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Zsolt BENCZE[1], *Ph.D., https://orcid.org/0000-0003-2130-7864*
László GÁSPÁR[2], *D.Sc., Prof., https://orcid.org/0000-0002-0574-4100*

[1] *Ferrobeton Private Limited Liability Company, Dunaújváros, Hungary*
[2] *KTI Institute for Transport Sciences Non-Profit Ltd., Budapest, Hungary*

BLAST FURNACE SLAG IN ROAD CONSTRUCTION AND MAINTENANCE

Abstract

Introduction. There is a global trend to increase the sustainability of road construction and maintenance technologies. The growing use of various industrial by-products as economical and eco-friendly construction and maintenance techniques can be observed in many countries.

Problem Statement. The utilization of various forms of blast furnace slag in the road sector can be cost effective, however, several special technological measures have to be taken.

Purpose Presenting best practices for the use of blast furnace slag in road construction and maintenance techniques based on Hungarian and other decade-long experiences.

Materials and Methods. The main types investigated are air-cooled blast furnace slag, expanded or foamed slag, pelletized slag, and granulated blast furnace slag. The utilization areas in road sector: asphalt layers, surface treatments, rut repair, hydraulically bound pavement layers, unbound base layers, frost protection layer, subgrade, cement production.

Results. Presenting best practices for the use of blast furnace slag in road construction and maintenance can be beneficial for the experts of countries with limited experience in the field.

***Keywords*:** blast furnace slag, industrial by-products, road construction, road maintenance, environmental protection

Introduction

There is a global trend to increase the sustainability of road construction and maintenance technologies. The growing use of various industrial by-products as economical and eco-friendly construction and maintenance techniques can be observed in many countries.

The elimination of waste products of various industries is a serious problem. They pollute the environment. Blast furnace slag is an industrial waste of iron making that is relatively widely used in several countries all over the world [1]. Its actual application is based on specific technical, economic and ecological criteria [2]. It is obvious that the utilization of blast furnace slag can avoid environment-polluting landfills and can limit the use of scarce natural aggregates.

The paper shows the forms of blast furnace slags, presents their road-related application areas with their requirements in the road sector. The most important part of the paper is dedicated to the Hungarian laboratory and site experiences in the field, then some important relevant foreign best practices are summarized. Finally, conclusions are drawn on the use of blast furnace slag in road construction and maintenance projects.

Application areas

The mechanical properties of slags are very favourable. They can be taken as artificial rocks with the same application properties as natural rocks. They have a compact structure, high strength and good resistance to abrasion. Their use can even improve the quality and durability of highways

and other construction products. The use of slags can trigger a considerable share of the mining of natural rocks, so the landscape and environmental destructive effects associated with rock extraction are not to be expected. Based on their good properties, metallurgical slags are especially suitable for: many construction projects, road base layers, asphalt production, concrete production, railway bedding, agricultural soil improvement, hydraulic engineering, recultivation, dam construction, thermal insulation material production (rock wool), insulation material production, sewage production, etc.

The main utilization areas in the road sector depending on the geometrical, physical, chemical and durability features of slag: asphalt layers, surface treatments, rut repair, hydraulically bound pavement layers, unbound base layers, frost protection layer, subgrade. Granulated blast furnace slag is used as a raw material for cement production and as an aggregate and insulating material, besides a supplementary cementitious material in Portland cement concrete.

Requirements for use

The geometrical requirements for the use of blast furnace slag in road construction or maintenance projects are as follows: fraction, gradation, grain shape and content of fines. Physical requirements: resistance to fragmentation by Los Angeles test, resistance to wear by micro-Deval test, particle density. Chemical requirements: acid-soluble sulphate content, AS (max. 1 %), sulphur content. Durability criteria: weight loss by freeze-thaw test (1–4 %), sodium sulphate crystallization soundness test (18–35 %).

Crushed air-cooled blast furnace slag is angular, roughly cubical, and has textures ranging from rough, porous surfaces to glassy (smooth) surfaces. However, there can be considerable variability in the physical properties of blast furnace slag, depending on the iron production process. The water absorption of slag can be as high as 6 percent.

