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Granulated Metallurgical Slag Market Research in Russia

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Summary

The present review is **the first edition** of a study of the market of granulated slag, which is generally made from blast-furnace slags at the metallurgical enterprises.

Monitoring of the market is conducted **since 2014**.

Research objective is the analysis of the Russian market of granulated slag.

Research object is granulated slag, which find applications in the ferrous metallurgy, a construction complex, at production of cement, etc.

By preparation of the present report by experts of Infomine, data of Federal State Statistics Service of the Russian Federation (Rosstat), the Federal Customs Service of the Russian Federation, the statistics of rail transportation, materials of annual and quarterly reports of issuers of securities, materials of various analytical companies, materials of the central and regional media, data of the websites of the described enterprises, etc. were used.

Chronological framework of a research: 2014-2017.

Research geography: the Russian Federation - a complex detailed analysis of the market.

The report consists of **4** chapters, contains **74** pages, including **37** Tables, **12** Figures and **2** Appendices.

The **chapter 1 of the report** is devoted to characteristic of granulated slag with the description of the state standard specifications, the technical specifications, to the description of advantages of its application at production of cement.

In **chapter 2** sources of granulated slag are analyzed. Data on production of granulated blast-furnace slag at the enterprises of the ferrous metallurgy of Russia are provided, and the manufacturing enterprises are presented.

The **chapter 3** of the report analyses the consumption of granulated slag, and the main industries consumers are determined.

Data on volumes of consumption of granulated slag by the enterprises of the cement industry are presented, with the particular discussion of volumes of consumption in the Siberian Federal District (SibFD) and the Far Eastern Federal District (FEFD). Data on production of cement in Russia are analyzed, including by the enterprises.

The enterprises-suppliers of granulated slag to the cement plant of the SibFD and the FEFD are determined.

The **chapter 4** of the report analyses the logistics of transportations of granulated slag, distances and tariffs of railway transportation of granulated slag for the cement enterprises of the SibFD and the FEFD are presented.

The **Appendix 1** presents options of calculations of railway tariffs for supply of granulated slag to the individual cement enterprises in the SibFD and the FEFD.

The **Appendix 2** gives the addresses and contact information of the Russian companies - participants of the market of granulated slag (the metallurgical and cement enterprises).

Target audience of a research:

- participants of the market of granulated slags: producers, consumers, traders;
- potential investors.

The presented research applies for **a handbook** role for the services of marketing and for experts working at the market of fluxing materials for metallurgy.

INTRODUCTION

Currently, the production of cement and other structural materials widely uses granulated slags, which allow to increase the production of cement, to cut a consumption of the electric power, limestone, etc.

Granulated slags in particular are used for production of cements (composition cements), which contain the special mineral additives improving it working characteristics. Now composition cements are successfully applied in many countries at construction works, the erection of hydraulic engineering structures, and the production of monolithic and combined concrete goods. With the use of composition cement the industrial release of concrete blocks and reinforced concrete structures is made.

In production of Portland cement in the world the active mineral additions of the natural and technogenic origin are widely applied. According to foreign standards (for example, EN) the clinker content in such cements shouldn't be less than 20%, according to drafts of the modern Russian standards - 40%. As mineral additives such cements in different combinations use blast-furnace granulated slag, etc.

Today most cement works of Russia apply as a mineral additive blast-furnace granulated slag, which cost of acquisition is comparable to the prime cost of the produced Portland cement clinker, and also other metallurgical slags (blast-furnace slags, converter slags, etc.).

The production of blast-furnace granulated slag is made generally at the metallurgical enterprises with the blast-furnace production.

1. Granulated slag - main characteristics (state standard specifications GOST, technical specifications TU); requirements for use at production of cements (chemical, size distribution). Advantages of application of granulated materials for the cement industry.

The metallurgy, to be exact the ferrous metallurgy, is one of the main suppliers of technogenic raw materials for the industry of structural materials. A feature of its waste is that technogenic raw materials already underwent high-temperature processing, their crystalline structures in a waste are created and they don't contain organic impurities.

