TRANSITION TO SYNTHETIC CASTING FLUXES IN INGOT CASTING AREA, ACCIAIERIE BERTOLI SAFAU CASE STUDY: ANALYSIS OF PROCESS VARIABLES AND QUALITATIVE IMPACT FOLLOWING THE FLY ASH SUPPLY CRISIS.

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The critical shortage of fly ash has driven a multistage transition in carbon fluxes for ingot casting: moving from traditional formulations, to fly ash free versions and finally to fully synthetic alternatives. While these alternatives aim for chemical equivalence, they exhibit fundamentally divergent melting kinetics and thermophysical properties. This study analyses the operational issues encountered in the casting phase, focusing on how the change in raw material matrix has triggered instabilities, with a subsequent impact on both the surface integrity and macro-cleanliness of the ingots. The current industrial framework demands a paradigm shift in the steel plant - supplier relationship; manufacturers must move beyond mere chemical specification compliance toward active co-engineering of flux performance. Current production scenario shows a significant qualitative regression compared to historical benchmarks. Current traditional powders no fly ash based, give extremely irregular surfaces and a critical frequency of powder entrapment. Conversely new synthetic solutions do not yet guarantee results equivalent to the past.

This paper documents a comprehensive optimization period focused on recalibrating specific consumption rates and flux positioning strategies, Furthermore, all the surrounding variables are analysed inherent to ingot casting. Findings demonstrate that the adoption of synthetic fluxes is not a "drop-in" replacement but an unresolved metallurgical challenge. The identification of a stabilized equilibrium remains a work in progress, requiring rigorous, continuous monitoring to mitigate material-specific limitations and restore process stability.

KEYWORDS: INGOT CASTING – BOTTOM POURING – CASTING POWDER – FLY ASH – POWDER ENTRAPMENT – SURFACE DEFECTS

INTRODUCTION AND INDUSTRIAL CONTEXT

Over the last few decades, continuous casting has emerged as the primary technology in steelmaking, achieving advanced levels of productivity, automation, and process control. Despite this technological evolution, ingot casting maintains a fundamental role in the manufacturing of special steels destined for applications with exceptionally severe metallurgical and quality requirements. The ingot route remains essential for specific dimensional classes, critical steel grades, and products demanding high internal integrity, where continuous casting is technically unsuitable.

In Acciaierie Bertoli Safau (ABS), ingot production operates as a complementary and strategically relevant asset alongside continuous casting lines. The complete vertical integration of steelmaking, casting, rolling, and forging within the same industrial site provides a significant technical advantage. This layout enables process engineers to monitor the material through the initial stages of the manufacturing chain and directly evaluate the impact of steel-shop and casting practices on the quality of the transformed product. Furthermore, ingot casting remains a field where process optimization is still deeply rooted in practical and empirical testing. Currently, computational simulation models are not yet sophisticated enough to replicate the complex and numerous real time variables of the casting phase, let alone capture the behavior of new materials, making rigorous industrial trials irreplaceable.

This work documents an industrial case study focused on the critical issues encountered following a significant performance shift in fundamental auxiliary material. The critical shortage of high-carbon fly ash forced powder

manufacturers to redesign historical formulations using alternative raw materials. Although these new products were nominally compliant with historical baselines in terms of chemical specification, their physical behavior and kinetics during casting diverged fundamentally. The purpose of this paper is to analyze the relationship between the altered raw material matrix of the powders, process stability during casting, and the quality indicators of the final ingot. This study demonstrates that, under drastic raw material changes, nominal chemical equivalence alone is insufficient to guarantee equivalent industrial performance. Ultimately, this historical transition highlights the necessity of a structured, proactive technical collaboration between the steelmaker and powder suppliers to understand new material behaviors, calibrate operational parameters, and preserve final product quality.

