

M. DZIARMAGOWSKI*

POSSIBILITIES OF CONVERTER SLAG UTILIZATION

MOŻLIWOŚĆ UTYLIZACJI ŻUŻLA KONWERTOROWEGO

Up to 85% of the produced steelmaking slag is utilized in the world. Some converter slag is used as a return material in the blast furnace process and in steelmaking processes. Some is separated magnetically. The material obtained is used mainly for road construction and in the construction material industry. At the same time new methods of utilization of the growing mass of steelmaking slag are sought. Research on the converter slag reduction process in an electric arc furnace carried out for many years can be counted among the new methods. Findings of this research have been compared with the findings of author's own research carried out under laboratory and industrial conditions.

W świecie zagospodarowuje się do 85% wytwarzanego żużla stalowniczego. W charakterze materiału zwrotnego w procesie wielkopiecowym i procesach stalowniczych wykorzystuje się pewne ilości żużla konwertorowego. Część żużla poddaje się separacji magnetycznej. Otrzymany materiał wykorzystuje się głównie do budowy dróg i w przemyśle materiałów budowlanych. Jednocześnie od wielu lat poszukuje się nowych metod zagospodarowania narastającej masy żużla stalowniczego. Do nowych metod można zaliczyć prowadzone od wielu lat badania procesu redukcji żużla konwertorowego w elektrycznym piecu łukowym. Wyniki tych badań porównano z wynikami badań własnych prowadzonych w warunkach laboratoryjnych i przemysłowych.

1. Introduction

The growing mass of slag is a result of steel production. It calls for search of various methods of its utilization. About 300 mln Mg of blast furnace and steel making slag is produced in the world annually [1, 2]. 100% of blast furnace slag and up to 85% of steelmaking slag is utilized. [2].

* FACULTY OF METALLURGY AND MATERIALS SCIENCE, AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY, 30-059 KRAKÓW, AL. MICKIEWICZA 30, POLAND

Use of converter slag as an additive to the blast furnace charge is restricted by its high P_2O_5 content. In recent years also use of converter slag as a return material in steelmaking processes has been limited. By using mechanical slag processing combined with magnetic separation metal skulls contained in slag can be recovered but at the same time difficulties related to rational utilization of fragmented non-metallic phase containing metal oxides occur. The slag reduction in an electric arc furnace can be counted among new methods of slag processing.

At the moment many research projects on comprehensive utilisation of converter slag are being carried out in the world. In this study various methods of converter slag utilization, which either are applied in the industrial practice or are expected to be applied in the future, are presented and discussed.

2. Possibilities of utilization of converter slag as a return material in the blast furnace process and in steelmaking processes

Crushed converter slag of 0-10 mm grain size can be used in the blast furnace process. Addition of slag to sinter charge can be up to 30 kg/Mg of sinter [3]. It enables reduction of iron ore and lime stone additions. The high P_2O_5 content in converter slag does not allow to use its higher additions.

For the first time converter slag was used as a return material in a converter plant in the Wakayama Steel Plant in Japan in 1975 [4]. Use of the process with return slag added in the amount of 25 kg/Mg of steel enabled reduction of lime consumption by 10 kg/Mg of steel and complete elimination of fluorite. In Poland converter slag was used as a return material in 1983 in vessels of 300 Mg capacity. The slag was prepared to the process by screening through a 50×50 mm mesh. Use of return slag in the quantity of up to 15kg allowed reduction of lime consumption by 6-5 kg/Mg of steel and dolomite consumption by 0.5-7.0 kg/Mg of steel subject to silicon content in the hot metal [5].

Much better results were obtained in Poland than in Japan. It stemmed from different process objectives. The return slag addition in the Wakayama Plant was calculated on the basis of CaO content in converter slag. As the converter slag contained under 50% of CaO, 2.5 kg of return slag substituted for 1 kg of lime. In Poland also lime dissolution rate in the presence of liquid return scrap was taken into account. The return scrap would pass into the liquid state within the first 2-3 minutes of the process due to its low melting temperature of 1300°C. In these circumstances the process of lime dissolution in primary slag was accelerated and its utilisation rate was increased.

After the favourable results in the BOF process had been obtained, converter slag was used as a return material in electric arc furnaces of 140 Mg capacity in a domestic electric melting shop in 1983. Converter slag was fed with the charge in the amount of 17.5-18.5 kg/Mg of steel. It allowed acceleration of the slag forming process during meltdown and its foaming at the end of meltdown. Foaming of the forming slag was caused by processes of reduction of oxides contained in the converter slag, especially

ferrous oxides, by carbon brought in by carburiser. It enabled furnace operation with a covered electric arc and limited its destructive effects on the refractory lining [6-9].