Granulated blast furnace slag is a glassy granular material that varies, depending on the chemical composition and method of production, from a coarse, popcorn-like friable structure greater than 4.75 mm in diameter to dense, sand-size grains passing a 4.75 mm sieve. Grinding reduces the particle size to cement fineness, allowing its use as a supplementary cementitious material in Portland cement concrete.

Because of their more porous structure, blast furnace slag aggregates have lower thermal conductivities than conventional aggregates. Their insulating value is of particular advantage in applications such as pavement base courses over frost-susceptible soils.

Relevant Hungarian experiences

Some general information

The actual utilization of blast furnace slag started in Hungary already in the 1950's; that time it was built in water-bound macadam base courses without any previous screening. From 1976 on, research works at the predecessor of KTI , Budapest have concentrated on the elaboration of proper technologies using crushed and sieved slag as aggregate in asphalt and cement concrete mixtures. Besides, it was shown that granulated blast furnace slag could be advantageously used — together with lime — as binder for base courses and pavement strengthening layers.

On the initiation of KTI Institute for Transport Sciences Non-Profit Ltd., slags were officially qualified from waste materials to construction products meeting the relevant standard [4–5] requirements. Therefore, the need for air-cooled and crushed blast furnace slag has considerably increased causing shortage of the materials in some regions of the country.

ISD DUNAFERR Private Limited Company produces blast furnace slag and converter slag as a result of its metallurgical activity in Hungary. Since 2015, Ferromark Trading Ltd. sold metallurgical slags in the following shares:

– granulated blast furnace slag 38 %;
– ground blast furnace slag 18 %;
– converter slag 23 %;
– ground slag from dump 21 %.

92 % of granulated blast furnace slag is utilized for cement industry and concrete production.

A huge blast furnace slag dump of ISD DUNAFERR Private Limited Company, in Dunaújváros can be seen in **Figure 1**.

Figure 1 — Slag dump of ISD DUNAFERR Private Limited Company, in Dunaújváros [3]

Blast furnace slag in asphalt mixtures

Blast furnace slag can be used in asphalt mixtures if the geometrical, the physical, the chemical and the durability requirements mentioned before are fully met [6]. Besides, volume constancy is also expected; that is why too "fresh" product might not be utilized for high quality asphalt mixes (the appearance of gas bubbles causing cracks in the course has to be avoided); dicalcium-silicate fragmentation should be checked. Otherwise, volume constancy is basically influenced by MgO-content of the slag. When blast furnace slag is used in asphalt base course, lower requirements have to be met.

Adding (30–60) % blast furnace slag to the coarse aggregate fraction can improve the performance of mixtures of „traditional" composition. It was shown that the skid resistance of asphalt wearing coarse surfaces containing blast furnace slag is much better than the reference values. The harder binder need of these asphalt mixtures is below that of relatively soft bitumen (with higher penetration).

Blast furnace slag is appropriate also as the aggregate of asphalt (bituminous) emulsion bound cold mixtures.

Asphalt mixtures with blast furnace slag aggregate are appropriate for the repair of rutted pavement surfaces due to their high internal friction and increased bitumen absorption.

Surface dressing

Single and multiple surface dressing is widely built for increasing water permeability and/or skid resistance of pavement surface. The technique needs the high stability of aggregate used and the

good adhesion of binder (typically bituminous emulsion) to aggregate grains. Blast furnace slag surface dressings have proved to be extremely long lasting due to their durable skid resistance as well as their good adhesion to binder and the underlying pavement structural layer.

Blast furnace slag can be successfully applied in road maintenance, e.g. the shallow (max. 4 mm deep) ruts can be repaired without surface milling by single or multiple surface dressings with washed and screened slag (an additional advantage can be the penetration of the grains of first surface dressing in the old asphalt wearing course improving its resistance to deformation).

Hydraulically bound pavement structural layers

Hydraulically bound mixtures used in road construction and maintenance can have the following binder types: cement, fly ash, granulated blast furnace slag, trass, active lime. When hydraulically bound mixtures with granulated blast furnace slag + quicklime binder are produced, granulated slag should be milled for attaining the needed activity (at least 15% of the material have to be below 80 μm). The binding activity of the granulate increases with higher share of lime, and together with it strengthening period is also reduced. The laid and compacted pavement structural layer can be opened to traffic, without any delay. With bituminous emulsion surface dressing, the layer has a considerable durability.

