

A Critical Review of Wear Mechanisms in Chilled Cast Iron for Food Processing Applications

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Abstract

Original Research Article

Chilled cast iron is the dominant material used in food processing equipment throughout sub-Saharan Africa and South Asia, particularly for staple food milling. Its duplex structure consists of a hard white iron surface layer ranging from 400 to 600 HBW and a tough grey iron core between 150 and 250 HBW, providing an effective combination of abrasive resistance and fracture toughness at low cost. Recent studies using magnetic separation, scanning electron microscopy, and atomic absorption spectrophotometry have demonstrated that cast iron grinding discs release metallic wear particles up to 1.7 grams per 10 kilograms of milled grain, with mean diameters of 43 micrometres and measurable levels of chromium, lead, and cadmium. Despite these contamination figures and related health concerns, major knowledge gaps persist regarding how microstructural evolution influences wear rate progression, which wear mechanisms dominate under different food processing conditions, and how particle characteristics relate to processing parameters. This review offers an integrated perspective linking tribological degradation, microstructural design, and public health consequences through methodical evaluation of published work. As a consolidation, it compiles and quantifies particle release data, identifies transitions between wear mechanisms under food-relevant conditions, and suggests approaches for reconciling the opposing demands of wear resistance and food safety. The review also proposes a quantitative wear model, provides a consolidated repository on contamination, assesses alloying strategies including vanadium additions up to 1.2 percent, and presents a decision-making protocol for manufacturers, moving the discipline from descriptive observation towards prescriptive engineering practice.

Keywords: Abrasive wear; Chilled cast iron; Food processing; Food safety; Metallic contamination; Microstructure.

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1. INTRODUCTION

Staple food production in developing economies relies heavily on locally fabricated grinding equipment. Cast iron grinding wheels are integral to these systems, yet they are typically produced by small-scale foundries with limited quality control. In service, these wheels undergo

severe abrasive conditions that progressively degrade their working surfaces. Component lifespan and milling efficiency depend primarily on microstructure, which governs hardness, fracture toughness, and wear resistance.

Chilled cast iron emerged in the mid-nineteenth century following James Oliver's patent for the



chilling process used in cast-iron ploughs. By controlling composition and cooling rates, Oliver achieved a hard wear surface combined with a tough, crack-resistant substrate. Hermann Gruson later adapted this technique for demanding applications such as armour plating, crushers, and industrial rolls, where resistance to prolonged abrasive loading proved essential. Modern characterisation of Gruson's material has confirmed the hardness gradient responsible for its wear performance (Dieck et al., 2023).

Despite its historical legacy and ongoing use in food processing equipment, particularly in West African markets, the tribological behaviour of chilled cast iron under food-relevant conditions remains poorly understood. No comprehensive study has linked microstructural changes during service to wear rate progression or declining grinding efficiency. This gap is compounded by growing evidence that metallic wear debris from grinding surfaces enters processed foods, posing a health risk (Talabi et al., 2025). The associated hazards have yet to be quantified, and regulatory oversight is largely absent in many producing regions.

This review aims to identify the microstructural factors governing wear resistance in chilled cast iron, determine the dominant wear mechanisms in food processing, evaluate the effect of heat treatment on wear performance, examine the extent and mechanisms of metallic contamination from wheel degradation, derive practical manufacturing parameters for small-scale foundries, and identify research gaps for future work.

2. CONCEPTUAL FRAMEWORK

2.1. Framework Overview

The interconnections between material structures, wear behaviour, particle emission, and biological response form a dynamic system with two dominant feedback mechanisms, as shown in Figure 1.

Loop A (Reinforcing, Material Degradation): Microstructural heterogeneities, including porosity, secondary phases, or weak grain boundaries, lower resistance to abrasive and adhesive wear. The resulting debris and subsurface strain hardening, phase changes, or tribo-film formation alter near-surface properties, which can shift wear from mild oxidation to severe delamination. This cascade increases particle generation rates, creating a self-accelerating degradation cycle. Research on locally fabricated grinding discs in Nigeria has shown that constant friction causes the discs to wear out quickly, producing metallic particles that contaminate processed food (Busari *et al.*, 2021). The wear process involves particle detachment from first bodies, formation of third body layers, and eventual ejection from the contact, with the wear rate determined by the balance between debris formation and ejection rates.

