EVALUATION OF SLAG AS A COARSE AGGREGATE IN HOT MIX BITUMINOUS CONCRETE

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ABSTRACT

This paper is mainly concerned with discussing the possibility of utilizing both types of steelmaking slag, produced as a by-product from the Egyptian Copper Works Company as a coarse aggregate in hot mix bituminous concrete which is used in road airport surfacing. The study led to the following conclusions: 1. Eliminating the disposal of steelmaking slag as a waste material 2. The economic employment and efficiency of steelmaking slag, when used as a coarse aggregate in bituminous concrete.

INTRODUCTION

Environment of earth is a closed system, hence, it is obliging to recycle the industrial wastes, as possible, if we want to minimize the pollution. Industrial by-products are now the main reason of pollution, due to their accumulation.

Judicious management is needed to overcome such a problem. Many research works were performed to utilize industrial by-products, in order to minimize their effect on the environment.

In Egypt, the numerous iron and steelmaking companies, suffer the accumulation of slag which is the molten material produced during refining the metals. However, only the Helwan Iron and Steel Company uses the blastfurnace slag in cement manufacture. In Alexandria, the Egyptian Copper Works suffer from the accumulation of steelmaking slag (5000 m^3/year), which is produced from the open-hearth and electric arc furnaces. A big deal of money is spent annually to discard the slag. This slag have never been used apart from landfilling.

This study aims, firstly, to analize and characterize the slag to promote its feasible application, moreover, to facilitate the burden of its discard. Secondly to investigate the applicability of steelmaking slag as coarse aggregate in road surfacing, in order to improve the durability of pavement.

Chemical, physical and mechanical properties of both types of slag of steelmaking slag were examined before processing. The slag passed several tests and complies to certain standards (ASTM and BS). Test data were compared to those of natural aggregates, in order to achieve a better interpretation of the slag properties.

Trial mixes of asphalt concrete were made in order to examine the effect of steelmaking as coarse aggregate on the pavement durability. The asphalt concrete containing slag as coarse aggregate proved to sustain high stability and possess a very high skid resistance properties. In consequence, heavier traffic loading, longer period of service and lower road maintenance cost would be achieved.

MATERIALS

In the Following, results collected from the tests carried out for the investigation of the materials properties are presented and compared with the specifications limits.

Aggregates

Natural sand and cement used in the investigation of slag as a coarse aggregate for cement concrete were also used in the current study as a fine aggregate and as filler, respectively.

Physical and mechanical properties of sand and cement were presented in Tables 1 and 2.

Table 1. Physical properties of fine aggregate.

Property	Natural Sand	ASTM Limits
Bulk specific gravity water Absorption	2.60 0.92	1.6 - 3.2 0.2 - 2.0
Unit Weight (ton/m^3) Compacted Loose	1.68 1.56	1.2 - 1.76
Voids ratio (%) Compacted Loose	32.2 37.2	
Moisture Content (%)	0.50	
Percentage of material finer than No. 200 sieve	0.86	< 5.0 %

Table 2. Physical and Mechanical properties of Ordinary Portland Cement.

Property		Test results	B.S.S. No. limits
percentage of water to give a standard part		25.6%	
Setting test (vicat test)	Initial Final	1.68 1.56	not less than 15 min not more than 10 h
Compressive Strength of motor in kg/cm^2	3 days 28 days	211 285	> 150 > 230
Percentage of fineness modulus		5.50%	not more than 10%
Soundness in cement paste		0.93 MM	not exceed 5 mm

Asphalt Cement

The characterization of the asphalt cement are given in Table 3. Test results were compared with the specification limits. It is clear that the asphalt cement used is lying within the specification limits.MARSHALL TEST RESULTS

Asphalt cement concrete mixtures were prepared and tested according to ASTM. Voids density analysis was carried out to calculate the unit weight, percentage of air voids and percentage of voids in mineral aggregates.

Results of the Marshall test obtained at five different asphalt contents and representing the average of five specimens in each series of mixes are shown in Table 4. Besides, the design criteria is also given in the same table.

Unit weight, stability, specimens flow, percentage of voids in mineral aggregates and percentage of air voids are plotted against asphalt cement content.

Table 3. Characteristics of asphalt cement.

