

Eeva-Liisa Pisilä

**DEVELOPING PRACTICES FOR PROTECTIVE SAND IN SLAG
POTS**

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Eeva-Liisa Pisilä
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ABSTRACT

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Author: Eeva-Liisa Pisilä

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Supervisors: Simo Isokääntä, Tauno Jokinen

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This thesis was commissioned by SSAB Merox. The object of the thesis was to study and develop the practices related to protecting the slag pots with the protective sand in the Raahe steel plant. The desulphurisation slag and ladle slag pots are cooled off for couple of days and the LD slag pots are emptied right away when produced. The purpose of the thesis was to do a literature study about the usage of the protective sand globally. Additionally a testing period was to be carried out with the possible new materials found from the literature and with the materials that have already been in use at Raahe steel plant, the natural sand and the LD slag.

The literature study was done by searching information from internet databases and books found in the library of the Raahe steel plant. The protective sand was not mentioned in the literature found in the study. There were no internal reports about the subject. The information of the usage in the other steel plants of the SSAB was gathered by interviews. Since new materials were not found, the natural sand and the LD slag were decided to be tested with different amounts. The follow-up of the tests was conducted by gathering the data about how well the pots emptied, observing the emptying of the pots and interviewing the slag pot carrier truck drivers.

As the result of the tests it was noticed that the desulphurisation slag and ladle slag pots emptied well with both materials and even with smaller amounts. The amount of the protective sand in these pots could be reduced to at least 400 kg. The LD slag pots instead had problems even with larger amounts of the protective sand. Because of the impreciseness of the test results it is hard to determine which material was the absolute best. The amount of the protective sand in LD slag pots might need to be increased. The functionality of the sanding station in which the slag pots are fed with the protective sand should be reviewed and the feeding of the sand should be developed.

Keywords: Slag pot, protection, slags, LD slag, natural sand, melting shop

PREFACE

Nöyrimmät kiitokset kaikille niille tahoille, jotka ovat osaltaan olleet työssäni mukana.

Kiitän tuesta ja neuvoista työni ohjaajia yliopettaja Tauno Jokista sekä kehityspäällikkö Simo Isokääntää. Kielenohjauksesta kiitän lehtoreita Elina Bergrothia sekä Tuija Juntusta.

Eriyiskiitokset koko Meroxin porukalle kannustuksesta ja avusta. Kanssanne on ollut kunnia työskennellä.

Haluan myös kiittää siskoani, mummuani ja Teemua kannustuksesta ja tuesta.

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GLOSSARY

Al_2O_3	Aluminium Oxide
CaC_2	Calcium Carbide
CaO	Calcium Oxide
CAS-OB	Secondary metallurgical process in steelmaking, short for Composition Adjustment by Sealed Argon Bubbling – Oxygen blowing
LD-KG	Combined blowing converter with top and bottom blowing, short for Linz-Donawitz and Kawasaki Gas
LD slag	The steel slag from basic oxygen furnace known also as Linz-Donawitz converter
SiO_2	Silicon Dioxide
Skull	A block consist of slag and significant amount of steel or iron
VIU	Value-In-Use, determines the value for the material when it is recirculated to be used instead of virgin materials or purchased materials

1 INTRODUCTION

This thesis is commissioned by SSAB. The objective of the thesis is to study and develop the usage of the protective sand in slag pots used to collect and transport slags produced in the melting shop at Raahé steel works. The melting shop produces different kinds of slags as by-products. These slags are collected separately based on the part of the process they are taken from. The slags are called primary and secondary desulphurisation slags, Linz-Donawitz converter (LD) slag, and ladle slag.

The purpose of the slag is to absorb harmful elements, such as non-metals, sulphur and phosphorus, from iron and steel. Slag also protects the refractory linings against the wearing and prevents steel from oxidising with the atmosphere. When produced, slag is poured to the slag pot and transported to be processed by a special slag pot carrier truck. When being poured, the temperature of the slag is about 1200–1600 °C. There is a chance that steel with the temperature of more than 1600 °C may get in the pot with the slag.

When the empty slag pot is transported to the melting shop, the lime based suspension is sprayed onto the walls of the slag pot and the protective sand is fed to the bottom of it. The function of the lime suspension and the protective sand is to protect the slag pot against the thermal effect of the slag and ease the slag to loosen when poured out. Currently used material is natural sand which was taken back in to use in summer of 2016. Before that used material was crushed LD slag for several years and before that the natural sand and other various slags.

In this thesis it is investigated whether the sand actually has the effect on protecting the slag pot and if it helps loosen the slag when the pot is emptied. It is also investigated if the absence of the sand creates problems with different kinds of slags. Additionally, the functionality of the different protective sand materials is determined, taking into account the behaviour in thermal stress, possible melting, influence on the quality of the end product, and cost efficiency.

The subject of this thesis is not particularly covered in the literature. There are no internal reports, and no thorough research or calculations have been made. The protective sand being relatively big expense to the company, there is a need to determine the most cost efficient and the best working material to be used.

Challenging conditions bring their own problems to the slag pots. The LD slag is dipped instantly when the pot is full thus slag being hot and molten. The desulphurisation and the ladle slag pots are being cooled off in the pots before dipping for couple of days.

The goal of the thesis is to study the protective sand being used globally as well as practices related to the subject in other steel mills. The study is conducted by interviews and literature survey. Additionally, a testing period is carried out including possible alternative materials that could be found in the study. At least the crushed LD slag and the natural sand are tested. If the use of the slag pots without the protective sand proves to be worth trying, a testing period will be carried out.

2 SSAB AND MEROX

SSAB is a global steel company established in Sweden and having production plants in Sweden, Finland, and the US. In Sweden and Finland the iron ore based productions are carried out by the blast furnaces, and in the US the scrap-based production is dealt with electric arc furnaces. The company produces plate, strip and tubular products as well as Advanced High-Strength Steel (AHSS) and Quenched & Tempered Steel (Q&T) products. In total, SSAB has a capacity of approximately 8.8 million tonnes of steel annually. (SSAB in brief. 2017)

SSAB Europe Oy is the division of the SSAB operating on the home market of the Nordic region and selective areas of the continental Europe as well as internationally. With an annual capacity of 4.9 million tonnes of steel, SSAB Europe has its main production sites in Raahe and Hämeenlinna, Finland, and in Borlänge and Luleå, Sweden. The division has approximately 6900 employees and in 2016 the sales were 25,831 million SEK, which covers about 39 percent of the total sales of the SSAB. (SSAB Europe. 2017.)

SSAB Merox AB is a part of the SSAB concern. The purpose of Merox is to add value to SSAB by handling by-products, steel scraps, and wastes respecting the principles of sustainable development and value creation. Merox shares its vision "*a stronger, lighter, and more sustainable world*" (SSAB Europe. 2017.) with SSAB.

As shown in figure 1, according to the strategy of the Merox the most important function is to recycle materials back to the production of the SSAB. Function number two is to sell the materials that SSAB has no use to the external customers. Finally, if materials cannot be recycled or sold outside, they are placed in a landfill or disposed correctly. All the operations are conducted with the excellence and the organisation is highly performing and knowledge-orientated. (Merox company presentation September 2015.)

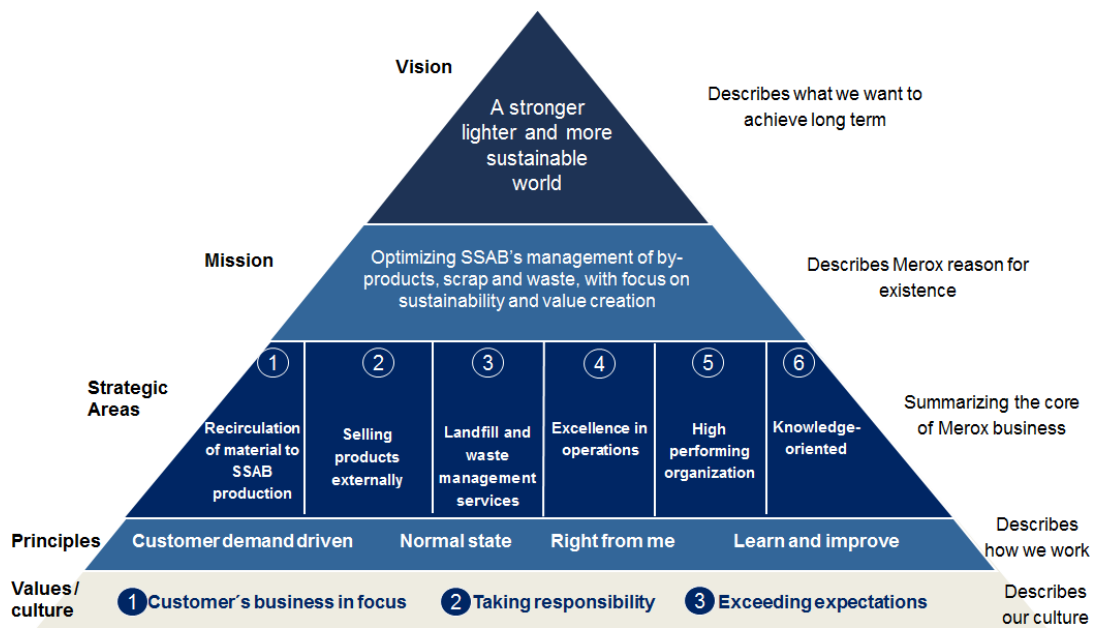


FIGURE 1. The values, strategies, mission and vision of the company form a frame in which Merox operates (Merox company presentation September. 2015)

Merox operates in Finland and Sweden in the areas of research and development, production, marketing and sales. In Sweden Merox operates in Luleå, Oxelösund and Borlänge, and in Finland operation takes place in Raahe and Hämeenlinna. By-products are sold externally in the fields of earthworks and road constructions, soil liming and industrial raw materials. (Merox company presentation. 2015.)

3 STEEL SLAGS

The slag is usually a by-product of the iron and steelmaking process. The main purpose of the slag is to bind the harmful and impure elements such as non-metals, sulphur and phosphorus from the steel. It also works as an insulator between the air and the steel in the ladle thus preventing the oxidation of the steel and protects the refractory linings against wearing. (Holappa, Lauri 2011. 2.)

As shown in figure 2, the slag is produced in the different parts of the process. The slags of the melting shop are produced in primary and secondary desulphurisation processes, converters, and secondary metallurgy processes, including a ladle furnace, a vacuum tank degasser, and CAS-OB stations.

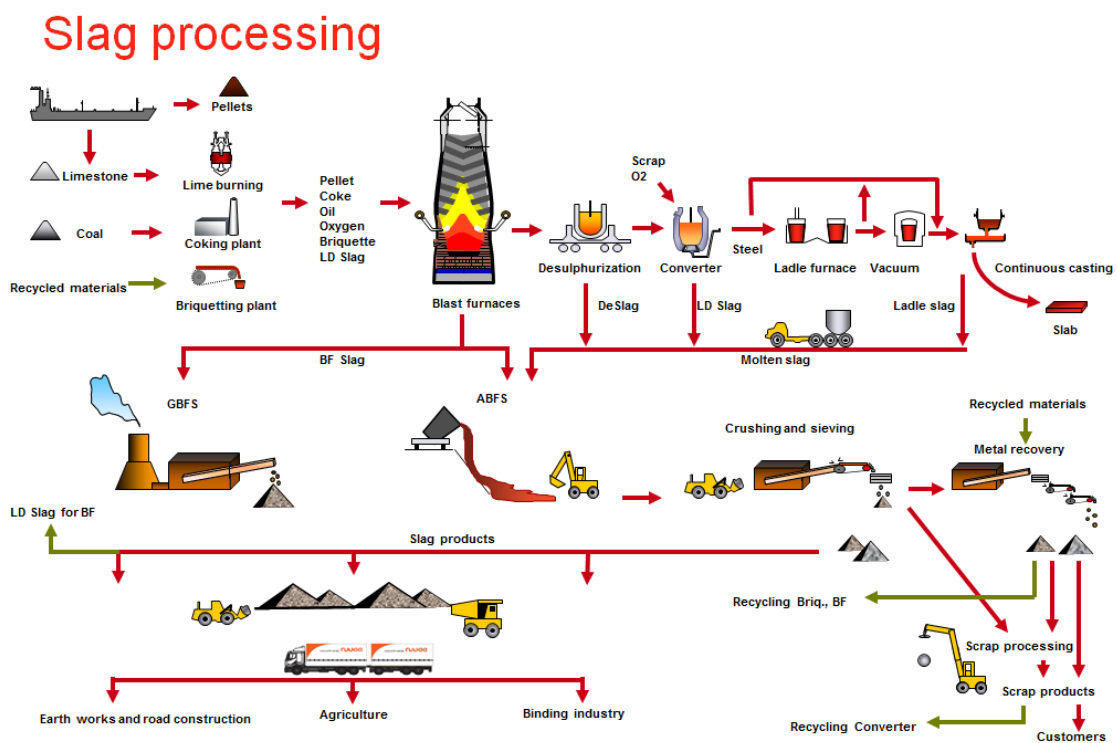


FIGURE 2. The steelmaking process and the processing of the slags (Merox company presentation 2015)

After the raw iron is tapped from the blast furnace it is transported to the melting shop through the desulphurisation station. In the station the raw iron ladles are

treated with the injection of burnt lime (CaO) which works as the reagent in order to remove the sulphur from the iron. This is called the primary desulphurisation process and it is done to all of the raw iron ladles. (Paananen – Ollila – Syrjänen – Mäkikyrö 2011. 19.)

