



DC casting line at Hualamin's facility in South Africa.

Toward Chlorine-Free Casting: Metallurgical Evaluation of Aluminum-Sheathed Refining Rod

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Alkali elements such as sodium (Na), calcium (Ca), and lithium (Li), together with non-metallic inclusions, are well-known contributors to defects in semi-finished aluminum products, such as rolling slabs, billets, and wire/rod. Elevated alkali levels can promote edge cracking during hot rolling (Figure 1) or limit billet extrusion speed, while inclusions compromise mechanical properties, surface finish, and downstream process stability.

For decades, chlorine fluxing has been one of the industry's main tools to control these impurities. Chlorine reacts with dissolved alkalis to form chlorides that separate from the melt as the bubbles reach the surface. It also assists in de-wetting inclusions, improving their flotation and removal.

Chlorine treatment is typically done at two locations in the casthouse, either in the furnace (where the major alkali and inclusion reduction is performed), or in the degasser (as a final metallurgical "fine-tune" before filtration and casting). However, despite its metallurgical effectiveness, gaseous chlorine (Cl_2) presents significant operational challenges. Therefore, greener alternatives have been considered by the industry, such as salt fluxing and the AluCLEAR™ refining rod. This article evaluates the refining rod technology through industrial validation at the Hualamin smelter in Pietermaritzburg, South Africa.

The Drawbacks of Gaseous Chlorine

From a health and safety standpoint, Cl_2 is highly irritating and corrosive to the respiratory system. Even at low concentrations, exposure may cause coughing and



Figure 1. Edge cracking of AA5182 caused by excess Na after coiling.¹

lung irritation; at higher levels, it can lead to severe pulmonary injury. In molten aluminum environments, chlorine can react with hydrogen to form hydrogen chloride (HCl), further increasing worker exposure risks.

From an environmental perspective, Cl_2 and HCl are regulated as hazardous air pollutants under the U.S. Clean Air Act (e.g., 40 CFR Part 63, Subpart RRR), requiring emission controls, continuous monitoring systems, qualified personnel, documentation, and administrative oversight—all of which increase operating costs without directly enhancing productivity. At the same time, en-

environmental expectations are rising, and many producers are seeking to eliminate gaseous chlorine as part of broader sustainability commitments.

From a maintenance standpoint, Cl_2 and HCl are highly corrosive, accelerating wear on ducting, fans, and instrumentation. It also requires dedicated infrastructure, such as chlorine rooms and leak detection systems. All of this increases maintenance costs.

Operationally, personnel must be trained to respond to chlorine alarms. When triggered, operators must wear breathing apparatus and safely interrupt the cast, which may result in scrapped metal if minimum slab or billet length is not reached. Training, emergency procedures, and specialized safety equipment further increase operating costs. Depending on the volume of chlorine gas, external large liquid chlorine tanks are installed close to the casthouse. A specific evacuation plan must be put in place in the event of a major leak, and it must be coordinated with local authorities, increasing operational costs.

The question, then, is no longer whether gaseous chlorine works—it does—but at what cost?

Salt Fluxing as an Alternative

Chloride salts, such as magnesium chloride (MgCl_2), have long been used in fluxing operations. Chemically, both chlorine gas and chloride salts convert alkalis into stable chlorides (e.g., NaCl , CaCl_2) while promoting inclusion de-wetting and flotation.

Published literature has demonstrated that furnace fluxing with salt can deliver metallurgical performance comparable to gaseous chlorine, both in terms of alkali reduction and inclusion removal.² In degassing systems, salt can also be introduced using a Flux Feeder for Degasser® (FFD), which feeds flux into one of the degasser rotors for dispersion into the molten metal. Industrial studies have shown that this approach can effectively replace chlorine under certain operating conditions.³

More recently, a new approach has been developed to deliver the same chloride-salt chemistry ($\text{KCl} + \text{MgCl}_2$) using a different injection concept: the AluCLEAR refining rod, consisting of a 40% KCl – 60% MgCl_2 fused flux encased in an aluminum sheath (Figure 2). Thanks to its manufacturing process, the fused salt is totally anhydrous compared to current granular fused salt, which can contain up to 1% moisture.