Specification designation	ASTM	Limits Max	Test results
Penetration at 25°C, 1/100 cm	60	70	66
Ductility at 25°C, cm	100		over 100
Solubility in Trichloroethylene	99		99.7
Flash point, °C	232		334

Table 4. Marshall test data for asphalt concrete containing slag as coarse aggreate.

Asphalt content (%)	Unit weight (Ib/ft^3)	Stability (Ib)	Flow (0.01 inch)	V.T.M. (%)	V.T.M. (%)
3.0	170.1	2040	7.5	14.62	6.3
3.5	171.0	2650	9.3	14.10	5.1
4.0	171.8	2930	10.6	13.68	4.1
4.5	17.9	2320	12.8	14.56	3.8
5.0	170.4	1940	15.2	15.40	3.61
Design * criteria	---	> 1500	8-16	> 13.0	3-5

*** Design criteria for heavy traffic according to the Asphalt institute.**

The following relationships are maintained :

a) Relation between unit weight of the mixture and the asphalt cement is shown in Figure (1). The unit weight of the mixture increases with increasing binder content until a maximum value is obtained, after which the unit weight decreases. This characteristic is similar to that observed when moisture is added to a natural soil. At first the binder acts as a lubricant and helps the aggregate particles to slide over each other, so the unit weight increases. Once an optimum amount of binder has been added, the wet unit weight decreases. Since the lighter asphalt replaces some of the aggregate, shoving the particles apart. The steelmaking slag bituminous mixture possesses higher unit weight than that of natural aggregate, which ranges between 140 to 1150 lb/ft^3.

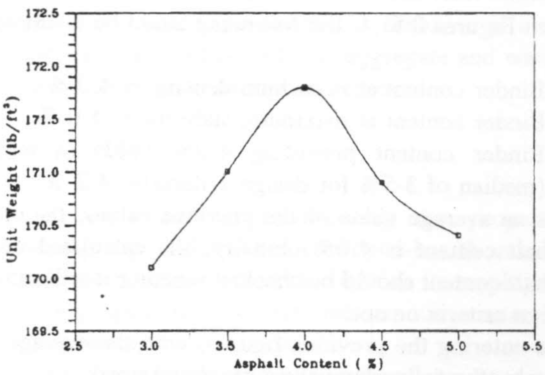

Figure 1. Relation between unit weight of the mixture and asphalt cement percentage by weight of total mix.

b) Figure (1) shows the relation between the Marshall stability value and the asphalt cement content. It is obvious that the stability value of the mixture also increases with increasing binder content until a maximum value is obtained, after which stability decreases. The optimum content for stability can be explained by noting that the Marshall test is actually a type of unconfined compressive strength test, in which some degree of lateral support is given to the specimen. Thus, the maximum stability value occurs at the binder content at which the combination of the internal friction component of stability, provided by the interlocking aggregates, and the cohesive component, provided by the viscous bituminous films coating the particles, is a maximum under testing conditions. Higher stability was achieved when steelmaking slag was used as coarse aggregate, due to its irregular shape which produces better interlocking and higher friction between slag particles.

The high stability of slag asphalt concrete was found to be a strong indicator of its stability to withstand submersion of the coarse aggregate. So, the slag asphalt concrete will retain sufficient coarse texture for high speed skid resistance.

c) Figure (2) illustrates the relation between the specimen flow and the asphalt cement content. The flow value increases as the binder content increases. In addition, the rate of deformation change is slow at low binder contents but increases at high binder content. Since, friction between steelmaking slag particles decreases with thicker asphalt films.

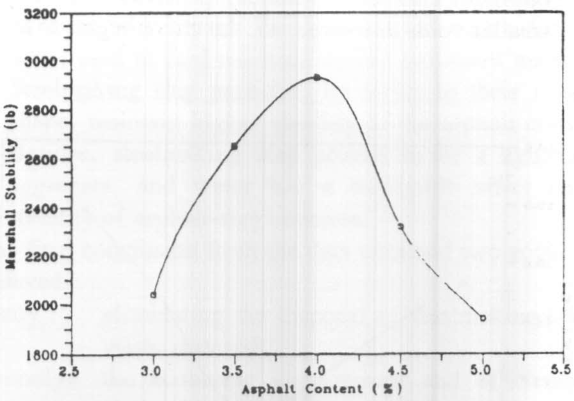

Figure 2. Relation between Marshall stability and asphalt cement percentage by weight of total mix.