This includes wastes of the ferrous metallurgy, including blast-furnace and steel-smelting slags and also wastes of the nonferrous metallurgy. The largest applications at production of structural materials have blast-furnace slags.

It is found that raw materials for production of mineral additives may efficiently include materials of both the natural and technogenic origin, in particular by-products of the power engineering; the ferrous metallurgy (molding sands, slags, mill scale); wastes of production of crystal silicon, etc.

Blast-furnace granulated slags are efficiently used for more than 100 years both as raw materials for production of clinker, and as a fine-grained active mineral additive.

Hydraulic properties of slag and economic advantages allow to make binding materials, in which the clinker content varies over a wide range.

It is revealed that heat-treated slags under certain conditions have bigger activity. The introduction of such slags to the structure of Portland cement increases an amount of the chemically bonded water that promotes the extent of hydration of clinker minerals, and, as a result, an increase in durability of final products.

In certain cases the increase of durability exceeds not only the durability of the samples made with the use of not-heat-treated slag but also of samples free of slag.

A growth of an activity of cement, containing granulated slag, is connected with a change of its structure, namely with the fact that high temperatures increase the degree of defectiveness of a vitreous phase, therefore promoting the formation of crystallization centers.

Slags are artificial silicates. They consist of oxides of silicon, aluminum, iron, calcium, magnesium, manganese, sulfur and other chemical elements. The same oxides are contained in natural rocks. Depending on the quantitative ratio of oxides and also on the cooling rate of slag melts, formed slags can have properties of granite or volcanic pumice.

And by their color slags are close to natural rocks. They can be bluish-black, snow-white, green, yellow, pink, or gray. Quite often they have silvery, nacreous and lilac shades. Slags can be dense and porous, heavy as basalt, and light as tuff

or shell rock. The density of slag fluctuates from 3,200 kg/m^3 to 800 kg/m^3. The specific gravity of slag, i.e. weight of its substance, is close to the weight of natural stone materials and makes 2.5-3.6 g/cm^3.

By their chemical composition blast-furnace slags are divided into the main, neutral and sour. Basic slags are slags with the basicity module ($M=(CaO+MgO)/(SiO_2+Al_2O_3)$) is more than one, sour slags - with less than one.

An approximate chemical composition of blast-furnace slags is as follows:

SiO_2 30-40%, CaO 30-50%, Al_2O_3 - 4-20%, MnO-0.5-2%, FeO-0.1-2%, SO_3 - 0.4-2.5%.

The mineralogical composition of metallurgical slags is characterized by existence of mineral a with lower basicity than minerals of the Portland cement clinker: melilite Ca_2AlSiO_7-$Ca_2Mg(Si_2O_7)$, larnite β-Ca_2SiO_4, rankinite $Ca_3Si_2O_7$, α-$CaSiO_3$ pseudo-wollastonite, anorthite $Ca_2Al_2(Si_2O_8)$, monticellite $CaMgSiO_4$, diopside $CaMg(SiO_3)_2$. The ratio of these minerals is defined not only by the chemical composition of slags, but also conditions of their cooling. For example, granulated slags consist mainly of vitreous formations with crystal inclusions of larnite and melilite. In dump slags crystals of the larnite, rankinite, pseudo-wollastonite, the melilite dominate, and in high-aluminous sour slags prevail anortite, at the increased contents of MgO - merwinite $Ca_3Mg(Si_2O_8)$, the monticellite, and diopside.

An introduction of slag into the composition of cement in an amount of 30-50% doesn't reduce the strength of Portland cement. And more than that, using the active vitreous slags, the plants produce the quick-hardening slag Portland cement with the increased durability.

Slag Portland cements find the broadest application in the construction practice. They play an especially important role in construction of massive hydraulic engineering constructions. The matter is that at its solidifying, cement with an addition of slags generates by 1.5-2 times less heat, than without additives, and that predetermines the increased crack resistance of concrete massifs.

Slag Portland cements are produced by a grinding in ball tube mills of Portland cement clinker and granulated slag, which amount depends on the brand of the slag Portland cement.