While the underlying refining reactions remain unchanged from the FFD, the injection method for the refining rod differs fundamentally. The rod must be injected into the first chamber of the degasser to maximize reaction kinetics. Unlike salt injection through a rotor, the rod melts at the metal surface and releases salt directly into the flowing aluminum. The aluminum sheath dissolves and becomes part of the alloy, with negligible effect on the chemical composition.

AluCLEAR can be used with its dedicated feeder (2–40 in/min) or with compatible grain refiner feeders. Installation requires minimal modification to existing degassing equipment. The product is manufactured in the U.S. by Think Aluminum Technologies Inc.,

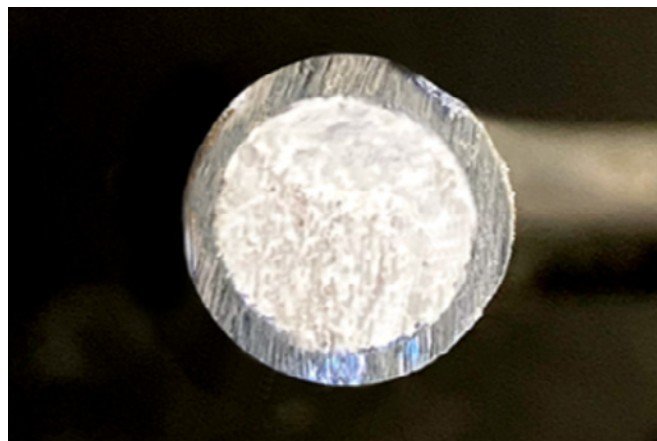


Figure 2. The patented refining rod, which consists of flux encased in an aluminum sheath.

supplied in 5,000 ft coils, and exclusively sold by STAS under a distribution license.

Because the injection method for AluCLEAR differs fundamentally from FFD, its performance could not be assumed to be equivalent and required validation under production conditions. While the refining rod technology has already been implemented in several facilities, no structured industrial campaign had been conducted to systematically collect and publish metallurgical data. A structured benchmarking campaign under controlled casting conditions was therefore conducted to confirm its ability to replace gaseous chlorine.

Industrial Validation

Industrial trials were conducted at Hualamin's Campsdrift facility in Pietermaritzburg, South Africa, on a VDC slab casting line to compare the performance of AluCLEAR with conventional chlorine degassing under production conditions. The objective was to demonstrate that the refining rod can replace gaseous chlorine in the degasser by achieving comparable or superior reduction of inclusions, alkalis, and hydrogen. Reference casts using chlorine were performed to establish a performance baseline. For a given alloy, casting parameters such as metal flow rate, rotor speed, and filtration configuration were kept identical to isolate the effect of the chlorine or the refining rod.

The DC1 configuration at the Campsdrift facility during the trials is shown in Figure 3. The refining rod was injected through the inlet baffle of a six-rotor ACD, and