The slag formed in the primary desulphurisation process is removed from the ladles before the raw iron is poured to the mixer which function is to be buffer storage between the continuous working blast furnace process and the batch working converter process. In addition, the mixer balances the composition and temperature of the iron. There are two mixers in the Raahe steel plant with the capacity of 1300 tonnes each. The primary desulphurisation slag is also called mixer slag due to the part of the process it is produced. (Teräskirja. 2014. 29.)

Depending of the desired sulphur level of the steel, some ladles are treated again in the secondary desulphurisation process before the converter. In this process the ladles are injected with a calcium carbide (CaC₂). Secondary desulphurisation slag is also called the desulphurisation slag of the mixers. The primary and secondary desulphurisation slags are mixed during the processing of the slags. (Teräskirja. 2014. 29.)

At the melting shop the raw iron is converted to the steel in the combined blowing converter (LD-KG). There are three converters in Raahe. During the process iron, scrap steel, burnt lime, and fluxing agents are charged into the converter. The main purpose of the process is decarburisation in which the carbon content is decreased from the level of approximately 4–5 percent to less than 0.2 percent by oxygen blowing. (Teräskirja. 2014. 36.)

In the decarburisation process the oxygen is blown through a lance with the velocity over the speed of the sound. At the same time argon gas or nitrogen are blown through the bottom of the converter. The process is controlled by adjusting the height of the lance and by changing the composition of the bottom blown gasses. In decarburisation the carbon monoxide gas forms and therefore the emulsion develops containing molten slag, drops of the iron, and gasses. (Teräskirja. 2014. 36.)

The slag formation process in the converter starts with the oxygen blowing. At first the silicon forms the silicon oxide (SiO_2). Along this the iron and manganese form oxides which assist in the dissolution of the calcium oxide and the slag formation. The amount of the burnt lime is set so the slag is a basic. The basic slag helps the other harmful substances, such as phosphorus and sulphur, to transfer to the slag. After the oxidisation of the silicon carbon starts to burn. When the desired level of the carbon is reached, the blowing is stopped and the steel is tapped. After that the slag is poured to the slag pot from the converter. (Teräskirja. 2014. 36.)

After the converter steel is treated in one or more secondary metallurgical processes. During the processes slag is formed on the surface of the steel ladles.

In the vacuum tank degasser process the unwanted dissolved gasses and elements, such as hydrogen, carbon monoxide, sulphur, oxygen and a bit of nitrogen, are removed from the steel. These elements transfer to the slag or to gas phase. (Stolte 2002. 64–69.)

The CAS-OB process is based on chemical heating in which the temperature of the steel is increased using the exothermic reaction from the oxidisation of the aluminium. In the process the aluminium is added to the ladle through a snorkel and argon and oxygen are blown to the melt. Al_2O_3 formed during the process transfers to the slag. (Stolte 2002. 116–118.)

The ladle furnace is used to raise the temperature of the steel in the ladles when adding the alloying elements. During the process the slag in the surface is melted. In the process harmful elements including sulphur and phosphorus are removed. Removed elements are transferred to the slag. (Stolte 2002. 99. 104. 108–109.)

After secondary metallurgical processes the ladles are transferred to the continuous casting process. There are three continuous casting machines in the Raahe. The steel is flown from the ladle to a tundish through a shroud tube and then from the tundish through a submerged entry nozzle to an air-mist cooled

copper mould (Isokääntä 2017.) When the steel is emptied from the ladle, the remaining slag is poured out to the slag pot. The slag produced in this part of the process is called the ladle slag or the continuous casting slag. (Teräskirja. 2014. 48.)

3.1 Processing slags

Depending of the amount of the slag, slags from one to three blows are tapped to the LD slag pot. When the pot is full, the LD slag is transported to the slag pit and poured. When the desulphurisation and the ladle slag pots are full, they are transported to be cooled off for a couple of days.

The cooling of the desulphurisation slag prevents the calcium rich dust from spreading to surrounding area. Pouring it hot and molten was dangerous because of the flaming of the slag. If the pots were emptied in headwind, the flames caused by oxidising components from the slag could reach the slag pot carrier truck. The LD slag behaves differently when dipped. It is more fluid and it does not flame so it is possible to dip it immediately.

The desulphurisation slags are poured into their own pit and LD slag to its own. Figure 3 shows the area of the dipping pits.



FIGURE 3. The dipping pits for the LD slag and the desulphurisation slags

The ladle slag is poured to its own pit, which is located apart from the pits for the desulphurisation slags and the LD slag. Pit for the ladle slag is shown in figure 4.



FIGURE 4. The dipping pit for the ladle slag

The processing of the slag was also shown in figure 2. Some of the slags are run through a metal recovery station where magnetic part is separated by an electromagnet for future use. Additionally some of the slags are crushed and sieved to desired fractions in the crushing station.

3.2 Usage of slags

The nonmagnetic part of the desulphurisation slags is currently used as a construction material within the factory area. The coarse metallic part of the desulphurisation slags is sold to external customers. The fine magnetic part can be circulated back to the blast furnace as it is or by briquetting it depending on the grain size. About half of the LD slag and the 0–8 mm fraction of the ladle slag are circulated back to the blast furnace where they are used to replace iron pellets and the limestone.

Because of the high calcium content, the ladle slag is used in agriculture as a liming agent. It lightens the soil and raises the pH-value of it. Due to the low amount of the heavy metals the ladle slag is also accepted to be used in the organic farming. (Peltojen kalkitukseen. 2017.)

In the area of earthworks and road constructions, mostly a granulated blast furnace slag (GBFS) and a mixture of the LD slag and the GBFS is used in the

beddings of the roads and buildings. The mixing ratio of the LD/GBFS product is either 30/70 or 50/50. The mixing is done at the mixing station. Due to the good bearing capacity and the heat insulation feature of the product it is possible to build thinner beddings than with the natural aggregates. (Maa- ja tienrakennus. LD-MaHk. 2017.)

4 SLAG POTS

The slag pots are used for the transportation of the slag. They are made of the casted steel EN 20293 GE 240 and there is no lining in the inside walls. The slag pot weighs 21 tonnes when empty and has a maximum safety load of 40 tonnes. Its volume is 11 m³. The slag pot used for the LD slag is shown in figure 5.



FIGURE 5. The slag pot used at the converters as the LD slag pot

When new slag pots are purchased, they are taken to be used in the converters because the conditions there are more demanding. When the pots are used for some time in the converters and they start to show wearing, they are taken to be used as the ladle slag pots. When the pots are starting to be in a bad condition, they are taken to be used as the desulphurisation slag pots. Figure 6 shows the slag pot in use for the desulphurisation slags.



FIGURE 6. The slag pot used at the mixers as the desulphurisation slag pot

Sometimes the slag or metal within the slag adhered to the walls of the pot and it has to be clattered. When clattered, the slag pot carrier truck turns the pot upside down towards the ground and drops it thus the slag and metal come loose. Clattering stresses the pots and it should be kept at minimum. Figure 7 shows the slag pot carrier truck used to transport LD slag pots.



FIGURE 7. The slag pot carrier truck used to transport the LD slag pots

Figure 8 shows different kinds of defects forming in the slag pot. Corners 1 and 2 show cracks probably caused by clattering. In corner 1 is deeper crack and in corner 2 is longer surface crack. Corner 3 shows hollows formed probably by drilling of the skull from the walls. Corner 4 shows skull formation.



FIGURE 8. Different kinds of defects in the slag pot

5 USAGE OF PROTECTIVE SAND

When the empty slag pot is being transported to the melting shop, a lime based suspension and the protective sand are fed to the slag pot. The material currently used is the natural sand in the grain size of 0–10 mm. The current material was taken back to be used in summer of 2016 replacing the LD slag since the blast furnaces demanded the LD slag and the value for recirculating it back to the blast furnaces was higher.

The lime suspension is sprayed onto the walls of the pot in order to protect the walls from slag, steel, and iron. After that, approximately 1000 kg of the protective sand is fed to the bottom of the pot. The function of the sand is to protect the bottom of the pot from slag, steel, and iron and to make the slag come loose more easily when being dipped. The layer of the protective sand in the bottom of the pot also reduces thermal shocks and increases the service life of the pot. The slag pot with the lime suspension and the protective sand is shown in figure 9.



FIGURE 9. The slag pot with the lime suspension and the protective sand

The protective sand is dried and supplied to the silo of the sanding station by Fescon Oy. The sand has to be dried carefully because high moisture in the sand could cause the slag to explode when tapped to the pots. On the other hand, if the moisture would accumulate to the bottom of the pots for example because of the snowing or raining, the protective sand would absorb it thus reducing the possibility and extend of the explode of the tapped slag.

The steel getting into the slag pot is problematic because of its high temperature. The temperature of the steel alternates depending on the part of the process. At the converters the temperature is approximately 1600–1700 °C (Teräskirja. 2014. 36) and at the continuous casting machine 1550 °C (Isokääntä 2017.)

Figure 10 shows result of steel getting into the LD slag pot. The slag pot had to be cooled off and clattered. The protective sand has most likely been melted

because of the high temperature of the steel. The base of the block was almost perfectly rounded which indicates that there has not been the protective sand.



FIGURE 10. A lot of steel was tapped to the slag pot

Sometimes it is known in advance that the significant amount of the steel will get to the pot with the slag. For example when the converter is prepared for relining which is done couple of times in a year. In this situation the lime and the protective sand might not be enough to prevent steel from adhering to the walls. The solution is a so-called shell pot, in which the slag has adhered to the walls of the slag pot. The shell of the slag insulates the heat and prevents the steel from adhering to the walls and breaking the slag pot. The shell pot is shown in figure 11.



FIGURE 11. The shell pot

There are several factors affecting the emptying of the slag pot. Steel might adhere to the walls regardless of the amount or the material of the protective sand since the sand only protects the bottom. Even small amount of the skull forming in the walls of the pot may cause the pot not to empty without clattering it.

The composition of the slag varies depending of the demanded quality of the steel. The quality of the iron affects the blowing practise of the converters thus having effect on the LD slag forming. Sometimes the composition of the LD slag has an effect on the viscosity of the slag making it to stick strictly to the walls.

If the slag does not fall at the centre of the pot when removed or poured to the slag pot but instead flows along the wall to the bottom, the slag might push all the protective sand aside. The fine fraction of the protective sand might be pushed aside when the slag is poured to the pot.

If the pot does not empty at once, some of the slag pot carrier truck drivers wait around ten minutes and then try to dip the slag again. Even the short waiting might cool the pot enough to ease the emptying. Some drivers transport the pot to be cooled for longer time or clatter them right away when it does not empty at once. The clattering of the pots should be kept at minimum. Nevertheless, sometimes there is no time to wait the pot to be cooled for some moment.

5.1 Sanding station

The sanding station was built approximately in 1996. Today the station consist of a silo with the capacity of 70 tonnes, two vibrating conveyors to feed the sand to the pots, a tank for the lime suspension, and a pneumatic spray nozzle to spray the pots with the suspension. The blueprint of the sanding station is shown in figure 12.

