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Implementation of Coupled DEM-FEM to Investigate Mechanical Behavior of Roller Screen Rolls in Classification of Green İron Ore Pellets

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Abstract

Because roller screens are connected to the pelletizing discs on one side and the green iron ore induration furnaces on the other side in pelletizing plants, they play a crucial role in the plant's productivity and steel production process. Consequently, an optimal performance and structural design are essential in this context. A significant issue with roller screens during the classification of green pellets is the deformation of the rolls caused by the force exerted by the pellets during operation. This deformation disrupts the uniformity of the gap between the rolls, thereby reducing the efficiency of the screen, and the overall performance of the circuit, as well. Despite the importance of this issue, no studies have been conducted to investigate the force exerted by the pellets during classification on the screen or the subsequent mechanical behavior of the rolls. Therefore, this study employs the discrete element method–finite element method (DEM-FEM) coupling simulation technique to examine, for the first time, the mechanical behavior of rolls and to optimize their structural design. The results indicated that decreasing the roll diameter from 80 mm to 30 mm led to 1088 times increase in the average total deformation of the rolls. Furthermore, increasing the thickness of the polyurethane liner from 3 mm to 14 mm caused the average total deformation to rise by 54 times.

1. Introduction

The roller screen utilized for the classification of green iron ore pellets has become increasingly prevalent owing to its numerous advantages, which play a crucial role in enhancing the efficiency and productivity of the pelletizing circuits. Its benefits include high efficiency and capacity in classifying green pellets, low noise generation, minimal space requirements, ability to handle highly sticky materials with elevated moisture content, and reduced damage to green pellets. These features have made this equipment essential for preparing a suitable feed for induration kilns. The roller screen serves as a vital link between the pelletizing and balling equipment, such as pelletizing discs or drums and induration furnaces, which effectively connect these machines and create a closed circuit. Thus, ensuring the optimal design, construction, and operational efficiency of the roller screen is critical, as it significantly contributes to increasing the productivity of the pelletizing plant [1]. Green pellets produced from pelletizing disks or drums are transferred to a roller screen for size classification and typically range from 6 to 22 mm in diameter. As illustrated in Figure 1, the roller screen utilized in both laboratory and industrial settings consists of several rolls with a specific diameter, inclined at a particular angle, and rotating at a designated speed. This design facilitated the movement of pellets along the roller screen. During this process, the gaps between the rolls allow for the separation of green pellets based on their dimensions. According to Figure 1, there is an area referred to as the initial three-quarters of the screen length that features a gap opening of 9.5 mm. This

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configuration enables fine-grained pellets measuring 6–9.5 mm to pass through. In the remaining quarter of the screen, the gap opening increases to 15.5 mm, allowing for the separation of on-size pellets ranging from 9.5 to 16 mm which are subsequently directed to the induration furnace as the feed [2]. The appropriate gap opening size assigned to each segment of the roller screen area depends on the pelletizing plant strategy and downstream flow requirements [3].

As shown in Figure 2(a), during the sizing process of green pellets, the continuous collisions of the pellets with the surface of the rolls generate an impact, resulting in a sustained force exerted by the pellets onto the rolls. Based on Figure 2(b), F_T represents the total force exerted by the pellets on the rolls. Therefore, the rolls remain consistently under load throughout the roller screen operation.

In this context, the application of F_T to the rolls, along with the reaction forces exerted by the supports that connect and stabilize the rolls on the body of the roller screen, essentially functioning as bearings, can be analyzed. As illustrated in Figure 3(a), these factors establish the boundary conditions for the rolls of the roller screen during the green pellet classification process. As shown in Figure 3(b), the applied force of F_T on the surface of the roll consistently induces a bending stress along its length. As illustrated in Figure 3(a), the bending stress results in elastic deflection. Ultimately, when the stress exceeds the yield strength, permanent plastic deformation occurs, particularly in the central region of the roll [4].

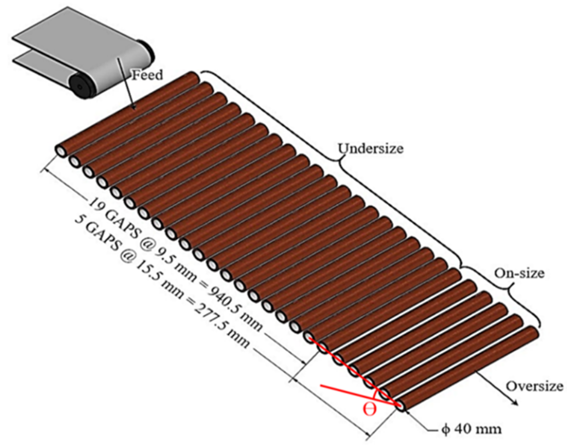
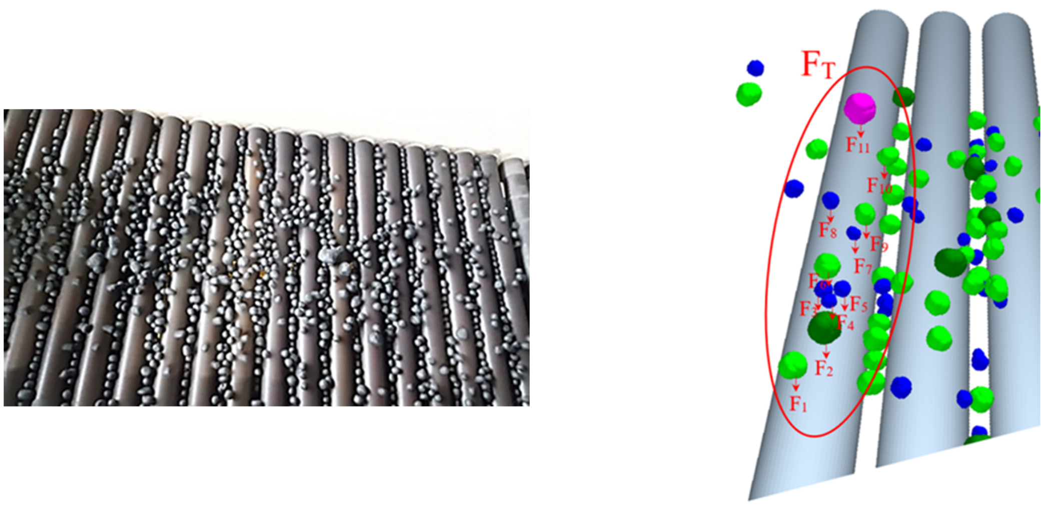


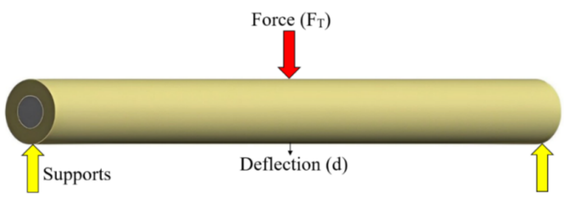
Figure 1. Different constituent parts of the roller screen.