Granulated slags are also used for production of slag-lime cements, which are the hydraulic binding materials received by a fine grinding of granulated slag together with a low-hygroscopic alkaline component or a closing of ground slag with solutions of compounds of alkali metals: sodium, lithium or potassium.

Not granulated blast-furnace slag is produced at the air cooling of slag with the subsequent crushing and screening. It is used mainly in the road construction as the crushed stone. It possesses no hydraulic properties.

Granulated blast-furnace slag is made when smelting cast iron by a quick quenching. It is used in construction, as the active mineral addition in cement, etc.

The industry accumulated the considerable experience of the use of metallurgical slags. In particular, blast-furnace granulated slag finds broad

applications at production of cement (cement with additives, slag Portland cement).

The active materials, contained in slag, improve technical properties of cement, increase its quality and the durability of building constructions. It allows to reduce an expense of the slag Portland cement by 5% in comparison with a Portland cement at production of concrete.

The use of blast-furnace slags at production of the slag Portland cement allows to replace clay, to cut a limestone consumption by 1.2-1.6 times, to increase the cement output, to cut an electric power consumption by 40%, and to improve ecological characteristics in the region.

Currently the granulated slag is produced according to GOST 3476-74 (Slags blast-furnace and electrothermophosphoric granulated for the production of cements) and also by technical specifications, which are developed by the separate enterprises or the consumers within SRO (self regulating organizations) regulations.

GOST 3476-74 (Slags blast-furnace and electrothermophosphoric granulated for the production of cements) defines the technical specifications to granulated slags. An assessment of hydraulic properties of the blast-furnace granulated slag is defined by means of coefficient of quality (K), which is determined by formulas:

- at the magnesium oxide content up to 10%:

$$K = \frac{\%CaO + \%Al_2O_3 + \%MgO}{\%SiO_2 + \%TiO_2};$$

- at the magnesium oxide content above 10%:

$$K = \frac{\%CaO + \%Al_2O_3 + 10}{\%SiO_2 + \%TiO_2 + \%(MgO - 10)}$$

Depending on the coefficient of quality and the chemical composition blast-furnace granulated slags are subdivided into three grades (Table 1).

Table 1: Grades of granulated slags depending on the coefficient of quality and chemical composition

Indicators	Standards for grades		
	1	2	3
Coefficient of quality, at least	1.65	1.45	1.20
Content of alumina (A_2O_3), %, at least	8.0	7.5	Not rated
Content of magnesium oxide (MgO), %, at most	15.0	15.0	15.0
Content of titanium dioxide (TiO_2), %, at most	4.0	4.0	4.0
Content of manganous oxide (MnO), %, at most	2.0	3.0	4.0

Source: GOST 3476-74

Electrothermophosphoric granulated slags by the chemical composition have to meet the following requirements:

content of silicon dioxide (SiO_2), %, at least..... 38

content of the sum of calcium oxide (CaO) and

magnesium oxide (MgO), %, at least..... 43

content of phosphorus pentoxide (P_2O_5), %, at most..... 2.5.

The humidity of slags is established by an agreement between the supplier and the consumer.

The amount of the large pieces of slag (which didn't undergo granulation) in a batch shouldn't be more than 5% by weight. The sizes of such pieces shouldn't exceed 100 mm on the greatest measurement.

Chemical analysis of slag is made in accordance with GOST 5382.

Besides, GOST defines acceptance rules and testing methods of granulated slag; transportation and storage and guarantees of the supplier.

PAO Severstal carries out production of granulated blast-furnace slag according to TU 14-105-863-09 and TU 14-105-684-09 and GOST 3476-74 according to which parameters (fraction, humidity, etc.) and also the chemical composition (Tables 2-4) are set.

