




## Novel roller screening technology for enhanced reduction of fine particles in iron ore fired pellets production

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### ABSTRACT

Direct reduction (DR) furnaces are highly sensitive to pellet size distribution; fines (<5.0 mm) raise bed pressure drop and sticking risk, impacting plant productivity and more frequent shutdowns. Conventional vibrating screens, commonly used to handle hard particles, struggle in screening efficiency due to blinding, screen media wear behavior, and impact-induced degradation. This work presents and evaluates a roller-screen solution adapted for hard particles, tested with iron ore fired pellets and pellet screening. Laboratory trials used 20 rolls of 300 mm length deck, operating at intense laboratory loading ( $\sim 221.1 \text{ t h}^{-1} \text{ m}^{-2}$  of screening surface) and confirmed the effectiveness of the process. Further, industrial prototyping employed a 30-roll unit of 1200 mm length. Data was collected over 17 days of operation, processing more than 3000 t of material with controlled variation of the feed rate, roll speed and gap opening. Wear test using iron ore fired pellets was also performed to assess the roll's lifespan.

Industrial trials using roller screening technology conducted with fired pellets showed an average screening efficiency of 95.1%, combining 91.6% undersize removal with 97.3% good-size retention. For the pellet screening type of material (feed containing 89.5% <6.3 mm fines), average global efficiency was 82.5% with 85.1% of screening efficiency to remove fines, what is explained by the higher amount of near-size pellets contained in the pellet screening feeding the equipment, presenting a higher amount of goodsize particles to the recirculating load. Results indicate that an optimal gap opening seems to be between 5.0 and 7.1 mm. Rolls showed no damage visually after 40 hr of closed-loop lab operation and after the industrial campaign. Collectively, the industrial data demonstrated that fired-pellet classification with the roller screen adapted to handle hard particles is feasible, efficient, and provided softer handling, providing higher screening efficiencies if compared with conventional vibrating screens.

Future research should focus on developing numerical models to enhance process understanding and optimization of roller screen handling hard particles, investigate the optimization of roller screen gap settings for pellet screening, assess performance with other hard materials and evaluate roll lifespan under real operating conditions.

### 1. Introduction

The steel sector accounts for approximately 7% of global anthropic CO<sub>2</sub> emissions, making it a major target for decarbonization efforts (Kang et al., 2022). One of the most advanced strategies currently

available involves using gas-based direct reduction (DR) combined with electric arc furnace (EAF) technology. This approach can cut direct process emissions by as much as 60% and provides a practical pathway for shifting from natural gas to green hydrogen, as renewable energy becomes more accessible (Hamadeh et al., 2024; Jang et al., 2025). In

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DR shaft furnace configurations, fired iron ore pellets are the main feed material. Their mechanical strength and, above all, particle size distribution play a decisive role in maintaining bed permeability, controlling heat and mass transfer, reducing sticking potential, and optimizing productivity and energy efficiency (Li et al., 2025; Midrex, 2024). Reducing the fines fraction in gas-based DR shafts improves bed permeability and gas distribution, lowers pressure drop, mitigates sticking/cluster formation, and boosts metallization and productivity, whereas even ~2 to 5 wt% fines can materially degrade these parameters and increase process losses and dust load (Boechat et al., 2018a, b; Chevrier, 2019; Kamble et al., 2020). This improved permeability directly influences productivity levels and helps reduce the specific energy requirements of DR plants (Feng et al., 2023; Midrex Technologies, 2024; Young, 2024).

Fines arise predominantly during post-induration handling and screening. Mineralogy modulates fracturing, causing hematite-hematite grain surfaces/edges to break more easily than magnetite-magnetite ores (Patankar et al., 2025; Smith and Müller, 2024). Packed-bed experiments show a near-linear increase in pressure drop ( $\Delta P$ ) with fines content: each additional 1% of <6.0 mm material adds roughly 7.0 to 10.0 mbar/m at typical gas fluxes in a DR shaft (Li et al., 2025). Complementary computational fluid dynamics (CFD) results predict gas bypass and hot-spot formation that can elevate local temperatures by up to 80 K, initiating sticking and intermittently arresting bed descent (Smith and Müller, 2024). Field data from Athayde, de Souza (Athayde et al., 2017) corroborates the laboratory trends: fines fractions of iron ore pellets decrease plant productivity and negatively impact pellets quality.

Vibrating screens were the original standard in pelletizing plants in the late 1950s to handle green pellets, but their operating principle, screening by high-frequency excitation, subjects green pellets to repeated impacts and shear, which can markedly increase degradation of on-size pellets and reduce process efficiency. In addition, vibrating screens typically require intensive maintenance (e.g., mesh wear, frequent interventions) and may transmit dynamic loads to surrounding structures, with the risk of structural fatigue depending on vibration frequency and excitation conditions (Andrade et al., 2022).

Initial pelletizing operations relied on vibrating screens to screen iron ore green pellets, but this approach frequently resulted in high levels of pellet degradation and poor screening performance. The emergence of roller conveyors in the late 1950s, and their subsequent transformation into roller screen systems by the 1960s and 70s, introduced a gentler and more efficient screening alternative (Meyer, 1980). In a roller screen, a collection of parallel rolls rotates in the same direction, driven by a single electric motor or by individual motors, at a defined speed, and the rolls are arranged to maintain a controlled gap opening between adjacent rolls to allow undersized material to pass through while retaining oversized particles, effectively classifying the product based on size (Andrade et al., 2022; Carvalho et al., 2023; Silva et al., 2017; Silva et al., 2025). Classification is governed primarily by this gap-opening strategy: particles smaller than the effective opening are expected to pass (undersize), while larger particles are retained and conveyed onward (on-size/oversize), but also with an important impact of the rolls rotation speed and screen deck inclination angle. Because the bed is transported by roll rotation rather than vibration, pellets are generally exposed to lower mechanical stress than on vibrating decks, which helps preserve green-pellet integrity (Meyer, 1980). Research has shown that roller screens can achieve up to 25% greater classification efficiency than traditional vibrating screens, while significantly reducing mechanical damage to the green pellets (Meyer, 1980). Additional benefits include lower recirculation rates, more consistent pellet size distribution, and increased throughput capacity under industrial conditions (Goncharenko et al., 1982). Historic comparisons also suggest that roller screen classification can outperform conventional vibrating screens when the objective is to preserve particle integrity and maintain sharp separation (Meyer et al., 1980; Goncharenko et al.,

1982). This architecture proved excellent for green pellets (not a mechanically resistant material) but struggled with fired pellets, whose hardness (>250 kg/pellets) accelerated roll wear, widened gaps, and eroded separation sharpness (Andrade, 2024; Inc, 2024; Metso, 2024).

It is important to explain the differences between green iron ore pellets and fired iron ore pellets, while the first one is an agglomerate of iron ore concentrate with binder, dolomite, coal and water, the last one counted by 8.5 to 10.5%, presenting a very adhesive behavior and low mechanical strength. Fired iron ore pellets are the green pellets after passing through a firing process in a travelling grate, straight grate or rotary kiln furnaces, improving the mechanical strength to a range of 250 to 350 kg/pellets and adjusting its chemical characteristics for the steelmaking processes, moisture content is theoretically equal to zero, but the pellets can absorb a small amount of water from the environment after the furnace (in the stockyards), anyhow the adhesion characteristics of fired pellets is reduced compared to iron ore green pellets.

From an operational standpoint, roller screening is best described as a probabilistic separation process controlled by pellet motion and stratification over the roll deck. As pellets flow across the rolls, rearrangement of the moving bed promotes percolation of smaller particles toward the gaps and “floating” of larger particles toward the bed surface, increasing the likelihood that undersize pellets reach the gap and pass through. This sequence: feed distribution, bed rearrangement/segregation, probability of particle–gap interaction, and separation, captures the fundamental contrast with vibrating screens, where stratification and passage are driven predominantly by vibration-induced transport and repeated particle-deck impacts (Drahn and Bridgwater, 1983; Williams, 1976). Overall, the key difference between the technologies is the dominant transport and classification mechanism: vibrating screens rely on vibration driven conveyance and repeated impacts against a screening surface, whereas roller screens rely on controlled, continuous rolling conveyance with separation dictated by inter-roll gap geometry and the evolving bed stratification over the deck. For green pellets, where mechanical fragility and moisture sensitivity are critical, this distinction explains why roller screening is commonly associated with lower pellet degradation, more stable separation at elevated moisture, and downstream benefits tied to tighter size distribution (Andrade et al., 2022). Therefore, while the vibrating screening relies on the vibration motion to displace particles and screen the material, shaking particles in the device, reducing the specific probabilities for each particle to reach the open meshes and increasing the wear pattern and clogging on the vibrating meshes, the roller screen relies on a linear displacement of particles over the rollers, which increases the probabilities of particles to reach the gap openings and be properly screened out. Fig. 1 presents a schematic of the mechanisms used in a vibrating screen and in roller screen technology.

Table 1 presents a comparative analysis of the physics mechanisms governing the roller screen and vibration screen technologies, specially showing the benefits of roller screen technology in terms of adhesion, squeezing and wear behaviors.

Despite the adoption of advanced screen media on vibrating screen technology, such as polyurethane or rubber panels with modular or self-cleaning configurations, the operational lifespan continues to be a key constraint on classification performance and equipment availability. Over time, screen apertures can become deformed, or wires may break, leading to shifts in the effective cut size, increased bypass of near-size material, and reduced separation precision. These problems often require frequent maintenance interventions, which disrupt plant throughput. The issue is further compounded when processing hard and abrasive materials like fired pellets, sinter, or crushed ore, where the combined effects of impact and sliding abrasion accelerate media degradation compared to softer feedstocks. Engineered media generally outlast woven wire, but the basic trade-off—durability vs. open area and maintenance windows—persists, so wear management remains central to sustaining efficiency and availability (Flsmidth, 2024; Causes of failures in vibrating screens, 2024; Flsmidth, 2024; Metso, 2025; Mining

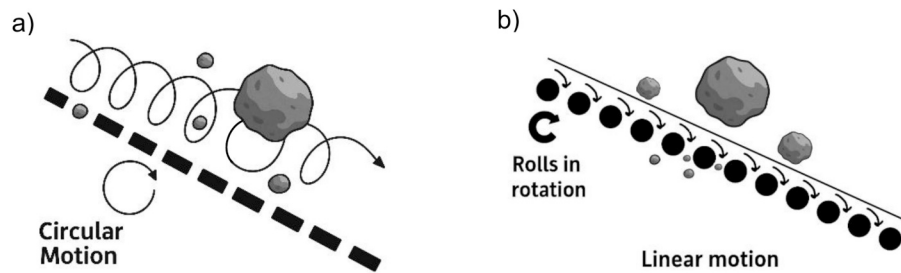


Fig. 1. Screening mechanisms. (a) Vibrating screen. (b) Roller screen.