The following quality parameters are specified when granulated blast furnace slag is used in hydraulically bound mixtures: grading, CBR-value, compressive strength, tensile strength, elastic modulus. The hydraulic activity of granulated blast furnace slag depends on its chemical composition, share of fine fraction, use of reactivity increasing additives [7]. Among others, the product of CaO-content and Al_2O_3-content is an important factor in the evaluation.

Blast furnace slag cannot be used for the manufacturing of cement concrete pavements since typically it is not able to meet the relevant high requirements. The by-product can be generally utilized for the production of cement concrete base courses.

If the granulated blast furnace slag is used for the partial binder substitution of cement, it has to fulfil the requirements of relevant standard [8]. The suitability of the cement-slag binder mix has to be tested using the relevant standard [9]. It is to be noted that the length of strength test should be lengthen to 63 days if the share of granulated blast furnace slag in the mix exceeds 60 %.

Unbound pavement structural layers

The following unbound layers can come into play: well-graded crushed stone base course, gap graded macadam base course, mechanical stabilization. Their design specification can be found in the relevant Road Technical Specifications [10] with the following main requirements:

- mineral composition (volume constancy);
- grain shape (share of flaky particles);
- fragmentation (rock physical classes);
- durability (sulphate crystallisation test);
- environmental harm in accordance with MSZ EN 1744-1;
- content of fines below 0.063 mm;
- grading curves with grading limits;
- compactability (Proctor-test);
- maximum grain size;
- frost susceptibility.

Other road-related application areas

In addition to the utilization of blast furnace slag in road pavement structures, there are some more road-related application areas, as frost protection layer that keeps water from rising into the pavement, and as a result, prevents frost damage to the surface layer; soil improvement layer and subgrade. Crushed blast furnace slag coming from ISD Dunaferr dump was successfully used as subgrade material in a quantity of 800,000 m^3 at the construction of motorway M6 section between Érd and Dunaújváros in 2005. (The chemical analysis of the samples taken of every 500 m^3 slag was regularly performed to check whether

contents of various heavy metal types in the material do not exceed predetermined limit values, which could endanger the contamination of neighbouring ground water by leaching). Its durability has proved to be more favourable than that of any of the «traditional» soil types in a motorway embankment.

The sand fraction of blast furnace slag can also be used for de-icing in winter road maintenance replacing the less environmentally friendly rock salting (NaCl).

KTI Institute for Transport Sciences Non-Profit Ltd. compiled a country-wide cadastre (cadaster) for recording the blast furnace slag deposits with their main physical characteristics; their majority meets the requirements for road crushed stones [12].

Some foreign experiences

Slag was first applied as an aggregate in asphalt mixtures in 1969. A trial road section was built in Toronto, on which steel slag was utilized as an aggregate in asphalt base and wearing courses [13]. The experimental layers had good bearing capacity, resistance to external impacts, and durability. In 1974, in Ontario, Canada 17 trial road sections were constructed where slag was used in asphalt concrete course built for friction rehabilitation of a concrete pavement with a view to increasing surface friction [14]. Good resistance to friction and favourable adhesiveness of road surfaces were proved by the significant reduction in traffic accidents on the section in question. It was shown that weathering is not a critical criterion in the utilization of slag in asphalt layers if relatively small (max. 13 mm) slag fractions are used. The pre-coating aggregate grain with bitumen film limits expansion.

A research work at the University of Nottingham concentrated on the use of secondary materials in road construction covers technical aspects, mechanical properties of waste materials and the environmental implications of their use [15]. New methodologies were presented for the mechanical examination of secondary aggregates and for the environmental assessment. The mechanical assessment includes conventional characterisation and classification tests on both unbound and lightly treated pavement materials, as well as repeated load triaxial tests and repeated load indirect tensile tests. The environmental assessment indicates how the leaching concentration of contaminants from intensive testing can be used for assessing the environmental acceptability of a secondary material.

