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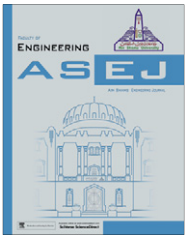

CIVIL ENGINEERING

Evaluation of steel slag and crushed limestone mixtures as subbase material in flexible pavement

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KEYWORDS

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Abstract Steel slag is produced as a by-product during the oxidation of steel pellets in an electric arc furnace. This by-product that mainly consists of calcium carbonate is broken down to smaller sizes to be used as aggregates in pavement layers. They are particularly useful in areas where a good-quality aggregate is scarce. This research study was conducted to evaluate the effect of quantity of steel slag on the mechanical properties of blended mixes with crushed limestone aggregates, which used as subbase material in Egypt. Moreover, a theoretical analysis was employed to estimate the resistance for failure factors such as vertical deformations, vertical and radial stresses and vertical strains of subbase under overweight trucks loads. These loads cause severe deterioration to the pavement and thus reduce its life. The results indicated that the mechanical characteristics, and the resistance factors were improved by adding steel slag to the crushed limestone.

1. Introduction

Chang in modern traffic characteristics has led to higher vehicle loads, tire pressures and traffic volumes. Current research illustrates that truck weights over 113.4 ton (250,000 lb) and tire pressures of 150 psi have been frequently reported. These changes represent a serious challenge to the pavement layers as they have caused predatory occurrence of distresses, permanent deformation/rutting and fatigue failure [1]. This deformation causes map cracking, chuck holes, settlement and undulations similar to those observed in some Egyptian roads. Certainly, accumulation of these deformations reduces the pavement life, increases the maintenance costs and may cause a complete failure of the pavement. Increasing the resistance of flexible pavement layers, against permanent deformation, definitely, will increase pavement life, decrease maintenance cost as well as prevent the early reconstruction. Researches on the available aggregates have shown that there is a general scarcity of good-quality aggregates since most of the available limestone aggregates are friable carbonates of sedimentary origin. These aggregates have been low crushing strength, low resistance to weathering, and low resistance to traffic abrasion.

Abbreviations: CBR, California bearing ratio; FE, finite element; OMC, optimum moisture content; MDD, maximum dry density; MR, resilient modulus; SSP, steel slag percentage

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Thus, they are unsuitable for use in areas where a high skid resistance is required (e.g. roundabouts, slopes, wet surfaces and intersections) [2].

Steel slag is a by-product formed during the steel manufacturing process. It is a non-metallic ceramic material formed from the reaction of flux such as calcium oxide with the inorganic non-metallic components present in the steel scrap. The use of steel slag reduces the need of natural rock as constructional material, hence preserving our natural rock resources and reducing the need for dumping ground. Screening of the steel slag will be done to ensure the aggregate is suitable for use as construction material. Since 1993, steel slag aggregates have been used commercially in the region for road surfacing [3].

Steel slag contains significantly higher calcium oxide and iron oxide compared to granite rock. Granite rock contains high silica and alumina content and is generally hydrophilic. The good resistance to stripping by the steel slag aggregates indicates that the material is more superior to natural granite as road surfacing material. The superior adhesion of the steel slag with bitumen would also minimize potential moisture damage of the steel slag mix. The formulation of the road mixes using steel slag as aggregates has shown to give better rut resistance and mechanical stability, which indicates a more lasting wearing course for the road [4].

Researches regarding recycling and utilization of steel slag in different fields have been carried out in recent years. It was used as mineral additive for cement-based materials to improve mechanical properties of concrete. Some studies used steel slag to produce Portland cement with iron slag and limestone, and confirmed that the compressive strength of concrete was above standard values. Other researches studied the characteristics of bricks made from steel slag and revealed that it reduced the required firing temperature. Steel slag could also be used to remove some hazardous substances such as ionic copper and ionic lead from waste water. In many researches, steel slag was used as aggregate in concrete. Researches have confirmed that the durability of concrete with steel slag was improved, and the compressive strength and split tensile strength were much higher than that with limestone. However, few reports were found about utilization of steel slag as aggregate in asphalt mixture [5].

Although there are advantages in each application, the use of steel slag as a granular material is a promising area due to the following reasons [6]:

(i) Larger quantities of steel slag can be used as a granular material, compared with another usage.
(ii) The process for granular use is technically sound, simpler and well developed.
(iii) There are fewer concerns on long-term stability in unbound conditions, highway granular base and subbase, for instance.
(iv) Volume expansion test method has also been developed.
(v) The steel slag industry has maturely placed their production and marketing emphasis on granular materials for unconfined utilizations.

Steel slag treating and processing technology has been well developed for the last couple of decades which have made it possible for steel slag to be used as granular base or subbase materials in large scales. However, the fact is that steel slag aggregate has not been extensively used in construction, especially its use as a granular material. The main reason for the low scale utilization is the lack of quantified criteria to guide the appropriate use for a special steel slag in a special use. It is imperative to establish different criteria for different utilizations of steel slag [6]. Accordingly, Adding steel slag to the limestone aggregates may cause an improvement to the bearing capacity and frost action of granular soil.

For all above reasons, this work intended to explore the feasibility of steel slag aggregates for subbase mixture, and compare it with limestone aggregate. This study was conducted to ascertain the mechanical properties and failure factors characteristics of subbase layer prepared with steel slag and limestone aggregates.

2. Problem statement and study objective

During the last few years excessive damages were observed on several highways, mostly on high volume major roads. The reasons behind can be observed: layers strength and thickness, mixture design, change in traffic load, etc. In Egypt, there are many types of heavy vehicles of 6-axles of total weight ranging over from 42 to 52 ton. These heavy vehicles cause severe deterioration to the pavement and thus reduce its life.

Extensive researches have been conducted for the application of steel slag in broad areas of road construction. Steel slag contains significant amounts of free iron, which gives the material high density and hardness and makes it as a suitable artificial source of aggregates for road construction [7]. It can be used as an aggregate in surface layers and in unbound bases or sub-bases, due to its high strength and durability.

A few studies have tried to quantify the benefits of steel slag in reducing the failure factors through the subbase layer, but no firm conclusions can be drawn due to differences of results. Thus, an important need exists to quantify the benefits derived from stabilizing limestone layer with steel slag. On the other hand, until now, the steel slag is not used on a large scale in Egyptian roads construction compared to other countries in the region.

Thus, the main objective of this research is to study the effect of using steel slag that combined with limestone aggregates by different ratios on improving the mechanical properties of the unbound layer mixes and increasing the resistance for failure factors such as vertical deformations, vertical and radial stresses and vertical strains under overweight trucks loads. Hence determine the optimal steel slag ratio. In this study, experimental program was achieved to determine the mechanical properties of the mixes such as resilient modulus MR. Moreover theoretical program was achieved using MR that obtained from experimental work to determine the failure factors by the aid to the finite element method.

3. Literature review

The utilization of industrial by-products from the steel-making industry like blast furnace slag and steel slag has been established in a number of applications in the civil engineering industry. Production of steel, calls for the removal of excess silicon and carbon from iron by oxidation. In the production of steel, the furnace is charged with iron ore or scrap metal,