**Table 1**  
Comparative of parameters of roller screen and vibrating screen.

| Parameter                              | Roller screen   | Vibrating screen  |
|--|---|---|
| Driving mechanism                      | Continuous rolling conveyance; separation occurs as particles encounter inter-roll gaps while the bed rearranges and segregates (Andrade et al., 2022; Carvalho, 2023)  | Oscillatory motion (frequency, amplitude/stroke, motion profile) transports and stratifies particles on a screen surface (Sullivan, 2013)                       |
| Transport mechanism                    | Linear transport over the rolls   | Vibration/oscillation motion  |
| Parameters controlled by the equipment | Rolls rotational speed, gap opening, deck inclination angle   | Vibration/oscillation intensity   |
| Contact particles – equipment          | Soft contact of pellets and rolls in rotation (Andrade et al., 2022; Meyer, 1980; Carvalho, 2023; Silva et al., 2017; Goncharenko et al., 1982; Inc., M., Roller screening and balling solutions., 2024; Jafari et al., 2025; Silva, 2017a; Silva et al., 2018; Silva et al., 2019) | High impact of particles with the screen meshes   |
| Particles stratification               | Particles segregation with the rotational movement of rolls   | Particles segregation depending on the vibration/oscillation intensity  |
| Adhesion behavior                      | Minimal, due to the rotational movement of rolls. Often cited as more tolerant for moist/sticky and deformable materials, with reduced build-up compared with screen cloths in similar tasks (Andrade et al., 2022; Jafari et al., 2025)  | High, moisty and sticky material can promote blinding/plugging of screen apertures and loss of effective area (Goncharenko, 1982)                               |
| Squeezing behavior                     | Minimal, due to the rotational movement of rolls  | High, due to the intense impact of particles on the screening meshes  |
| Wear pattern                           | Low, due to quick contact of particles and the rolls surface in rotation  | High, due to the vibration/oscillation mechanism and high impact and contact time of particle with meshes.  |
| Maintenance profile                    | Wear concentrates on rolls, coatings, and drive components; fewer issues with blinding, but roll surface wear and gap stability are key (Andrade et al., 2022; Carvalho, 2023)  | Vibration exciters, bearings, and screening media are wear-critical; condition monitoring focuses on motion/stroke/frequency to avoid failures (Flsmidth, 2024) |
| Structural/dynamic loads               | Typically no transmitted vibration to structures because the system is not intentionally oscillated (Andrade et al., 2022)  | It can transmit dynamic loads to supporting steel/concrete; motion control and avoiding resonance are important operational considerations (Flsmidth, 2024)     |

Review, 2025; Scales, 2016; Trelleborg, 2025). Pilot trials (Kingsford, 1991) on a  $1.2 \times 3.6$  m inclined vibrating screen at Hamersley Iron

showed that even with a so-called non-blinding surface, the removal efficiency for  $<6$  mm fines plateaued at  $\sim 72\%$  once throughput exceeded 450 t/h, while on-size pellet breakage added another 0.8% to the fines stream. Computational fluid dynamics coupled with Discrete Element Methods (CFD/DEM) work by Donohue, Cleary (Donohue et al., 2017) corroborates these observations: fines adhering to coarser particles can depress screen efficiency by up to 15%, especially when aperture-to-particle ratios fall below 1.2. Meanwhile, retrofits on sinter plants at Cherepovets raised fines capture by  $\sim 25\%$  after installing high-frequency vibrators, yet deck wear remained the principal bottleneck (Zepov and Nikiforov, 1974). Industrial guides describe similar trade-offs: in practice, vibrating-screen efficiencies commonly fall in the 80–90% range, it could be lower when higher amount of near-size material is present (PowderProcess.net, 2025). High-frequency screens can deliver fine cuts and high capacity, but they often require stricter feed pretreatment to limit blinding. Flip-flow designs mitigate blinding by cyclically stretching elastic mats and operate at very high accelerations (reported up to  $\sim 500 \text{ m s}^{-2}$ ), which enhances passage of sticky fines; however, such energetic motion can increase impact/attrition risk for brittle, hard particles (e.g., fired pellets, sinter), so application should be validated for the specific feed (AG, B.C. BIVITEC Flip Flow Technology (Brochure), 2019; Cavalcanti et al., 2019; Gustafsson et al., 2017; Tavares et al., 2018). Complementary laboratory and modelling studies on inclined linear and high-frequency vibrating screens typically report 60–80% undersize removal efficiency when handling near-size particles, with performance degrading at higher throughputs or when fines adhere to coarser surfaces (Wang and Tong, 2011; Zhang et al., 2016). Table 2 presents a comparative analysis of the vibrating screening and roller screening performances handling hard particles, the table does not intend to perform a detailed comparison between both technologies, since the type of material, feed tonnages, cut sizes, etc. may change from one application to another; therefore the table intends to collect the best vibrating screen performances found in the literature and compare with roller screen technology handling hard particles.

Building on a comprehensive investigation of screening practice in iron-ore pelletizing, Andrade, Beaudin (Andrade et al., 2022; Andrade et al., 2024) describe the main operating variables, the range of devices available on the market, and how these choices shape plant performance. In their treatment, roller screening is inherently probabilistic: the likelihood that a particle reports to the correct stream depends on pellet motion, deck inclination, particle orientation and shape, feed size distribution, inter-roll gap uniformity, and residence time. Screening outcomes are further governed by capacity geometry, often expressed as a screening ratio ( $\text{t m}^{-2}$ ), and by design choices such as the number of rolls, rolls diameter, rolls length, and the applied feed rate (Andrade et al., 2022; Silva et al., 2025; Andrade, 2024; Silva et al., 2019; Javaheri et al., 2021; Thomazini, 2020). Increasing the rolls quantity at fixed tonnage lowers the screening ratio and increases available surface area, thereby raising the probability that particles encounter a gap; however, it also expands the required footprint and tends to drive CAPEX/OPEX upward. Excessive roll amount can impair pellet transport (the so-called “cigarette effect”), where particles lodge and bridge, distorting their shape and partially occluding apertures (Andrade et al., 2022).

**Table 2**  
Comparative of vibrating screen performance handling hard particles.

| Author                                      | Type of research                | Type of material screened   | Technology       | Screening efficiency to remove fines           |
|---|---------------------------------|---|------------------|--|
| Kingsford (Kingsford, 1991)                 | Pilot plant                     | Fired iron ore pellets + fines (< 6 mm)   | Vibrating screen | ≈ 72%  |
| Zhang, Gong (Zhang, 2016)                   | Experimental + LS-SVM modelling | Fine particulate material on probability screen ( $a \approx 0.9$ mm; <0.6 mm fraction of interest) | Vibrating screen | ≈50 – 80%                                      |
| Silva, Cangani (Silva, B.P.d., 2017)        | Experimental                    | Iron ore sinter   | Vibrating screen | 74%  |
| Portnov, Koverzin (Portnov et al., 2014)    | Experimental                    | Iron ore sinter   | Vibrating screen | ≈ 55 to 60%                                    |
| PowderProcess.net (PowderProcess.net, 2025) | Theoretical / design guide      | Generic bulk solids   | Vibrating screen | 80—90% (theoretical)                           |
| Wang and Tong (Wang and Tong, 2011)         | DEM 3D simulation               | Generic granular material   | Vibrating screen | < 60%  |
| Kumar, Vardhan (Kumar et al., 2020)         | Experimental                    | Powdered slag   | Vibrating screen | ≈ 59.3% to 65.9%                               |
| <b>This work – lab-scale roller screen</b>  | Experimental                    | Fired pellets (5 mm and 12.5 mm cuts)   | Roller screening | – 5.0 mm gap: 98.33% / – 12.5 mm gap: ≈ 70.13% |
| <b>This work – industrial roller screen</b> | Experimental                    | Fired pellets, cut at 5 mm  | Roller screening | = 91.6%  |
| <b>This work – industrial roller screen</b> | Experimental                    | Pellet-screening (~85% < 6.3 mm fines)  | Roller screening | = 85.1%  |

Reducing roll diameter, allows for an increase in the quantity of rolls for the same footprint, it expands the screening area and typically improves fines removal, quantified in DEM supported trials that showed higher proportion of undersize removal as diameter decreased (Silva et al., 2018; 2019). Longer rolls increase screening width and area, improving classification probability at constant feed. By contrast, overfeeding lifts the screening ratio and shortens effective residence time; both experiments and simulations show that overloaded decks lose efficiency, with more undersize carried forward and more oversize misplacement (Wang and Tong, 2011). Uniform gap settings, sustained through maintenance, wear control, and appropriate hard-facing, are critical; irregular wear increases recirculation and broadens product particle size distribution (PSD) (Andrade et al., 2022; Silva et al., 2018; 2019). Mechanical straightness of rolls affects actual gaps under load, so bending or poor manufacturing tolerance degrades classification (Silva et al., 2018). Even bed distribution across the width influences efficiency: better feed spreading reduces localized loading, slows uneven wear, and improves the probability of fines accessing the gap (Silva et al., 2018). Finally, surface roughness, roll speed, and screen angle interact to set transport velocity and residence time; higher speeds modify residence time, rolling dynamics, and bed shear conditions within the separation zone, while deck angle changes the transport regime and the extent of particle rearrangement over the deck. Tests and models show that optimizing rotational speed and angle can improve removal of <6 mm material without sacrificing good-size retention (Goncharenko et al., 1982; Wang and Tong, 2011; Javaheri et al., 2021; Bérubé and Dubé, 2013).

Peer-reviewed coverage of fired-pellet roller screens remains limited; existing studies largely focus on green-pellet classification or generic bulk-solids handling (Andrade et al., 2022; Silva et al., 2017; Silva et al., 2025; Goncharenko et al., 1982; Andrade et al., 2024; Inc, 2024; Jafari et al., 2025; Silva, 2017; Silva et al., 2018; Silva et al., 2019; Javaheri et al., 2021; Thomazini, 2020; Bérubé and Dubé, 2013; Beaudin and Godin, 2021; Branco et al., 2023). This gap motivates the present work, which sets out to characterize separation efficiency of a roller screen specially designed to handle hard particles under lab and industrial loads. This technology represents an innovative solution since it has never been used in application with hard particles. Conventional roller screening systems are typically constructed with metallic or hard-faced rolls, which limit their application to hard materials due to the elevated risk of equipment damage and/or granule breakage during the screening process. Another innovation of the proposed approach is the incorporation of a rubber lining on the surface of metallic rolls within a conventional roller screening configuration, demonstrating effective

performance in the processing of hard particles, such as fired pellets. The rubber coating plays a critical role in enabling the treatment of hard particles. In situations where pellets become compressed between adjacent rolls, the elastomeric liner, when designed with adequate thickness, undergoes elastic deformation, allowing the particles to pass through the gap openings. After load release, the liner recovers its original geometry, preserving both equipment integrity and particle quality. In contrast, when fully metallic rolls are employed under similar loading conditions, the mechanical stresses are transmitted directly to either the rolls or the particles, resulting in equipment damage, excessive wear, or pellet crushing. The paper also defines a wear tests setup adapted to simulate the roller screen conditions and investigate the lifespan of 7 different rubber coating types under the same lab-scale tested conditions, some limitations are imposed, specially related to rubber aging effect and particles temperature. The paper presents the results of laboratory scale tests and industrial prototyping of using roller screening technology to handle iron ore fired pellets and pellet screening. The results are mainly presented in terms of screening efficiency.

## 2. Materials and methods

Laboratory tests were conducted by using a set-up with a roller-screen device containing 20 rollers of 77.5 mm in diameter and 300 mm in length, a feed conveyor belt, discharge conveyor belts and a drum (for use with wet iron ore pellets, not used for fired iron ore pellets). This set-up accepts samplings at the discharge point of retained and passing materials, the screening efficiency is calculated based on these samplings and considering the particle size distribution at the feeding material. The screening efficiency is defined by the capacity of the screen to remove undersized pellets and to keep goodsized pellets in the final product, as presented by Andrade, Beaudin (Andrade et al., 2022). The set-up also accepts a closed-loop circuit, to evaluate the mechanical robustness of the screening device and rollers behavior. Fig. 2 presents the set-up used in the lab-scale tests for screening efficiency and closed-loop evaluation. To collect samples to validate the particle size distribution at the discharge of retained and passing materials after screening, a deflector is installed to split the load of retained and passing materials without mixing both loads, in this evaluation, only the items 1 and 2 of the setup presented in Fig. 2 was used. For the closed-loop test the complete configuration presented in Fig. 2 was used, whereas the charge of retained and passing materials fall off at the same conveyor belt, since samples are not collected.

