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White Paper

Advancing aluminium wheel casting with NUCLEANT* grain refining fluxes

AUTHORS: GAEL ZARAGOZA, MARK STAPLETON, HAYATI SAHIN, PHILIPPE KIENTZLER

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VESUVIUS

CONTENTS

EXECUTIVE SUMMARY

Several challenges plague aluminium wheel casting, including porosity, shrinkage, and inconsistent grain structure due to low feedability and undercooling.

Grain refinement is essential for mitigating these issues. This is traditionally achieved using Ti-B master alloy rods, which whilst effective in most applications are higher cost per treatment than the alternative of flux grain refinement Foseco's NUCLEANT 158X family of grain refining fluxes offers a solution. These Ti-B-based granulated fluxes are introduced during melt degassing, forming fresh titanium diboride (TiB_2) and aluminium boride (AlB_2) particles in situ. This results in a more uniform distribution of the grain refiner, reduced fading, and finer, more consistent grain structures.

Experimental results from wheel foundries show that NUCLEANT-treated castings maintain comparable mechanical properties to those refined with Ti-B rods; however, they require significantly lower addition rates and yield a cleaner melt.

Case studies from real-world applications reinforce these operational benefits. With over 400 million wheels produced using NUCLEANT products globally, these fluxes represent a more efficient and reliable alternative to traditional grain refinement methods in aluminium casting.

Keywords: NUCLEANT 158X, grain refining fluxes, aluminium casting, wheel casting.

Introduction

Low Pressure Die Casting of Aluminium wheels is a widely used process in automotive manufacturing due to the castings' lower weight, high strength, corrosion resistance, excellent heat dissipation, and appealing aesthetics. However, Low Pressure Die Casting of Aluminium wheels is not without challenges, such as excessive porosity and shrinkage exacerbated by low feedability. Aluminium alloys also generally have moderate to low fluidity, which is problematic when casting complex or thin-walled components.

Grain refinement plays a critical role in overcoming these challenges and improving the soundness of aluminium castings. Traditional grain refinement practice involves the addition of titanium-boron (Ti-B) master alloys, which contain Nuclei that suppress the growth of larger particles, resulting in a fine, equiaxed macrostructure [1].

Although Ti-B rods are reasonably effective as grain refiners, there remains room for improvement. Foseco developed its NUCLEANT 158X family of grain refining fluxes to solve some problems Ti-B rods pose, delivering several performance benefits. The remaining article will discuss the NUCLEANT approach to grain refinement, including experimental validation and using NUCLEANT 158X products in real-world applications.

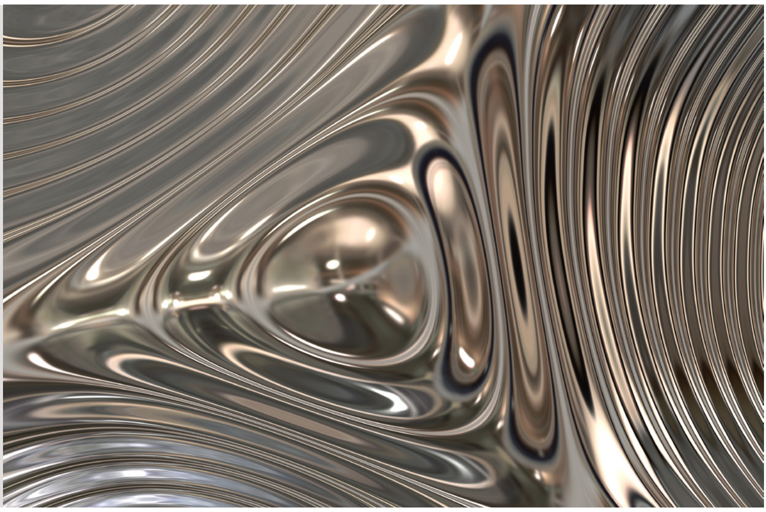
Technical background: Some principles of grain refinement

According to to Began, B. and Careil, P., "those castings with slower cooling rates and larger variation in casting thickness require grain refinement more than other casting designs". This includes wheel foundries where "grain refinement and cleaning are crucial for achieving the required feeding and cosmetic surface finish" [3].

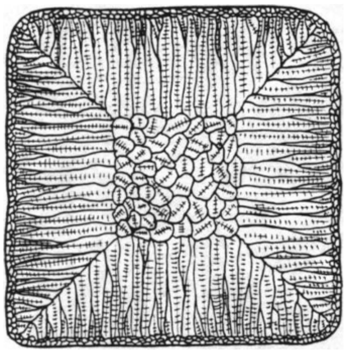
By promoting the formation of a finer granular structure in the casting, grain refinement improves feeding, elongation, and mechanical properties; increases fatigue resistance; improves casting machinability, reduces hot tears; helps disperse micro-shrinkage; decreases the size of porosities; and reduces thermal treatment cycles.

