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POSSIBILITIES FOR THE UTILIZATION OF METALLURGICAL SLAG IN THE CONDITIONS OF THE POLISH ECONOMY

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The article presents the current possibilities for the utilization of blast-furnace and steelmaking slag in the realities of the Polish economy. Particular consideration is given to the legislation applicable to this area and to the physical and chemical requirements imposed on this material. Some aspects of environmental protection are described, and selected indicators are given, which must be met by this material to be used in various fields, such as road construction or cement production. Economical factors that are crucial to perceiving the slag as a standard valuable metallurgical product is also taken into consideration in the analysis.

Key words: blast-furnace slag, steelwork slag, utilization

Mogućnost uporabe metalurške troske u uvjetima ekonomije Poljske. Članak prikazuje sadašnje mogućnosti uporabe visokopećne i čelične troske u ekonomiji. Posebna pozornost pridaje se zakonodavstvu iz tog područja i zahtjevanim fizikalno-kemijskim svojstvima materijala. Opisani su neki oblici zaštite okoliša i izdvojeni pokazatelji koje je neophodno poznavati da bi se navedeni materijal mogao primjenjivati u različitim područjima, kao što su cestogradnja ili proizvodnja cementa. Također su analizirani ekonomski čimbenici presudni za poimanje troske kao vrijednog metalurškog proizvoda.

Ključne riječi: visokopećna troska, čeličanska troska, uporaba

INTRODUCTION

The changes that have been occurring over the last period of a dozen or so years as a result of ongoing system transformation and the process of Poland's integration with the European Communities, have been particularly observable in iron and steel metallurgy. The adjustment to the market economy rules and the requirements imposed by the European Union have compelled many enterprises to implement far-reaching changes of organizational, technological, ownership, and economic nature, among other things. Those changes, in the sphere of iron and steel metallurgy, have been and are still being carried out based on restructuring programmes being constantly updated by the Government of the Republic of Poland. In these programmes, the environmental protection issue has been one of the basic tasks to be carried out so that the impact of the metallurgical industry on the environment be minimized as far as possible. The ecological aspect of the restructuring process has been, on the one hand, the result of intentional pro-ecological activities and, on the other hand, the consequence of a number of other processes occurring in recent years in the Polish iron and steel metallurgy. The most important of them include the permanent closure of, most often technologically obsolete, metallurgical installations (lines, departments, ironworks and steelworks), or the implementation of new technical and technological solutions.

The predominating types of waste forming in iron and steel metallurgy are: metallurgical slag, scale, dust and sludge from waste gas purification, and melting loss. In Poland, the utilization of metallurgical waste is currently dealt with, in a majority of cases, by specialized companies. In other countries, notably in Western Europe and in the USA, ironworks treat part of their waste (e.g. slag) as a full-value product [1 – 4]. As some types of "waste" are included in the general economic accounting of a metallurgical enterprise, this approach forces changes in the production system and creates the need to treat this "waste" as a full-value product equally with the other elements of the process output vector.

LEGISLATION

The Polish environmental protection legislation is based on three basic acts and related implementing regulations. These include: the Act – Environmental law (of 27 April, 2001); the Act – Water law (of 19 July, 2001); and the Act on Waste (of 27 April, 2001). Contrary to general opinion, the Polish metallurgical industry, and

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so iron and steel metallurgy, does not belong to those industries, where the largest amounts of waste are generated (with 6,3 % of the overall amount of waste generated [5]). However, ironworks and steel mills use installations in their manufacturing process, whose functioning, due to the type and scale of their environmental impact, require the so called Integrated Permit to be obtained. This is granted for a period no longer than 10 years, and once every 5 years its review should also be made by the issuing authority. The Permit specifies the following, among other things: the conditions and quantities of emissions of gases or dust; the conditions of water intake under provisions laid down in the Act – Water law; the permissible noise level; the conditions to be met by discharged waste water; the conditions of generation and the methods of handling the waste under provisions laid down in the Act on Waste; and requirements for the Best Available Techniques (BAT) for installations covered by the Permit. The above-mentioned legal measures are already an element of the EU legislation setting the directions of the ecological policy, in which the utilization of waste plays an important role.

The Act on Waste provides for the implementation of a new system for handling any types of waste. This procedure should be followed in several successive steps: the prevention of waste formation, the selection of waste and its economic utilization as a substitute for raw-materials; waste disposal; storage, as an element of waste disposal (e.g. as a floor in a mine); landfill deposition. The Act in question has also obliged competent authorities to draw up a National Waste Management Plan for the years 2002 - 2014, in which the waste handling rules would provide a basis for the formulation of long-term tasks. Such tasks are necessary for carrying out the objectives set in the State's ecological policy geared towards achieving EU standards.