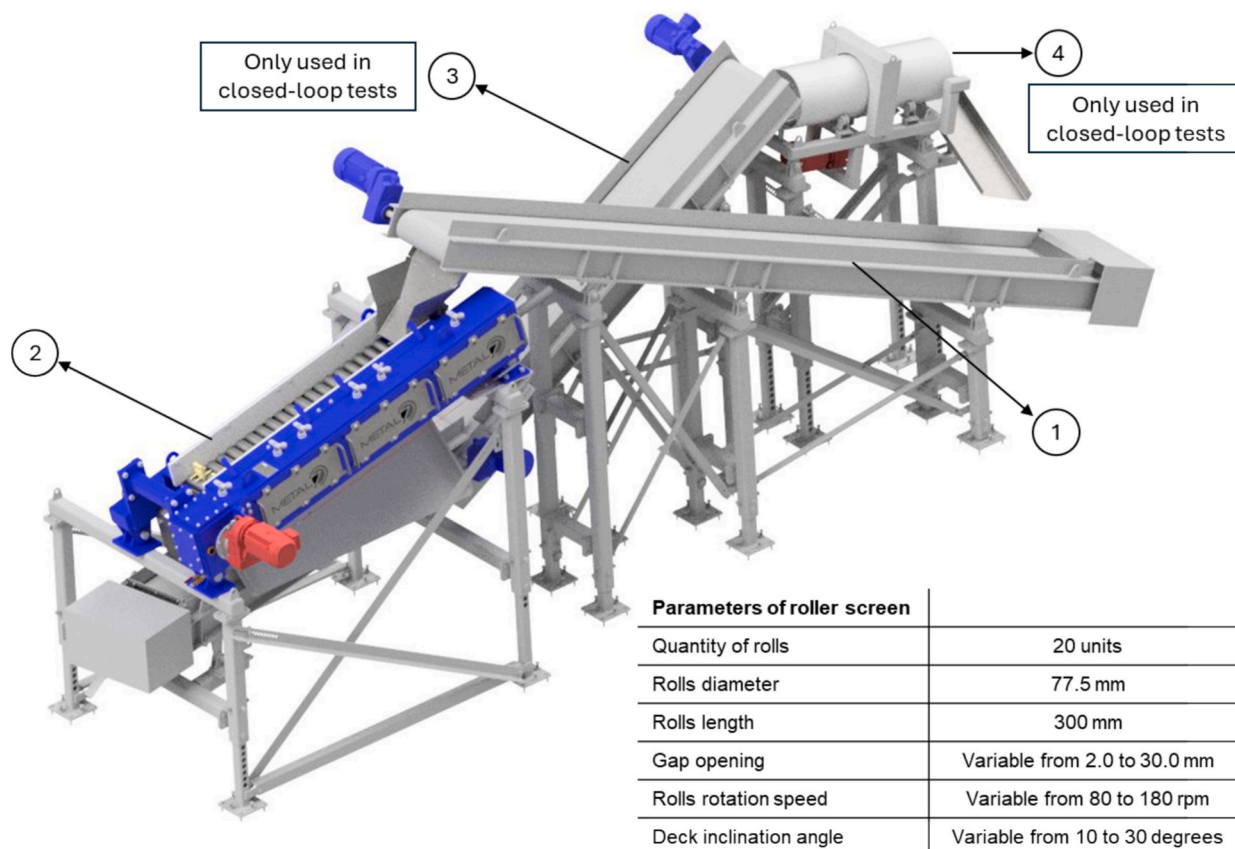


Fig. 2. Set-up used in the lab-scale tests with the (1) feed conveyor, (2) roller screen, (3) transport conveyor and (4) balling drum.

The lab-scale trials had the main objective to identify the screening efficiencies of the roller screen by handling iron ore fired pellets. Therefore, for that, it was run trials by using two different gap opening strategies, at 5.0 mm to simulate the removal of fines after the induration furnace and 12.5 mm to simulate the hearth layer separation done by vibrating screens after the induration furnace. For the screening efficiency assessment, the trials were conducted by batch, using a feed rate calculated to simulate the industrial application and evaluating the particle size distribution at the feeding point and discharge of goodsized particles. All the feeding and discharge of goodsized material were collected to validate the particle size distribution. The sample volume for each test is defined in Section 3.1. Rolls rotation speed was fixed at 100 rpm for all the tests conducted. Deck inclination angle was fixed at 13 degrees. For the closed-loop trials, the primary objective was to evaluate the operational robustness of the rolls and drive system, enabling estimation of real-scale equipment performance. Therefore, no intermediate sampling was performed during the 40-hour continuous closed-loop operation, as no process optimization or screening efficiency assessment was required at this stage.

In the closed-loop configuration, both the passing and retained fractions were discharged onto a collecting conveyor belt and automatically recirculated to the system, eliminating the need for continuous addition of fresh material and allowing sustained operation under steady-state recirculating conditions.

The particle size distribution of the iron ore pellets was evaluated in accordance with ISO 4701:2019 (ISO, 2019), which specifies the method for determining the size distribution by sieving. The Taylor meshes used to evaluate the screening efficiency are 0.0 mm, 5.0 mm, 6.3 mm, 8.0 mm, 9.5 mm, 11.2 mm, 12.5 mm, 14.0 mm, 16.0 mm and 18.0 mm.

The industrial trials were conducted in a stockyard of an iron ore pelletizing plant and used two different types of material, iron ore fired pellets and pellet screening. Three (3) samples are collected per day to

compound a daily sample, the particle size distribution analysis is done over the daily sample. Each individual sample had a mass of 10 kg. Sampling was performed at three predefined time intervals during the operating day, specifically at 10:00 h, 13:00 h, and 15:00 h.

For all the test presented in the paper, moisture content is below 2.0%, therefore adhesion forces are minimized and were not observed during the trials. It is important to mention that adhesive forces combined with high moisture content, such as presented in iron ore green pellets, may imply in build-up over the rolls and for this kind of application a standard roller screen will better fit, since it uses specific anti-wear and anti-adhesion coatings. For a small moisture content, even if there is a small adhesion on the rolls surface, the elastic behavior of the rubber coating self-cleans the rolls surface during operation.

For the typical iron ore fired pellets after the induration furnace, the screening efficiency was calculated based on sampling conducted at three key points of the screening process: the feed, the discharge of the passing material, and the discharge of the retained material. It is considered the cut size fraction at 5.0 mm for this group of material. The analysis also considered the respective tonnages of feed, passing, and retained fractions. Complete particle size distribution analyses were conducted on the feed, retained, and undersize (passing) materials from the screen. These analyses enabled a direct comparison of the fines and goodsized fractions in both the feed and the final product.

This second material is the reject of the vibrating screen after the induration furnace, which is sold as pellet feed for the steelmaking industry. Tests were carried out with gap openings of 5.0 mm and 7.1 mm and roller rotation speeds of 40.4, 56.5, 72.6, and 96.8 rpm. The main objective of this screening step is to recover goodsized particles (>6.3 mm) of the group of pellets named pellets screening and reincorporate it in the iron ore fired pellets as a goodsized product. The cut size fraction at 5.0 mm is considered for this group of material. Pellet screening is a term used for the reject stream of vibrating screens after the induration

furnace. It is important to note that during normal operation, this type of material is not screened a second time to recover the goodsize pellets in it, presenting around 15–20% of goodsize material in the reject. So, for example, considering a Pellet Plant with annual production of 5 MTPY (million tons of pellets per year), considering 3% of reject, it represents 150,000 tons of pellets and considering 15% of goodsize pellets in this volume of material, it represents 22,500 tons of goodsize material lost annually. The screening efficiency calculation for the pellet screening follows the same procedure used for the pellets. However, the weighing was performed on the retained material, considering its smaller quantity compared to the undersize material. It is important to note that this type of material contains approximately 85% fines (<5.0 mm), which forces a large portion of material to pass through the roller gap openings. This significantly reduces screening efficiency compared to pellets.

For the industrial trial, a semi-industrial prototype was fabricated containing 30 rolls of 77.5 mm in diameter and 1200 mm in length. Fig. 3 presents the semi-industrial prototype.

The results are based on data collected over 17 days of trial, 10 days handling iron ore fired pellets and 7 days with pellet screening material, totaling more than 3000 tons of material processed in the industrial prototype. Rolls rotation speed and gap opening were modified during the trials depending on the feed rate and particle size distribution at the feeding material to better configure the roller-screen device. Fig. 4 presents the set-up used for the industrial prototype trial.

As explained by Andrade, Beaudin (Andrade et al., 2022) the screening efficiency in a roller-screening process is defined by the capacity to keep the goodsize particles in the final product, and the capacity to remove the undersized and oversize particles from the process. When only the fines are removed, it is the capacity to remove fines and keep goodsize particles in the final product.

$$\%SE = \left(\frac{GS_f}{GS_i}\right) \times \%GS_i + \left(\frac{US_f - US_i}{US_i}\right) \times \%US_i \tag{1}$$

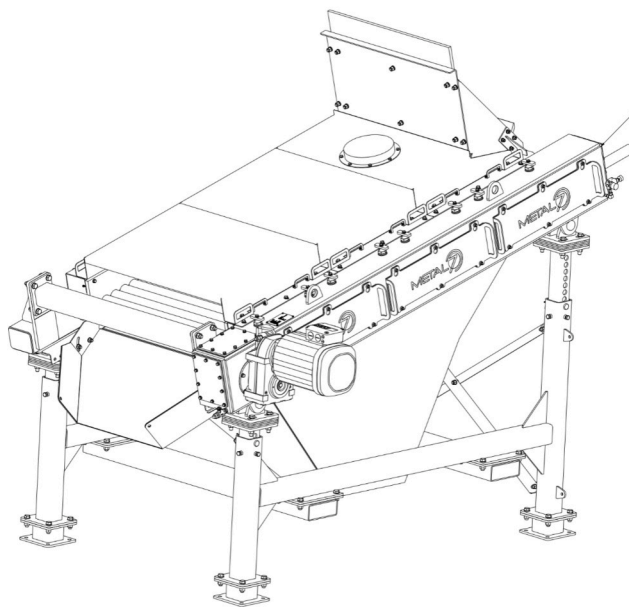
where, %SE =screening efficiency,  $GS_f$  = goodsize particles in the product stream (t/h),  $GS_i$  = goodsize particles in the feeding point (t/h),  $\%GS_i$  = percentage of goodsize particles in the feeding point.  $US_f$  = undersized particles in the product stream (t/h),  $US_i$  = undersized particles in the feeding point (t/h),  $\%US_i$  = percentage of undersized particles in the feeding point.

The results are presented in Section 3, separately in the following subsections according to Table 3.

The operational parameters summarized in Table 3 were selected based on industrial pellet quality specifications, feed particle size distribution (PSD), and probabilistic screening theory. Gap openings were defined according to the targeted separation objective: (i) 5.0 mm to simulate fines removal after the induration furnace (<5.0 mm fraction), (ii) 12.5 mm to simulate hearth layer separation (>12.5 mm), and (iii) 7.1 mm to investigate recovery of goodsize pellets (>6.3 mm) from pellet screening material.