NEED FOR GRAIN REFINEMENT

When solidifying aluminium, three different grain morphologies are possible: equiaxed, columnar, and twinned columnar [2]. Ungrained aluminium castings typically exhibit a columnar structure (Figure 1), resulting in poor castability (fluidity and porosity) and mechanical properties, as noted above.



Typical columnar grain structure



Pure aluminum with columnar grains

Figure 1. Ungrained refined aluminium structure.

Grain size is primarily a factor of cooling rate: slower cooling typically results in coarser grains, while faster cooling results in a finer structure [4].

Although this rule works in general, there are complications, namely undercooling. Undercooling occurs when the alloy is cooled below its equilibrium

UNDERCOOLING CHALLENGES

Rapid cooling without nucleation sites causes undercooling, delaying solidification and increasing defects like hot tearing and shrinkage. Smooth moulds worsen this problem.

(liquidus) temperature but does not immediately solidify; it happens when cooling occurs quickly and there is a lack of potent nucleation sites in the alloy.Undercooling matters because it delays solidification and increases grain size; it can also lead to hot tearing, shrinkage, segregation, and misruns. Undercooling is also a particular issue when using smooth mould surfaces (as in wheel casting) because smooth moulds reduce heterogeneous nucleation. Began and Careil note that coarser particle sizes ensue when undercooling is high or lasts for an extended period; in contrast, very fine grain sizes are achieved when there is no undercooling [3]. Grain refiners address the issue of undercooling by adding or promoting nucleation in the molten metal.

Although widely used in aluminium casting, Ti-B grain refiners have their limitations [4]. Rod quality is paramount: rods containing oxides have the potential to form porosity in the casting, deteriorating casting quality. The size of intermetallic phases (TiB_2, Al_3Ti, and AlB_2) must also be as fine as possible, as larger sizes impede grain refinement efficiency. A second crucial problem is the decreasing efficiency of the grain refiner over time, known as fading, due to the refiner settling toward the crucible bottom. Higher-density solid particles, such as grain refiners, experience more gravitational pull and settle faster (as per Stokes' Law). Finally, in aluminium-silicon (Al-Si) alloys, Si compounds can form on the surface of the Ti-B refiner, inhibiting grain refinement (known as poisoning).

These drawbacks led Foseco to develop NUCLEANT 158X family of grain refining fluxes.

A new approach to grain refinement: NUCLEANT 158X grain refining fluxes

NUCLEANT 158X products are Ti-B-based grain refining fluxes appropriate for all aluminium alloys, including those with high silicon contents. They can be used in any aluminium foundry using Ti-B rods, including manufacturing OEM wheels using low-pressure die-casting (LPDC) and gravity casting, auto suspension and chassis parts, and any aluminium castings that experience severe micro-shrinkage, alloy fluidity and mould filling issues, and hot tear (cracking) defects.

Unlike traditional Ti-B rods, NUCLEANT 158X fluxes come as granulates added to the melt during degassing. These fine granulates contain high titanium and boron concentrations, forming titanium diboride (TiB_2) and aluminium boride (AlB_2) in situ, leaving fresh nuclei throughout the melt. These finely dispersed nuclei promote a fine equiaxed grain growth during solidification; they also distribute more homogenously through the melt, resulting in less fading.

UNDERCOOLING CHALLENGES

NUCLEANT 158X grain refining fluxes thus offer several benefits over traditional Ti-B rods:

- High efficiency, reducing the required addition and associated flux-related costs.
- Cleaner melt due to oxide removal. This allows NUCLEANT fluxes to replace drossing fluxes, again delivering cost savings.
- Automation friendly through flux feeders, with automated addition being essential for process control and safety in the automotive industry.

Figure 2. Comparison of aluminium macrostructure. Note the more homogenous structure in the NUCLEANT-treated sample.

Experimental data backs up these performance benefits. In one customer trial using the NUCLEANT 1582 product version, performance was tested against Ti-B rod (Al5Ti1B) at a wheel foundry using an A360 alloy [8]. Rods were added at a 1kg /1t melt ratio; the NUCLEANT flux was added at a 0.55 kg/1 t ratio during degassing with a Foseco MTS 1500 system in a 900kg transfer furnace. Samples were taken from every fifth wheel from three locations (hub, spoke, and rim).