An extensive suite of environmental and geotechnical tests was undertaken in Australia to thoroughly assess the feasibility of using granulated blast furnace slag as a road construction material [16]. There are no environmental risks when using this industrial by-product, nor is there any leaching with it being used as an aggregate in construction applications. High friction angle, free-draining nature, acceptable resilient modulus and suitable CBR value of granulated blast furnace slag was found to be an ideal material for usage in highway fill applications. Another important finding of the Australian researchers was that this material could be reused without the need of further processing.

Chinese researchers used slag as a filler for asphalt mixes, and the effect of its rheological properties was investigated. According to the results of their scanning electron microscopy, there are several pores of 0.5–5 μm on the surface of the slag, while the surface of the limestone flour is smooth. Oxidation studies have shown that the main constituents of both substances are CaO and SiO_2, but they also contain Fe_2O_3 and other oxides in some amounts. Slag as an asphalt filler increases the value of the shear modulus of the mortar. By combining slag and limestone flour, the low temperature cracking resistance of asphalt could be minimized.

Concluding remarks

The use of blast furnace slag in road construction and maintenance should be encouraged since it offers several economical and eco-friendly techniques. Metallurgical slags are especially suitable for the following areas: road construction projects, road base layers, asphalt production, concrete production,

road maintenance, railway bedding, agricultural soil improvement, hydraulic engineering, recultivation, dam construction, thermal insulation material production (rock wool), insulation material production, sewage production, etc.

The results gained indicate that the analysed slag types present no hazard for the environment if used in road construction. It is obvious that slag is suitable for use in concrete under normal environmental conditions and has more fire resistance than the commonly used aggregate, but when combined with Portland cement, slag does not provide increased fire resistance to concrete.

As a summary, it can be emphasized that the variety of industrial by-products — among others, blast furnace slag — should be utilized in many national economy branches. Therefore, the publications presenting the economic and environmental advantages of the use of these materials, for example, in the road sector can have an important role in widening the list of countries where the positive consequences of the utilization of these by-products become obvious for every stakeholder.

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Жолт Бенце[1], *канд. техн. наук, https://orcid.org/0000-0003-2130-7864*
Гаспар Ласло[2], *д-р техн. наук, проф., https://orcid.org/0000-0002-0574-4100*

[1] *Товариство з обмеженою відповідальністю "Ферробетон" Дунаюварос, Угорщина*
[2] *Інститут транспортних наук КТІ, некомерційне ТОВ, Будапешт, Угорщина*

ВИКОРИСТАННЯ ДОМЕННОГО ШЛАКУ У БУДІВНИЦТВІ ТА ПРИ ЕКСПЛУАТАЦІЇ ДОРІГ

Анотація

Вступ. Існує загальносвітова тенденція підвищення стійкості об'єктів дорожнього будівництва та технологій їх утримання. Збільшення використання різних побічних продуктів промисловості, економічних та екологічно чистих методів будівництва та утримання можна спостерігати у багатьох країнах.

Проблематика. Утилізація різних форм доменного шлаку в дорожньому секторі може бути економічно вигідною, однак для цього слід вжити декілька спеціальних технологічних заходів.

Мета. Представлення найкращих практик використання доменного шлаку в технологіях будівництва та утримання доріг на основі досвіду Угорщини та інших напрацьованих практик десятиліття.

Матеріали і методи. Основними матеріалами досліджень є доменний шлак охолоджений повітрям, розширений або спінений шлак, гранульований шлак та гранульований доменний шлак. Сфери використання в дорожньому секторі: шари асфальтобетону, обробка поверхні, ремонт утвореної колії, гідративно укріплені шари дорожнього покриття, неукріплені шари основи, мороз захисний шар, земляне полотно, виробництво цементу.

Результати. Представлення найкращих практик використання доменного шлаку при будівництві та технічному утриманні доріг може бути корисним для експертів країн, які мають обмежений досвід у цій галузі.

Ключові слова: доменний шлак, побічні продукти промисловості, будівництво доріг, утримання доріг, охорона навколишнього середовища.