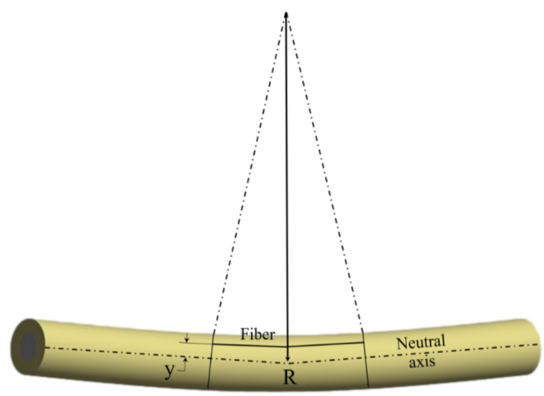
b). Applied total force of F_T to the surface of the roll **a). Classification of green iron ore pellets by roller screen**

Figure 2. Applied forces to the surface of the roll due to the collision of each pellet and consequently the total force of F_T.

According to Figure 3(b), the elastic or plastic deformation of the roll, essentially roll bending, results in a loss of straightness. Under the influence of bending, the uniformity of the gap opening deviates significantly from the ideal state. As a result, transferring on-size pellets to the fine-grained area and fine grain pellets to the product area leads to both a quantitative and qualitative decrease in the efficiency of the roller screen [3]. Maintaining appropriate gaps between rolls is essential for effectively separating fine-grained materials from product materials and improving the performance of the roller screen. A review of the literature indicates that there is limited research on the comprehensive performance of roller screens during the pelletizing process. Consequently, the impact of key parameters on the proficiency of the roller screen remains unclear. Therefore, there is a lack of established knowledge regarding the screening process that utilizes roller screens. Furthermore, the suboptimal performance of the roller screen contributes to losses in pelletizing plants. Thus, it would be essential to conduct theoretical and practical research to evaluate and optimize its design, construction, and performance. This research is crucial for enhancing the efficiency and productivity of the entire plant, and is both justified and necessary [5]. Understanding the rolling screening process, particularly the interactions between the pellets and the roll surface, necessitates particle-scale studies. However, conducting experimental research in full-scale industrial plants poses significant challenges. However, online analysis is often hindered by spatial constraints. Even when space is available, investment costs associated with such installations are frequently deemed unjustifiable. While experimental tests yield valuable and reliable information, the inherent heterogeneity, discreteness, and anisotropy of particulate solids complicate the dynamic behavior of bulk materials owing to the interactions between particles and between particles and geometry. Moreover, the complexity and high costs associated with manufacturing laboratory equipment, along with the time and difficulty involved in conducting experimental studies, render it impractical to perform comprehensive investigations and parametric studies of particle systems [6].



(a): Applied forces to the roll. F_T and reaction forces are applied to the roll. by collision of pellet and supports (bearings), respectively.



(b): Applied bending stress to the roll along its length.

Figure 3. Applied forces and resultant bending stress to the roll while classification of pellet.

Simulations have become a widely utilized tool in the design and optimization of industrial processes. Owing to the highly discrete nature of granular materials, it is anticipated that particulate media will require a discrete simulation method. Mechanical modeling and numerical simulation using the discrete element method (DEM) can be employed, in order to investigate the classification behavior of green pellets on a roller screen. when properly calibrated and validated, this approach can effectively predict the dynamic and bulk behavior of pellets on rolls by considering both pellet-pellet and pellet-roll interactions. DEM is a widely utilized research and development tool that predicts the macroscopic behavior of particles through a microscopic approach [7]. By employing DEM, it is possible to simulate the interactions between pellets, including pellet-pellet and pellet-roll interactions. This results in the calculation of the force (F_T) exerted when a pellet collides with the roll surface [8]. After simulating the DEM and calculating the forces resulting from the pellet's impact on the roll surface, it is essential to evaluate the mechanical behavior of the roll, including the total deformation and equivalent stress. Finite Element Method (FEM) is the most effective method for simulating and calculating these behaviors. FEM is considered a robust and mature approach for addressing complex engineering problems involving materials with varying properties, intricate geometries, diverse loading conditions, and multiple boundary constraints [9]. Considering the advantages of FEM for investigating the reactions and behavior of roller screen rolls under the impact loads generated by green pellets, it is essential to transfer the forces calculated through DEM simulations to the FEM platform. The process of connecting and transferring data obtained from the discontinuous DEM simulation to the continuous FEM simulation is referred to as the coupled DEM-FEM method. This approach facilitates an accurate simulation of the interaction between the forces exerted by the impact of the pellets and the resulting deformation of the rolls caused by this impact [10]. The coupled DEM-FEM numerical simulation method effectively integrates the strengths of the DEM in characterizing granular particle behavior with the FEM which excels in addressing bending problems in rolls [11]. In this research work, the performance of roller screen rolls was modeled using FEM based on the principles of continuum mechanics, whereas the pellets were represented as distinct and independent particles through DEM to account for discontinuities.

Unlike vibrating screens, which have been extensively studied to simulate their operational and mechanical behaviors using DEM, FEM, and DEM-FEM coupling methods, comprehensive research on the functional simulation of roller screens using the DEM-FEM coupling method and FEM remains limited. Current simulation studies of roller screens are primarily restricted to the use of DEM alone. Cherepakha et al. employed DEM simulations to examine the effects of the diameter, length, and rotational speed of the rolls, as well as the inclination angle of the roller screen's surface and the number of rolls (length of the roller screen) on the efficiency and performance of the roller screen [12]. Javaheri et al. simulated and investigated various regimes of roll rotation speed and inclination angle of the roller screen's surface on the performance criteria of the roller screen using DEM simulations [13]. Jafari et al. also employed DEM to examine the effects of various performance parameters, including the inclination angle, diameter, and rotation speed of the rolls on the efficiency of the roller screen [14]. Silva et al. utilized DEM to examine the effects of rotation speed and diameter of the rolls, fine grain area gap, inclination angle of the roller screen surface, and feeding rate on the efficiency of single- and double-deck roller screens [15]. In another study, Silva et al. employed a DEM to investigate the effects of the moisture content and granulation distribution of the input feed on the performance of a single-deck roller screen. They also analyzed the impact of gap opening in a fine grain area [16]. Carvalho et al. conducted a DEM simulation study on a double-deck roller screen to investigate its performance concerning various factors, including load capacity, the number of constituent rolls, the length of the first deck, the inclination angle, and the gap opening between the rolls of the second deck [1].