In recent years utilization of converter slag as a return material in steelmaking processes is low. It is caused by the widespread use of low silicon hot metal which enables lower additions of lime and dolomite. However if the silicon content in hot metal is very low, introduction of lime in the amount necessary for correct process may cause excessive increase of the slag basicity. Therefore in such cases some return slag can be added [1]. At present in electric steel melting shops oxygen is injected and carbon materials are added to foam slag.

Increase in the amount of converter slag used as a return material in steelmaking processes was suggested in Australia and New Zealand. In these countries in 2000 about 800000 Mg of slag were manufactured in the BOF process and about 84000 Mg in EAFs. Only 64% of the converter slag and 54% of the EAF slag were utilized. In order to reduce the growing mass of slag it was suggested to use it as a return material in the basic oxygen process in a more sophisticated way as presented before. Results obtained in Japanese steel plants, where the hot metal is de-sulphurised and de-phosphorised and de-siliconised before the carbon oxidising process in the next converter, were utilised in the proposed method. The basic assumptions of the proposed method of converter slag utilization are presented in Fig. 1. [10].

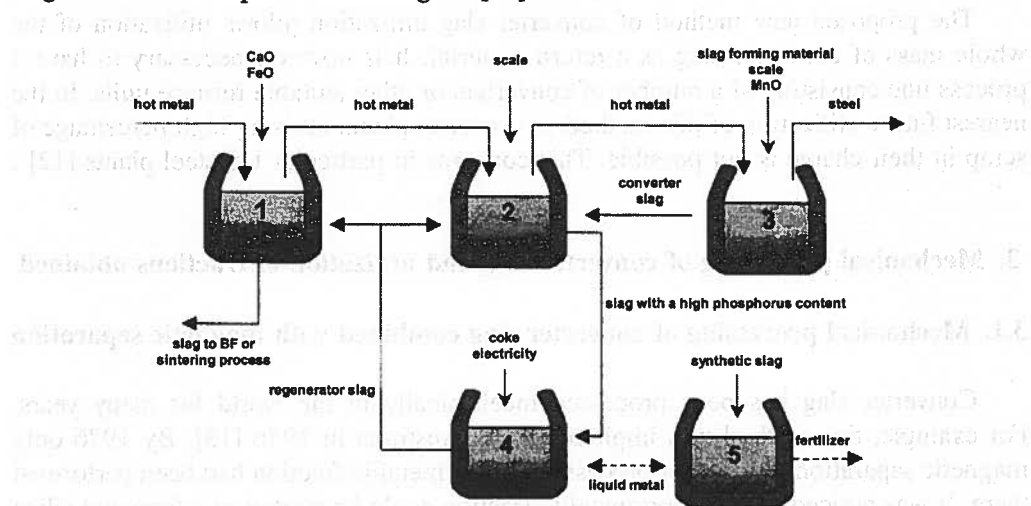


Fig. 1. Utilization of the converter slag as a return material in the basic oxygen process. 1 – hot-metal desiliconization, 2 – hot-metal dephosphorization, 3 – BOF, 4 – regenerator, 5 – liquid metal dephosphorization

The following stages can be distinguished in the proposed method of converter slag utilisation:

1. The whole mass of slag from the BOF 3 is transferred to the unit 2 where the hot metal dephosphorization process is carried out.

2. The whole mass of slag from the unit 2 where the hot metal is dephosphorized at the temperature of 1623K is transferred to the unit 4 called the regenerator.
3. In the regenerator 4 phosphorus passes from the slag into the melt at the temperature of 1873K.
4. The slag is transferred from the regenerator 4 to the units 1 and 2 where the hot metal is desiliconised and dephosphorised.
5. The whole mass of slag from the unit 1 where the hot metal desiliconization process is carried out at the temperature of 1623K is transferred to the blast furnace process.
6. The liquid metal is transferred from the regenerator 4 to the unit 5 where the de-phosphorising process is carried out at 1623K. Also synthetic slag is added into the unit. As a result of the process the slag containing over 10% of phosphorus is obtained, which can be utilized as a fertilizer. The liquid metal is returned to the regenerator 4.

The optimum conditions for carrying out the proposed process are laid down in reference [11]. It was determined that it was necessary to add coke to increase the carbon content in the melt so that the process carried out in the regenerator was correct. It was also determined that 50% of the regenerator slag should be transferred to the unit where the hot metal was desiliconized and 50% should be transferred to the unit where the hot metal was dephosphorized.

The proposed new method of converter slag utilization allows utilization of the whole mass of converter slag as a return material. It is however necessary to have a process line consisting of a number of converters or other suitable furnace units. In the nearest future utilization of this method in converter plants utilising high percentage of scrap in their charge is not possible. This concerns in particular US steel plants [12].