Loop B (Balancing, Health Risk Data): Released particles, including PM10 (particulate matter with a diameter of 10 micrometres or less), PM2.5 (particulate matter with a diameter of 2.5 micrometres or less), and nanoscale fractions, undergo atmospheric ageing through aggregation and oxidation before inhalation. Pulmonary deposition triggers oxidative stress, inflammation, and cytotoxicity. These dose-response data inform occupational exposure limits and material design criteria, including alloy substitution and coatings, constituting a negative feedback that aims to suppress future emissions. Investigations into burr mill wear in Nigeria have confirmed that iron filings from grinding discs contaminate food flour, and these metallic contaminants, which contain heavy metals, enter the human body and pose health risks including haemochromatosis, where excess iron stored in organs can lead to liver disease, heart problems, and diabetes (Busari *et al.*, 2021). Effective mitigation requires breaking Loop A through material toughening while strengthening Loop B through exposure monitoring and engineering controls.

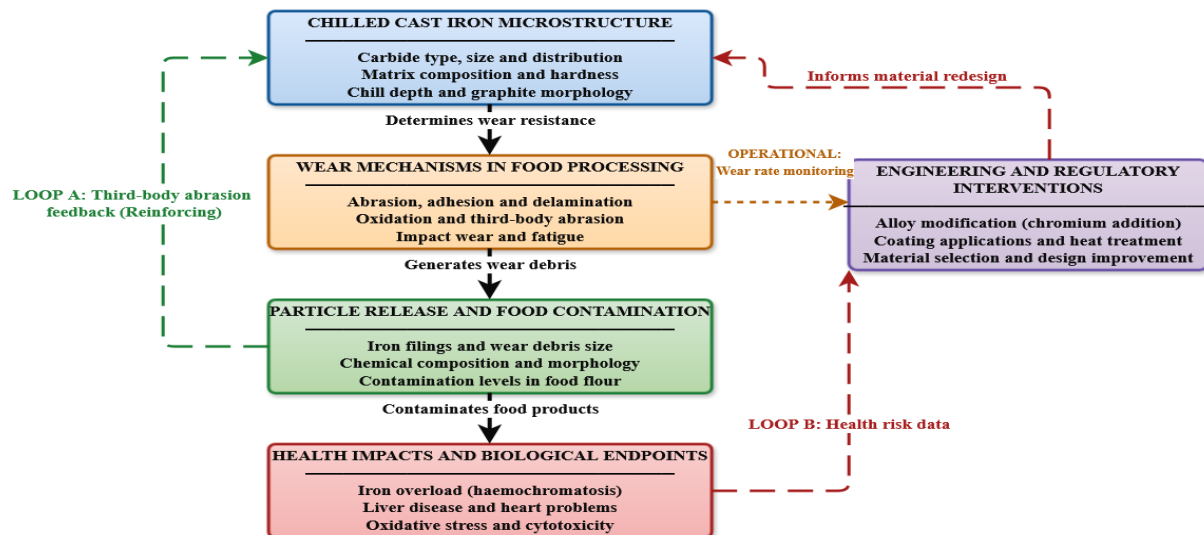


Figure 1. Conceptual framework of microstructure-wear-particle-health interrelationships. Two feedback loops are shown: Loop A, reinforcing, where microstructural defects promote wear, which modifies subsurface properties and accelerates further degradation; and Loop B, balancing, where released particles trigger biological responses that inform exposure limits and material redesign, reducing future emissions. Solid arrows indicate direct causal flows; dashed arrows indicate feedback and moderation effects. Colour code: blue for material properties, orange for tribology, green for particle characteristics, red for health endpoints, and grey for interventions.

2.2. Controlled Variables for Cross-Study Comparability

To enable robust comparison across heterogeneous experimental conditions, the following mediators were recorded for each study: tribological parameters including load, velocity, distance, contact geometry, and lubricant pH and temperature; environmental factors including humidity, ambient temperature, and atmospheric composition; and biological assay conditions including exposure concentration and duration, cell line, clearance rates, and assay type.

Research on wear characteristics of chilled cast iron has identified that particle size, shape, and

surface reactivity are critical determinants of biological response. Studies on locally fabricated grinding discs in Nigeria have shown that the wear rate depends on matrix microstructure, carbide type characteristics, volume fraction, fracture toughness, hardness, loading conditions, features of tribological environments, relative movement of the contact surface, and type and size of abrasive bodies (Busari et al., 2011; Aluko et al., 2003)

3. MICROSTRUCTURE OF CHILLED CAST IRON

3.1 The Duplex Structure

The white iron surface layer, typically 1 to 6 mm in depth depending on cooling rate and composition, consists predominantly of cementite (Fe_3C) in a pearlitic or martensitic matrix. This structure is graphite-free, with carbon retained as metastable iron carbide. Hardness ranges from 400 to 600 HBW, providing exceptional resistance to abrasive wear.

The grey iron core, by contrast, contains carbon as graphite flakes dispersed in a ferritic or pearlitic matrix. Hardness ranges from 150 to 250 HBW, offering toughness, damping capacity, and resistance to catastrophic fracture. The transition between the white iron surface and grey iron core occurs through a mottled zone

containing both cementite and graphite, with hardness ranging from 250 to 400 HBW.

