Utilisation of metallurgical by-products in road construction in the Czech Republic

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Abstract. Metallurgical by-products, primarily blast furnace slag and steel slag, have ranked among important alternative sources of fill as well as of material for the structural layers in highways. Main hazards of metallurgical by-products are closely connected to their chemical and mineralogical composition and they can be resulted in volume changes. Fears from possible deformations similar to the D47 motorway meant that metallurgical by-products were excluded from several public tenders of road construction. Comparison of blast furnace slag, steel slag and other metallurgical by products parameters allow us to define the most hazardous material as steelworks waste. Linear swelling of steelwork waste achieves more than 40% at 75°C and swelling pressure was higher than 1.5 MPa. Compositional heterogeneity of steelworks waste makes it difficult to establish the long-term behaviour of this material. At the present time we cannot ascertain which maximum values can be reached by deformation and what are the swelling pressures acting on the material while the volume changes are in progress.

1. Introduction

Metallurgical by-products, primarily blast furnace slag and steel slag, have ranked among important alternative sources of fill as well as of material for the structural layers in highways.

The properties of aggregates based on blast furnace or steel slag are determined to a decisive degree by the process employed by the specific ironmaker or steelmaker in question, or as the case may be, the specific producer of a nonferrous metal.

Such metallurgical by-products tend to be termed ‘slags’ not just by laymen but even by the professional public. An accurate description and the use of correct terminology in designating the material are indispensable for determining the marginal conditions of its application as well as in retrospect, for analyzing any defects or failures of structures caused by volume changes of the metallurgical by-products.

The terms and definitions applicable to the various metallurgical by-products are in Czech republic listed in Technical Specifications (TP) 138 as well as technical requirements of their utilization in road construction [9].

Air cooled blast furnace slag was historically the first used in earthworks and as aggregate. Utilisation of steel slag was occurred at the end of 20th century. Non-ferrous metal slags were only tested and their utilisation in mass scale is more limited. Finally, so-called steelwork waste was after several trial tests used as fill in embankments of the D47 motorway in Czech republic. The knowledge
about this material was very limited especially its long term behaviour. However, it was certified as a product and therefore it was used without its detailed study [3].

Main hazards of metallurgical by-products are closely connected to their chemical and mineralogical composition and they can be resulted in volume changes.

Pavement deformation of the D47 motorway does not constitute Czech Republic’s first example of damage to an engineering structure due to volume changes of metallurgical by-products, but since this problem became widely known it drew greater attention to the problems of volume stability of the metallurgical by-products.

However, fears from possible deformations similar to the D47 motorway meant that metallurgical by-products were excluded from several public tenders of road construction.

![Figure 1. Pit KSJ22 (km 155.876 of the D47 motorway, right lane) with visible deformed layers of the active zone (capping layer) resulting by the volume changes in underlying steelwork waste in embankment.](image)

2. Marginal conditions of metallurgical by-products utilisation

The boundary conditions that have to be met in order to allow for the application of metallurgical by-products within the construction limits of highways are in Czech Republic stated in Technical Specification (TP) 138; they can be defined as follows.

The maximum admissible sulfur content is 1.5% where there is contact with concrete structures. This is a general requirement that follows from standards for concrete structures. In most cases this parameter is met by the metallurgical by-products.

The free lime content as per Technical Specification (TP) 138 must be lower than 4.5%

Volume stability

- Blast furnace slag - this is established by the disintegration test conducted by steaming in an autoclave (as per Technical Specification TP 138). The test is conducted on the 8-16 mm fraction, at the temperature of 105°C and the pressure of 0.20 MPa, for the duration of 2 hours. The disintegration index must be lower than 5%.
Steel slag - this is established by the expansibility test (as per ČSN EN 1744-1). The fraction subjected to the test is 0-22 mm, and the test is carried out at the steam temperature of 100°C. Test duration is 24 hours for LD slags and 168 hours for BOF and EAF slags. Expansibility must be lower than 5%.

Materials which are defined more unambiguously and materials which are more homogeneous (blast furnace and steel slags) can be applied within the construction limits of highways, provided that the aforementioned prerequisites are met. General recommendation is to use the coarser-grained fractions (above 32 mm), inasmuch as the major portion of the volume changes can be attributed to the fine-grained fractions (usually, 0-4 mm).

Steelworks waste as raw material represents a distinctly regional by-product. Its use was widespread in the Ostrava region only. The determining properties of steelworks waste include:

- heterogeneity;
- volume instability;
- variable mineralogical and chemical compositions;
- difficulty of predicting its long-term behavior.

