GRANSHOT Iron Granulation for Optimized Plant Logistics

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Abstract
This article describes GRANSHOT iron granulation technology, operational experience and the usability of the end product in steelmaking operations. The GRANSHOT granulation process converts liquid metal into granules by rapid solidification in water. A ready–to–use bulk material is produced directly from liquid metal, without any intermediate crushing and sieving steps and producing little to no fume emissions and no dust. The equipment is more robust than comparable size pig casters due to its simplicity and absence of moving components. A GRANSHOT plant decouples ironmaking and steelmaking operations when required, and can be designed to process the entire output of the blast furnace. Optimization of plant logistics is illustrated by means of cases. Operational experiences with GRANSHOT plants of different sizes installed at integrated steelmaking plants are discussed. Metallurgical properties are summarized, such as carbon content in the metal matrix that reduces the energy usage when used as feedstock for Electric Arc Furnaces (EAFs).

Keywords
Pig iron, granulation, blast furnace, granshot, beaching, sand bed casting, sand bed pooling, GPI, environment

Introduction: Challenges in Hot Metal Logistics
In integrated steelmaking, plant managers and operators are asked to match their production to downstream or client demand with respect to output as well as metallurgical parameters. In addition, the plant performance that they’re held accountable for is assessed in terms of raw material consumption, achieved campaign lives of equipment and health, safety and environmental performance. Recent years have brought our industry times of exceptionally high demands calling for optimized synchronization in plant logistics, followed by times of unprecedented pressure from a decline in demand and surging raw material prices.

BOF shop operations focus on achieving optimum economy by producing heats that meet specifications exactly, i.e. with minimized heat repairs and minimized heats that are beyond specifications. Since the BOF process is a batch–wise process, as are downstream processes, a heat–based approach is justified. The major anomaly in plant logistics is in the BF–BOF hot metal supply, which connects processes that are continuous and batch–wise in nature.

Lack of synchronization that is the inevitable part of day–to–day operations may be buffered in torpedo or hot metal transfer ladles. Availability is, however, limited and prolonged buffering may be undesirable. Fluctuating demand from the BOF shop may also be met by fluctuating the output of the blast furnace. However, this comes at considerable penalties, since a destabilized BF process may escalate at severe consequences and process stability is essential for achieving maximum campaign life. In addition, the penalty for enabling the process to accommodate fluctuations is a steep increase in carbon source consumption. Being able to optimize the blast furnace process for stability is highly beneficial for campaign life as well as raw material consumption. The GRANSHOT process allows this process stability to be preserved by providing an outlet for hot metal when the steel plant is not able to use it.

Finally, blast furnace operators are faced with increasingly challenging raw material supply. While unprecedented demands from emerging economies are driving price levels to historically high levels, steelmakers are under pressure to keep their operations within environmental boundaries posed by governments and pricing boundaries that are dictated by markets that are unable to absorb steel prices that are in fact justified by the cost of raw materials and transport. More and more steelmakers find themselves testing their safe limits in raw material specifications and sources. Stabilizing and optimizing the blast furnace process using lower quality raw materials may be feasible, however stabilizing and optimizing the process while raw material qualities also vary is close to impossible. Where the fluctuation in raw materials and corrections to compensate for this translates into out of spec hot metal, the Granshot process provides the possibility of processing an out of spec batch of hot metal, not directly suitable for use in the steel plant as the main converter feed, but suitable to be added in small proportions as granulate.
Any pressure exerted on the blast furnace operator in addition to environmental and economic pressure from governments and the market may seriously jeopardize a plant’s competitiveness. Sub-standard process stability will be felt all along the production process, while avoiding this will undermine economy of operations. Eliminating the anomaly of having to synchronize a continuous process and a batch-wise process and being able to optimize the blast furnace process as if it were isolated is of great value to any steelmaker.

**GRANSHOT high capacity pig iron granulation process**

The GRANSHOT pig iron granulation process is designed for granulation of large batches of hot metal, currently up to 250 tonnes/h per single granulation unit. The process, was developed in the 1970s by UHT of Sweden, former Uddeholm Technology, and is today used whenever a metal producer wishes to turn his liquid metal into a solid material. The granulation process consists of four steps, (see also Figure 1):

- **Control** of hot metal flow
- **Granulation** by forming of metal droplets and rapid quenching
- **Discharge** of granules by ejector
- **Dewatering** of granules and transport to storage location

Control of hot metal flow is achieved by tapping into a tundish, where the nozzle limits the volume output. The hot metal exits the tundish and strikes a refractory spray-head as to form liquid metal droplets, Figure 2. These are evenly distributed over the granulation tank’s water surface, immediately quenched as they hit the cooling water surface.