Figure 2 provides a schematic representation of this duplex arrangement, while Figure 3

illustrates how cooling rate varies with section thickness to produce the different microstructure zones. Key boundaries occur at 6 mm (white to mottled) and 25 mm (mottled to grey). Table 1 summarises the main features of each zone.

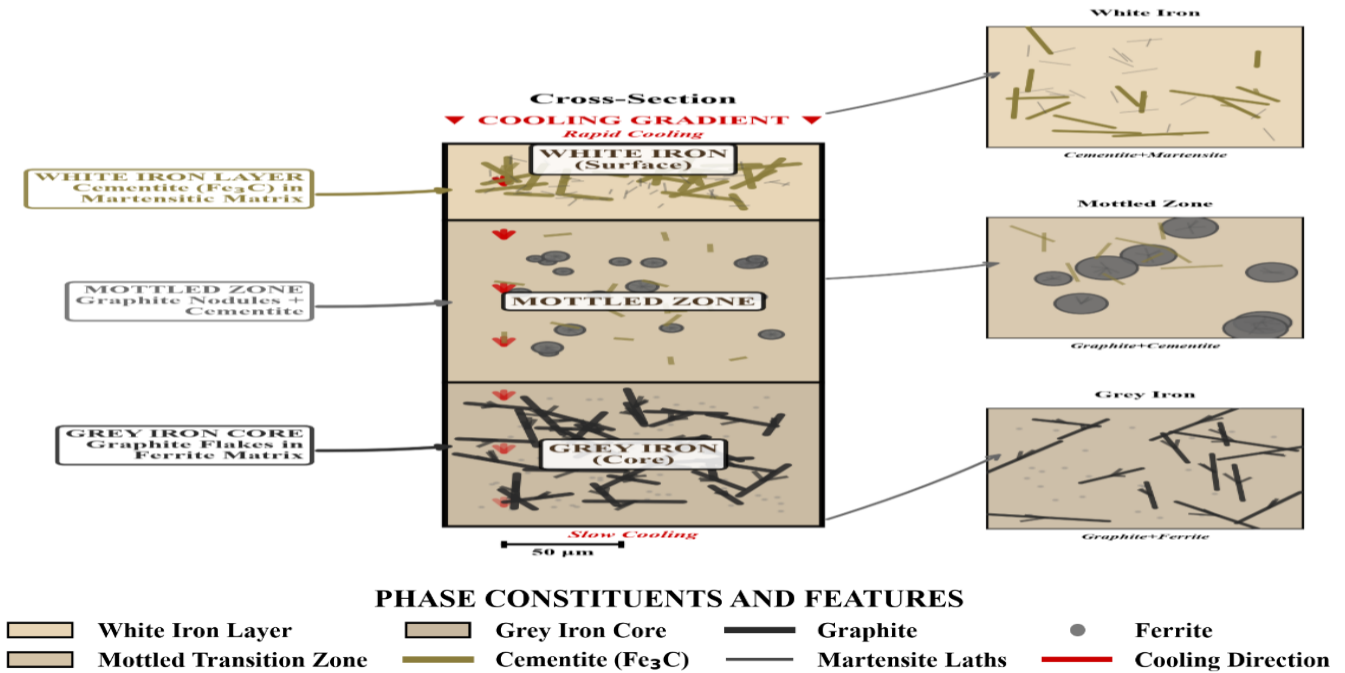


Figure 2. Schematic representation of the duplex microstructure in chilled cast iron, showing the white iron surface layer, which consists of cementite dispersed in a martensitic matrix; the mottled transition zone; and the grey iron core, which comprises ferrite with graphite flakes. The cooling gradient from the surface to the core is indicated by arrows

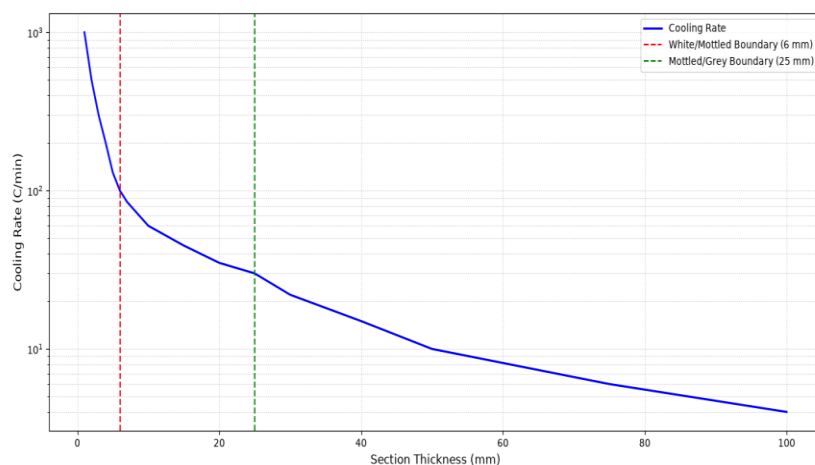


Figure 3: Relationship between cooling rate and section thickness with corresponding microstructure zones. Mark critical boundaries at 6 mm between white and mottled iron and at 25 mm between mottled and grey iron.