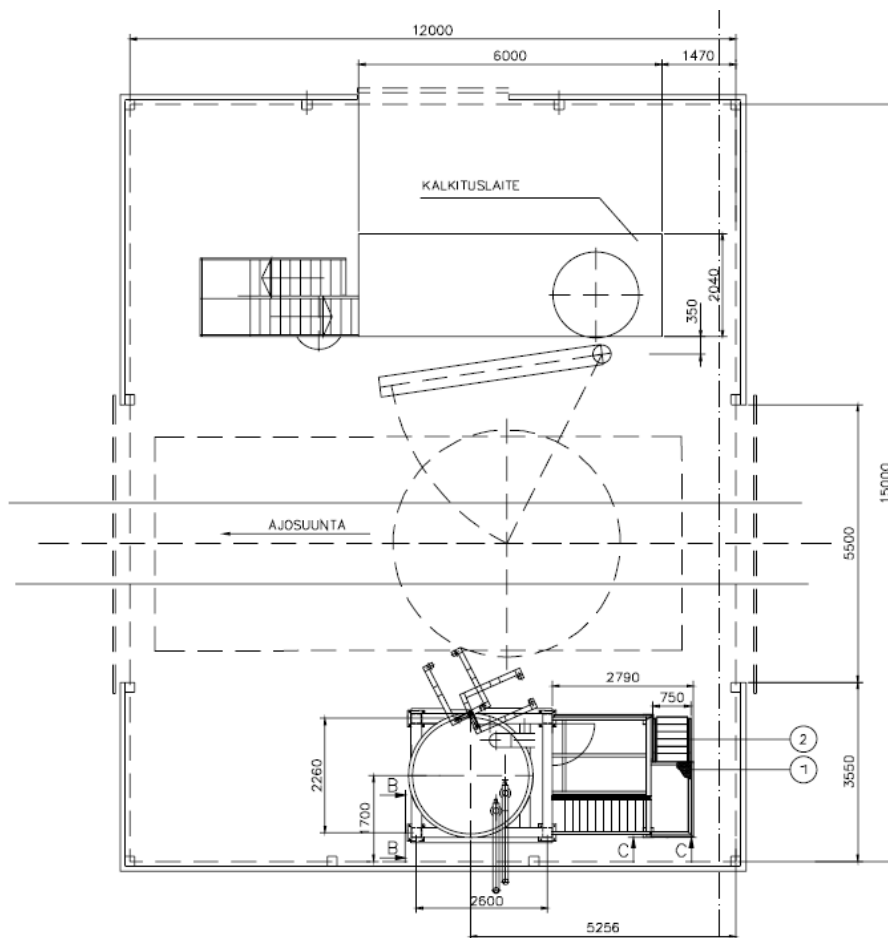


FIGURE 12. The sanding station

The station is operated with the remote control device which turns on the pneumatic pump that operates the nozzle. The nozzle turns above the slag pot and sprays the pot with the lime suspension. After that the nozzle turns away and a chute delivering the sand turns above the pot. When the chute is turning, the vibrating conveyor turns on and the sand starts to run from the chute. The vibration runs for approximately 2.5 minutes, stops, and the chute turns away. Figure 13 shows the slag pot carrier truck in the station. In the left corner is the chute and in the right is the lime nozzle.



FIGURE 13. The slag pot carrier truck in the sanding station

The vibration time is possible to change with the software in the stations. The amount of the sand can also be adjusted by changing the intensity of the vibrations. However, this is rather inaccurate and the changing the amount of the sand requires adjusting the vibrations randomly and weighting the sand until the desired amount is reached. The weight of the sand might differ since the grain size differs.

5.2 History of protective sand

In the beginning of the 1990's there was no protective sand used in the slag pots. Absence of the sand brought problems while dipping the slag. The metal and slag adhered to the walls and bottom of the pots and they had to be repaired often. Also the service life of the pots was shorter. The idea of using the protective sand came from an initiative made by an operator. The material of the very first protective sand was the natural sand in the grain size of 3–6 mm. Being the prime quality and expensive product it was decided to change the material. (Majanen 2017.)

The new materials were a variety of slags and sands that had no use at the time and the costs were low. There were problems with the new materials because the composition of the materials was not good and the sand had too much clay. (Majanen 2017.)

The material of the protective sand was decided to change to the LD slag. The LD slag was used up until the summer of the 2016 when due to the bigger demand for the blast furnaces the material was changed back to the natural sand. The value of the LD slag was calculated to be higher in the blast furnace than in the pots.

5.3 Testing ladle slag as protective sand

In 2014 a test investigating a possibility to use the ladle slag in the LD slag and the ladle slag pots was carried out. At that time there was a fraction of the ladle slag in the grain size of 12–40 mm that had no use. The test was carried out by feeding the ladle slag to the slag pots with a wheel loader. There were five test pots and an intention was to investigate the possible melting of the protective sand and whether the dipping of the slag had any problems. (Projektikortti. 1–2.)

Two of the test pots were LD slag pots. At the first test there was steel in the bottom of the pot and the high temperature of the steel melted the protective sand. Three of the test pots were ladle slag pots. Two of them emptied easily

and without any problems but one had some problems which were not specified in the report. (Projektikortti. 3–13.)

In conclusion, the ladle slag was not an ideal protective material for LD slag pots. In case of the steel getting in to the pots, the protective sand would melt. In case of no steel, the ladle slag would work just fine. For ladle slag pots instead it would be a good choice because of the easy dipping and also for the end products quality. (Projektikortti. 13–14.)

It was noticed that the best solution for the protective sand would be separately put the LD slag to the LD slag pots and the ladle slag to the ladle slag pots. However, it was impossible to use two different protective sands because there was only one silo at the sanding station. (Projektikortti. 13.)

5.4 Usage of protective sand at other mills

The usage of the protective sand at the other steel mills was investigated by searching literature from the library of the Raahе steel works and from the internet databases. The databases used in the thesis were ProQuest and Elsevier ScienceDirect. The information about the protective sand was insufficient but there were articles about protecting the slag pots with the lime suspension and refractory paint. Furthermore, inquire was done about the usage of the protective sand at Luleå and Oxelösund, the other melting shops of the SSAB.

5.4.1 SSAB Luleå

In the melting shop of the Luleå steel plant the LD slag is used as protective sand as well. Approximately 150–200 kg of the LD slag in the grain size of 0–50 mm is used there to ease the slag to come loose from the pot and for protection against the thermal shocks. (Muotka 2017.)

Since starting to use the protective sand, there have not been problems with the steel adhering to the walls of the pots. Furthermore, the slag pots are not cooled off after being filled but instead emptied immediately so the steel has no time to

adhere to the pot. The protective sand is fed to the pots with a radio controlled conveyor belt which is shown in figure 14. (Muotka 2017.)



FIGURE 14. Approximately 150–200 kg of the protective sand is being fed to the melting shop's slag pot in Luleå (Virtala 2017)

Using the slag pots without the protective sand has been tested in Luleå. The absence of the protective sand caused problems for the emptying of the slag pots. The slag shells solidified in the pots and they had to be turned around and let to be cooled thus the slag shells were shrunk and loosened. (Muotka 2017.)

5.4.2 SSAB Oxelösund

In the melting shop of the SSAB steel plant in Oxelösund the dried LD slag is used to protect the pots. The dimension used there is 20–70 mm. Approximately 2–3 m³ or 5–8 tonnes of the LD slag is put to the bottom of the pots. The other materials have not been used. Other fractions of the LD slag instead have been tried. If the grain size was too big the slag or metal would go through it and stick to the walls. (Lindell 2012.)

Earlier a refractory paste was sprayed to the walls of the slag pots but it was given up at 2012 since the benefits were not significant. The testing period was carried for three weeks and no problems were realised. (Lindell 2017.)

In Oxelösund there are hardly any problems with the slag adhering to the walls. The LD slag and the desulphurisation slag are poured right away to the pit but the ladle slag is cooled off for approximately 20 hours. (Lindell 2012.)

5.4.3 Global

In the literature the protective sand is not mentioned. However, the lime suspensions are mentioned in several articles and reports. At the steel plant of the Magnitogorsk Metallurgical Combine the slag pots were sprayed with the lime suspension in order to extend their durability. The spraying was done by automatic system in the production line. The lime suspension was fed to the pots with a nozzle which was operated with a compressed air at the pressure of 3–4 bars. (Siamidi – Ventskovskii – Arapov 1980, 19.)

At the steel plant of the Taganrog Metallurgical Works the slag pots were sprayed with the lime suspension as well. Furthermore, the slag pots were treated with a paint made of the refractory materials. The paint contained fine particles of the refractory substances in grain size less than 0.05 mm, such as powered quartz. (Fomin – Golov – Zvereva – Kochetov – Pishchulin 1978. 25–26.)

In the manual for the slag pots used in the Oxelösund made by CAST-COM Engineering GmbH & Co. it is mentioned that the dried and approximately fist-sized dried slag pieces should be placed on the bottom of the pots before pouring the molten slag to the pot. It is said to protect the pot from the energy shocks of the poured slag and metal. If there is moisture in the pot the dried slag prevents or decreases the explosion of the slag and the reaction between the slag and water. (CCE 169-061-010 / Slaggrytor 14.5 kbm. 2014. 7.)

It is also instructed that the molten slag should be poured directly to the centre of the pot over the dried slag in the bottom. The molten slag should not be let

run along the walls to the bottom. (CCE 169-061-010 / Slaggrytor 14.5 km.
2014. 7.)

6 TESTS

Since new materials were not found in the literature the materials decided to be tested were the natural sand and the LD slag with different amounts. The testing periods are shown in table 1. The tests were conducted during April and May 2017. Since experiences without the protective sand seemed to be mostly negative, it was decided not to do the testing period without it.

TABLE 1. The chosen materials and amounts for the testing periods

The material	Amount per slag pot [kg]	The length of the period
The natural sand	600	One week
The natural sand	400	One week
The LD slag	1000	One week
The LD slag	600	One week
The LD slag	400	One week

6.1 Preparations

For the preparation it was necessary to specify the right set-up for the vibrating conveyor of the sanding station. At first the current set-up was driven twice and the sand portions were fed to the wheel loader which was equipped with a scale. Only one portion of the latter set-ups was driven to the wheel loader. These portions were weighted repeatedly because the impreciseness of the scale in wheel loader. Resolution of the scale on the wheel loader was 50 kg.

In the table 2 are shown the results of the weigh-ins and corresponding values for the vibrators. The first portion weighed 650 kg and the second 500 kg. The big difference for the desired amount of 1000 kg was considered to be explained by the current set-up being set for the LD slag. The specific weight of the LD slag is higher than the one for natural sand. Portions for latter set-ups were weighed couple of times because the scale on the wheel loader gave alternating results.

TABLE 2. Values for the vibrators and corresponding weights with the natural sand

Set value for the first vibrator	Set value for the second vibrator	The weight of the load [kg]
3.4	6.7	650 500
2	5	400 350
1.9	3.5	100 150 150
1.9	4	250 300 250

The adjustments for the LD slag were done when the material was taken into use. The values and corresponding weights are shown in table 3. The adjustments were done by the same way as with the natural sand. The values for the vibrators were set lower and the portions were scaled. With exception, the weigh for the first values of the vibrators was measured by feeding the portion to the slag pot and taking the slag pot to a truck scale. Resolution of the truck scale was 50 kg.

TABLE 3. Values for the vibrators and corresponding weights with the LD slag

Set value for the first vibrator	Set value for the second vibrator	The weight of the load [kg]
3.4	6.7	1050
2	5	700 600 600
1.9	4.5	650 600 500 500
1.9	4	400
1.9	3.8	400 300 300 350

The follow-up of the testing periods was done by gathering the forms filled by the slag pot carrier truck drivers. Additionally, the forms made by the drivers on a daily basis for billing were gathered. The loosening of the slag was evaluated by observing the dipping of the slag and interviewing the truck drivers.

6.2 Natural sand

The natural sand used in the tests was delivered by Fescon Oy. The grain size of the sand was 0–10 mm. The material is shown in figure 15.



FIGURE 15. The natural sand 0–10 mm

Composition of the natural sand in Finland is mostly SiO_2 , approximately 80 percent (Borgström 1924. 3.) The melting point of the material is approximately 1610 °C (Hammond 1993. 4-95.) This means that if the steel from the converter gets to the pot the natural sand might melt.

The downside of using the natural sand is due to its fine fraction. When the slag first hits the bottom of the slag pot, fine fractions might be pushed aside or melt.

6.3 LD slag

The LD slag used in the pots was in the grain size of 8–16 mm. The used fraction of the LD slag is shown in figure 16.



FIGURE 16. The LD slag 8–16 mm

Figure 17 shows the most important elements and calculated their average percentages. According to the analysis, most of the LD slag is CaO.

Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P	S	K ₂ O	CaO	Ti	V	Cr	Mn	Fe
%	%	%	%	%	%	%	%	%	%	%	%	%
XRF	XRF	XRF	XRF	XRF	XRF	XRF	XRF	XRF	XRF	XRF	XRF	XRF
0,08	1,55	1,67	13,90	0,416	0,069	0,074	45,70	0,55	1,85	0,232	2,00	18,3
0,12	1,46	1,79	14,40	0,400	0,075	0,105	47,90	0,53	1,85	0,211	1,90	16,6
0,10	1,58	1,96	15,60	0,405	0,068	0,110	48,60	0,57	1,90	0,265	1,96	18,0
0,08	1,81	1,96	15,00	0,406	0,068	0,083	47,90	0,54	1,83	0,253	1,97	17,3
0,08	1,35	1,81	14,80	0,431	0,066	0,062	47,00	0,51	1,86	0,232	1,87	15,8
0,06	1,75	1,72	13,50	0,397	0,070	0,059	45,90	0,55	1,77	0,244	2,00	18,0
0,07	1,53	1,79	14,20	0,404	0,072	0,065	46,10	0,53	1,79	0,248	1,94	17,4
0,11	1,48	1,90	15,70	0,398	0,062	0,104	46,10	0,57	1,73	0,252	1,91	15,9
0,05	1,71	1,75	12,90	0,438	0,072	0,027	47,40	0,58	1,88	0,244	1,95	17,4
0,06	1,71	1,43	12,60	0,420	0,071	0,039	44,60	0,46	1,69	0,283	1,90	17,7
0,08	1,59	1,78	14,26	0,41	0,07	0,07	46,72	0,54	1,82	0,25	1,94	17,24

FIGURE 17. The most important elements of the LD slag

The estimated melting point of the material can be obtained from the phase diagram. Since the LD slag is mostly CaO, SiO₂ ja Fe, the melting point can be found in the phase diagram for CaO-FeO_x-SiO₂ slags which is shown in figure 18. Fe had to be converted to iron oxide, which gave the percentage of 22,5 for FeO. The melting point of the LD slag is approximately 1700–1800 °C.