3. Mechanical processing of converter slag and utilization of fractions obtained

3.1. Mechanical processing of converter slag combined with magnetic separation

Converter slag has been processed mechanically in the world for many years. For example, this method was implemented in Australia in 1956 [13]. By 1976 only magnetic separation and further processing of the metallic fraction had been performed there. It was noticed that the non-metallic fraction could be treated as a lime and silica source in the blast furnace process. Since then up to 200000 Mg of the non-metallic fraction obtained as a result of magnetic separation of converter slag have been used in this process annually. Further growth of consumption of the non-metallic fraction in the blast furnace process is limited by its high P_2O_5 content. The non-metallic fraction has also been attempted to be used for the lower base course of expressways. However problems with surface swelling have occurred. This effect is caused by antogenous disintegration of the non-metallic fraction as a result of transition of the $\beta CaO \cdot SiO_2$ form into the γ form. This can be prevented only in the case of long-term ageing of slag under atmospheric conditions.

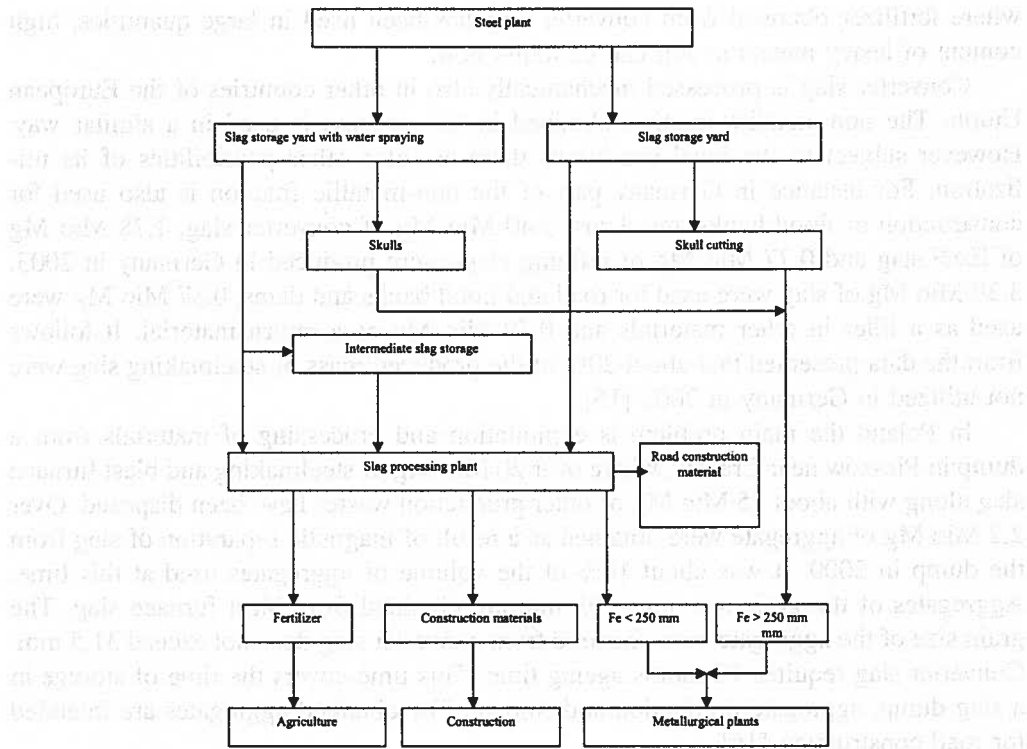


Fig. 2. Flow chart of converter slag processing in Voest Alpine

The mechanical processing of converter slag used in Europe is presented in Fig. 2 where the process used by the slag processing plant in Linz in Austria is shown as an example [14]. Maintaining of two slag storage yards is a characteristic feature of this process. The slag from the first storage yard can be directly processed mechanically in combination with magnetic separation. The obtained non-metallic fraction can be used as a Ca-Mg fertilizer or an additive to construction materials. The second storage yard is divided into 5 fields where converter slag is aged under atmospheric conditions. 5 years is considered the optimum ageing time. After completion of the ageing process the slag is subjected to magnetic separation. In the USA 6 months is deemed a sufficient time for the slag ageing process. In this time the free lime hydration and calcium orthosilicate allotropic transformation processes causing increase in the slag volume should be completed [1]. The obtained non-metallic fraction is used for road base course construction or as an additive to bituminous pavement to improve its roughness and grindability.

A relatively high degree of contamination of the Ca-Mg fertilizer with heavy metals is a drawback of the method used in the Linz plant. In Poland use of Ca-Mg fertilizer made from converter slag by magnetic separation is not permitted due to the high iron content in soil. It should be emphasised that in the Czech Republic and in Slovakia,

where fertilizer obtained from converter slag has been used in large quantities, high content of heavy metals in soil can be found now.

