

# EFFECT OF MN PRESENCE IN IRON ORE ON PELLETISATION PROPERTY AND SINTER PROPERTY AND PRODUCTIVITY

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## **Abstract**

*Manganese in iron ore influences nearly every stage of iron ore agglomeration, and its effects appear most clearly during pelletisation, sintering and the final productivity of the plant. In pelletisation, manganese changes how the feed absorbs moisture, forms green balls and responds to thermal treatment. Its oxides interact differently with binders and iron oxide surfaces, which can alter pellet growth, drying behaviour and induration strength. When manganese is present in higher proportions, it may slow oxidation during firing or create bonding phases with different melting characteristics. These shifts affect the fired pellet's mechanical strength, reducibility and behaviour inside reduction furnaces.*

*In sinter plants, manganese affects granule formation, bed permeability and the progress of the flame front. It alters the wetting behaviour of fines, changes granule density and modifies how the mix responds to fluxes. These changes can either accelerate or slow down melt formation, which influences the development of calcium ferrites and other bonding phases essential for sinter strength. High or inconsistent manganese can create uneven heating, weak bonding zones and lower sinter quality. Once charged into a blast furnace, such sinter may degrade, swell or generate excess fines, all of which reduce burden permeability and furnace efficiency.*

*Across both pellet and sinter routes, manganese affects productivity through increased fuel demand, variable oxidation rates, potential sticking tendencies and changes in the mechanical stability of the agglomerates. Plants often respond by tightening blending controls, adjusting flux levels or operating at narrower process windows. These interventions stabilise quality but reduce operational flexibility. As a result, manganese concentration becomes an important factor guiding chemical limits, process optimisation and the overall performance of ironmaking units.*

**Keywords:** *Manganese, Pelletisation, Sintering, Bonding phases, Permeability, Productivity.*

## **INTRODUCTION:**

Manganese is a metallic element commonly found with iron minerals. In iron ore processing, it affects oxidation behaviour, melting characteristics and the formation of bonding phases during pellet firing and

sintering. Its oxides can change how the material heats, reacts and bonds, which directly influences the quality and performance of agglomerates.

Iron ore is the raw mineral source used to produce iron and steel. It contains iron oxides such as hematite and magnetite along with other elements like silica, alumina and manganese. Its chemical composition and physical properties determine how it behaves during agglomeration and how efficiently it can be used in a blast furnace or direct reduction process.

Pelletisation property refers to how iron ore fines behave when converted into spherical pellets. This includes moisture absorption, green ball formation, strength development during drying and firing, and final pellet quality. Any component such as manganese that alters bonding, oxidation or melt formation will change these properties.

Sinter property describes the behaviour of iron ore fines during sintering, a process where fines are heated to create a porous, bonded mass. Key properties include granulation efficiency, bed permeability, bonding phase formation, mechanical strength and reducibility. Elements like manganese influence melt formation and mineral transitions, which shape the final sinter quality.

### **THE OBJECTIVE OF THE STUDY:**

This study examines how manganese in iron ore affects pelletisation, sintering behavior and overall plant productivity.

### **RESEARCH METHODOLOGY:**

This study is purely based on secondary data sources such as articles, research papers, books, journals and other sources.

### **Influence of Manganese on Pellet Feed Chemistry and Green Ball Formation**

Manganese enters the pelletisation circuit through the iron ore feed, and even modest variations in Mn content influence how the mix behaves during green ball formation. In most pellet plants, the basic physical demands of pellet feed are predictable: the material should offer uniform moisture absorption, consistent surface activity and enough plasticity for stable growth in the disc or drum. When Mn is present, these fundamentals shift because manganese minerals such as pyrolusite, manganite or braunite follow different hydration and surface-energy patterns compared to hematite or magnetite. They can either promote or resist water uptake, depending on their oxidation state and grain size, which then controls the moisture window for balling. Operators sometimes find that feeds containing higher Mn require tighter control of water addition because the green balls may become either brittle or sluggish to nucleate.