Table 1: Comparison of Microstructural Zones in Chilled Cast Iron

Property	White Iron Surface	Mottled Transition	Grey Iron Core
Section thickness	Up to 6 mm	6 to 25 mm	Over 25 mm
Cooling rate	Above 100°C/min	30 to 100°C/min	Below 30°C/min
Graphitisation	Completely suppressed	Partial	Fully realised
Cementite stability	Highly stable	Moderately stable	Unstable
Microstructure	Cementite + martensite	Cementite + graphite	Ferrite + graphite
Hardness range (HBW)	400–600	250–400	150–250
Machinability	Poor	Fair	Excellent
Wear resistance	Excellent	Moderate	Low

3.2. Assessment of Existing Literature

The current understanding of wear phenomena in food grinding equipment is constrained by several significant limitations. For high-volume, continuous grinding applications, chilled cast iron remains the established standard due to its ability to form a massive volume fraction of hard iron carbides (M_3C) within a white-iron matrix (Laird et al., 2000). While high-chromium alloys offer superior corrosion resistance, their premium cost and reduced machinability make them economically unjustifiable for most food-contact wear parts.

The Archard abrasion equation has shown promise in predicting wear rates in various tribological contexts, but validation for food grinding applications remains extremely limited. The complex tribological conditions encountered during food processing, including abrasive particles, variable moisture content, frictional heating, and organic acids, have not been thoroughly investigated using Archard-based predictive frameworks.

No cohesive framework governs wear testing of grinding discs or similar food processing machinery components. While standards exist for certain food-contact applications, no equivalent standard addresses the specific requirements of food grinding operations. This absence is especially concerning because

tribological degradation produces metallic wear debris that is unintentionally ingested with ground food (Talabi et al., 2025).

Current knowledge is heavily concentrated on West African food processing contexts, particularly Nigeria. Research has quantified metallic contaminant generation during maize grinding and characterised the corrosion susceptibility of grinding discs. However, analogous data for other regions where similar grinding practices are prevalent remain sparse.

4. WEAR MECHANISMS IN FOOD PROCESSING ENVIRONMENTS

4.1 Fundamental Wear Theory

Abrasive wear in chilled cast iron grinding wheels is classically described through the Archard wear equation. For this work, the cumulative wear volume over a processing campaign is adopted as the primary metric, given the practical need to assess total material loss during maintenance intervals. This is expressed as:

$$W_{\text{abrasive}} = k_1 \times \frac{P}{H} \times v \times t \quad (1)$$

Where:

W_{abrasive} is the total abrasive wear volume (mm^3),

P is the normal contact force (N),

H is the material hardness (MPa),

v is the sliding velocity (m/s),

t is the total processing time (s), and

k_1 is a dimensionless wear coefficient.

For hard brittle materials such as chilled cast iron, the coefficient k_1 is not constant. It decomposes into a micromechanical efficiency factor k_2 , defined as the proportion of displaced groove volume released as wear debris. Hardness

H determines penetration depth, while k_2 governs debris removal efficiency. In chilled cast iron, microfracture of the ledeburitic carbide network yields $k_2 > 1.0$ because fragmented debris volume can exceed groove volume (Singh and Gupta, 2024). For hard brittle materials, the wear coefficient evolves with microstructure, confirming that hardness alone is insufficient to predict wear performance (Sanusi and Yakubu, 2026). Table 2 summarises these micromechanical regimes and the conditions under which each dominates.

Table 2: Micromechanical Wear Regimes and Dominant Conditions in Chilled Cast Iron

Mechanism	Description	k_2 Range	Dominant Conditions	Material Loss
Micro-ploughing	Displacement of material to the sides; no debris removal	0.01–0.05	Low attack angles; ductile matrix; rolling abrasives	Very Low
Micro-cutting	Direct shearing and removal of chip-like debris	0.5–0.9	High attack angles; constrained abrasives (fixed)	Moderate–High
Wedge formation	Accumulation of prow-like mass ahead of abrasive, later detached	0.05–0.3	Moderate attack angles; high work-hardening materials	Moderate
Micro-fracture	Crack propagation and fragmentation of the hard carbide network	>1.0	Brittle ledeburitic carbides; high contact stresses	High (Accelerated)

The total wear is conceptualised as a superposition of three simultaneously acting mechanisms:

$$W_{total} = W_{abrasive} + W_{corrosion} + W_{fatigue} \quad (2)$$

In Equation 2, the abrasive component $W_{abrasive}$ is the k_2 -corrected Archard term from Equation 1:

$$W_{abrasive} = \frac{k_2 \cdot k_1 \cdot P \cdot v \cdot t}{H}$$

Where k_2 is selected from Table 1 according to the dominant wear regime for the given contact conditions.