Converter slag is processed mechanically also in other countries of the European Union. The non-metallic fraction obtained in this process is used in a similar way. However subject to the local conditions there are also other possibilities of its utilization. For instance in Germany part of the non-metallic fraction is also used for construction of flood banks and dams. 3.40 Mio Mg of converter slag, 1.78 Mio Mg of EAF slag and 0.77 Mio Mg of refining slags were produced in Germany in 2003. 3.36 Mio Mg of slag were used for road and flood banks and dams, 0.37 Mio Mg were used as a filler in other materials and 0.79 Mio Mg as a return material. It follows from the data presented that about 20% of the produced mass of steelmaking slag were not utilized in Germany in 2003 [15].

In Poland the main problem is exploitation and processing of materials from a dump in Pleszów near Cracow, where over 20 Mio Mg of steelmaking and blast furnace slag along with about 15 Mio Mg of other production wastes have been disposed. Over 2.2 Mio Mg of aggregate were obtained as a result of magnetic separation of slag from the dump in 2000. It was about 10% of the volume of aggregates used at this time. Aggregates of the grain size up to 63 mm are obtained from blast furnace slag. The grain size of the aggregate manufactured from converter slag does not exceed 31,5 mm. Converter slag requires 12 months ageing time. This time covers the time of storage in a slag dump, aggregate production and storage. The obtained aggregates are intended for road construction [16].

To sum up the above presented examples it can be said that the use of mechanical processing of converter slag in combination with magnetic separation depends on the possibilities of utilization of the obtained non-metallic fraction for road construction, in the construction material industry, for construction of flood banks and dams and in a restricted scope in the blast furnace process. This fraction should not be used as a Ca-Mg fertilizer due to contamination with heavy metals. The metallic fraction obtained at the same time can be used as a charge material in metallurgical processes. The metallic fraction obtained as a result of magnetic separation is very fine and contaminated with non-metallic particles. Therefore the use of this fraction as a charge material in steelmaking processes is limited. If higher additions of the metallic fraction are used in the charge, it should be briquetted first. It is also desirable to dispose of as much as possible non-metallic particles.

3.2. Use of the INMETCO method for metallic fraction processing

The INMETCO direct reduction process was used in a laboratory and in a pilot plant in the mid 70's in Canada. As a result of the process chromium and nickel were recovered from metallurgical wastes formed at production of alloyed steels. In 1978 the INMETCO method was used in Germany, where a pilot installation was built. The installation enabled processing of dusts, sludge, oiled scales and the metallic fraction separated from slag [17-21].

In the INMETCO process metallurgical wastes are reduced in a rotating hearth furnace at the temperature of 1250°C. Carbon containing pellets constitute the charge material. As a result of the process iron sponge is obtained, which later is processed in an electric furnace into a low phosphorus hot metal intended for converter plants. Also such metals as zinc, lead and cadmium are separated in the process in the form of secondary dusts. The above mentioned metals can be recovered from the dusts in suitable metallurgical processes.

Up to 300000 Mg of metallurgical wastes can be processed into 175000 Mg of hot metal in the INMETCO installation annually. The process can be restricted to obtaining of iron sponge in a rotating hearth furnace, which is subjected to briquetting. The briquettes obtained are intended for the blast furnace process or converter plants.

Pellets are manufactured in the INMETCO process in a disk pelletizer from a mixture containing fine oxide materials, pulverised coal and a small amount of binding substances. Next the pellets are transferred into a rotating hearth furnace fired with gas burners. The flue gas flows in a direction opposite to the hearth rotation so that heat is exchanged with the pellets in the counter-current. The process is carried out so as to heating and reduction zones form in the material. Pellets in the heating zone are heated to the reduction temperature. At the reduction temperature carbon contained in the pellets reacts with ferrous oxide and other metal oxides. The course of reduction in the pellet layer and in the pellets is controlled by a micro-atmosphere with a high CO content, which separates the pellet layer from the furnace atmosphere and thus prevents re-oxidizing of the pellets.

The process is carried out at the temperature of 1100-1350°C. Iron oxides contained in the pellets undergo reduction in 92% in 10-14 minutes. The carbon content in the obtained iron sponge depends on the carbon content in the pellets. An important feature of the INMETCO method is the possibility of carbon content control in the iron sponge within the range 1.5-10%, which enables to obtain hot metal containing 6-7% of carbon.

During production of the iron sponge also zinc, lead and cadmium are reduced and alkalis, chlorides and fluorides are partially evaporated. The reduced heavy metals evaporate in the off gas stream and there they re-oxidise. The forming secondary dust precipitates in filters. Metals contained in the dust concentrate can be obtained with metallurgical methods.