The temperature of the iron granules is lowered as they sink to the bottom, exchanging heat with the counter-flowing cooling water. The water cooling and handling system is carefully balanced in order to ensure that the large amount of heat added by the liquid metal will be removed.

At the bottom of the granulation tank, the granules are discharged out of the tank by the ejector, which is powered by water and compressed-air. After dewatering, the granules are stocked in an intermediate or final storage area or silo. The granules, Figure 3, have ideal properties for logistical handling, making them easy to transport by conveyor belts, front-loaders, magnets etc.

The GRANSHOT process has some inherent characteristics that make it highly suitable to handle solidification of hot metals in Iron & Steel plants:

- Short stand–by time, typically 20–30 minutes
- Rapid processing time of 30 seconds from hot metal to a cooled granule
- Unaltered chemical analysis due to rapid quenching
- Close to 100% process yield
- Rugged process with high availability, low on staff and with limited maintenance
After preheating of tundish and nozzle for some 20–30 minutes the process is ready for use. The stand-alone granulation unit is completely automated, allowing one person to run the entire operation. The throughput time is around 30 seconds and has a process yield of close to 100%, which is a great improvement over traditional sand pit pooling and crushing operations. The granule itself has due to the rapid quenching process preserved the hot metal analysis. The granule shape, flattened sphere, results in a high bulk density of some 4000 kg/m³ and a high angle of repose, which allows for effective transport and storage. The rugged and in-use proven equipment design ensures highest availability and a minimum of maintenance.

Since the inception of the GRANSHOT process, it has been implemented at numerous plants around the world and for numerous applications. GRANSHOT is fully flexible with respect to the type of metal that is granulated in the unit; the straightforward nature of the process allows for implementation in all industries without fundamental changes.

**Implementation in Integrated Steelmaking**

When the GRANSHOT unit is implemented in an integrated steel plant to eliminate buffering requirement in hot metal logistics, the unit can be located either at the blast furnace site or closer to or inside the BOF shop complex. Both locations have their advantages. The final choice for a location may be dictated by the capacity balance between the blast furnace and BOF side of pig iron logistics. Whatever the variety of contributing factors, the selection of the location for the GRANSHOT unit deserves due investigation based on solid operational knowledge and experience.

**Plant Logistics**

Synchronizing a blast furnace, which strives for maximum stability, with a BOF steel plant, which is operated batch-wise and has to produce various steel grades and dimensions, is difficult and sometimes seemingly impossible. The most common way of tackling this in integrated steelmaking logistics means disrupting production. In reality this means that when one unit is experiencing operational problems the other will be idled. Thus the total metal flow through the plant is disrupted.

Disturbances in the production units downstream may in some cases require the Blast Furnace to reduce its production rate. Whether or not this can be avoided depends on the available buffering capacity of the fleets of torpedo and hot metal transfer ladles. Insufficient buffering capacities induce more frequent process disruptions for the blast furnace. These disruptions are highly detrimental.

Implementing GRANSHOT eliminates the detrimental consequences for the blast furnace process of the lack of buffering capacity. Beaching and pig casting do the same, albeit at far inferior environmental performance and for a much harder to process end product (see applicable paragraphs).

**The Blast Furnace Process**

Although the blast furnace process is continuous in nature, it can be disrupted if the tapped hot metal cannot be processed downstream. However, the ability to accommodate these disruptions comes at a substantial penalty in terms of carbon source consumption. Steering the process away from its optimum coke rate comes at higher cost and increased environmental footprint. In addition, process disruptions make it harder to maintain a fully stable process. A stable process, with minimized chemical, thermal and mechanical attack, is pivotal for achieving maximum campaign lives. Process escalations, which are not unlikely, especially when the furnace is operated on raw materials of lower and/or varying quality, may be catastrophic and risk thereof should be minimized or preferably eliminated wherever possible.