Rotation speeds were selected to evaluate the influence of roll kinematics on energy transfer to the bed, contact-force distribution, bed shear rate, and the resulting particle rearrangement/stratification, particularly under high near-size concentration. For pellet screening material, where fines represent approximately 85–90% of the feed, parameter adjustments were driven by the need to balance fines removal efficiency and goodsize retention, given the strong near-size effect observed in this material.

The tests conducted to assess the lifespan of the rolls were performed using the laboratory-scale equipment illustrated in Fig. 2. The



| Parameters of roller screen |                                |
|-----------------------------|--------------------------------|
| Quantity of rolls           | 30 units                       |
| Rolls diameter              | 77.5 mm                        |
| Rolls length                | 1200 mm                        |
| Gap opening                 | Variable from 2.0 to 30.0 mm   |
| Rolls rotation speed        | Variable from 80 to 180 rpm    |
| Deck inclination angle      | Variable from 10 to 30 degrees |

Fig. 3. Roller screen semi-industrial prototype used in tests with iron ore pellet.

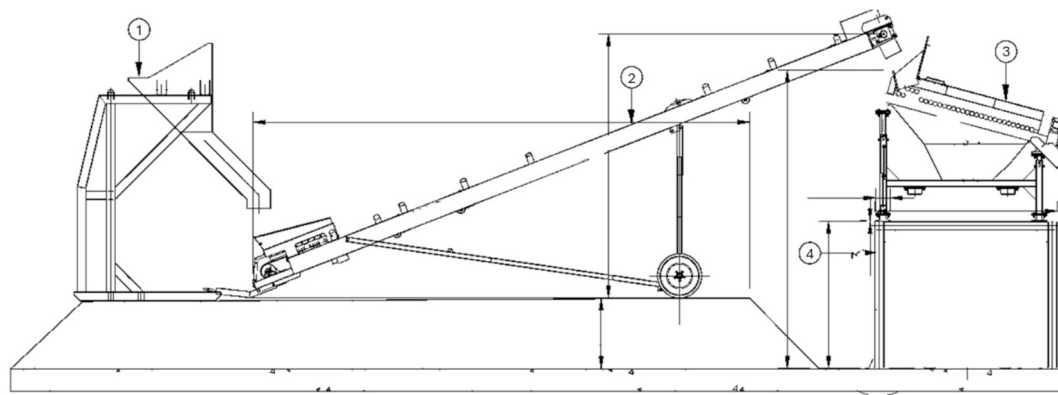


Fig. 4. Set up for the industrial trial: (1) feed silo, (2) feed conveyor belt, (3) roller screen and (4) elevated support structure.

Table 3

List of trials presented in the next sections.

| Experimental setup   | Material              | Gap opening (mm) | Deck angle (°) | Rotation speed (RPM) | Cut size evaluation (mm) | Estimated tonnage screened (t/h) | Selection basis / technical rationale  |
|----------------------|-----------------------|------------------|----------------|----------------------|--------------------------|----------------------------------|--|
| Lab-scale setup      | Iron Ore fired pellet | 5                | 13             | 100                  | 5.0                      | 106 t/h                          | Gap selected to simulate industrial fines removal (<5.0 mm) after induration furnace. Cut size aligned with ISO 4701 sieve definition and DR shaft operational requirement. High rotational speed (100 rpm) is used to simulate worst-case loading and assess screening robustness under severe bed depth. |
|                      |                       | 12.5             | 13             | 100                  | 12.5                     |                                  | Gap selected to simulate hearth layer separation (>12.5 mm)  |
| Industrial prototype | Iron Ore fired pellet | 5                | 15             | 40.4                 | 5.0                      | 30 – 40 t/h                      | Gap defined according to industrial specification for DR plants (<5.0 mm removal). Speed selected to evaluate performance under moderate kinematics and lower feed rate.   |
|                      |                       |                  | 15             | 56.5                 | 5.0                      |                                  | Increased speed selected to increase roll-to-bed energy transfer, contact forces, and bed shear, thereby promoting particle rearrangement, fines percolation, and more effective stratification before separation.   |
|                      | Pellet screening      | 5                | 15             | 72.6 / 96.8          | 6.3                      |                                  | Initial gap maintained at 5.0 mm to evaluate fines removal under high fines loading (~85% <5.0 mm). High speeds tested to compensate fines overloading and limited bed stratification. Cut size evaluation set at 6.3 mm to match industrial pellet classification (>6.3 mm goodsizes).                    |
|                      |                       | 7.1              | 15             | 40.4 / 56.5 / 96.8   | 6.3                      |                                  | Gap increased to 7.1 mm after observing limited fines passage at 5.0 mm due to dominance of near-size particles (0.5—6.3 mm).  |

experimental setup was modified by incorporating separators after every four rolls to ensure particle retention within the system. A minimum roller gap of 1.0 mm was maintained to minimize the loss of fine particles. The experimental configuration employed for the evaluation of roll lifespan is schematically presented in Fig. 5. In total, 7 distinct coatings formulations were tested. Roll wear was quantified through diameter measurements, with three measurements obtained for each roll at every evaluation interval: one at the right end, one at the left end, and

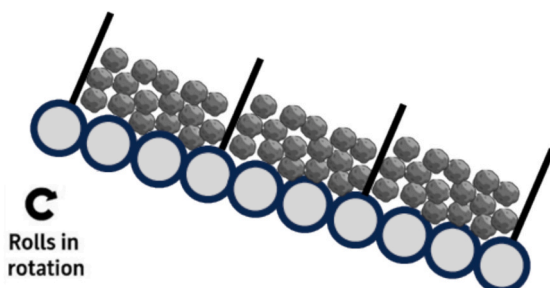


Fig. 5. Scheme of rolls lifespan tests.

one at the midpoint. These measurements were performed at each 400-hour interval throughout the testing campaign using a digital caliper. Iron ore fired pellets were used as the feed material during the trial. Pellets bed layer was kept constant at 2-inches over the trial period. The performance of the rolls under hot pellet conditions was not evaluated in this study.

The trials were conducted under continuous operating conditions, 24 h per day and 7 days per week, over a total testing period of 2,290 h (95 days). The tests were carried out at ambient temperature. A fixed rolls rotation speed equal to 110 rpm was used in the trial. All the coatings were tested at the same time, environmental and operational conditions.

Due to intellectual property, coating characteristics are not presented in the paper. Coating thickness for all tested formulations are 7.0 mm.

### 3. Results and discussion

#### 3.1. Lab-scale tests

The particle size split of the feeding material used in the lab-scale

tests is presented in Table 4. As can be seen in the table, for the tests aiming to remove fines, the amount of fines (<5.0 mm) is equal to 1.2% and the main objective is to remove the fines as much as possible. For the second objective of the tests, to separate the hearth layer particles to be used in the grate cars in the induration furnace, particles above 12.5 mm are aimed, and this material is used to protect the grate bars and green pellets for thermal shock. This particle size is evenly important to allow a good gas permeability over the green iron ore pellet layer. Fines are defined, in both cases, as the fraction below the cut size apertures, being <5.0 mm in the first tests and <12.5 mm in the second test.

It is important to note that the feed rate used in the lab-scale tests is much higher than what is found in the typical industrial applications for green pellets (as reference, since presently the roller screen technology is only used to handle green iron ore pellets). While the lab-scale tests used 80 kg of feed load for each individual test, for a screening area of 0.48 m<sup>2</sup> of the lab-scale set-up, which gives a ratio of 221.1 t h<sup>-1</sup> m<sup>-2</sup> of screening area. This increased amount of material was used to evaluate the worst-case scenario in lab-scale evaluations. According to Silva, Cunha (Silva et al., 2019) and Thomazini (Thomazini, 2020), typical industrial iron ore green pellets applications uses a ratio of 60–70 t h<sup>-1</sup> m<sup>-2</sup> of screening area. This fact in itself can have a negative impact on screening efficiency, since a greater amount of material fed into the roller screen means a lower probability of each individual particle reaching the openings and being properly screened (Andrade et al., 2022; Carvalho et al., 2023; Silva et al., 2019; Thomazini, 2020).

Table 5 presents the mean screening efficiencies found in lab-scale tests for the cut sizes at 5.0 mm and 12.5 mm, according to the screening efficiency definition presented in Eq. (1). For tests using cut size at 5.0 mm, screening efficiency to remove fines is 98.3% while the screening efficiency to keep goodsize pellets is 95.8%. Even though the high load over the screening deck, the lab scale tests using 5.0 mm of gap opening presented a high performance to remove fines (<5.0 mm). It is important to mention that fines distributed in the feeding stream are randomly dispersed, requiring a residence time to segregate and reach the gap openings of the roller screen technology, so as higher is the pellet bed layer, more residence time is required for all the fines to reach the gap openings. The ability to retain goodsize particles (>5.0 mm) was slightly inferior, but still presenting a high performance, the inefficiency is caused by the elastic deformation of the rubber coating under pressure of the pellet bed layer, forcing part of particles higher in diameter than the gap opening to pass through the spaces between the rolls, it was caused specifically by the elevated amount of material used in the tests. It is important to mention that vibrating screening performance at a similar process presents a maximum screening efficiency of 80%, as presented in Table 2.

In tests with a 12.5 mm cut-off particle size, the screening efficiency showed a lower result, see Table 5. This is explained by the fact that 62.5% of the load is composed of particles <12.5 mm (which is called Fines in this case), presenting a much higher concentration of particles near-size compared to the gap opening of 5.0 mm. It overloads the gap openings of the screening device and reduces screening efficiency, since near-size particles have around the same probability to be retained or passing through the gap openings. The result of 70.1% screening efficiency to remove fines indicates that part of fines, in this case particles <12.5 mm, remains in the material retained in the screening deck and it is strongly related to the particles near-size. The result of 95.1% screening efficiency to keep goodsize particles (>12.5 mm in this case)

**Table 4**  
Particle size split of the feeding material and cut size definition.

| Objective                          | Cut size | Feed         |           |
|------------------------------------|----------|--------------|-----------|
|                                    |          | Goodsize (%) | Fines (%) |
| Remove fines (<5.0 mm)             | 5.0 mm   | 98.8%        | 1.2%      |
| Hearth layer separation (>12.5 mm) | 12.5 mm  | 37.5%        | 62.5%     |

**Table 5**  
Screening efficiency in lab-scale trials.

| Objective                           | Efficiency to remove fines (%) | Efficiency to keep goodsize (%) |
|-------------------------------------|--------------------------------|---------------------------------|
| Remove fines (< 5.0 mm)             | 98.3%                          | 95.8%                           |
| Hearth layer separation (> 12.5 mm) | 70.1%                          | 95.1%                           |

shows that most of the targeted particles remain in the final product, presenting a low amount of goodsize in the fines stream. Increasing the residence time (or reducing the rolls rotation speed) can improve the results, especially the fines removal efficiency. The screening process is a probabilistic method, depending on the particle size, shape, particle orientation, etc., whereas pellets can be retained or pass through the gap openings at the same probabilities, as explained by and Zhang, Gong (Zhang et al., 2016).

Table 6 presents the fines percentage before and after the screening process. In the configuration with 5.0 mm gap opening, the percentage of fines (<5.0 mm) in the feed was 1.20%, while after the screening process it dropped to 0.02%, it represents a clean product stream showing a low amount of fines in the final product. In the test configuration with a 12.5 mm opening, the percentages of fines (<12.5 mm in this case) decreased from 62.5% to 34.37%, still presenting a good amount of fines in the final product, since the increase amount of near-size particles presented in the feed stream, in this situation, the residence time of particles over the screening deck should increase and/or a different gap strategy should be applied, for example slightly increasing the gap openings to remove more fines.