CaO-FeO_x-SiO₂

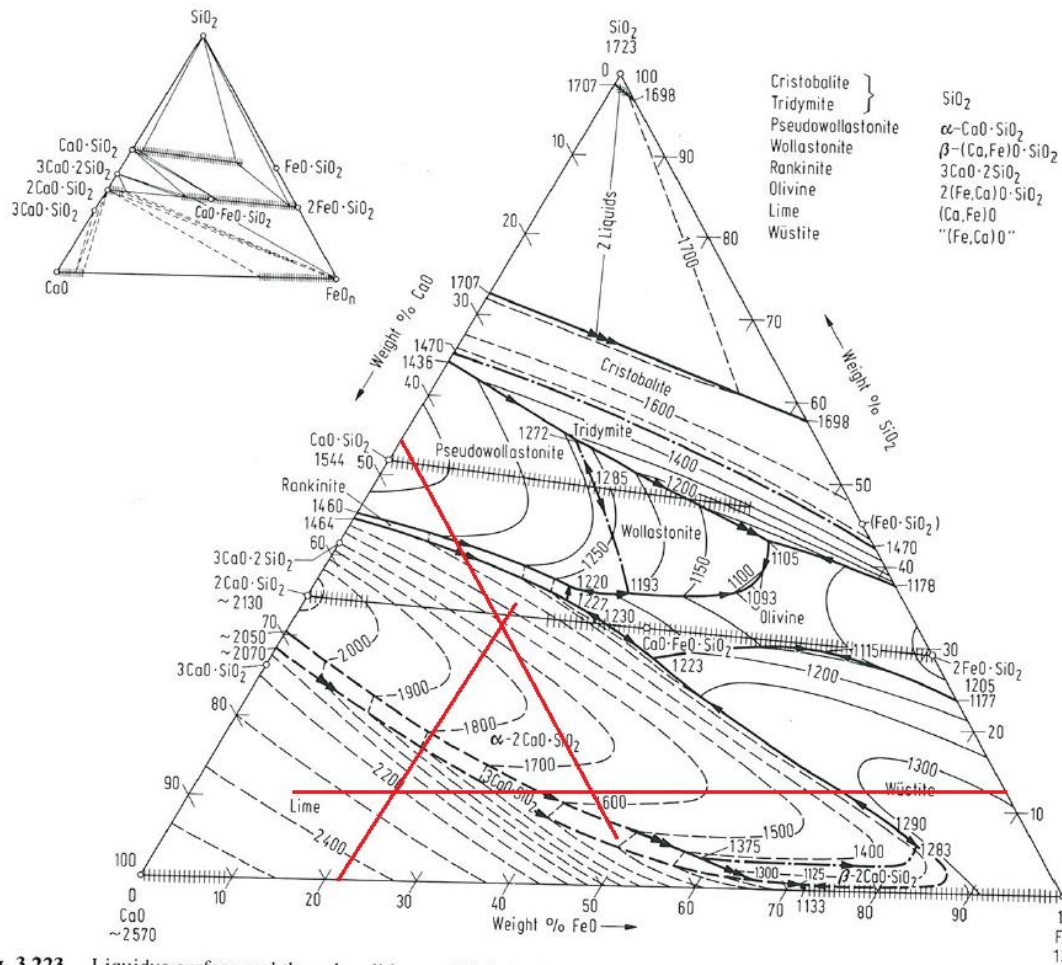


Fig. 3.223. Liquidus surface and the sub-solidus equilibria in the CaO-FeO_n-SiO₂ system as drawn by Osborn, Muan [1] according to experimental results by Bowen et al. [2], Allen, Snow [3], Schenck, Wiesner [4], and Bishop et al. [5]. For Fe₂O₃ contents in melts at liquidus temperatures, see original paper by Bowen et al. [2]. The composition of saturated liquid (between 1450 and 1650 °C) were also investigated by Trömel, Görl [6], Görl et al. [7], and Timucin, Morris [8].

FIGURE 18. The phase diagram for slag consisting mostly CaO, FeO and SiO₂ (Kowalski – Spencer – Neuschütz 1995. 126)

Because of the roughness of the material it was necessary to add a fine fraction of the natural sand with it in order to help the material to be unloaded from the tank truck to the silo of the sanding station. The coarse grain size also brings problems when the material is unloaded to the silo via a hose. Rough pieces erode the hoses and they might burst creating the possibility for bodily injuries.

7 TEST RESULTS AND ANALYSIS

The functionality of the materials was investigated by categorising how well the slag pots were emptied during the testing periods. If the pot did not empty it was defined whether the pot had to be clattered or if the pot was taken back to the melting shop as shell pot. If the pot was emptied successfully at the first dip it was categorised as “emptied at once.” If the pot was let to be cooled for couple of minutes and emptied well after that it was categorised as “emptied at second dip.” If the pot had to let be cooled for a longer time and then emptied it was categorised as “emptied after cooling.”

Additionally, the behaviour in thermal stress was investigated. By following the dippings it was observed if the material melted or if the material was pushed aside while pouring the slag to the pot.

7.1 Natural sand 600 kg

The results of the testing period for 600 kg of natural sand are shown in figure 19. Based on the result there were no problems with emptying the desulphurisation slag pots. Before the cooling of the desulphurisation slag pots there were a lot of need to clatter the pots. The situation with the ladle slag pots was almost as good since approximately 95 % of the ladle slag pots emptied without problems. With the LD slag pots the emptying was not as good. Approximately 85 % of the LD slag pots emptied.

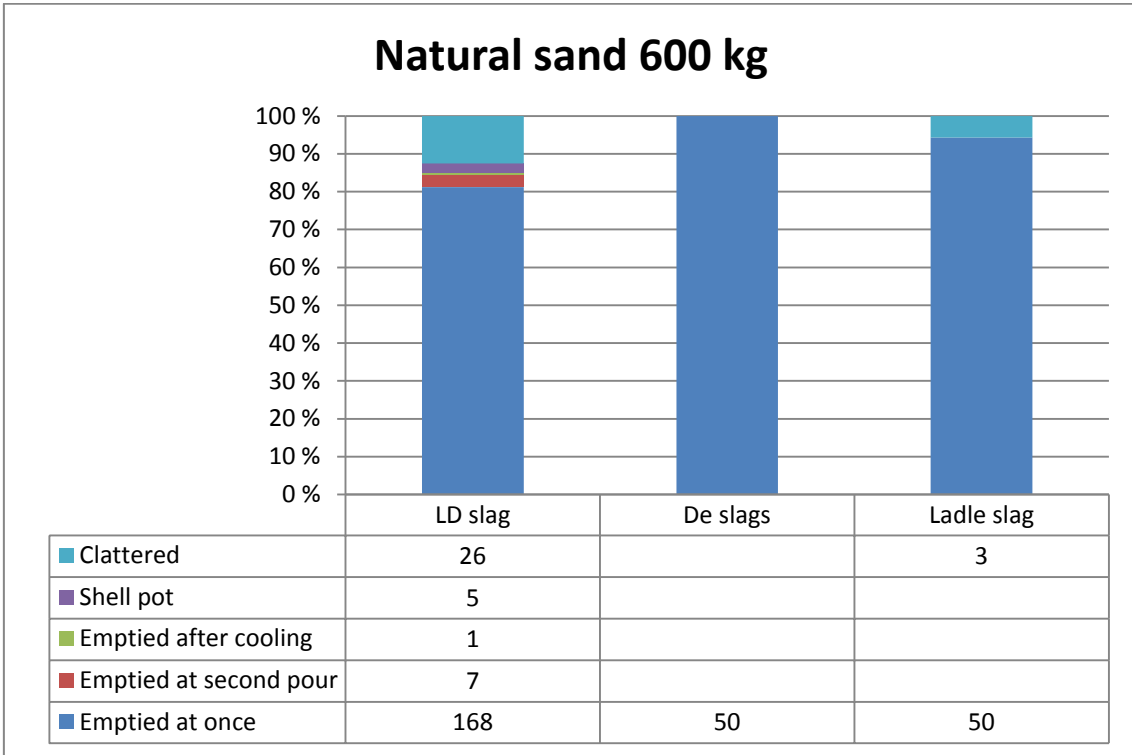


FIGURE 19. Results of the testing period with 600 kg of the natural sand

7.2 Natural sand 400 kg

The results of the testing period with 400 kg of the natural sand are shown in figure 20. All of the desulphurisation slag pots and 95 % of the ladle slag pots emptied. The percentage for emptying was significantly lower for LD slag pots since only 64 percent of the pots emptied.

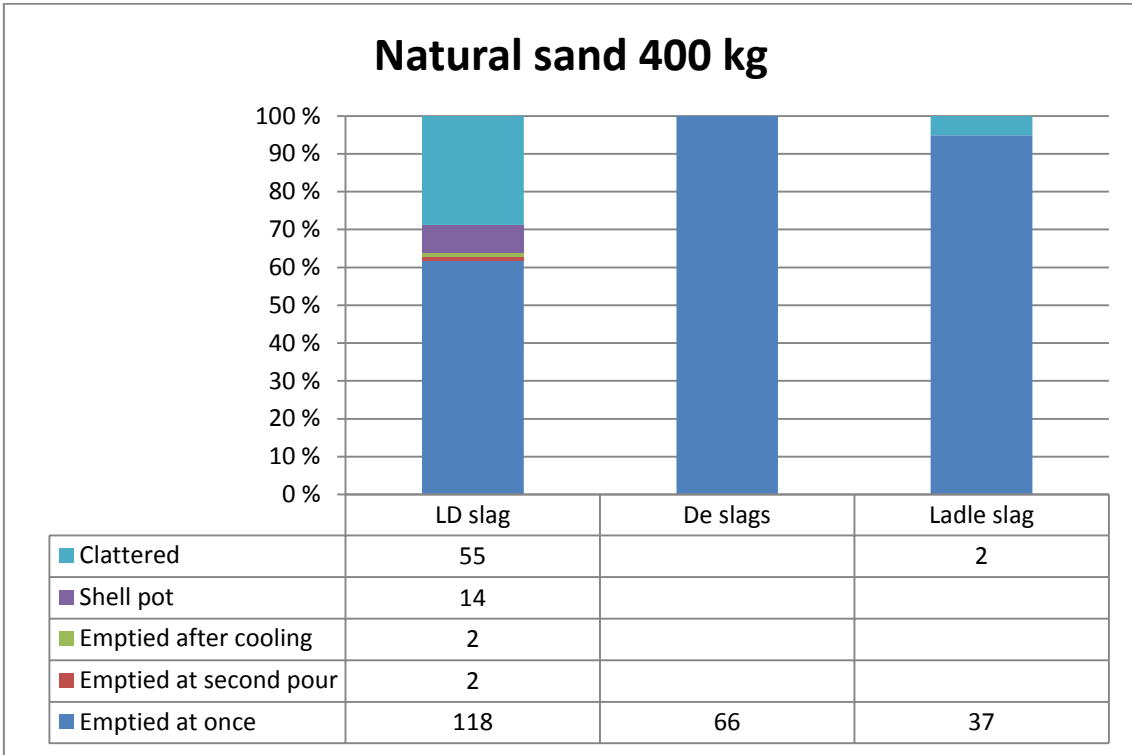


FIGURE 20. Results of the testing period with 400 kg of natural sand

Figure 21 shows round shaped bottoms of the LD slag blocks. It seems that there were no steel within the slag. This indicates that the protective sand has likely been pushed aside when the slag was poured to the pot. However, the absence of the visible natural sand indicates that it has been melted or blended in with the slag.



FIGURE 21. The natural sand has either been melted or pushed aside

Figure 22 shows the desired occurrences with the protective sand in the LD slag pots. The shapes of the bottom of the slag blocks are flat and the natural sand is clearly visible. This indicates that the sand has been in its place and worked as it should. However, all the pots seen in figure 22 had to be clattered, as they did not empty at once.



FIGURE 22. The natural sand stayed at the bottom yet all the pots had to be clattered

Figure 23 shows the occurrences in which the natural sand has been partly pushed aside. The bottoms are almost round and have bit sand in them.