**Upstream Implementation**

Implementation of GRANSHOT close to the blast furnace or blast furnaces may be the obvious choice in most cases. An advantage of upstream implementation is the ability to feed hot metal to the GRANSHOT unit over a “hot” connection. If casthouse lay-out (and in the case of multiple blast furnace operations, furnace location) allows, this may be a feasible option. Also, the blast furnace department is usually responsible for supplying hot metal to the BOF plant as well as keeping the blast furnace performance at an optimum and this is where GRANSHOT fits in.

**Downstream Implementation**

Although it may not be the responsibility of the BOF plant to accept any hot metal that the blast furnace produces, implementation of GRANSHOT at the BOF premises may be very attractive given its advantages. Firstly, it allows for hot metal to be granulated after it has been desulphurized, which is impossible with granulation at the blast furnace. Secondly, granulating caster returns is possible in case plant operators decide it is too expensive, too unattractive or simply impossible to repair an off-spec heat, since GRANSHOT can be used to granulate any metal, including liquid BOF steel. Additionally, existing overhead cranes for handling of ladles and tundishes can be used when GRANSHOT is installed at the BOF premises.
Multiple Applications of GPI, Granulated Pig Iron

The granulated pig iron, GPI, is a prime iron product with excellent metallurgical and logistical properties for internal use in many metallurgical/steelmaking operations, or for sales to external customers. Some typical characteristics of the GPI are listed below.

Metallurgical:
- Homogeneous composition
- Very low oxide content
- High metallic yield (close to 100%)
- Excellent preheating properties and fast melting/dissolution when added to metallurgical process
- GPI includes iron carbide in the matrix, which is beneficial for scrap replacement in EAF operations

Logistical:
- High bulk density
- Inert during shipping and storage
- The granule shape (deformed spherical) is excellent for raw material handling with conveyor belt, magnet, front-end loader, bin systems and scrap skip.
- GPI has a high physical strength and a rounded shape. This eliminates break-offs during handling and reduces dusting
- GPI is easily handled during all stages of transportation from the producer to the consumer
- GPI shows no pyroforic behavior, so can be transported and handled without concerns of combustion

In Table 1 a comparison of GPI to alternative virgin iron sources such as Direct Reduced Iron (DRI) and Hot Briquetted Iron (HBI) is shown. Apart from the chemical differences there are also some major physical differences as discussed above.

<table>
<thead>
<tr>
<th>Properties</th>
<th>DRI/HBI</th>
<th>GPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comp. (wt-%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>1.5</td>
<td>4.2</td>
</tr>
<tr>
<td>Si</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>FeO</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Slag oxides</td>
<td>3.8</td>
<td>0</td>
</tr>
<tr>
<td>Fe</td>
<td>88.7</td>
<td>95.3</td>
</tr>
<tr>
<td>(Cu+Ni+Mo+Sn)</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Bulk density (kg/m³)</td>
<td>1600–2700</td>
<td>4000</td>
</tr>
</tbody>
</table>

Table 1 GPI in comparison to DRI/HBI [1, 2]

Blast Furnace Feedstock

At times when hot metal demand from downstream facilities exceeds the reduction capacity of the blast furnace, stockpiled GPI may be top-fed into the blast furnace to be melted. This is an excellent solution for achieving a temporarily increased output. The GPI, which was excess hot metal at an earlier time, re-enters the process in liquid form and before the desulfurization plant.

BOF Feedstock

The BOF converter is the vessel of choice for processing GPI or, in the case of GRANSHOT implementation for granulating caster returns, granulated steel. With chemical and metallurgical boundaries for scrap replacement in place, the ability to feed GPI instead of scrap introduces a major instrument for achieving economy in BOF operations. The high density and shape of the GPI allows for efficient feeding, rapid melting and yield when entered into the BOF process.

As illustrated in Figure 4 below, scrap availability is and will remain tight, adding to the likelihood of substantial pricing dynamics in the near future. These price dynamics call for instruments that allow for scrap replacement; GRANSHOT will definitely contribute, given ability to use GPI based cooling charges when scrap prices exceed hot metal production costs.

![Figure 4 Scrap Tightness](image)

EAF Feedstock

The uniform size, high density and the free flow characteristics also make the GPI suitable for continuous charging at an Electric Arc Furnace. This in turn allows for longer power on times, longer periods at maximum power and better metal temperature control. GPI can also be used for addition via the scrap basket. In this case the material is loaded by using an overhead crane and magnet. The high bulk density of the material is an advantage as the number of baskets can be minimized. In addition, high density (granulated) pig iron can be used to compact fluffy scrap like home sheet and busheling in the scrap bucket.

