

Cold-agglomerated briquettes as alternative of ferrous burden for blast furnaces

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Abstract

The key factor in reducing CO_2 emissions in the steel industry depends on decreasing fossil fuel consumption in reduction reactors, whether through process optimization or the adoption of disruptive technologies, such as the use of hydrogen and new methods for obtaining primary iron. In this context, cold-agglomerated briquettes stand out as a sustainable alternative, as they require less fossil energy to be produced and exhibit suitable properties for use in blast furnaces. The binder technology developed allow the production of a material with physical, chemical, and metallurgical characteristics compatible with the requirements of these reactors, after curing at low temperatures. This technology has been proven through industrial tests in blast furnaces of various sizes. This paper presents the evaluation of two types of cold-agglomerated iron ore briquettes: one to replace acid pellets and another, with appropriate proportions of CaO and MgO , designed to replace semi-fluxed pellets and sinter. The latter has unique high temperatures properties compatible to high-performance ferrous burden with potential to decrease CO_2 emissions by up to 10% in hot metal production.

Keywords: Cold-agglomerated briquettes; Iron ore; Blast furnace.

1 Introduction

The global steel industry is undergoing a profound transformation driven by the imperatives of decarbonization, resource efficiency, and operational flexibility. Within this evolving landscape, the development of alternative iron ore burden materials that reduce environmental impact and enhance process efficiency has become increasingly important. Among these, cold-agglomerated briquettes - produced through low temperature agglomeration of fine iron ores and binders - have garnered renewed attention as a low-carbon feedstock option for both blast furnace and direct reduction process.

Iron ore fines, while abundant and chemically favorable, are generally unsuitable for direct use in reduction reactors due to their fine particle size, resulting in a poor permeability when applied without previous agglomeration. Conventional agglomeration routes, such as sintering and pelletizing, remain widespread but are energy-intensive and major sources of CO_2 emissions, particularly from the combustion of fossil fuels [1]. In contrast, cold agglomeration offers the potential to eliminate high-temperature processing altogether, allowing for the valorization of ultra-fines, industrial by-products, and waste materials in a more sustainable way [2,3].

Recent advances in binder technology, curing methodologies, and process control have improved the technical feasibility of cold-agglomerated briquettes in industrial-scale operations. Studies have shown that cold-agglomerated briquettes can achieve compressive strengths above 200 kgf/briquette, sufficient for handling, transport, and in some cases, charging into shaft furnaces and blast furnaces [4-7]. However, challenges remain particularly regarding the balance between mechanical strength and metallurgical performance. High binder content can lead to excessive slag generation or reduced reducibility, while insufficient binder may compromise the briquette's integrity during storage, transport, or reduction [8,9].

While much of the literature remains focused on laboratory-scale formulations, industrial case studies are crucial to bridge the gap between research and industrial application. Understanding how cold-agglomerated briquettes behave under actual operating conditions - subject to real furnace atmospheres, mechanical handling, and thermal cycling - is essential to assess their viability as a commercial product. This work introduces the main characteristics of a new product, the cold-agglomerated iron ore briquettes.

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The flexibility of process, the technological solution of binder and additives developed allows to achieve a product with unique properties that meets the needs of the blast furnace process. The acid cold-agglomerated briquette is designed to replace acid ferrous burden such as lump ore and acid iron ore pellets. For the replacement of fluxed pellets and sinter, the High Reducibility (HR) cold-agglomerated briquettes, with appropriate proportions of CaO and MgO, were developed. Both briquettes were tested in blast furnaces under real process conditions. This study consolidates the physical and metallurgical properties of the cold-agglomerated briquettes and compares it with the traditional blast furnace burdens. Finally, insights into the main performance indicators of some of the blast furnaces trials were discussed.

By grounding the analysis in an actual production context, this work contributes to the growing body of knowledge on low-carbon agglomeration technologies and supports ongoing industry efforts toward circular economy practices, raw material flexibility and green steelmaking.

2 Materials and methods

2.1 Cold agglomerated iron ore briquettes

The main steps of production of cold agglomerated briquettes were raw materials preparation and mixing using a horizontal intensive mixer (Eirich® mixer model R07). The next step was the agglomeration, where the raw mix pass through the parallel rolls of a briquetting machine (Komarek® model DH300), producing the pillow shape briquettes. Finally, the product passes through a movable conveyor furnace for curing and for the achievement of its final physical properties.