$W_{corrosion}$ dominates when acidic food products chemically attack the exposed metallic binder between carbides, undercutting the hard asperities. This is expressed as:

$$W_{corrosion} = k_c \cdot A_c \cdot C_{acid} \cdot t \quad (3)$$

Where:

$W_{corrosion}$ is the corrosion wear volume (mm³);

k_c is the corrosion wear coefficient;

A_c is the active surface area of exposed asperities (mm²);

C_{acid} Is the acid concentration or pH-related corrosivity factor and t is the exposure time (s).

$W_{fatigue}$ dominates under repeated contact cycles from rotating or reciprocating machinery, leading to sub-surface delamination of the carbide asperities. This is expressed as:

$$W_{fatigue} = k_f \cdot \sigma_{cyclic}^n \cdot N_{cycles} \quad (4)$$

$W_{fatigue}$ is the fatigue wear volume (mm^3);

k_f is the fatigue wear coefficient;

σ_{cyclic} is the cyclic contact stress (MPa);

n is the material-dependent fatigue exponent; and

N_{cycles} is the number of loading cycles.

4.2 Dominant Wear Mechanisms

Three primary wear mechanisms operate during food grinding operations.

Micro-ploughing occurs when abrasive particles displace material without cutting, forming grooves with raised shoulders. This mechanism is promoted by low attack angles, abrasive particles free to roll, and ductile wear-resistant materials. The wear rate is relatively low as most material is displaced rather than removed. This mechanism is shown schematically in Figure 4(a).