INGOT CASTING ROUTE AT ABS

ABS operates several rising casting stations, served by a 100 ton nominal capacity ladle car with manually regulated slide gate flow control. The ladle to column connection is inertized with Argon through a toroidal diffuser, and the steel flow is further shrouded by a dedicated refractory system to limit atmospheric exposure and reoxidation. The product range is round, square, and polygonal ingots weighing approximately 6 to 44 ton, across steel families including structural, quenched and tempered, case hardening, high aluminum, high sulfur, high chromium, and bearing steels, for an average annual output of about 130.000 ton. Ingots are subsequently processed internally through bar rolling or forging or sold directly as as-cast. The availability of downstream facilities on the same industrial site allows the operating conditions adopted during casting to be directly correlated with final product quality, verified through surface and internal (ultrasonic) inspections. Given this wide variability in weight, geometry, steel grade, and end use, robust and repeatable casting practices are essential, and within this context, the behavior of the powders used in ingot casting plays a significant role in casting stability, surface quality, and internal cleanliness.

CASTING PRACTICE AND FUNCTIONAL ROLE OF POWEDERS

The standard bottom pouring practice requires the use of casting powder contained in bags and suspended inside the mold prior to casting. These bags are positioned centrally over the inlet nozzle (trumpet outlet), at a height of approximately 300 mm from the mold bottom. As liquid steel enters and fills the mold, the intense radiant heat burns the bags, releasing the powder directly onto the meniscus, where it expands and distributes across the liquid steel surface to develop the necessary functional layers [1].

The initial filling phase is characterized by severe fluid-dynamic turbulence, high speed currents, and rapid fluctuations of the steel level. During these critical moments, parameters such as bag positioning, initial opening speed, powder spreading capacity, powder melting kinetics, and general behavior become fundamental. Any nonuniform behavior or restricted expandability can trigger local powder accumulations, crust formation, or partially melted agglomerates. These defects are highly susceptible to mechanical entrapment by the turbulent steel stream and can be trapped within the solidifying steel matrix.
Historically, the consumption rate of the rising powder was optimized through long industrial experience at ABS, setting quantities within the typical range of 1–2 kg per ton of liquid steel. This specific consumption is not a universal benchmark, but a tailored operating window that depends directly on the individual ingot weight, geometry, and visual behavior during casting. It is fundamental to distinguish this casting powder from the insulating covering powder, which is applied manually to the hot-top area only after mold filling is completed, although both materials interact with the liquid steel meniscus, they are introduced at different stages and serve distinct metallurgical purposes.

The powders evaluated in this study are silica-alumina-based insulating materials characterized by high free-carbon content. The primary functions of the casting powder during mold filling and early solidification include atmospheric protection, thermal insulation, and meniscus lubrication. The industrial performance of the rising powder cannot be evaluated independently of the global casting parameters: its effectiveness is governed by the synergy between material properties (density, particle size distribution, expansion rate, melting kinetics,

slag viscosity) and operational variables (ingot geometry, filling rate, bag position, and specific consumption). Under the historical framework, centralized bag positioning and consolidated consumption rates consistently guaranteed highly repeatable, defect-free results with traditional powder formulations. However, the forced transition away from fly ash altered the physical behavior and operational kinetics of the new alternative products; consequently, the historical practice was no longer automatically transferable, exposing an urgent need for a systematic re-evaluation and optimization phase.

INDUSTRIAL ISSUE AND QUALITY IMPACT

Towards the end of 2024, a sequence of interconnected operational anomalies emerged across several stages of the production process at ABS. These issues manifested as casting complications during casting, surface and internal cleanliness defects on the final products, and maintenance difficulties in the reheating furnaces. A systematic evaluation of plant parameters indicated that these concurrent industrial signs were correlated with an altered operational behavior of the mold powders. As detailed in the following sections, this performance shift is strongly linked to the historical shortage of high-carbon fly ash that simultaneously affected major mold flux manufacturers.

As cast ingot surface quality

Visual control of the as-cast ingots pointed to a reduction in surface uniformity. Affected areas showed irregularities and a less homogeneous surface. In specific cases, localized macro entrapments of unmelted powder were observed on the ingot surface. Casting observations suggested a premature consumption or altered melting kinetics of the powder layer, which accelerated its consumption compared to the historical standardized quantities, leaving the upper meniscus less protected during the rise.