The properties listed above are interrelated and interacting. Volume instability can be attributed to the variable mineralogical and chemical compositions. The components of the material do not lend themselves to macroscopic separation. Particularly the fine-grained fractions that determine volume stability are constituted of mixtures of steel slag, refractories, and other materials. It can be stated that in steelworks waste material, each and every grain is different [5].

The volume changes associated primarily with the hydration and carbonation processes are long-term changes, as has been demonstrated by the results of experimental laboratory tests conducted at higher temperatures on saturated samples.

Also, compositional heterogeneity of steelworks waste makes it difficult to establish the long-term behavior of this material. At the present time we cannot ascertain which maximum values can be reached by deformation and what are the swelling pressures acting on the material while the volume changes are in progress. Further research and laboratory testing will be necessary, and this will be mostly of an experimental character.

Steelworks waste cannot be recommended without reservation for use within the construction limits of highways. In view of the negative experience acquired, it is improbable that this material will ever be used again. Similar conclusions were also arrived at by experts from Germany, France, the U.S. and other countries where the use of secondary by-products of metallurgical, except for blast furnace and steel slags, is prohibited [10], [11].

3. Volume stability of metallurgical by-products

Volume stability of metallurgical by-products has not been systematically studied in Czech republic so far. Tests and criteria used in Germany were adopted for blast furnace slag aggregates. Similar situation was also in case of steel slag. However, a question of long-term development of properties has not been analysed. Also the comparison of short term tests (autoclave tests, steam chamber tests) and long term tests (swelling in the CBR mould) have not been assessed. Last but as not least topic is chemical composition of metallurgical by-products and its influence of their mechanical properties.

Juckes discussed the various types of tests employed to determine the volume stability of slag based aggregates and compared them with the on-site behaviour of steel slag which often was diametrically different from the laboratory results [2]. The expansibility tests (as per EN 1744-1) or the hot water bath tests give results that better approximate the behaviour of the steel slag at actual construction sites. On the other hand, the test which gave the best result in situations where steel slag was used for unbound layers was the long-term CBR swell test.
The measurement of volume changes in laboratory conditions is limited. Short time tests under higher temperature and pressure (e.g. autoclave test) provide results very quickly; however, it is complicated to correlate them with behaviour of material under normal conditions. Methodological limits represent difficulties, too. Autoclave test is carried out on the fraction 8/16 and according to the present specifications it is valid for blast furnace slag aggregate only (see appendix A of TP138) [9]. Steam test according to the EN 1744-1 [7] is used only in case of steel slag aggregate and test is carried out for fraction 0/22.5. General short term test for any material has not been installed, yet.

Long term tests than remains to analyse volume changes. They are applicable for any material (both natural and artificial origin). It is the swell test in the CBR mould according to the EN 13286-47 [8]. A disadvantage of this test is fact that volume changes are slow and results are obtained during several months, even years. Comparison of test results of steelwork waste swelling under standard and non-standard conditions is shown in Figures 8 and 9.

The volume changes of water saturated samples tested at the temperature of 75°C amounted to 27.4% after 122 days for the samples compacted by 100% Proctor Standard energy, and 43.1% after 188 days for the sample compacted by Proctor Modified energy (Figure 2). The volume changes of steelwork waste sample under normal temperature and pressure after 5 years achieve 8.5% and still the trend to stabilization has not been observed (Figure 3).

**Figure 2.** Progression with time of the increment of vertical deformation of steelworks waste samples soaked with water at the temperature of 75°C.

**Figure 3.** Progression with time of the increment of vertical deformation of steelworks waste samples soaked with water under normal pressure and temperature (period of 30.1.2012-15.2.2017).

Swelling pressure values of steelwork waste were measured in case of experimental samples only. The swelling pressure value of 1.548 MPa obtained for the sample from the D47 motorway after 48 days at 70°C was higher than the values obtained from the autoclave test conducted at the pressure of 357 kPa and the temperature of 137°C for 1 hour (max. 1.28 MPa) presented by Wang [6] for samples of BOF steel slag.

It has to be pointed out, however that we still lack the values of correlation between swelling pressure values obtained in environments that accelerate the changes of volume (at higher temperatures) and those that would be obtained in tests performed at standard temperature and pressure.

Another problem is to estimate in which stage of volume changes a steelwork waste material is. The velocity of mineralogical and phase changes is well described in case of pure minerals. In case of such heterogeneous mixture which is represented by the steelwork waste, it is not possible definitely to set any prognosis.

