# USE OF SLAG AS A BASE COURSE FOR FLEXIBLE PAVEMENT

Gomaa Kh. M. Moussa
Transportation Department Faculty of Engineering, Faculty of Engineering,
Alexandria University, Alexandria, Egypt.

## ABSTRACT

The use of waste materials as substituent to natural aggregates in construction of base course layer of flexible pavements, helps to conserve the supplies of good quality aggregates and assists in solving problems arising from the disposal of waste materials. The use of slag in road construction can be traced back to 1919 when air-cooled blast furnace slag was used as a subbase material. Since then, the road construction industry has long been the largest consumer of slag. In Egypt, increasing quantities of steelmaking slag are becoming available from iron production. This study aims to discuss the possibility of using slag produced as a by-product from Egyptian Copper Works Company, as a constituent in the construction of base course layers of flexible pavements for highways and airports. Comprehensive studies have shown that sorted slag can be used without problems by the construction firms as a base course layer. The results indicated that the mixtures with 30% sand or limestone + 70% slag gave higher California Bearing Ratio values than the other percentages of mixtures.

*Keywords: Slag, Waste Materials, and California Bearing Ratio Test.*

## INTRODUCTION

Existing supplies of natural aggregates are depleted and the demand for aggregates continues to rise. Because the remaining aggregate supplies are less and less accessible for convenient and economical use, the supply problem is compound. There is a need now to develop replacements for conventional aggregates. If any of the materials that are now treated as solid waste can be effectively utilized as aggregates, then the amount of waste that must be disposed of will be reduced, and aggregate resources will be conserved at the same time.

Moreover, the environment of earth is a closed system. Hence it is obliging to recycle the industrial by-products as much as possible, in order to minimize 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[1,2,3]. Moreover, many countries used the waste materials as base course materials in flexible pavements[4,5]. In Egypt, the iron and steelmaking companies which are spread all over the country suffer from the accumulation of slag whose discarding constitutes an acute problem. In Alexandria, the Egyptian Copper Works Company suffers from accumulation of steelmaking slag which is produced from open-hearth and electric-arc furnaces. Due to these increased quantities, the problems involved in shooting the materials are aggregated. Therefore, a study was initiated into the possibilities of recycling the slag in base course layers of flexible pavements.

## MATERIALS

### Course Aggregate

The slag used in this investigation as a base course was obtained from the Egyptian Copper Works Company in Alexandria.

### Fine Aggregates

Limestone and sand were used as fine aggregates.

The quarries from where limestone was obtained are situated in a series of hills near of Alexandria city at 60 Km. Sand was used as a secondary fine aggregate in this investigation. The sand was taken from station (68 Km) from Alexandria, on Alexandria-Cairo desert highway.

## Testing Mixtures and Methods of Testing

To achieve the objective of this study, five different mixtures of slag + limestone and five mixtures of slag + sand were investigated. These mixtures are:

1- 90% slag + 10% limestone or sand
2- 80% slag + 20% limestone or sand
3- 70% slag + 30% limestone or sand
4- 60% slag + 40% limestone or sand
5- 50% slag + 50% limestone or sand

Referring to the above mixtures, sand and limestone were mixed separately from steelmaking slag in amounts that ranged from 10% to 50% by weight of the mix. Sand and limestone contents that exceeded 50% were considered to be uneconomical. The mixture specimens were tested using the standard proctor test. The specimens were prepared according to ASTM D 1997[6]. The California Bearing Ration (CBR) tests were conducted according to ASTM D 1883-87[6]. These specimens had been compacted to their maximum dry density and optimum water contents. The strength of the mixtures were evaluated in terms of CBR values. The CBR tests were carried out on unsoaked and soaked specimens. The strength of soaked specimens was measured after a period of 4 days. The effect of water contents on CBR values surrounding the optimum water content value, 2% above and lower the optimum moisture, was tested for all mixtures.

## Sieve Analysis of Slag

Sieve analysis of a representative oven-dried sample of the slag was made in the laboratory. The materials retained on sieve number 3/4 inch were removed. The results of sieve analysis are illustrated in Figure 1. From this figure it can be noted that 18% of slag passed from sieve size No. 50 and 2.3% of slag passed from 200 sieve size. These percentages are very small, therefore in this investigation limestone and sand were used as a fine aggregates. The selected aggregate gradation used in this research is shown in Figure 1. This gradation lies within the grade (aggregate base course with maximum size 1") according to the Egyptian specification.