In summary, previous studies on DEM simulation of roller screens have primarily focused on evaluating the performance of these screens in relation to structural and process parameters. However, the physical and dynamic behavior of particles, particularly the forces generated during collisions with the geometry of the roller screen, especially the rolls, has not been simulated or analyzed. Therefore, a comprehensive study addressing the interaction between continuous geometry and discrete particles for the design and optimization of roller screens, both structurally and functionally, is lacking. Several studies have been conducted on various types of vibrating screens (linear, circular, or flip-flow) using the DEM method. These studies not only simulated particle movement but also investigated the dynamics and interactions between the particles and the screen plates and meshes. Consequently, the inertia and forces exerted on the screen plates by the particles were simulated effectively [17]. Thus, the positive outcomes of these studies highlight the potential benefits and effectiveness of employing DEM in roller screens. It is important to note that all of the aforementioned DEM studies of roller screen utilized a spherical pellet shape and the Hertz-Mindlin elastic contact model. Previous research [18], along with results from experimental tests conducted on a laboratory roller screen and the calibration of contact parameters, indicates that employing the actual shape of the pellet and a hysteretic spring contact model, owing to its elastoplastic properties, produces DEM simulation results that are more consistent with realistic experimental outcomes. So, these results are considered more reliable and repeatable. In this study, a roller screen is investigated for the first time using DEM and FEM techniques to develop a coupled DEM-FEM model. Following the establishment of this coupling as a novel design tool for the roller screen, the mechanical behavior of the rolls, including the total deformation and equivalent stress experienced, are assessed in response to the impact load of the pellets during the classification process. The coupled DEM-FEM method used in this study represents an innovative approach that enables parametric design analysis of roller screen. To address issues such as bending which can reduce the efficiency of the screening process during the classification of green pellets, a thorough parametric design analysis is conducted. Consequently, optimal construction conditions are proposed, along with design recommendations concerning the roll diameter and thickness of the polyurethane (PU) liner for the rolls. These recommendations aim to minimize the adverse effects of the deformation and bending of the rolls, thereby addressing the significant technical and financial challenges encountered by pelletizing plants.

2. Material and Methods

2.1. Laboratory roller screen tests

At the outset, experimental tests of the roller screen were conducted using the laboratory roller screen illustrated in Figure 4, with the structural and functional characteristics detailed in Table 1 and Figure 5. These experimental studies on the roller screening process of green pellets provide the foundation for the coupled DEM-FEM simulations discussed in this study. They are comprehensively detailed in reference [2].

Figure 4. Performing laboratory roller screen tests for classifying green iron ore pellets.

Table 1. Specifications and operating parameters of the laboratory roller screen

Specification		Value
Construction parameters	Roll diameter (mm)	40
	Roll length (mm)	480
	Material type of roll liner	Polyurethane (PU)
	Material type of roll shaft	Structural steel
	Roll number	25
Operational parameters	Feeding rate (t/h)	1-1.5
	Feeding conveyor belt speed (m/s)	0.35
	Roll rotation speed (rpm)	10-500
	Inclination angle (degrees)	Adjustable to 20

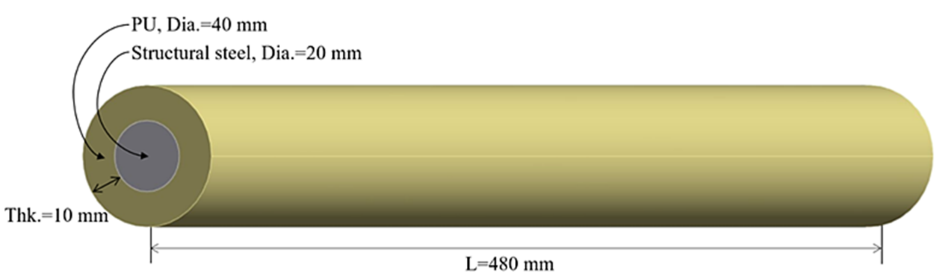
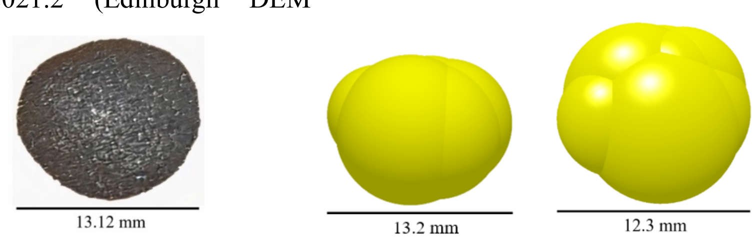


Figure 5. Specification of the roll of laboratory roller screen.

2.2. Pellet shape modelling

Modeling the actual shape of magnetite green pellets which contain 8% moisture and 1% bentonite, was conducted based on the analysis of images obtained from experimental tests. The results of these tests are shown in Figure 6. EDEM software version 2021.2 (Edinburgh DEM Solutions) was utilized to perform both pellet shape modeling tests and DEM roller screen tests [19]. Additionally, Digimizer software was utilized to analyze the pellet images [19]. Details of pellet shape modeling, along with experimental tests measuring contact parameters and their calibration, are presented in reference [19].



(a): Real shape of pellet **(b): Simulated shape of pellet.**

Figure 6. Modeling the shape of magnetite pellet with 8% moisture and 1% bentonite in EDEM [19].

2.3. Determination of contact parameters

In this study, for the first time, experimental tests regarding the green pellet were conducted to determine the contact parameters of the magnetic pellet, including drop, inclined plane, sliding, angle of repose (AOR), and tumbling drum tests. Additionally, physical tests, such as specific gravity and dimensional distribution, as well as mechanical tests, including Young's modulus and yield strength tests, were performed. Calibration tests for pellet-pellet and pellet-roll interactions were conducted using DEM simulations as a novelty, the results are presented in Table 2 [19]. The dimensional distribution of the pellet feed used for the simulation is illustrated in Figure 7 [19].

A DEM simulation test of the roller screen was conducted based on the contact parameters listed in Table 2. The specifications of the roller screen used to conduct the DEM tests are shown in Figure 8. The DEM simulation test is illustrated in Figure 9. In this test, the operational parameters were as follows: feed rate=1.5 t/h, deck angle=13°, roll speed=225 rpm, roll diameter=40 mm, roll length=480 mm, undersize gap=9.5 mm, on-size gap=15.5 mm, and particle shape=real shape.