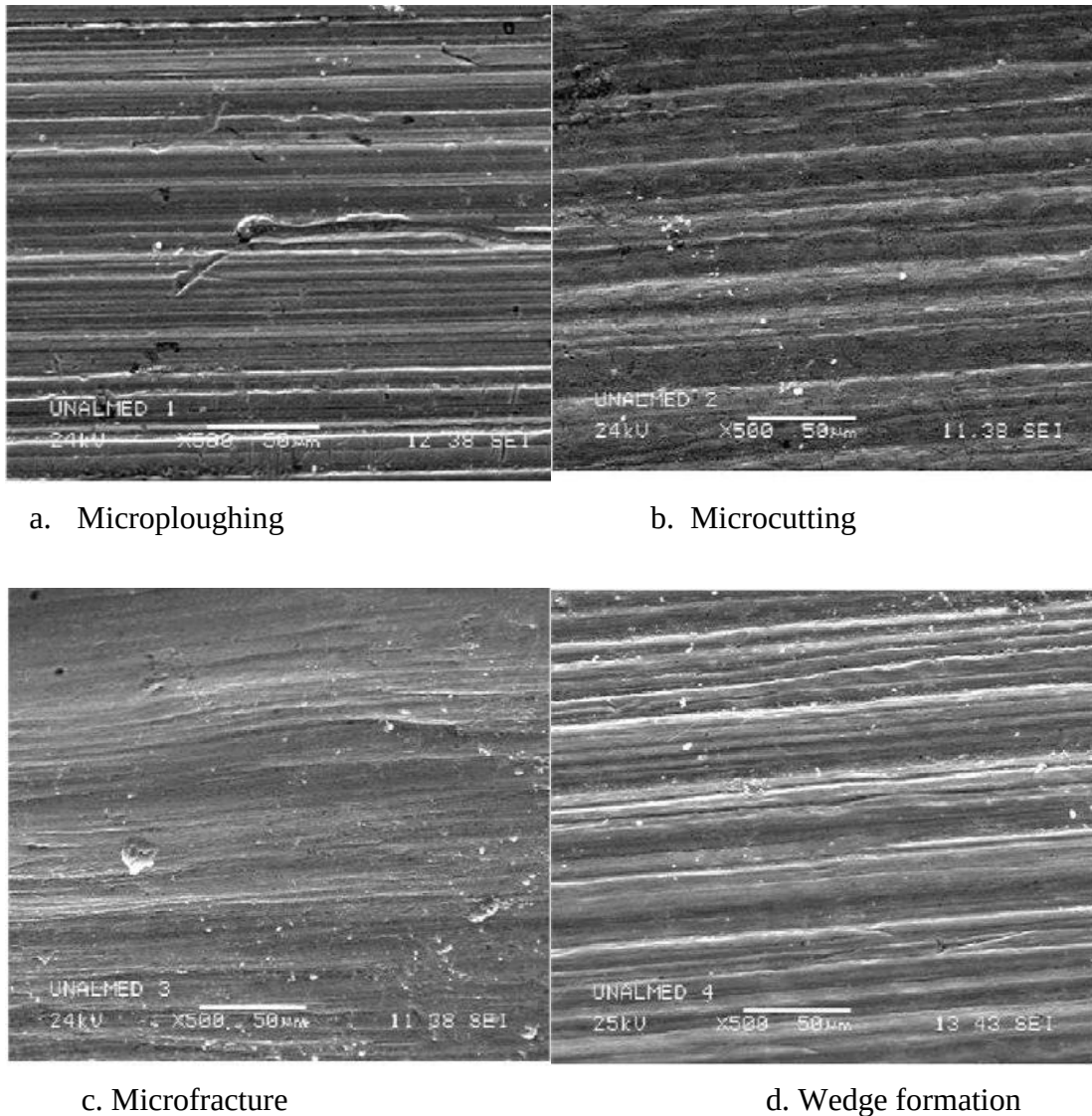


Figure 4: Schematic of abrasive wear mechanisms in chilled cast iron: (a) micro-ploughing; material displaced to groove shoulders without debris formation; (b) micro-cutting; material removed as chip-like debris ($k_2 \approx 0.5-0.9$); (c) microfracture; crack propagation through ledeburitic carbide network ($k_2 > 1.0$); (d) wedge formation; prow-like accumulation detached by cyclic loading ($k_2 \approx 0.05-0.3$). (Adapted from Mann and Brar, 2015)

Micro-cutting involves the removal of material as debris, comparable to conventional machining. This mechanism is promoted by high attack angles, constrained abrasive particles, and less ductile materials. The wear rate is higher than micro-ploughing, with k_2 values typically between 0.5 and 0.9. Figure 4(b) illustrates this cutting action.

Micro-fracture occurs in brittle materials when abrasive particles induce cracking and fragmentation. This mechanism is promoted by excessive hardness and brittleness. When micro-fracture dominates, k_2 can exceed 1.0, resulting in severe wear despite high hardness (Singh and Gupta, 2024). This behaviour is represented in Figure 4(c).

Wedge formation is a wear mechanism in which a hard sliding asperity displaces ductile material into a prow-like accumulation ahead of it. This occurs under moderate attack angles and repeated sliding with materials that exhibit high work-hardening. The wear rate is moderate, with k_2 values approximately ranging from 0.05 to 0.3 (Singh and Gupta, 2024). The final mechanism,

wedge formation, is depicted in Figure 4(d).

4.3 Vanadium Addition and Wear Resistance

Recent studies have explored alloying modifications to enhance the wear resistance of chilled cast iron. Gao et al. (2023) investigated the effect of vanadium addition on the microstructure and wear resistance of chilled cast iron. Their results showed that increasing vanadium mass fraction refined the microstructure and produced more uniform carbide distribution, with carbide morphology transforming from network to long strip structures. However, vanadium fractions exceeding 1.2% caused carbide coarsening and aggregation. The optimal impact abrasive wear resistance occurred at 1.2% vanadium, where the wear mechanism transitioned from micro-cutting to plastic fatigue under impact conditions. Table 3 summarises the wear rate values and particle release measurements reported in these investigations, allowing a direct comparison across different material systems and operating conditions.

Table 3: Summary of Key Studies on Wear and Particle Release in Milling Roll Materials

Study	Material	Test Conditions	Wear Rate (mm ³ /Nm)	Particle Release (mg/kg)	Major Finding
Talabi et al. (2025)	Chilled Cast Iron	Maize grinding	*Not reported	170 mg/kg	Corrosion-wear synergy
Mesaki et al. (2001)	Chilled Cast Iron roll	Wheat grinding	$\sim 2.3 \times 10^{-6}$	Not reported	Speed differential effects
Gao et al. (2023)	Cast Iron + 1.2% Vanadium	Impact wear	$\sim 1.8 \times 10^{-6}$	Not reported	Optimal Vanadium addition

**Wear rate (mm³/Nm) not reported in original study. Particle release of 170 mg/kg is equivalent to 1.7 g per 10 kg grain, which provides a comparable metric for wear-related material loss. Conversion to mm³/Nm is not possible without additional data on density, applied load, and sliding distance.*

5. HEAT TREATMENT EFFECTS ON WEAR PERFORMANCE

Heat treatment exerts a profound influence on the microstructure and wear resistance of chilled cast iron. At elevated temperatures, the hard cementite phase becomes thermodynamically unstable and undergoes graphitisation, decomposing to ferrite and graphite. The rate and extent of this transformation depend on temperature, time, and alloy composition, particularly silicon content.

