ARCHIWUM INŻYNIERII PRODUKCJI
PRODUCTION ENGINEERING ARCHIVES

2016, Vol. 11, No 2, pp 2-5
ISSN 2353-5156 (print version)
ISSN 2353-7779 (online version)

Article history: Received: 16.05.2016 Accepted: 15.06.2016 Online: 30.09.2016

Available online on: http://www.qpij.pl **Exist since 4rd quarter 2013**

Processing and utilization of metallurgical slags

Alena Pribulová[1], Peter Futáš[1], Dana Baricová[1]

[1]Institute of Metallurgy, Faculty of Metallurgy, Technical university in Košice, Park Komenského 14, Košice, Slovakia, +421 55 6022752, alena.pribulova@tuke.sk

Abstract Metallurgy and foundry industry create a huge amount of slags that are by-products by production of pig iron, steel and cast iron. Slags are produced in a very large amount in pyrometallurgical processes, and are huge sources of waste if not properly recycled and utilized. With rapid growth of industrialization, the available land for land-filling of large quantity of metallurgical slags is reducing all over the world and disposal cost becomes increasingly higher. Metallurgical slags from different metallurgical processes are treated and utilized in different ways based on the different slag characteristics. The most economic and efficient option for reducing the metallurgical waste is through recycling, which is a significant contribution to saving natural resources and reducing CO_2 emissions Characteristic of slags and their treatment and utilization are given in the paper. Slags from pig iron and steel production are used most frequently in building industry. From experiments using blast furnace slag and granulated blast furnace slag as grave an water glass as binder follows that the best results – the best values of compression strength and tensile strength were reached by using of 18% of water glass as solidification activating agent. According to cubic compression strength, mixture from 50% blast furnace gravel, 50% granulated blast furnace slag and 18% water glass falls into C35/45 class of concretes. This concrete also fulfils strength requirements for road concrete, it even exceeds them considerably and therefore it could find an application in construction of road communications or in production of concrete slabs.

Key words – metallurgical slag, waste, concrete, cement

1. Introduction

Metallurgical slags have been used for tens of years with good results and they have their own loyal users. The EU Directive on Waste (75/442/ETY) defines waste as follows: "Waste" shall mean any substance or object, which the holder discards or intends or is required to discard. In addition to the definition of waste, the European list of wastes (2000/532/EC) can be used to define whether a material is waste or not. (HAMI S. 2005).

Metallurgical slags from different metallurgical processes are treated and utilized in different ways based on the different slag characteristics. The most economic and efficient option for reducing the metallurgical waste generation is through recycling.

It is possible to divide the metallurgical slags from ferrous metallurgy in 6 types: blast furnace slag (BFS), basic oxygen furnace slag (BOFS), electric arc furnace slag (EAFS), electric induction furnace slag (EIFS), cupola furnace slag (CFS) and slag from secondary metallurgy (PRIBULOVÁ A. 2014)

Blast furnace slag forms about 20 – 35% of the amount of hot metal produced. Molten slag tapped from the blast furnace is quenched mainly using two alternative methods (REUTER M. 2004):

- Rapid water quenching, which does not give slag time to crystallise, but it vitrifies. Granulated blast furnace slag can also be used in earth and road construction.

- Slow air quenching, in which slag crystallises and solidifies into thick layers. Air quenched slag is crushed and screened to products required by the customers. Air quenched blast furnace slag products are mainly used for earth and road construction.

Compared to blast furnace slag, steelmaking slag shows a considerably higher content of iron, manganese, and magnesium (GANDHEVAR V.R. 2011 REX M. 2013) along with the lower silicon content i.e. higher CaO/ SiO2 ratio, and, finally, it contains almost no sulphur at all. Slag from EAF has more weight, higher hardness and density, it is less porous and highly resistant to polishing and wear and as such is very suitable for road building (LEWIS D.W. 1982, MOTZ H. 2001).

Electric arc furnace (EAF) slag can be used as inexpensive absorbing agent (RASTOVČAN-MIOČ A. 2006).

The largest amount of steel slag is used in construction industry. However, its usage in case of more demanding applications is only possible after the free lime stabilization. In such a case slags can be used as support slag gravel in road-building or fine gravel aggregate in asphalt surface (MERKE T. 2007). This material is suitable for use as protection of river banks from erosion, as stabilization of profiles of water courses, or as a material for bank dike construction (KUJALA K. 2005) .Very interesting usage options are desribed in literature references (TAKAHASHI T. 2002) where steel slag was utilized in production of the so-called sea blocks used in artificial cliff building.