Aluminium treated with the NUCLEANT flux showed a more homogenous macrostructure than the rod-treated metal (Figure 3). Microstructurally, grain size measurements showed the rod and NUCLEANT flux resulted in similar grain sizes (Figure 3), although the NUCLEANT-treated metal showed shorter dendrite arm length (Figure 4).

Testing of mechanical strength (UTS and elongation) revealed consistency between rod-treated samples and those treated with the NUCLEANT flux (Figure 5).

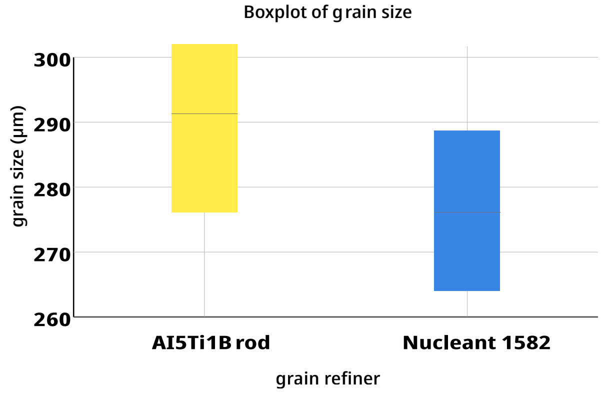


Figure 3. Grain size change with different grain refiners.

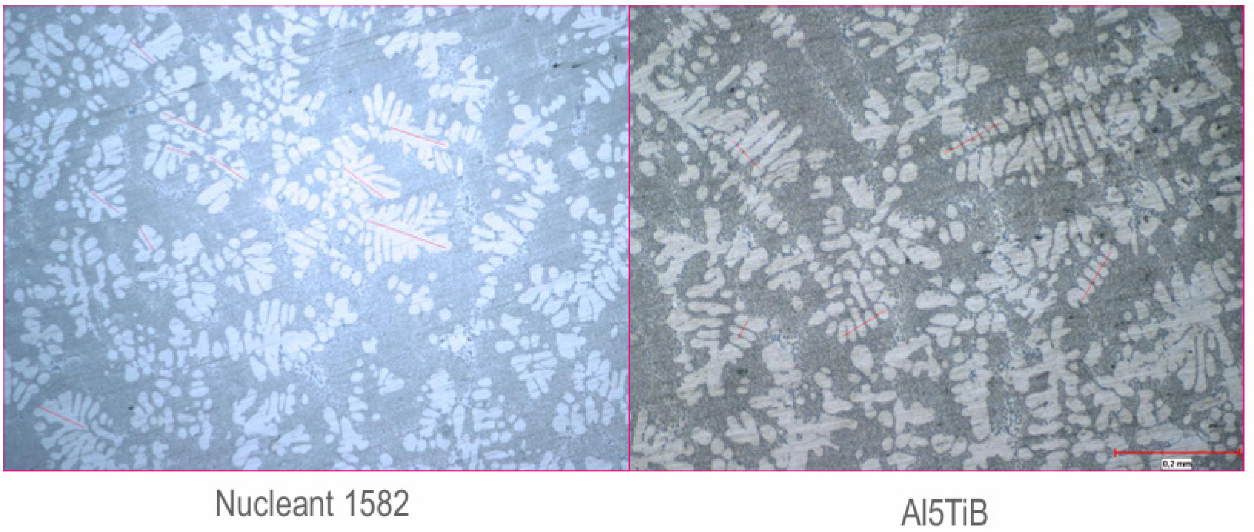


Figure 4. Comparison of aluminium dendrites. Note the shorter dendrite arm length in the sample treated with the NUCLEANT flux.

