METAL Minutes

Titanium-Aluminide Production

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Titanium Aluminides are finding expanded applications in both the aerospace and automotive markets. However, this demand has also highlighted many of the issues associated with the production of these alloys, not least of which being material segregation and shrinkage porosity. These are especially prevalent in the production of small diameter round bars used as casting and forging stock. Further contributing to these difficulties, melting systems and the accompanying processes are based on historical context whereby multiple vacuum arc remelt (VAR) steps are performed using compacted electrodes. Needless to say, this is problematic at best and doesn't really solve the underlying issues with the alloy or the cost drivers for production.

Beginning in 2011, Retech Systems, with Ti-Solutions in Bremen, Germany, worked to develop an advanced process to allow for production of small diameter, homogeneous bars in lengths up to 1.2 meters using a plasma arc melting (PAM) system. Specifically directed to demand in automotive and aerospace markets, this work has successfully yielded consistent chemistry, homogeneity, fine grain structure, >99% density and, for some applications, without the need for subsequent VAR or hot isostatic press (HIP) cycles. Additionally, this development work had to be done in a manner that provided not just a technical solution, but real economies of production that included a focus on a commercialize-able processes & products as the end result.

Background:

As a result of environmental concerns, new legislation has specifically been aimed at improving performance efficiencies in automobiles as well as aircraft. Titanium Aluminides are consistently finding new uses whereby they provide improved fuel economies through lower mass and enhanced properties. Less mass is specifically important in aerospace where, in some instances it has been suggested that saving 1 lb. in a jet engine can save 4 lbs. in the airframe. Additional performance gains are being realized through lower rotational forces combined with higher rpms. The base Titanium-Aluminide (TiAl) materials we are familiar with, 48-2-2 as an example, are being supplanted by improved alloys tailored to specific applications. Our development has centered on a couple of these; the TNM & RNT family of gamma-Ti alloys.

The Aluminum (Al) content in the gamma-Ti alloy is higher than Ti 6-4, meaning a 10% base mass savings for the same 6-4 volume, 50% mass improvement compared to commonly used Nickel-based alloys, as well as improved high temperature performance and resistance to oxidation. However, that comes with some challenges.

As a result, new techniques really have had to be developed to address the ever more complex designs being incorporated into modern vehicles. Significant attention has been paid to addressing the homogeneity & density issues that have been endemic in much of the currently available material. Further, due to the focus on making the production commercially viable, a cost comparison to those target application materials, such as those Nickel alloys, has been imperative. Finally, downstream demand and time constraints meant theses very specific alloys had to be the focus areas of development for our team.

Challenges:

Conventional methods of alloy production are firmly based on a historical model for larger batches of different Titanium alloys. In such a process, loose feed material is blended and compacted into on-chemistry electrodes and then run through two vacuum arc remelting cycles to produce an ingot which would then subsequently be put through a consumable caster and turned into bars before going to be cast or, alternatively, HIP'd, forged & machined. As can be expected, melting the material three times is expensive, time consuming and has been shown to be a source of inclusions. Further, typical ingots have contained center-line shrinkage, which is well illustrated here, along with significant stratification of elements.

Despite these shortcomings, the process has yielded a useable product. However, it hasn't thus far guaranteed homogeneity, density or been cost effective. As a result, new melting techniques are required to bring down production costs while ensuring quality standards.