2. Utilization of blast furnace slag for concrete production

Concrete is a composite material composed mainly of water, aggregate, and cement. Usually there are additives and reinforcements included to achieve the desired physical properties of the finished material. When these ingredients are mixed together, they forms a fluid mass that is easily molded into shape. Over time, the cement forms a hard matrix which binds the rest of the ingredients together into a durable stone – like material with many uses.

"Aggregate" consists of large chunks of material in a concrete mix, generally a coarse gravel or crushed rocks such as limestone, or granite, along with finer materials such as sand. Concrete can be formulated with high compressive strength, but always has lower tensile strength. For this reason it is usually reinforced with materials that are strong. Fine and coarse aggregates make up the bulk of a concrete mixture. Sand, natural gravel, and crushed stone are used mainly for this purpose. Recycled aggregates (from construction, demolition, and excavation waste) are increasingly used as partial replacements of natural aggregates, while a number of manufactured aggregates, including air-cooled blast furnace slag and bottom ash are also permitted (BŐMER S., ET ALL. 2007, YILDIRIM I.Z., PREZZI M. 2011,)

3. Methodology of research

At the Institute of Metallurgy the blast furnace slag grave was used for concrete production with cement and within it.

The blast furnace slag was used as a grave for cementless concrete. The proportion of ground granulated slag, which substituted cement was established experimentally and amounted to 50% of the mixture consisting of blast furnace gravel and ground granulated slag. By initial experiments 25% granulated slag was used what approximately corresponded to a proportion of cement in cement concrete mixtures, but prepared cementless mixtures had low value of strength, the amount of granulated blast furnace slag was double.

Determination of proportion of particular fractions of blast furnace gravel was based on Fullers´ curve. Fraction of 0 – 4 mm (43%) and 4 – 8 mm (7%) were used (BARICOVÁ D.,PRIBULOVÁ A.,DEMETER P., BUĽKO B., ROSOVÁ A.2012, BARICOVÁ D., PRIBULOVÁ A., DEMETER P., BUĽKO B., FUTÁŠ P. 2011). Subsequently, water-glass as an activating agent of solidification was added into homogenized mixture and all mixture was stirred for two minutes. Cubic and cross – beam moulds were filled by the mixture, which was subsequently rammed by pneumatic ramming machine and then set for 24 hours. After this, the samples were unmoulded and submerged into water environment (D sample was also set on the air) for 7 and 28 days.

Water glass, as the activating agent of solidification, was chosen based on acceptable price, good manipulability, as well as air-setting option.Three various types of water glass were examined for cementless concrete production : 36-38°Bí, 44-46°Bé, 50-52°Bé. The best compression and tensile strength were achieved by mixtures with water glass 50-52°Bé, which became the basis for next experiments.

Six mixtures with 50% blast furnace slag (43% fraction 0-4 mm and 7% fraction 4-8mm), 50% granulated blast furnace slag and different additon of water glass (6,12,16, 18, 20 and 22%) were made.

Table 1 shows the addition of water glass in single mixtures and reached the values of compression and tensile strength. Mixture "A" and "B" with 6 and 12% of water glass were disintegrated after 12 hours.

Table 1. Content of water glass in mixtures and reached values of compression and tensile strength

Mixture	Water glass 50-52°Bé [MPa]	Compression strength [MPa]	Tensile strength [MPa]
A	6	-	-
B	12	-	-
C	16	34.5	2.9
D	18	42	5.8
E	20	41	5
F	22	42	4.4

Source: own study.

3. Results and discussions

The best mechanical properties were reached by mixture D with 18% water glass, compression strength was 42 MPa and tensile strength 5,8 MPa. It is generally known that strength properties change over time, the strength increase sligthy and then remains stable. Table 2 shows that compression strength after 7 days was 41,5 MPa but after next 21 days it increased on 49 MPa. The similar situation was with tensile strength.

Table 2. Compression and tensile strength of mixture D (50%blast furnace slag-50%granulated slag+18% water glass) after 7 and 28 days

Compression strength [MPa]		Tensile strength [MPa]	
7 days	28 days	7 days	28 days
41.5	49	4.3	5.1

Source: own study.

As an alternative to water environment, in which all prepared mixtures were set for the time being, the environmental of air atmosphere was chosen for the process of hardening. This was caused by concerns that water environment may reduce the hardening effects of water glass, because water reduces its density, Table 3. It results from the values of compression and tensile strength that a difference of compression strength is minimal and even in favour or water environment, which is more distinctive at tensile strength. It is possible to state that water environment does not reduce the hardening effects of water glass.