Fig.1 Surface irregularities detected during visual inspection of as cast ingots

Longitudinal surface defects in rolled products

Data received from the rolling mill showed an upward trend in a specific defect: fine and shallow longitudinal surface cracks. The morphology of these defects links the problem to pre-existing superficial or sub-superficial ingot discontinuities that open and elongate during hot deformation. Specifically, these cracks are compatible with the deformation of micro gas entrapments, such as pinholes or blowholes, or with localized irregularities present before rolling, such as entrapment of unmelted powder under the skin.

While sub-surface pinhole formation is a multi-variable phenomenon driven by initial filling turbulence rather than powder behavior alone, its higher statistical frequency coincided directly with the transition to the new powder batches. Consequently, this correlation led to a deeper process analysis investigating the link between powder melting kinetics, meniscus stability, mechanical entrapment risk, and the generation of gaseous sub-surface defects.

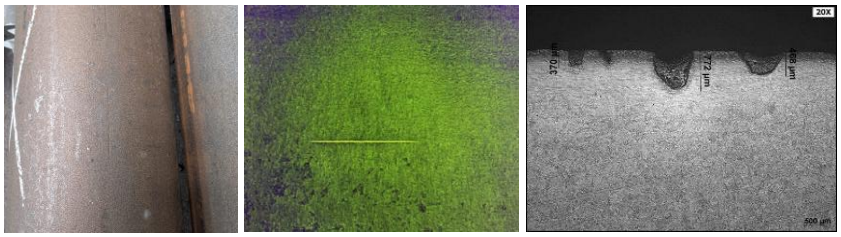


Fig.2 (a) Visual aspect of the crack on the rolled bar; (b) evaluation of the fine crack through MPI inspection; (c) microscopic analysis of the cracks visible in cross-section

Internal Cleanliness and Forging Product Evaluation

Additional evidence emerged from the forging plant, where non-destructive ultrasonic testing (UT) registered an increased frequency of internal indications. Several analyses confirmed that these internal defects consisted of exogenous macro inclusions directly related to the rising powder matrix. These powder entrapments were primarily identified in two distinct structural regions: in bars corresponding to the original bottom of the ingot, highly compatible with mechanical entrapment of un-melted powder aggregates carried into the liquid steel shell by the severe fluid-dynamic turbulence characteristic of the initial filling step, and in specific cases, in core zones, where powder residues were detected deeper within the central macro-structure of the ingot. This central distribution implies a more complex transport mechanism: entrapped slag particles are carried by convective currents into the liquid core and subsequently trapped and redistributed by the downward movement of solidifying sedimentary crystals, a mechanism that could be associated with crystal-rain phenomena [2].

These internal defects are particularly critical for forged products destined for high-stress applications. Subsequent plastic deformation can elongate, open, or amplify any pre-existing ingot discontinuity. Given the stringent quality standards and severe ultrasonic cleanliness specifications required by end-users, minimizing the presence of foreign material and internal discontinuities during the earliest casting stages is a priority.

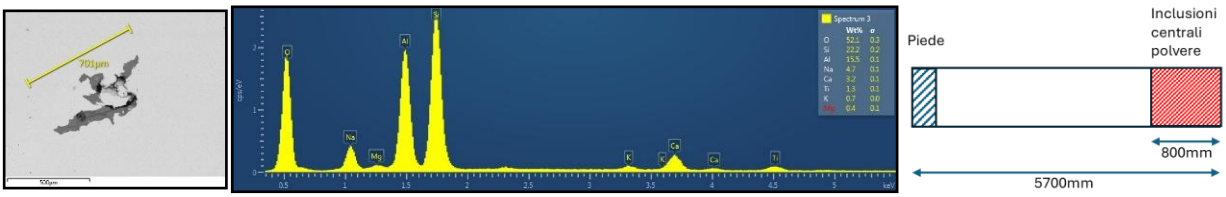


Fig. 3 (a-b) SEM-EDS analysis of the detected powder entrapment; (c) position of the defect and bar length

