Evaluation of the Suitability of Auger Pressing Briquettes for Blast Furnace Use

Olli Vitikka[1], Mikko Iljana[1], Anne Heikkilä[1], Timo Fabritius[1], Nikita Koriuchev[2], Illia Tkalenko[2] and Andrey Malkki[3]

[1]Process Metallurgy Research Unit, University of Oulu, Finland
[2]AMCOM GROUP LLC, USA
[3]Kivisampo Oy, Finland

Summary

One way to improve the recycling of by-products from iron and steel production is briquetting, a process in which fine materials unsuitable for use as such are agglomerated to achieve a larger particle size. This work is about the high-temperature properties of auger pressing briquettes mainly consisting of blast furnace sludge and mill scale. The aim was to determine the suitability of the briquettes for blast furnace (BF) ironmaking by studying the reduction, swelling and cracking behavior using blast furnace simulator (BFS) furnace.

The BFS, which can perform non-isothermal reduction experiments with changing gas atmospheres, was used to simulate the reducing conditions in a BF. In the BFS experiments, different stages of reduction up to 1100 °C were simulated. A commercial olivine pellet and another industrial blast furnace briquette were used as reference samples. The weight losses were monitored by thermogravimetry, swelling as a change in the external dimensions, and cracking by visual inspection. TG-MS analysis was carried out to study the presence of potentially harmful volatiles. The samples were analyzed using LOM and FESEM to study the phase transformations.

The auger pressing briquettes proved to be a promising raw material for BF use. They were of self-reducing type due to their carbon content, and they were reduced to metallic iron faster compared to the reference briquettes. The swelling was slight, and despite minor cracking the auger pressing briquettes did not degrade. No harmful volatile substances were found.

Key Words

Auger press, blast furnace, briquette, ironmaking, reduction, steelmaking by-product, swelling

Introduction

One of the most significant challenges facing the metallurgical industry is reducing the CO_2 emissions and recycling is a key factor in CO_2 reduction [1–2]. As with many other processes, numerous by-products and wastes are produced in steelmaking. These include different kinds of dusts, scales, sludges and slags. Recycling the by-products back into the process as raw materials is possible for a significant portion of them. Such action is both profitable and environmentally friendly as it reduces material losses and decreases need for landfilling. However, the particle size of the by-products is often far too small for direct recycling. [2] Therefore, the focus of this work was on materials processed into briquettes in order to become recyclable.

The main goal of the study was to evaluate the usability of Kivisampo (part of AMCOM group) auger pressing briquettes as an input material for the blast furnace process considering the factors of reducibility, swelling and cracking. The briquettes studied in this work mostly consist of blast furnace sludge and mill scale and contain about 2 wt-% binder and wt-3% slaked lime. In the experiments, the blast furnace simulator (BFS) furnace was utilized to study the reduction of the materials simulating an actual blast furnace process in various temperature – gas atmospheres.

Blast Furnace and Briquettes

Mainly there are two main options to produce hot metal: using blast furnace – basic oxygen furnace option (BF-BOF) and melting steel scrap or direct reduced iron in electric arc furnace (EAF) [3]. Due to blast furnace process being the more common process, it was selected as the process to be simulated.

In–plant residue materials can be utilized in blast furnace process in the form of briquettes, the properties of which were also studied in this work. Cold briquetting is a way to recycle typical steelmaking by-products such as blast furnace dust, mill scale and BOF sludge. In the past, it has been standard practice to either recycle those materials through a sinter process, sell or landfill them. Briquettes are manufactured by using a binder, usually a cement that enables high cold strength but weaker reduction–disintegration features. [4]

The strength of the briquettes is determined by the plasticity or brittleness of the binder and the cohesive and adhesive strength to the surface of the particle. The strength results from van der Waals forces, valence bonds and interlocking between the particles. When the density of the briquettes is increased, the adhesion and interlocking increase, while the volume of void decreases. [5] Binders can be added to the agglomerated products before or during the agglomeration process and they affect the strength directly or after the curing step. It is important to use an appropriate binder to increase the mechanical strength. [6]

The blast furnace process has extreme conditions that place a wide range of requirements on the quality of charge materials. The raw materials used must have adequate reducibility, high cold strength, low reduction–disintegration index (RDI), small variations in chemical composition, appropriate particle size, and in addition to those, quantity and type of binders used must be chosen wisely. [6] Despite the demanding requirements, briquetting as a recycling method has become widespread at a good pace. SSAB is an example of steel producer that has moved from sintering to briquetting processes.