The iron sponge is processed into hot metal by direct melting in an electric furnace at the temperature about 900°C without air contact. Non-metal components, ash introduced by coal and sulphur under reductive conditions pass into the slag, chemical composition of which corresponds to the typical blast furnace slag.

The iron sponge is continuously added to the slag melt in the furnace from the top through loading pipes. Slag foaming caused by residual reduction of the iron sponge causes maintaining of the pellets in the slag and metallurgical reactions occurring first in the pellets and than with the involvement of the slag. At that time the reduced iron is carbonised with carbon which is excessive in pellets. This leads to reduction of the melting temperature, fast dissolution and results in distribution of phases. Tapping of

the hot metal and slag is performed in a non-continuous manner. Flue gases with a high CO content are collected, cleaned and then supplied to the rotating furnace as an energy carrier.

The iron sponge can be melted also in typical facilities for steel melting. To this end blast furnaces, basic oxygen furnaces and electric arc furnaces can be used. The iron sponge should be hot briquetted for storage and transportation so that the required strength is obtained and re-oxidising is prevented. Due to the strength requirements the carbon content in the iron sponge intended for hot pressing should be 1.5-2.0%.

Steelmaking slags cannot be directly processed with the INMETCO method, only the metallic fraction separated from the slags. The non-metallic fraction separated magnetically can be used for road construction, manufacturing of construction materials and in the blast furnace process. However methods of utilization of slag forming at hot metal melting in an electric arc furnace should be sought.

4. The converter slag reduction process in an electric arc furnace

4.1. Research in the world

The first trials of converter slag reduction in an electric arc furnace were carried out in Japan in 1979. The reduction process proceeded at the temperature of 1800°C and began from the intense and short-lived foaming of the slag under reduction. The heats carried out resulted in metallic and non-metallic phases. Based on the research carried out it was found that the non-metallic phase can be utilised as clinker for Portland cement production. To this end it is necessary to run the process for 15 minutes as of the moment the foaming ends and to quench it with compressed air while tapping to stabilize the $\beta 2\text{CaO}\cdot\text{SiO}_2$ allotropic form in the non-metallic phase. If there is no quenching the allotropic transformation of the $\beta 2\text{CaO}\cdot\text{SiO}_2$ form into the γ form can occur resulting in increase in volume, the phase disintegrates autogenously and loses its binding qualities.

The obtained non-metallic phase was utilized for production of Portland cement. The final adjustment of the chemical composition of the obtained phase was made in a muffle furnace using CaO or SiO₂ additions. The metallic phase was utilized in converter processes [22].

Information about erection of a slag processing plant with the annual capacity of 250000 Mg planned by the Belgian GBR group was realised in 1984. Converter slag was to be processed by reduction in an electric arc furnace of 2 Mg capacity. Based on the tests it was found that it was possible to obtain clinker from the mixture of converter slag and alumina carriers added to lower the temperature of the process. The investment costs were assessed at about 1 billion Belgian franks. The expected production costs were estimated at 506 million Belgian franks. The costs covered first and foremost the costs of electricity (61%), costs of raw materials (13%) and

remuneration. The depreciation period was provided for 5 years [23]. However there is no further information on the planned investment in available sources.

Trials of reduction of converter slag mixed with graphite reducer were also carried out in an induction furnace in China in 2003. The reduction process was carried out at the temperature of 1650 and 1800°C in a graphite crucible. As a result of the process iron and manganese were reduced to very small amounts. The phosphorus content was reduced by 95.5%, 62.7% of which was reduced to the metallic phase and the balance constituted evaporation losses. It was also observed that free CaO reacted with carbon at the temperature of 1800°C producing carbide CaC_2 [24].

It is a disadvantage of the abovementioned methods of converter slag processing that the process is aimed mainly at production of Portland clinker. With fluctuating slag chemical composition it is possible that the desired chemical and mineralogical composition and clinker characteristics are not obtained. Therefore it is necessary to adjust the chemical composition of the obtained non-metallic phase by lime addition.

4.2. Own research of the author

The trials presented constituted the premise for carrying out tests on the converter slag reduction process. The aim of the tests was to determine the scope of chemical composition adjustments to the obtained non-metallic phase intended for Portland clinker as well as to determine the conditions of the reduction process when utilizing it as the Ca-Mg fertilizer [25-28].

The research was carried out under laboratory conditions in a single-electrode electric arc furnace. Ground converter slag blended with a ground graphite electrode were subjected to the reduction process in a graphite crucible. The mass of slag was 1000g, the mass of reducer was 40g. In order to increase the CaO content in the obtained non-metallic phase also heats with pure CaO added to the charge in the amount of 20g were made [25-26]. Suitability of the obtained non-metallic phase as a Ca-Mg fertilizer was assessed on the basis of a test were 5000g of slag mixed with 250 g of reducer was subjected to the reduction process. The percentage of the reducer was increased to obtain a higher degree of reduction. [27]. During laboratory tests no quenching was applied. The obtained material was taken out of the crucible after several hours, after it had cooled down slowly.