Mn can also influence the binder's action. Bentonite interacts with iron oxide surfaces through electrostatic mechanisms, and when Mn oxides are mixed in, the distribution of charges within the green pellet changes. This affects how the binder spreads through the matrix. In feeds with elevated Mn, the binding layer can become thinner or patchier unless conditioning steps are extended. This shows up as variations in drop number, green compressive strength and the tendency for fines to slough off during handling. Plants that rely on organic binders notice the effect more strongly because these binders depend on consistent surface chemistry to create polymer bridges. When manganese substitutes for part of the iron matrix, the surface reactivity shifts and can reduce the green ball's robustness unless dosage adjustments are made.

Another influence comes from the bulk density of manganese minerals. Mn oxides are often denser than hematite, which changes the overall particle-packing dynamics inside a forming pellet. Higher density particles tend to settle differently during rolling, which can produce internal voids or localised hard spots. This uneven structure increases the chance of pellet breakage in the early drying stage. To counter this, pellet plants sometimes refine the grind size or perform additional homogenisation to distribute the Mn minerals as evenly as possible. If the Mn is present in coarse liberated grains, the effect is even more visible because such grains do not embed smoothly in the pellet matrix. They can behave like rigid inclusions that interrupt the cohesive network needed for strength.

Mn-bearing ores may also alter the oxidation behaviour during the early stages of thermal treatment. Even though this becomes more pronounced in induration, it still has a preliminary effect during green ball formation because operators anticipate how the pellet will respond later in the furnace. The knowledge that Mn-rich pellets tend to shrink differently or reach oxidation equilibrium slower pushes plants to enforce stricter limits on green pellet size distribution. If the green pellets vary too much in size, the Mn-containing ones might end up oversintered or undersintered depending on where they sit in the furnace bed.

Manganese tends to increase the abrasiveness of the feed, depending on the mineral form. This influences the wear characteristics of disk or drum balling equipment. Higher Mn levels sometimes push plants to run at lower rotational speeds or adjust scraper arrangements to prevent accelerated equipment erosion. These operational modifications also influence how the green balls grow, which indirectly affects pelletisation efficiency. In many plants, these adjustments are subtle but necessary whenever Mn exceeds a threshold where its physical and chemical characteristics begin to dominate pellet feed behaviour.

### **Impact of Manganese on Pellet Drying, Induration and Fired Pellet Quality**

Once green pellets enter the thermal circuit, the presence of Mn alters several stages of heat transfer and reaction kinetics. During drying, pellets with manganese often lose moisture at a different rate because manganese oxides may absorb or retain water differently compared to pure iron oxide matrices. If the dehydration curve becomes uneven, the shell of the pellet can dry too fast while the core retains moisture, leading to differential shrinkage.

This sometimes results in surface cracks or internal fissures that reduce fired pellet yield. These defects can increase if Mn-rich particles cluster within the pellet, creating micro-zones that heat at a different rate from surrounding iron oxide. As the temperature rises toward oxidation and sintering ranges, manganese begins to influence the diffusion processes that convert magnetite to hematite. Mn can substitute for iron atoms in the crystal lattice and modify the diffusion coefficients. This often slows down the oxidation rate, meaning that pellets containing higher Mn may require longer oxidation periods to reach the desired fired strength. If oxidation is incomplete, the pellet core remains weak and negatively affects reducibility during downstream processing. Plants that operate on fixed furnace timings sometimes experience lower firing uniformity when Mn content fluctuates, prompting them to implement tighter chemical blending practices.

Mn also influences the formation of the slag-bonding phase within the pellet. During induration, silicates, alumina and alkaline compounds interact with iron oxide to create a glassy phase that cements the pellet structure. Manganese participates in this melt phase by modifying its viscosity and melting point. A small amount of Mn can make the melt more fluid, improving neck formation between grains and increasing compressive strength. However, excessive Mn tends to lower the softening temperature too much, causing pellets to deform or stick. This sticking tendency forces plants to reduce bed depth or alter furnace traveling-grate parameters to maintain pellet quality. Reduction properties are another critical area where manganese plays a role. Mn-rich pellets tend to show a slightly higher reduction degradation index because manganese oxides behave differently under reducing conditions. They form intermediate manganese phases that do not reduce at the same rate as iron oxides. This can create internal stress during reduction, which may break down the pellet into smaller fragments. Steel plants relying on high-shaft furnaces or gas-based direct reduction often impose tight Mn limits for this reason. When Mn is too high, even well-formed pellets can degrade during the reduction cycle, increasing dust generation and lowering productivity.