Majority of the requirements apply to pellets and sinter, and there are no mentions about briquettes in the ISO standards related to iron burden materials. The standards must be applied to briquettes and therefore, for agglomerates of different sizes.

Since the weights of the products can range from 35 to 500 g, their behaviors vary, especially in a drop test. For example, there is more abrasion than impacts due to falling with small and numerous iron ore pellets or sinter pieces. In the case of large-sized briquettes, the situation is the opposite. Also, for a reduction-disintegration test, the briquettes should be cut in order to use the apparatus.

AMCOM has developed Vacuum Auger Pressing technology in order to produce briquettes efficiently and economically from finely dispersed natural and technogenic materials and to suit different metallurgical needs as well as possible. High-pressure technology allows using materials with a particle size of up to 8 mm and low proportion of binder, about 1 wt-%. The process scheme is shown in Figure 1a.

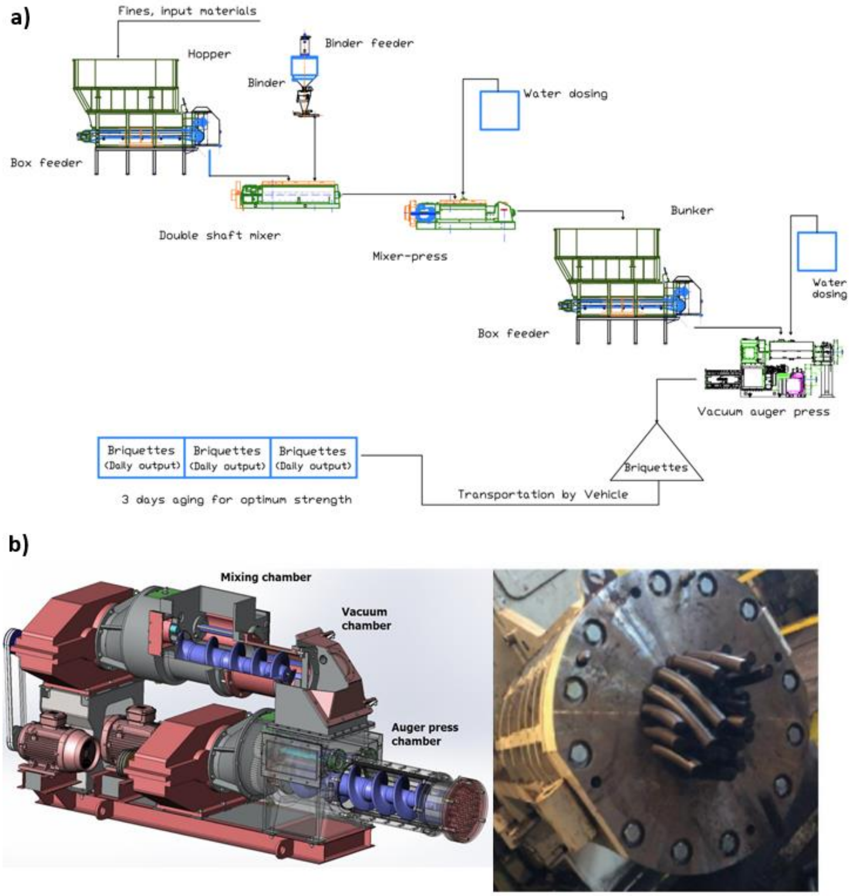

Figure 1. a) Technological scheme of briquette manufacturing. b) Vacuum Auger Pressing technology: Left: Schematic view of the auger press; Right: Production of briquettes in Russia.