According to the lab-scale results, the screening efficiency to remove fines <5.0 mm is considered high compared to vibrating screens, presenting mean screening efficiency to remove fines of 98.33%, whereas the vibrating screens present in average 75–80% efficiency depending on the type of material screened, as presented in Table 2. As explained previously, the screening efficiency is impacted by the amount of near-sized pellets and for the gap opening of 12.5 mm there is a higher quantity of near-sized particles which reduces the screening efficiency for this specific set-up. Especially for this second set-up, a reduction in screening efficiency does not cause a negative impact in industrial operations, since hearth layer (particles higher than 12.5 mm) is reused in the process and it is not lost as a rejected material.

### 3.2. Industrial prototype trials

#### 3.2.1. Iron ore fired pellets

For the iron ore fired pellets trials, the gap opening used was 5.0 mm, as the main objective is to remove undersized pellets and cracked material (<5.0 mm) from the final product, and two different roller rotation speeds were tested, at 40.4 and 56.6 rpm.

Fig. 6 presents the particle size distribution of the fired pellets and pellet screening (the results of the second one are presented in Section 3.2.2). As can be seen, there is a major difference in the material feeding the roller screening, while the fired pellets presented 7.5% of <5.0 mm, the pellet screening material presented 60.6% of <5.0 mm. The PSD differences is due to the pellet screening group of material represents the fines rejected by the vibrating screens at the discharge of the induration furnace. And as it can be seen, for the pellet screening material there is around 40% of goodsize material possible to be

**Table 6**  
Percentages of fines before and after screening.

| Objective                          | Fines in the feed (%) | Fines in the final product (%) |
|------------------------------------|-----------------------|--------------------------------|
| Remove fines (<5.0 mm)             | 1.20%                 | 0.02%                          |
| Hearth layer separation (>12.5 mm) | 62.50%                | 34.37%                         |

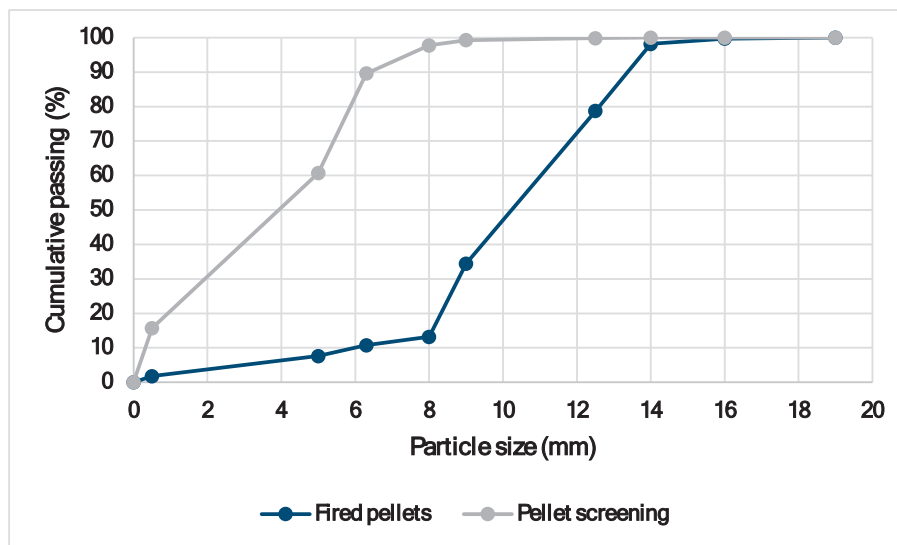


Fig. 6. Particle size distribution of feed material – Fired Pellets and Pellet screening.

recovered from this material, representing the inefficiency of the vibrating screens in operation.

The average screening efficiency to retain goodsize particles in the final product was 97.3%, while the average screening efficiency for removing fines was 91.6%. Based on these results, the average global screening efficiency achieved during the tests was 95.1%. At a roll rotational speed of 40.4 rpm, reduced fines removal efficiency was observed (in average). This behavior can be attributed to the combined effect of low roll kinematics and reduced feed rate, which limited particles kinetics and the driving forces required to promote particle rearrangement and passage through the screen apertures. Under these operating conditions, particle's percolation was insufficient to increase the probability of passage of undersize and near-size particles. Furthermore, the low solids throughput resulted in inadequate bed depth, impairing the screening kinetics. Instead of facilitating fines migration toward the apertures, the shallow and weakly mobilized bed favored material accumulation between the rolls, thereby decreasing the effective screening area and increasing the likelihood of material deposited between the rolls. Material bed depth combined with rolls' rotation speed are critical parameters governing screening performance. An adequate solids load enhances particle – particle interactions and improves the shear-assisted percolation of undersize particles, while promoting the downstream transport of near-size particles and mitigating aperture blockage. When the roll rotational speed increased to 56.6 rpm, fines removal efficiency improved significantly. The higher rotational speed increased energy transfer to the bed and intensified roll-induced shear and contact-force transmission, which promoted particle rearrangement, stratification, and percolation of undersize particles toward the inter-roll gaps.

Table 7 illustrates the daily screening efficiency values for the trial period, the information is presented in a daily basis, compounded by 3 individual samplings.

The screening efficiency to remove fines showed small variation with an increase of rolls rotation speed from 40.4 to 56.6 rpm, moving from 90.1 to 92.4%, but no major variation in the screening efficiency to keep goodsize in the final product was observed, 96.8 versus 97.7%. The improvement in fines removal with increasing roll rotational speed can be associated with higher energy transfer from the rolls to the pellet bed, which increases contact forces, promotes particle rolling and bed shear, and enhances particle rearrangement and stratification. Under these conditions, undersize and near-size particles more readily migrate toward the inter-roll gaps, improving fines separation. In the other hand, the small feed rate observed during the tests may mislead the global

Table 7

Screening efficiency – iron ore fired pellets (daily compound results).

| #              | Rolls rotation speed (RPM) | Screening efficiency to remove fines (<5.0 mm) | Screening efficiency to keep Goodsize | Global screening efficiency (weighted average of fines and goodsize efficiencies) |
|----------------|----------------------------|--|---------------------------------------|---|
| 1              | 40.4                       | 85.9%  | 94.7%                                 | 93.6%   |
| 2              | 40.4                       | 93.4%  | 98.4%                                 | 98.0%   |
| 3              | 40.4                       | 83.0%  | 94.6%                                 | 94.3%   |
| 4              | 40.4                       | 98.2%  | 99.4%                                 | 99.4%   |
| <b>Average</b> |                            | <b>90.1%</b>                                   | <b>96.8%</b>                          | <b>96.3%</b>  |
| 5              | 56.6                       | 91.0%  | 94.8%                                 | 94.2%   |
| 6              | 56.6                       | 87.9%  | 97.6%                                 | 97.5%   |
| 7              | 56.6                       | 95.7%  | 99.5%                                 | 99.3%   |
| 8              | 56.6                       | 93.0%  | 99.9%                                 | 98.9%   |
| 9              | 56.6                       | 95.2%  | 97.6%                                 | 97.2%   |
| 10             | 56.6                       | 91.6%  | 96.8%                                 | 96.4%   |
| <b>Average</b> |                            | <b>92.4%</b>                                   | <b>97.7%</b>                          | <b>97.3%</b>  |

screening efficiency, this limitation was imposed by the test set-up.

Fig. 7 presents the samples from each group in their respective containers after a daily sampling (composed by 3 individual samplings). The PSD analysis presents the split of the feed material in the product stream (retained on the screen deck) and in the reject stream. While the feed material was composed by 92.36% of particles >5.0 mm, the retained material (named as Final Product) is composed of 99.41% of particles higher than 5.0 mm and the reject stream is composed of 79.2% of fines <5.0 mm. From the reject stream analysis, it is also possible to see that 61.78% consists of particles between 0.5 and 5.0 mm and 17.42% represent particles between 0.0 mm and 0.5 mm and only 0.39% of the material is higher than 6.3 mm, demonstrating a good screening performance overall. The visual comparison clearly shows that the final product is notably clean, with minimal presence of fines or broken pellets, confirming the high screening efficiency observed in the analytical results.

To better illustrate the separation quality achieved by the roller screen in real operation, Fig. 8 presents pictures of the retained pellets (named Final Product) and the passing material <5.0 mm (named Reject) obtained after the screening process. It is clearly observed that the screened product exhibits a clean appearance, free of fines particles, while the passing material contains virtually no goodsize particles, only presenting fines and broken particles. These visual observations are consistent with the high screening efficiency results reported in Table 7.

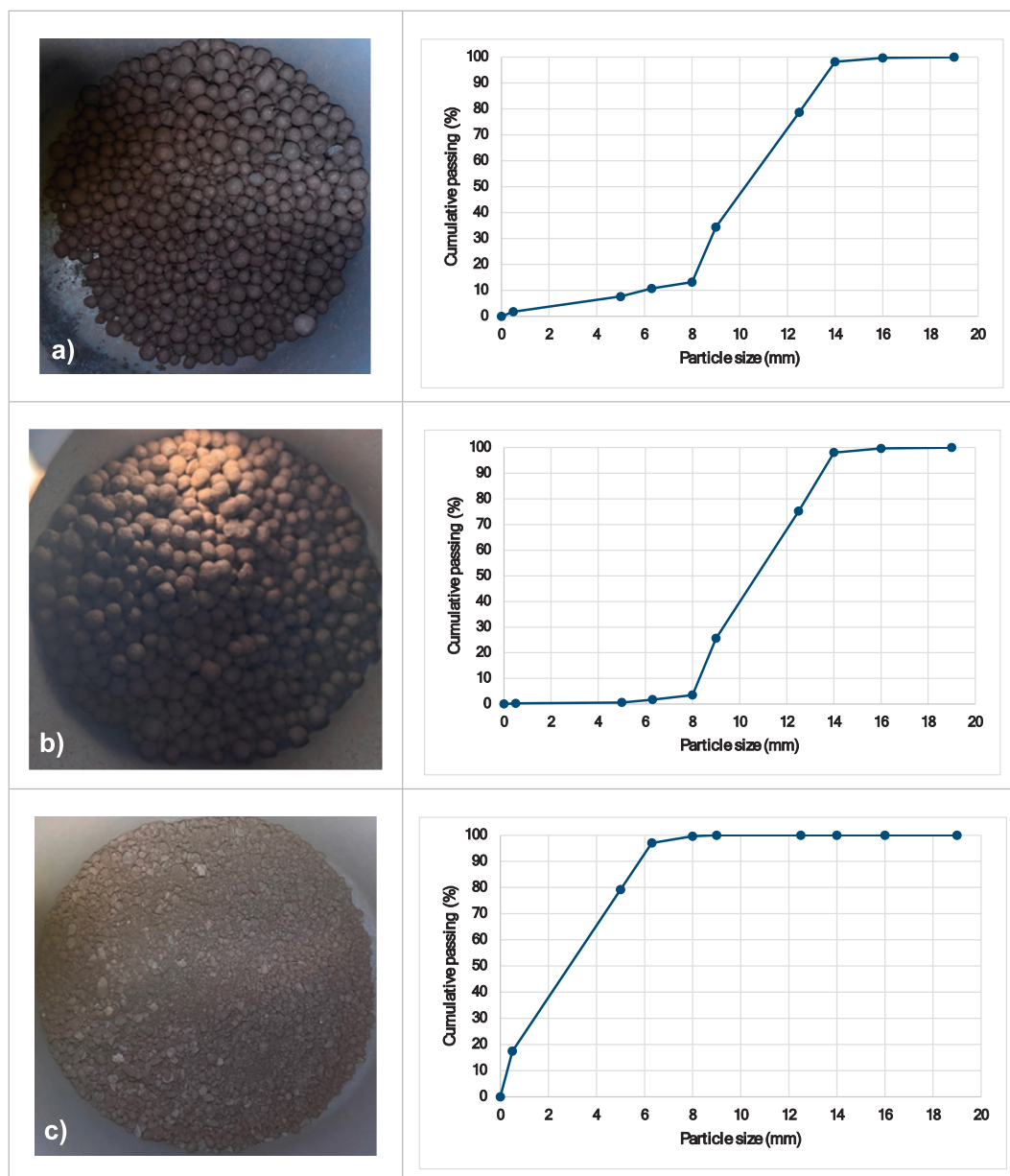


Fig. 7. Pellet samples and PSD in (a) feed, (b) final product, and (c) reject, shown in sampling containers.