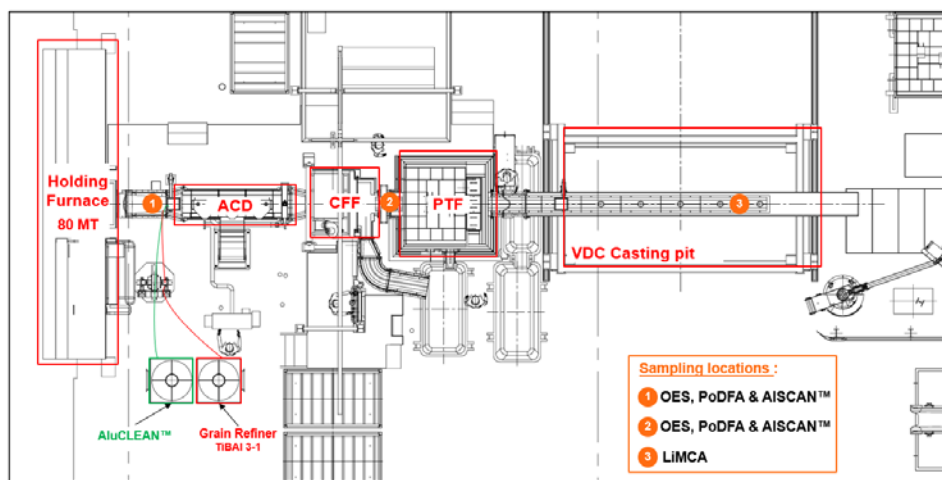


Figure 3. DC1 configuration at Hualamin.

Criteria	Parameter(s) Analyzed	Analysis Method	Sampling Location(s)
Alkalis	Na concentration (ppm)	Spark-OES	Before degasser
	Ca concentration (ppm)		After CFF
Inclusions	Inclusion count N20 (K/kg)	LiMCA	Casting table
	Inclusion content (mm ² /kg)	PoDFA	Before degasser After CFF
Hydrogen	H ₂ concentration (ml H ₂ /100 g Al)	AISCAN™	Before degasser
			After CFF

Table I. Evaluation criteria for the industrial trial at Hulamin.

the feed rate was adjusted to match the equivalent chlorine treatment rate used during standard production.

Overall, results from ten casts were gathered, including four casts of AA3104 aluminum alloy, two of which used gaseous chlorine and two used the AluCLEAN refining rod, and six casts of AA6061 alloy, of which three used gaseous chlorine and three used the refining rod. Performance was assessed by evaluating the removal of alkalis, inclusions, and hydrogen (Table I).

Inclusion Removal: Porous disk filtration analysis (PoDFA) showed comparable inclusion reduction for

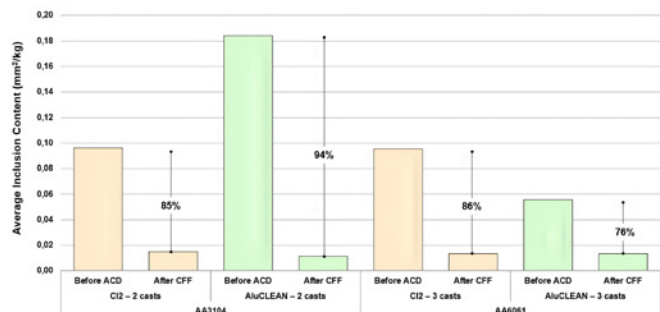


Figure 4. PoDFA analysis results.

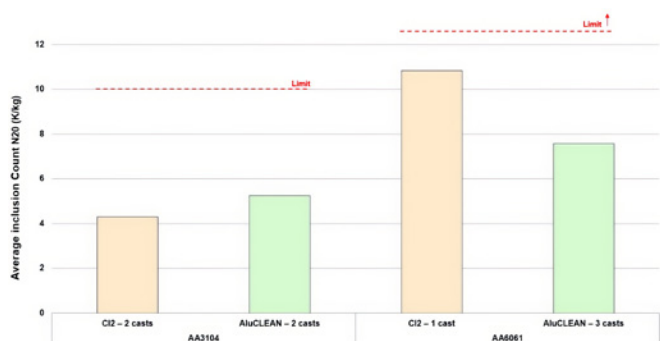


Figure 5. LiMCA N20 analysis results.

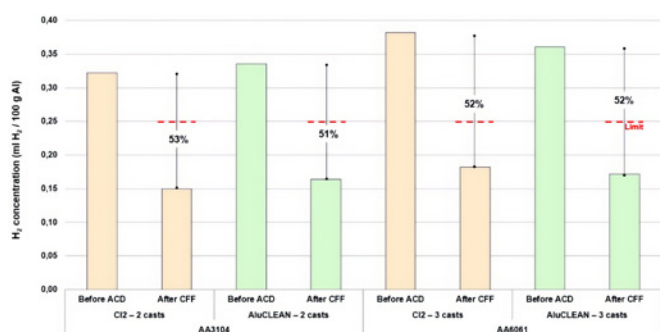


Figure 6. AISCAN analysis results.

chlorine- and AluCLEAN-treated casts (Figure 4). Where available, liquid metal cleanliness analyzer (LiMCA) measurements confirmed that, for a given alloy, no statistically significant difference in inclusion counts were observed (Figure 5). In all cases, average N20 values remained well below specification limits for both AA3104 and AA6061.