Table 2. Properties and interaction parameters utilized in EDEM simulation of the roller screen test for magnetite pellets with actual shape

Parameters	Unit	Values
Pellet properties		
Pellet type	-	Magnetite
Pellet moisture content	%	8
Pellet bentonite dosage	%	1
Pellet density (ρ)	kg/m^3	4893
Geometry density (ρ)	kg/m^3	1215
Poisson's ratio (ν)-(Pellet; Geometry)	-	[0.25; 0.41]
Shear modulus (G)-(Pellet; Geometry)	Pa	[2.015e+06; 1.02e+08]
Pellet yield strength	Pa	0.0554e+06
Pellet shape model	-	Overlapping spheres
Pellet size distribution	mm	6–22
Test method	-	Bulk pellet
Pellet mass	kg	26, 30, 40, 50 and 70
Feed rate	kg/s	0.417
Time step	s	2.93e-05
Time step	%	20
Simulation time	s	85
Contact parameters		
Physics for interaction of Pellet-pellet	-	Hertz-Mindlin with JKR
Physics for interaction of Pellet-geometry	-	Hysteretic spring
Surface energy for the interaction of pellets 6–9.5 mm to pellets 9.5–22 mm	J/m^2	1.9
Damping factor	-	-0.0077
Stiffness factor	-	0.125
[1]COR_{P-P}; COR_{P-G}	-	[0.104; 0.09]
[2]μ_{sP-P}; μ_{sP-G}	-	[0.23; 0.6]
[3]μ_{rP-P}; μ_{rP-G}	-	[0.31; 0.2]

[1]COR_{P-P} and COR_{P-G}=coefficient of restitution for pellet-pellet and pellet-roll interactions, respectively
[2]μ_{sP-P} and μ_{sP-G} = static friction coefficient for pellet-pellet and pellet-roll interactions, respectively
[3]μ_{rP-P} and μ_{rP-G} = rolling friction coefficient for pellet-pellet and pellet-roll interactions, respectively

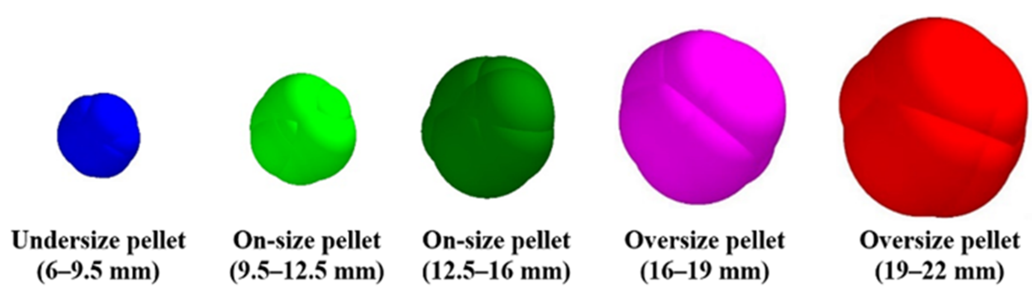


Figure 7. Different particle sizes of pellet for DEM simulation of roller screen [19].

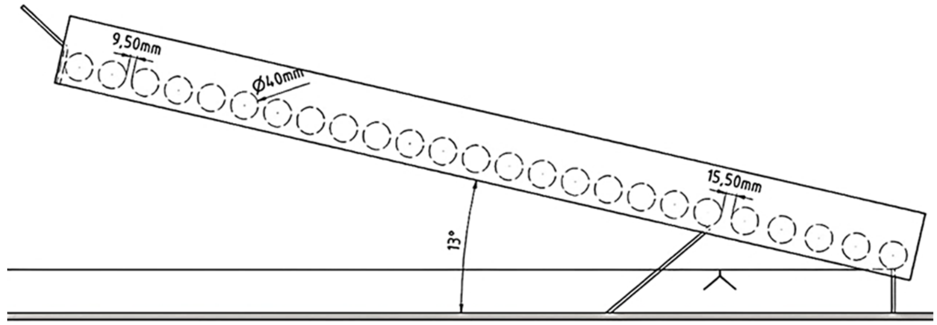
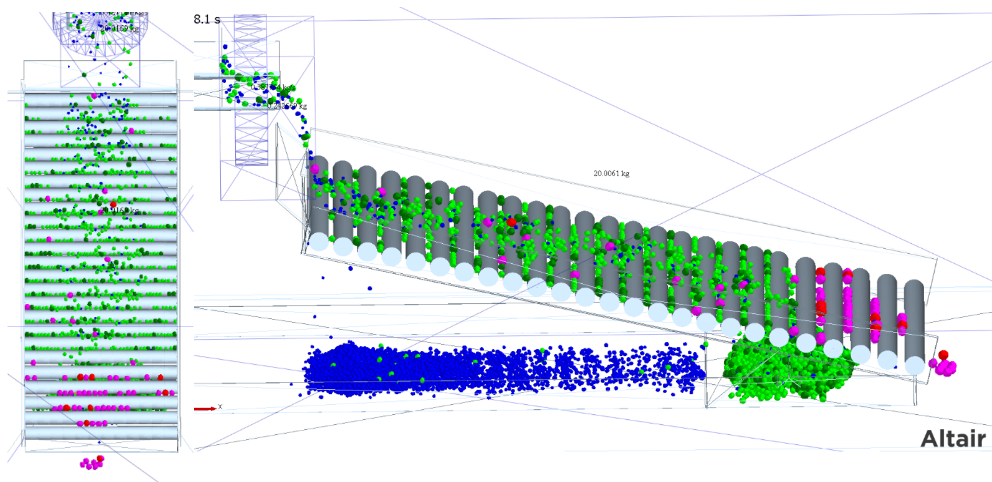


Figure 8. Specification of applied roller screen for DEM simulation tests.



(a) (b)

Figure 9. EDEM simulation of roller screen to classify green pellets.

2.4. Modeling roll geometry

To conduct FEM simulation tests on the roller screen, analysis of the mechanical behavior of the rolls, including the total deformation and equivalent stress are aimed in response to the forces exerted by the pellets during dimensional separation. According to Figure 10(a), the geometry of the roller screen, particularly its rolls, was modeled using Autodesk Inventor software and Design Modeler in ANSYS version 2022 R2, in accordance with the specifications provided for the laboratory roller screen (Table 1). The boundary conditions for the roll shown in Figure 5, utilized in the FEM simulations, are illustrated in Figure 10(b).