Table 3. Compression and tensile strength of mixture D (50%blast furnace slag-50%granulated slag+18% water glass) by different conditions of solidification

Condition of solidification	Compression strength [MPa]	Tensile strength [MPa]
D_{air}	41.5	4.3
D_{H2O}	42	5.8

Source: own study.

4. Summary and conclusions

Metallurgy and foundry industry creates a huge amount of slags that are by-products by production of pig iron, steel and cast iron. They are treated and utilized in different ways based on the different slag characteristics. The most economic and efficient option for reducing the metallurgical waste generation is through recycling.

Slags from pig iron and steel production are used most frequently in building industry.

The highest quantity of slags from foundry industry create in cupola furnace. Properties of cupola furnace slag are very similar to blast furnace slag but its utilization is minimal. From experiments using blast furnace slag and granulated blast furnace slag as a gravel and water glass as a binder follows that the best results – the best values of compression strength and tensile strength were reached by using of 18% of water glass as solidification activating agent.

According to cubic compression strength, mixture D falls into C35/45 class of concretes. This concrete also fulfils strength requirements for road concrete, it even exceeds them considerably and therefore it could find an application in construction of road communications or in production of concrete slabs. It is necessary to examine the properties of given concrete during long-term field application. Production of such concrete mixtures would ensure the efficient utilization of secondary raw materials developed from blast-furnace slag.

Acknowledgement

This work was supported by the Scientific Grant Agency of the Ministry of Education of the Slovak Republic No.VEGA 1/0703/16

Literature

1. HAMI S. 2005. Slag: product or waste – the present situation. EUROSLAG. Slags – Providing Solutions for Global Construction and other Markets, 4th European Slag Conference. Proceeding, Euroslag Publicatio. Oulu (Finland).
2. LEWIS D.W. 1982. Properties and Uses of Iron and Steel Slags. National Slag Association. Symposium on Slag National Institut for Transport and Road Research, South Africa.
3. MOTZ J., GEISLER J. 2001. Products of Steel Slag an Opportunity to Save Natural Resources. Waste Management 21.
4. PRIBULOVÁ A., FUTÁŠ P., BARICOVÁ D., DEMETER,P. 2014. Waste management – metallurgical slag: waste or secondary material? Toyotarity. Management of technology. Alba Iulia.
5. REUTER M., XIAO Y., BOIN U. 2004. Recycling and environmental issues of metallurgical slags and salt fluxes. VII International Conference on Molten Slags Fluxes and Salts, The South African Institute of Mining and Metallurgy. Johannesburg.
6. GANDHEVAR V.R., BANSOD S.V., BORADE A.B. 2011. *Induction furnace – a review.* International Journal of Engineering and Technology Vol.3.No.4.
7. REX M. 2013. *The use of BF, converter and ladle slags in European agriculture-benefits or risks?* Slag-Providing solutions for global construction and other markets. In: 4th European Slag Conference. Oulu (Finland).
8. RASTOVČAN – MIOČ A., SOFILIČ T., MIOČ B. 2006. *Study of Potential Electric Arc Furnace Slag Application.* Proceedings Book of 7th International Foundrymen Conference. Opatija.
9. MERKE T. 2007. Steel Slag for Railway Tracks. 5th European Slag Conference. Luxemboug.
10. TAKAHASHI T., YABUTA K. 2002. Applications for Iron and Steelmaking Slag. NKK Technical Review. No. 87.
11. KUJALA K. 2005. Use of industrial co-products in civil engineering in Slag-Providing solutions for global construction and other markets. 4th European Slag Conference. Oulu (Finland).
12. BŐMER S., et all. 2007. Aggregate case study. Final Report referring to contract n° 150787-2007 F1SC-AT. Vienna.
13. YILDIRIM I.Z., PREZZI M. 2011. Chemical, Mineralogical, and Morphological Properties of Steel Slag. Advances in Civil Engineering. Vol. 10.
14. BARICOVÁ D., PRIBULOVÁ A., DEMETER P., BUĽKO B., ROSOVÁ A. 2012. Utilizing of the metallurgical slag for production of cementless concrete mixtures. Metalurgija. Vol. 51. No. 4.
15. BARICOVÁ D., PRIBULOVÁ A., DEMETER P., BUĽKO B., FUTÁŠ P. 2011. Analysis of metallurgical slags utilization in the road engineering. SGEM 2011 11th International Multidisciplinary Scientific GeoConference. Bulgaria. Albena.