THE UTILIZATION OF METALLURGICAL SLAG

In the overall waste forming in metallurgical processes, blast-furnace slag and steelmaking slag make up the largest amounts deposited. Their quantity is closely related with the production volume of pig iron and crude iron. In last five years (2003 – 2007) level of blast furnace slag production was 4,4 – 6,4 Mt in Poland and 670,1 – 946,3 Mt overall in the world. In 2007 polish production of pig iron was about 5 % of EU production (27 countries) and 0,61 % of world production [1]. If we take on to assumption that there is about 0,25 Mt of slag on 1 Mt of pig iron (0,15 – 0,35 Mt, for example Deutschland 0,24 kg [4,5]) we have 1,45 Mt of blast furnace slag in Poland, in EU 29,2 Mt and in the world 236,6 Mt. Similarly in Poland level of crude steel production in 2003 – 2007 was 8,3 – 10,6 Mt and in the world 969,7 – 1344,3 Mt. Polish production was about 5 % of EU production and 0,79 % of overall world production. Last year in Poland production in bottom oxygen furnace was 58 % and in electric arc furnace 42 % (analogically EU – 59,6 %/40,25 %, and world 66,35 %/31,2 %) [1]. Based on literature for statistical purposes [4, 5] on every 1 t of steel we have 0,1 t of slag (both electric and oxygen process, including secondary metallurgy) – this means that in 2007 in Poland were generated 1 Mt of slag (EU – 21 Mt, world – 134 Mt).

The increasing world's demand for metallurgical products is thus the cause of formation of an increasing volume of slag, which forces searching for various methods of its utilization. Presently, 100 % of blast-furnace slag and approx. 75 % of steelmaking slag are utilized [3] 83 % of waste from steel industry were utylized in Poland in 2007 [2]). Due to their physicochemical properties, slag materials could have wide application in cement production and in construction.

In the case of cement production, the slag is used as one of the basic additives to enhance the cement properties (e.g. to increase strength and resistance to chemical corrosion, and to reduce gas and liquid permeability by the cement pastes of mortars and concretes). In cement plants, chiefly granulated blast-furnace slag finds application, where it is used in the manufacturing process in quantities depending on the type of cement being manufactured (even up to 60 %). As indicated by publicly available data [2, 6] related to the production of pig iron and cement, the volume of generated blast-furnace slag is lesser by several times than its demand. Thus, it can be stated that, as a rule, the total quantity of blast-furnace slag forming in current iron production is wholly utilized. It should be added, however, that the estimated size of demand concerns the slag in the form of granulate of specified chemical composition, as required by cement plants. In accordance with the standard EN-197-1, granulated blast-furnace slag to be used for cement production must meet the following quality requirements: a minimum vitreous phase content of 67 %; and a minimum $(CaO+MgO)/SiO_2$ ratio of 1. In practice, for technological reasons, the $SiO_2/(Al_2O_3+Fe_2O_3)$ ratio and the Al_2O_3/Fe_2O_3 ratio, or so called hydraulic properties, expressed by the relationship $(CaO+MgO+Al_2O_3)/SiO_2$, are also specified, Table 1. In addition, blast-furnace slag to be utilized in the cement industry should contain the least possible contents of such elements, as sodium, potassium, chlorine, chromium, as well as heavy metals and alkalis.

Research work on steelmaking slag is underway, which is aimed at increasing the potential of its utilization. Due to the fact that the mass fraction of Bessemer slag accounts for approx. 70 % of the overall mass of steelmaking slag generated, a decided majority of research works focus on increasing the potential of its further utilization [3]. This type of slag, together with the slag forming in the smelting of carbon steels in electric arc furnaces, are now largely utilized (the most difficult for utilization is the slag forming in the production of stainless steels, due to the high chromium and nickel contents). In Europe, of the whole volume of steelmaking slag, nearly half, accordly to data from 2004 – [3], finds application in construction (the construction of roads, dams, levees, and as building material additives), and a further 17 %, being deposited on temporary landfills, might be utilized in the future, e.g. in road construction. Particularly prospective in the Polish conditions seems to be the utilization of slag in the construction and upgrading of roads and motorways (e.g. road subsoil reinforcement, substructure dewatering, making binding layers and wearing courses, embankments, etc.).

Table 1. **Values of technological coefficients of blast-furnace slag for present (october 2007) activities of cement plant (RCM Poland group)**

Slag examples	$\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
Slag I	4,1	5,1
Slag II	2,5	8,0
Slag III	4,3	6,8
Slag IV	4,3	6,1
Slag examples	$\frac{CaO + MgO + Al_2O_3}{SiO_2}$	$\frac{CaO + MgO}{SiO_2}$
Slag I	1,56	1,35
Slag II	1,75	1,41
Slag III	1,58	1,37
Slag IV	1,49	1,29