2.2 Physical, chemical and metallurgical characterization

Following their production, the acid and HR cold-agglomerated briquettes were characterized as detailed in Table 1. Although there is currently no ISO standard specifically addressing the characterization of briquettes, the analysis were conducted in accordance with established procedures commonly applied to pellets and sinters.

2.3 Softening & Melting (S&M) test

The methodology for evaluation of high temperature properties of ferrous burden is based on procedure proposed by a Japanese steelmaker. The equipment and methodology are more deeply explored in previous work [10,11]. Briefly, the experimental procedure consists of charging the ferrous burden sample between two layers of coke in a graphite crucible (100 mm in diameter and 180 mm in height) that is positioned in the central region of the furnace. Both ferrous burden and coke were sized between 10-16 mm. The reducing gases enter the system at 800°C and heating occurs until the material drips [12].

In S&M test, various high temperature parameters of ferrous burden are monitored and determined, specially:

- Temperature of start of cohesive zone (T_{s200}): this temperature corresponds to the moment when the pressure drop reaches 200 mmH₂O during the heating of sample;
- Temperature of end of cohesive zone (T_{e200}): this temperature corresponds to the moment when pressure drop again reaches 200 mmH₂O, after passing a peak of pressure drop;
- Temperature range of cohesive zone (ΔT): the temperature difference between start and end of cohesive zone;
- Drip temperature (T_d): the temperature of starting to drop of liquid phase;
- S area (S): it is an indicator of overall permeability of bed during the test. This is a calculation of the area under pressure drop curve between the moment that pressure drop reaches 200 mmH₂O, and passes through a maximum and reaches again a pressure drop of 200 mmH₂O;
- Maximum pressure drop (ΔP_{max}): this is maximum pressure drop of gases achieved during the test;
- Reducibility Indexes: during the test the gas analysis composition of outlet gases was done. Based on it, the reducibility at different temperatures was calculated.

Table 1. Characterizations performed based on ISO standards

Characteristics	ISO Standard
Chemical analysis (%)	ISO 2597, ISO 11535, Thermogravimetric analysis
Size distribution (%)	ISO 4701
Tumble Index (% > 6.35 mm) Abrasion Index (% < 0.50 mm)	ISO 3271
CCS (daN)	ISO 4700
Shatter (% > 10.0 mm)	JIS M8711
Reducibility, RI (%)	ISO 7215
RDI (% < 2.83 mm)	ISO 4962
Swelling Index (%)	ISO 4698

In summary, this test aims to reproduce the behavior of ferrous burden at the cohesive zone of the blast furnace and during its descent over the shaft. These parameters could be grouped as temperature parameters, which shows an indication of the position of the cohesive zone (T_{s200}), its thickness ($\Delta T = T_{e200} - T_{s200}$) and the primary liquid phase melting point (T_d). The pressure drop is measured during all tests and gives the indication of how the gases flow through this region. This information could be grouped as permeability parameters, allowing determination of the ΔP_{max} and the calculation of S area.

Finally, with the outlet gas analysis, the estimative of reduction behavior of the burden during its descent at the shaft of blast furnace could be inferred. High performance burdens have high temperature of beginning of cohesive zone together with a high reducibility.

3 Results and discussion

3.1 Main characterizations

The cold-agglomerated iron ore briquettes have a pillow shape measuring $25 \times 21 \times 13$ mm as shown in Figure 1. This material has a narrow size distribution which is very good for processing in ironmaking reactors.

Table 2 presents the chemical composition of the cold-agglomerated briquettes produced under laboratory conditions, alongside the typical composition range for acid and semi-fluxed pellets and sinter, as derived from an internal database.

Regarding physical and metallurgical properties, Table 3 and 4, respectively, summarize the results obtained from laboratory testing of cold-agglomerated briquettes,



Figure 1. Cold-agglomerated iron ore briquettes.