As indicated above, blast furnace quality iron sources have a chemical composition that is advantageous when compared to DRI/HBI. Beside the considerably higher (fully reduced) iron content, the higher carbon content introduces benefits for the EAF process as well.
Lab analysis of GPI (see Figure 5) has demonstrated that the carbon is included in the matrix in the shape of iron carbide as the result of rapid cooling of the iron droplet in the GRANSHOT unit. The carbon in GPI is more efficiently used in the EAF compared to external carbon additions. While coal and graphite additions to the EAF give yields of 40% or less, due to particle blow-off and high ash content, the carbon in GPI has a yield of 100%. Therefore, it is also a more economic solution for carbon addition. This adds to the reduction in power requirement when using (granulated) pig iron in general as opposed to when using DRI/HBI. As a result, energy consumption for melting GPI in the EAF stands at 268 kWh/ton Fe while DRI/HBI require 439 kWh/ton Fe.

Sale to other parties
Any of the advantages illustrated hold when the GPI is sold to a sister company or external consumers. Given its excellent materials handling characteristics, GPI is far preferred over pigs. Its advantages are proven by the long list of references in other industries, e.g. Ferro-alloy and precious metals, where GRANSHOT has been used to solidify saleable end-product for decades.

Benefits: Commercial
First and foremost, the benefits of GRANSHOT are found upstream. De-coupling the iron reduction process from downstream operations allows for process optimization with monetary benefits that can be easily evaluated for every plant. Eliminating the requirement for accommodation of swings or even interruptions in demand will reduce coke requirement. Cost differences between beaching and GRANSHOT were evaluated in an internal study conducted with a leading European integrated steelmaker and were found to be over 12 EUR/t in the favor of GRANSHOT. The evaluation included utilities consumption, manpower requirement, maintenance, refractory material consumption and processing costs (crushing, etc.) In modern day operations, beaching hardly ever averages under 1% (2% is more common) of the total annual hot metal production.

When the blast furnace process is optimized for maximum production and excess production is diverted to GRANSHOT for sale to external parties, the added value for hot metal production is an added quantifiable benefit without significant contributions to higher depreciation/amortization existing equipment. A feasibility study for a pig iron plant based in the European Union, which diverts 100% of its production to an existing pig casting machine, a pay-back time for the investment in GRANSHOT of well under one year was found.

Given the elimination of buffering requirement in integrated steelmaking, a reduction of the torpedo ladle fleet may be considered. Reduced maintenance costs as well as depreciation/amortization introduce a potential cost benefit.

Health, Safety & Environment
GRANSHOT as an alternative to beaching or pig casting has far superior HS&E aspects. The process has a slight manpower requirement, but operators work in a safe environment. The process has little to no emissions and there is no solid waste.

Health, Safety & Environmental performance of the three processes is compared in the matrix below.

<table>
<thead>
<tr>
<th>Process Type</th>
<th>Beaching</th>
<th>Pig caster</th>
<th>GRANSHOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time consuming, more than two days for cooling, crushing, screening</td>
<td>Large caster in separate building and rapid processing</td>
<td>30 seconds processing time, automatic handling of GPI possible</td>
<td></td>
</tr>
<tr>
<td>Personnel</td>
<td>Little personnel required, but unhealthy working environment (fumes, explosions)</td>
<td>Hands-on operating personnel required, hazardous working environment (see Figure 7, next page)</td>
<td>Operating personnel required, safe working environment</td>
</tr>
<tr>
<td>Emissions</td>
<td>Substantial dust and fume emissions (see Figure 6, next page)</td>
<td>Dust and fume, steam. Exposure of graphite.</td>
<td>Low environmental impact</td>
</tr>
<tr>
<td>Land use</td>
<td>Vast areas with heavy pollution</td>
<td>Big casting houses</td>
<td>Small footprint, usually inside existing premises</td>
</tr>
</tbody>
</table>
GRANSHOT facilities in operation

4 major steel makers in Europe, Africa and India have adopted the GRANSHOT granulation process as to handle their production of pig iron. The common feedback from operations is:

- Excellent metallurgical and logistical properties of granulated pig iron material
- Reliable and available industrial and high capacity process
- Rapid processing and low environmental impact
- Easy integration and cost effective operation