Hydrogen Removal: Hydrogen reduction measured by AISCAN™ was equivalent for both chlorine and the refining rod (Figure 6), with all values remaining well below the specified limit of 0.25 ml H₂/100 g Al.

Alkali Reduction: Under the trial conditions, sodium (Na) and calcium (Ca) concentrations at the furnace outlet were already below 1 ppm, thanks to the use of Rotary Gas Injector® (RGI) technology. At such low levels, it was not possible to draw a meaningful conclusion regarding comparative alkali removal performance between chlorine and the refining rod.

Operational Observations: Beyond metallurgical data, operational behavior was carefully monitored throughout the trials (Figure 7). When using the refining rod technology, operators reported reduced chlorine-related fumes and smell, drier dross formation in the ACD, and significantly fewer thermite reactions compared to gaseous chlorine. The drier dross and reduction in thermite reactions help limit aluminum losses over time, thereby contributing to lower operating costs.



Figure 7. Monitoring of AA3104 aluminum using chlorine (top) and AluCLEAN (bottom).

Trial Outcome and Future Implementation: The trials demonstrated that AluCLEAN can achieve metallurgical performance comparable to gaseous chlorine in both inclusion removal and hydrogen reduction. Based on these results, Hulamin plans to transition to chlorine-free operations by 2028, replacing its RGI systems with Rotary Flux Injectors® (RFI) and implementing AluCLEAN across all three casting lines. This decision reflects the company's commitment to reducing environmental impact and

prioritizing the health and safety of its workforce, while maintaining high metallurgical standards.

Selecting the Appropriate Technology

Beyond metallurgical performance, the choice between FFD and AluCLEAN refining rod often comes down to practical and economic considerations. FFD systems typically benefit from lower operating costs (OPEX), as bulk flux salt (in bags) is generally less expensive per unit of active salt compared to the refining rod. For facilities with high and continuous flux consumption, this can translate into a lower cost per ton of treated metal. However, installation complexity and capital expenditure (CAPEX) are generally higher, and maintenance requires qualified personnel.

AluCLEAN, by contrast, involves a much lower CAPEX and can be implemented with minimal modification to existing degassers. Installation is relatively rapid, particularly when using its dedicated feeder, and it is very easy to operate and maintain with minimal training. The trade-off is a higher consumable cost compared to FFD.

In practical terms, FFD may be advantageous in high-volume operations with sustained flux consumption. AluCLEAN is better suited for facilities seeking lower upfront investment, simplified operation, or fluxing limited to selected alloys.

Both systems enable chlorine-free operation. Ultimately, the choice between the two technologies depends on plant configuration, production volume, consumption rate and investment strategy. It is important for suppliers to work closely with customers to evaluate these parameters and provide objective guidance to determine the most appropriate solution for their specific operational needs.

Conclusion

Gaseous chlorine has long been an effective refining tool in aluminum casting. Its effectiveness in alkali and inclusion control has been clearly established. Yet, industrial constraints are evolving. Environmental pressure, safety considerations, and operational complexity are driving producers to reconsider traditional approaches.

Industrial trials at Hulamin demonstrated that AluCLEAN can match chlorine performance in inclusion removal and hydrogen reduction under production conditions. Additional trials under higher alkali base-lines would further quantify alkali removal efficiency.

Ultimately, the transition toward chlorine-free casting is more achievable than ever. With multiple salt-based technologies now available (RFI, FFD, and AluCLEAN), aluminum producers have multiple proven pathways to eliminate gaseous chlorine from their operations while maintaining high metallurgical standards.

References

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