2.5. Investigation of affecting parameters on mechanical behavior of roll

After conducting a simulation of the DEM-FEM coupling method for the roller screen, investigation of the mechanical behavior of the first roll of the roller screen which is the most critical component during the roller screening process, aimed to establish a comprehensive study methodology. In this section, additional simulation tests for performing parametric study of roller screen roll were examined for the first time which includes some of the most significant parameters that influence the structural design of the roll.

2.5.1. Diameter of roll

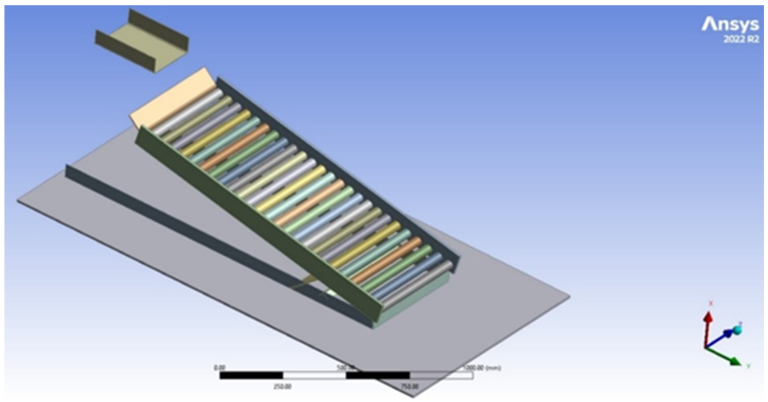
Because the diameter of the roll is a critical geometric parameter that influences its mechanical behavior, various FEM simulations of the first roll were conducted to examine the effect of the roll diameter. The conditions for the FEM simulation were as follows: roll diameters of 30 mm, 40 mm, 50 mm, 60 mm, 70 mm, and 80 mm, a PU thickness of 10 mm, and PU shear modulus of 102 MPa.

2.5.2. Thickness of PU

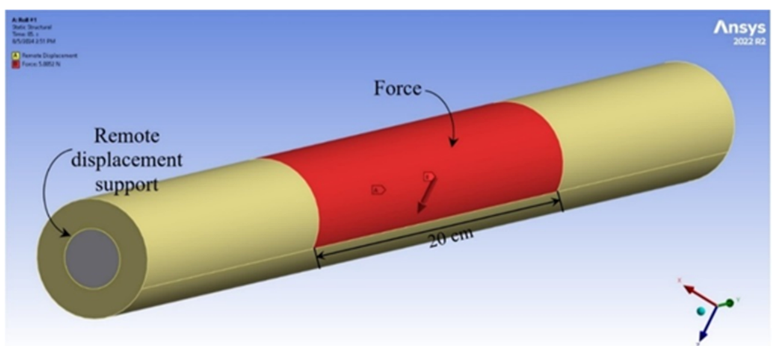
Because PU is used as a liner for roller screen rolls owing to its high wear resistance, various FEM simulation tests of the first roll were conducted under different PU thickness conditions. The parameters for the FEM simulation were as follows: roll diameter=40 mm, PU thickness=3 mm, 6 mm, 8 mm, 10 mm, 12 mm, and 14 mm, and PU shear modulus of 102 MPa.

2.5.3. Shear modulus of PU

In addition to the thickness and geometric characteristics of PU, its mechanical properties, such as the shear modulus, are crucial for analyzing the mechanical behavior of rolls during the roller screening process. As PU is a polymer and a chemical substance, altering its molecular structure, particularly its molecular weight, changes its mechanical properties. To optimize the mechanical behavior of the roll in response to impact forces, it is essential to consider the effects of these changes on the characteristics of PU. Accordingly, various FEM simulation tests were conducted under different PU shear modulus conditions. In these tests, the parameters for FEM simulations were as follows: roll diameter=40 mm, PU thickness=10 mm, PU shear modulus=5 MPa, 10 MPa, 20 MPa, 50 MPa, 102 MPa, 150 MPa, and 200 MPa.



a) A three-dimensional geometry of the roller screen prepared by Autodesk Inventor software and imported to the ANSYS software.



b) Applied boundary conditions for FEM simulation of roll

Figure 10. Modeling geometry of roller screen rolls and applied boundary conditions for FEM simulations.

3. Results and Discussion

3.1. Applied force resulting from impact load of pellets

The total force (F_T) applied to each roll during the pellet classification process, along with the average total force exerted on the rolls, is shown in Figure 11. The highest force is exerted on the first roll where the pellets collide during their transfer from the chute to the roller screen. This force measures 6.67 N, which is 3.05 times greater than the average force applied to the rolls of the roller screen.

3.2. Analysis results of mechanical behaviors of roll

The results of the analysis of the mechanical behaviors of the first roller screen roll, along with their distribution, are presented in Figure 12.

Based on Figure 12(a), it is evident that total deformation reaches its maximum value in the central region of the roll, encompassing its entire cross-section, including the surface area near the point of force application and the roll axis. A concentration of deformation was primarily observed in these areas. Conversely, the minimum value of the total deformation occurs at the edges of the roll, specifically at the base where the support and bearing are connected. According to Figure 12(b), the equivalent stress applied to the surface and axis of the roll which demonstrates a uniform distribution, was minimal. However, at the connection points between the structural steel shaft and PU liner in the upper and lower sections of the roll shaft axis, there is a concentration of stress. As the stress concentration approaches to the axis of the roll, its magnitude diminishes, ultimately reaching a minimum value. According to Figure 12(c), the stress applied to the surface path of the roll was maximized in the central region. As one moves toward the edges of the roll, values decrease, ultimately reaching their minimum at the edges. Furthermore, Figure 12(d) indicates that the stress along the roll axis path is at its minimum in the central region, with values rising toward the edges and ultimately reaching a maximum value.