FIGURE 23. Some of the sand has been pushed aside thus the almost round shape

7.3 LD slag 1000 kg

The results of the testing period with 1000 kg of the LD slag are shown in figure 24. All the desulphurisation slag pots and the ladle slag pots emptied. The LD slag pots emptied with the success rate of 79 percent.

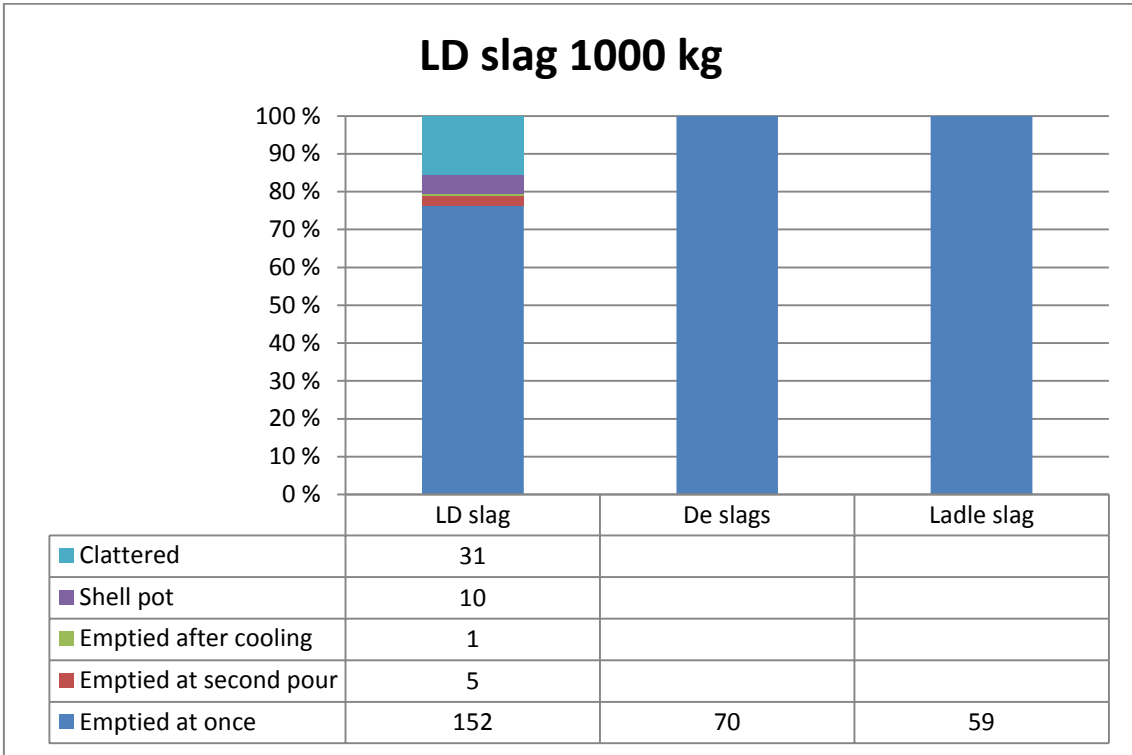


FIGURE 24. Results of the testing period with 1000 kg of the LD slag

Figure 25 shows correctly emptied dippings. The dippings have scattered and there is a lot of LD slag visible.



FIGURE 25. The large amount of the LD slag is clearly visible and pots emptied correctly

Figure 26 shows round shaped bottoms. The LD slag has either been pushed aside or it has been melted. It seemed that there were no steel within the slag.



FIGURE 26. The LD slag has either been melted or pushed aside thus round shape

7.4 LD slag 600 kg

Results of the testing period for 600 kg of LD slag are shown in figure 27. All of the desulphurisation pots and 98 percent of the ladle slag emptied. For the LD slag pots the success rate was not as good since only 67 percent emptied.

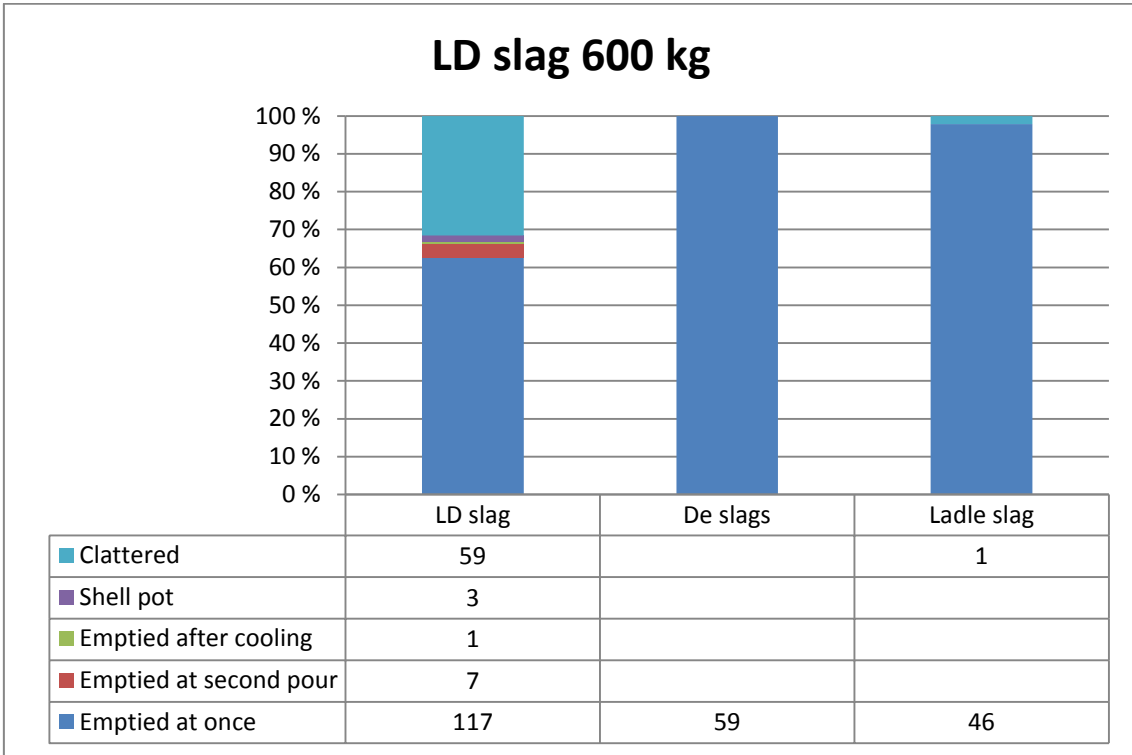


FIGURE 27. Results of the testing period for 600 kg of the LD slag

Figure 28 shows flat shaped dippings which indicated that the LD slag has been in its place. The LD slag and a bit natural sand within it are visible. However, the amount of the protective sand is rather small.



Figure 28. The LD slag stayed at its place in the bottom of the pots

Figure 29 shows the dippings in which the LD slag has been pushed aside. Bottoms are almost round shaped and there is a bit of protective sand visible.



FIGURE 29. Some of the LD slag has been pushed aside

7.5 LD slag 400 kg

Results of the testing period for the LD slag 400 kg are shown in figure 30. Again both the desulphurisation slag and ladle slag pots emptied completely. The LD slag pots emptied with the success rate of 76 percent.

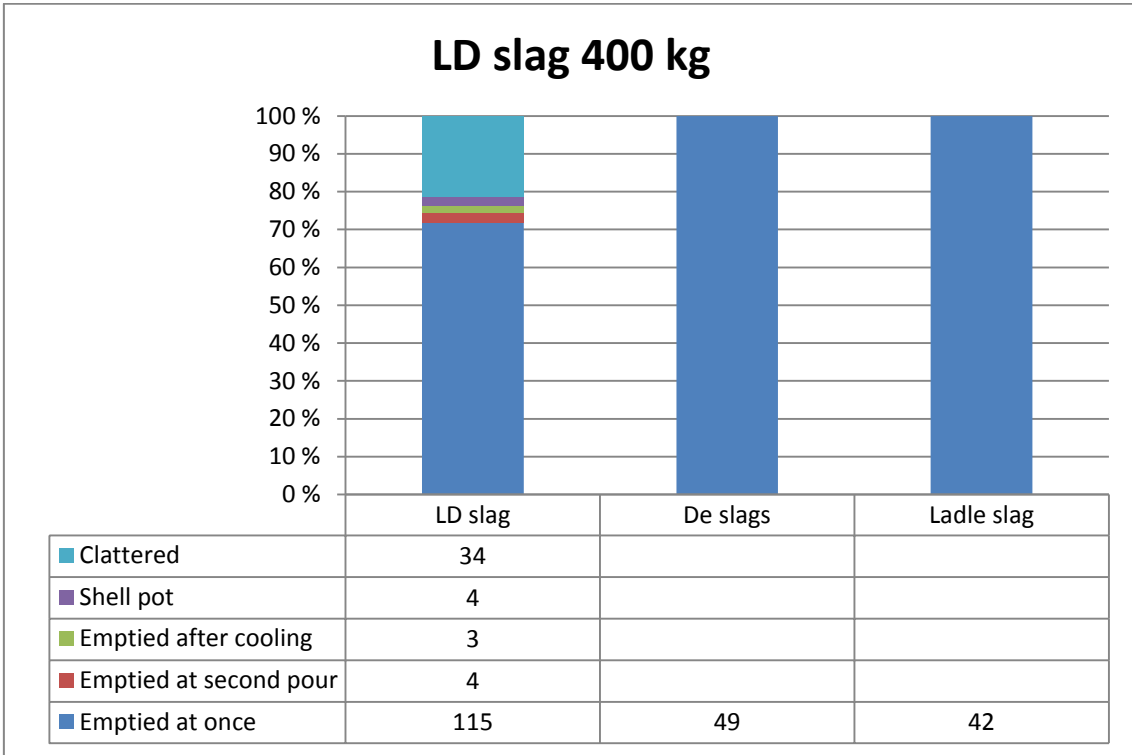


FIGURE 30. Results of the testing period with 400 kg of LD slag

Figure 31 shows flat shaped bottoms and a lot of visible protective sand. When comparing the pictures of the LD slag pots between the testing period with 600 kg and 400 kg, the amount of the visible protective sand is clearly greater in the tests for 400 kg. There was also a lot of natural sand within the LD slag.



FIGURE 31. The LD slag stayed at the bottom of the LD pots as it should

In figure 32 the amount of the protective sand is great. Also the amount of the natural sand among the LD slag is significant. All of the dippings emptied as they should.

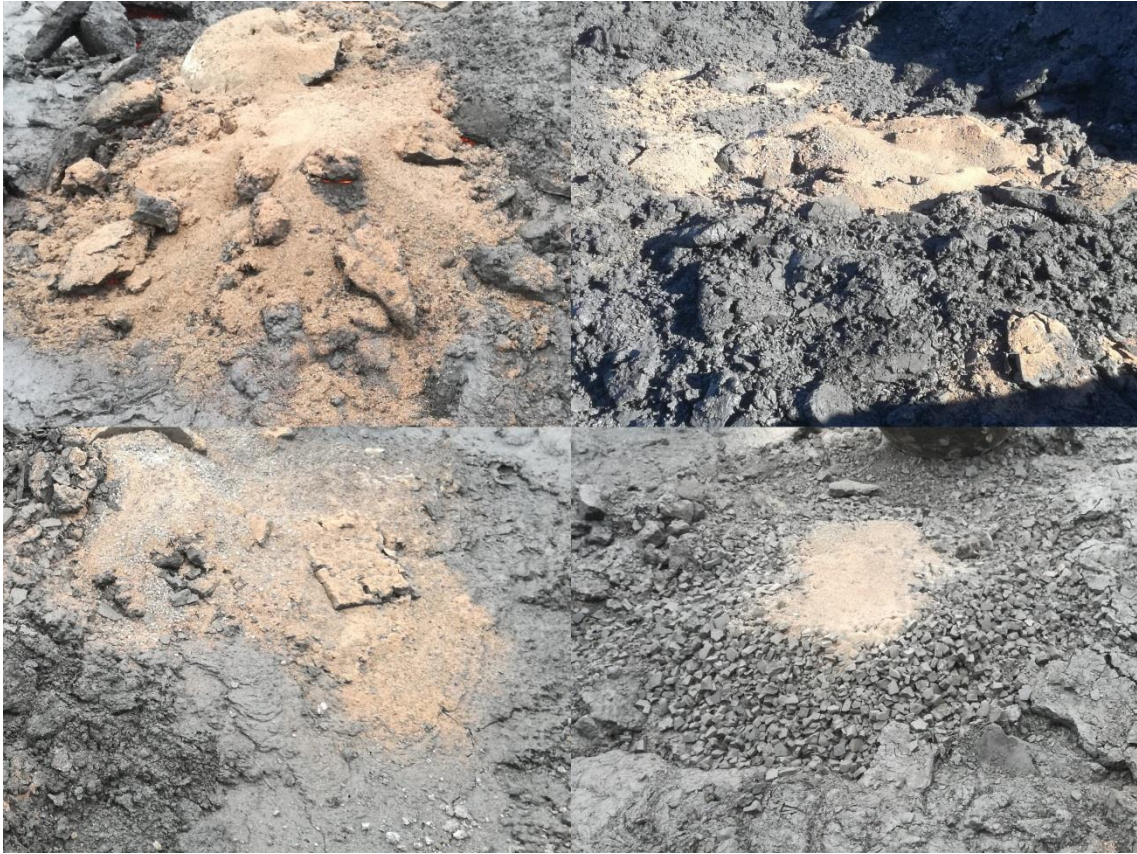


FIGURE 32. A lot of natural sand was in the portions with the LD slag

Figure 33 shows round shaped bottoms. The protective sand has either been melted or pushed aside. There might have been steel among the slag.