The findings were verified on the basis of a heat under industrial conditions made in an electric arc furnace. The furnace had the nominal capacity of 7.5 Mg, magnesia bricks lining and the working layer were made of burned dolomite. Reduction of 2 Mg of converter slag had been planned. 500 kg of converter slag divided into 5 portions supplied onto a 4 Mg melt were subjected to the reduction process. Each portion was mixed with 6 kg of ground carburite. After the melting period the slag had been removed and the melt had been deoxidised with ferrosilicon, three portions of slag were supplied. After 15 minutes the 4th portion of slag was added and after next 10 minutes the 5th one. The process carried out at the temperature of 1700°C was terminated after 10 minutes as of the addition of the last portion even though the slag foaming had

not been finished yet and the planned mass had not been added. It was caused by a concern about complete local destruction of the refractory lining [28]. The findings of these tests are presented in tables 1 and 2.

TABLE 1
Findings of chemical composition tests of the non-metallic phase obtained under laboratory conditions

No	Material	Mass[g]	Chemical composition [%]										
			C	CaO _c	CaO _w	SiO ₂	MgO	FeO	MnO	Cr ₂ O ₃	Al ₂ O ₃	P ₂ O ₅	ΣS
1	Converter slag	1000 5000	—	44.50	1.68	16.63	5.26	23.25	5.40	0.16	1.68	1.24	0.11
2	Phase 1	561.1	0.27	61.50	1.82	23.21	5.19	3.01	4.13	—	1.40	0.83	0.12
3	Phase 2	568.0	0.28	62.63	2.55	22.28	2.91	4.51	3.78	—	1.96	0.74	0.12
4	Phase 3	1715.9	0.44÷ 0.48	62.60÷ 63.40	1.90÷ 2.32	23.00÷ 29.20	2.03÷ 2.57	0.56÷ 5.13	0.58÷ 2.06	0.016÷ 0.064	1.62÷ 1.66	0.05÷ 0.016	0.09

Phase 1 – without CaO addition

Phase 2 – with addition of 20 g CaO

Phase 3 – Ca-Mg fertilizer

TABLE 2
Findings of chemical composition tests of the non-metallic phase obtained under industrial conditions

No	Material	Chemical composition [%]										
		C	CaO _c	SiO ₂	MgO	FeO	Fe ₂ O ₃	MnO	Cr ₂ O ₃	Al ₂ O ₃	P ₂ O ₅	ΣS
1	Portland clinker	—	63÷67	21÷24	Max 5	—	2÷4	—	—	4÷7	—	Max 1.5
Research in Japan												
2	Converter slag	—	50.4	15.3	2.01	16.3 Fe	5.21	—	1.00	2.28	—	—
3	Non-metallic phase	5.93	68.3	19.8	0.84	0.45 Fe	0.20	—	1.36	0.44	—	—
Research in Belgium												
4	Converter slag	—	46.4	12.9	3.0	21.9 6.4	5.7	0.1 Cr	0.9	2.0	0.1 SO ₃	—
5	Non-metallic phase	—	53.2	21.4	4.9	3.2 Fe	2.2	—	11.1	0.7	0.1	—
Own research of the author												
6	Converter slag	—	41.53	14.62	5.13	22.39	6.43	6.70	0.87	1.04	0.82	0,08
7	Non-metallic phase	0.17	52.51	21.34	6.85	6.22	4.48	4.84	0.48	1.67	0.53	0.16

Based on the tests carried out in a single-electrode electric arc furnace it was found that a non-metallic phase not undergoing autogenous disintegration could be obtained at slow cooling if its phosphorus content did not exceed 0.3% molar concentration. This phase could be utilized as Portland clinker after adding CaO to the charge in the amount of about 2% of the converter slag mass. This would cause increase in CaO content in the non-metallic phase by over 1%. At the same time the SiO₂ content would decrease by about 1%. The mineralogical composition of the obtained phase changed along with its chemical composition. The alite 3CaOSiO₂ content increased and the belite 2CaOSiO₂ content decreased [26].

If the non-metallic phase is intended to be utilized as a Ca-Mg fertilizer it is necessary to obtain the slag reduction rate over 21% and the P_2O_5 content under 0.3% molar concentration. Under this conditions a non-metallic phase undergoing autogenous disintegration as a result of transformation of the $\beta CaOSiO_2$ into the γ form can be obtained. About 70% of the fraction under 0.5 mm grain size is suitable for soil liming. Coarser fractions contained too much of iron oxides, even up to 10%. This prevents use of these fractions as a fertilizer due to the relatively high iron content in domestic soils [27].