Eliminated restrictions for ESSAR Steel

The granulation unit was commissioned during end of 2010. There a 150 tonnes/hour GRANSHOT unit handles the hot metal from the new blast furnace and Corex® unit. The Granulated Pig Iron, GPI, is mainly used in the CONARC’s as to deoxidize the hot heel steel. Surplus GPI is used as an alternative iron source to HBI or scrap within ESSAR production or it is sold as an easily used and highly reactive merchant pig iron. Mr. Atul Misra, Sr. Vice President at ESSAR Steel Hazira concludes that; “GRANSHOT allows the blast furnace to produce pig iron with less restrictions from the steel making plant” making it an important process as to make blast furnace operations overall more effective.

World’s largest pig iron granulation unit at SSAB Oxelösund

SSAB had a 240 tonnes/hour capacity GRANSHOT® commissioned in 2007. The unit is designed for a continuous granulation of all blast furnace output during periods of steel plant maintenance. This allows that blast furnace production can be optimized, also that hot metal quality, i.e. temperature and analysis, are without major variations. The more stable blast furnace operations reduce stress on refractory.

Granulation of pig iron meets the demand of flexibility and rapid start up in order to function as a back-up facility. The produced GPI proves as an excellent ferrous feedstock for internal use in the BOF and for shipping overseas to EAF operators. The small footprint allowed it to be placed in the steel plant casting bay to allow for granulation of both pig iron and steel during maintenance or caster problems. Earlier sand pit pooling procedure with related environmental problems has now come to an end.
Productive granulation at ArcelorMittal Saldanha
The 120 tonnes/h capacity unit, installed in 2002, is located in a stand-alone building and handles excess iron produced in the Corex® iron making unit. The granulated iron is used as raw material in the downstream Conarc® electric steelmaking furnace, partly substituting merchant scrap and internally produced DRI as well as used as reduction agent to minimize the use of aluminium.

The operational cost of the granulator is considerably lower compared to sand bed pooling and the prime metal product shows excellent performance as a raw material feed into the steelmaking operations. Benefits have been seen on the Corex operation due to an increase in stability. Also the Conarc steelmaking operation has been enhanced by the use of a metallic feedstock with high levels of Si and C and without any content of gangue or unreduced oxides. The granulation unit also served to replace pooling as to minimize impact on the delicate habitat which surrounds the Saldanha steel plant location.

Compact integration at voestalpine Donawitz
GRANSHOT granulation was installed in 2000. The compact footprint of the 120 tonnes/h metal granulation unit allowed placing it inside the existing steel plant premises. The main task is iron granulation but the location also allows for granulation of steel. The granules are used as an additive in the converters or sold as a feedstock to other steel plants.

Studies
Since 2008, Uván Hagfors Teknologi (UHT) in Sweden and Danieli Corus have been working together on the implementation of GRANSHOT systems in integrated steel plants, their combined knowledge and technologies allowing them to assess plants and to create optimal solutions. The technology is proven in over 40 installations; however the benefits to a particular plant configuration need to be defined prior to making the decision to invest in such a system. By undertaking a techno-economic feasibility study on the Blast Furnace and steelmaking capacities and logistical arrangements, the areas for savings can be clearly highlighted. In many cases, this will be where there is either inherent or temporary mismatch between the Blast Furnace output and the steelmaking requirement, or indeed between the steelmaking plant and the continuous casting machines. Not addressing this mismatch may have a substantial ripple effect to the whole production chain. Alternatively, it can be taken out of the production stream and dealt with by the GRANSHOT system, allowing the production stream to continue without hindrance.

A feasibility study can quantify benefits for an individual plant and easily demonstrate where investments will be paid back more quickly.

Conclusions
• Implementation of GRANSHOT eliminates anomalies in plant logistics, allowing for full optimization of the blast furnace process, regardless of BOF plant performance
• The GRANSHOT process is superior to existing alternatives for processing excess hot metal
• Reduced maintenance and personnel requirement and higher yield make GRANSHOT financially attractive, even if a steel producer has an existing pig casting machine
• GPI is easy to process and has optimum properties for processing in the blast furnace, BOF converter and electric arc furnace
• Locating the GRANSHOT unit at the BOF premises allows for processing of hot metal after desulphurization as well as processing of caster returns
• GRANSHOT complies with health, safety & environmental regulations

References

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