Widder et al. (2021) conducted hot hardness tests on chilled high-chromium cast irons and demonstrated that these materials maintain substantial hardness up to approximately 500°C. At higher temperatures, the matrix softens and the beneficial effect of carbides on wear resistance diminishes. However, an important finding was that incorporation of SiC abrasive particles in the wear zone leads to in-situ wear protection, which was especially effective at 300°C, increasing wear resistance compared to room temperature.

Experimental investigations have shown that annealing, normalising, quenching, and tempering each reduce hardness relative to the as-cast condition. This decline results from thermally activated dissociation of cementite (Fe₃C) into iron and carbon. Silicon, typically present at 1.80 wt% in domestically manufactured grinding wheels, weakens the Fe-C bond, lowering the activation energy for cementite decomposition and promoting graphitisation during heating. Sanusi and Yakubu (2026) confirmed this mechanism, showing that water quenching could not suppress

graphitisation in this composition; the 1.80 wt% silicon limited hardenability, preventing martensite formation and steering the microstructure toward cementite dissociation.

For grinding wheel applications where wear resistance is paramount, the as-cast chilled condition is optimal. All post-casting heat treatments reduce hardness relative to the as-cast controlled sample and significantly increase calculated wear rates (Sanusi and Yakubu, 2026). Manufacturers should prioritise controlling casting conditions to achieve the desired chill depth, rather than relying on thermal processing for property optimisation.

6. HEALTH AND CONTAMINATION RISKS

6.1 The Scale of the Problem

Research has provided alarming evidence of metallic contamination from cast iron grinding discs used in food processing. Talabi et al. (2025) revealed that foodstuffs such as maize, pepper, and spices ground with local machines are contaminated by metallic wear particles and corrosion products from deteriorating discs. The deterioration takes two main forms: tribological wear caused by friction between the wheel during grinding, and corrosion triggered by chemical reactions with water and oxygen. Microscopic metallic fragments, including iron, chromium, and manganese oxides, were found in the ground food samples. For every 10 kg of maize ground, up to 1.7 g of metallic magnetic contaminant with an average size of 43 µm was recovered. The concentration ranges for these elements, together with their associated health effects, are set out in Table 4.

Table 4: Metallic Contamination from Cast Iron Grinding Discs

Element	Concentration Range (mg/kg)	Potential Health Effect	Reference
Fe	41.70–49.16	Iron overload, organ damage	Talabi <i>et al.</i> (2025)
Zn	2.03–40.00	Zinc poisoning (children at risk)	Talabi <i>et al.</i> (2025)

Mn	3.12–21.00	Neurological disorders	Talabi <i>et al.</i> (2025)
Cu	3.00–26.92	Liver damage at high intake	Talabi <i>et al.</i> (2025)
Cr	0.54–6.80	Carcinogenic (Cr VI)	Talabi <i>et al.</i> (2025); Petinrin <i>et al.</i> (2021)
Pb	0.55–1.58	Neurotoxicity, developmental effects	Talabi <i>et al.</i> (2025); Petinrin <i>et al.</i> (2021)
Cd	0.73–3.44	Kidney damage, carcinogenic	Petinrin <i>et al.</i> (2021)
Ni	0.40–7.17	Carcinogenic, allergic reactions	Petinrin <i>et al.</i> (2021)

6.2 Health Implications

The health implications of chronic metallic particle ingestion are serious and multifaceted. Chronic exposure to iron particles can lead to intestinal lacerations, organ damage, and digestive disorders. Iron accumulation in tissues (haemosiderosis) can cause organ dysfunction, particularly in the liver, heart, and pancreas.

Chromium contamination is particularly concerning due to the interconvertibility of chromium ions. While trivalent chromium is relatively less toxic, hexavalent chromium is a known carcinogen with DNA-damaging effects. The grinding process, which reduces particle size, may generate particles small enough to penetrate different organs in the body.

Manganese contamination also warrants attention, as chronic exposure can cause neurological disorders similar to Parkinson's disease. The daily intake of manganese for an adult is expected to be between 2 and 6 mg/day; concentrations detected in grinding discs far exceed this range.

6.3 Corrosion in Food and Gastro-Intestinal Environments

Ahmed *et al.* (2023) conducted a comprehensive assessment of corrosion susceptibility of grinding discs in simulated gastro-intestinal environments. Their key finding was that all grinding discs exhibited profound corrosion susceptibility in simulated gastric solution regardless of the manufacturing method. The

wheels, containing iron and silicon as dominant alloy elements existing predominantly as iron carbide and ferrosilicon phases, showed significant corrosion degradation in the gastric environment. Importantly, porosity observed in one of the discs aggravated the severity of its corrosion degradation, highlighting the critical importance of quality control during production.