At a roller speed of 40.4 rpm, the percentage of fines in the final product was reduced on average from 4.3% to 0.4% (90.7% of reduction). At a roller speed of 56.5 rpm, a similarly effective reduction was observed, with the fines' content decreasing from 9.7% in the feed to 0.8% in the final product (92.0% of reduction). These results demonstrate the high efficiency of the roller screen in removing fines, even under varying operating conditions. Table 8 illustrates the percentage of fines in the feed compared to the final product, highlighting the consistent performance of the system, the information is presented in a daily basis. Considering a theoretical vibrating screen with 75% screening efficiency, the fine percentages will be in the range of 1.1% and 3.1% for 40.4 and 56.6 rpm, respectively, which demonstrates the impact of roller screen handling iron ore fired pellets.

A retention curve represents an empirical probability model derived from the experimental results obtained during the trials. As discussed by Andrade, Beaudin (Andrade et al., 2022), roller screening is a probabilistic separation process governed by particle motion over the screen deck, particle orientation (for non-spherical particles), particle shape, residence time, and gap opening. Based on this framework, particles

with sizes close to the gap opening would theoretically present a retention probability of approximately 50%. However, the present trial results showed a retention of only 36% for 5.0 mm particles using a 5.0 mm gap opening. Based on Fig. 9, 50% partition may be present between 5.0 mm and 6.3 mm. This deviation can be explained by the transfer of energy from the rotating rolls to the particles, as well as by the contact forces generated by the roll surface, including the influence of the roughness and texture of the rubber coating. These effects promote particle rearrangement, percolation, and forced passage of near-size particles through the gap opening, thereby reducing their retention probability on the roller screen deck. In addition, the elastic behavior of the rubber coating allows local deformation when near-size particles become trapped between adjacent rolls or are forced through the gap under contact loading. This elastic deformation increases the effective probability of passage compared with a rigid metallic surface. Based on the results presented in Fig. 9, the 50% partition point appears to lie between 5.0 mm and 6.3 mm. From a practical standpoint, depending on the target cut size, slight adjustments in gap opening should be considered to account for this specific behavior. This effect is



Fig. 8. (a) Screened iron ore fired pellets (final product). b) Rejected material (<5.0 mm).

Table 8

Fines percentage < 5.0 mm in the feed versus in the final product.

| #  | Rolls rotation speed (RPM) | Fines in the feed (%) | Fines in the product (%) | Fines reduction (%) |
|----|----------------------------|-----------------------|--------------------------|---------------------|
| 1  | 40.4                       | 2.60                  | 0.40                     | 84.6%               |
| 2  | 40.4                       | 8.30                  | 0.60                     | 92.8%               |
| 3  | 40.4                       | 1.10                  | 0.20                     | 81.8%               |
| 4  | 40.4                       | 5.30                  | 0.10                     | 98.1%               |
| 5  | 56.6                       | 14.60                 | 1.60                     | 89.0%               |
| 6  | 56.6                       | 0.80                  | 0.10                     | 87.5%               |
| 7  | 56.6                       | 4.40                  | 0.20                     | 95.5%               |
| 8  | 56.6                       | 13.70                 | 1.10                     | 92.0%               |
| 9  | 56.6                       | 17.10                 | 1.00                     | 94.2%               |
| 10 | 56.6                       | 7.50                  | 0.70                     | 90.7%               |

particularly relevant for roller screens handling fired pellets and is not typically observed to the same extent in roller screening of green pellets.

These results exceed the performance of conventional screening

technologies reported in the literature (see Table 2), particularly regarding fines removal, where vibrating screens typically achieve around 75% efficiency, the roller screen presented an average screening efficiency to remove fines of 91.6% and screening efficiency to keep goodsize particles in the final product of 97.3%.

### 3.2.2. Pellet screening

As defined in Table 3, for the pellet screening type of material, it was used a cut size of 6.3 mm, especially for the screening efficiency calculations, since the main objective of this screening step is to recover the goodsize pellets, in this case particles above 6.3 mm, from a pile of rejected material (called pellet screening). The gap opening strategy used in this test was 5.0 mm and then moved to 7.1 mm, since it was observed that using 5.0 mm in gap opening was not enough to promote good fines removal.

In screening processes, particles can be classified into three groups relative to the aperture size: clear undersize (diameter << aperture size), clear oversize (diameter >> aperture size), and near-size particles

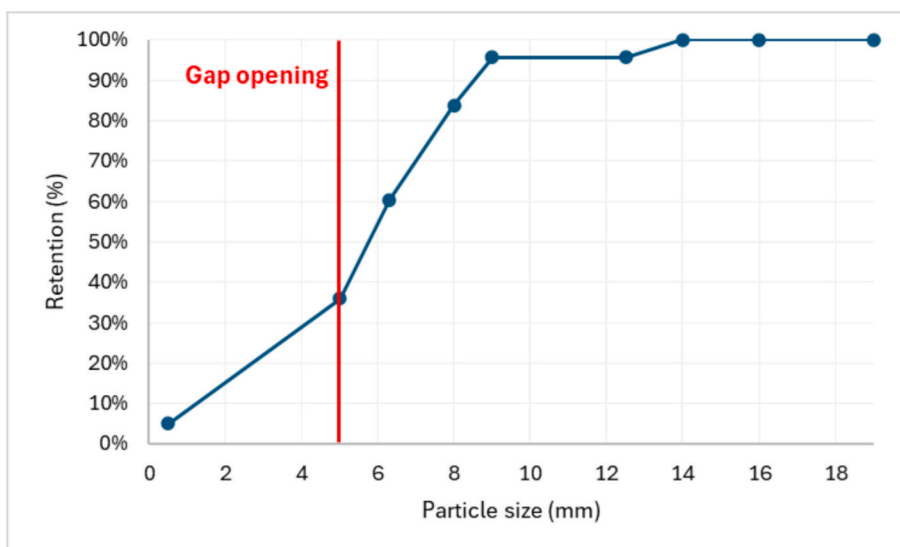


Fig. 9. Retention curve handling fired pellets.

(diameter ≈ aperture size). While clear undersize and oversize particles exhibit high probability of correct classification, near-size particles display transitional behavior, depending on orientation, shape, local bed packing, and dynamic forces.

In roller screening, where separation occurs through controlled transport and probabilistic gap encounters rather than high-frequency vibration, near-size effects become particularly significant when the feed PSD is concentrated around the aperture size. Under these conditions, classification sharpness decreases and efficiency becomes highly sensitive to gap-opening adjustments.

The pellet screening material evaluated in this study represents a near-size-dominated system, which explains the strong dependence of separation efficiency on small changes in gap opening and the observed inverse relationship between fines removal and goodsize retention.

The average screening efficiency to remove fines (in this case <6.3 mm) using the gap opening of 5.0 mm was 58.0%, while the screening efficiency to keep goodsize in the final product was 96.5%. For the gap opening of 7.1 mm, the screening efficiency to remove fines was 95.9%, while the screening efficiency to keep goodsize in the final product was 43.5%. Using a gap opening of 5.0 mm and considering that the PSD was predominantly concentrated in the 0.5–6.3 mm size range (representing 82.0% of the feed material), a significant fraction of fines was retained on the screening deck, thereby reducing fines removal efficiency. The high proportion of particles close to the aperture size limited the probability of passage, particularly for near-size particles, resulting in increased retention on the screen surface and reduced separation sharpness.

For the 7.1 mm gap opening, an improvement in fines screening efficiency was observed due to the larger aperture size, which increased the probability of passage of undersize particles. However, this condition also promoted the unintended removal of near-size and good-size particles, reducing the efficiency of retaining the desired size fraction in the final product. This behavior indicates a trade-off between fines removal efficiency and product size selectivity as a function of aperture dimension.

Table 9 illustrates the antagonistic relationship between fines removal efficiency and goodsize retention as a function of gap opening. This behavior can be interpreted within the framework of screening probability theory, where separation efficiency is governed by the interaction between particle stratification dynamics and aperture geometry. In high-fines systems such as pellet screening material, bed stratification becomes less effective due to the limited size contrast between particles. The high proportion of near-size particles reduces the probability between passage and retention. Consequently, small increases in gap opening disproportionately increase the percolation of both undersize and near-size particles. The results indicate that, under these conditions, gap opening is the dominant parameter controlling separation performance, while roll rotation speed plays a secondary role, mainly influencing residence time rather than classification sharpness.

An average global screening efficiency of 82.5% was obtained in the tests (considering both gap openings tested). The efficiency to maintain goodsize for the tested parameters was not high, indicating the need for better adjustments, especially in gap openings. It seems to have a switching point occurring with the gap opening ranging from 5.0 mm to 7.1 mm, where the screening efficiency to remove fines and the

**Table 9**  
Screening efficiency per gap opening – pellet screening.

| Gap opening | Screening efficiency to remove fines (<6.3 mm) | Screening efficiency to keep Goodsize | Global screening efficiency (weighted average of fines and goodsize efficiencies) |
|-------------|--|---------------------------------------|---|
| 5.0 mm      | 58.0%  | 96.5%                                 | 63.1%   |
| 7.1 mm      | 95.9%  | 43.5%                                 | 90.2%   |

screening efficiency to retain goodsize particles show an inverse relationship. However, this hypothesis was not validated during this trial.

Table 10 presents the daily sampling results considering modification in the rolls' rotation speed. As can be seen, the results vary significantly depending on the gap opening (as explained previously) and it is less dependent on the rolls' rotation speed. This is due to the high amount of fines on the feed stream, which overloads the first zone of the equipment independently of the rolls rotation speed. An exception is observed for the rotation speed of 56.5 rpm, which the authors do not have elements for a deeper explanation.

Fig. 10 shows the PSD of the samples from each group in their respective containers, especially for the tests using 7.1 mm in gap opening, which was analyzed in the physical characterization laboratory. The PSD analysis presents the split of the feed material in the product stream (retained on the screen deck) and in the reject stream. While the feed stream presented 89.5% of particles <6.3 mm, the retained material (named as Final Product) consists of 56.5% of particles >6.3 mm and the reject stream consists of 89.5% of fines <6.3 mm. Specially for the gap opening of 7.1 mm, a good performance to remove fines is observed, but as mentioned previously, the near-size particles (close to 6.3 mm) tends to be removed by the screening device, this explains the amount of 36.8% < 6.3 mm presented in the retained stream. A granulometric difference between the retained and the undersize material from the screen can be observed visually, although some contamination is present in both fractions.

Based on the performance of the roller screen handling pellet screening particles, it is concluded that screening efficiency is good but need further testing to validate the impact of different gap openings, rolls' rotation speeds, feed rates, and even screen deck inclinations, to achieve higher screening efficiencies, to be closer to those obtained with iron ore fired pellets presented in section 3.2.1.