The non-metallic phase under industrial conditions was stored for 48 hours in a box. 46 kg underwent autogenous disintegration. It constituted about 10% of the mass of the non-metallic phase. The relatively high mass of the non-metallic phase resulted from high wear of the refractory lining in the process which was estimated as twice as high as the usual wear and tear. The usual wear and tear of such a lining during steel melting does not exceed 44kg/Mg.

The chemical composition of the non-metallic phase not undergoing autogenous disintegration was similar to the chemical composition of the clinker manufactured in accordance with the Belgian method [23]. The same CaO and SiO_2 contents were obtained and the MgO content higher by about 2% was obtained which resulted from high wear of the refractory lining. The iron and manganese oxide content was twice as high due to earlier termination of the reduction process. At the same time the Al_2O_3 content was lower by about 10% which improved clinker characteristics.

By comparing the chemical composition of the obtained non-metallic phase with the chemical composition of the phase obtained in Japan [22] it was found that much lower CaO and MgO content had been obtained. At the same time higher iron and manganese oxide contents had been obtained. The differences had been caused by higher CaO content in the slag reduced in Japan and by carrying out the reduction process in Japan for 15 minutes after the end of the slag foaming.

The test performed under industrial conditions allowed to state that the converter slag reduction process could be carried out in a classic EAF on condition that the charge material was added in portions. In the case of a single addition it was necessary to increase the furnace height due to intensive foaming of the slag during reduction. It was also necessary to replace a basic lining with a graphite one because of its earlier wear. If the non-metallic phase was intended for Portland clinker, quenching with compressed air or water while tapping was necessary to stabilize the $\beta 2CaOSiO_2$ form and to obtain the non-metallic phase not disintegrating autogenously. Also calcium should be added to the charge to increase the CaO content in the resulting non-metallic phase or it should be added during the cement production.

5. Summary

100% of the blast furnace slag and up to 85% of the steelmaking slag are utilized in the world. Therefore new methods of utilization of steelmaking slag are sought. Trials of converter slag reduction in an electric arc furnace can be counted among the new methods.

Trials of converter slag reduction in an electric arc furnace were carried out in Japan and Belgium in 1979 and 1984 respectively. In 2003 research on the converter slag reduction process in an induction furnace was carried out in China. The research enabled to determine conditions of the process performance and utilisation of the resulting metallic and non-metallic phases. The obtained phase can be utilized for production of Portland cement. To this end it is necessary to carry out reduction for 15 minutes as of the end of intensive foaming of the slag occurring at the beginning of the process. The obtained material should be subjected to intensive quenching so that it does not disintegrate autogenously and binding properties are not lost.

It is a disadvantage of the abovementioned methods of converter slag processing that the process is aimed mainly at the production of Portland clinker. With highly fluctuating chemical composition of slag it is possible that the desired chemical and mineralogical composition of the non-metallic phase are not obtained. In this case it is necessary to adjust the composition by lime addition. Therefore own research under laboratory and industrial conditions was carried out. The aim of the tests was to determine the scope of chemical composition adjustments to the obtained non-metallic phase intended for Portland clinker as well as to determine the conditions of the reduction process when utilizing it as a Ca-Mg fertilizer.

Based on the research performed it was found that the resulting non-metallic phase could be utilized as Portland clinker after adding CaO in the amount of about 2% of the mass of converter slag. The CaO could be added as a charge material before starting the reduction process. If the non-metallic phase was intended to be utilized as a Ca-Mg fertilizer it was necessary to obtain the slag reduction rate over 21%. About 70% of the fraction under 0.5 mm grain size was suitable for soil liming.

REFERENCES

- [1] R. T. J o n e s, Economic and environmentally beneficial of slags in DC arc furnace. VII International Conference on Molten Slags, Fluxes and Salts, 363-376. The South African Institute of Mining and Metallurgy, 2004.
- [2] R. H i l t u n e n, A. H i l t u n e n, Environmental aspects of the utilization of steel industry slags. VII International Conference on Molten Slags, Fluxes and Salts, 357-361. The South African Institute of Mining and Metallurgy, 2004.
- [3] Wykorzystanie żużła konwertorowego z Huty Katowice w procesie spiekania. IMŻ report No 2698/82