Operational Impact on Refractory Linings and Furnace Reheating

Simultaneously with the product quality observations, an increased frequency and intensity of an already known operational condition was observed: reheat-furnace slag accumulation. This phenomenon manifests as the formation of glassy, vitrified slag deposits in specific furnace zones, particularly in areas highly exposed to material falling or scaling off from the ingot surfaces and hot-tops. To confirm the origin of these massive deposits, samples collected from the furnace were analyzed via X-ray fluorescence (XRF).

The analysis confirmed that these residues contained explicit chemical tracers characteristic of the casting powders (Na_2O, MgO, Al_2O_3, SiO_2), mixed with conventional iron oxides and scale. This evidence demonstrates that un-melted or partially melted casting powder residues remained adhered to the solid ingot skin after stripping. During the reheating cycle, these residual materials melt upon reaching their liquidus temperature; driven by convective gas currents within the furnace, the liquid slag stick to the refractories, accelerating residue buildup and requiring more intensive furnace-cleaning cycles than historical campaigns.

Ultimately, the intensification of furnace slagging served as a critical indicator of a fundamental change in the thermal and physical behavior of powder residues. The presence of this vitrified material, and its response during reheating, confirmed that nominal chemical specifications alone are insufficient. To fully understand the transition, a comprehensive investigation was required into the physical properties of the powders, including their melting kinetics, expandability capacity, surface distribution, and high-temperature transformations.

Fig. 4. (a) Massive, vitrified slag residue detected in the hot top area; (b) positioning of the ingots inside the reheating furnace; (c-d) vitrified residue mixed with scale present on specific furnace components

Cross-Process Impact and Diagnostic Correlation

The collected evidence revealed that the operational shift was not a localized casting anomaly, which might have been countered by merely adjusting specific consumption rates, but a systemic issue visible across the entire manufacturing chain. The chronological alignment between the new powder formulations and the altered processing behavior established a clear, industrially significant correlation. Critically, these challenges emerged even before the powder suppliers officially notified the steel plant of the structural changes made to the raw material matrix.

CASTING OBSERVATIONS, CONSUMPTION INCREASE AND POWDER CHARACTERIZATION

A thorough process control was carried out, analyzing every parameter and material involved in casting. Given that no operational changes had been introduced during the period under review, clear indicators emerged suggesting that the mold powder could have been the cause of the decrease in ingot performance.

The primary industrial evidence associated with the reformulated powder batches was a systematic increase in specific consumption rates across all ingot formats. Under identical initial feeding weights and deployment procedures, the alternative material was no longer sufficient to sustain a continuous, stable protective layer throughout the upward filling phase inside the mold (Fig. 5). Under the historical framework, the established specific consumption and the centralized bag positioning successfully maintained a well-protected casting meniscus, a condition internally referred to as the “black practice.” This setup minimized direct atmospheric exposure and ensured a stable thermal profile at the meniscus. During the transition period, however, keeping the operational parameters constant led to progressive consumption of the powder layer before full mold filling was achieved.

Fig. 5 No completed filling and already exposure of the bath surface

This reduced powder availability also triggered unexpected operational variances among molds within the same assembly. Despite being fed symmetrically from the central trumpet, individual molds showed distinct coverage conditions and different intensities of luminous emission from the steel meniscus. While this luminous intensity does not constitute a quantitative thermal measurement, it can be a reliable qualitative indicator of uneven powder distribution and localized layer discontinuity (Fig. 6). This discrepancy across nominally identical casting plates confirmed a clear lack of industrial consistency among incoming batches.