FIGURE 33. All or most of the LD slag has been melted or pushed aside

7.6 Weighing during tests

Portions of the protective sand were weighed during the tests in order to verify the actual amount in the testing periods. The weighing was done by feeding the portion to the slag pot and weighing it at the truck scale. Variation among the portions in each testing period was expected.

Two portions of the natural sand were weighed during the tests for 400 kg of natural sand. In the first weighing the result was 400 kg of natural sand. In the second weighing the result was 350 kg.

During the tests for 1000 kg of LD slag one portion of the protective sand was weighed. The weigh was made with the slag pot carrier truck and the result was 1050 kg of the LD slag.

Three portions of the protective sand were weighed during the tests for 600 kg of LD slag. At the first weighing the portion weighed only 300 kg. The second

portion weighed 550 kg and the third 350 kg. Even though the variation of the weight was expected the difference of 300 kg was too much. It has to be taken into account that there might have been a lot of variation during the testing period and the results might not be accurate.

Two portions of the protective sand were weighted during tests for 400 kg of LD slag. Both of the portions weighted 400 kg. During the tests it was observed that the overall impression was that the amount of the protective sand seemed to be a lot greater in than the testing period for LD slag 600 kg.

7.7 Comparison

The comparison is done by reviewing different slag pots respectively and how they emptied with different materials and amounts. This comparison is done by dividing the emptying into “yes” or “no.” The pots that emptied at once or with second dip are categorised as “yes.” Shell pots, clattered pots, and the pots that had to be cooled are categorised as “no,” whether the latest emptied or were clattered.

7.7.1 LD slag pots

When the LD slag tests started there was a need to have more LD slag pots at the converters. A couple of well-shaped ladle slag pots were taken to be used as LD slag pots. Pot number 30 emptied poorly. In the testing periods for 1000 kg and 400 kg it did not empty once and in the period for 600 kg it had to be clattered 12 times out of 16.

Also pot number 40 started to collect the skull on its walls and had to be clattered every time in the testing period for 1000 kg of the LD slag. It was transported to be repaired and when taken back to be used at the testing period for 400 kg of the LD slag it emptied with the success rate of 82 %.

Since the problems with the emptying were so obviously caused by the bad shape of the pots number 30 and 41, they were decided to be removed from the comparison. A bar chart showing the emptying of each slag pot made from the

original non-manipulated data is shown in appendix 1. The removed pots are marked in the appendix.

The comparison between different materials and different amounts in the LD slag pots made based on the manipulated data is shown in figure 34. When looking the percentages, the best emptying was reached with the natural sand at the amount of 600 kg and with the LD slag at the amount of 1000 kg. The worst emptying was with the natural sand at the amount of 400 kg.

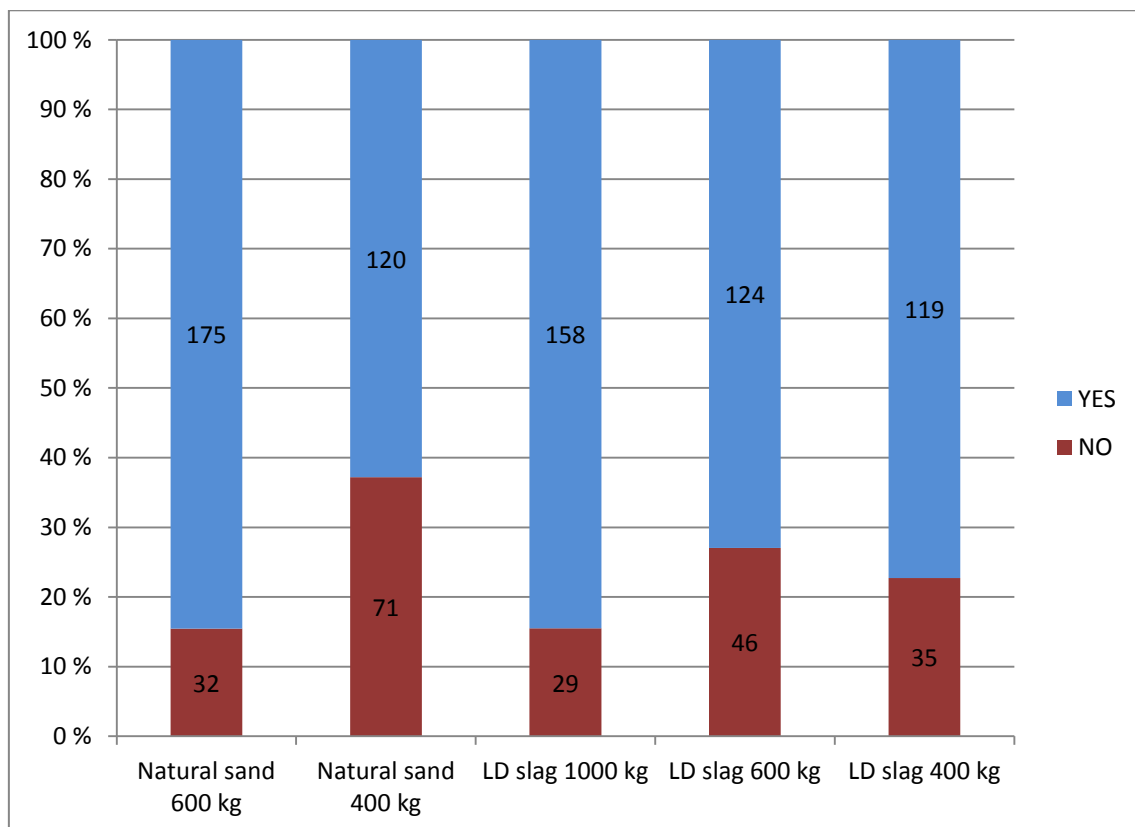


FIGURE 34. Comparison between different materials and different amounts in the LD slag pots

When the material from the testing periods was changed from natural sand to LD slag summer substitutes came to the steel plant. It is possible that this had effect on the amount of the steel getting into the pots and thus having effect on the emptying of the pots.

Having the hypothesis of more sand – more emptied pots, the results for LD slag tests are strange. With the hypothesis and observations which indicated

that the overall amount of the protective sand in testing period for 600 kg was apparently lower than one for 400 kg and since the variation in the weigh-ins was so large it is legitimate to assume that the amount of the LD slag was indeed lower in the tests for 600 kg.

Statistical hypothesis test was decided to do to the results. In the tests the null hypothesis is that there is no statistically significant difference on the emptying which means that the difference in results is not caused by outward factor. If the gained p-value is lesser than the select α -value, in this case 0.05, there is a statistical significance in the results, and the null hypothesis should be rejected. If the p-value is more than the α -value, it is wrong to reject the null hypothesis. (Ruohonen 2011. 29.)

The two proportions test was used to define whether there is a statistically significant difference among the different materials and amounts. The results of the tests are gathered up in table 4. More specific results are shown in appendix 2. The tests were conducted by the statistical analysis program Minitab. The comparison between the results from the testing pair LD slag 1000 kg and natural sand 600 kg and the comparison between the testing pair LD slag 400 kg and LG slag 600 kg gave the result of no statistically significant difference on emptying. This means that the null hypothesis applies. Other testing pairs gave the result of the statistically significant difference.

TABLE 4. Results for the statistical hypothesis tests

	P-value	Result
LD slag 1000 kg – Natural sand 600 kg	0.989	No significance
LD slag 600 kg – Natural sand 600 kg	0.006	Statistical significance
Natural sand 400 kg – LD slag 400 kg	0.003	Statistical significance
Natural sand 400 kg – Natural sand 600 kg	0.000	Statistical significance
LD slag 1000 kg – LD slag 600 kg	0.007	Statistical significance
LD slag 400 kg – LD slag 600 kg	0.367	No significance

7.7.2 Primary and secondary desulphurisation slag pots

The comparison for desulphurisation slag pots is shown in figure 35. As it was stated before, there were no problems emptying the pots since all of the pots emptied with both materials and with all amounts. As it seems, the cooling of the desulphurisation pots has a significant positive influence on emptying.

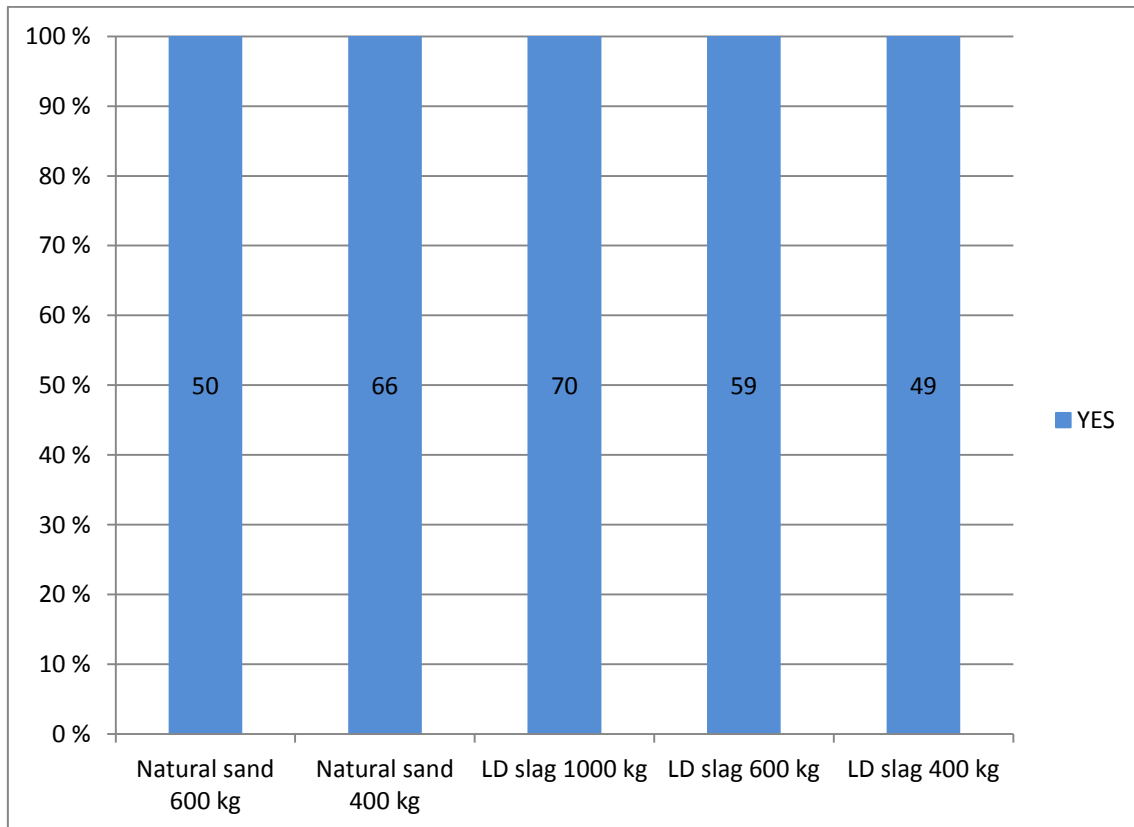


FIGURE 35. The comparison between the different materials and different amounts in the desulphurisation slag pots

If there had been non-emptying desulphurisation pots, it would have been reasonable to review whether those pots would have been primary or secondary desulphurisation slag pots. Since all the pots emptied, the review is obviously unnecessary.

Figure 36 shows the pit for the desulphurisation slags. It is difficult to distinguish the LD slag as the protective sand from the desulphurisation slag.



FIGURE 36. The desulphurisation slag dippings in their pit

7.7.3 Ladle slag pots

The comparison for the ladle slag pots is shown in figure 37. All the pots in the tests from LD slag 1000 kg and 400 kg emptied. In the other tests there were couple of pots that needed to be clattered. It seems that the cooling of the ladle slag pots eases the emptying.