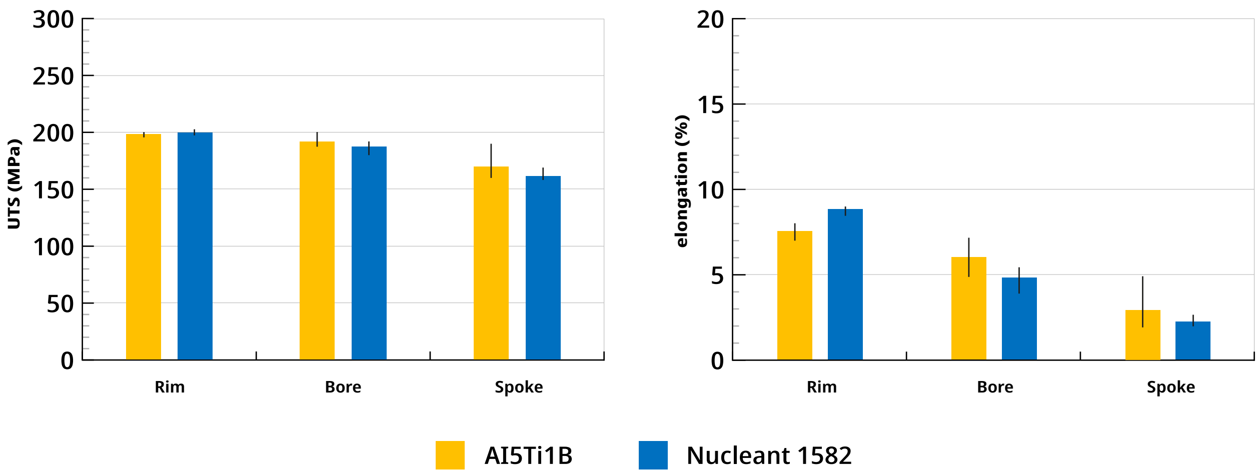
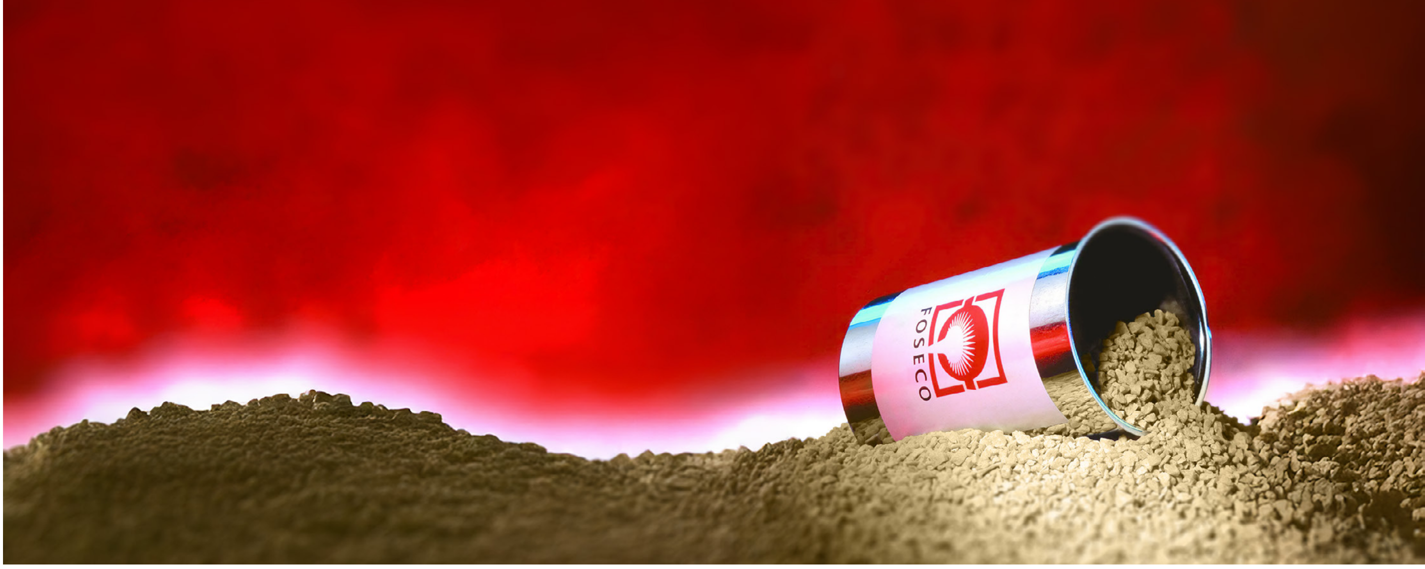


Figure 5. Mechanical properties of the machined wheels (Al5TiB added at 1kg/T; NUCLEANT 1582 added at 0.55kg/T)



Interestingly, when the melt's titanium (Ti) content was tested, the rod-treated sample showed lower Ti content over time—a classic demonstration of fading. This caused the aforementioned heterogeneous microstructure: particle size increased as grain refinement efficiency decreased over time.

Ti content in the melt treated with the NUCLEANT 1582 flux showed no such decrease through the casting process (Figure 6).