Fig. 6 Different powder behavior in molds from the same casting plate

The accelerated consumption directly compromised the metallurgical functions of the rising powder. Inadequate surface coverage lowered the thermal insulation of the rising steel, restricted continuous lubrication, and induced premature shell freezing. Furthermore, an under-protected ingot head at the end of the pour increased radiant heat losses, altering the conditions for the subsequent application of the hot-top insulation powder: instead of stratifying over a stable, pre-existing slag layer, the hot-top coverage powder came into direct contact with the liquid steel meniscus. This improper interaction compromised feeding

efficiency during solidification, increasing susceptibility to shrinkage-cavity defects and providing a potential mechanism for the entrapment and internal transport of non-metallic macro inclusions into the ingot core.

Chemical and physical characterization

Following the findings from the casting control, it was decided to analyze and further investigate the measurable properties of the mold powders. In parallel, the powder suppliers who had not yet been engaged up to that point were also involved. The suppliers subsequently confirmed that a change had occurred in the raw materials used for powder production.

The initial stage of the investigation focused on fundamental properties accessible through standard laboratory testing, including chemical analysis of major constituents, total carbon content, particle size distribution, and the measurement of characteristic temperatures. Liquid slag viscosity was also calculated, alongside comparative samples in their as-received state. The scope of this laboratory campaign was not to isolate a single property responsible for all plant anomalies, but to verify whether products declared as equivalent to historical benchmarks exhibited hidden variations in behavior.

Chemical analyses performed on the available samples confirmed that all examined formulations strictly complied with the tolerance limits specified in the suppliers' technical data sheets. The concentrations of primary constituents remained entirely consistent with nominal values and historical specifications. Despite this, the characteristic melting and fluidity temperatures were lower than those declared by the suppliers. To provide a standardized metallurgical comparison, the main oxide components are reported in Table 1, normalized to 100% by excluding both the free-carbon fraction and loss on ignition (LOI).

Parameter	Powder X			Powder Y		
	Technical sheet	Technical sheet	Analyzed	Technical sheet	Technical sheet	Analyzed
	Avg %	Norm 100%	Norm 100%	Avg %	Norm 100%	Norm 100%
SiO2 (wt%)	34.4	approx 55	55.1 ≈	32	approx 49.2	54.2 ≈
CaO (wt%)	2.8	approx 4.6	3.9 ≈	5	approx 7.7	7 ≈
MgO (wt%)	1.8	approx 2.8	2.7 ≈			1.3 ≈
Al2O3 (wt%)	13.5	approx 21.2	21.7 ≈	14	approx 21.5	20.4 ≈
Cfree (wt%)	//	//	//	26	//	//
Ctot (wt%)	30	//	//	27	//	//
Others elem.	Balance	approx 16.4	16.6 ≈	Balance	approx 22	17 ≈
T soft (°C)	approx 1030		1090 ↑	approx 1080		1060 ≈
T melt (°C)	approx 1210		1160 ↓	approx 1260		1110 ↓
T fluid (°C)	approx 1260		1220 ↓	approx 1390		1180 ↓

Tab.1 Comparison between datasheet specifications and chemical characterization results for conventional powders (similar value ≈ in respect of technical sheet, ↑/↓ higher or lower value in respect of technical sheet)

Despite matching nominal chemical specifications, casting powders exhibited industrial performance discrepancies compared to historical formulations, demonstrating that composition alone does not ensure equivalent ingot casting results. Key operational factors, such as raw material morphology, particle size, melting kinetics, and liquid slag behavior, are critical for determining process stability and product quality [3].

Fly Ash Shortage and powder reformulation

During the investigation, suppliers officially confirmed a severe supply shortage of high-carbon fly ash, a raw material that historically formed the fundamental matrix component of conventional ingot casting powders. This shortage stems from regulatory and technological shifts in power-generation emission controls, which have progressively restricted the availability of combustion products with stable, high-carbon fractions.

Fly ash does not merely contribute to the chemical composition of the powder: its specific morphology and distributed carbon phase define how the material expands, burns, and distributes across the liquid meniscus.