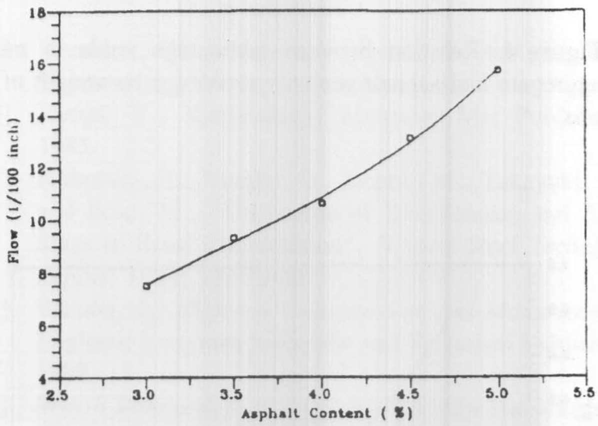

Figure 3. Relation between specimen flow and asphalt cement percentage by weight of total mix.

d) Relation between the percentage voids in mineral aggregates and asphalt cement content is shown in Figure (3). The percentage of voids in mineral aggregates is approximately apposite to the density curve, since the mass of aggregates is the main component of the total mass of the mix. It is important to note that, unless the percentage of voids in mineral aggregates is large, the paving mixture will be deficient in binder content or air voids, or both.

e) Figure (4) elucidates the relation between the percentage of voids in the total mix and the asphalt cement percentage. The percentage of the voids in the total mix is critical as regards durability, since the greater the air voids content, the more easily air and moisture can attack the binder and the binder-aggregate bond. The percentage of voids in the total mix decreases with increasing binder content. This could be referred to the amount of voids which could be filled with asphalt cement, the higher the asphalt content the lower the voids content. Once the optimum content is reached, penetration of asphalt in smaller voids decreases, so, the curve begins to level off.

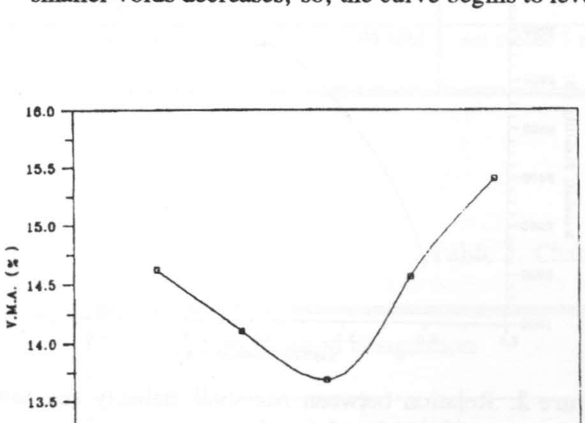

Figure 4. Relation between percentage voids in mineral aggregate and asphalt cement percentage by weight of total mix.

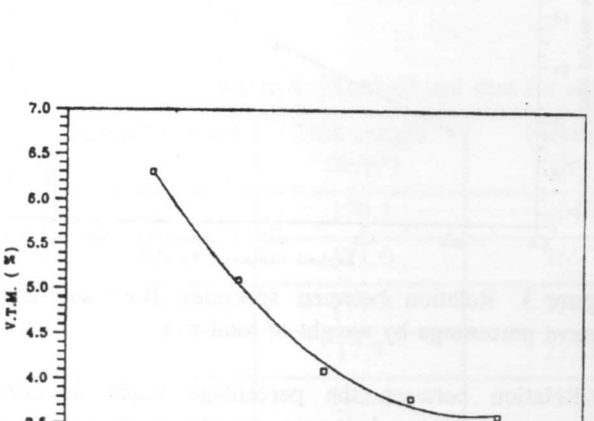

Figure 5. Relation between percentage voids in total mix and asphalt cement percentage by weight of total mix.