- [4] H. Nashiwa, T. Mizuno, J. Ohi, K. Katohgi, Effective use of returned LD slag and dolomite and operation with sublance system, *Ironmaking Steelmaking* **5**, 3, 95-102 (1978).
- [5] M. Kruciński, J. Starczewski, M. Dziarmagowski, A. Michaliszyn, Wykorzystanie stałego żużła konwertorowego w tlenowym procesie konwertorowym, *Hutnik* **60**, 2, 51-53 (1984).
- [6] M. Dziarmagowski, M. Kruciński, W. Białowas, J. Okoń, Wytapianie stali w elektrycznych piecach łukowych o dużej pojemności z wykorzystaniem stałego żużła konwertorowego we wsadzie, *Hutnik* **60**, 10, 361-363 (1984).
- [7] M. Dziarmagowski, M. Karbowniczek, Ocena możliwości dotychczas stosowanej technologii wytapiania stali ze świeżeniem rudą w elektrycznych piecach łukowych, *Oszczędność Energii i Materiałów w Hutnictwie 121-131*, II Krajowa Konferencja Elektrotermii, Wisła 1984.
- [8] M. Dziarmagowski, M. Karbowniczek, Możliwości nowej technologii wytapiania stali w piecach łukowych dużej pojemności, *Wiadomości Hutnicze* **42**, 5, 83-86 (1986).
- [9] M. Kruciński, Z. Wcisło, M. Dziarmagowski, J. Okoń, Możliwości stosowania tanich materiałów żużlotwórczych i nawęglających we wsadzie dla elektrycznych pieców łukowych, *Hutnik LVI*, 6, 208-211 (1989).
- [10] R. Dippenaar, Industrial uses of slag – The use and re-use of iron and steelmaking slags, VII International Conference on Molten Slags, Fluxes and Salts 57-69. The South African Institute of Mining and Metallurgy, 2004.
- [11] H.G. Li, H. Suito, M. Tokuda, Thermodynamic analysis of slag recycling using a slag regenerator, *ISIJ International* **35**, 9, 1079-1088 (1995).
- [12] E. Aukrust, Trends in steel developments and their impact on ferroalloy production, *Iron and Steelmaker* **14**, 4, 22-27 (1987).
- [13] D.E. Jones, S.J. Murrie, Utilisation of steelplant slag products in Australia. Recycling in The Steel Industry, 1st Process Technology Conference, vol. 1, Washington D.C., USA, 146-157 (1980).
- [14] Slag Utilization VAI – Technology Voest Alpine, Linz, 1992.
- [15] Report des FEhs – Instituts, 1/2004, www.fehs.de.
- [16] Informator Techniczny Slag Recycling, Kraków, October 2003.
- [17] J.K. Pargeter, H.J. Lehmkühler, Recycling of waste and flue dust from the steel industry using the Inmetco – Process, Process 44 th Electric Steelmaking Conference, ISS – AIME, 403-408 Dallas, USA, (1986).
- [18] Jahrestagung 1987 der Eisenhütte Südwest, *Stahl und Eisen* **107**, 14/15, 663-666 (1987).
- [19] Jahrestagung 1988 der Eisenhütte Südwest, *Stahl und Eisen* **108**, 11, 523-526 (1988).
- [20] K. Grebe, G. Grütznier, H.J. Lehmkühler, H. Schmauch, Die Metallurgie der Direktreduktion von Hüttenreststoffen nach dem Inmetco-Verfahren, *Stahl und Eisen* **110**, 7, 99-106 (1990).
- [21] Werkstoffe aus Hütten – Reststoffen; INMETCO Direkreduktion, DST Demag Steelplant Technology, Duisburg, 1992.
- [22] T. Kubodera, R. Koyama, R. Ando, R. Kondō, An approach to the full utilization of LD slag, *Transactions of The Iron and Steel Institute of Japan* **19**, 7, 419-427 (1979).

- [23] J. Piret, A. Dralants, Verwertung von LD – Schlacke zur Erzeugung von Portlandzementklinker und Roheisen, Stahl und Eisen **104**, 16, 774-778 (1984).
- [24] G. Li, F. Zhang, L. Zhang, Z. Sui, Recycle of converter slag by high temperature carbon thermal reduction, Journal of Materials and Metallurgy **2**, 3, 167-172 (2003).
- [25] M. Dziarmagowski, Investigations on the reduction level of the converter slag during its melting in an electric arc furnace, Archives of Metallurgy **47**, 3, 287-295 (2002).
- [26] M. Dziarmagowski, Assessment of properties of non-metallic phase obtained during the converter slag reduction process, Archives of Metallurgy **48**, 2, 201-207 (2003).
- [27] M. Dziarmagowski, The assessment of suitability of the non-metallic phase obtained from the converter slag for soil fertilisation, Archives of Metallurgy **49**, 1, 73-81 (2004).
- [28] M. Dziarmagowski, Investigation on the converter slag reduction, Archives of Metallurgy and Materials **49**, 3, 695-700 (2004).

KBN, grant nr 4T08B02825

Received: 20 September 2004.