Maintaining a uniform, stable powder layer is essential to restrict atmospheric reoxidation and preserve the thermal conditions at the ingot head [3]. The conventional formulations examined in this study historically featured a high free-carbon content, typically around 30%; free carbon acts as a thermal moderator, controlling the melting rate of the oxide matrix [4]. However, carbon efficiency depends on particle morphology, grain size distribution, and reaction kinetics rather than total elemental volume alone. While minor batch-to-batch variations in raw materials occurred historically, they fell within manageable tolerances and were easily countered by minor adjustments to specific consumption rates.

In contrast, the transition period represented a major operational discontinuity. To offset the fly ash deficit, manufacturers substituted the historical matrix with alternative carbon sources, including more reactive forms of coal. Although these substitutions successfully maintained bulk chemical compliance within datasheet tolerances, they drastically altered combustion kinetics: the higher reactivity accelerated carbon burn-out, directly modifying the melting rate, expansion capacity, liquid slag formation, and viscosity response of the powder.

This metallurgical mechanism aligns with the industrial anomalies described before: nominally compliant powders exhibited accelerated consumption and premature meniscus exposure, undermining the vital insulation, protection, and lubrication functions required at the steel mold interface. This confirms that a radical change in the raw material matrix, specifically, the reduction or substitution of the high-carbon fly ash fraction, profoundly alters the functional properties of the product, and that nominal composition boundaries alone cannot guarantee the consistency of critical process parameters such as expansion capacity, layer stability, melting kinetics, and lubrication.

These laboratory and casting findings proved that alternative formulations developed during the fly ash crisis cannot be considered drop-in replacements based on chemical compliance alone. The qualification protocol for casting powders must therefore evolve beyond elementary chemical validation, integrating advanced physical and thermal characterization, high-temperature comparative trials, and structured industrial validation under representative plant conditions. Based on these industrial insights, ABS started a systematic evaluation of alternative powder families designed around tightly controlled raw material matrices, aimed at mitigating fly ash dependency. The following chapter details the synthetic solutions investigated, alongside the operational practice adaptations deployed to re-establish process stability in casting.

TRANSITION TO ALTERNATIVE POWDERS AND PROCESS ADAPTATION

The operational issues encountered with reformulated conventional batches demonstrated that nominal chemical equivalence alone cannot guarantee equivalent industrial performance. The accelerated consumption rates, bad meniscus coverage, and high batch-to-batch variability necessitated a technological shift toward alternative powder families capable of ensuring raw material supply stability and reproducible functional properties.

In response, manufacturers developed synthetic powders engineered from highly controlled, selected raw materials. Synthetic powder formulations are a mature technology widely integrated into continuous casting lines, where properties such as viscosity, melting point, and heat transfer control are customized [4]. In ingot casting, however, they have historically lacked extensive adoption; consequently, transitioning to these synthetic alternatives requires rigorous validation of their behavior under actual industrial conditions.

New formulations

To systematically evaluate these solutions while respecting industrial confidentiality, the newly introduced candidate products were identified using anonymized technical codes:

- Powders A, B, and C: selected as alternative formulations for general purpose use.
- Powder D: evaluated in a separate exploratory trial, specifically configured to investigate the impact of lower free-carbon content and altered combustion rates on the mitigation of longitudinal defects detected downstream in the bar rolling mill.

Technical characteristics of alternative formulations

Powders A, B, and C were engineered as synthetic variants designed to maintain a high free-carbon content. Their characteristic softening and melting ranges were technically aligned with standard casting parameters. In contrast, Powder D was introduced as a highly divergent, low carbon formulation, originally developed for sensitive steel applications such as high aluminum grades. The nominal properties and core chemical compositions of the investigated alternative powders are summarized in Table 2.