7. RESEARCH GAPS AND FUTURE DIRECTIONS

7.1 Quantitative Wear Testing

Wear assessment of chilled cast iron grinding wheels has relied primarily on pin-on-disc and ball-on-flat tribometers, with normal loads of 5–50 N, sliding speeds of 0.1–1.0 m/s, and test durations up to 10^5 cycles (Gao *et al.*, 2023; Drees *et al.*, 2025). These studies demonstrate non-linear increases in wear rate with load and speed, with a micro-cutting to micro-fracture transition at contact stresses above approximately 800 MPa for ledeburitic carbide structures (Singh and Gupta, 2024). Laboratory tests, however, consistently under-predict field wear rates by a factor of 2 to 5, owing to the absence of corrosive media and cyclic loading in standard protocols (Drees *et al.*, 2025; Figueiredo *et al.*, 2025).

7.2 Surface Engineering for Food Safety

Surface engineering offers an intermediate strategy to reduce metallic contamination by enhancing corrosion and wear resistance without

complete material substitution. Physical vapour deposition coatings, including chromium nitride and titanium boron nitride, have been validated for food-processing components, showing significant improvements in tribological performance (Hidalgo-Badillo et al., 2024). Chromium nitride on cobalt-base alloys provides superior corrosion protection in saline and humid conditions relevant to moist and acidic food matrices.

Geometric and capture-based interventions also offer promise. Redesigned grinding geometries with reduced clearance gaps and optimised relief angles decrease metal debris generation, while magnetic traps and filtration stages have proven effective for post-processing removal of ferrous particles (Talabi et al., 2025). Manufacturers should prioritise physical vapour deposition coatings on high-wear surfaces, controlled chilling heat treatments, and geometric redesign with magnetic capture systems as secondary barriers.

7.3 Alternative Materials and Regulatory Framework

Stainless steel has been advocated for food grinding equipment to prevent metallic contamination (Talabi et al., 2025). It offers superior corrosion resistance and reduced particle release compared with cast iron. Adeyeye et al. (2025) found that stainless steel components enhance corrosion resistance and cleanability, though higher fabrication costs challenge small-scale producers.

Regulatory standards are essential to address health hazards from metallic contamination. Talabi et al. (2025) observed that consumers ingest contaminants without sufficient knowledge of their composition or health effects, underscoring relevance to UN Sustainable Development Goal 3. ISO 14159 requires food-contact surfaces to be constructed without crevices from corrosion-resistant materials to enable effective cleaning (Adeyeye et al., 2025). Drawing upon tolerable daily intake values from the World Health Organisation, together with contamination data in Table 4, the following provisional limits are proposed: lead not

exceeding 0.3 milligrams per kilogram of food, cadmium not exceeding 0.1 milligrams per kilogram, hexavalent chromium not exceeding 0.05 milligrams per kilogram, and total metallic particles not exceeding 100 milligrams per kilogram. These thresholds are intentionally conservative to accommodate cumulative exposure.

8. CONCLUSIONS

Chilled cast iron is widely used in food processing equipment because its duplex microstructure offers an optimum balance of surface hardness and core toughness, providing exceptional abrasive wear resistance at low cost. The chilling principles established by Oliver and Gruson remain valid. However, the same mechanisms that enable wear resistance, namely micro-cutting and micro-fracture of hard carbide phases, generate metallic debris that contaminates food. Recent findings indicate contamination can reach 1.7 grams of metallic particles per 10 kilograms of processed maize, with toxic elements such as chromium, lead, cadmium and nickel posing additional health hazards.

Wear resistance and food safety are fundamentally at odds. Heat treatment generally reduces hardness and wear resistance, whereas the as-cast chilled structure maximises wear performance but releases particles during service. Alloying with vanadium up to 1.2 percent may offer an option to improve wear resistance while preserving the chilled structure.

Addressing this challenge requires concurrent strategies: optimising manufacturing practices, developing surface engineering solutions, establishing regulatory standards, raising public awareness, and investigating alternative materials. Future work must prioritise quantitative wear testing, particle characterisation, durable coatings and field validation to translate findings into practical interventions.

9. RECOMMENDATIONS

1. Manufacturers should optimise casting practice using metal moulds or chills to accelerate cooling, promote white iron

formation, and reduce porosity. Heat treatment after casting must be avoided.

2. Regulators should enforce safety limits on lead, cadmium, chromium and nickel particle release, supported by regular monitoring and public awareness campaigns.
3. Researchers should study wear under realistic food contact conditions, characterise particle size, morphology and composition, and explore durable coatings, field studies, and alternative materials such as stainless steels and ceramic composites.
4. Equipment users should minimise contamination through regular disc inspection, prompt replacement of worn parts, proper seasoning, and thorough washing of ground produce before consumption.

10. ACKNOWLEDGEMENTS

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