The observed inversion between fines removal efficiency and goodsize retention when increasing the gap opening from 5.0 mm to 7.1 mm suggests the existence of a transition regime governed by near-size particle dominance. In probabilistic screening systems, separation sharpness depends on the ratio between particle diameter and effective aperture size. When a high fraction of particles lies close to the cut size (as observed in pellet screening, where 82% of the feed lies between 0.5–6.3 mm), the contact-driven rearrangement becomes highly sensitive to small variations in gap opening.

At 5.0 mm gap opening, the aperture-to-particle ratio is insufficient to promote efficient passage of near-size particles (<6.3 mm), leading to reduced fines removal efficiency. Conversely, increasing the gap to 7.1 mm significantly increases the rolling dynamics of near-size particles, but simultaneously raises the probability of unintended passage of particles slightly above the commercial cut size (6.3 mm), thereby reducing goodsize retention.

This behavior is characteristic of probabilistic separation processes operating in near-size-dominated systems and indicates the presence of a switching regime in which the two efficiencies metrics become inversely correlated. Further investigation into intermediate gap openings would

**Table 10**  
Screening efficiency – pellet screening.

| # | Gap opening | Rolls rotation speed (RPM) | Screening efficiency to remove Fines (<6.3 mm) | Screening efficiency to keep Goodsize | Global screening efficiency (weighted average of fines and goodsize efficiencies) |
|---|-------------|----------------------------|--|---------------------------------------|---|
| 1 | 5.0         | 72.6                       | 56.4%  | 100.0%                                | 61.8%   |
| 2 | 5.0         | 96.8                       | 59.6%  | 93.1%                                 | 64.4%   |
| 3 | 7.1         | 40.4                       | 96.7%  | 44.0%                                 | 88.7%   |
| 4 | 7.1         | 40.4                       | 99.8%  | 63.7%                                 | 97.3%   |
| 5 | 7.1         | 40.4                       | 87.3%  | 34.2%                                 | 84.0%   |
| 6 | 7.1         | 56.5                       | 95.9%  | 15.7%                                 | 86.1%   |
| 7 | 7.1         | 96.8                       | 99.8%  | 60.1%                                 | 94.9%   |

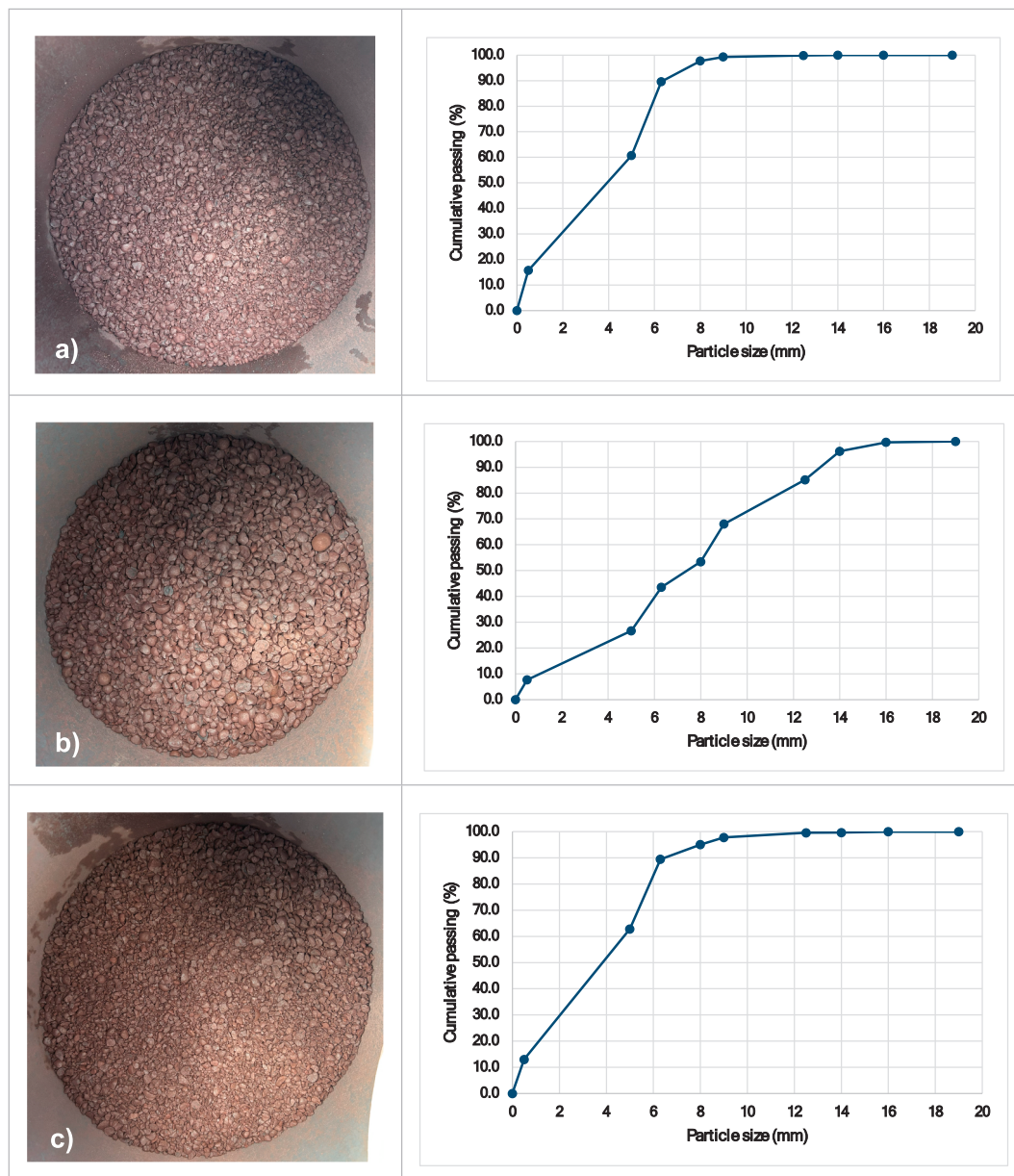


Fig. 10. Pellet screening samples and PSD in (a) feed, (b) final product, and (c) reject material, shown in sampling containers – tests at 7.1 mm gap opening.

be required to identify the optimal balance point.

Table 11 presents a summary of results found in this paper.

Based on the pellet screening trials conducted with a 7.1 mm gap opening, a retention curve was developed to represent the probability of retention as a function of particle size. Since a 7.1 mm sieve mesh is not commercially available, it was not possible to directly determine the exact partition value at the nominal gap opening used in the roller

screen device. Nevertheless, based on the empirical evaluation of Fig. 11, the partition at 7.1 mm can be estimated to be approximately 33%, indicating a behavior similar to that observed in the fired-pellet assessment.

The results further suggest that the 50% partition point is shifted to approximately 7.8 mm particle size. This displacement indicates that the effective separation behavior does not coincide exactly with the nominal

Table 11

Summary of lab-scale and industrial trials results.

| Experimental setup   | Material              | Gap opening (mm) | Cut size evaluation (mm) | Screening efficiency to remove fines (%) | Screening efficiency to keep goodsize (%) | Global Screening efficiency (%) |
|----------------------|-----------------------|------------------|--------------------------|--|---|---------------------------------|
| Lab-scale setup      | Iron Ore fired pellet | 5.0              | 5.0                      | 98.3%                                    | 95.8%                                     | 95.8%                           |
|                      |                       | 12.5             | 12.5                     | 70.1%                                    | 95.1%                                     | 79.5%                           |
| Industrial prototype | Iron Ore fired pellet | 5.0              | 5.0                      | 91.6%                                    | 97.3%                                     | 95.1%                           |
|                      | Pellet screening      | 5.0*             | 5.0                      | 58.0%                                    | 96.5%                                     | 63.1%                           |
|                      |                       | 7.1              | 6.3                      | 95.9%                                    | 43.5%                                     | 90.2%                           |

\*The process does not seem to be adapted to handle pellet screening using gap opening of 5.0 mm.

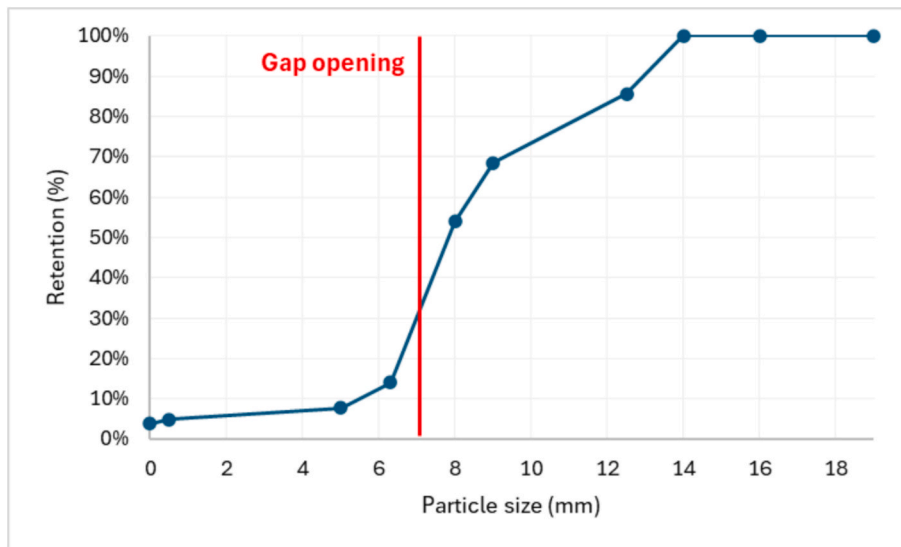


Fig. 11. Retention curve handling pellet screening.

geometric gap opening. As discussed previously for Fig. 9, this effect can be explained by the transfer of energy from the rotating rolls to the particle bed, the contact forces generated at the roll-particle and particle-particle interfaces, and the elastic deformation of the rubber coating. Together, these factors promote particle rearrangement, percolation, and forced passage of near-size particles through the gap, thereby reducing their probability of retention at the nominal opening.

Based on the measured efficiency reported in Table 10. An investigation on the sensitivity of the gap size and roller speed was conducted to determine the importance of these variables, which shall lead further investigation on this topic in the next phase of research. However, given the limited dataset obtained with pellet screening material, these models

should be interpreted as preliminary approximations rather than fully predictive tools.