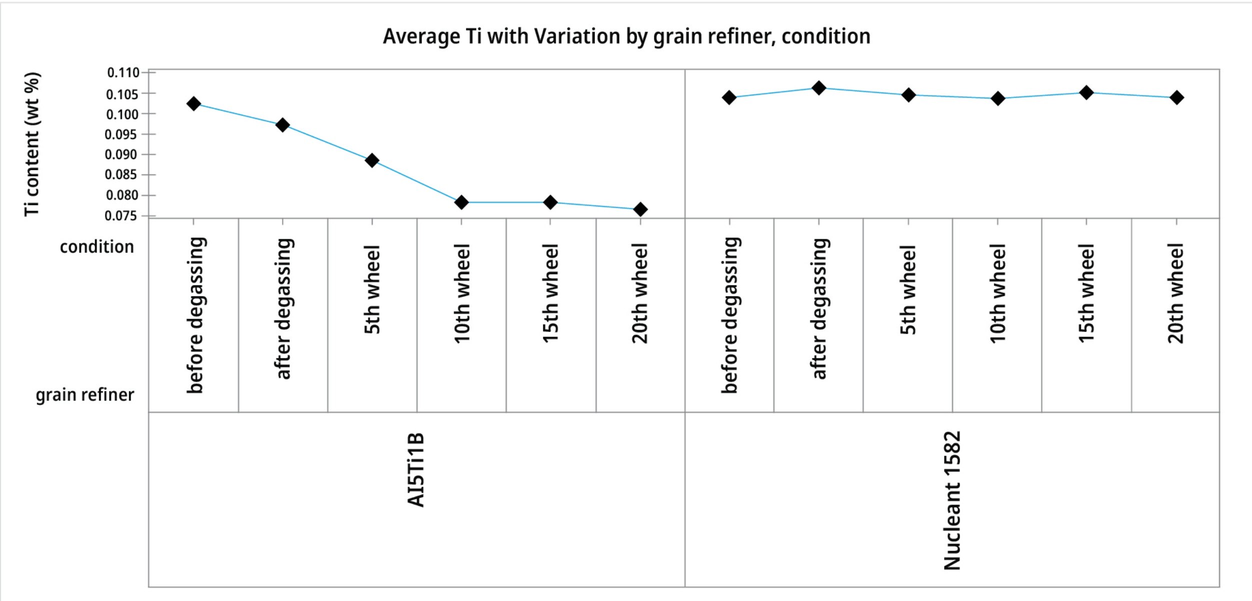


Figure 6. Changing Ti content during wheel casting [5].

Case studies

Since its introduction in 2012, the NUCLEANT 158Xfamily of grain refining fluxes have been used to manufacture more than 400 million OEM wheels in Europe, North America, and Asia. They have also been used to produce safety-critical components such as suspension arms and knuckles.

Recently, trials of the NUCLEANT 1587 product have further demonstrated these fluxes' benefits. In one such trial, the flux was added to the following operating conditions:

- Alloy : A356 (Al-Si7%-Mg0.3%).
- Transfer ladle capacity: 1,200kg.
- Grain refining and degassing temperature: 710-730 °C.
- Degassing equipment: MTS 1500 SMARTT Rotostativ.
- Degassing rotor : FDDR 250.70 diameter 250 mm.
- Nitrogen flow rate: 20 l/min.
- Flux reaction time/degassing time: 45 sec / 5 min.

Using the grain refiner reduced additions from 700g with a Ti-B rod to 360g in this application, a 48% saving was achieved. The NUCLEANT flux also achieved a 45% smaller grain size and a 19% lower Aluminium content in the dross. Mechanical properties were similar to the rod-based process.

In a second trial, again using the NUCLEANT 1587 product, the flux was added to the following operating conditions:

- Alloy : A356 (Al-Si7%-Mg0.3%).
- Transfer ladle capacity: 1,200kg.
- Grain refining by addition of Ti-B rod: 0.580kg/t.
- Cleaning flux addition (Coverall Pure 1565): 0.280kg/t.
- Grain refining and degassing temperature: 710-730 °C.
- Degassing equipment: MTS 1500 SMARTT type Rotostativ.
- Nitrogen flow rate: 20 l/min.
- Flux reaction time/degassing time: 45 sec / 5 min

In this application, using the NUCLEANT 1587 flux resulted in a 30% reduction in grain refiner addition, while delivering a similar grain size and comparable mechanical properties.

THE CONCLUSION

The NUCLEANT family of grain refining fluxes provides an alternative to Ti-B master alloy rods in aluminium casting applications. Countering the critical deficiencies of traditional grain refining solutions, they offer a cleaner, more efficient, and consistent casting process.

Importantly, they deliver similar, if not improved, grain size reduction and mechanical properties, while substantially reducing the amount of grain refiner used per ton of melt.

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FOSECO INTERNATIONAL LTD.
DRAYTON MANOR BUSINESS PARK
B78 3TL TAMWORTH
UK

www.Foseco.com
Foseco.communications@Foseco.com