Table 2: Slag blast-furnace granulated according to TU 14-105-863-09 of production of PAO Severstal

	Normalized indicators	Standard
	Fractions (mm)	0–2.5
	Humidity (%)	no more than 20%
	Bulk density (kg/m3)	800–1000
Chemical composition (weight fractions, %)	CaO	35.0–44.4
	SiO_2	34.4–38.9
	Al_2O_3	7.1–10.3
	MgO	8.4–12.5
	MnO	0.15–0.69
	FeO	0.55–7.05
	S	0.67–0.92
	TiO_2	0.47–1.59
	Effective specific activity of natural radionuclides	1st class (all types of construction)

Source: PAO Severstal

Table 3: Slag blast-furnace granulated according to TU 14-105-864-09 of production of PAO Severstal

	Normalized indicators	Standard
	Fractions (mm)	0–2.5
	Humidity (%)	no more than 20%
	Bulk density (kg/m^3)	800–1000
Chemical composition (weight fractions, %)	CaO	35.0–44.4
	SiO_2	34.4–38.9
	Al_2O_3	7.1–10.3
	MgO	8.4–12.5
	MnO	0.15–0.69
	FeO	0.55–7.05
	S	0.67–0.92
	TiO_2	0.47–1.59
	Effective specific activity of natural radionuclides	1st class (all types of construction)

Source: PAO Severstal

Table 4: Parameters of blast-furnace granulated slag in accordance with GOST 3476-74 of production of PAO Severstal

	Normalized indicators	Standard
	Fractions (mm)	0–2.5
	Humidity (%)	no more than 20%
	Bulk density (kg/m^3)	800–1000
Chemical composition (weight fractions, %)	CaO	35.0–44.4
	SiO_2	34.4–38.9
	AI_2O_3	7.1–10.3
	MgO	8.4–12.5
	MnO	0.15–0.69
	FeO	0.55–7.05
	S	0.67–0.92
	TiO_2	0.47–1.59
	Effective specific activity of natural radionuclides	1st class (all types of construction)

Source: PAO Severstal

The normative documents regulating the use of blast-furnace granulated slag in the road construction are:

GOST 30491-2012 Organomineral mixes and the soils, strengthened with organic binding substances, for road and airfield construction. Technical specifications;

GOST 12801-98 Materials on the basis of organic binding substances for road and airfield construction. Test methods;

GOST 3344-83 Crushed stone and sand slag for road construction. Technical specifications;

GOST 8269.0-97 Crushed stone and gravel from the dense rocks and a wastes of the industrial production for construction works. Methods of physico-mechanical tests;

GOST 8269.1-97 Crushed stone and gravel from the dense rocks and a wastage of the industrial production for construction works. Methods of a chemical analysis;

SP 34.13330. Construction Norms and Regulations 2.05.02-85*. Revised edition. Highways (item 7.21, item 8.45);

SP 78.13330.2012 Construction Norms and Regulations 3.06.03-85. Revised edition;

SP 99.13330.2016 Construction Norms and Regulations 2.05.11-83. Revised edition. Intraeconomic highways in collective farms, state farms and other agricultural enterprises and the organizations;

SP 243.1326000.2015 Design and construction of highways with low intensity of driving;

SP 288.1325800.2016 Forest roads. Rules of design and construction.

Besides, can be of interest the following documents:

Methodical recommendations about strengthening of soils with low-strength stone materials and wastes of the industry with binding materials for their use at construction of roads (including in the non-chernozem areas of RSFSR);

The guide to the soils and materials strengthened with organic binding materials of the Ministry of Transport of the Russian Federation 2003;

Reference to Construction Norms and Regulations of 3.06.03-85 A reference on construction of coverings and foundations of highways and airfields from the soils strengthened by cementing materials, to Construction Norms and Regulations 3.06.03-85 and Construction Norms and Regulations 3.06.06-88.

Kosogorsky MZ carried out the production of blast-furnace granulated slag by its fast cooling. The plant carried out the slag supply to the cement enterprises of Russia. Kosogorsky MZ produced granulated slag according to GOST 3476-74 (Slag granulated)..

PAO Tulachermet, which is the largest producer of commodity cast iron in Russia, releases granulated slag according to GOST 3476-74 and TU 14-127-269-2008.

Some consumers within SRO (self regulating organization) approve the list of documents, which regulate the use of granulated slags.