DETERMINATION OF OPTIMUM BINDER CONTENT

The design criteria, appropriate to the heavy traffic, shoul be borne in mind when determining the optimum asphal cement content. The optimum asphalt content should compl with the following requirements :

- An adequate amount of asphalt to ensure a durabl pavement.
- An adequate mix stability to prevent unacceptabl distortion when traffic load is applied.
- Adequate voids in the total compacted mixture to permi a small amount of compaction when traffic load i applied without loss in stability. Simultaneously, voids i the total mix should be low enough to prevent harmfu penetration of air and moisture into the compactin mixture.

From Figures 0 to 4, the following could be determined :

- Binder content at maximum density = 4.0 %
- Binder content at maximum stability = 4.0 %
- Binder content providing 4.0% voids in total mi (median of 3-5% for design criteria) = 4.2 %

As an average value of the previous values, the optimu asphalt content is 4.0%. Finally, the calculated optimu asphalt content should be checked whether it will satisfy th design criteria or not.

Re-entering the previous figures, with the average bind content, the following values are determined :

Unit Weight = 171.8 (lb/ft^3)
Stability = 2930 (lb)
Flow = 10.6 (0.01 inch)
Percentage voids in mineral aggregates = 13.7 %
Percentage voids in total mixture = 4.2 %

It is clear that the stability value is well above th requirement (1500 lb), the flow value is within the limitin range (8-16), the percentage of voids in mineral aggregat exceeds the recommended figure (13.0%) and the percentag voids in total mixture is within the limiting range (3-5%) So, the calculated optimum asphalt content lies within th specification limits.

HYDROPHELICITY OF SLAG

The durability of an asphalt pavement is greatly depende upon the ability of the asphalt cement to adhere to th aggregate in presence of water. Therefore, the effect o soaking on the asphalt cement concrete containin steelmaking slag as coarse aggregate was carried o according to ASTM D1075-82. Test results are summariz in Table 5.

Table 5. Effect of soaking on slag-asphalt concrete.

Group No.		Stability (Ib)	Average value	Flow (0.01 in)	Average value
Group I (Soaked in Water)	1	2490		11.40	
	2	2540	2510	10.90	11.00
	3	2510		10.70	
Group II (unsoaked)	1	2980		10.10	
	2	3010	3010	10.40	10.50
	3	3050		11.30	

Stability of the soaked group (2510 lb) was lower than the stability of unsoaked group (3010 lb). The stability retention, which is the ratio between the soaked and unsoaked group, was 83.3%.

It is palpable that the stability value of the soaked group is well above the requirement (1500 lb). The flow value is also within the permissible limits (8-16). Thus, it is clear that steelmaking slag is a hydrophobic aggregate and water does not affect its adhesion to asphalt cement.

CONCLUSION

This work aimed at investigating the properties of steelmaking slag produced from the open-hearth and electric-arc furnaces in order to shed the light on its employment as coarse aggregate in hot mix bituminous concrete. The following concepts were realized :

1- Steelmaking slag should be weathered or, aged prior to usage in any confined matrix in order to guard against volume instability. Weathering of slag for a period of six months prior to its usage in asphalt concrete proved to adequate to avoid deterioration (stripping).

2- No incompatibility was noticed upon concomitant use of steelmaking slag with Ordinary Portland Cement as a mineral filler. This was confirmed from the test data obtained from the alkali-slag reaction which demonstrated that both types of slag are more stable than gravel in morton-bar test, by a percentage of 0.01 % in terms of terms of length increment.

3- Compared to natural aggregate (gravel), steelmaking slag proved to possess higher unit weight (1.9 ton/m^3) and higher specific gravity (3.4). Besides, the mechanical properties of slag, especially in its resistance to abrasion, were higher than that of gravel by an average value of 40%.

4- Steelmaking slag was found to exhibit high resistance to abrasion and impact. This is reflected on its durability when used in skid-resistant asphalt pavement material.

5- Steelmaking slag particles, by virtue to their irregular shape, maintain higher stability to the asphalt concrete. Besides, steelmaking slag proved to be a hydrophilic aggregate, and water has a negligible effect on the stability of asphalt-slag concrete.

As final conclusion from the data obtained two goals were achieved :

Firstly : eliminating the disposal of steelmaking slag as waste material

Secondly: the economic employment and efficiency of steelmaking slag, when used as coarse aggregate in asphalt concrete.

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