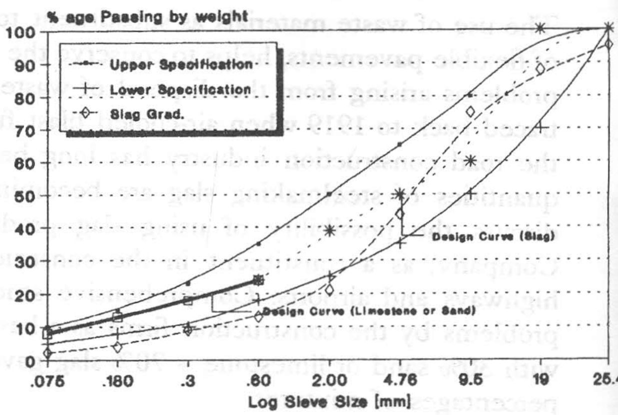


Figure 1. Slag Gradation and Design Curves of selected Slag, Limestone and Sand.

## Geometric Characteristics of Slag

The total geometric characteristics, angularity and shape of slag are determined by the Elongation Particle Test. Elongation Particle is equal to the length-to-width ratio greater than 3 according to TP Min StB [7]. The test is performed according to the standard procedure in which each sample is separated by sieve into the following size:-

Passing from sieve size 1/2" and retained on sieve size 3/8"

passing from sieve size 3/8" and retained on sieve No. 4

Passing from sieve No. 4 and retained on sieve No. 10.

The results of the Elongation Particle Test for different sizes are lower than the limit of the German specification (50% maximum specification) [8]. Moreover, the particle shape of slag is determined. The results of manual and visual investigation showed that the slag surface texture angular and rough.

## Chemical Analysis

The chemical analysis of the slag, limestone and sand is shown in Table 1. It is clear that calcium oxide represents 42% of the slag, while magnesium oxide represents 7.2%. Crushed limestone contains 91% calcium oxide, while sand contains 3.8%. Magnesium oxide represents 2.29% of the crushed limestone and only 0.96% of the sand. On the other hand, silicon dioxide is found in slag with percentage 22%.

**Table 1. Chemical Analysis for Slag, Limestone and Sand.**

| Chemical Composition | Slag | Limestone | Sand |
|---|---|---|---|
| Calcium Oxide | 42% | 91% | 3.8% |
| Magnesium Oxide | 7.2% | 2.29% | 0.96% |
| Sulphate Oxide | 1.8 | 0.98% | 0.11% |
| Silicon Oxide | 17% | 1.21% | 89.8% |
| Aluminum and Iron Oxide | 6% | 4.26% | 1.1% |
| Metallic Content ($F_e$+$M_n$) | 26% | 0.26% | 4.23% |

## Physical Properties

The specific gravity refers to the volume of solid materials excluding all pores. A number of tests for specific gravity of steelmaking slag, crushed limestone and sand were run according to ASTM [9]. Specific gravity, absorption and abrasion are summarized in Table (2). From this table it can be seen that the high specific gravity of slag was expected because of the high iron content. Moreover, the water absorption of slag is low compared to crushed limestone. This could refer to the low volume and small number of internal pores which may be filled with water. It is evident from the results given in Table 2, that the slag exhibits high resistance to abrasion, in the range of 12.3% weight loss.

## Maximum Dry Density and Optimum Water Content

It is essential to determine the maximum dry density and water content for every unbound material used in the pavement layers. Because, if the material has high dry density, it will give a minimum deformation under traffic loading repetitions during the lifetime of the pavement. Also, it allows the layers to bear heavy wheel loads without excessive deformation.

**Table 2. Physical Properties of Slag, Limestone and Sand.**

| Properties | Slag | Limestone | Sand |
|---|---|---|---|
| Bulk Specific Gravity. | 3.42 | 2.62 | 1.62 |
| Apparent Specific Gravity. | 3.44 | 2.63 | 1.67 |
| Water Absorption [%]. | 0.67 | 16 | - |
| Loss Angeles Abrasion Test After 500 rev. [%].( 12 steel balls) | 12.3 | 65 | - |

The relationship between dry density and water contents is plotted in Figures 2 and 3 for all types of mixtures. From these figures it can be noted that the steelmaking slag concentration has remarkable effect on the maximum dry density values of mixtures composed of slag and limestone. The maximum dry density decreases from 2.390 g/cm$^3$ to 2.121 g/cm$^3$ with decreasing the percentage of slag from 90% to 50% in the mixtures, respectively. This reduction is equal to 12.7% of the maximum dry density. Similarly, in the mixtures of slag and sand, the maximum dry density decreases from 2.384 g/cm$^3$ to 2.172 g/cm$^3$ with decreasing the concentration of slag from 90% to 50% in the mixtures, respectively. The reduction is equal to 9.8%. Referring to the above results it can be noted that the maximum dry density of mixtures containing 50% slag and 50% sand or limestone have almost equal values.