Table 2. Chemical composition of cold-agglomerated iron ore briquettes and typical values for acid and semi-fluxed pellets, and sinter

	AC Briquette	HR Briquette	AC Pellet ⁽¹⁾	Semi-flux Pellet ⁽¹⁾	Sinter ⁽¹⁾
Fe %	65.0	57.1	63-65	64-66	53-59
FeO %	0.15	0.11	0-0.2	0-0.2	6.5-8.5
SiO ₂ %	5.3	4.4	2.4-5.3	2.5-3.3	5.2-7.7
Al ₂ O ₃ %	0.36	0.33	0.8-2.0	0.7-1.8	1.2-1.6
P %	0.010	0.016	0.060 max	0.060 max	0.090 max
CaO %	0.22	5.90	1.1-1.6	2.5-2.8	8.7-14.0
MgO %	0.07	1.05	0.4-0.6	--	0.7-1.3
Na ₂ O %	0.59	0.61	--	--	0.10
LOI %	0.64	6.2	--	--	--
B ₂ (CaO/SiO ₂)	0.04	1.35	0.30-0.50	0.85-1.00	1.7-1.8

⁽¹⁾Typical values based on internal database.

Table 3. Physical quality of cold-agglomerated iron ore briquettes and typical values for acid and semi-fluxed pellets and sinter

	AC Briquette	HR Briquette	AC Pellet ⁽¹⁾	Semi-flux Pellet ⁽¹⁾	Sinter ⁽²⁾
Tumble Index, % > 6.35 mm	90.4	86.7	88.0-93.0	90.0-93.5	60.0-70.0
Abrasion Index % < 0.50 mm	9.3	13.1	5.0-7.5	5.5-7.5	7.0-12.0
Shatter % > 10.0 mm	98.8	99.8	--	--	85.0-93.0
CCS daN/Pel or Brq	517	268	220-260	220-260	--

⁽¹⁾Typical values based on internal database. ⁽²⁾Typical values based on internal database and reports from literature [13,14].

Table 4. Metallurgical quality of cold-agglomerated iron ore briquettes and typical values for acid and semi-fluxed pellets and sinter

	AC Briquette	HR Briquette	AC Pellet ⁽¹⁾	Semi-flux Pellet ⁽¹⁾	Sinter ⁽²⁾
Reducibility, %	50	72	60-65	75-85	65-75
RDI, % > 2.83 mm	8	4	5-8	3-6	20-40
Swelling Index, %	25	20	20-25	13-15	--

⁽¹⁾Typical values based on internal database. ⁽²⁾Typical values based on internal database and reports from literature [13,14].

Table 5. Main chemical parameters for the pellets and sinters tested in S&M furnace

	Pel 1	Pel 2	Sinter 1	Sinter 2
Fe %	63.0	65.7	53.0	59.0
FeO %	0.2	0.7	6.7	7.6
SiO ₂ %	5.0	2.6	7.7	5.2
Al ₂ O ₃ %	0.8	0.8	1.6	1.3
MgO %	0.5	--	1.3	0.7
B ₂ (CaO/SiO ₂)	0.30	0.93	1.77	1.73

Table 6. S&M test results, Δp_{\max} and S area for cold-agglomerated iron ore briquettes, acid and semi-fluxed pellets, and sinter

Code and material description	Permeability parameters	
	S (kg. ^o C/cm ²)	ΔP_{\max} (mmH ₂ O)
BQT AC Acid Briquette	80	7,061
BQT HR High Reducibility Briquette	41	5,070
Pel 1 Semi-fluxed pellet	57	3,659
Pel 2 Acid Pellet	112	8,261
Sinter 1 Low Fe sinter	51	4,786
Sinter 2 High Fe Sinter	32	3,736

conducted in accordance with the relevant ISO standards previously mentioned. For comparison, the physical and metallurgical properties data for acid and semi-fluxed pellets were sourced from internal database, while the sinters were from internal database and reports from literature [13,14]. The results of Tables 2 to 4 showed that acid briquettes were similar to acid pellets, while HR briquettes are like semi-fluxed pellets and sinter.

3.2 S&M test

To promote a comprehensive evaluation and comparison between cold-agglomerated iron ore briquettes and conventional blast furnace agglomerated burdens, two distinct types of iron ore pellets were selected: an acid pellet and a semi-fluxed pellet.