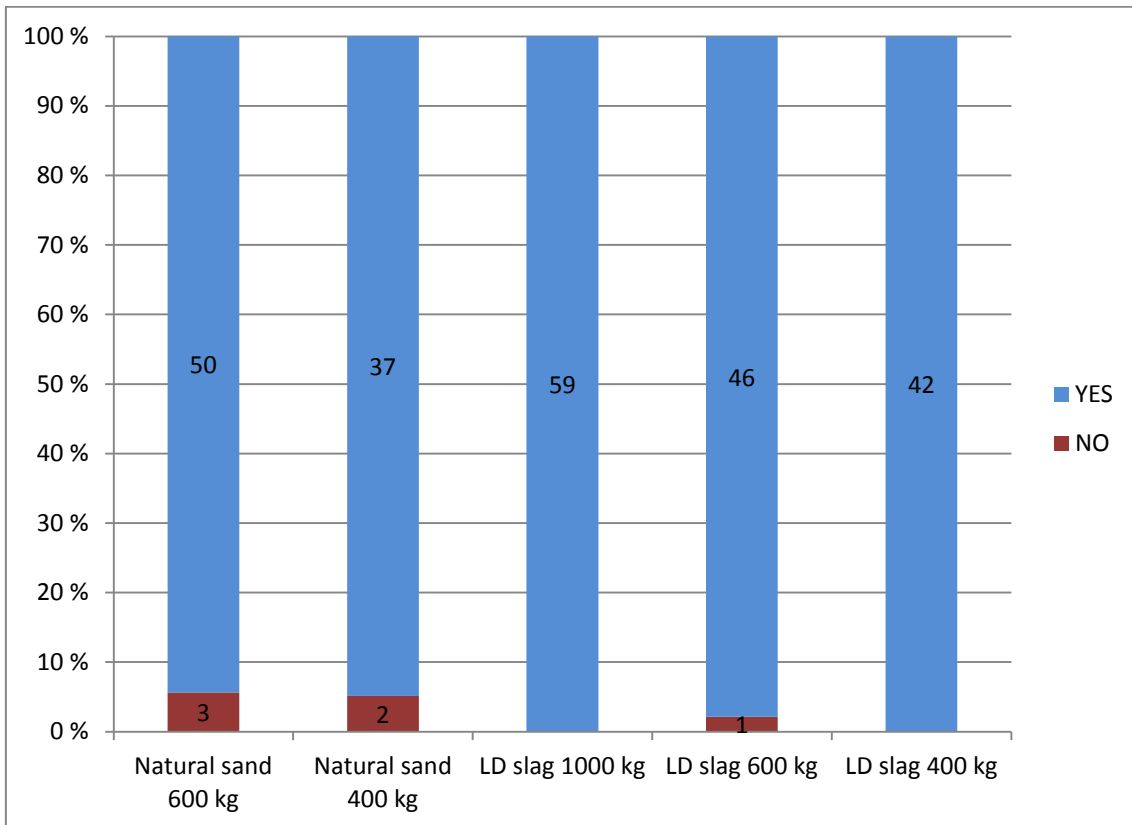


FIGURE 37. The comparison between different materials and different amounts in the ladle slag pots

Since the amount of the pots that needed to be clattered is so small, it can be assumed that it is caused by dispersion occurring in the process. Because of this it is hard to tell which material or which amount would be the absolute best. However, the good success rate of all tests indicates that the amount of the protective sand can indeed be reduced.

Figure 38 shows the ladle slag blocks. The bottoms of the blocks are flat, which means that the protective sand has stayed in its place.



FIGURE 38. Emptied ladle slag blocks in which the protective LD slag stayed at the bottom, thus flat shape

The comparison between round and flat shaped bottoms of the ladle slag is shown in figure 39. Since there are lots of steel in the ladle slag pots, and the temperature of the steel at the casting phase is approximately 1550 °C degrees, it is unlikely that the LD slag would have been melted. It has probably been pushed aside when the ladle slag has been poured to the pot.



FIGURE 39. Emptied ladle slag, comparison between flat and round shaped bottoms

8 COSTS AND POSSIBLE SAVINGS

This paragraph is concealed at the request of the commissioner. The paragraph contains calculations based on contract prices.

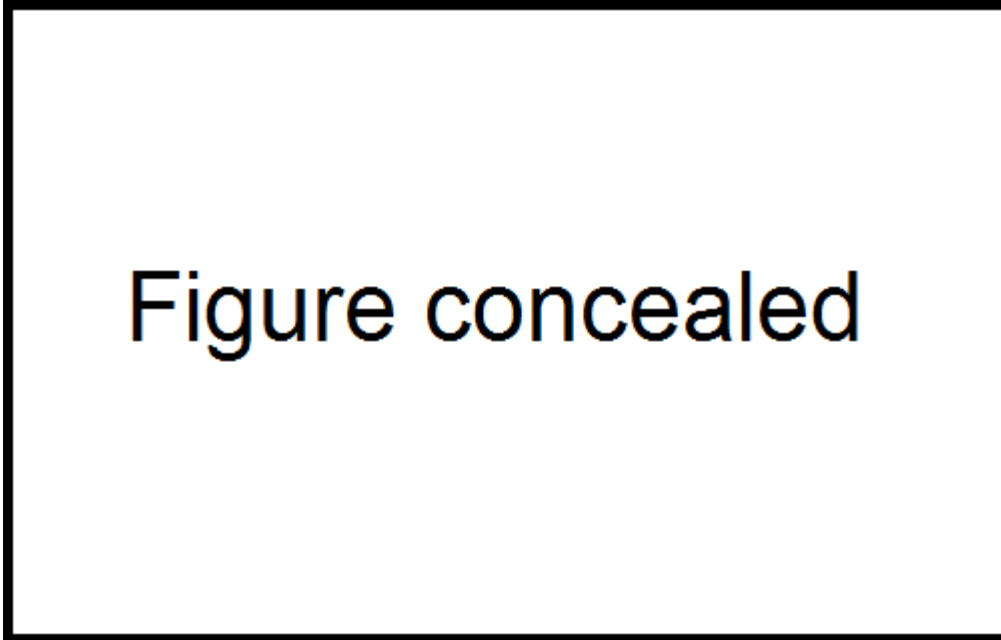


FIGURE 40. Total tonnages at different amounts of the protective sand

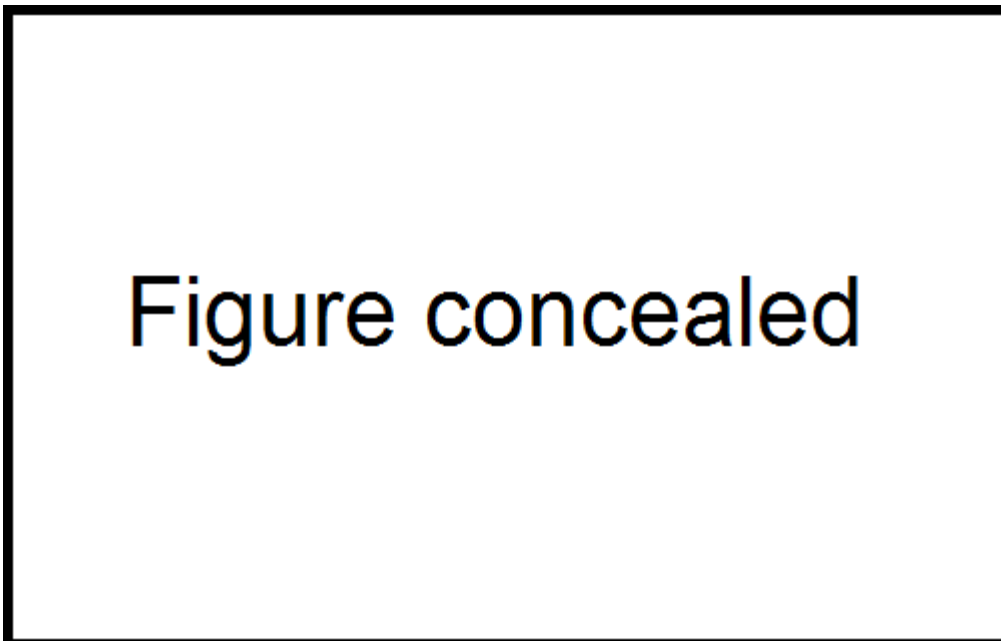


FIGURE 41. Annual costs for tested materials and amounts

Figure concealed

FIGURE 42. Annual VIU for LD slag

Figure concealed

FIGURE 43. Savings when amount of the natural sand is decreased in desulphurisation and ladle slag pots

Figure concealed

FIGURE 44. Savings when amount of the LD slag is decreased in desulphurisation and ladle slag pots

9 CONCLUSION

The goal of the thesis was to do a literature study about the protective sand used globally. Additionally, a testing period was to be carried out with the possible materials found from the literature. If the new materials were not to be found, the intention was to test at least the natural sand and the LD slag which have already been in use before in the Raahe melting shop. The results were to be investigated and the ideas of the development were to be presented.

The study did not reveal new materials for the protective sand but different solutions for spraying the pots with the lime suspension came up. In Sweden the crushed LD slag is also used in the slag pots. However, the fraction was bigger than in Raahe. The testing period was decided to be carried out with the natural sand at the amount of 600 kg and 400 kg and the LD slag with the amount of 1000 kg, 600 kg and 400 kg.

The results of the testing period indicated that the desulphurisation and ladle slag pots emptied well with all materials and all amounts of the protective sand. None of the desulphurisation pots had to be clattered. Only couple of ladle slag pots had to be clattered. The amount of the clattered ladle slag pots is not significant.

The LD slag pots had problems emptying even with the largest amount. The best results were at the tests for natural sand 600 kg and LD slag 1000 kg. 85 percent of these pots emptied. The worst results were at the testing period for natural sand 400 kg with 63 percent emptied pots.

According to the results of the test period it is rather clear that the amount of the protective sand in the desulphurisation and ladle pots could be decreased at least to level of 400 kg. Since the emptying of the pots was so successful it would be worth doing the test period without any protective sand at all.

Tests indicate that the amount of the protective sand in the LD slag pots should be kept at maximum. The clattering causes stress in the pots and it should be

kept as low as possible. It should be considered to try cooling the LD slag pots even for a few hours and act upon the received results.

Increasing the amount of the protective sand even more in LD slag pots should be considered. Since the desulphurisation and the ladle slag pots emptied well with the lesser amounts it should be investigated whether the sanding station could be adjusted so that it would be possible to put different amount of the protective sand to different pots.

The subject was not covered in the literature. There were no mentions about the protective sand. However, there were articles about the lime suspensions and the slag ladles that had refractory linings. There has also been an initiation report about the start of the usage of the protective sand but the report was lost when the initiative archives were cleared out. A lot of the background of the thesis was covered with interviews, observations and oral notifications leaving the foundations of the thesis slightly frail.

More problems occurred because of the imprecise functioning of the sanding stations adjustment and feeding systems. The adjustments had to be done by randomly adjusting the vibrators of the feeding system and weighing the portions with the wheel loader leaving the possibility for weighing to be inaccurate. Even if weigh-ins would be accurate, the inaccurate feeding system creates variations for the weighing.

The compressed air unloading system at the sanding station created problems with the bigger fractions of the protective sand. Fine natural sand had to be added among the LD slag in order to ease the unloading from the tanker.

These problems with the sanding station caused the validity of the results to be questioned. The amount of the LD slag in tests for 600 kg was observed to be a lot lesser than in the tests for 400 kg. In both of these tests there were observed to be a significantly big amount of the natural sand among the LD slag.

The workability and validity of the equipment of the sanding station could have been defined and the calibrations of the scaling equipment could have been conducted. However, this would have required a lot more time and a separate

report. Even though the uncertainty of the sanding station and scales, the results recreated well the functioning and importance of the protective sand.

During the LD slag tests the summer substitutes came to work at the converters, and this might have increased the amount of the steel in the slag pots, thus making the emptying harder. Also the bad condition of the certain LD slag pots might have skewed the results. This was tried to be prevented by deleting the obviously poor conditioned pots from the data for comparison between different materials and amounts in LD slag pots. Generally, the amount of the steel getting to the slag pots should be reduced at the melting shop.

Because of the many different factors affecting the emptying the results are suggestive. It is difficult to tell which material is the absolute best. The duration of the testing periods should have been way longer and the outward factors affecting the reliability should have been eliminated to get more valid results.

The natural sand might melt if the steel would get to the LD slag pots. There is also a possibility for it to be pushed aside when the slag is poured to the pot. The LD slag has an effect on the quality of the slag products used in the agriculture. However, the amount of the LD slag in the slag products used as liming agent is so small it does not exceed the required limits. The natural sand has no effect on the quality of the slag products.

The usage of the different refractory suspensions was mentioned in the old articles. However, the message from the steel plants of the SSAB in Sweden was that the sprayed suspension did not bring significant benefits. It should be investigated if the lime suspension used in Raahe has significance in the emptying of the slag pots. The testing period should be conducted without the lime suspension.