Value (%)	Historical fly-ash based	A	B	C	D
Type	Conventional	Synthetic	Synthetic	Synthetic	Synthetic
SiO2	≈32	≈45	≈35	≈33	≈40
Al2O3	≈14	≈10	14	≈16	≈7
CaO	≈5	≈4	≈6	≈4	≈31
MgO		≈0.3			≈2
Cfree	≈26	≈24	≈29	≈27	≈3
Ctot	≈27	≈25	≈30	≈28	≈5
T soft (°C)	≈1080	Not declared	≈1150	Not declared	Not declared
T melt (°C)	≈1260	Not declared	≈1240	≈1200	≈1240
T fluid (°C)	≈1390	Not declared	≈1260	Not declared	Not declared

Tab.2 Nominal chemical and physical properties of the investigated alternative powders

Experimental trial design and initial application practice

In the initial testing phase, all powders were used with the same configuration historically established for conventional formulations, i.e., suspended centrally inside the mold. This approach enabled a direct comparison between the new formulations and the historical baseline under identical initial conditions. An increased feeding quantity, approximately 1.5 times the historical baseline, was established in accordance with supplier recommendations. The different powder variants were evaluated simultaneously within the same casting sequence. This methodology minimized the influence of external process variables, such as superheat, steel grade, filling rate, and mold configuration. While direct comparison does not reduce industrial variance, it provides a much more robust framework for evaluating the performance of each formulation.

In mold behavior and post solidification results

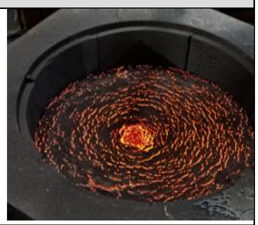
Industrial trials revealed a distinct behavior between the new formulations (A, B, and C) and the historical fly ash based reference. Due to reduced spontaneous spreading and lower surface mobility, the new powders showed a propensity to remain concentrated in the application zone, forming a more compact layer with limited liquid phase evidence. Post solidification assessments confirmed that these casting anomalies directly affected ingot quality, causing localized lubrication failures, surface irregularities, and poor ingot bottom quality across all tested products.

Powder D, instead, was implemented to mitigate gas related defects and the resulting longitudinal cracks on the rolled product. However, this powder induced severe criticalities regarding ingot surface quality. The resulting surface was highly irregular, exhibiting periodic discontinuities that suggested localized shell tearing during the upward rise of the steel.

A fundamental clarification must be made: the respective mold behaviors and final product quality depend significantly on ingot format. Small formats (e.g. 6-ton square ingots) exhibit entirely different filling and upward rise dynamics compared to larger formats. Consequently, the present discussion should be understood as a generalized summary of the observations collected across the comprehensive industrial trials.

The synthesis provided in Table 3 is directly supportable and verifiable by the pictures or visual evidence presented Table 4.

Powder type	Fly Ash Historical	A Syntetic	B Syntetic	C Syntetic	D Syntetic low carbon content
Spreading capability	High	Low, compensated with quantity			
Surface Layer Consistency	Good coverage	Stable, with rare agglomerates	Stable, homogeneous uniform dark layer	Stable, with rare agglomerates	Agglomerates
Observations	/	Localized blue gasses emissions recorded	/	/	/
Ingot quality aspect					
Bottom quality	Optimal uniform lubrication and smooth surface finish	Lubrication failures and surface irregularities	Minor surface defects and signs of under lubrication	Minor surface defects and signs of under lubrication	Surface defects
Upper quality	Optimal consistent surface quality	Improved but persistent local defects	Satisfactory but below historical baseline	Satisfactory but below historical baseline.	Surface like oscillation marks
Corner filling	Uniform	Localized underfilling near corners due to crusting	Uniform	Uniform	Uniform
Hot top	Optimal	Premature solidification with reduced feeding capacity	High regular complete filling with a flat surface	Satisfactory thermal insulation and flat profile.	Bad feeding

Current fly ash powder	Powder A	Powder B	Powder C	Powder D
				
				
				
				

SYSTEMATIC QUALIFICATION FOR ALTERNATIVE CASTING POWDERS

The main outcome of this work is that the transition from conventional powders to synthetic powders cannot be managed as a direct, drop-in replacement. A formulation that matches the same nominal chemical composition, or that exhibits comparable melting temperatures, does not necessarily guarantee the same spread ability capacity, coverage, distribution, or lubrication behavior during casting.