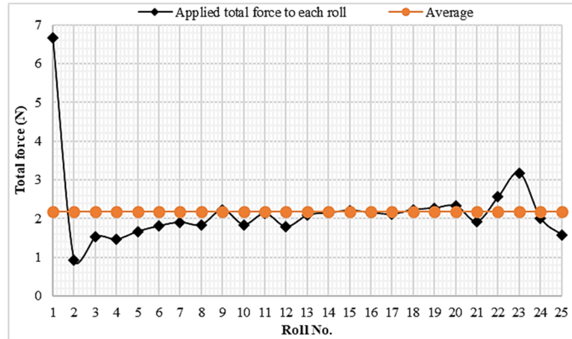
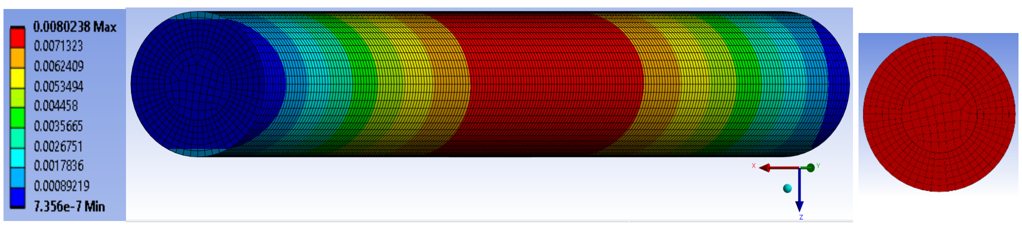
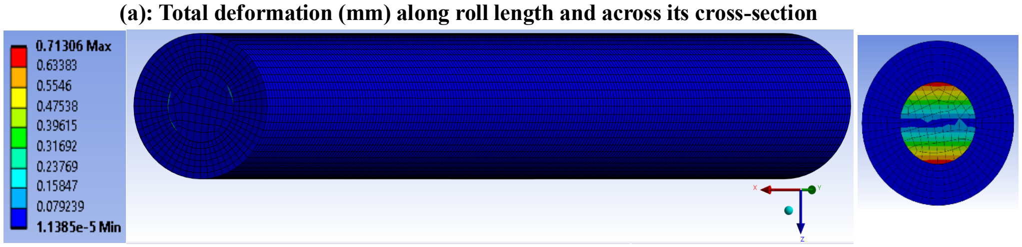


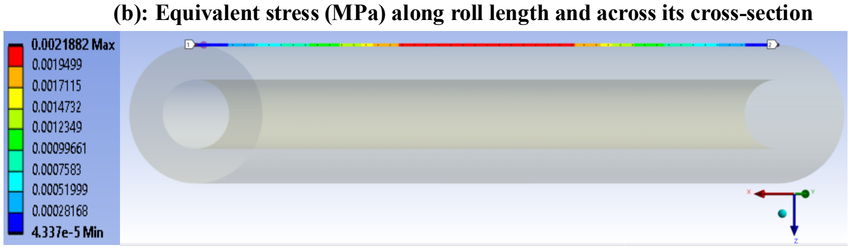
Figure 11. Analysis results of applied total force by collision of green pellets on the rolls.



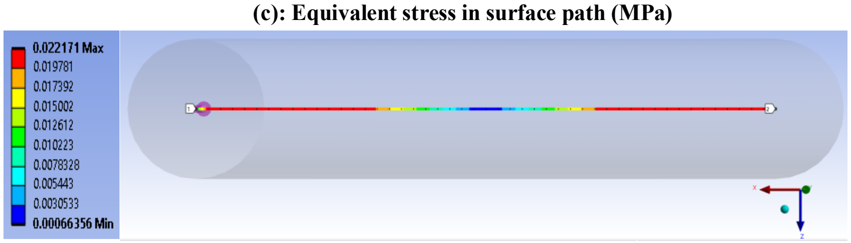
(a): Total deformation (mm) along roll length and across its cross-section



(b): Equivalent stress (MPa) along roll length and across its cross-section



(c): Equivalent stress in surface path (MPa)



(d): Equivalent stress in axial path (MPa)

Figure 12. Distribution contours of mechanical behaviors of roll 1 along its length and across its cross-section, accompanied by a legend to illustrate the corresponding values.

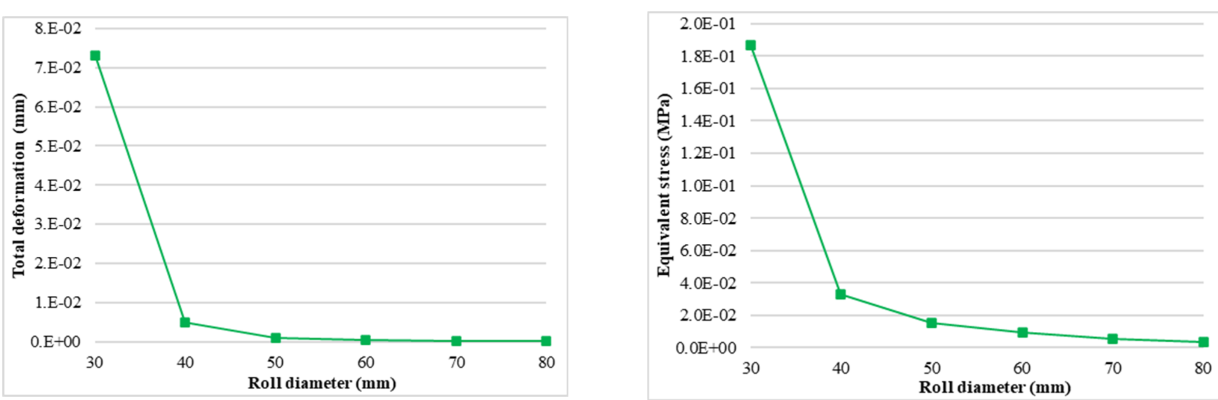
3.3. Analysis of effects of structural variables on mechanical behavior of rolls

3.3.1. Diameter of roll

As illustrated in Figure 13, for a roll with a diameter of 30 mm, the average values of total deformation and equivalent stress applied were 1088 and 51 times greater than those for a roll with a diameter of 80 mm, respectively. This indicates that the diameter of the roll has an inverse relationship with the average values of its mechanical behavior in response to the forces generated by the pellet impact. In this scenario, with the force exerted on the roller screen roll held constant, the general relationship of the stress suggests that as the diameter of the roll increases, the surface area also increases, leading to a decrease in the stress experienced by the roll. Under a consistent load, increase in roll diameter enhances the resistance to deformation within the roll, which consequently results in reduced strain values. Therefore, the deformation resulting from the collision and impact of the pellet on the roll surface is also reduced. To mitigate the deformation and stress and to minimize the negative effects on the alignment and spacing between the rolls, it is recommended that the diameter of the primary roll, designated as the impact roll, be larger than that of the other rolls.