Preliminary calculations of the road industry's demand for metallurgical slag have been made in this study (the values presented herein have been calculated based on data obtained from specific road sections). The calculations show that ~ 40000 t slag can be used for the construction of one kilometre of motorway, while ~ 3200 t for the upgrading of 1 km of local roads. Similarly as in the case of cement production, slag used in construction must meet a number of physicochemical requirements. Those requirements, however, are not specified by the customer who wants to utilize the waste, but are strictly laid down by standards being presently in force in Poland. Two basic European standards (in accordance with the Directive 89/106/EEC) have already been applicable to building aggregates for several years in Poland, namely PN–EN 13043: 2004 and PN–EN 13242: 2004. European standards have redefined many concepts in a manner different from that which was used previously, e.g. the division into mineral and artificial aggregates, which was functioning according to the common understanding of these materials, has been abolished. Generally, it can be accepted that the equivalent for the former classes are physical requirements, and for the grades – geometrical requirements, which means that the basic of classification is the set of characteristics of an aggregate. The substitution of the aforementioned European standards for several Polish standards, e.g. PN–B–11115: 1998 or PN–B–23004: 1988 has not involved in practice any changes. By the end of 2007, there were still no technical specifications referring to the new standards, which would define requirements for a specific structural layer of a given traffic route. As a consequence, construction companies are still bound by criteria being established based on, e.g., the PN–B–11115 standard of 1998. The purpose and range of application of a given lot of a building material having the attestation of the State Hygiene Institution is specified in the so called Manufacturer's Declaration of Conformity. The statements contained therein should be supported by the complete set of tests required by the standards. These tests include the determination of: density, foreign matter content, grain size distribution, grain shape, absorbability, freeze resistance, bitumen adherence, calcium decomposition, iron decomposition, and wearability. In addition, an aggregate must meet the requirements imposed by relevant Regulations of the Council of Ministers. In general, the ecological assessment of steelmaking or blast-furnace slag aggregates, based on chemical analysis, should state that the road aggregate made from slag may be used, e.g., as an asphalt course base, and does not contaminate soil or surface water, due to its very low solubility in water solution.

The excess of steelmaking slag, whose utilization is not possible due to various reasons, shall be deposited on dumps. Today the steel plants have to pay 100–400 US$ per ton for external treatment [7]. This operation entails incurring additional economic costs, part of which could certainly be avoidable, if the deposition process included appropriate segregation that would allow for the diversity of chemical composition, and so physicochemical properties of the material being deposited. Indeed, it happens that a particular type of slag coming from within the same steelwork, Table 2., and even from the same heat, exhibits a composition which is diverse enough to cause problems with slag utilization in some areas. Another, equally important criterion (besides the properties) which is decisive to the use of slag in construction is the economic justification of transporting this material beyond some distances.

Slag dumps are situated in strictly defined areas, in a decided majority also in one region of Poland (the Silesian province), which largely limits its utilization, e.g., for making the foundation of different types of road. Another, equally important criterion (besides the properties) which is decisive to the use of slag in construction is the economic justification of transporting this material beyond some distances.

Table 2. **Chemical composition of steelmaking slag from analyzed steelwork**

	$Fe_{tot.}$	FeO	SiO_2	CaO	MgO	Al_2O_3	MnO	P_2O_5	TiO_2	Cr_2O_3	$\frac{CaO+MgO+Al_2O_3}{SiO_2}$
	wt%										
Slag I	26,86	23,73	9,53	35,57	8,67	2,06	3,82	0,61	0,27	0,70	4,9
Slag II	32,10	32,12	13,84	25,52	9,24	3,03	3,5	0,8	0,36	0,90	2,7
Slag III	30,09	30,96	14,68	21,71	10,85	3,49	6,5	0,85	0,28	1,26	2,4
Slag IV	20,1	19,2	13,2	37,7	5,2	3,3	5,6	0,6	0,38	2,3	3,5
Slag V	17,4	17,4	17	36,7	6,5	3,7	6,2	0,85	0,41	1,9	2,7
Slag VI	37,22	36,77	8,22	26,8	5,81	2,52	3,91	-	-	-	4,3
Slag VII	37	39,28	9,37	24,4	8,24	1,98	4,87	0,58	0,25	1,51	3,7

Comment: The designation was performed with following methods: FeO with titration method with potassium dichromate according to IBL2483 norm. SiO_2, CaO, MgO, MnO, Al_2O_3, P_2O_5, TiO_2, Cr_2O_3, with the inductively coupled plasma (ICP) technique. S with the method of the combustion analysis in LECO analyser according to IBL2102 norm. Samples for analysis were received by technologist from slag before tapping of slag according to PN – H – 04000 norm.

SUMMARY

Although slag has the largest quantitative share in the overall metallurgical waste, its physicochemical properties offer a high potential for its utilization. Blast-furnace slag is already today utilized in 100 % in Poland in the production of cement, and only part of the steelmaking slag is deposited on dumps. This quantity could be further reduced, if - following the example of Western Europe or the USA - Polish ironworks and steel mills treated the slag not as waste, but as a full-value product. This approach requires the introduction of a number of changes, e.g. well-thought-out scrap management aimed at the stabilization of charge conditions; nevertheless, with an appropriate ecological policy of the State, such activities should bring about measurable economic advantages.

However, slag properties are a necessary, but insufficient condition for a given batch of material to be utilized, e.g., in road construction. Another very important criterion is the economic factor. The cost of transport contributes significantly to the price of aggregate (above 50 km price of aggregate's transport is twice as much as its price on slug dumps – data from Poland in 2007), which, in the case of steelmaking slag, can limit the potential for its use in the construction or upgrading or local roads or motorways to areas situated in the vicinity of slag dumps.

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Note: Translation on english language is responsible Mr. C. Grochowina, Poland.