Key parameters for powder qualification

The qualification of a new powder must therefore consider the entire system. The materials properties must be evaluated together with the practice used to apply the product and with the specific casting conditions. In particular, the following aspects must be taken into account: ingot geometry and weight; steel grade and casting conditions; specific powder consumption; initial quantity and residual availability during the rise; position, number, and distance from the bottom of the bags in the mold; powder expansion and spreading capacity; melting rate and liquid phase formation; powder behavior in the hot top area; surface and internal quality of the ingot; and material performance during downstream transformation.

The historical practice based on central bag positioning was developed in relation to the expansion and spreading capacity of conventional, fly ash based powders. The trials carried out have shown that this practice is not automatically transferable to the new formulations: for powders characterized by lower expandability, uniform coverage of the bath surface requires a more controlled distribution of the initial quantity.

Future development will therefore need to include trials with bags positioned both centrally and near the mold walls. The objective is to compensate for the reduced spontaneous spreading capacity, ensuring sufficient material coverage across the entire free surface from the earliest stages of the rise. The new practice will need to be defined as a function of ingot section and validated separately for the main dimensional classes.

Simply increasing the powder quantity is not sufficient: a larger quantity can prevent premature exposure of the bath, but it can also increase the risk of unmelted or partially melted material being present under conditions of high turbulence. The optimization strategy must therefore combine total quantity, initial position, radial distribution, and where necessary the method and timing of subsequent additions.

Open aspects

The exploratory trials with the low free carbon Powder D provided a preliminary indication regarding the defects observed on products destined for the rolling mill. On some smaller sized ingots, the formulation showed an improvement in the frequency of nonconformities compatible with the deformation of surface or sub surface gaseous discontinuities.

This result does not allow the origin of the defects to be unambiguously attributed to the free carbon content of conventional powders. The formation of pinholes and blowholes can depend on several other variables, deoxidation conditions, interaction between steel and materials or turbulence conditions. The low carbon formulation also showed unsatisfactory performance in terms of surface regularity and hot top feeding, particularly on the larger ingot formats for forging.

The trials with Powder D should therefore not be interpreted as an immediately applicable solution, but rather as a useful input for defining future development activities. Further investigation will be required into the relationship between carbon content and type, combustion kinetics, possible gas generation or powder entrapment, and the formation of surface or sub-surface discontinuities. The currently available, fly-ash-free conventional powders have been managed by increasing their specific consumption, together with targeted improvements on other casting related aspects not covered in detail in this paper. Hot ingot cleaning through hydro blasting has been introduced to limit the accumulation of powder residues in the reheating furnaces. In collaboration with the powder suppliers and based on the results of the trials described above, upgraded formulations addressing the observed surface criticalities have been developed.

At present, at least two distinct powder solutions have been defined, one for smaller ingots destined for internal

rolling, and one for other formats. Bag positioning inside the mold has also been optimized, moving from an exclusively central arrangement to a combination of central and near wall positions for the larger ingot formats. All these actions are being carried out in close collaboration with the suppliers and through teamwork between the steel shop, casting area, and the internal rolling and forging departments, which allows the outcome of each trial to always be verified on a semi-finished product that has already went through hot deformation and heat treatment.

CONCLUSIONS

The transition to alternative raw materials significantly modified essential functional properties of casting powders, including spreading capacity, consumption rate, liquid-phase kinetics, and thermal behavior of the slag. These differences generated severe process and quality criticalities, such as premature meniscus exposure, degraded surface lubrication, susceptibility to inclusion entrapment, and increased slagging in reheating furnaces. While synthetic formulations offer a promising pathway to enhance raw material control and reduce fly-ash dependency, their industrial implementation demands a structured, comprehensive qualification period, as the observed discrepancies cannot be compensated simply by increasing the feeding rate. A robust qualification framework must integrate thorough assessment of both the solidified ingot and the downstream rolled or forged products. Crucially, specific process parameters, such as specific consumption rate, bag placement configuration, and powder distribution pattern must be individually tailored for each formulation and ingot dimension.

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