3.3.2. Thickness of PU

In this section, the impact of variations in the thickness of the PU liner on the mechanical behavior of the first roll of the screen was examined. As illustrated in Figure 14, the roll with a PU liner thickness of 14 mm exhibited average values of total deformation and equivalent stress that were 54 and 8 times greater, respectively, than those of the roll with a PU liner thickness of 3 mm. This indicates a direct relationship between the thickness of the PU liner and the average mechanical performance of the roll in response to the forces generated by the pellet impacts. The underlying reason for this phenomenon is the lower shear modulus of the PU compared to that of the structural steel shaft; the shear modulus of the roll shaft is 754 times greater than that of the PU liner. This disparity is resulted in increased deformation and stress on the roll. To mitigate deformation and stress and ultimately reduce bending effects on the rolls, thereby preserving their straightness and maintaining the gap between them, it is recommended to minimize the thickness of the PU liner on the first roll as much as possible while still considering its anti-wear function. This should be balanced with the maximum thickness of the structural steel shaft.

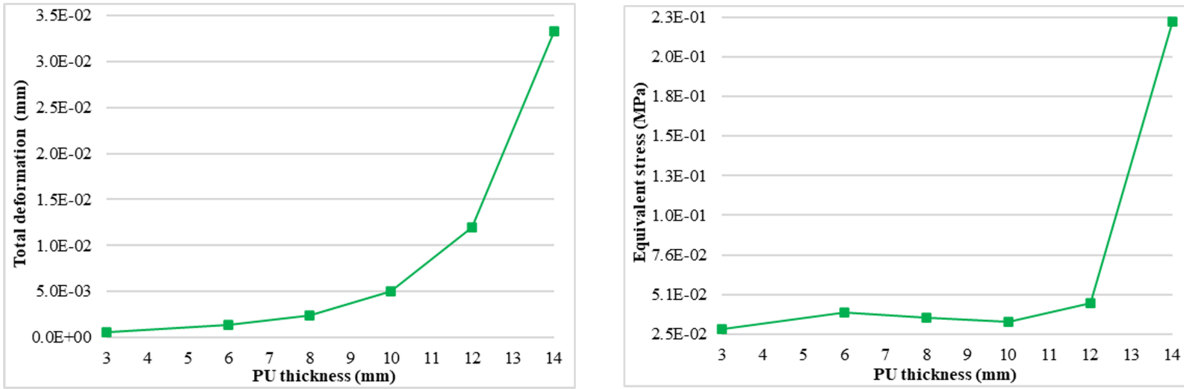


a). Effect of roll diameter variation on the total deformation **b). Effect of roll diameter variation on the equivalent stress**

Figure 13. Variation of the mechanical behaviors of roll 1 with different diameters.

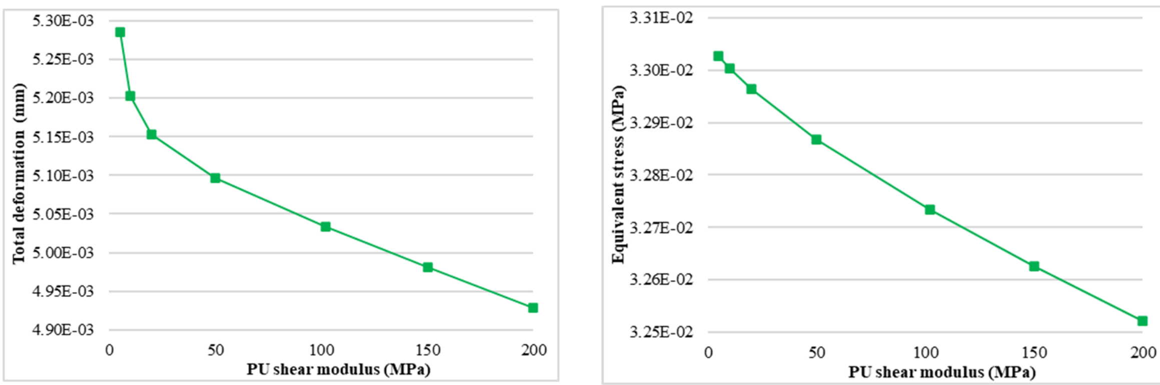
3.3.3. Shear modulus of PU

This section examines the impact of variations in the shear modulus of the PU liner on the mechanical behavior of the first roll of the roller screen. As shown in Figure 15, for the roll with a PU liner modulus of 5 MPa, the average values of total deformation and equivalent stress are 1.07 and 1.02 times greater, respectively, compared to those for the roll with a PU liner modulus of 200 MPa. This finding indicates an inverse relationship between the modulus of the PU liner and the average values of its mechanical behavior. To minimize deformation and stress, as well as the bending caused by the collision of pellets with the roll, which adversely affects the efficiency of the roller screen, it is recommended that the modulus of the PU liner for the first roll be maximized.



a). Effect of PU thickness variation on the total deformation b). Effect of PU thickness variation on the equivalent stress

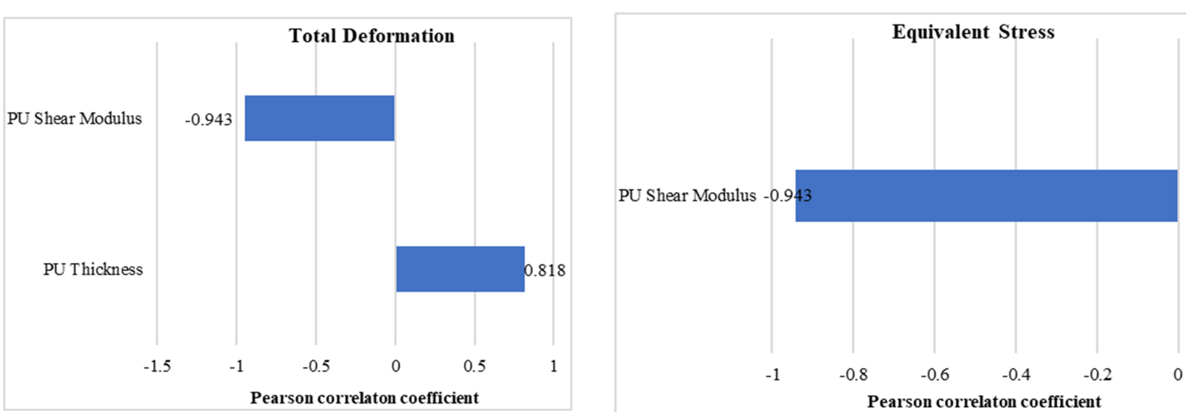
Figure 14. Variation of the mechanical behaviors of roll 1 with different PU thickness.



(a): Effect of PU shear modulus variation on the total deformation **(b): Effect of PU shear modulus variation on the equivalent stress**

Figure 15. Variation of the mechanical behavior of roll 1 with different PU shear modulus.

The results of the examination of the mechanical behavior of the roller screen's initial roll related to structural design factors were analyzed using statistical methods and the Pearson correlation coefficient with a 95% confidence interval using SPSS software. These findings are presented in Figure 16.