The auger pressing technology consists of double shaft mixer with pre-compaction function, vacuum chamber, and auger press chamber shown in Figure 1b. The auger press chamber consists of three zones with decreasing diameters from left to right: the mixing zone, the pre-compression zone and the compression zone. The briquettes are forced through the holes in the die, as shown in Figure 1b.

A wide range of briquettes is produced by utilizing iron and steelmaking by-products such as BF dust, mill scales, EAF gas cleaning dust, ferrochrome, scrap, hot briquetted iron (HBI) screenings and aluminum oxide. Harmless individually developed materials are used as binders. Mechanical strength is ensured by the addition of polymer-mineral composite. Cold mechanical strength is ensured by tests for dropping, abrasion and compression before studying the metallurgical properties.

Materials, Strength Tests and Methods

The auger pressing briquettes received from the AMCOM GROUP LLC laboratory in Russia mainly consisted of unprocessed BF sludge and mill scale obtained from steel plants located in the Russian Federation. Slaked lime and binder, which is a mix of organic polymer and mineral components, were added. Strength tests were carried out in the laboratory before shipping the samples to Finland. The briquettes were 60–120 mm in length, had a good plasticity and were cured for 3 days (Figure 2).

Figure 2. Left: Kivisampo briquettes pictured before and after the curing step. Right: The dependence of moisture content on time after molding.

The mechanical crushing strength was tested after aging for 72 hours. The average crushing strength of the briquettes in normal conditions was 24.65 kg/cm. The mechanical drop strength was tested by 3-fold dropping from 2 m. 98.5 wt-% of the briquettes were more than 5 mm in size after the test. For the abrasion strength test, the test drum was rotated a total of 200 revolutions and the fractions were studied after 25, 50, 100 and 200 revolutions (see Figure 3). The abrasion strengths, defined as portions exceeding 5 mm in size, were 93%, 89%, 80% and 64%.

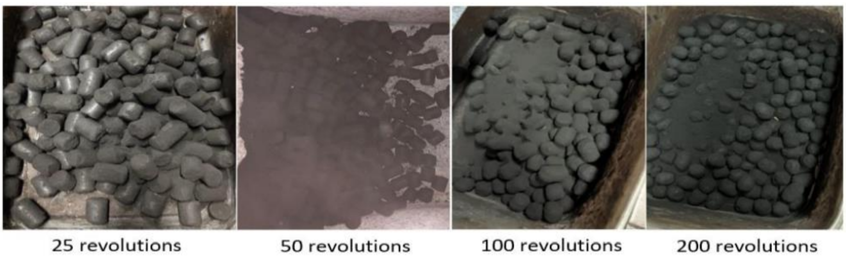

Figure 3. Kivisampo briquettes pictured during the abrasion test after 25, 50, 100 and 200 revolutions.

Commercial olivine pellets were used as a reference sample. The average weight of a 10.0–12.7 mm sized pellet was 3.4 g. To compare reduction behavior between briquettes, large ~400 g punch-and-die pressed industrial blast furnace briquettes received from the SSAB steel plant in Raahe, Finland were used. The reference samples are pictured in Figure 4.

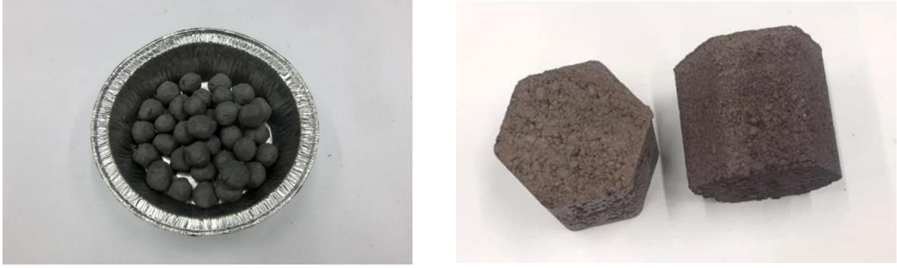

Figure 4. Left: Commercial olivine pellets. Right: Industrial blast furnace briquettes.

The chemical compositions of all three samples used in the experiments are summarized in Table 1 for case of comparison.