Additionally, two sinter samples with similar basicity levels were also chosen, characterized by variations in their

SiO₂ and Fe contents. All pellets and sinters were sourced from an internal database.

Table 5 described the main chemical parameters of the pellets and sinters which were in line with the range presented in Table 1. Acid briquettes have a chemical composition similar to acid pellets. HR briquettes has lower Fe content, when compared with semi-fluxed pellets and sinter, due to the presence of limestone on their composition.

Table 6 shows the results of Δp_{\max} and S for the materials evaluated in the S&M furnace. The performance of acid briquettes was comparable to that of acid pellets, suggesting their potential as viable complementary ferrous burden alongside sinter. The combination of acid briquette with sinter, may enable the optimization of the sinter chemical quality, given better physical and metallurgical properties to this ferrous burden component.

The HR briquettes have better permeability parameters compared with semi-fluxed pellets and in line with sinter,

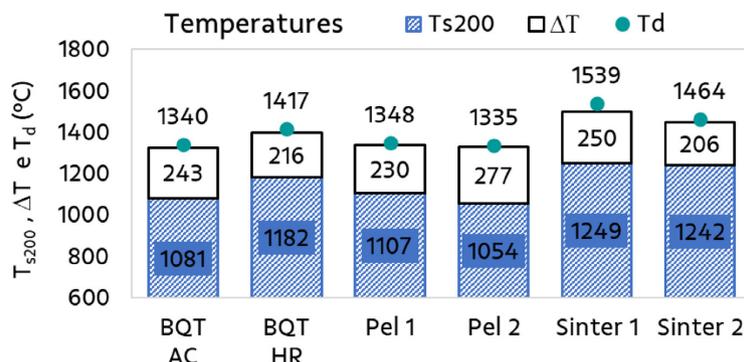


Figure 2. Temperatures obtained in S&M test for cold-agglomerated iron ore briquettes, pellets and sinter.

depending on their chemical composition. This material could work as a complementary burden and as main burden as it has the adequate chemical composition for full replacement of sinter and semi-fluxed pellet in BF burden.

Figure 2 shows the temperature results obtained from S&M test for the materials investigated in this work, Ts200, ΔT and Td. Acid briquettes demonstrated superior performance compared to acid pellets. HR briquettes have suitable temperature properties within the cohesive zone, indicating their potential as major component of the ferrous burden in blast furnace operations. In certain cases, their performance even surpassed that of regular sinters typically used as blast furnace ferrous burdens.

Figure 3 presents the results of the Reducibility (Figure 3a) and the R_{s200} versus T_{s200} (Figure 3b) obtained from the S&M test. The Reducibility behaviour of both types of briquettes are similar to that of the respective burden materials they are intended to replace. Clearly, both briquette types are favourably positioned on the R_{s200} versus T_{s200} curve, indicating suitability as either complementary or major ferrous burden components in blast furnace operations.

It is important to note that the softening and melting results presented in Table 6 and Figures 2 and 3 refer to single burden performance. In practical applications, however, where these materials may be used complementarily, there is potential for further optimization and improved outcomes. For instance, incorporating acid pellets into sinter-based burden could allow for an increase in sinter basicity, which is generally associated with enhanced productivity and improved reducibility of the sinter [15,16].

3.3 Industrial trials

Table 7 presents some qualitative results of the main trials performed with cold-agglomerated briquettes since 2019.

In general, the cold-agglomerated briquettes technology developed for blast furnace applications has demonstrated consistent performance, aligning with results achieved at the laboratory scale. Industrial trials performed by multiple customers confirmed the performance of the briquettes, with all customers reporting favourable outcomes. The briquettes exhibited superior characteristics compared