(a) **(b)**

Figure 16. Analysis results of Pearson correlation coefficient of mechanical behavior of initial roll related to structural design factors.

Based on Figure 16(a), it is evident that the total deformation of the first roll exhibits an inverse relationship with the PU shear modulus and a direct relationship with the PU thickness whereas Figure 16(b) indicates that the equivalent stress is inversely related to the shear modulus of PU.

Therefore, the following relationships can be derived to describe the mechanical behavior of the roll in relation to its structural parameters:

$$Total\ deformation \propto \frac{T_{PU}}{G_{PU}} \quad (1)$$

$$Equivalent\ stress \propto \frac{1}{G_{PU}} \quad (2)$$

Where are:
T_{PU} = thickness of PU (mm)
G_{PU} = shear modulus of PU (MPa)

By identifying the stress concentration points during the operation of the screen used for classifying the green pellets, it is possible to extend the lifespan of the rolls, which are the most critical components of the screen. This can be achieved by modifying the geometric characteristics, such as the roll diameter and mechanical properties, including the shear modulus and thickness of the PU liner. Consequently, utilizing the obtained results allows for the design of an optimal structure, thereby enhancing the performance of the screen. This improvement ultimately increases both the quantitative and qualitative efficiencies of the screen, as well as those of the induration furnace and pelletizing circuit. The frequency and duration of screen downtime were significantly reduced, which, in turn, enhanced plant productivity. A larger volume of material can be processed using a roller screen. The results obtained can be applied to the study of other processing equipment such as ball mill lifters.

3.4. Validation of obtained results

Considering the low values of the forces exerted by the pellets during the laboratory tests, as well as the industrial studies conducted, it is evident that the stresses applied to the rolls occur over extended periods of screen operation. This prolonged exposure leads to deformation of the rolls and, consequently, a decrease in their efficiency. To validate the findings of the laboratory tests and coupled DEM-FEM simulations regarding the effects of roll diameter, particularly for the first roll, which serves as an impact roll and endures the highest levels of force, deformation, and stress, as well as the mechanical strength and thickness of its liner in industrial screens, the diameter of the roll should be increased. Additionally, a polyurethane liner with a higher shear modulus and reduced thickness should be used. After a specified period, the results should be examined and compared with the state prior to the changes, which will be the focus of future research.

4. Conclusions

According to studies and simulation tests conducted in the fields of DEM and FEM, and more importantly, the coupled method employed in this study, the following results were obtained:

- The actual shape of the green pellet, determined through image analysis and employing the elastic-plastic hysteretic spring contact model, was utilized in the DEM studies of the green pellet classification process.
- It was evident that the DEM simulation facilitated the calculation of the average force exerted on the roller screen rolls owing to the impact load from the pellets during the screening operation. Furthermore, this method allows for the identification of both the maximum values and specific locations where these forces are concentrated.
- According to the DEM studies on the rolls of the roller screen, the average force resulting from the impact of the green pellet on the first roll is 3.05 times greater than the average force applied to all rolls, respectively.
- The highest levels of total deformation occurred in the central section of the roll. This deformation results in a loss of straightness, which subsequently affects the uniformity of the gap opening between the rolls and ultimately diminishes the efficiency of the roller screen.
- As the diameter of the roll decreased from 80 mm to 30 mm, the average values of the total deformation and equivalent stress applied to the roll increased by 1088 and 51 times, respectively. Therefore, the diameter of the roll, particularly the first roll, can be increased to mitigate the negative effects of deformation on the roll and resulting gap.
- By increasing the thickness of the PU liner of the rolls from 3 mm to 14 mm, while maintaining a constant roll diameter, the values of the total deformation and equivalent stress applied to the roll increased by 54 and 8 times, respectively. In this context, it is advisable to reduce the thickness of the PU liner while maintaining its anti-wear properties, considering the relationship between the liner thickness and the deformation and stress experienced by the roll.
- By decreasing the shear modulus of the PU liner of the rolls from 200 MPa to 5 MPa, the values of the total deformation and equivalent stress applied to the roll increased by 1.07 and 1.02 times, respectively. Therefore, maximizing the shear modulus of the PU liner is advisable to minimize the deformation of the roller screen rolls.

- Finally, it was concluded that the coupled DEM-FEM numerical simulation method is a suitable and effective approach for improving the design, structure, and efficiency of roller screens.

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اجرا روش کوپل DEM-FEM برای بررسی رفتار مکانیکی غلتک‌های سرند غلتکی در طبقه‌بندی گندله‌های خام سنگ آهن

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کلمات کلیدی

غربال غلتکی
DEM
FEM
کوپلینگ
تغییر شکل کلی

چکیده

از آنجا که سرندهای غلتکی در کارخانه‌های گندله‌سازی از یک طرف به دیسک‌های گندله‌سازی و از طرف دیگر به کوره‌های پخت سنگ آهن خام متصل هستند بنابراین نقش حیاتی در بهره‌وری کارخانه و فرآیند تولید فولاد ایفا می‌کنند. در نتیجه، عملکرد بهینه و طراحی ساختاری آن‌ها در این زمینه ضروری است. یک مسئله مهم در مورد سرندهای غلتکی در طول طبقه‌بندی گندله‌های خام، تغییر شکل غلتک‌ها ناشی از نیروی اعمال شده توسط گندله‌ها در حین کار است. این تغییر شکل، یکنواختی فاصله بین غلتک‌ها را مختل می‌کند و در نتیجه باعث کاهش راندمان سرند و عملکرد کلی مدار می‌شود. با وجود اهمیت این موضوع، هیچ مطالعه‌ای برای بررسی نیروی اعمال شده توسط گندله‌ها در طول طبقه‌بندی روی سرند یا رفتار مکانیکی غلتک‌ها انجام نشده است. این مطالعه برای اولین بار از روش شبیه‌سازی کوپل اجزای گسسته (DEM)-اجزای محدود (FEM) برای بررسی رفتار مکانیکی غلتک‌ها و بهینه‌سازی طراحی ساختاری آن‌ها استفاده می‌کند. نتایج نشان داد که کاهش قطر غلتک از ۸۰ میلی‌متر به ۳۰ میلی‌متر منجر به افزایش ۱۰۸۸ برابری در میانگین تغییر شکل کلی غلتک‌ها می‌شود. علاوه بر این، افزایش ضخامت آستر پلی‌اورتان از ۳ میلی‌متر به ۱۴ میلی‌متر باعث افزایش ۵۴ برابری میانگین تغییر شکل کل می‌شود.

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