Moreover, it can be seen that the optimum water content for mixtures containing 90% slag is lower than the optimum water content for other mixtures under investigation in this study. On the other hand, the percentage of limestone in the mixtures of slag - limestone has an effect on the optimum water content. The optimum water content of these mixtures was recorded to be 8% at any type of mixtures. Also, it can be seen that the optimum water content will be significantly affected by increasing the percentage of sand from 10% to 30% in the mixtures of slag-sand. The optimum water content increases from 4% to 8% while increasing the percentage of sand from 10% to 30%, the CBR values at different percentages of slag for both soaking and unsoaking mixtures of slag-sand and slag-lime respectively. It can be seen that, higher CBR values were recorded for unsoaked slag-limestone mixtures and lower CBR values for soaked slag-sand mixtures as compared to their unsoaked condition. Values shown indicate that the CBR values have increased by 292 % when 30% of limestone was added to slag before soaking and by 121% after soaking. Similarly, the CBR values have increased by 380% when adding 30% of sand to slag before soaking and by 303% after 4 days soaking. Furthermore, the increase of percentage of sand and limestone in mixtures does not cause any increase in their strength above the optimum value. However, the optimum sand and limestone content that give a higher CBR value was 30% for both soaking and unsoaking conditions.

The water content surrounding the optimum water content affects the CBR value of slag mixtures. The maximum CBR value of the slag-limestone mixtures was obtained at the optimum water content. Whereas slag-sand shows a higher CBR value at a moisture content 2% lower than the optimum water content. An increase in CBR values of about 15% for unsoaked specimens and about 25% for soaked samples were recorded for a lower water content as compared with CBR values at the optimum water content. These changes are attributed to interaction between the limestone and slag particles as explained earlier. Furthermore, significant reductions in CBR values were achieved for slag-sand and slag-limestone mixtures of 2% greater than the optimum water content. These reduction were about 35% for unsoaked and 43% for soaked slag-limestone mixtures and 25% for unsoaked and 38% for soaked slag-sand mixtures.

Table 3. The CBR Values at Different Percentages of Slag for Different Mixtures.

| Percentage of Slag in Mix. [%] | Slag + Limestone | | Slag + Sand | |
|---|---|---|---|---|
| | Unsoaked | Soaked | Unsoaked | Soaked |
| 50 | 55.5% | 104.0% | 75.6% | 57.8% |
| 60 | 160.0% | 97.8% | 54.4% | 50.0% |
| 70 | 277.7% | 150.0% | 145.6% | 115.5% |
| 80 | 127.7% | 82.2% | 58.9% | 63.3% |
| 90 | 70.9% | 67.8% | 30.0% | 28.7% |

## CONCLUSIONS

The main contribution of this study is to demonstrate the possibility of using the slag product by the Egyptian Copper Works Company in a base course of flexible pavement. From the results of the testing and the above analysis, the following conclusions have been drawn:

1- The relationship between the maximum dry density and percentage of slag in the mixtures of slag - limestone and slag - sand may be approximated by a liner equation with a excellent correlation coefficient, 0.9923 and 0.9148 respectively,

2- The optimum percentage of slag in the mixtures of slag-limestone and slag-sand that gives the highest CBR value is about 70% by weight of mixture for both conditions, unsoaked and soaked.

3- The use of limestone as a fine material in the mixtures of slag-limestone gives a better results of CBR values than sand. However, the use of any of the two fine materials controls the cost-benefit analysis of each individual case.

4- The maximum CBR values of slag - limestone mixtures were obtained at the optimum water content. Whereas, slag - sand mixtures show that a higher CBR values at a moisture content 2% lower than the optimum water content.

## REFERENCES


[1] W.C. Ormsby and D.G. Fohs, "Use of waste and By-Products in Highway cónstruction", Geotechnical Engineering, TRR 1288, 1990.

[2] M.M. Ismial and Others," Utilization of Copper Blasting Grit Waste as a Construction Material", Waste Management, vol. 11. pp. 35-40, USA, 1991.

[3] M. BRAJA Das and Others," Geotechnical Properties of a Copper Slag" TRR 941, 1982.

[4] T.K. Wong, "Use of Granulated Slag as Stabilizing Agent", 16th ARRB Conference Part 2, Perth, Western Australia 1992.

[5] Brett Lemass,"Slag Solution for Heavy Duty Road Pavements" 16th ARRB Conference, Part 2, Perth, Western Australia 1992.

[6] Soil and Rock, Annual Book of ASTM Standards, vol. 04.08, ASTM Philadelphia, 1992.

[7] Technical Specification Tests for Aggregates in Roadway Construction, TP Min.-StB, Federal Ministry of Transportation, Department of Highway Engineering, Bonn, Germany 1990.

[8] Technical Delivery Conditions for aggregate in Roadway Construction- TL Min.- StB 83, Federal Ministry of Transportation, Department of Highway Engineering, Bonn, Germany 1983.

[9] American Society for testing and Material: Paving Materials, Annual Book of ASTM, Annual Book of ASTM Standards, vol. 04. 03, Philadelphia, 1992.