For a further development it would be desirable to consider changing the unloading and feeding of the protective sand in the sanding station. The unloading could be conducted for example by an elevator easing the unloading of rougher fractions and making it possible to try to use even bigger dimensions.

The safety would also be improved since the possibility for the hose to burst during unloading would be eliminated.

The feeding of the protective sand to the slag pot would be more accurate if it would be done for example by belt conveyor. It should also be considered to find a way to monitor the consumption of the protective sand. There is a scale in the silo of the sanding station, but it is not working.

Taking into account the economical point of view as it was calculated in paragraph 8 it is more profitable to use the demanded amount of the LD slag than the natural sand in the bottom of the pots. However, since the VIU for recirculating the LD slag to the blast furnaces is so high, theoretical profit is always higher when using the LD slag in the blast furnaces and natural sand in the slag pots. If the demand for LD slag in the blast furnaces is low and the storage for the LD slag starts to grow it should be used in the slag pots.

Decreasing the amount of the protective sand to 400 kg in desulphurisation and ladle slag pots and leaving the amount in LD slag pots untouched would gain savings in costs. Compared to the current set up, 600 kg of the natural sand, the amount in the LD slag pots could be increased up to 780 kg and the costs would be the same. Compared to the previous normal state 1000 kg of LD slag the corresponding increase in LD slag pots could be up to 1380 kg.

During the tests it was discovered that when the linings of the ladles for raw iron are rebuilt there are portions of the refractory bricks which are not recycled. The possibility to use the chamotte and the high alumina bricks within the protective sand should be investigated. This would be sustainable and the bricks would bring more refractory features to protect the slag pots.

Being mostly Al_2O_3 and SiO_2 , the bricks should not have effect on the quality of the slag products. Since the amount of the bricks would be small within the protective sand it should not create any problems when recirculating them within the LD slag to the blast furnaces. The functionality of the crushed rock stone as the protective sand should also be investigated.

REFERENCES

Borgström, L. H. 1924. Suomen kvartsihiekkä. Helsinki: Valtioneuvoston kirjapaino. 3. Available at: http://tupa.gtk.fi/julkaisu/geoteknillinen/gt_s_023.pdf. Date of retrieval 5 June 2017.

CCE 169-061-010 / Slaggytor 14.5 kbm. 2014. Manual. CAST-CON Engineering GmbH & Co. KG. 7.

Fomin, N. A. – Golov, G. V. – Zvereva, L. V. – Kochetov, N. N. – Pishchulin, G. N. 1978. Protecting slag pots. Translation by Plenum Publishing Corporation. Metallurg, No. 8. 25 - 26.

Hammond, C. R. 1993. Properties of the Elements and Inorganic Compounds. In: Bass, Michael – Brewer, Leo – DiSalvo, F. J. – Donnelly, Russel J. – Karger, Barry L. – Lineberger, W. C. – Palmer, David, A. – Seyferth, Dietmar – Westbrook, Jack H. 1993. Handbook of Chemistry and Physics. Boca Raton: CRC Press Inc. 4-1...4-159.

Holappa, Lauri 2011. Kuonareaktiot. Kuonat prosessimetallurgiassa -training 12 to 13 April 2011. Oulu: Pohto Oy. 2.

Projektikortti. Internal report. Ruukki. Kierrätys- ja mineraalituotteet.

Isokääntä, Simo. Head of R&D, SSAB Europe Oy Merox, Raahe. Verbal notification. Spring 2017.

Kowalski, M. – Spencer, P. J. – Neuschütz, D. 1995. Phase diagrams. In: Allibert, M. – Gaye, H. – Geiseler, J. – Janke, D. – Keene, B. J. – Kirner, D. – Kowalski, M. – Lehmann, J. – Mills, K. C. – Neuschütz, D. – Parra, R. – Saint-Jours, C. – Spencer, P. J. – Susa, M. – Tmar, M. – Woermann, E. 1995. Slag atlas. D-Düsseldorf: Verlag Stahleisen GmbH. 21 - 214.

Lindell, Karri 2012. Internal report. SSAB.

Lindell, Karri 2017. Technician. SSAB. SV: Protection of the slag pots. E-mail correspondence. 25 May 2017 to 21 May 2017.

Maa- ja tienrakennus. LD-MaHk. 2017. Merox. Available at: <http://www.ssab.fi/ssab-konserni/merox/products/infrastructure>. Date of retrieval 6 May 2017.

Majanen, Eero 2017. Liiketoimintajohtaja. Fescon Oy. Interview 6 March 2017.

Merox. 2017. SSAB. Available at: <http://www.ssab.fi/ssab-konserni/merox>. Date of retrieval 15 March 2017.

Merox company presentation. 2015. Internal PowerPoint-presentation. Merox.

Muotka, Lars 2017. Technician. Merox. SV: Protection of the slag pots. E-mail correspondence. 15 to 22 March 2017.

Paananen, Timo – Ollila, Seppo – Syrjänen, Antti – Mäkikyrö, Marko 2011. Malmipohjaisen teräksensuorituksen kuonat. Kuonat prosessimetallurgiassa – training 12 to 13 April 2011. Oulu: Pohto Oy.

Peltojen kalkitukseen. 2017. Brochure. Merox.

Ruohonen, Keijo 2011. Tilastomatematiikka. 29. Available at: <http://math.tut.fi/~ruohonen/TM.pdf>. Date of retrieval 17 Sept 2017.

Siamidi, L. A. – Ventskovskii, G. É. – Arapov, G. N. 1980. Automatic whitewashing of slag pots in the production line. Translation Plenum Publishing Corporation. Metallurg, No. 10. 19.

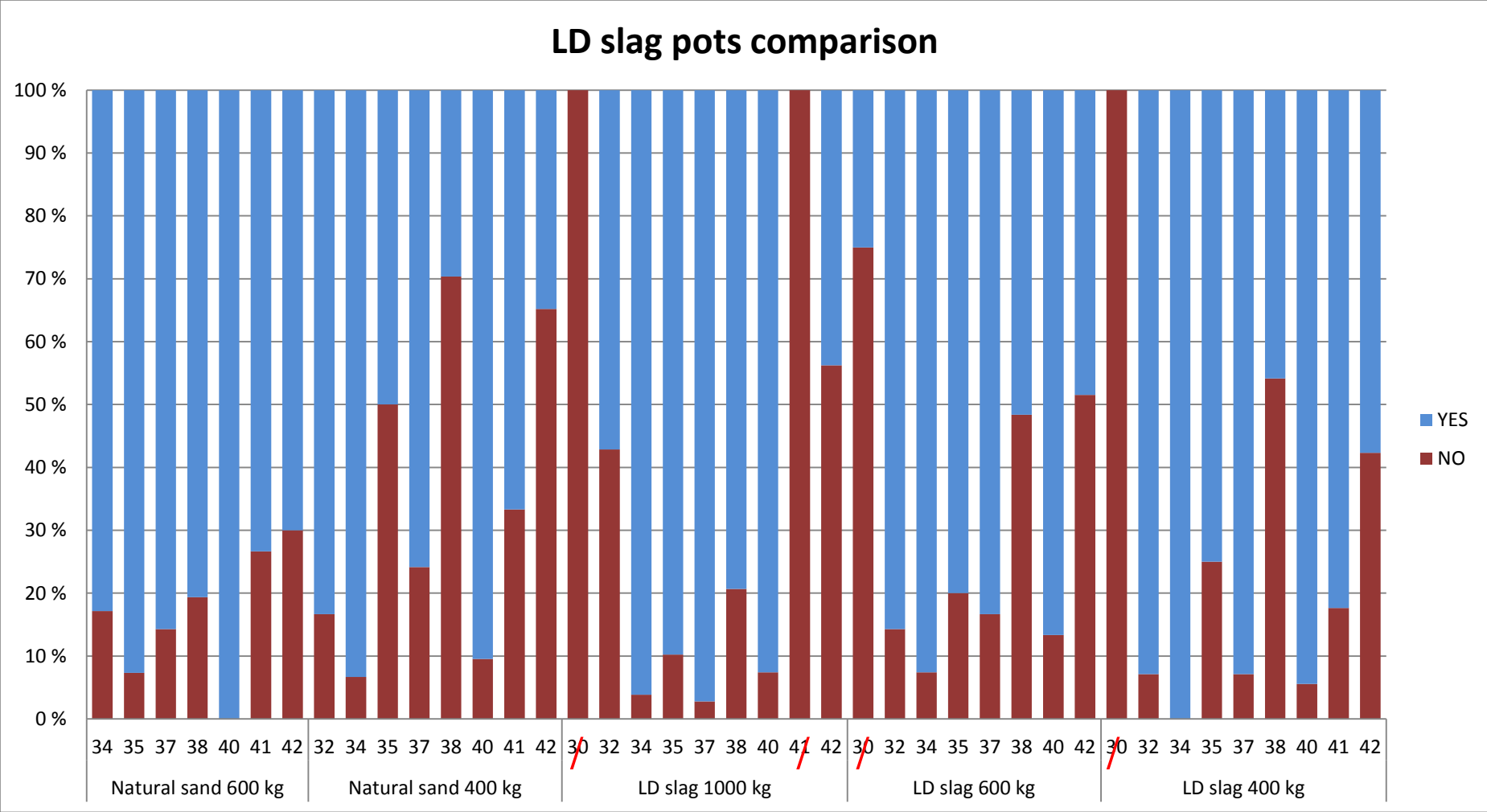
SSAB Europe. 2017. SSAB. Available at: <https://www.ssab.com/company/about-ssab/our-business/ssab-europe>. Date of retrieval 15 March 2017.

SSAB in brief. 2017. SSAB. Available at: <https://www.ssab.com/company/about-ssab/ssab-in-brief>. Date of retrieval 15 March 2017.

Stolte, Gerd 2002. Secondary Metallurgy : Fundamentals Processes Applications. Düsseldorf: Verlag Stahleisen GmbH.

Teräskirja. 2014. 9. Painos. Porvoo: Metallinjalostajat ry.

Virtala, Jan 2017. SV: Protection of the slag pots. E-mail correspondence. 17
March 2017.



Test and CI for Two Proportions: Emptied; Material/qty (NS 600, LD 1000)

Event = YES

Material/qty	X	N	Sample p
LD-slag 1000	158	187	0.844920
Natural sand	175	207	0.845411

Difference = p (LD-slag 1000) - p (Natural sand)
 Estimate for difference: -0.000490842
 95% CI for difference: (-0.0720243; 0.0710427)
 Test for difference = 0 (vs ≠ 0): Z = -0.01 P-Value = 0.989

Test and CI for Two Proportions: Emptied; Material/qty (LD 600, NS 600)

Event = YES

Material/qty	X	N	Sample p
LD-slag 600	124	170	0.729412
Natural sand	175	207	0.845411

Difference = p (LD-slag 600) - p (Natural sand)
 Estimate for difference: -0.115999
 95% CI for difference: (-0.198976; -0.0330213)
 Test for difference = 0 (vs ≠ 0): Z = -2.74 P-Value = 0.006

Test and CI for Two Proportions: Emptied; Material/qty (NS 400, LD 400)

Event = YES

Material/qty	X	N	Sample p
LD-slag 400	119	154	0.772727
Natural sand	120	191	0.628272

Difference = p (LD-slag 400) - p (Natural sand)
 Estimate for difference: 0.144455
 95% CI for difference: (0.0491769; 0.239733)
 Test for difference = 0 (vs ≠ 0): Z = 2.97 P-Value = 0.003

Test and CI for Two Proportions: Emptied; Material/qty (NS 400, NS 600)

Event = YES

Material/qty	X	N	Sample p
Natural sand	120	191	0.628272
Natural sand	175	207	0.845411

Difference = p (Natural sand) - p (Natural sand)
 Estimate for difference: -0.217138
 95% CI for difference: (-0.301533; -0.132743)
 Test for difference = 0 (vs ≠ 0): Z = -5.04 P-Value = 0.000

Test and CI for Two Proportions: Emptied; Material/qty (LD 1000, LD 600)

Event = YES

Material/qty	X	N	Sample p
LD-slag 1000	158	187	0.844920
LD-slag 600	124	170	0.729412

Difference = p (LD-slag 1000) - p (LD-slag 600)

Estimate for difference: 0.115508

95% CI for difference: (0.0309407; 0.200075)

Test for difference = 0 (vs ≠ 0): Z = 2.68 P-Value = 0.007

Test and CI for Two Proportions: Emptied; Material/qty (LD 400, LD 600)

Event = YES

Material/qty	X	N	Sample p
LD-slag 400	119	154	0.772727
LD-slag 600	124	170	0.729412

Difference = p (LD-slag 400) - p (LD-slag 600)

Estimate for difference: 0.0433155

95% CI for difference: (-0.0507095; 0.137340)

Test for difference = 0 (vs ≠ 0): Z = 0.90 P-Value = 0.367

Appendix concealed

Appendix concealed

Appendix concealed