Thermal swelling behaviour also changes with Mn. Some manganese minerals cause pellets to swell excessively under reducing conditions because of the formation of low-density phases. This swelling can compromise bed permeability in blast furnaces. When burden permeability drops, the furnace consumes more coke and delivers lower hot-metal output. Pellet plants anticipating this downstream effect sometimes adjust the flux composition to counteract Mn-driven swelling. For example, adding small amounts of MgO can stabilise the pellet microstructure and reduce the tendency to expand. In the induration machine, Mn can influence the heat pattern of the entire furnace because the energy demand shifts with the changing chemistry. Pellets with Mn may need more or less heat input depending on how the manganese phases transition. This affects fuel consumption as well as the dwell time in each zone. Plants running at high throughput sometimes struggle to maintain consistent fired quality when Mn varies rapidly. They must then apply stricter quality control, more precise temperature profiling and improved blending to stabilise the process.

## Role of Manganese in Sinter Mix Granulation and Bed Permeability

In sinter making, granulation sets the stage for everything that follows. The presence of Mn affects how the raw mix forms granules because manganese minerals alter surface roughness, wettability and particle cohesion. Iron ore fines usually granulate well because hematite and magnetite interact predictably with water and return fines. When Mn enters the mix, the balance changes. Some manganese minerals have smoother surfaces or different porosity levels, so they modify the water distribution through the granule. This can lead to two contrasting effects: either the granules become too dense and less porous, or they become irregular with weak clustering. Both situations harm bed permeability. Mn also changes how the mix responds to assimilation during heating. Before melting, the sinter bed relies on proper airflow to ignite and propagate combustion. Granules that were formed with distorted internal structure due to Mn-bearing fines may collapse prematurely or form hard clusters that block air passages. Operators often notice that high Mn in the mix narrows the optimum moisture range for granulation. If moisture is slightly too high, Mn minerals can produce sticky granules that form mud balls. If moisture is too low, they may segregate, reducing granule strength and causing dusting in the bed.

The distribution of Mn within the granule impacts how coke breeze burns. A uniform distribution allows the flame front to advance smoothly, while uneven distribution can produce cold spots. Manganese minerals frequently have higher thermal stability than iron oxides, so they heat differently during the early stages of sintering. This impacts how the flame front moves from the top to the bottom of the bed. When Mn is concentrated in patches, those areas may resist heating and slow the downward migration of the flame front. This raises the overall sintering time and reduces strand productivity. Mn content also influences the mix's response to fluxes like limestone, dolomite and serpentine. These fluxes normally melt at predictable temperatures to form liquid bonding phases. When Mn participates in these reactions, it modifies the mineralogical pathway. Some manganese compounds can lower the melting point, causing premature formation of liquid phases in the upper part of the bed. This makes the granules stick together before adequate heat penetration, causing uneven voidage. Poor voidage means air cannot pass uniformly through the bed, resulting in slower ignition, weaker suction and lower productivity.

In many sinter plants, manganese-bearing ore fines also contribute to variations in bed shrinkage. When materials shrink unevenly during heating, cracks or channels may develop in the sinter layer. These channels allow air to bypass some areas, further distorting the burn-through pattern. Manganese compounds expand or contract at different rates compared to iron oxides, causing localised distortions in bed height. This not only affects productivity but also the stability of the sinter cake when it is discharged from the strand.

Transport behaviour of the granules is another indirect effect. Mn minerals often increase the abrasiveness of the mix. This promotes the generation of extra ultra-fines during handling and charging. The presence of more fines lowers granule growth efficiency and raises the risk of high pressure drop across the bed. Excess fines restrict airflow and reduce the vertical velocity of gases, both of which slow sintering. Plants typically respond to these

effects by adjusting the proportion of return fines or modifying the drum speed to maintain suitable granule size distribution. Altogether, Mn affects granulation not by a single mechanism but through a network of interactions involving moisture, surface chemistry, thermal stability and mechanical behaviour. These changes influence bed permeability directly and therefore shape the productivity and stability of the entire sintering operation.

