	990
Flow (mm)	2.45	2.11	2.375	2.25
MQ (Kg/mm)	591.83	507.1	471.5	440

As seen in Table 5 and Table 6 the maximum Marshall stability values were obtained for 60% SSA mixture and the SSA mixtures have higher values of Marshall Stability than the control mixture. Also the flow values are improved using SSA.

The asphalt concrete mixtures containing SSA yield higher values of MQ than that of the control mixtures. It is well recognized that the MQ is a measure of the resistance of material to shear stresses and permanent deformation.

B. Indirect tensile strength

The indirect tensile strength test results are presented in Fig. 1. The ITS of the mixtures containing steel slag coarse aggregate is higher than control mixtures containing limestone coarse aggregate. This indicates that mixture prepared with SSA yields greater cohesive strength compared to mixture prepared with limestone aggregate. It was also indicated that 60% SSA mixture has the higher ITS for both "4-C" and "3-D" mixtures.

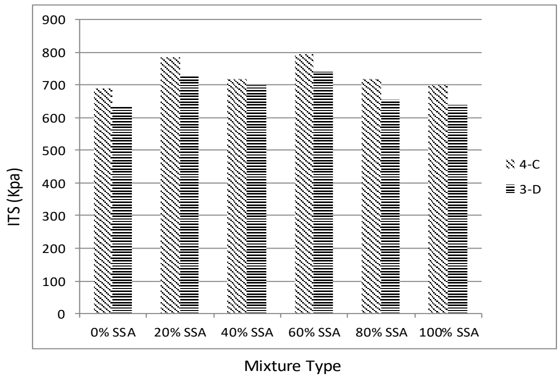

Fig. 1. ITS values for the different mixtures

C. Loss of stability test

A comparison was made between the stability before soaking and after soaking in water at a temperature of 60°C for 24 hours.

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The results are shown in Fig. 2. The results demonstrated that the average resistance to moisture values for SSA mixtures was higher than the control mix; this behavior is attributed to the porosity of the SSA aggregate, which allowed the asphalt cement to penetrate more than in the limestone aggregate, creating better bonding and resistance to stripping.

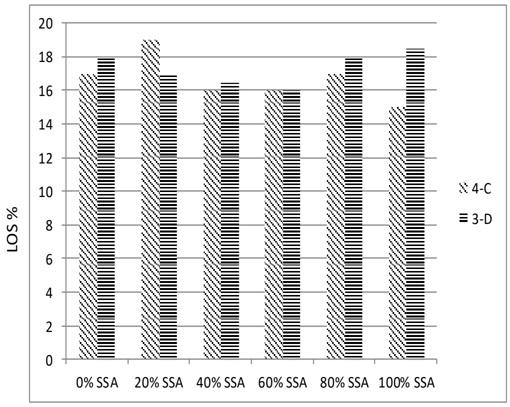

Fig. 2. Los of Stability values for the different mixtures

V. CONCLUSIONS

In this research the most used types of asphalt mixtures in Egypt were investigated (4-C and 3-D). 0%, 20%, 40%, 60%, 80%, 100% of the limestone coarse aggregate (materials retained on sieve No. 4, size 4.75mm), were replaced by SSA and used in different AC mixes. The effectiveness of replacing limestone aggregate by SSA was judged by the improvement in Marshall stability, flow, MQ, ITS, and LOS. The following conclusions can be drawn:

1) SSA can be used in AC mixes, since its properties meet both Marshall consensus properties and the Egyptian Code of Practice (ECP 2008) requirements.
2) The required asphalt quantity increases with the increase in SSA content, but using the OAC for the traditional mixes will give a satisfactory results.
3) Replacing up to 60% of the limestone coarse aggregate by SSA improved all tested mechanical properties of the AC mixes.
4) Full replacement (100%) of the limestone coarse aggregate by SSA improved all the tested mechanical properties of the AC mixes except the resistance to moisture.

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