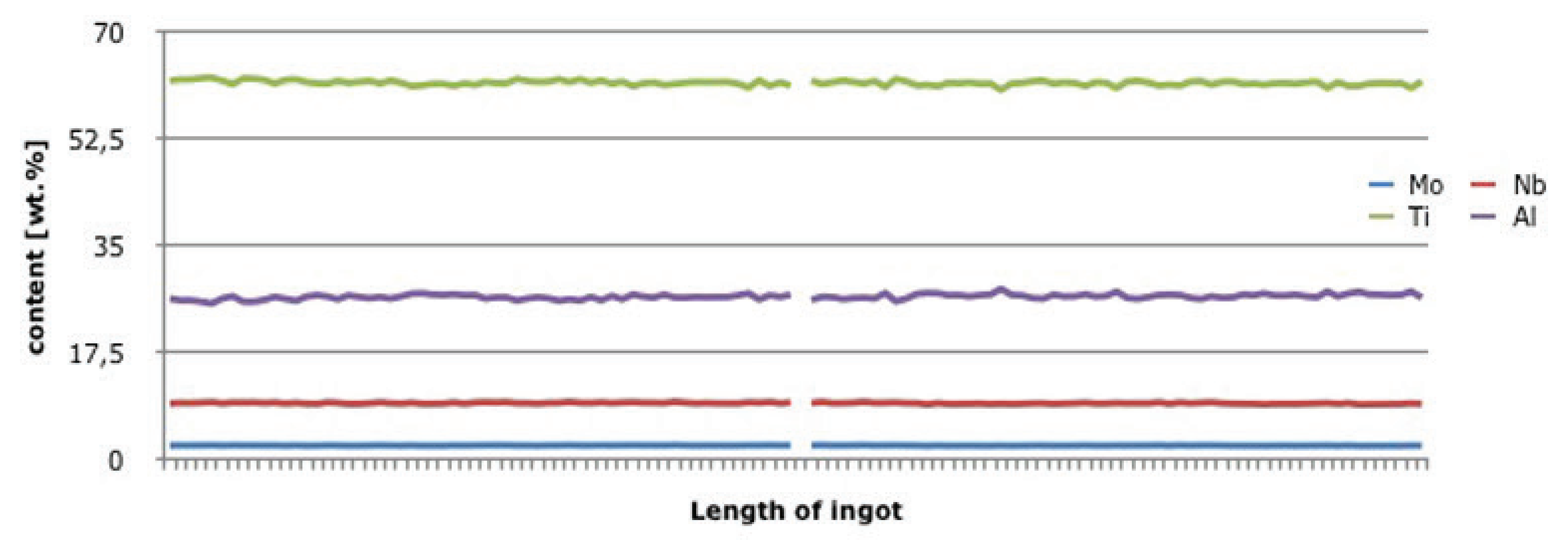
Method:

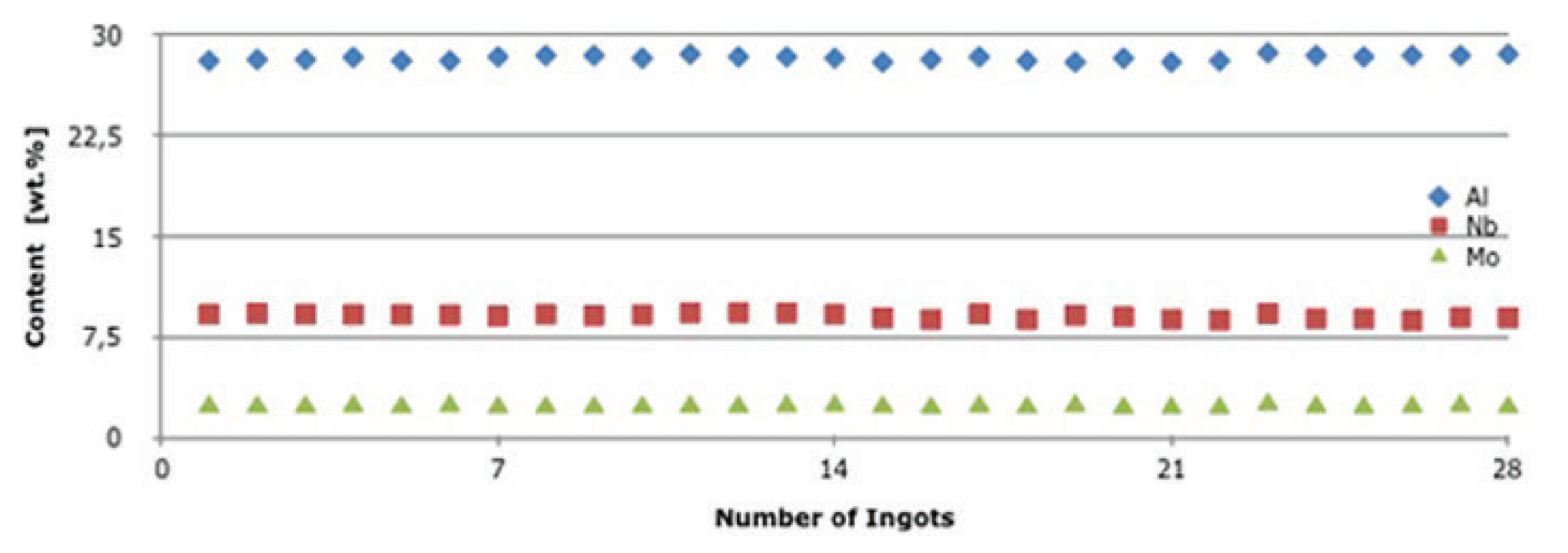
The Retech / Ti-Solutions team approached this task with very specific goals. The first was a focus on small diameter bar production had to the greatest number of application opportunities as use in forgings, casting and atomization. Second was simple determination that a reduction in the amount of melting steps would be a simple way to bring down costs while also minimizing the proportion of yield losses. Thirdly, elimination of as many of the common issues seen in the conventional production processes would need to be resolved. These include shrinkage porosity, non-homogeneity, thermal stress, poor surface finish and limitations to bar lengths. Finally, we had to embrace the concept of a short development cycle given market growth and application development, industry wide. In essence, we gave ourselves 3 years to get this done. The result is something we call Gamma-PAM (γ-PAM).