Mineralogical analyses before and after autoclave tests were carried out in case of the Ikea shopping centre samples to find out changes in mineralogical association. It was observed that after
autoclave tests a share of calcite increase comparing with share of portlandite. However, it was not possible to quantify mineralogical changes after autoclave tests to predict behaviour of this material in the future [4].

**Figure 4.** View of a sample compacted by 100% Standard Proctor energy at the temperature of 75°C after 65 days water at the temperature of 75°C.

**Figure 5.** View of sample of steelworks waste samples soaked with water under normal pressure and temperature (period of 30.1.2012-15.2.2017).

**Figure 6.** Composition metallurgical by-products, including the steelwork waste, HMG [1] (Hüttenmineralstoffgemischen) in the phase diagram CaO-SiO₂-Al₂O₃. The unstable area from the point of view of C₂S disintegration.

Unfortunately, chemical composition of metallurgical by-products is not able to answer if these products are stable or not. Recommended ranges of content of SiO₂, Al₂O₃, CaO and MgO are defined in the TP138 for blast furnace slag, only [9]. However, some experts used these recommended values for all metallurgical by-products and deduced from it that materials outside these boundaries are non-stable. This statement is not right. E.g. steel slag usually contains higher amount of CaO and it is
mostly stable. Statements concerning volume stability derived only from chemical composition are very confusing and they may lead to wrong conclusions.

4. Conclusions
From the analyses performed so far it follows that the cardinal error committed in the case of the D47 motorway was the use of a material (steelworks waste) in respect of which no experience was available from other applications within the construction limits of a scope comparable to those of highways.

Results of tests show that although deformations lasted for many years their stabilization has not been definitely proven. Therefore we are not able to predict how many years deformations will be lasted. Values of swelling pressure are so high which show results of tests under non-standard conditions (temperature of 75°C), when there were measured values so far unpublished, but also consequences of volume changes in constructions where steelwork waste was used.

This very expensive experience, because the remedial works of steelwork waste usage will be very expensive, maybe increase the cautiousness in case of utilization of unknown and untested materials. On the other side probably the opposite extreme will not occur when good secondary material (blast furnace or steel slag) will be excluded from constructions only therefore that they have its origin in metallurgical production.

It is necessary to stress that well described and properly tested metallurgical by products are valuable alternative materials used in earthworks.

There are many questions, however, we do not know if they will be anytime answered because research financing to understand properties of this material is not actual in comparison of legal disputes.

References
[1] Jaschke K et al 1998 Merkblatt über die Verwendung von Hüttenmineralstoffgemischen, sekundärmittallurgischen Schlacken sowie Edelstahlsschlacken im Straßenbau, Forschungsgesellschaft für Straßen und Verkehrswesen (FGSV Verlag GmbH Köln)
[2] Juckes L M 2003 The volume stability of modern steelmaking slags Mineral processing and Extractive metallurgy 112(3) pp. 177-97
[3] Kresta F 2012 Secondary materials in highway construction (VŠB TU Ostrava)
[4] Kresta F 2014 Metallurgical by-products in earthworks, hazards of their utilisation Advanced Materials Research 1020 pp 98-109
[5] Kresta F 2015 Steelwork waste – non-standard metallurgical by-product International Journal of Advance Research in Science and Engineering 14(02) pp 5-16
[6] Wang G 2010 Determination of the expansion force of coarse steel slag aggregate Construction and Building Materials 24(10) pp 1961-66
[7] European Committee for Standardization (CEN) 2010 Tests for chemical properties of aggregates - Part 1: Chemical analysis (EN 1744-1)
[8] European Committee for Standardization (CEN) 2010 Unbound and hydraulically bound mixtures - Part 47: Test method for the determination of California bearing ratio, immediate bearing index and linear swelling (EN 13286-47)
[9] Ministry of Transport of Czech Republic 2011 Technické podmínky: Užití struskového kamenevá do pozemních komunikací /Technical specification: Utilisation of slag aggregate in road construction (TP138) (in Czech)
[10] US Department of Transport Federal Highway Administration 1998 User Guidelines for Waste and Byproduct Materials in Pavement Construction (FHWA RD-97-148)
[11] FGSV Verlag GmbH Köln 2013 Technische Lieferbedingungen für Böden und Baustoffe im Erdbau des Straßenbaus, Zusätzliche Technische Vertragsbedingungen und Richtlinien für Erdarbeiten im Straßenbau (TL BuB E-StB 07)