### **Effect of Manganese on Sinter Mineralogy, Bonding Phase Formation and Strength**

Sinter strength depends heavily on how mineral phases develop during heating, assimilation and melt solidification. Manganese changes these mineralisation pathways because it can enter the lattice structures of major iron-bearing minerals or form new manganese-rich phases. One of the most important effects arises during the formation of the primary bonding phases: calcium ferrites, including SFCA and SFCA-I. These are responsible for much of the sinter's mechanical integrity. When Mn is present, it may substitute for Fe in these ferrites or create mixed Mn-Fe oxides that alter the melt composition. A modest amount of Mn can stabilise certain ferrites and create a stronger bonding network, but higher concentrations disrupt the delicate balance required for strong, porous sinter.

During heating, fluxes and iron oxides undergo partial melting. The viscosity of the resulting melt determines how well particles bond. Manganese oxides lower the melting point and can make the melt too fluid. A melt that becomes excessively fluid flows too easily, reducing the number of well-formed necks between particles. This leads to weaker sinter because the bonding phase forms thin films rather than robust bridges. In addition, if the melt drains into the lower layers of the sinter bed, the upper layers become deficient in bonding material, producing friable top sections that crumble during handling.

Mn also influences the assimilation behaviour of iron ore fines. Assimilation involves the partial melting and absorption of smaller particles into a liquid phase formed by fluxes. When Mn participates in assimilation reactions, the rate at which hematite grains dissolve into the melt may slow down. This delay can create zones where particles remain unmelted even after the flame front has passed. These unmelted clusters act as weak points in the sinter structure because they do not bond well with surrounding material. Plants often detect this through lower tumbler index or reduced cold crushing strength. The mineralogical structure of the finished sinter is further affected by how Mn partitions during cooling. Some manganese compounds crystallise as rhodonite or other silicate phases, which can introduce brittleness. Others remain as fine oxides that sit at the grain boundaries. These oxides can weaken the bond between hematite and ferrite matrices. The presence of such phases increases the chance of microcracks forming when the sinter cake cools. These cracks lower the mechanical stability of the product and generate more fines during screening.

Another important aspect is the effect on reducibility. High Mn in sinter can produce phases that reduce slowly in the blast furnace. Slow-reducing sinter holds onto oxygen longer and resists softening, which may seem beneficial at first, but the mismatch between the reduction rate of iron phases and manganese phases creates internal stresses. These stresses break down the structural cohesion of the sinter at mid-reduction temperatures. Reduced strength at these temperatures decreases bed permeability inside the furnace, which can raise coke rate and lower hot metal output. The thermal behaviour of sinter is also altered. Manganese-bearing phases often exhibit different heat expansion characteristics. As the sinter heats in the blast furnace, these phases expand at different rates, causing uneven stress distribution. This can lead to fragmentation of the sinter burden. Fragmented sinter produces more fines, and these fines create bottlenecks in gas flow. The furnace then consumes extra energy to push air through, reducing operational efficiency. Because manganese shifts the balance of mineralogy and bonding, many plants enforce strict Mn limits in their sinter feed. When Mn levels vary, operators must adjust basicity, coke breeze rate or strand speed to maintain strength and reducibility. Without these adjustments, sinter quality deteriorates quickly, and downstream effects appear in furnace behaviour and productivity.