Table 1. Chemical compositions of the samples used in the experiments.

Sample	**Elements, wt.%**									
	Fe	**P**	**SiO_2**	**CaO**	**MgO**	**Al_2O_3**	**Zn**	**H_2O**	**C**	**Basicity**
Auger Pressing Briquette	56.3	0.07	2.05	3.65	3.9	0.88	0.17	0.60	9.87	1,78
Reference Briquette	48.4	0.05	8.1	11.1	2.1	2.4	0.01	~7.5	8.28	1,37
Reference Pellet	66.7	0.01	1.85	0.43	1.3	0.32	<0.003	1.5	-	0,23

The following devices and methods were used:

- **Blast furnace simulator (BFS)** for the study of reduction and swelling behavior of briquettes and pellets.
- **Microscopes** for the high-resolution imaging of microstructures for the further study of mineralogical and structural analysis.
- **Thermal gravimetric mass spectrometry (TG-MS**) which was carried out for the original briquette sample to find out whether any harmful components were released from briquettes during blast furnace operation.

Sample Preparation and Device Setup

The auger pressing briquette sample received from Kivisampo included five pieces of briquettes, weighing a total of 0.6 kg. To avoid moisture absorption, the samples (Figure 5) were kept in a temperature cabinet at 105 °C overnight. The samples were weighed before and after drying and the moisture content of the briquettes was about 1 wt-%. Four briquettes were used in one of the BFS Experiments A–D. A piece of the original briquette sample was used in the TG-MS experiment. Polished sections were prepared for Light Optical Microscope (LOM) and were later platinum coated for a Field Emission Scanning Electron Microscope (FESEM).

Blast furnace simulator (BFS) (see Figure 5), first introduced by Iljana et al. in 2012 [7], was utilized to perform each non-isothermal reduction experiment. The sample basket was carefully inserted into the BFS reduction tube and attached to hang from a hook connected to the scale of thermogravimetric analysis (TGA) that continuously measured the sample weight during the experiments. The video camera was used to monitor the external changes during the reduction.

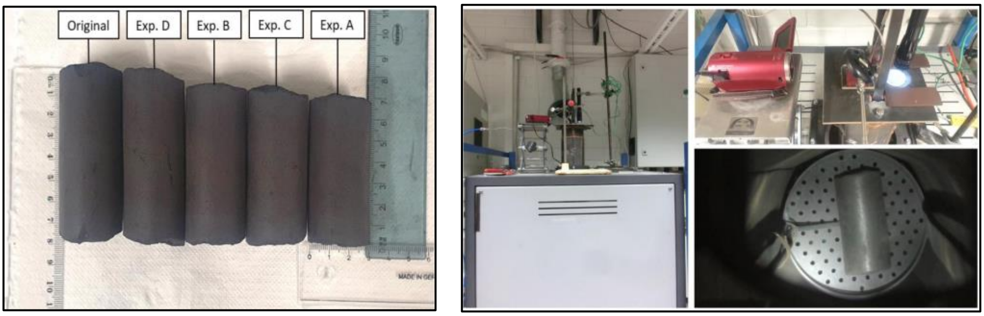

Figure 5. Left: Briquette samples for different experiments. Right: BFS setup. A view from front of the BFS; a view from above the BFS, showing the mouth of the reduction tube closed by a lid, a hanging sample basket, a flashlight, a mirror and a video camera; and the video camera image on tablet.

Blast Furnace Simulator Experiments

Four different reduction experiments were carried out for the auger pressing briquettes in different reduction stages. Experiments A and B were continuous 260-minute experiments with the aim of achieving reduction to metallic iron. The briquette samples were weighed, and the dimensions were measured before and after the experiment. Experiment A was continued isothermally at 1100 °C for 40 minutes whereas for Experiment B, this isotherm was not used. Experiments C and D were interrupted experiments aimed at achieving reduction to wüstite and magnetite to study the structural differences between the samples reduced to different stages. The temperature in Experiment C was 800 °C and for Experiment D, 500 °C.