Two multivariate 2nd order predictive equations were developed to predict the respective screening efficiency for fines removal and good-size retention. The resulting equations are presented below, where “Gap” [mm] represents the gap opening between rollers and RS is the roller speed [RPM]:

$$Fines_{eff}(\%) = 1.56 \bullet Gap^2 + 0.446 \bullet Gap + 0.0007 \bullet RS^2 + 0.0005 \bullet RS + 11.8$$

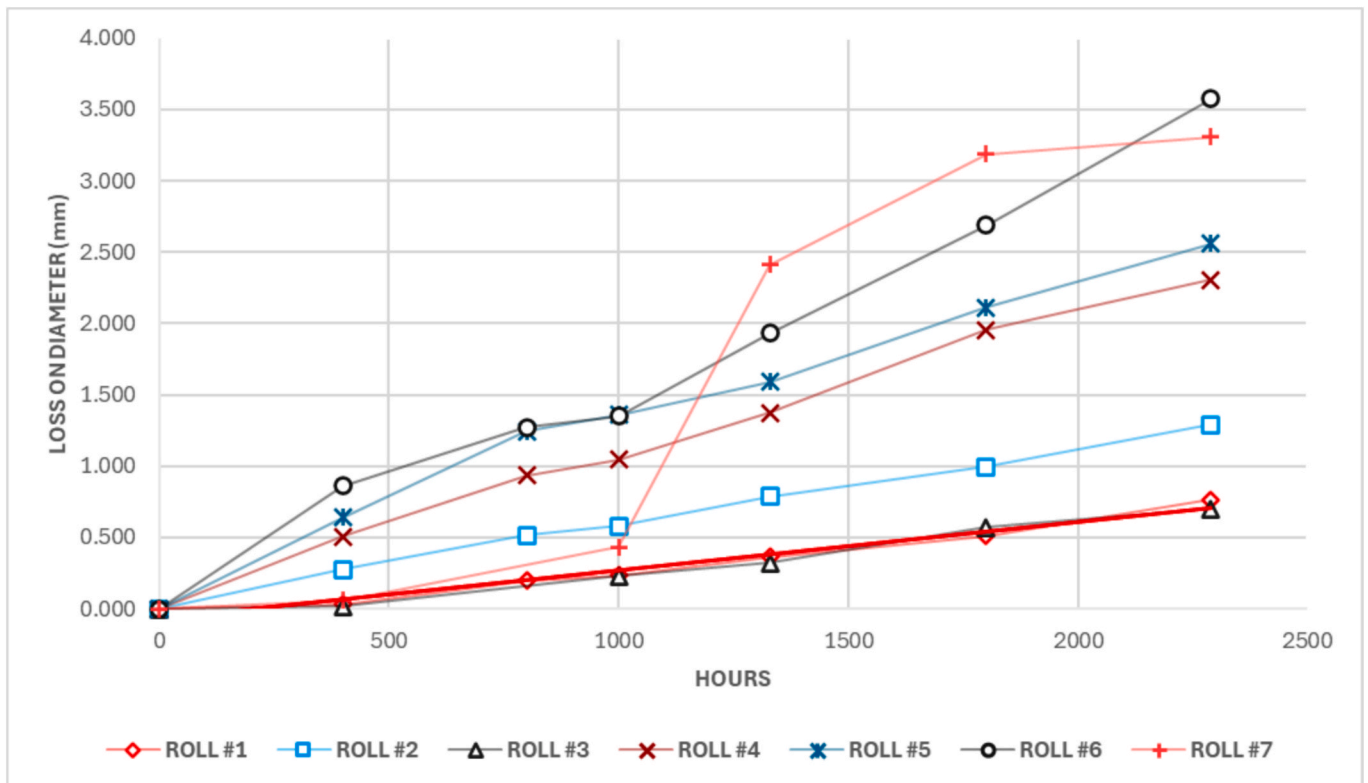


Fig. 12. Rolls lifespan evaluation in laboratory setup.

**Table 12**  
Rolls lifespan assessment.

|                              | Roll #1 | Roll #2 | Roll #3 | Roll #4 | Roll #5 | Roll #6 | Roll #7 |
|------------------------------|---------|---------|---------|---------|---------|---------|---------|
| Maximum wear in radius (mm)  | 5.000   | 5.000   | 5.000   | 5.000   | 5.000   | 5.000   | 5.000   |
| Test duration (h)            | 2290    | 2290    | 2290    | 2290    | 2290    | 2290    | 2290    |
| Measured wear in radius (mm) | 0.381   | 0.644   | 0.350   | 1.152   | 1.279   | 1.787   | 1.654   |
| Lifespan (years)             | 3.5     | 2.0     | 3.8     | 1.1     | 1.0     | 0.7     | 0.8     |

$$Goodsize_{eff}(\%) = 0.0656 \bullet Gap^2 + 23.63 \bullet (5 - Gap) + 0.001311 \bullet RS^2 + 85.2$$

The screening efficiency for fines removal shows a relatively good fit with the sample collected with a Root Mean Square Error (RMSE) of 5% and a Mean Absolute Error (MAE) of 5%. On the other hand, the predictive accuracy of goodsize retention screening efficiency with an RMSE score of 15% and a MAE of 12% indicating that gap size and roller speed alone are not sufficient to explain the variance of the results and that other factors likely account for these differences.

The sensitivity of both factors on the efficiency of fines removal screening was investigated by exploring the variability of the output provided by the predictive equation in a gap range of 5–8 mm and a roller speed of 40–80 RPM. It is found that the gap is the dominant parameter to control to improve the process, with a predictive efficiency fluctuating nearly linearly between 50 and 100% in the range studied. On the other hand, the screening efficiency caused by the roller speed only modified the predictive efficiency of fines particles by  $\pm 2\%$ . It is important to consider that roller speed is not necessarily negligible in all cases. On the contrary, the roller speed, the material flowrate (tons/hr) and the nominal surface area of the roller screen ( $m^2$ ) are in constant interaction and there is likely a threshold where the screening efficiency will be affected. While the cases included in this study appear to be under that threshold, further numerical studies could pave the way to confirm that this threshold exists, improve the understanding of the screening process and provide more efficient industrial design.

Due the inaccuracies in the predictive fit for goodsize retention efficiency, the sensitivity of input variables was not investigated with the same level of details. However, gap size is also the dominant variable, affecting linearly and negatively the efficiency, while roller speed has a negligible impact on the results.

### 3.3. Rolls lifespan assessment

The assessment of roll lifespan was performed through the analysis of roll diameter reduction resulting from wear. Roll surface temperature was monitored daily using a digital infrared (laser) thermometer with the purpose of evaluating overheating on the roller surface and avoid mechanical damage of the set up. The trial was carried out between March and September 2025 for a total period of 2,290 h of operation, a sufficient duration to establish a wear pattern with a clear trend for extrapolating the expected lifespan of the roll coating. During the trial, fired pellets were progressively worn by abrasion resulting from pellet-pellet interactions and contact with the roller surfaces and side walls, generating fine particles. These fines passed through the gap openings and were continuously removed from the system. To maintain a constant pellet bed depth over the rolls, part of the material was periodically replenished. Pellet replacement was carried out on a weekly basis, with 2.5 kg of fresh material added for each coating type evaluated.

It is important to note that the trials were performed at ambient temperature, and, in real operation it may happen that ambient temperature and/or particles temperature will be higher, for example at the discharge of a furnace. In those cases, typical engineering references report maximum temperatures ranging from 90 °C to 200 °C, depending on the rubber type (Engineering, 2026). From a material selection standpoint, these differences highlight the importance of considering

thermal stability as a critical criterion in applications involving continuous or cyclic exposure to high temperatures. It is also important to note that, in many cases, the temperature resistance of rubber materials is inversely related to their wear resistance. As such, coating selection should be assessed as a trade-off between thermal stability and expected roll lifespan.

Under thermal-oxidative conditions, degradation is associated with antioxidant depletion, oxidative attack on unsaturated polymer chains, increased crosslink density, and the progressive development of surface cracking, with these effects becoming markedly more severe at temperatures between 150 °C and 200 °C than at moderate temperatures such as 95 °C (Li et al., 2023). In addition, a more recent mechanistic analysis describes the aging of elastomers as a coupled mechanical-chemical-diffusion process, emphasizing that thermo-oxidative damage evolution cannot be interpreted solely as a simple thermal decomposition phenomenon, but rather as the result of interacting chemical and physical aging mechanisms (Jalalpour et al., 2024).

The results of the wear tests are presented in Fig. 12. Rolls #1 and #3 exhibited the best performance, with diameter reductions of 0.763 mm and 0.700 mm, respectively. Since the coating/rubber formulations are confidential, no deeper details can be provided.

Based on these results and considering an initial coating thickness of 7.0 mm and a minimum allowable residual coating thickness of 2.0 mm prior to roll replacement, the total roll lifespan was estimated (considering regapping activities to keep the correct gap opening in operation). Under these assumptions, Roll #1 exhibited an estimated lifespan of 3.5 years, while Roll #3 exhibited an estimated lifespan of 3.8 years. The evaluated roll lifespan results are summarized in Table 12.

The effect of coating aging was not considered in the evaluation, since aging effect appears after 2 years of operation for each roll, making it impossible to validate. Although the wear tests were not conducted under fully representative industrial conditions, the estimated lifespan should be regarded as an approximation, and variations may occur in actual operating environments.

## 4. Conclusion

A new screening methodology to screen hard particles is presented, the adapted roller screen for hard particles proved effective for fired-pellet classification and robust under industrial environments. In laboratory trials, two gap strategies were assessed: 5.0 mm (final product cleaning) delivering 98.33% screening efficiency to remove fines from the feed, reducing the amount of fines (<5.0 mm) from 1.2% to 0.02%. Whereas 12.50 mm cut size showed lower efficiency due to the higher amount of near-size pellets. Despite a high loading in the lab-scale tests ( $\sim 221.1 \text{ t h}^{-1} \text{ m}^{-2}$  of screening surface), after 40 h of closed-loop tests the device maintained its robustness not presenting damages on the drive system nor in the rolls surface.

In the industrial prototype, using a 5.0 mm gap opening handling fired pellets, the average screening efficiency to keep goodsize (>5.0 mm) is 97.3% and 91.6% of screening efficiency to remove fines, totaling 95.1% global screening efficiency. In average, fines content reduced from 4.3% to 0.4% at 40.4 rpm and 9.7% to 1.6% at 56.5 rpm, confirming stable performance across operating conditions. For pellet screening material (feed containing 89.5% < 6.3 mm), screening behavior was governed primarily by the high concentration of near-size particles. The experimental results revealed a trade-off between fines

removal efficiency and goods size retention when increasing the gap opening from 5.0 mm to 7.1 mm, suggesting the presence of a transition regime typical of probabilistic screening systems dominated by near-size fractions. The identification of this switching behavior highlights the importance of optimizing aperture size relative to the particle size distribution. Future investigations should focus on identifying the optimal gap opening within this transition region to maximize global screening efficiency while preserving product selectivity.

The roll's lifespan assessment clearly indicates that roller screens provide a robust and durable solution, offering extended component lifespan, projected 3.5 – 3.8 years for iron ore fired pellets, and reduced maintenance demands when compared to vibrating screen technologies, specially related to mesh wear. As the wear tests were performed under controlled laboratory conditions that may not fully replicate industrial operating environments, the resulting lifespan estimates are subject to variability under real-world conditions.

For future studies, the authors suggest investigating the optimal gap opening of roller screens handling pellet screening, aiming to enhance overall screening efficiency. Further research should also focus on the screening performance of roller screen technology handling other hard materials, such as sinter and sponge iron. Additionally, an evaluation of roll lifespan in lab-scale considering and under real operating conditions (high ambient and particles temperature) with fired pellets and other hard particles is recommended. To assess the effect of elevated ambient temperatures, a laboratory setup similar to that described in Section 3.3, with the addition of a controlled heating system, could be used. However, evaluating the influence of pellet temperature on coating performance would require an industrial trial under representative operating conditions, in which the material is fed to the equipment at its actual process temperature. Finally, the development of a numerical simulator that accurately models both particle behavior and roll surface characteristics would provide valuable insights for process optimization.

#### Credit authorship contribution statement

**Alexandre Gonçalves Andrade:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation. **Steve Beaudin:** Validation, Supervision, Methodology. **Eric Tremblay:** Writing – review & editing, Conceptualization. **François Cloutier-Poirier:** Investigation. **Hilcker Scopel Damasceno:** Resources, Project administration, Methodology. **Luiz Carlos Gavazza Junior:** Resources, Project administration, Methodology. **Lukas Dion:** Writing – review & editing, Validation, Supervision, Methodology. **Patrick Faubert:** Writing – review & editing, Validation, Supervision.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Data availability

Data will be made available on request.

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