### **Influence of Manganese on Overall Pellet and Sinter Productivity and Plant Performance**

Manganese content in iron ore affects productivity across the value chain because it influences both the physical and chemical behaviour of pellets and sinter. Productivity in pellet plants largely depends on green ball quality, induration efficiency and fired strength. When Mn complicates green ball formation, plants often slow down disc speeds, adjust water addition more frequently or apply extra mixing time. These adjustments reduce throughput because the circuit loses some of its operating flexibility. If Mn causes more breakage during drying or early induration, operators must run with narrower size distributions or lower bed depths to avoid producing off-spec pellets. Lower bed depth directly reduces machine output. In many plants, fluctuations in Mn also force operators to trim production to maintain consistency. Induration machines operate most efficiently when process variables remain steady. If Mn shifts oxidation kinetics or melt behaviour unpredictably, operators introduce extra buffer time or reduce firing temperature swings. These stabilising measures protect quality but take away from maximum attainable productivity. In extreme cases, the sticking tendency introduced by high Mn can cause bed agglomeration on the grate. Recovering from such incidents requires shutdowns or extended cleaning cycles, both of which reduce effective plant capacity.

On the sintering side, manganese influences productivity through its impact on granulation efficiency, bed permeability and burn-through time. Sinter machines rely on a predictable and uniform vertical flame front. When Mn increases fines generation or disrupts granule structure, the suction required to pull air through the bed rises. Higher suction means higher power consumption, and even then the flame front may still travel slowly. A slower flame front increases sintering time and limits how much material can be processed per hour. Plants that operate near their suction limits experience even stronger productivity losses because they cannot compensate for

Mn-driven airflow restrictions. Mn-related mineralogical effects also change the energy profile of the sintering process. If Mn slows assimilation or forms melts that are either too early or too fluid, the ignition furnace may need more fuel to achieve proper bed heating. Higher fuel injection increases operational cost and may still not completely offset the slower burn-through. If the bottom layers of the bed remain underheated due to Mn interference, the resulting sinter becomes weak. Producing weak sinter forces adjustments in strand speed and sometimes requires reprocessing more return fines. Handling extra return fines taxes the system and reduces the net output of standard-sized sinter.

In the blast furnace, both Mn-rich pellets and Mn-rich sinter contribute to poor permeability when they degrade or swell. To maintain furnace stability, operators may reduce the burden descent rate or increase coke rate. These compensations indirectly reduce the viable charging rate of pellets and sinter, effectively constraining the productivity of upstream plants. So even if the pellet or sinter plant pushes for higher output, the blast furnace may limit the acceptance of product containing higher Mn levels. This feedback loop forces upstream units to operate at moderated production rates. Maintenance cycles also become more frequent in Mn-influenced circuits because manganese minerals often increase abrasiveness. Increased wear on drums, discs, sinter screens, crushers and transfer chutes requires more downtime. The cumulative effect of these maintenance interruptions reduces the annual effective capacity of both pellet and sinter plants. Because manganese affects physical handling, thermal behaviour, reduction properties and mineralogy, its impact on productivity is not limited to one stage but ripples across the entire production chain. Plants respond by applying chemical blending, adjusting flux ratios, tightening operating windows and modifying residence times. These interventions keep quality in control but consume operational margin that would otherwise be used to maximise output. Over time, the presence and variability of Mn becomes a major determinant of both stability and productivity in iron ore agglomeration.

## CONCLUSION

The presence of manganese (Mn) in iron ore significantly impacts pelletisation, sintering, and overall productivity in metallurgical processes. Mn alters the physicochemical behavior of the ore feed, affecting green-ball formation, binder interactions, and moisture control. In pellet induration, Mn modifies oxidation kinetics and the development of bonding phases, leading to variation in pellet strength, reducibility, and thermal stability. During sintering, manganese changes granulation behavior, bed permeability, and flame-front dynamics, ultimately influencing sinter quality via its effect on melt viscosity and mineral phase formation. High Mn levels can lead to weaker bonding phases, microstructural inhomogeneity, and reduced mechanical strength, which undermine the stability and reducibility of the sinter product. From a productivity standpoint, Mn introduces operational challenges — increased fuel consumption, altered process windows, potential sticking, and more maintenance. While plants can mitigate some of these issues through tighter blending, flux adjustments, or enhanced control, these countermeasures often reduce throughput. Therefore, managing Mn content in iron ore

becomes critical for balancing quality and efficiency. Controlling Mn within optimal limits or adopting advanced process techniques is essential to maintain high agglomerate strength and maximize plant productivity.

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