Gamma-PAM:

First and foremost, the upstream material is still blended and compacted, however, it is melted just once using a plasma arc melting system. Despite the removal of two traditional melting steps, this process yields > 99% dense, small diameter bars, in this case approx. 2", all while maintaining the alloy homogeneity. Combined with a copper hearth, we further ensure thorough heating without concern for inclusions. Of further interest, the as-cast surface finishes on these ingots has been shown to be easily removed through machining, but as a result of the process, it isn't necessary for forgings. Meaning, this material can be used as-is, or as-cast.

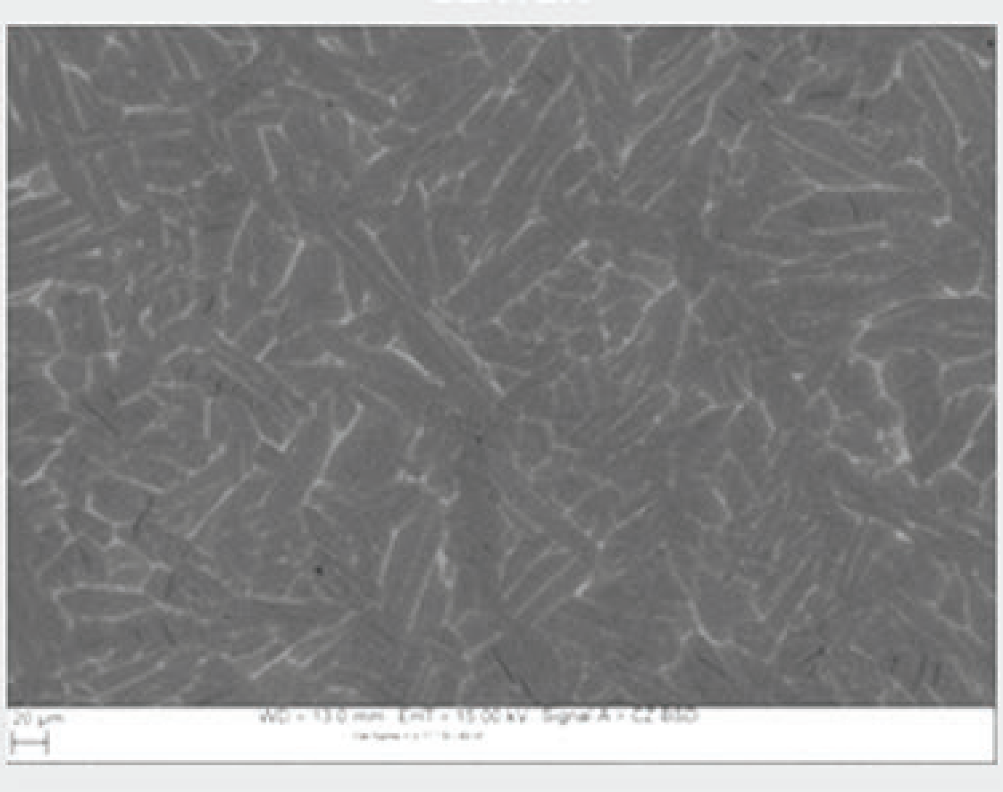
Chemical analysis has shown the produced alloys to be homogeneous not just across the entire length of ingots with 0.2% deviation in Al content, but also consistent between different batches, thus proving the process repeatability.