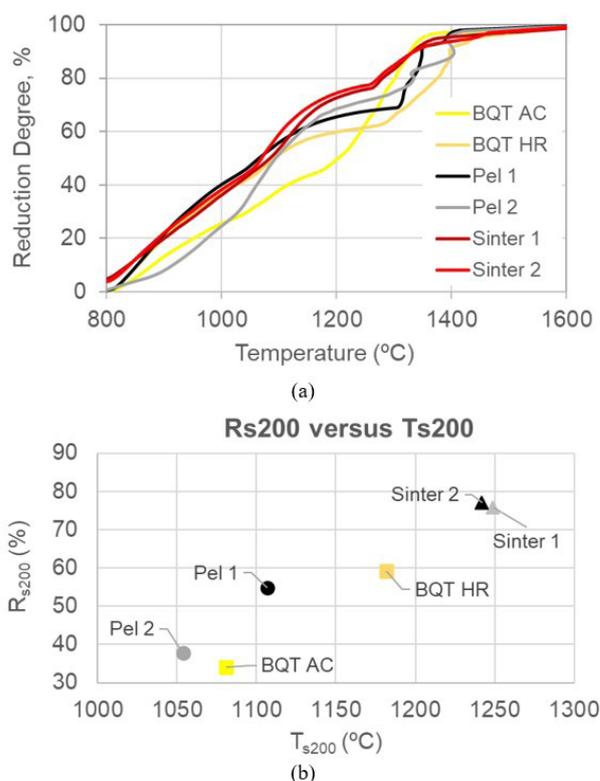


Figure 3. Reducibility results from S&M test for cold-agglomerated iron ore briquettes, pellets and sinter: (a) Reduction degree curve along the S&M test; (b) Reduction degree at the beginning of cohesive zone (R_{s200}) versus temperature of the beginning of cohesive zone (T_{s200}).

to other materials previously tested, positioning them as an excellent low-carbon alternative for enhancing blast furnace operations, such as increasing productivity and fuel consumption. Furthermore, despite the presence of sodium in the briquettes, all industrial trials indicated that the sodium removal via slag was satisfactory and did not adversely impact blast furnace performance.

The majority of customers who have tested the briquettes are currently engaged in co-located plant projects. Furthermore, these customers have expressed interest in carrying out longer-term trials to assess the product's performance and stability in different operational conditions.

Table 7. Overview of main briquette trials to date

	# Trials				
	A	B	C	D	E*
BF Size	< 300 m ³	> 3,000 m ³	<1,000 m ³	< 1,000 m ³	< 300 m ³
Days of trial	22 days	9 days	12 days	20 days	10 days
Year	2019	2021	2022	2023	2025
Briquette type	Acid	Acid	HR	HR	Acid
Material replaced	Lump	Pellets	Sinter	Pellets	Pellets and Lump
% Used	50%	20%	20%	35%	100%
Fuel type	Charcoal	Coke	Coke	Charcoal	Charcoal
Productivity	Improved	Same	Same	Slight increase	Same
Fuel Rate	Improved	Same	Same	Slight decreased	Same

*Regular use of 60% (replacing lump and pellets) of acid briquettes in BF burden for more than 6 months.

4 Conclusions

The industrial-scale validation of cold-agglomerated iron ore briquettes marks a significant advancement in the pursuit of sustainable and flexible ironmaking solutions. These briquettes have demonstrated excellent physical and metallurgical performance under blast furnace conditions, confirming their viability as an alternative to traditional burden materials such as lump ore, sinter, and pellets. A key advantage of these briquettes lies in their ability to incorporate ultra-fines and industrial by-products through low-temperature processing. This not only contributes to reduced CO₂ emissions but also aligns with circular economy principles and the broader transition toward low-carbon steelmaking.

The study underscores the critical role of industrial trials in bridging the gap between conceptual innovation and practical application. The successful implementation of both acid and high-reducibility (HR) briquettes highlights the versatility of the cold agglomeration process in meeting diverse operational requirements. These briquettes exhibited physical integrity, favourable metallurgical behaviour, and high-temperature performance comparable to - or even surpassing - that of conventional materials like acid and fluxed pellets and sinter.

Softening and melting tests revealed favourable permeability and cohesive zone characteristics, ensuring efficient gas flow and structural stability during descent in the furnace shaft. Industrial trials across various blast furnace sizes further validated these findings, with briquettes maintaining or improving productivity and fuel consumption metrics. Notably, the presence of sodium did not lead to operational issues, as it was effectively removed via slag, with no evidence of scaffold formation or alkali buildup.

Finally, cold-agglomerated briquettes emerge as a technically robust and operationally flexible solution for optimizing blast furnace performance. Their adoption supports the steel industry's decarbonization strategies and paves the way for a more sustainable and resilient future in iron and steel production.

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