Experiments E and F refer to the experiments with reference samples, i.e., the commercial olivine pellet and the industrial blast furnace briquette. The same reduction program as in Experiment B was used in Experiment E performed on the olivine pellets. Since there is no carbon in the pellets, now the interest was on how much reduction occurs during the non-isothermal reduction program. For Experiment F, the reference briquette was reduced with the same program as the sample in Experiment A, because the effect of the isothermal period was of interest.

Swelling behavior was observed by measuring the volumes of the briquette samples before and after the reduction. Swelling of the reference pellets was not studied. TG-MS experiment was carried out for the original auger pressing briquette sample by heating from room temperature up to 1100 °C in inert argon gas of a purity of 99.999 vol-% or more. The temperature was raised 5 °C/min and the gas volume flow was 100 ml/min. Mass spectrometer measurements were performed by using an analog scanning mode and a detection range of 1–150 amu.

Results and Discussion

The changes in sample weights are presented in Figure 6 as total weight losses and weight losses as a function of time for each experiment.

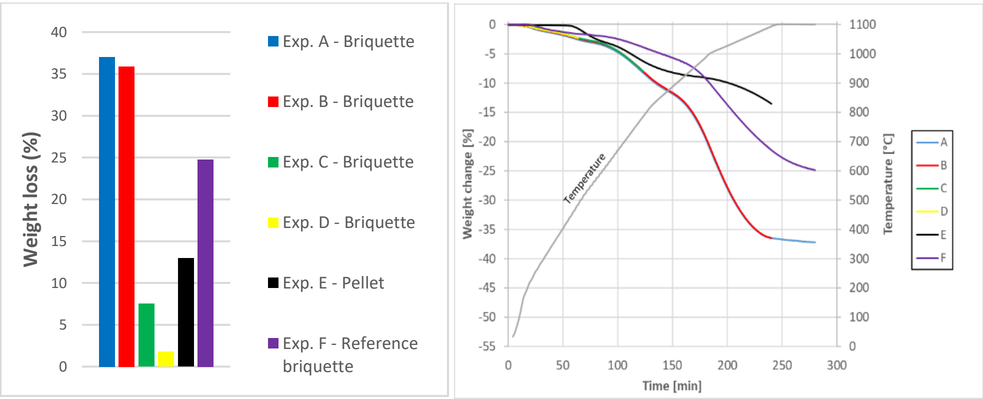

Figure 6. Left: Total weight losses of the auger pressing briquette samples. Right: Weight losses as a function of time in the reduction experiments for auger pressing briquettes.

Relative weight losses were largest for the auger pressing briquettes. The results were reproducible, as the relative weight change curves of the experiments of different lengths overlapped. The auger pressing briquettes were of self-reducing quality due to their carbon content. Unlike the reference samples, auger pressing briquettes were completely reduced to metallic iron during the full 260-minute experiments. They also reduced considerably faster than the reference samples. Essentially, they were reduced even before the 40-minute isotherm, during which only 1.1 wt-% of the sample weight was removed. The weight already began to decrease at the beginning of the experiments probably due to carbonatation reaction between slaked lime and CO_2. According to FESEM-EDS analysis, every sample still contained traces of coal, but its amount clearly decreased as a result of gasification during the isotherm.

The swelling of the briquettes was slight, and despite the minor cracking the samples remained in one piece. The briquettes swelled by 5–11 vol-% during the full reduction experiments, and cracking occurred above 1000 °C when wüstite was reduced to metallic iron. The swelling of the reference briquette was more significant, about 24 vol-%. The auger pressing briquettes remained structurally almost unchanged when exposed to temperatures of 500 and 800 °C.

Conclusion

Based on the study and the experiments carried out, it can be stated that AMCOM Vacuum Auger Pressing technology was able to produce blast furnace briquettes with promising high-temperature properties. The results of the cold strength tests carried out by AMCOM were also quite promising. It was found out that the briquettes were of self-reducing type due to their carbon content, and they also were of uniform quality and structurally durable, showed low swelling, and no components harmful to blast furnace scrubbers were found although their existence cannot be completely ruled out.

Acknowledgments

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