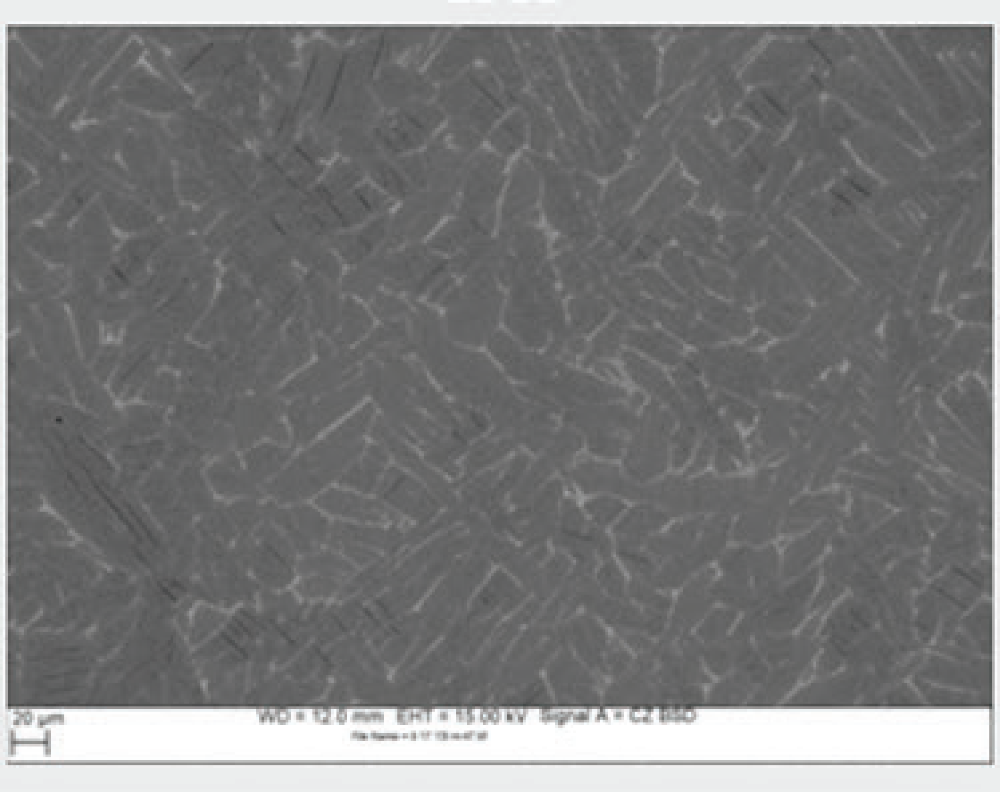


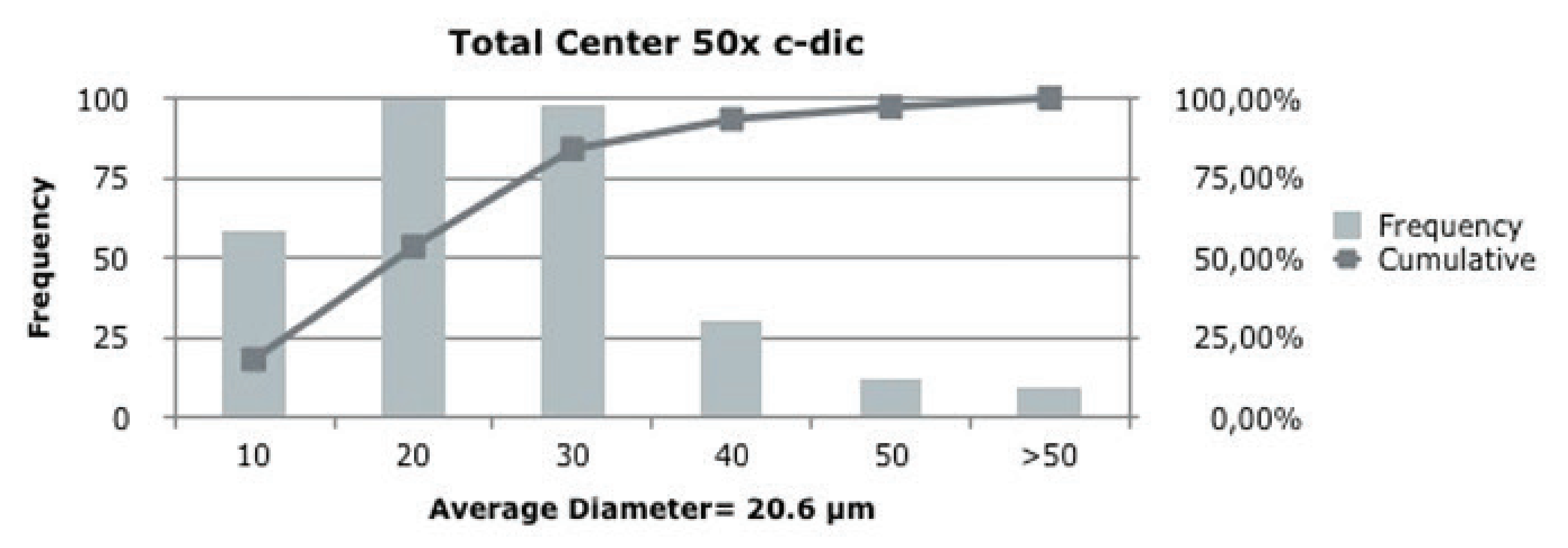
Further microstructure analysis has been shown to be clear and consistent between edge and center sections.

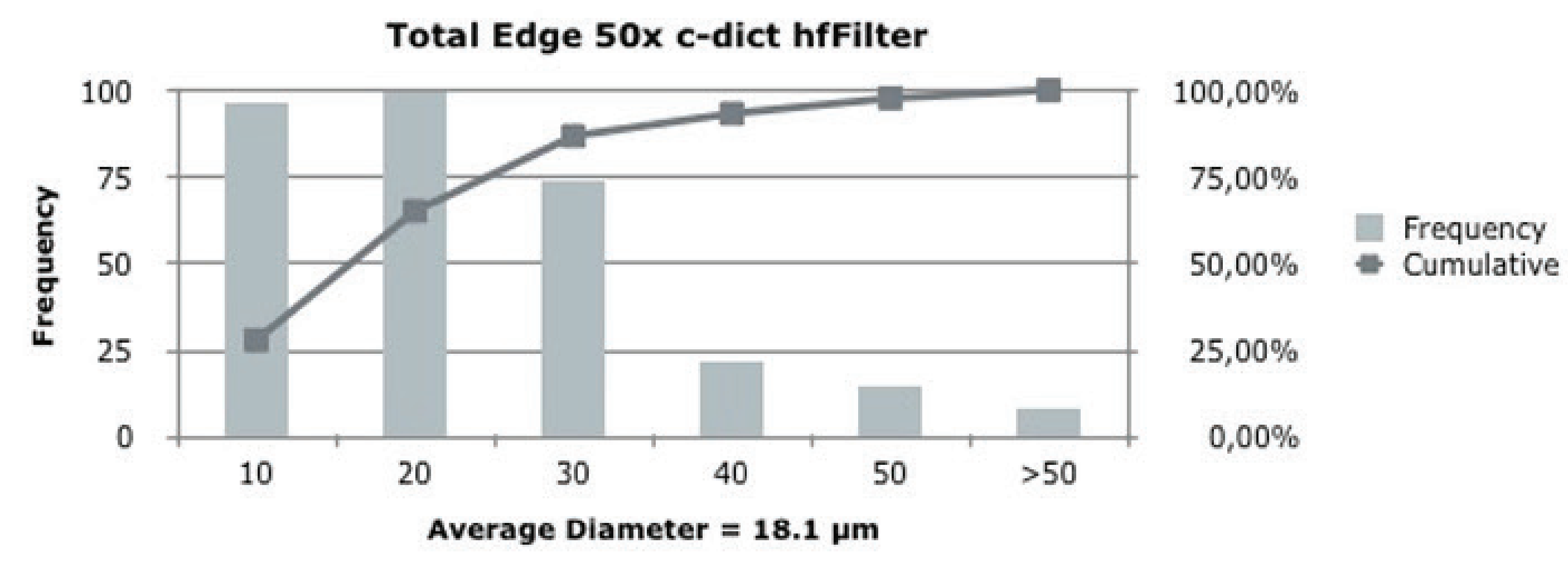
CENTER



EDGE







The pilot scale system installed, at Retech in California, was used for process proof and production of gamma TiAl ingots of up to 1.2 meters (~46 in.) as well as economic model testing. Of course the next step is the determination as to the final configuration of a commercial-scale plasma system in order to address the industry needs at a marketable price. Initially, from our perspective, such a system would probably be able to melt something just south of 200 tons per year and consist of a 2-plasma torch melter pouring into a single mold.

Conclusions:

The simple take away is the idea that it is possible to produce small diameter ingots of gamma-TiAl alloys which are homogenous; which are >99% dense; and actually do meet the density microstructure as well as chemical specifications for automotive and aerospace applications without much, if any, subsequent processing. Further, and maybe most importantly, it is possible to do this in a way that's, in fact, cost effective and could reasonably aid in pushing the use of these alloys throughout a range of industries and markets. This last point has been shown to be valid on the pilot scale and therefore, should be likewise achievable in larger, commercial-scale systems.